Abstract

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# ISPSA 2018

The 19th International Symposium on the Physics of Semiconductors and Applications

"Energy Harvesting & Wearable Photonics"

**July 1** (Sun.) ~ **5** (Thu.), **2018**

Ramada Plaza Jeju Hotel, Jeju, Korea

Hosted by 한국물리학회 The Korean Physical Society, KVS The Korean Vacuum Society

Organized by 전북대학교 반도체물성연구소 Semiconductor Physics Research Center SPRC, SUNG KYUN KWAN UNIVERSITY(SKKU), SEJONG UNIVERSITY Graphene Research Institute

Supported by KOFST, Jeju Special Self-Governing Province, Jeju CVB Jeju Convention & Visitors Bureau 제주컨벤션뷰로, KOREA TOURISM ORGANIZATION

# Program at a Glance

| | Time | Room A (Ramada Ballroom 1) | Room B (Ramada Ballroom 2) | Room C (Ramada Ballroom 3) | Room D (Ramada Ballroom 4) | Room E (Mara) |
|---|---|---|---|---|---|---|
| July 1 (Sun.) | 19:00~21:00 | Welcome Reception (Outdoor Pool, 5F) | | | | |
| July 2 (Mon.) | 09:00~09:30 | Opening Ceremony (Ramada Ballroom 1) | | | | |
| | 09:30~10:30 | [Plenary Talk I] Displays Based on Light-Emitting Diodes - *Jin Jang (Kyung Hee Univ., Korea)* | | | | |
| | 10:30~11:00 | Coffee Break | | | | |
| | 11:00~12:00 | [Plenary Talk II] Van der Waals Heterostructures: Techniques, Properties, and Materials - *James Hone (Columbia Univ., USA)* | | | | |
| | 12:00~13:30 | Lunch | | | | |
| | 13:30~15:00 | [MoA1] Wide-bandgap materials and applications I | [MoB1] Flexible and wearable devices I | [MoC1] Organic semiconductors and colloidal quantum dots I | [MoD1] Nano-bio-materials and devices | [MoE1] Sejong Special Session: GRI-TPC IRC Workshop I |
| | 15:00~15:30 | Coffee Break | | | | |
| | 15:30~17:00 | [MoA2] Compound semiconductors | [MoB2] Flexible and wearable devices II | [MoC2] Organic semiconductors and colloidal quantum dots II | [MoD2] Topological matters I | [MoE2] Sejong Special Session: GRI-TPC IRC Workshop II |
| | 17:00~18:30 | Poster Session I (Convention Lobby, 2F) | | | | |
| July 3 (Tue.) | 09:00~10:00 | [Plenary Talk III] Continuous Health-Monitoring with Skin Sensors - *Takao Someya (The Univ. of Tokyo, Japan)* | | | | |
| | 10:00~10:30 | Coffee Break | | | | |
| | 10:30~12:00 | [TuA1] Wide-bandgap materials and applications II | [TuB1] Flexible and wearable devices III | [TuC1] Sensors and applications I | [TuD1] Topological matters II | |
| | 12:00~13:30 | Lunch | | | | |
| | 13:30~14:30 | [Plenary Talk IV] Periodic Resonant 3D-Confined Semiconductor Quantum Structures - *James J. Coleman (The Univ. of Texas at Dallas, USA)* | | | | |
| | 14:30~15:00 | Coffee Break | | | | |
| | 15:00~16:30 | | [TuB2] Spintronics I | [TuC2] Sensors and applications II | [TuD2] 2D materials and heterostructures I | [TuE2] Sejong Special Session: GRI-TPC IRC Workshop III |
| | 16:30~16:50 | Break | | | | |
| | 16:50~18:20 | | [TuB3] Spintronics II | [TuC3] Sensors and applications III | [TuD3] 2D materials and heterostructures II | [TuE3] Sejong Special Session: GRI-TPC IRC Workshop IV |
| | 18:30~20:30 | Banquet (Ramada Ballroom 1) | | | | |
| July 4 (Wed.) | 09:00~10:00 | [Plenary Talk V] Piezotronics and Piezo-phototronics of 3rd Generation Semiconductors - *Zhong Lin Wang (Georgia Inst. of Tech., USA)* | | | | |
| | 10:00~10:30 | Coffee Break | | | | |
| | 10:30~12:00 | [WeA1] Spintronics III | [WeB1] Special Session: SKKU IBS-Center for Integrated Nanostructure Physics Session I | [WeC1] Plasmonics, meta-materials and optoelectronics I | [WeD1] 2D materials and heterostructures III | |
| | 12:00~13:30 | Lunch | | | | |
| | 13:30~14:30 | [Plenary Talk VI] Organic-Inorganic Hybrid Perovskite Materials and Applications - *Nam-Gyu Park (Sungkyunkwan Univ., Korea)* | | | | |
| | 14:30~15:00 | Coffee Break | | | | |
| | 15:00~16:30 | [WeA2] Energy harvesting and storage I | [WeB2] Special Session: SKKU IBS-Center for Integrated Nanostructure Physics Session II | [WeC2] Plasmonics, meta-materials and optoelectronics II | [WeD2] 2D materials and heterostructures / Quantum information | |
| | 16:30~16:50 | Break | | | | |
| | 16:50~18:20 | [WeA3] Energy harvesting and storage II | [WeB3] Special Session: SKKU IBS-Center for Integrated Nanostructure Physics Session III | [WeC3] Plasmonics, meta-materials and optoelectronics III | [WeD3] Quantum information I | |
| July 5 (Thu.) | 09:00~10:30 | [ThA1] Si and group IV semiconductors | [ThB1] Compound semiconductors / Energy harvesting and storage | [ThC1] Plasmonics, meta-materials and optoelectronics IV | [ThD1] Quantum information II | |
| | 10:30~11:00 | Coffee Break | | | | |
| | 11:00~12:30 | Poster Session II (Convention Lobby, 2F) | | | | |
| | 12:30~13:00 | Closing Ceremony (Ramada Ballroom 1) | | | | |

# Performance improvements in AlGaN-based deep-UV LEDs using AlN/Al reflectors

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AlGaN-based deep ultraviolet light-emitting diodes (DUV-LEDs) have applications in wide areas such as water purification, biological analysis, epoxy curing, white light illumination, and UV adhesives. However, the efficiency of such LEDs is much lower than that of the visible LEDs because of light absorption in p-GaN contact layers along with AlGaN epitaxy issues. Typical external quantum efficiency (EQE) of UV LEDs, particularly in the DUV region (100–280 nm), is less than 10%. To improve such a low efficiency, Kashima et al. employed highly reflective photonic crystals and Ni/Mg electrodes, and reported ~10% EQE from AlGaN DUV-LEDs [1].

In this study, we report over 7% EQE from simple AlGaN DUV LEDs with AlN/Al reflectors. Prior to deposition of Al reflector, AlN layers were deposited on p-AlGaN contact layers, followed by the electrical breakdown process to achieve Ohmic contact by create conductive filaments (CFs) at the p-AlGaN/AlN interface under electric fields. These CFs are known to provide not only channels for hole carrier injection, but also effective means for Ohmic contact by reducing the Schottky barrier height at the p-AlGaN/AlN interface due to the increase of effective work function of AlN and Ga out-diffusion from p-AlGaN contact layers [2]. AlN layers also prevent the absorption of UV light and reflection loss of a single Al layer. The reflectance of the AlN/Al layer was measured to be over 98%, much higher than those of the conventional Ni/Au and Ni/Al reflectors. Compared to the reference LEDs with Ni/Au and Ni/Al reflectors, our deep-UV LEDs exhibited more stable operations with a forward voltage of 8.4 V, an output power of 26 mW at 100 mA, and an EQE of 7.1. Details on the fabrication and device performance will be presented at the conference.

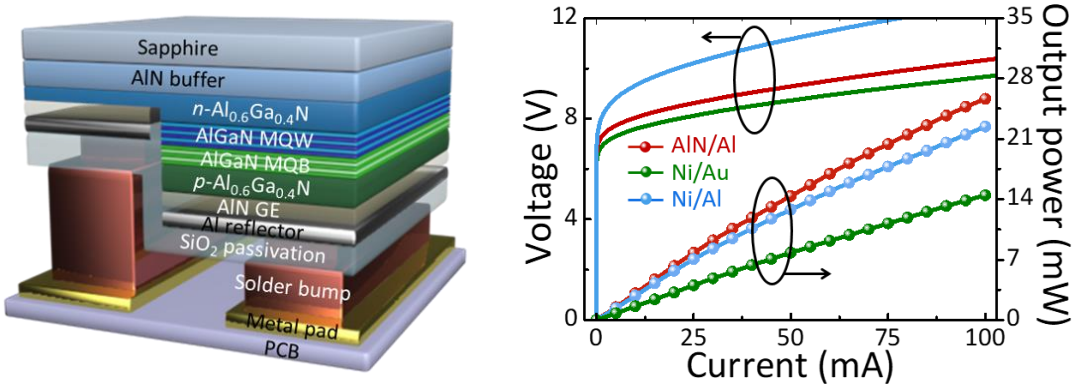


**Figure 1 Schematic (left) and voltage and light-output power versus current characteristics (right) measured for AlGaN-based DUV LEDs with three different kinds of reflectors**

References

[1] Y. Kashima, et al, Appl. Phy. Exp. 11, 012101 (2018)
[2] T. H. Lee, et al, Appl. Mater. & Inter. 9, 43774, (2017)

# High efficiency Deep-UV AlGaN MQW structure emitter

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In this paper, it is reported the growth and characterization of high efficiency deep ultraviolet (DUV) AlGaN multi-quantum wells (MQWs) emitters on high quality AlN/sapphire substrate. To overcome the limitation of poor hole concentration in the p-layer, the graded AlGaN EBL structure was introduced in the DUV LEDs and compared with the conventional EBL structure.

Also, we report deep ultraviolet emitting core-shell-type AlGaN MQWs grown on the AlN nanorods which are prepared by lithography free process. The AlGaN MQWs are grown on AlN nanorods on a sapphire substrate by polarity-selective epitaxy and etching (PSEE) using high-temperature metal organic chemical vapor deposition. The AlN nanorods prepared through PSEE have a low dislocation density because edge dislocations are bent toward neighboring N-polar AlN domains. The photoluminescence (PL) intensity of MQWs grown on AlN nanorods is approximately 40 times higher than that of MQWs simultaneously grown on a planar structure. The detailed results will be presented at the conference.

# Fabrication of nano-cavity patterned sapphire substrates and their application to the growth of GaN

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GaN-based light-emitting diodes (LEDs) have been investigated intensively due to various applications such as general lighting, and full-color display, etc. Although GaN-based LEDs have already been commercialized via significant technological advancement such as patterned sapphire substrate, the efficiency and cost competitiveness must be improved. Recent studies using hollow nanosphere-coated substrate [1] and cavity-engineered substrate [2] have been reported to show that voids inserted in GaN not only improve the LED performance but also relax the film stress. We have fabricated a nano-cavity patterned sapphire substrate (NCPSS), which has periodic nano-cavity patterns on sapphire, using polystyrene (PS) sphere patterning. Coating of self-assembled PS (1 μm in diameter) spheres by spin coating and $O_2$ reactive ion etching enabled the fabrication of nanoscale non-close-packed hexagonal PS array on sapphire substrate. Subsequently, 63 nm-thick alumina was deposited by atomic layer deposition and the substrate was annealed at 1100 $^oC$ for two hours in air ambient, resulting in the NCPSS. Then, GaN layer was grown on NCPSS by metal-organic chemical vapor deposition. The coalescence of GaN on the NCPSS was achieved by the formation of relatively large GaN islands and enhanced lateral overgrowth of the GaN islands over several nano-cavity patterns. The threading dislocation density (TDD) was significantly reduced from $2.4\times10^8$ $cm^{-2}$ to $6.9\times10^7$ $cm^{-2}$ by using the NCPSS. Raman spectroscopy revealed that the compressive stress in the GaN layer was reduced by 21% due to the embedded nano-cavities. In addition, the diffuse reflectance of GaN on the NCPSS was enhanced by 54% ~ 62% by breaking the total internal reflections.

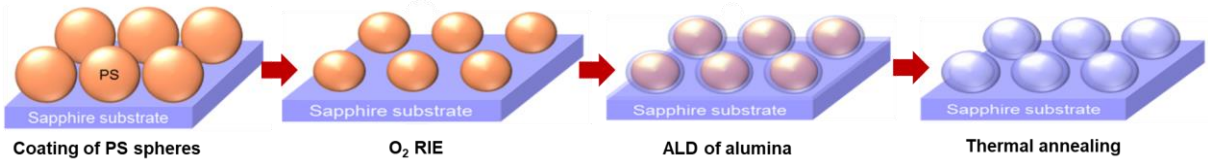


**Fig. 1. Schematic fabrication process of the NCPSS**

*We gratefully acknowledge the support by the Brain Korea 21 Plus project for SNU Materials Division for Educating Creative Global Leaders (F15SN02D1702).*

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[2] J. Jang *et al*., *J. Cryst. Growth* 430, 41 (2015).

# Broad Ultraviolet Light Emitter using GaN Quantum Dots Grown on Multi-facet Three-dimensional Structures

Jong-Hoi Cho[1], Seung-Hyuk Lim[1], Min-Ho Jang[1], Chulwon Lee[1], Hwan-Seop Yeo[1], Young Chul Sim[1], Je-Hyung Kim[1], Samuel Matta[2], Blandine Alloing[2], Mathieu Leroux[2], Seoung-Hwan Park[3], Julien Brault[2], and Yong-Hoon Cho[1,*]

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Ultraviolet (UV) light emitter have received much attention due to their versatile applications such as disinfection and UV curing. Conventionally, arc-lamps such as xenon- and mercury-arc lamps have been widely used as ultraviolet light emitter. However, their bulk system, heat generation and low efficiency make underutilized. In this respect, group III-nitride semiconductors-based UV light emitter have been suggested to replace conventional arc-lamps. In particular, GaN quantum dots (QDs) enable strong carrier localization within QDs and manipulation of emission wavelength via quantum confinement effect[1-2], which makes attractive for the UV light emitter.

In this work, we propose the GaN self-assembled QDs formed on GaN-based truncated pyramid structures including (0001) polar and {10-11} semi-polar facets. Since growth rate and intrinsic built-in electric field are different depending on the facets, it makes various emission wavelength from GaN QDs for each facets, which ultimately render broad UV emission spectrum covering from UV-A (~400 nm) to UV-C (~270 nm). Consequently, broad UV emission spectrum from these unconventional structures could satisfy various requirements for each UV applications. This result presents a potential to demonstrate broad ultraviolet light source based on solid-state emitter.

*This work was supported by the National Research Foundation (NRF-2016R1A2A1A05005320, NRF2016K2A9A2A12003785) of the Korean government (MSIP) and the Climate Change Research Hub of KAIST (Grant No. N11170054).*

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# Biocompatible Sensing Platforms

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Sensors in biomedical applications monitoring critical chemical information (e.g., pH and glucose) and physical vital signs (e.g., Temperature and ECG) are utilized with rigid electrodes and thus, limit intimate integration with our bodies that are soft, curved, stretched, and continuously evolving. The mismatch of mechanical properties between sensors and dynamic living biological systems causes tissue damage and/or induce the foreign body response, leading to inaccurate measurements. Additionally, unconformable contact of sensors on body system impedes their function of the device in biomedical and wearable health monitoring application. Therefore, my research has been focused on developing biosensors to enable quantitative analytical detection along with enhancing the biocompatibility of mechanical and chemical properties of devices. These unconventional biosensors hold great potential to improve human life and health indeed. Herein, I will present the development of biocompatible biosensors with various platforms including: (1) ultrathin injectable sensors [1, 2]; (2) porous, ion selective sensors capable of natural convection of biofluids [3], and (3) epidermal microfluidic sensor with wireless communication electronics for sweat monitoring [4, 5]. Each sensor was specifically developed to eliminate profound mismatch in mechanical properties or to mimic active biological system exploiting the role of a living system. These unique approaches in developing biomedical sensors bring significant advances in biomedical and mobile health applications.

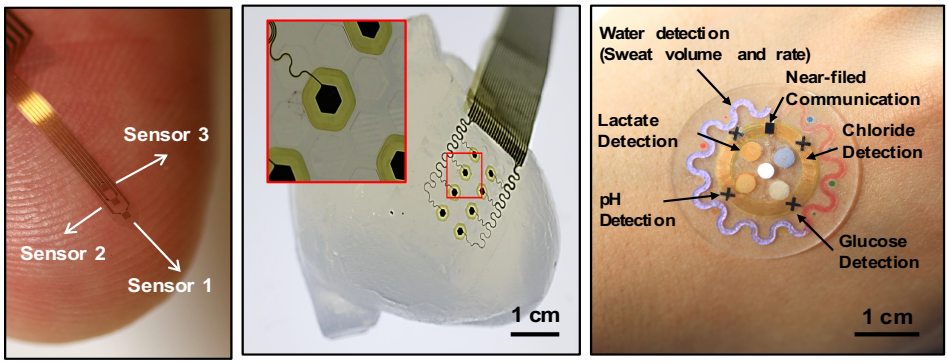


**Fig.1.** Various platforms of biocompatible sensing systems: needle-type sensor (left; [1]), porous chemical sensors (middle; [3]), skin-mountable microfluidics (right; [4]).

## References

[1] A. Koh, et al., *Adv. Health. Mat.* **5**, 373 (2016)
[2] X. Yu et al., *Nat. Biomed. Eng.* **2**, 165, (2018)
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[4] A. Koh et al., *Science Tran. Med.* **8**, 366ra165 (2016)
[5] S. B. Kim et al., *Small*, 1703334 (2018)

# Hacking Nervous System: Opportunities in Soft Wireless Bioelectronics

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Bioelectronics targets development of a technology platform that can modulate neural activities with a goal of advancing understanding and treatment of neurological disorders. Technology platforms available use hard neural interface and provides poor spatial resolution. In addition, electronics that control neural interfaces rely on bulky wired and/ or wireless hardware instruments. Hard neural interface platforms can damage neural tissues due to mechanical mismatch and indiscriminate electrical stimulation muddies clinical effects. Optogenetics that is one of the most powerful tools available achieves some capabilities in this context. However, cumbersome physical tethering impedes movement which can alter behavior and natural motion of an animal in a complex cage. This report introduces ultraminiaturized, fully implantable, soft optoelectronic systems designed for wireless optogenetics that can achieve such capabilities.

In comparison with previous technology, the biocompatible optoelectronic system in Fig.1A is substantially smaller, softer, and lighter [1, 2]. Employment of stretchable electronic concept allows robust operation under an extreme mechanical deformation or physiological strain conditions in Fig. 1A & B [3]. To determine utilities of these systems in studies of pain pathway and deep brain circuit regions, we tested whether these devices could optogenetically modulate sciatic and spinal cord nerves of mice expressing ChR2. In behavioral experiments performed in a modified Y-maze where one of arm is exposed to radio frequency signals, implanted devices lit up and cause the mice to feel discomforts when mice walked through a specific region in the maze. Upon leaving that part of maze, devices turned off and discomforts dissipated. As a result, animals quickly learned to avoid the region. These results are summarized in Fig.1C. Optogenetic stimulation of sciatic and/or spinal cord neurons in ChR2 mice produced robust and reversible nocifensive behavior that is entirely absent in control mice.

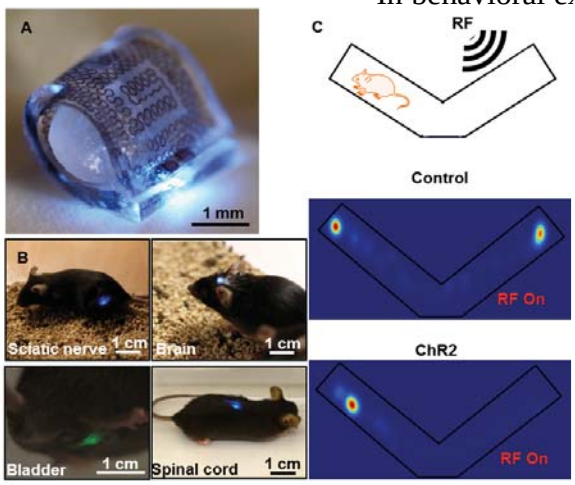


**Figure 1. Images of a soft optoelectronic device (A) and animals with the device implanted (B). Behavioral experiment results in a modified Y-maze.**

## References

[1] T. Kim et al., *Science* 340, 2013, pp. 211–216.
[2] S.I. Park, et al., *JNE* 12, 2015, No. 5.
[3] S.I. Park, et al., *Nat. Biotech.* 33, 2015, pp. 1280-1286.

# Two-dimensional titanium carbide sheets based high performance flexible wire type solid state supercapacitors

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2D transition metal carbides have attracted much attention in the electrochemical energy storage sectors. In this work, we demonstrated the fabrication and performance of titanium carbide-based wire type supercapacitors (WSCs) towards next generation energy storage devices. The layered titanium carbide sheets are prepared via selective extraction of Al from the precursor $Ti_2AlC$ using hydrofluoric acid and are extensively characterized using X-ray diffraction, field emission scanning electron microscope, high resolution scanning electron microscope, Fourier transform-infrared spectrum, and laser Raman spectral analyses, respectively. The X-ray photoelectron spectroscopy studies confirmed the presence of oxygen and fluorinated functional groups attached on the surface of titanium carbide. The electrochemical studies of the fabricated titanium carbide WSC devices showed ideal capacitive properties with a specific length capacitance of 3.09 mF $cm^{-1}$ (gravimetric capacitance of about 4.64 F $g^{-1}$), and specific energy density of about 210 nWh $cm^{-1}$ (in length) or 315 mWh $kg^{-1}$ (in gravimetric) with excellent cyclic stability. Further, a detailed examination on the capacitive and charge-transfer behavior of titanium carbide WSCs was investigated via electrochemical impedance analysis using Nyquist and Bode plots. Additionally, we also demonstrated the practical application of the titanium carbide WSCs, highlighting the path for its huge potential in energy storage and management sectors.

**Acknowledgement:**

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**References**

[1] Krishnamoorthy et al., *J. Mater. Chem. A, 5 (2017) 5726-5736.*

# Highly flexible and stretchable organic-inorganic electrode prepared by co-sputtering for wearable devices

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We fabricated highly stretchable organic-inorganic hybrid electrodes by co-sputtering on stretchable TPU substrate for used as stretchable electronics. Based on understanding of hetero-interfaces between nano-ITO/nano-structured metal, we will design and realize a high quality 2D/3D stretchable transparent electrode by hybridization of materials and processes (Vacuum/Printing/Transfer/Nano-imprint) to overcome the limit of current ITO and other transparent electrodes. Based on exact understanding of electronic structure/microstructure of the hetero interfaces, we will develop high quality stretchable 2D/3D transparent hybrid electrodes with a zone confining structure to apply in stretchable electronics. We investigated electrical, optical and mechanical properties using specially designed inner/outer bending test, stretching tests, twisting test and rolling test of organic-inorganic hybrid electrode fabricated by hybrid process. Effective combination of the inorganic and organic materials led to metallic conductivity and outstanding stretchability of organic. The optimized hybrid electrode showed a higher strain(~15%) than single inorganic electrode on TPU substrate. These results provide its potential and various applications in stretchable displays and electronic devices.

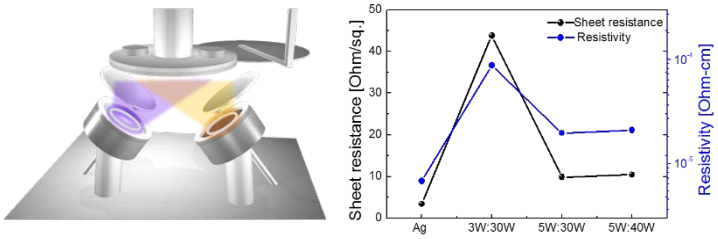


Fig. 1. Process of sputtering(left) and sheet resistance and resistivity of organic-inorganic hybrid films(right).

## References

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# The effect of shape anisotropy and materials composition on the optical gain properties of colloidal semiconductor nanoparticles

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Colloidal semiconductor nanoparticles (CSNs) are unique as optical gain media given (i) that their wavelength of emission can be tuned over a large spectral range by varying their shape, size and composition; (ii) their flexible surface chemistry which allows them to be incorporated into a myriad of optical cavities; (iii) their ease of fabrication by wet-chemical synthesis. However, the multi-fold degeneracy of their band edge states necessitates the formation of biexcitons (or higher order excitons) to realize optical gain, which inevitably introduces fast non-radiative Auger recombination processes. This is the primary reason amplified spontaneous emission (ASE) or lasing in CSNs typically requires optical excitation at high pump fluence from a pulsed laser. In this talk, our efforts to lower the optical pump threshold for achieving ASE and lasing in CSNs will be elaborated on - such as reducing Auger recombination rates by wavefunction engineering and increasing action cross-section by tuning the shape and size of the nanoparticles. The potential applications of CSN based gain media will also be highlighted, as well as obstacles that need to be overcome before they can be utilized in a practical manner.

# 3D-Configurational Organic Field-Effect Transistors via Self-Organization of Organic Semiconductors:Insulating Polymer Blends

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Recently, organic semiconductors blended with polymeric binders have been the topic of intensive investigations as a promising approach to improve the performance of the Organic field-effect transistors (OFETs). In this work, we realized unique OFET devices with 3-dimensional configuration based on self-organization of organic semiconductor: insulating polymer blends. Our key finding is that organic semiconductor molecules are vertically segregated on top of a polymer phase and simultaneously crystallized at the center of the printed line pattern immediately after solvent evaporation without the use of an additive, as shown in Figure 1[1]. The centro-apically phase-separated bilayer structure of the organic semiconductor:polymer blend was characterized and shown to readily form the OFET semiconductor and dielectric layers in a single step. In addition, we successfully demonstrated a highly sensitive OFET pressure sensor based on a combination of the three-dimensional organic semiconductor microstructure and an elastomeric top-gate dielectric [2].

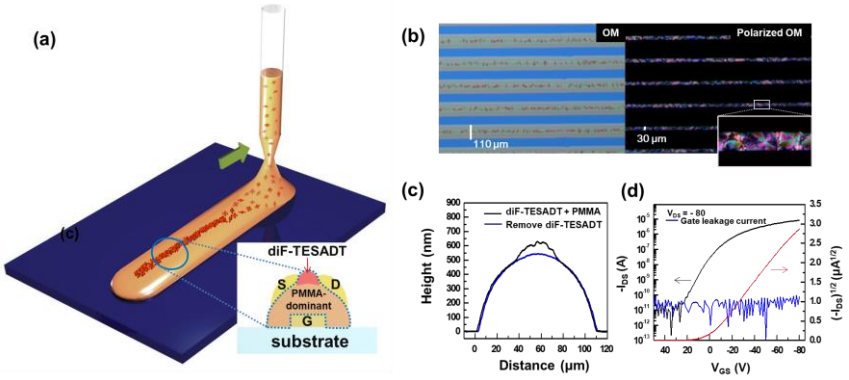


**Figure 1. (a) Schematic illustration on the centro-apical self-organization of diF-TESADT in the printed line patterns. (b) OM and POM images of the printed blend structure. (c) Comparison of the height profiles of the printed blend line before and after the selective removal of diF-TESADT. (d) Transfer curve of transistor based on one-step printed blend line.**

## Acknowledgements

*This work was supported by National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT & Future Planning (MSIP) (2017R1A2B2002721) and the Future Resource Research Program of the Korea Institute of Science and Technology (KIST).*

## References

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# Broad Ultraviolet Light Emitter using GaN Quantum Dots Grown on Multi-facet Three-dimensional Structures

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Ultraviolet (UV) light emitter have received much attention due to their versatile applications such as disinfection and UV curing. Conventionally, arc-lamps such as xenon- and mercury-arc lamps have been widely used as ultraviolet light emitter. However, their bulk system, heat generation and low efficiency make underutilized. In this respect, group III-nitride semiconductors-based UV light emitter have been suggested to replace conventional arc-lamps. In particular, GaN quantum dots (QDs) enable strong carrier localization within QDs and manipulation of emission wavelength via quantum confinement effect[1-2], which makes attractive for the UV light emitter.

In this work, we propose the GaN self-assembled QDs formed on GaN-based truncated pyramid structures including (0001) polar and {10-11} semi-polar facets. Since growth rate and intrinsic built-in electric field are different depending on the facets, it makes various emission wavelength from GaN QDs for each facets, which ultimately render broad UV emission spectrum covering from UV-A (~400 nm) to UV-C (~270 nm). Consequently, broad UV emission spectrum from these unconventional structures could satisfy various requirements for each UV applications. This result presents a potential to demonstrate broad ultraviolet light source based on solid-state emitter.

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# Design of conductive and non-biodegradable hydrogel using supramolecular self-assembling peptide for brain probe

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Self-assembling biomolecules have great advantages for developing a new material in terms of controlling assembly structure with tailored, high-level functions. Extensive researches have shown that advanced functional biomaterials can be developed by rationally designing the secondary structure of self-assembling peptide, but unwanted proteolytic degradation of peptide-based material imposes challenges on chronic *in vivo* utilization. To address the limitation, our focus was on peptidomimetic foldamer, particularly a β-peptide because it has not only the ability to mimic the structural and chemical characteristics of natural peptides, but excellent structural and proteolytic stability. We tested our hypothesis that the controlled complexation of self-assembling β-peptide with conductive nanomaterial would provide a functionally advanced biomaterial that can be used chronically *in vivo*. Here, we demonstrate a rational design of supramolecular β-peptide-based hydrogel for conductive and non-biodegradable hydrogel. Small-angle X-ray scattering (SAXS) and transmittance electron microscopy (TEM) images revealed the end-to-end assembling of β-peptide hexamers to construct axially-grown nanofibers. Interestingly, β-peptide nanofiber is found to wrap single wall carbon nanotube (CNTs) bundles in a way of superhelical mode, and effectively disperse the CNTs in the hydrogel. We demonstrated that the conductive hydrogel can be used both as surface electrocorticography (ECoG) electrode and local-field potential (LFP) electrode and collectively augment neural signals by inducing a tight coupling with neural tissue. The enzymatically and electrochemically enhanced self-assembling peptides and their nanomaterial complexes hold promising future as a new type of biomaterials for biosensor, tissue engineering, and regenerative medical devices.

# Cell drug reaction measured by temperature/impedance sensor

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In this study, a temperature/impedance sensor was fabricated to measure the cell-drug reactions by an electrical method[1]. In order to improve the performance of the sensor, the substrate of the sensor was made on 10 ㎛ thin silicon membrane by using the MEMS process[2]. A platinum pattern was deposited on this substrate using a sputtering process. For cell culture, polylysine treatment was performed and HeLa cervical cancer cells were cultured for 5 days. After culturing the cells, Cisplatin, an anticancer drug, was injected and the electrical and thermal drug reaction characteristics of the cells were monitored by measuring impedance and resistance. The measured results were compared with biological results, i.e. staining images, viability and CCK-8 test.

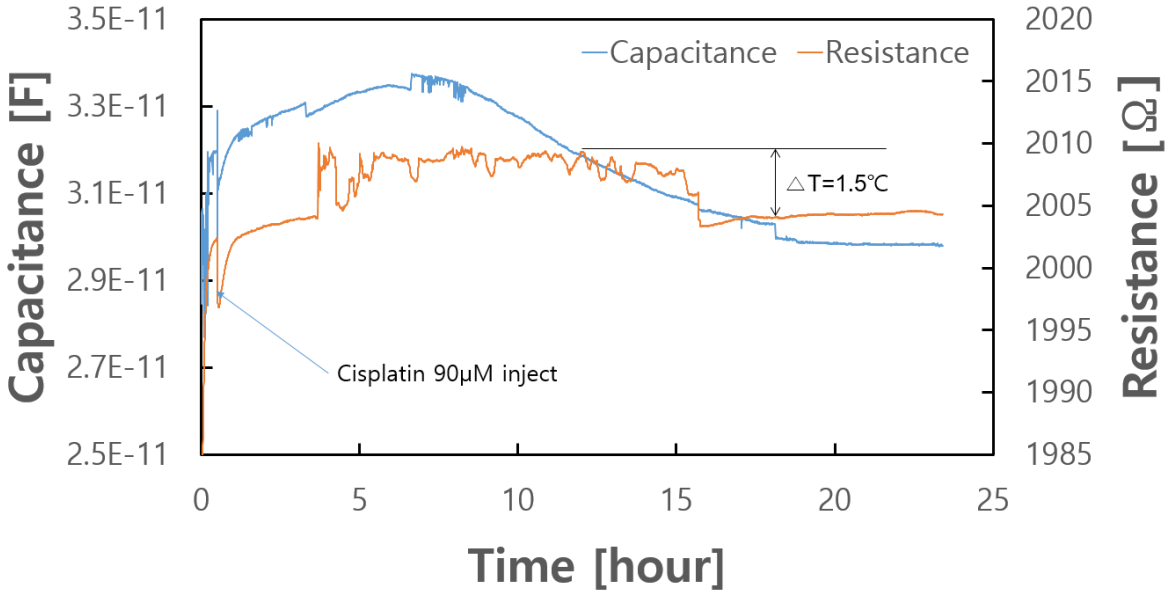


Fig 1. Resistance/Capacitance variation by cell drug reaction

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# High-efficiency $Eu^{3+}$-doped $BiF_3$ red-emitting nanoparticles for solid-state lighting and field emission displays

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Nowadays, the phosphor-converted white light-emitting diodes (WLEDs) are regarded as potential candidates to replace conventional lighting devices because of their advantage of high luminescent efficiency, low energy consumption, long working lifetime and eco-friendly feature. However, the commercial combination of yellow-emitting phosphors and a blue chip shows the shortage of low color rendering index (CRI) and high correlated color temperature (CCT) as a result of the insufficient red-emitting component in the luminescent spectrum. To modify the CRI and CCT values of the developed WLED device, another strategy using a near-ultraviolet (NUV) chip to excite the hybrid blue-green-red phosphors was proposed. Obviously, designing a highly efficient single red-emitting phosphor, which can be pumped by the NUV or blue light, is very important to improve the performance of the WLEDs. In this presentation, the $Eu^{3+}$-activated $BiF_3$ nanoparticles were prepared by a simple chemical precipitation method at room temperature. The phase composition, morphology, decay time, photoluminescence and cathodoluminescence properties of the prepared samples were studied in details. To explore the practical feasibility of the synthesized samples in solid-state lighting, a WLED device by coating the resultant nanoparticles, commercial blue-emitting and green-emitting phosphors onto a NUV chip was prepared and measured.

# Parameter Controls for Enhanced Peak-to-Valley Current Ratio in $MoS_2/MoTe_2$ van der Waals Heterostructure

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The $I_{ds}$-$V_{ds}$ properties of a van der Waals cross-junction of a few layers $MoS_2/MoTe_2$ were investigated, and the physical device parameter was altered in order to transform the conduction mechanism from thermionic to interband tunneling. The pristine heterostructure demonstrated a rectification behavior of typical p-n junction diodes, because of the p-type and n-type natures of $MoTe_2$ and $MoS_2$, respectively. Lowering the contact resistance between the metal and channel materials, by changing the electrode metals from Au to Pd and Ti, alone did not give rise to the carrier conduction through the hetero-interband tunneling between $MoTe_2$ and $MoS_2$. In addition to the reduction in contact resistance, the chemical doping of $MoS_2$ using BV achieves hetero-interband tunneling between $MoTe_2$ and $MoS_2$, which probably narrows the depletion layer by degenerating $MoS_2$. The peak-to-valley ratio of the tunneling current of the BV-doped heterostructure of $MoS_2/MoTe_2$ is about 4.8, which is comparable to that of the commercially available Si tunneling diode. [1]

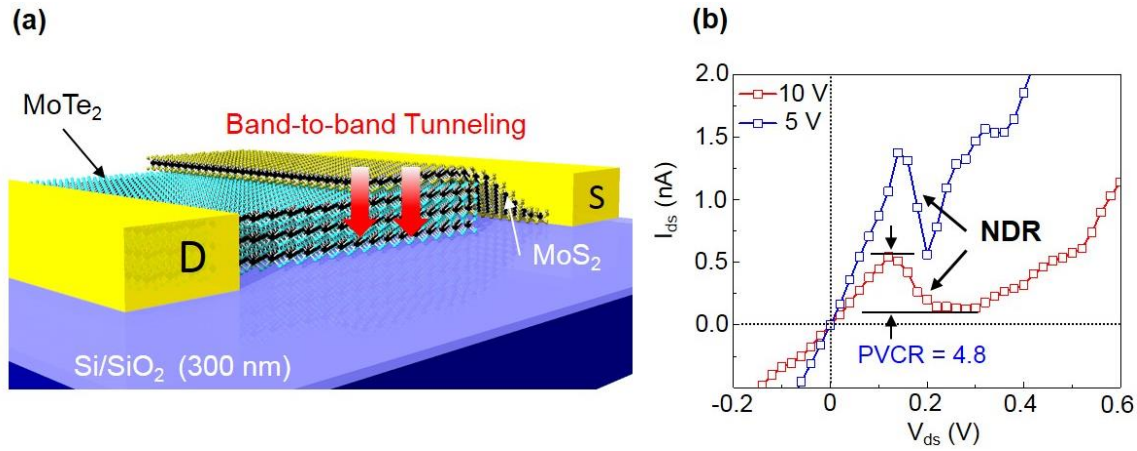


**Fig. 1. (a) Three-dimensional schematic diagram of the $MoS_2/MoTe_2$ heterostructure. (b) $I_{ds}$-$V_{ds}$ characteristics of the heterostructure with the observation of Negative Differential Resistance (NDR).**

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# Integrable Narrow Spectral Linewidth Surface Grating DBR Diode Lasers

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Broad area lasers are capable of very high power levels but typically have greatly broadened spectral linewidth (up to 10s of nm) and more than one emission wavelength. In many applications, including high power pump lasers for molecular or solid state laser systems and THz generation by optical heterodyning, these base spectral linewidths are often far too wide for efficient application. Laser emission with narrow spectral linewidth and on a single emission peak can be obtained by introduction of a suitable wavelength selective grating structure. In this work, we describe a family of distributed Bragg reflector (DBR) surface grating lasers that can have spectral linewidths narrower than 500 kHz and offer the possibility for multiple emission wavelengths for heterodyning applications.

*This work was supported by the University of Texas at Dallas Photonics Center*

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# Monolayer $WS_2$ Photonic Crystal Lasers

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Future large-scale integrated photonic system demands devices at atomic scales wit h virtually zero-energy consumption. [1] One of the key components in integrated phot onics is lasers, which limits the scaling and energy efficiency of the integrated photoni c systems. Over the years, various photonic cavities have been explored towards compact and nano-scale lasers, with photonic crystal (PhC) cavities to be one of the most promising one. [2-4] We report here a heterostucture photonic crystal cavity with high quality factor and strong lateral confinement based on a low index contrast material system (silicon nitride on quartz). [5] A room temperature continuous wave laser was also demonstrated based on monolayer $WS_2$ integrated onto such a PhC cavity. Low threshold lasing and highly directional beam have been obtained. We will also discuss progresses related to scaling of lasing cavity and scaling of gain materials towards few photon sources.

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# Au/$MoS_2$ Contacts: Charge Transfer and Interfacial Band Alignment

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Among numerous 2D semiconductors (SCs), $MoS_2$ is the most intensively studied one due to its desirable electrical and optical properties. Metal/SC contacts are essential components for the electrical characterizations of SCs and for SC device fabrication. Experimental and theoretical works have revealed that the 2D SC contacts have unique features distinct from those of 3D counterparts. In this talk, I will introduce recent research activities in my group to understand the electrical properties of the Au/$MoS_2$ contacts.
First, we studied the relationship between the resistance ($R$) and surface potential ($V_{surf}$) of CVD-grown $MoS_2$ trilayers with and without Au nanoparticles (NPs) while varying the gas ($N_2$, $O_2$, and $H_2/N_2$) environment. The ambient gas largely varied the $V_{surf}$ but could not cause measurable $R$ change for both the bare and NP-coated samples. The charges transferred from the gas adsorbates might be insufficient to change $R$ and/or be trapped in the defect states. The smaller $V_{surf}$ and larger localization length of the NP-coated sample, compared with the bare sample, suggested that more carriers and less defects enhanced the electrical conduction in $MoS_2$. Secondly, we investigated $V_{surf}$ of exfoliated $MoS_2$ flakes on bare and Au-coated $SiO_2$/Si substrates. The $V_{surf}$ of $MoS_2$ monolayers was much larger on Au than on $SiO_2$. $V_{surf}$ reached the bulk value at a number of layers was increased up to 30 and 120 on $SiO_2$ and Au, respectively. These results suggested that the difference in the interfacial electric field and the screening length depended on the underlying layers. The density functional theory calculations showed that the large electric dipoles formed at the $MoS_2$/Au interface could explain the notable $V_{surf}$ difference. All the measured and calculated results yielded the band alignment at the Au/$MoS_2$ contact, providing us with valuable insights to understand the electrical properties of metal/$MoS_2$ contacts.

# Opportunities of III-V/Si Hybrid Integration for Optical Modulation and Switching

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Si photonics is an indispensable platform for large-scale photonic integrated circuits (PICs). On Si PICs, an optical phase shifter is one of the fundamental functionalities for manipulating guided optical signal in a Si waveguide. For an optical modulator, the free-carrier effect such as the plasma dispersion effect in Si has been widely used to modulate optical phase. However, its low modulation efficiency and large optical loss are obstacles for large scale integration. The thermo-optic effect is another way to modulate optical phase particularly for an optical switch. However, the large power consumption and slow switching speed in the thermo-optic phase shifter limit its scalability and applications.

To provide a versatile scheme of optical phase shift, we have introduced the III-V/Si hybrid integration into a Si photonics platform. As shown in Fig. 1, a thin InGaAsP layer is bonded on a Si waveguide with an $Al_2O_3$ gate dielectric, which form a Si hybrid MOS capacitor. By applying a gate voltage, electrons accumulate at the InGaAsP MOS interface, modulating optical phase through the electron-induced refractive index change in InGaAsP. We have successfully demonstrated efficient and low-loss optical phase modulation using the Si hybrid MOS capacitor, promising for optical modulators and optical switches.

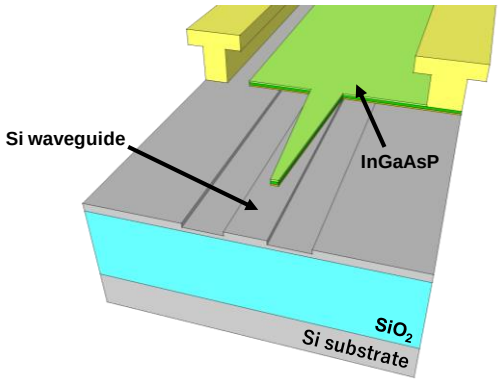


Fig. 1 Schematic of optical phase shifter based on III-V/Si hybrid MOS capacitor.

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# Semiconductor nanowires for optoelectronic and energy applications

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The excitement of nanowire research is due to the unique electronic and optical properties of these nanostructures. Both axial and radial heterostructure nanowires have been proposed as nano-building blocks for the next generation devices. The unique properties stem from their large surface area-to-volume ratio, very high aspect ratio, and carrier and photon confinement in two dimensions. These nanowires are usually grown by the so-called vapor-liquid-solid mechanism, which relies on a metal nanoparticle to catalyze and seed the growth. An alternative technique to grow the nanowires is by selective area growth technique, where a dielectric mask is first patterned on the substrate prior to growth.

I will present an overview of compound semiconductor nanowire research activities at The Australian National University. The optical and structural properties of binary and ternary III-V nanowires grown by metal-organic vapour phase epitaxy will be presented. Various issues such as tapering of the nanowires, compositional non-uniformity along nanowires, crystal structure and carrier lifetime will be discussed. Our results of enhancing the quantum efficiency of nanowires by using plasmonics are promising to improve the performance of nanowire devices. Finally, the results from our nanowire lasers, photodetectors, solar cells and photoelectrodes for water splitting will be presented.

# Effects of thermal and electrical stress on defect generation in InAs

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ABSTRACT

Defects in $HfO_2$ dielectric film caused by indium and arsenide diffusion from InAs were investigated. To investigate the thermal stability during post-deposition annealing (PDA) at 600 °C, we analyzed the ratio of elements on the surface of oxide layer and the chemical states using Time-Of-Flight Secondary Ion Mass Spectroscopy and X-ray Photoelectron Spectroscopy, respectively. In–As bonding was dissociated and In and As atoms were diffused through the $HfO_2$ layer from InAs. Fortunately, the diffusion and trap density could be controlled by using a 1-nm-thick $Al_2O_3$ passivation layer. In addition, we used the nitridation process to control the trap density. We evaluated the thermal and electrical stability of three samples, $HfO_2$/InAs, $HfO_2$/$Al_2O_3$/InAs, and nitrided $HfO_2$/$Al_2O_3$/InAs, by analyzing the change in trap density before and after PDA at 600 °C and stress-induced leakage current. In conclusion, the passivation layer effectively improved the thermal and electrical stability, whereas nitridation process using $NH_3$ gas did not. Moreover, although nitridation could reduce the interfacial defect states, due to structure distortion it induced the degradation of the device.

# Investigation of Optical Properties of InAs/GaSb Multiple Quantum Wells by Photoreflectance Spectroscopy

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We have investigated optical transitions in the InAs/GaSb multiple quantum wells (MQWs) by photoreflectance (PR) spectroscopy with various temperatures and excitation intensities. PR measurements were performed using a 405 nm laser diode as an excitation source. The probe beam obtained from a tungsten-halogen lamp dispersed through a monochromator. The reflected beam was collected by using a Si (400 ~ 1100 nm: high energy region) and InGaAs (1200 ~ 2400 nm: low energy region) photodiodes. The PR was employed to investigate the inter-band transitions such band-to-band ($\boldsymbol{E}_{GaSb}$), spin-orbit split off ($\Delta_0$), $\boldsymbol{E}_1$ and of GaSb [1] as well as their interface quantum states (IQS).

The room temperature PR spectra show near band transitions and above band transition for InAs/GaSb (5 ML/50 nm) MQW, respectively. PR spectra of the InAs/GaSb MQWs showed the $\boldsymbol{E}_{GaSb}$, the Franz-Keldysh oscillation (FKO) and IQS. We confirmed the transition energies from 0.72 eV, 1.52 eV, 2.07 eV and 2.53 eV corresponding to the $\boldsymbol{E}_{GaSb}$, $\boldsymbol{E}_{GaSb} + \Delta_0$, $\boldsymbol{E}_1$ and $E_1+\Delta_1$, respectively. Moreover, at room temperature PR spectrum, we observed sharp transition features due to the IQSs from the interface of InAs/GaSb. At near 1.2 eV region, we found unidentified transitions (UIS) and which were investigated by excitation intensity and temperature dependent PR. At low temperature PR result, we found the transitions between confined electrons states in InAs QW and GaSb valence band at energy of 0.506 eV.

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# High Performance Mechanically Flexible CMOS Technology for System Moore Integration

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Over recent years, flexible electronics has attracted considerable attention for its ability to enable new functional use cases. Healthcare, wellbeing, wearable electronics, structural monitoring, sport, telecommunication, security chips, smart textiles all belong to market segments that can take advantage of mechanically compliant electronic systems. Although printed and organic electronics can fill the demand for very simple systems such as tags, antennas, chipless RFID, it still struggles to address certain application classes for which increased complexity and bandwidth is needed. The basic idea developed in this paper is to combine the advantages of a high performance CMOS technology with mechanical flexibility based on substrate thinning. The distinctive feature of our approach is to push the thinning process to its ultimate limit by totally removing the silicon handler of CMOS-SOI substrates thereby leaving in place the minimum vital layers [1]. The transfer bonding of this minimal stack onto a judiciously selected host substrate subsequently determines the peculiar targeted augmented property such as mechanical flexibility, transparency or improved electrical performance [2]. We show that ultimate thinning and transfer bonding (UTTB) can be applied to demanding use-cases where the package becomes an integral part of systems with new functional properties in line with the so-called System Moore paradigm [3].

**Fig. 1:** Array of 12 CMOS chips transferred onto a paper sheet using the UTTB method. Excellent bendability is demonstrated by winding the host paper substrate on itself. (Insert) Transparency is obtained over the chip area not fully covered by the metal interconnection layers.

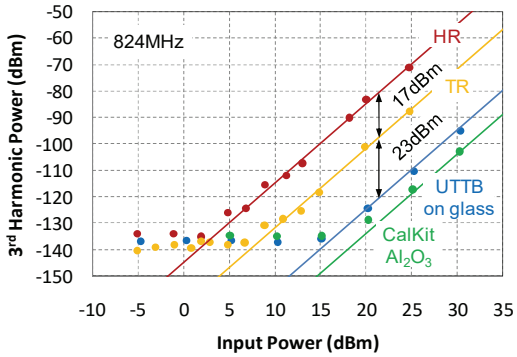


**Fig. 2:** Quantification of substrate non-linearity for a high-resistivity (HR), trap-rich (TR) and UTTB-on-flexible glass transmission lines. CalKit refers to a identical CPW on alumina for calibration. Significant third harmonic generation mitigation is obtained.

*This work was supported by: i) the STMicroelectronics-IEMN common laboratory, ii) the NANO2017 program, iii) the French government through the National Research Agency (ANR) under program PIA EQUIPEX LEAF ANR-11-EQPX-0025 and iv) the French RENATECH network on micro and nanotechnologies.*

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# Two Dimensional Materials for Human Interactive Wearable Electronics

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With the emergence of unusual format electronics such as flexible and wearable devices, an effort has been made to integrate devices with various functions in smart clothing and human body for providing enhanced convenience for the users. However, it is difficult to accomplish such emerging electronics with conventional rigid inorganic materials. 2D materials such as graphene and $MoS_2$, the thinnest elastic material, has superb electronic properties that make it a promising host for device applications and it has a good mechanical property, offering a great opportunity to flexible and wearable electronics that should maintain a stable operation under a high strain. In this talk, I will present various human interactive wearable electronic applications for including touch and tactile sensors and self-powered communication device.

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# Doped graphene layers as anode and cathode electrodes for semitransparent and flexible solar cells

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Semitransparent and flexible photovoltaic cells are advantageous for effective use of solar energy in many fields such as building-integrated photovoltaic systems and portable solar chargers. Many researchers have studied indium tin oxide (ITO)-based organic solar cells (OSCs).[1,2] However, the ITO electrode is not suitable for flexible applications in view of light transmittance, rigidity, and flexibility. Recently, Graphene (GR) has attracted much attention as a next-generation flexible transparent conductive electrode due to its outstanding properties. Here, we report semitransparent and flexible solar cells with bis (trifluoromethanesulfonyl)-amide (TFSA)- and triethylenetetramine (TETA)-doped GR layers as anode and cathode electrodes, respectively. The OSCs are composed of TFSA-GR/PEDOT:PSS/P3HT:PCBM/ZnO/TETA-GR, as shown in Fig. 1(a). Power conversion efficiency (PCE) of 3.30 and 3.12% are achieved by illumination through TFSA-GR and TETA-GR sides, respectively. Figs. 1(b) and (c) show normalized PCE of a typical flexible OSC as functions of inner/outer bending radius (R) for R = ∞, 12, 10, 8, and 6 mm. The OSCs maintain more than 99% of their original PCE values even after the bending tests at R = 12 − 6 mm. We also apply similar approach to flexible perovskite solar cells to obtain maximum PCE of 11.59%. The entire processes reported here are scalable and may pave the way for the development of very efficient building-integrated solar energy harvesting systems.

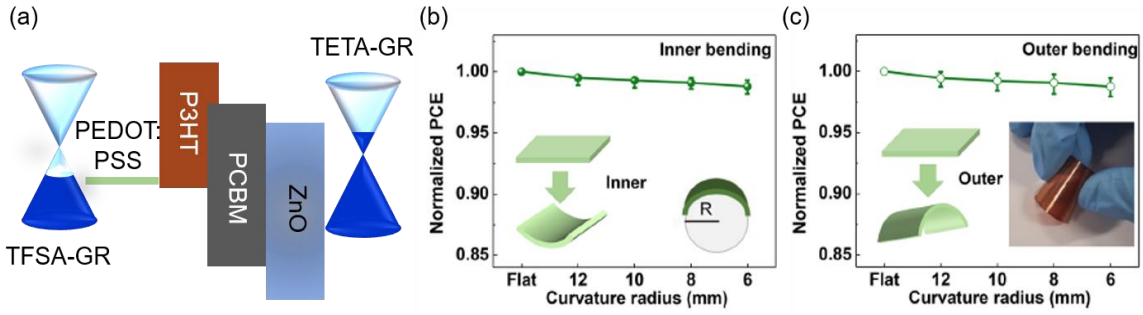


**Figure 1. (a) Energy band structure of a typical OSC. Changes of normalized PCEs as functions of bending cycles at R = ∞, 12, 10, 8, and 6 mm under (b) inner bending and (c) outer bending. The insets describe the bending tests and show a real image of a typical OSC.**

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**Hardness control of plastic frameworks to develop polyhedral image sensor**

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Polyhedral image sensors that detect objects in multiple directions overcome the limited field of view of a conventional planar image sensor with a given lens system. Among the related technologies, assembling planar images sensors on a mounting framework devices, as the recently commercially available products, seems to be simple but requires a framework to mount the sensory modules, which can be inefficient use of space. On the other hand, developing ultrathin image sensors and transforming into a wanted geometry should be promising as long as the device can be fabricated by using conventional silicon-based technology without losing special efficiency. The issue in this technology is to control hardness of the flexible layer of the ultrathin sensor. In this work, we used an acrylonitrile butadiene styrene (ABS) as a framework to support the electronic layer and controlling hardness of the framework by exposing acetone plasticizer. The mechanical, optical, and electrical analysis shows that the plasticization of ABS reduces the applied stress of fragile Au electrode below ultimate stress during transformation. Finally, a tetrahedral image sensor fabricated by this method demonstrates an omnidirectional optical system with minimal aberration.

# Exploring Solution Processible Solar Cells – Interface & Architecture

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Solar energy provides limitless resource for human being to address the terawatt energy challenge. The ideal photovoltaic (PV) technology needs to be earth abundant, non-toxic, and very low cost etc. Solution processed solar cell based on organic polymer (Macromolecule) and organometal halide hybrid perovskites are both promising candidates for printable PV technologies. The advantages include low material cost, low temperature fabrication and their compatibility with printing/coating processes (roll-to-roll), high material utilization etc. They also provide attractive properties like flexibility, light weight, and transparency.

For polymer solar cells, the progress in single junction architecture is encouraging, but still need major boosts to make it competitive in the solar photovoltaic technology landscape. With the single junction cell now reaching 12% level, it is an exciting time to push it further forward. Multijunction or tandem structure solar cell, with complementary bandgaps, can overcome the Schockley-Quiesser efficieny limit of single junction solar cell. Adopting the beautiful theory to enhance polymer solar cell efficiency while at the same time preserve the low cost promise, is the reasoning behind the solution process tandem polymer solar cells.

In this presentation, I will talk about the journey in the efforts towards high efficiency single junction, double junction and triple junction tandem polymer solar cells[1], different device architectures[2], the promise and practice to integrate solution process solar cell with other mature solar technologies[3, 4].

My group in HK is also interested in exploring the application of hydrophobic organic semiconductors in Perovskite Solar Cells[5]. We incorporated p-type π-conjugated polymer (PBDB-T) into the anti-solvent process of perovskite film formation. PBDB-T triggers a heterogeneous nucleation over the perovskite precursor film and passivate the trap states of the mixed perovskite film through the formation of Lewis adducts between lead and oxygen atom in PBDB-T. The process improves charge-transport, and thr hydrophobic PBDB-T prevents moisture invasion into the perovskite active layers. This leads to high-efficiency ~20%, and significantly improved device stability (under 85$^{o}$C thermal stress as well as white illumination).[6] Results using other organic molecules will also be discussed. This approach provides an effective interface engineering direction for high-efficiency, high-stability and low-cost PSCs.

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# Nanocrystal Conversion Chemistry Confined within a Nano-sized Solid-State Medium

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The "NC conversion chemistry" concept, which involves the compositional, crystalline, and morphological transition of preformed nanocrystals during various chemical reactions, allowed us to access to more diverse and complex materials that cannot be obtained using traditional bottom-up methods. This approach has been the most successfully employed in the recent production of hollow nanoparticles (NPs) that have received considerable attention as attractive candidates for biomedical and catalytic applications. In this regard, our research was devoted to developing a simple and versatile solid-state conversion strategy that can contribute to the development of the method of fabricating hollow NPs of increasing complexity and functionalities, by exploiting an understanding of the transformation of NPs during their dimensionally confined reaction within a nanosized silica sphere. In this presentation, I would like to present recent findings that can contribute toward a more complete understanding of the pathway for the hollow transformation of the manganese oxide NC within the encapsulating silica nanosphere. During our study with $MnO_x$@$SiO_2$, containing a $MnO_x$ NC inside the $SiO_2$ nanosphere, we encountered an unexpected the transformation into a hollow manganese silicate nanoparticle (NP) at 600 °C. This transformation was finally revealed to be caused by the phase transition of initially separate MnO and $SiO_2$ into a thermodynamically stable manganese-silicate phase. Interestingly, the resultant hollow silicate nanospheres was found to revert to the initial core@shell structure when subjected to air oxidation by the filling of the interior cavities with a segregated $Mn_3O_4$ phase. Moreover, the additional incorporation of catalytically active Pt nanocrystals allowed another discovery of the reversible and cyclic conversion of its interior structure from solid to hollow and back to solid nanostructures during the oxidation and reduction cycles. On the other hand, the incorporation of $Ni^{2+}$ in the silica shell resulted in the growth of a single Ni NC at the newly generated hollow silicate cavity. This could be elucidated based on the preferential reduction of Ni over Mn in the in-situ generated $Ni_xMn_{1-x}O$ mixed-oxide phase. Along with providing an insight into the NC conversion mechanism, this finding was also exploited to devise a protocol for fabricating a colloidal hollow nanoreactor that can selectively catalyze organic reactions, thus extending the usefulness of our nanospace-confined solid-state conversion strategy.

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# Degradation mechanism analysis of localized region of perovskite films using the photo thermal induced resonance technique

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Organic-inorganic mixed halide perovskite ($MAPbX_3$: MA=$CH_3NH_3^+$, X =$Cl^-$, $Br^-$, or $I^-$) are attracting intense interest as promising absorber materials for solar cell due to its broad absorption range and long charge carrier diffusion length.[1] However, their poor stability remains a major challenge for high performance device and their commercialization.[2] Generally perovskite films based on $CH_3NH_3PbI_{3-x}Cl_x$ undergo rapid degradation when exposed to oxygen and light.[3] To overcome this problem, many researchers have been studied about the degradation mechanism of perovskite films. However, these results were not simultaneously obtained with structural and chemical properties of localized region of perovskite films. Thus it is not provided complete degradation mechanism analysis of perovskite films.

In this work, we investigated the degradation mechanism of localized region of perovskite films and also simultaneously obtained the structural and chemical results using the photo thermal induced resonance technique combined with atomic force microscope. Finally, this study will contribute to understanding of the mechanism of the degradation process of perovskite films and enhance the stability of perovskite optoelectronics field.

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# Energy Transfer from CdSe/ZnS Quantum Dots to Organic-Inorganic Mixed Halide Perovskite

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Recently, organic-inorganic halide perovskite ($MAPbX_3$; MA = $CH_3NH_3^+$, X = $Cl^-$, $Br^-$, or $I^-$) have attracted attention as the prospective materials for photovoltaic and optoelectronics. The perovskite (PS) film can be synthesized by using simple spin-coating method due to their self-assembling characteristic. However, PS film has a poor stability when it is exposed to moisture in air. In order to develop the air-stable PS film, we synthesized the mixed halide PS ($MAPbI_2Br$), which is well known as a better humidity resistance in air, and then CdSe/ZnS quantum dots (QDs) synthesized on top of the PS film to improve stability and quantum efficiency. The MABr and $PbI_2$ powders were dissolved in mixed solvent of N,N'-dimethylformamide (DMF) and dimethylsulphoxide (DMSO), and then the $MAPbI_2Br$ solution stirred at 60°C. The $MAPbI_2Br$ solution was coated onto the ITO substrate by two-step spin coating processes at 1000 rpm for 10 s and at 5000 rpm for 20 s, and then annealed at 100°C for 30 min. The powder of CdSe/ZnS QDs was dissolved in toluene, which were stirred at 60°C. The surface and crystallinity of the synthesized PS and QD/PS films have been examined by using scanning electron microscopy and X-ray diffraction, atomic force microscopy measurements, respectively. In this paper, we present the temperature- (T-) dependent energy transfer (ET) from CdSe/ZnS QDs to organic-inorganic mixed halide PS film investigated by using the T-dependent photoluminescence (PL) and time-resolved PL. The PL spectra of PS and QD/PS films exhibit the two gaussian peaks, which is attributed to the photoinduced halide segregation. The PL intensities of QD/PS film at 10 and 300 K are increased about 3 and 7 times than that of PS film, respectively, and the PL decay times for QD/PS film is longer than PS film. The calculated ET efficiency is about 60 % and the internal quantum efficiency of QD/PS film is higher than QD film. We demonstrate the enhanced quality and efficiency of PS films by T-dependent ET process from QDs to PS.

# Emergence of Weyl semimetals in topological phase transitions

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In topological semimetals, the band gap closes at generic points or lines, due to topological reasons. They include Weyl, Dirac and nodal-line semimetals. Weyl semimetals [1-3] are semimetals with nondegenerate 3D Dirac cones in the bulk. As we have shown in [1,3,4], a Weyl semimetal phase necessarily appears in a transition between topological and ordinary insulators for any inversion-asymmetric crystals. Namely, if the gap of an inversion-asymmetric system with time-reversal symmetry is closed by a change of an external parameter, the system runs either into (i) a Weyl semimetal phase or (ii) a nodal-line semimetal [4]. This transition is realized e.g. in tellurium (Te). Tellurium has a chiral lattice structure, and lacks inversion symmetry. At high pressure the band gap of Te closes and it runs into a Weyl semimetal phase, as shown by our ab initio calculation [5]. Weyl semimetals can arise in other types of topological phase transitions, e.g. topological phase transitions of topological crystalline insulators with glide symmetry [6].

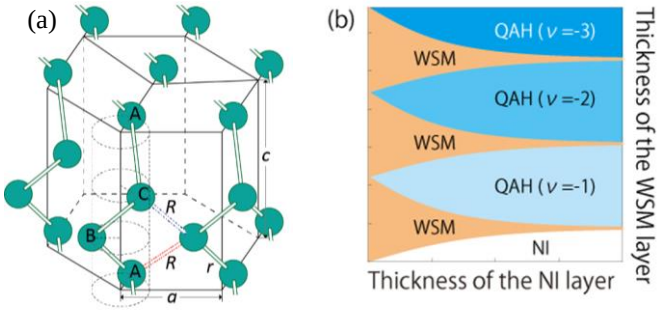


Fig.1 : (a) Lattice structure of Te [5]. (b) Phase diagram of the NI/WSM superlattice [7].

Such kind of interplay between symmetry and topology in Weyl semimetals also emerges when we make a superlattice. We show that a superlattice between a Weyl semimetal and an ordinary insulator shows a rich phase diagram, including a quantum anomalous Hall phase, with various Chern numbers [7].

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Title:
Chiral hinge states and surface quantum anomalous Hall effect in ferromagnetic axion insulators

Abstract:
A universal mechanism to generate chiral hinge states in the ferromagnetic axion insulator phase is proposed, which leads to an exotic transport phenomena, the quantum anomalous Hall effect on some particular surfaces determined by both the crystalline symmetry and the magnetization direction. A realistic material system Sm doped $Bi_2Se_3$ is then proposed to realize such exotic hinge states by combing the first principle calculations and the Green's function techniques. A physically accessible way to manipulating the SQAHE is also proposed, which makes it very different with the QAHE in ordinary 2D systems.

# Violation of Ohm's law as a signature of the three-dimensional Weyl metal

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Ohm's law is a fundamental paradigm in the electrical transport of metals. Any transport signatures violating Ohm's law would give an indisputable fingerprint for a novel metallic state. In this talk, we discuss violation of Ohm's law resulting from chiral anomaly in $Bi_{0.96}Sb_{0.04}$, which becomes a three-dimensional Weyl metal in parallel electric (E) and magnetic (B) fields. We observe nonlinear conductivity component proportional to $E^2$, which occurs only in the longitudinal configuration (E//B). This nonlinear conductivity in the longitudinal configuration is described by Boltzmann transport theory that incorporates chiral anomaly and resultant charge pumping phenomenon. As the Boltzmann transport theory suggests, the nonlinear conductivity components at different E and B are scaled into a single universal function. As a hallmark of the Weyl metal, the nonlinear conductivity of the Weyl metal opens the door for nonlinear optical applications and the development of a topological Fermi-liquid theory beyond the Landau Fermi-liquid theory.

# Atomic and electronic structures of 2D semiconductors

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Semiconducting materials are the basic building blocks of thermoelectric and solar cell device applications, and diverse bulk materials have been extensively investigated. To improve the device performances, nanoscale materials are also investigated as novel semiconductor materials with unusual electronic structures from confined atomic structures. Recently, research on 2D materials has been focused van der Waals materials such as graphene, h-BN and transition metal dichalcogenides (TMDs), and stabilized metal layers between oxides. The substrate oxide interacts strongly with metal atomic layer facilitating uniform atomic layer formation as well as modifying the atomic and electronic structures of the metal layer. In this talk, we will discuss about DFT modeling study on TMDs and oxide-stabilized metal layers with 2D semiconductor electronic structures. 2D semiconductors and their alloys are promising material platform to develop novel electronic and photonic applications.

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# Rapid Chemical Vapor Deposition of Graphene for Continuous Growth

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Controlling the properties of graphene is very important and attractive issue in graphene research. As we know the graphene get from natural graphite or artificially synthesized it and the latter case is easier than former which is manipulating the properties of graphene, relatively.

Based on this motivation, we have investigated the synthesis conditions of pristine and doped graphene using chemical vapor deposition (CVD)[1, 2] method with various organic precursors, such as methane($CH_4$), pyridine($C_5H_5N$)[3], liquid petroleum(LPG)[4] and so on. For the synthesis of high-quality graphene, the growth condition has optimized by controlling the CVD parameters. As a result, we have successfully grown the graphene and doped graphene under very short growth time. It has shown 10 times faster than typical growth condition using CVD with methane ($CH_4$), previously.

In Raman spectra, 2D/G ratio and D/G ratio of samples have shown significantly different results according to supplying sources. Especially, in the case of N-doped graphene grown by pyridine source, D-peak intensity is increase, G-peak is blue shift and 2D-peak intensity is suppressed.

In x-ray photoelectron spectra, our pristine graphene has shown clear C1s-peak, and N-doped graphene has shown asymmetric broad C1s-peak from C-N bond and N1s-peak from graphitic-N bond, dominantly.

In addition, based on these recipes, we developed the roll-to-roll CVD system for continuous growth. It can be produce a 10 m long graphene film within 1 h using this technique.

More details will be provided in the presentation.

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# Gate Modulation of Spin-orbit Interaction in Graphene/$WS_2$ Heterostructure and Its Applications

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We have fabricated a dual gate $WS_2$/bilayer graphene/$WS_2$ sandwich device to address the gate modulation of spin-orbit interaction (SOI) by measuring the quantum interference transport and Shubnikov-de Haas (SdH) oscillations. The bilayer graphene (BLG) sandwiched between $WS_2$ films shows the weak anti-localization (WAL) effect at low temperature. The WAL effect in the 2D system is a quantum interference phenomenon, which has assisted for a long time as a direct and precise method to probe the SOI in conductors. The giant SOI has been found in BLG, which is due to the interfacial interaction of $WS_2$ on both sides of graphene. The magnitude of SOI relaxation time ($\tau_{so}$) in $WS_2$-encapsulated BLG is almost 10 times smaller than $\tau_{so}$ in graphene on ordinary substrate. We also found that the SOI of BLG is tuned by applying gate voltages.

To confirm these results, we have also measured SdH oscillations, which provide unambiguous evidence of the zero-field spin-splitting due to a strong SOI. We performed two ways to estimate the magnitude of SOI in the framework of the Rashba SOI mechanism. The estimated values of SOI through WAL analysis and SdH oscillation analysis give similar results, supporting the self-consistency of our experimental results. The effective gate modification of SOI strength in the graphene-based system enables this study to explore new areas of the field-effect spin transport phenomenon. The SOI-induced spin-splitting changed from 5 to 25 meV depending on gate voltages. Given that the spin-orbit coupling constant was controlled effectively by gate voltage, the graphene/$WS_2$ heterostructure should be a strong candidate as a channel material for a spin field-effect transistor.

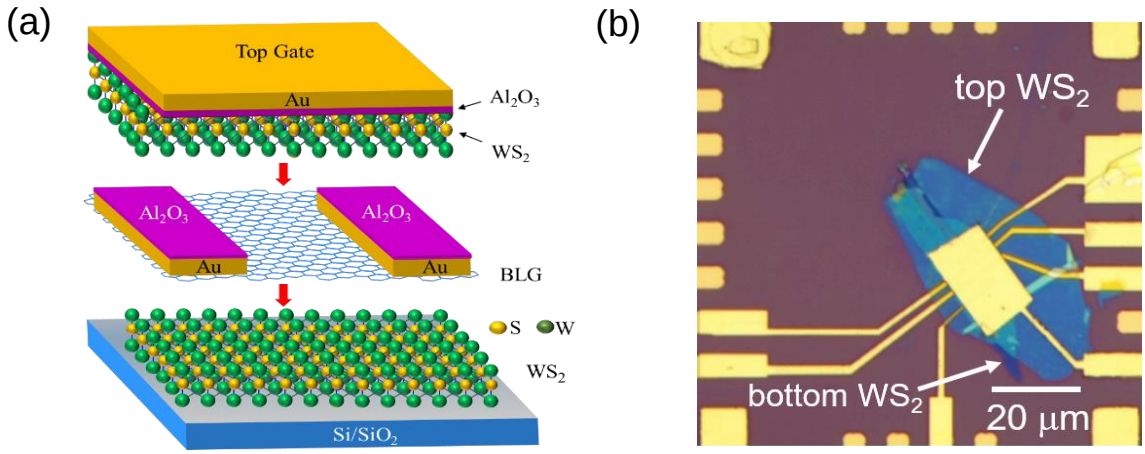


**Figure 1.** (**a**) Schematic of bilayer graphene sandwiched between multilayer $WS_2$. (**b**) Optical microscope image of the $WS_2$/BLG/$WS_2$ sandwich device.

# Band bending and light-induced changes on grain boundaries in high-efficient $Cu_2ZnSn(S,Se)_4$ thin-films with high photo-conversion efficiency

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Due to the suitable electrical and optical properties, $Cu_2ZnSn(S,Se)_4$ (CZTSSe) is one of the most promising materials for thin-film solar cells. As of 2018, the best power conversion efficiency of CZTSSe solar cells is 12.6%, which is yet much lower than of Si and $Cu(In,Ga)Se_2$ solar cells. In this study, we used CZTSSe thin-films which were grown by dual processes of sputtering. we investigated optoelectrical properties of the CZTSSe thin-films via Kelvin probe force microscopy (KPFM) under light-illumination having three different wavelengths: red (640 nm), green (532 nm), and blue (405 nm). Upward energy band bending at/near grain boundaries (GBs) has been observed in high-efficient kesterite thin-film surfaces grown from compound precursors [1,2]. On the other hand, the surface potential variation of the thin-films grown from metal precursors indicates upward potential bending. Under the illumination, the energy band bending showed a significant change and also a dependence of the locations of the GBs. Even though the GB potential barrier decreases, the band bending of the material can help the carrier separation between the interfaces. Thus, we can suggest the existence of interfacial states altering the band alignment to assist the carrier transport in the thin-film solar cell devices.

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# Characterization of conductive $SrVO_3$ thin films grown on various substrates by RF magnetron sputtering

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Thin films exhibiting high electrical conductivity and high optical transparency in the visible spectrum has proved challenging. It requires minimization of photon absorption and reflection while preserving a high carrier concentration and low carrier scattering rate. But the parameter combination of the $SrVO_3$ represents a better trade-off not attainable by conventional transparent conductors in the absence of strong electron correlation, and brings $SrVO_3$ films closer to ideal transparent conductors. We have been interested in transitional metal vanadium oxides having a perovskite structure accompanied by high transparent conductive performance. The transparent conductive thin films including $SrVO_3$ show significantly improved conductivity. For example, the $SrVO_3$ thin films may have electrical conductivity about two or three times higher than that of an ITO electrode.

$SrVO_3$ thin films with ~180 nm in thickness were grown on a-plane, c-plane, r-plane and m-plane sapphire, Si, $SiO_2$/Si and $LaAlO_3$ substrates under identical conditions by sputtering deposition from $SrVO_3$ targets. Considering the complex phases of $SrVO_3$ material system, the growth temperature and sputtering gas ambient were optimized and precisely controlled to yield conductive $SrVO_3$ phase. The sputtering pressure was set at 6 mTorr with 25% $H_2$/(Ar+$H_2$) gas. All samples were grown at 350~500 ℃. After sputtering, all samples were annealed. Using $H_2$ mixed gas, we succeeded in growing $SrVO_3$ phase. In contrast, only $Sr_2V_2O_7$ phase was grown using Ar gas during sputtering.

The structural and morphological properties of all samples were studied by X-ray diffraction (XRD), scanning electron microscopy (SEM), and Raman scattering. The Hall effect parameters of all samples were measured using Keithley 4200. The optical properties, i.e. dielectric functions and band gap energies, were measured using spectroscopic ellipsometry. Details of properties of conductive $SrVO_3$ phase will be discussed.

# ZnS Buffer Layers Grown by Modified Chemical Bath Deposition for CIGS Solar Cells

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ZnS thin films were prepared by the chemical bath deposition method using disodium ethylene-diaminetetraacetic acid ($Na_2EDTA$) and hexamethylenetetramine (HMTA) as complexing agents in acidic conditions. The film prepared using a preheated S-ion source showed full surface coverage, but some clusters were found that were generated by the cluster-by-cluster reaction mechanism. On the other hand, the film prepared without this source had a uniform, dense, and smooth surface and showed fewer clusters than the film prepared using a preheated S-ion source. The x-ray photoelectron spectroscopy spectra showed the energy core levels of Zn, O, and S components, and Zn-OH bonding decreased on the film using the preheated S-ion source. Especially, various binding energy peaks were found in the Zn 2p3/2 spectrum by Gaussian function fitting, and no peak corresponding to Zn-OH bonding was found for the film prepared using a preheated S-ion source. Moreover, the x-ray diffraction spectrum of the ZnS thin film using a non-preheated S-ion source showed amorphous or nanoscale crystallinity, but the emission peaks indicated that the structure of the film using preheated S-ion source was zincblende.

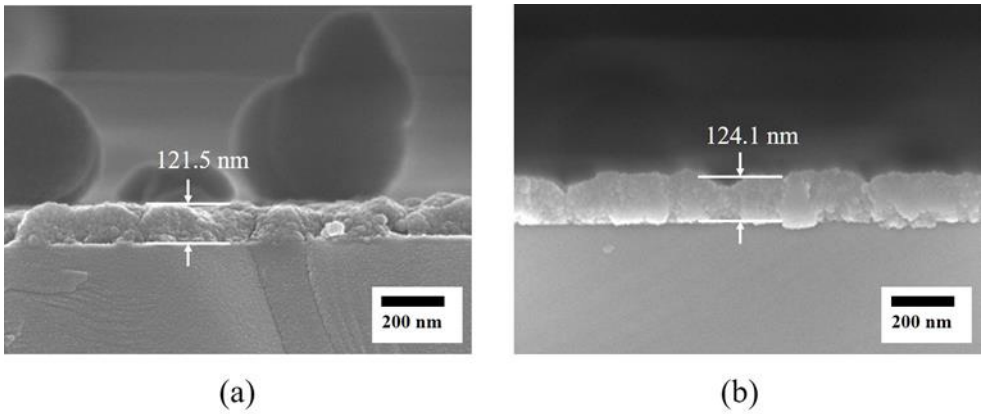


**Figure 1. Cross-sectional images of (a) ZnS-1 and (b) ZnS-2 films; the film thicknesses were 121.5 nm and 124.1 nm, respectively.**

*This work was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, Science, and Technology (2011-0024709), and by the Priority Research Centers Program (2009-0093818).*

# Semi-transparent organic solar cells for tandem with CIGS solar cells

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A promising approach for upgrading the performance of an establish low-bandgap solar technology without adding much cost is to deposit a high bandgap polycrystalline semiconductor on top to make a tandem solar cell. We use a transparent silver nanowire (AgNW) electrode on organic solar cells to achieve a semi-transparent device [1]. We place the semi-transparent cell in a mechanically-stacked tandem configuration onto copper indium gallium diselenide (CIGS) to achieve solid-state polycrystalline tandem solar cells with a net improvement in efficiency over the bottom cell alone. Since OPV can be prepared as a semi-transparent device, thanks to nanometer size of Ag NW, tandem cell can be constructed by positioning a OPV as a top cell. The P3HT/PCBM blend ($E_g$ =1.9 eV), which is a widely used organic photovoltaic material suitable for the short visible range, is chosen as the top subcell material. CIGS solar cell ($E_g$ = 1.7 ~ 1.0 eV, x = 0 ~ 1) is used as the bottom cell material, because of its performances in the long visible and infrared spectrum.

To our device the sample for a monolithic tandem of organic solar cells on CIGS, the Ag NW electrode has a 80% transmission with no parasitic absorption from the heterojunction window layers and for the top cell, 90% EQE with a sharp bandgap was assumed with an $E_g$-$V_{oc}$ gap of 0.3 V and a FF of 0.75. For the bottom cell, the system was composed of a DC sputter for the Mo back electrode, a co-evaporator for the CIGS absorption layer, and RF sputter for the ZnO and the TCO window layers. To estimate the tandem efficiency, the $V_{oc}$ was added from the top and bottom cells and the $J_{sc}$ and FF were chosen as the lower from the two cells. The results will be presented in detail

*This work was supported by the Basic Science Research Program (NRF-2011-0024709) through the National Research Foundation of Korea (NRF), funded by the Ministry of Education, Science and Technology and the Priority Research Centers Program (2009-0093818)*

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# Role of Ag, In and Te in AgInSbTe for superior Phase-Change Material

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Since Intel commercialized 3D X Point memory through Phase-Change Materials(PCM), attempts to design much adequate materials for Phase-Change Random Access Memory(PCRAM) are ignited again. Revealing Phase-Change mechanisms of superior PCMs such as AgInSbTe and GeSbTe are main question to design better PCM.

Phase-Change mechanism of AgInSbTe(AIST) in atomic scale is firstly established by Yamada et al. That is “crystallization of AIST is generated through avalanche of bond interchanges by Sb”. However, roles of the other elements, Ag, In and Te in local structural change are not analyzed yet in atomic level. Through XPS, how Ag, In and Te assure improved phase-change properties of SbTe such as thermal stability and cyclability is also studied.

# Temperature dependence of dielectric function of $Bi_{1.85}Gd_{0.15}Te_3$ by modeling

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Bismuth telluride doped gadolinium has been reported recently to be useful in topological insulator studies [1]. The complex dielectric functions of bismuth telluride doped gadolinium as a continuous function of temperature is required for engineering high-performance devices. However, no analytic representation on temperature dependence of these dielectric functions has been reported so far.

Here, we report the parameters required to calculate and represent the dielectric function of $Bi_{1.85}Gd_{0.15}Te_3$ over the energy range of 0.74 to 6 eV and the temperature range from 28 to 300 K using dielectric function parametric model (DFPM). The source data were taken by spectroscopic ellipsometry measurement. To obtain the best representation of the intrinsic dielectric response of the materials, the sample were well cleaved with a shiny surface perpendicular to the c axis and treated by Scotch tape method. The DFPM provides reasonably convenient means for accurately establishing the asymmetric characteristics of optical functions of the materials as the sum of polynomials and poles. We are therefore able to reconstruct the dielectric functions of $Bi_{1.85}Gd_{0.15}Te_3$ for arbitrary temperature in the specified spectral range. These results will be useful for high-performance topological devices based on $Bi_{1.85}Gd_{0.15}Te_3$.

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# Influence of growth temperature on the crystallinity of AlN films grown by pulsed sputtering deposition

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AlN has been studied for various applications such as UV light and acoustic wave devices. Recently, in addition to metal organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE), new growing methods such as laser deposition [1] and pulsed sputter deposition (PSD) [2] were adopted for the growth of high qualtiy AlN layer.

We have studied the AlN growth conditions of PSD. A sapphire substrate was used as the substrate. An ultra-high vacuum sputter with a load-lock chamber was used for the growth. In our previous research, the growth conditions such as plasma power and the gas flow amount were optimized in terms of the crystallinity of the AlN thin film. In this study, we investigated the influence of the growth temperature. Also, the experimental results were discussed focusing on the change of residual strain in the AlN thin film.

Growth conditions were as follows. The plasma power was 300 W and the Ar:$N_2$ gas flow ratio was 3:2. The operating conditions of the pulsed power supply were $t_{off}$ = 2μs at f = 50kHz. The growth temperature was varied from room temperature to 500 ℃.

As shown in the Fig. 1, when the growth temperature increased the full-width at half-maximum of AlN films decreased from 2000 arcsec to <1000 arcsec. Residual stress in the film was also reduced. These changes have been generally attributed to the increase in the migration length. We found that, however, the decrease in plasma damage also plays an important role in improving the crystallinity.

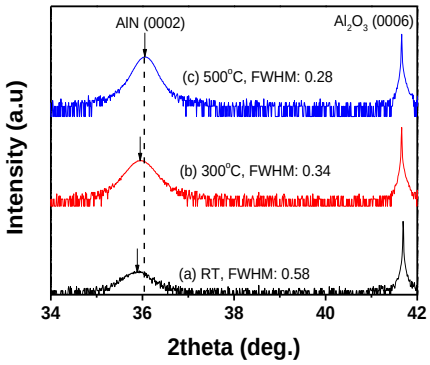


**Figure 1 XRD theta-2theta pattern of AlN films grown at (a) RT, (b) 300 ℃ (c) 500℃**

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## Acknowledge

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# Improved Performance of Zinc Oxide Thin Film Transistors with Reduced Graphene Oxide Embedded Active Layers

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Amorphous oxide semiconductor thin film transistors (AOS-TFTs) have been widely used to control a variety of display devices using liquid crystals, light-emitting diodes, and transparent and flexible materials. These AOS-TFTs have exhibited higher mobility and optical transparency in the visible region compared to conventional a-Si TFTs, along with good compatibility with existing a-Si TFT manufacturing processes. Currently, indium-gallium-zinc-oxide (IGZO) is one of the most popular materials used for AOS-TFTs, but indium-free materials such as ZnO have always been searched owing to indium's scarcity on earth and increasing cost. However, presently, the performance of ZnO TFTs are not good enough to drive large-scale, high-definition display devices due to their low carrier mobility and high subthreshold swing. To overcome these problems, ZnO/graphene combined structures have been employed in many groups. Jilani et al. reported hybrid TFTs with high mobility by getting ZnO nanostructures embedded in the graphene oxide [1]. Song et al. used ZnO/graphene bi-layer structures to improve the mobility and on-off ratio [2]. However, these hybrid ZnO TFTs showed ambipolar behaviors, not suitable as a switching element of the display, because of large power consumption even in off-state of the display.

In this study, we proposed a bottom-gate staggered ZnO TFT incorporating reduced graphene oxide (rGO) in the middle of the ZnO active layer. In this structure, the ZnO layer simply acts as an n-type channel layer under positive biases while the inserted rGO layer improves the electrical conductivity of the active layer. Under negative biases, the rGO layer acts as a p-type channel while insulating ZnO layers surrounding the rGO block the current. As a result, we obtained suitable unipolar switching characteristic TFT for the display application with high field effect mobility, on/off ratio and low subthreshold swing.

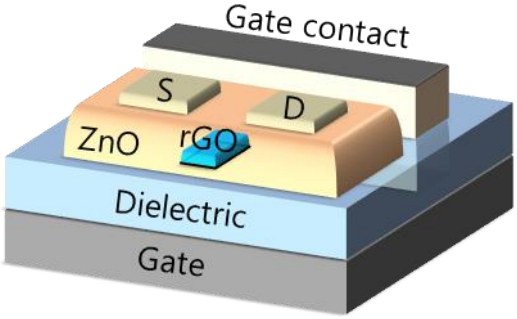


**Figure 1**: Schematic of the bottom-gate staggered ZnO TFT with an rGO-embedded active layer.

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# Effect of Ge doping in the electrical and optical properties of Zn-Sn-O semiconductor

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Transparent amorphous oxide semiconductors (TAOSs) have drawn special attention over organic and a-Si based thin film transistors (TFTs) due to their high electrical performance and transparency, which make them very promising and high potential candidate for the application in active matrix liquid-crystal displays (AM-LCDs) and active matrix organic light-emitting diode displays (AM-OLEDs) [1]. The Zn-Sn-O (ZTO) is a well-known semiconductor for TFT application due to its chemical stability in terms of oxidation and etching, it physical robustness, and potential to possess comparable electrical performance with IGZO [2]. However, ZTO contain many defects such as oxygen vacancy which provides carriers and simultaneously hinders pathway for electron transport. To enhance the electrical performance, several metal ions Hf, In, Si and Al were doped to investigate whether it act as carrier suppressor or enhancer [3]. In this study, we introduce 3, 5 and 10 at% of Ge into the ZTO semiconductor to examine the doping effect in the electro-optical properties and device performance. The amorphous Ge-doped ZTO thin film was deposited by RF-magnetron sputtering on the fused silica and $Si/SiO_2$ substrates using 75W power in various $Ar/O_2$, and annealed at 300$^{o}$C in air. An optimally processed Ge-doped ZTO turned out to be a promising candidate since it exhibited the hall mobility >25 $cm^2/Vs$ with low carrier concentration ~$10^{16}$ $cm^{-3}$. Details will be presented for a discussion.

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# Enhancement of thermal stability and operation energy in $Sb_2Te_3$ induced by Ag doping

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Non-volatile memory devices such as MRAM, ReRAM, PRAM become rising candidates for next-generation devices because of the high speed, low power consumption and typical application for emerging IoT industry. Among these devices, phase change random access memory(PRAM) is the most possible device for first commercial product. Not like Si-based devices, which use movement of electronic carrier for operation, operation of PRAM is based on change of atomic structure. Crystal structure and amorphous structure in PRAM are used as "1" and "0", and it make possible to operate faster and more efficiently than typical Si-based devices. Most of the researches about PRAM have been performed about $Ge_2Sb_2Te_5$, which has high stability and reliable operation speed. Although $Sb_2Te_3$ has much faster speed than $Ge_2Sb_2Te_5$, very poor thermal stability of $Sb_2Te_3$ make it hard to use in practical devices. To overcome this obstacle, many dopants for $Sb_2Te_3$ have been studied. However, most of the dopants decreased other phase change characteristics, such as operation speed or cyclability, although the thermal stability was enhanced.
In this study, we choose Ag for dopant to $Sb_2Te_3$, and enhancements in both thermal stability and operation energy are observed. Substitution of Ag for Sb is expected to induce reliable distortion in atomic structure of $Sb_2Te_3$, not break the structure, which makes $Sb_2Te_3$ more stable and causes intermediate state between crystalline and amorphous state. Since electrical phase change characteristics shows existence of intermediate state, both crystal-to-intermediate and amorphous-to-intermediate transitions occur with lower operation energy than conventional crystal-to-amorphous phase change. We suggest doped $Sb_2Te_3$ as the most possible candidate for next-generation device from this study.

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# Gallium-doped zinc oxide as highly stable electron transport layer for n-i-p perovskite solar cells

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We fabricated high-performance semi-transparent perovskite solar cells by using RF sputtered GZO films on ITO/Glass substrate. Recently low-temperature, solution-processed zinc oxide (ZnO) has been widely adopted as the electron transport layer (ETL) in perovskite solar cells (PSCs) because of its excellent electrical properties such as high charge mobility. However, the thermal stability of the perovskite films deposited atop ZnO layer remains as a major issue. Herein, we addressed this problem by employing gallium-doped zinc oxide (GZO) as the ETL and obtained extraordinarily thermally stable perovskite layers. We obtained an optimized GZO (20 nm) electron transport layer with a sheet resistance of 1531 Ohm/square and optical transmittance of 96.04 %. We fabricated highly transparent and conductive GZO graded ITO electrode prepared by a RF/DC graded sputtering for n-i-p perovskite solar cell. Due to the thermal stability of the GZO, the GZO graded ITO electrode with rapid thermal annealing at 600 ℃ showed a low sheet resistance of 15.69 Ohm/square and high transmittance of 96.84 %. Notably, the outstanding transmittance and conductivity also render GZO layer as an ideal candidate for transparent conductive electrodes, which enables a simplified n-i-p perovskite solar cell structure. The n-i-p perovskite solar cell fabricated on the GZO graded ITO electrode exhibited a power conversion efficiency 9.67 % greater than that of n-i-p perovskite on the reference ITO electrode. The successful operation of these semi-transparent perovskite solar cells on GZO/ITO/Glass substrate is apply to Building Integrated Photovoltaic System (BIPV).

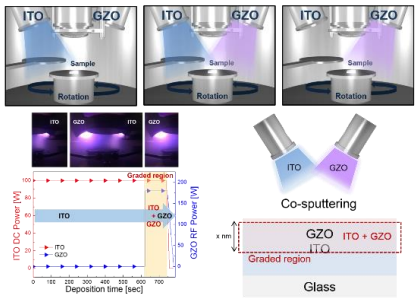


Fig. 1. Schematics of DC and RF power applied to GZO graded ITO target as a function for sputtering time to fabricate GZO graded ITO electrode.

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# Study of Plasma Optical Emission Spectra during Deposition of Titinium Dioxide Thin Films

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We have grown titanium dioxide thin films on glass substrate using reactive DC magnetron sputtering method. We monitored the plasma optical emission spectra during the thin-film growth and studied the power-dependence on plasma species and energy. In particular, we focused on the change in Ti*/TiO* (excited plasma species) and its effect on the structural and optical properties of the as-grown titanium dioxide thin films. The morphological and crystalline properties of the thin films were investigated by atomic force microscopic and x-ray diffraction methods. The optical energy band-gap and absorption properties ware identified by using UV / visible spectroscopy. We found the transition of amorphous to crystalline structure as well as the grain size and symmetry/orientations can be modulated by the plasma states of Ti*/TiO*. In this poster, we will present the details of the experimental results and our interpretations

*This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (No.* 2017R1D1A1B03036132*).*

# Growth of Titanium Suboxide Thin Films by Reactive DC Magnetron Sputtering

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Titanium suboxides have a various physical and chemical properties with a reactive nature, which is mainly controlled by crystallinity and stoichiometry. As compared to well-known titanium dioxides, the titanium suboxides can have a broad range of the optical band gap and electrical conductivity. However, the suboxides are in metastable states so that the growth window is very narrow and particular unequilibrium growth condition is required. By carefully adjusting oxygen to argon flow rate and growth speed, we have successfully grown the titanium suboxides with a different oxygen content. We then studied their structural and optical properties of the as-grown titanium suboxide thin films. Depending on each growth condition, we investigated the crystal structural properties of the thin films by x-ray diffraction and Raman spectroscopic methods. The electrical properties were also studied by current-voltage measurement. Furthermore, the optical properties and energy gap of the grown thin film were examined by using an UV / visible spectroscopy.

*This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (No.* 2017R1D1A1B03036132)

# Effect of Ar ion beam treatment on PET substrate with the mechanical and electrical stability of flexible IWO electrode grown by roll-to-roll sputtering system

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In this study, the effects of surface treatment on a flexible PET substrate using linear Ar ion beam treatment process in a lab-scale roll-to-roll (RTR) sputtering system was investigated. To optimize the Ar ion beam treatment on the surface of the PET substrate, we examined the surface properties of untreated and ion beam treated PET substrate using contact angle, FE-SEM and XPS. The results of the Ar ion beam treated PET substrate presented the significant decrease in contact angle from 63.37° to 36.83°, the different surface images of FE-SEM and the intensity changes from core C 1s and O 1s levels with untreated and ion beam treated PET substrate. we deposited IWO film using a RTR sputtering system to compare the characteristics of grown film on untreated and ion beam treated PET substrate. The optimized IWO films on the flexible PET substrate had a sheet resistance of 32.79 Ohm/sq., an average transmittance of 95.07% at visible range (400~800 nm). To investigate the mechanical stability and flexibility of the IWO films on untreated and ion beam treated PET substrate, we used various bending test mode such as outer/ inner bending test, rolling test and twisting test. The results of bending fatigue test with the IWO films presented different flexible stability at range of 9,000~10,000 cycles. There were no differences of a constant resistance ( $R/R_0$) of the IWO films with twisting test. However, the results of surface images of the IWO films with twisting test presented cracks on surface of the IWO film on untreated PET substrate. Furthermore, we investigated the heater characteristics using thermo-element tester to apply flexible, transparent heater electrode. Therefore, we verified that the Ar ion beam treatment on the PET surface could improve an adhesion between grown IWO film and the PET substrate in a RTR sputtering system.

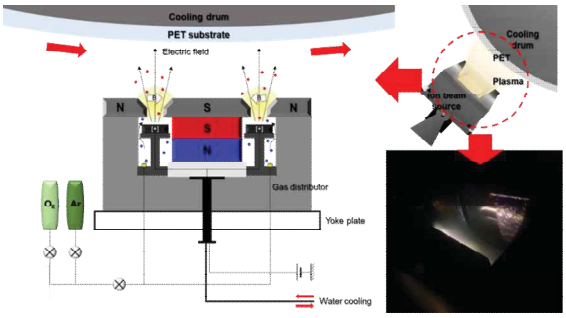


**Fig. 1** Process of a linear Ar ion beam treatment on a PET substrate by RTR sputtering system

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# Electrical and optical properties of amorphous vanadium-doped indium oxide thin films studied with spectroscopic ellipsometry

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We investigated the electrical and optical properties of amorphous vanadium-doped indium oxide (IVO) thin films grown using the co-sputtering deposition method at room temperature. The RF power of the $In_2O_3$ target was fixed at 80W, while the power applied to the $V_2O_5$ target was varied between 0W and 50W. Surprisingly, less than one percent of In doping transformed crystalline $In_2O_3$ films into amorphous IVO films. The optical constants were obtained from the measured ellipsometric angles, Ψ and Δ, using the Drude and parametric semiconductor models. We determined the optical gap energies of IVO thin films from the absorption coefficients (□). We calculated the effective masses of IVO thin films using Drude model. Hall carrier concentrations and Hall mobilities were measured. Comparing the ellipsometric and Hall data, we determined the effective masses of the IVO films. The effective masses of the IVO thin films varied from 0.3 $m_0$ to 0.66 $m_0$ with several V doping contents.[1]

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# Device performance of $(NH_4)_2S_x$-passivated GaAs and InGaAs solar cells

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III−V compound semiconductors have been of much interest for photovoltaic devices because of their direct bandgap and high absorption coefficient [1]. Much effort has been made in improving the electrical properties of compound semiconductor solar cells by surface passivation with a dielectric material such as $SiO_2$ or $SiN_x$. However, the vacuum-based process for the deposition of the surface passivation materials is slow and expensive. Additionally, these passivation layers result in high interface states at the semiconductor-dielectric interface, acting as a leakage current channel. A solution-based process using $(NH_4)_2S_x$ is a good alternative to conventional surface passivation techniques. It is reported that the sulfur passivation effectively reduces the surface states and surface recombination rate of GaAs based semiconductors [2].
In this study, we grew and fabricated *p-n* junction GaAs and $In_{0.53}Ga_{0.47}As$ solar cells using a metalorganic chemical vapor deposition and conventional photolithography. The fabricated solar cells were treated by a short dip in $(NH_4)_2S_x$ solution for sulfur passivation. The photoluminescence intensity from the passivated solar cells is stronger due to a significant reduction in nonradiative recombination at the surface states. The surface passivation effect is also evidenced by the increase of both open-circuit voltage and fill factor. The device performance parameters are improved as a result of the increase in the surface carrier lifetime [3]. Further optimization and characterization of the sulfur passivation are ongoing to achieve high conversion efficiencies of > 20% and > 10% under one-sun illumination at AM 1.5G condition for GaAs and InGaAs solar cells, respectively.

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# Study on Mid-Wavelength Infrared Light Emitting Diode (MWIR-LED)

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InGaAsSb quaternary semiconductor alloys lattice matched to GaSb are suitable for application to short and mid wavelength infrared light emitting diodes, as their band gap energy covers the range (0.725eV to 0.298eV) at 300K. Our aim here is to demonstrate the InGaAsSb/AlGaAsSb quantum well infrared light emitting diode as an application in a non-dispersive infrared (NDIR) gas detection technology operating at room temperature. [1, 2] The NDIR is an optical method which relies on the fact that many gases absorb specific wavelengths of infrared light.In this method gas concentration is calculated by passing a light through a defined length and measuring how much light is absorbed at the specific wavelength absorbed by the gas. NDIR sensors have crucial advantages such as accuracy, long term stability and power consumption for $CO_2$ measurement. Here in this paper we report our investigations of dual band quantum well light emitting diode consisted of InGaAsSb/AlGaAsSb heterostructure in which InGaAsSb as a well and the AlGaAsSb as a barrier layer as well as p-type and n-type AlGaAsSb layers serves as capping and cladding layer respectively. The structural, electrical and optical characterizations of this structure were studied by high resolution x-ray diffraction (HR-XRD), current-voltage (J-V) characteristics and electroluminescence measurement, respectively. The measured electroluminescence spectra of QW LED at room temperature at injection current of 0.3 and 1.1A shows single emission mode (2.06  m) and a double emission mode(1.97um/2.1 um) respectively. Here the detailed study of MWIR-LED as an application for NDIR technology is compiled.

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# Multi-layered structure with glancing angle deposition for anti-reflection on InGaAsP-based solar cells

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The solar cell with various composition of indium gallium arsenide phosphide has been studied, which reached the highest photoelectric conversion efficiency (PCE) among the all kinds of solar cell structure. Depending on the cell accumulation methods, this solar cell was reported to achieve nearly 46% of PCE using the tandem structure to absorb all region with major intensity of solar radiation.[1] In basic thin film optics, because of physical limitations, light is reflected on the interface between two different materials with different dielectric constants. This reflection depends on the angle, but can never be removed. However, light interference modification of solar radiation using transparent thin film make the absorption become nearly 100 %. In this study, multi-layered optical design with glancing angle deposition method was investigated based on the various composition of indium gallium arsenide phosphide solar cells. zinc sulfide was used for the optical design, which has high refractive index, high transparency, well stability at room temperature, and low solubility in water. The variation of refractive index was achieved by glancing angle deposition. The film was deposited by thermal evaporation, and reflectance was measured by U.V.-Visible spectrophotometer.

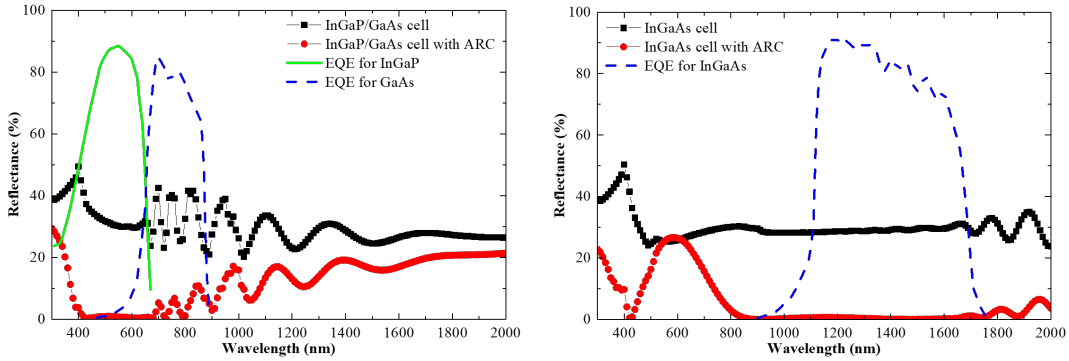


**Figure 1 Reflectance results of InGaP solar cell (left), and InGaAs cell (right)**

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# Luminescence properties of GaN nanowires grown on Si substrate

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The optical properties of GaN nanowires (NWs) grown on Si substrates by using a plasma-assisted molecular beam epitaxy method have been investigated by using excitation-power and temperature dependent photoluminescence (PL). The shape of GaN NWs was systematically controlled by adopting a Ga pre-deposition method. The GaN NWs with reverse-mesa and symmetric columnar shapes were optained by changing the RF power from 100 W to 200 W. The scanning electron microscopy images show the increased diameter of NWs with increasing RF power. The GaN NWs grown with 200 W show the asymmetric shapes, which is related to the presence of tensile strain due to the lattice mismatch between GaN NWs and Si substrates. This strain lead to an increase in quantum confined Stark effect (QCSE). The PL peak measured at 10 K is shifted to lower energy side from 3.45 to 3.40 eV as the RF power increases from 100 W to 200 W, respectively, which is attributed to the reduced quantized energy due to the increased diameter of GaN NWs and increased QCSE. With increasing the temperature from 10 to 300 K, the integrated PL intensities gradually decreased except for GaN NWs grown with 200 W. For GaN NWs grown with 200 W, the integrated PL intensities were increased up to ~70 K, and then decreased as temperature increases further up to 300 K. The increased integrated PL intensity at low temperature can be explained by increased wavefunction overlap, which is attributed to the screening of QCSE due to thermally excited carrier. It is found that the RF power determines the formation of GaN NWs, and thus it significantly affects the structural and optical properties of GaN NWs. The best luminescence properties are demonstrated by the sample grown with RF power of 100 W.

# High hole mobility p-type InGaSb with the compressive strain

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We designed the $In_{0.2}Al_{0.75}Sb$ /$In_{0.25}Ga_{0.75}Sb$/graded buffer-$Al_{0.8}Ga_{0.2}Sb$ quantum well (QW) by one-dimensional Schrodinger–Poisson equations self-consistently, which has not only high band gap (1.61eV) but also is lattice matched with the $In_xGa_{1-x}Sb$ (x: 0.25) channel layer. This novel structure wa band offset energy and can maintain compressively strain in channel layer from the bottom layer of $Al_{0.8}GaSb$. The QW layer was grown by molecular beam epitaxy (MBE) and the crystallinity and surface morphology was characterized using the transmission electron microscope (TEM). The result showed good crystalline behaviors and morphologies without any identifiable morphological defects. Furthermore, we investigated the strain characteristics in $In_{0.25}Ga_{0.75}Sb$ by measuring Raman shift. We found that $In_{0.25}Ga_{0.75}Sb$ has the compressive strain of 1.095%. Finally, we measured electoral characteristics of $In_{0.25}Ga_{0.75}Sb$ high hole mobility transistor using the hall effect measurement system, and benchmarks hole mobility $\mu_{hole}$ versus compressive strain value $\varepsilon_{xx}$ among published $In_xGa_{1-x}Sb$(x:0.2~0.3) channel on $Al_yGa_{1-y}Sb$ (y:0.7~0.9) buffer layer. In the same value of compressive strain, we have the highest hole mobility in room temperature above all published value.

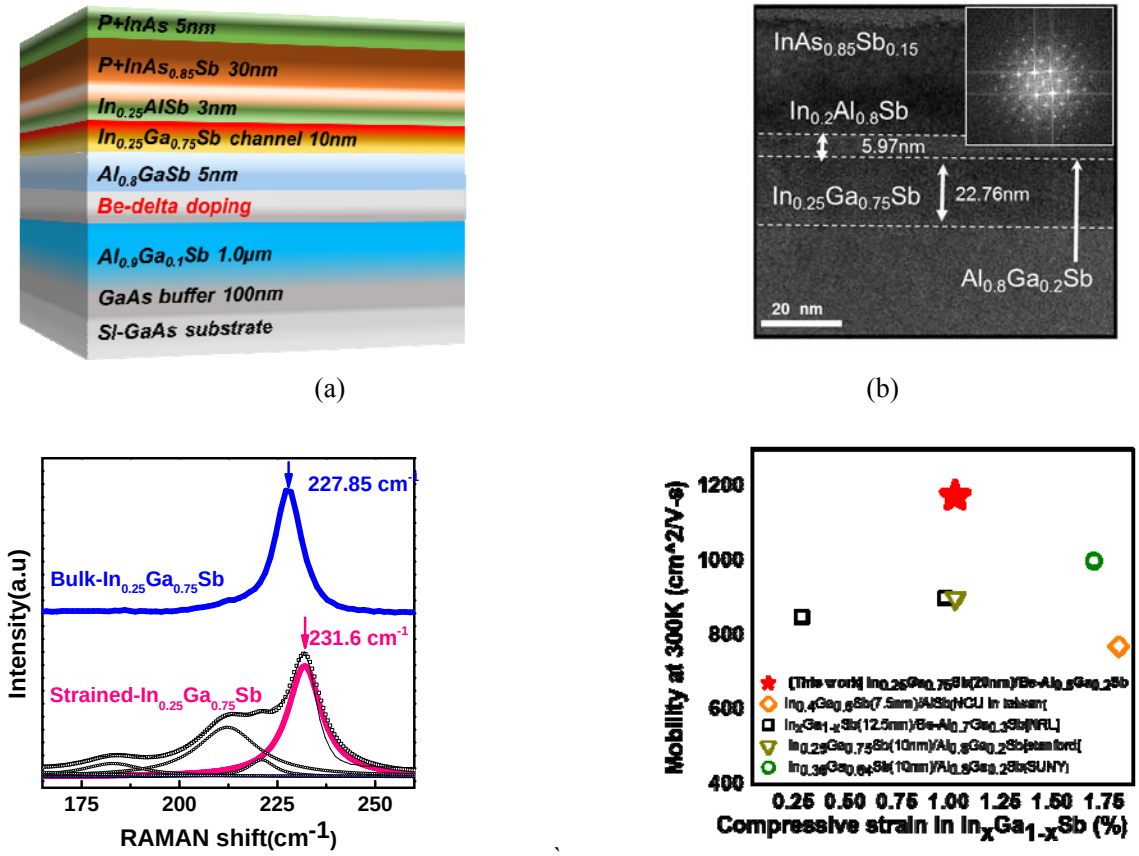


Fig.1. (a)The schematic of the $In_{0.25}GaSb$ High Hole mobility Transistor structure. (b)The TEM image of the $In_{0.2}AlSb/In_{0.25}GaSb/Al_{0.8}GaSb$ QW. (c) The comparative analysis of the fitted Raman shift spectra of the strained-$In_{0.25}Ga_{0.75}Sb$ with the sufficiently relaxed thick-$In_{0.25}Ga_{0.75}Sb$. (d) Benchmark of $\mu_h$ (hole mobility at 300K) vs. $\varepsilon_{xx}$ (value of the channel strain) for Strained-$In_xGa_{1-x}Sb$ channel on $Al_xGa_{1-x}Sb$.

*The authors acknowledge the support from the KIST institutional program, including the flag-ship program.*

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# Growth and Properties of $In_{0.2}Ga_{0.8}As$ Nanowires for the Anti-refection effect and Hybrid Energy Harvesting Characteristics

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Vertically aligned and dense InGaAs nanowires were grown on (111) Si substrates by Au-assisted molecular beam epitaxy and its antireflection characteristics were characterized. InGaAs allows a wide range of bandgap by tuning the In to Ga ratio. In this study, the composition Ga was fixed to ~0.8 and In to ~0.2 in order to obtain the bandgap of ~1.0eV. To epitaxially grow InGaAs nanowires vertically and with high density, the deposition parameters such as the substrate temperature ($T_s$), beam equivalent flux of $As_4$ ($F_{As}$), and growth time ($t_g$) were controlled. The obtained nanowires were vertically aligned with a diameter of ~20 nm near the top and ~44 nm at the bottom, a slightly tapered morphology. This microstructure was due to the difference in surface diffusivity and affinity to the Au catalyst of In and Ga. By controlling the deposition conditions, InGaAs nanowires with no significant staking defects, kinking, and bending was grown successfully on Si (111). The high-resolution transmission electron microscopy (HR-TEM) showed the length was maximum ~ 18 μm with pure-wurtzite crystalline structure over the whole nanowire. Photo-reflectometer and spectroscopic ellipsometry (SE) measurement demonstrated the anti-reflection effect of InGaAs nanowires by showing the significant reduction in the reflectance, less than ~ 5% for the normal incidence in the wavelength of 200 ~ 1700 nm and considerable reduction at the incident angles of 30 ~ 70° Moreover, piezoelectric properties were observed in all the areas where InGaAs nanowires were present caused by the polar c-axis for a hexagonal structure is in the <111> direction in 2 μm × 2 μm contact area.

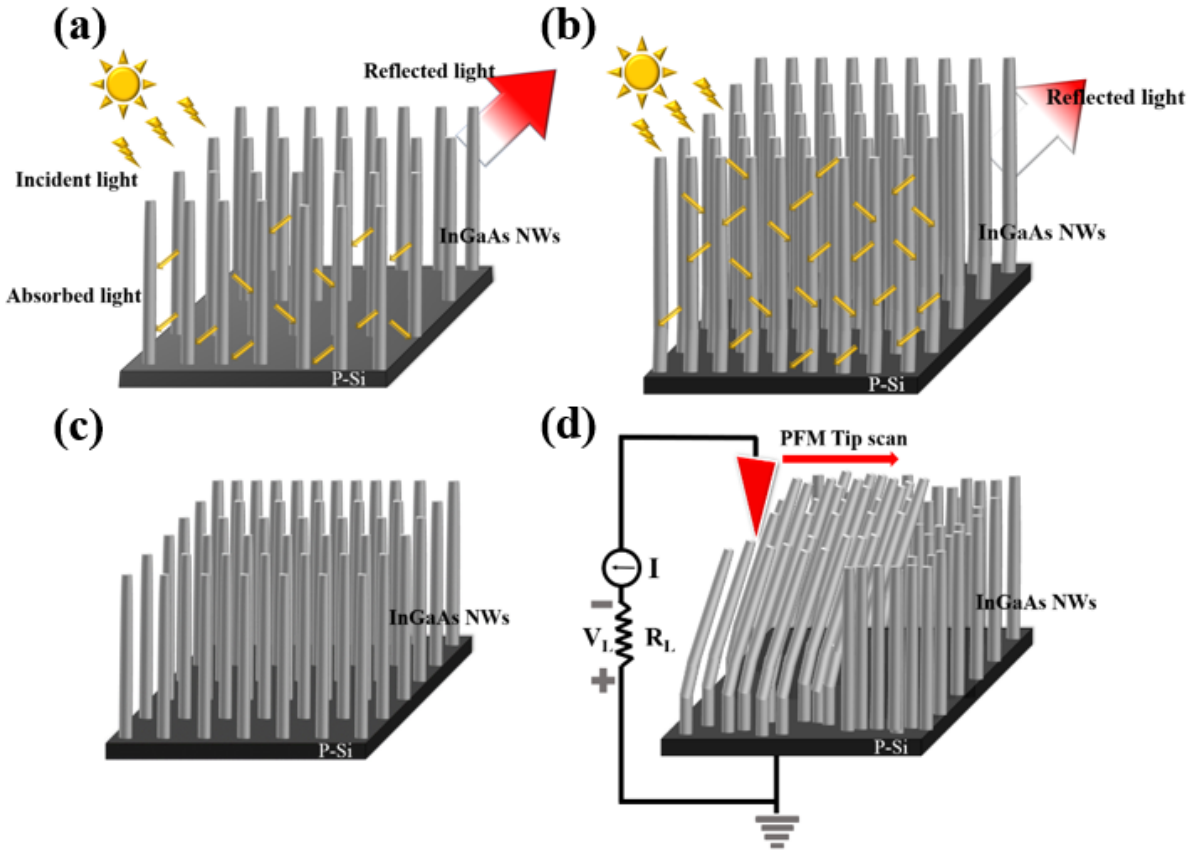


**Fig.1 Schematic of reflectance at normal incident light for depending the length of nanowires at (a) $t_g$ = 1hr and (b) $t_g$ = 3hr. Schematic of piezo response to confirm the piezoelectric properties of InGaAs nanowire as shown in (c) and (d).**

*The authors acknowledge the support from the KIST institutional program, including the Flagship program.*

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# Growth and Properties of InAs photodetector on GaAs (001)

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Indium arsenide (InAs), which is one of the III-V materials, has a high electron mobility of 30,000 cm2/V·s and its band gap of 0.4 eV. Due to the small bandgap, the detectors based on InAs can be applied for extending current telecommunication bandwidth of L-band. Although the physical property of InAs is a merit for the photo-detectors, manufacture of the detectors is difficult due to the cost of InAs which is more expensive than that of Si. GaAs substrates are cheaper than InAs substrates, however, the lattice mismatch of 7.4 % between GaAs and InAs is leading to defects such as misfit dislocations (MDs) and threading dislocations (TDs) which affect negatively physical properties of an InAs by electron-defect scatterings. To avoid the defects issue caused by lattice mismatch, it is essential to metamorphic growth technique, for example, there are low and high growth temperature (LT-HT), InxGa1-xAs step graded buffer and InxAl1-xAs step graded buffer layer. [1,2,3]

The dislocation density is reversely proportional to film thickness, and it is well known. In above mentioned metamorphic buffer layer method, quality of film is higher as buffer layer is increased in thickness. However, the thick buffer layer is not desirable for real applications and the thinner buffer layer is preferable.

In this work, the high-quality InAs film is obtained by $In_xAl_{1-x}As$ graded buffer layer, from x = 0 to x = 0.87. The composition x is gradually changed by variation of In and Al growth rate and simultaneously the growth temperature is gradual decreased. The $In_{0.87}Al_{0.13}As$ layer closed to an InAs film shows a enough insulating property for accurate hall measurement of InAs films. The effect of an $In_xAl_{1-x}As$ graded buffer layer for high-quality InAs film is better than LT-HT buffer layer types.

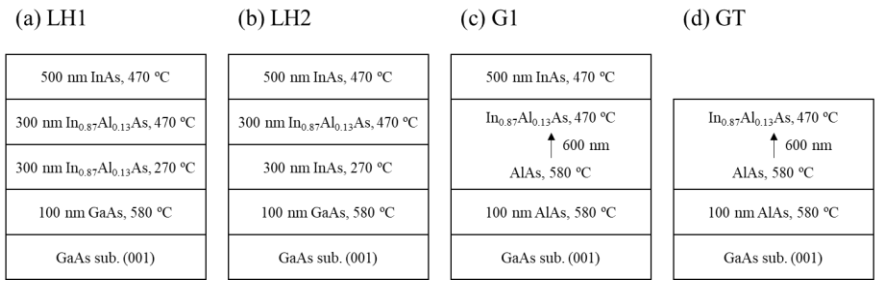


**Fig.1 Schematic of growth method (a) InAlAs-InAlAs LT-HT (b) InAs-InAlAs LT-HT (c) InAlAs graded buffer layer (d) InAlAs graded buffer terminated**

*The authors acknowledge the support from the KIST institutional program, including the Flagship program.*

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# Influence of substrate misorientation on the properties of InGaP/GaAs and InAlP/GaAs heterostructures

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InGaAlP alloys lattice-matched to GaAs have been attractive for optoelectronic device applications, such as visible light laser diodes, light emitting diodes, and solar cells [1]. In particular, $In_{0.49}Ga_{0.51}P$ alloy with low interface recombination rate and low oxygen incorporation is a promising absorbing material for high efficiency multi-junction solar cells. $In_{0.51}Al_{0.49}P$ alloy is typically employed as a window layer of InGaP solar cells because of its higher bandgap of ~2.3 eV, which enhances the surface passivation of InGaP emitter [2, 3].
We grew a series of InGaP/GaAs and InAlP/GaAs heterostructures on 2°, 6°, 10° misoriented GaAs substrates to the [001] direction using a metalorganic chemical vapor deposition system. For comparison, InGaP and InAlP heterostructures were grown on exact (001) GaAs substrates under the same growth condition as a reference. X-ray diffraction (XRD) analysis reveals that the XRD peak for InGaP and InAlP is shifted more toward the substrate peak. This indicates that higher misorientation angles of the substrate suppress the formation of a CuPt-B type superlattice in InGaP and InAlP, caused by the preferential ordering of mixed group III or V atoms on alternative {111} lattice planes [4]. Further analysis is underway to determine the elastic strain, alloy composition, bandgap of InGaP and InAlP alloys from XRD reciprocal space mapping and photoluminescence measurement.

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# Coaxial $In_xGa_{1-x}N$/GaN MQDs with quaternary capping layer grown on n-GaN NW by MOCVD system for blue emission

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Nanowires based devices are among those techniques and have drawn much attention in the last few years for improving device performances.[1,2] In This abstract demonstrates for the merits of an immediate InAlGaN capping layer over self-assembled $In_xGa_{1-x}N$/GaN GaN multi-quantum dots (MQDs) coaxially grown on the m-plane and r-plane of n-GaN nanowires on Si (111) substrate using metal organic chemical vapor deposition. Figure 1. (a) ~ (b) show the UHR-SEM image & schematic of the proposed structure with $In_xGa_{1-x}N$ MQDs on a single n-GaN NW when quaternary capping was applied over dots in the active region. InAlGaN capping layer acted as a strain-driven phase separation alloy. Inhomogeneous surface strain over the dots helped this quaternary alloy in forming an indium concentration gradient over $In_xGa_{1-x}N$ MQDs and thus, indium out-diffusion from the dots was reduced. Quaternary alloy capped samples exhibited vertically stacked, highly dense, $In_xGa_{1-x}N$ /GaN MQDs of improved carrier confinement grown as the active region on n-GaN NWs. In contrast, the nonexistence of InAlGaN capping over $In_xGa_{1-x}N$ /GaN MQDs caused deformation of the dots due to In-Ga inter-diffusion between the dots and the GaN barrier layer. The temperature dependent PL study was carried out for the sample composed of quaternary alloy capped $In_xGa_{1-x}N$ MQDs on n-GaN NWs. This coaxially fabricated $In_xGa_{1-x}N$ /GaN MQDs on defect free n-GaN nanowires have various excellent characteristics and can be widely applicable to new optoelectronics semiconductor devices.

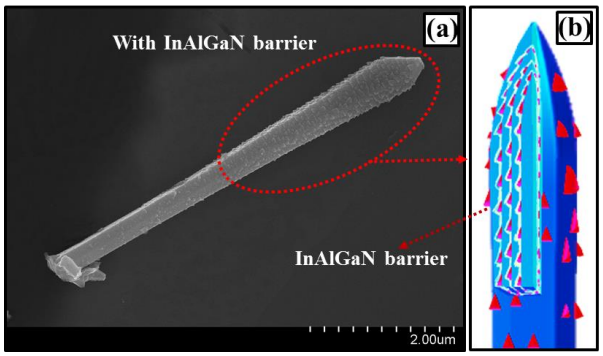


**Figure 1 (a) UHR-SEM image shows high density of $In_{0.19}Ga_{0.81}N$ QDs on surface of NW. (b) Schematic to represent of InAlGaN capping over $In_{0.19}Ga_{0.81}N$ QDs grown on n-GaN NWs.**

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# Fabrication of AlGaN having unique nanostructure on Si substrate via MOCVD for the photoconductive ultraviolet-C Photodetector

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$Al_xGa_{1-x}N$ alloy films and nanostructures have attracted extensive research attention for ultraviolet and deep ultraviolet optoelectronic applications owing to the band gap tuning capability in the range of 3.4-6.2 eV [1,2]. Here, we attempted to realize Si-doped n-type compositionally uniform $Al_{0.48}Ga_{0.52}N$ alloy with flower-like morphology (nanoflower) by MOCVD utilizing a special growth method. The quasi vertically aligned and preferentially c-axis oriented *n*-AlGaN nanostructures are consisted of a large number of self-assembled 1D nanowires which tend to grow radially from the center leading to a flower-like morphology. The elemental mapping of the n-AlGaN nanoflowers (NFs) are shown in figure 1 (a-c). Scanning transmission electron microscopy images showed that the realized n-AlGaN nanowires are single crystalline in nature and grow along (002) crystal direction. Low temperature (77 K) cathodoluminescence spectra of AlGaN nanoflowers displayed strong band edge emission at ~ 280 nm and negligible defect emission. To investigate the optoelectronic device applicability of the realized nanoflower structure, a planner photoconductive device has been fabricated and photocurrent was measured under UV illumination. The larger photoresponsivity and sensitivity of the nanoflowers based device is attributed to the higher density and large surface-to-volume ratio of n-AlGaN nanoflowers which facilitates photoconductivity due to the enhanced photon absorption.

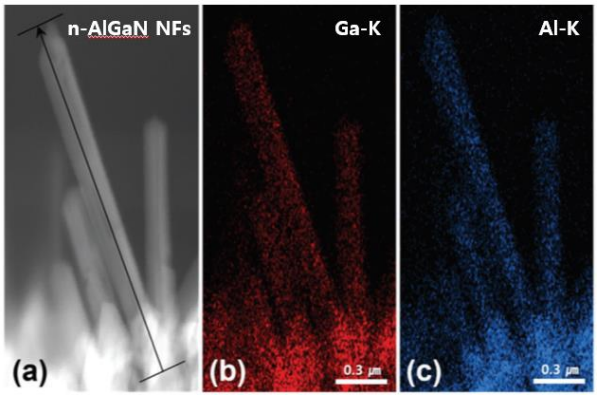


**Figure 1 (a) FE-SEM images of n-AlGaN NFs, (b) EDX analysis of n-AlGaN NFs showing the elemental distribution of Ga and (c) EDX analysis of n-AlGaN NFs showing the elemental distribution of Al.**

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# Investigation of optical properties for InSb/GaSb quantum dots grown by droplet epitaxy

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Droplet epitaxy can achieve high uniformity quantum dot (QD) structures even lattice match and mismatch compound semiconductor materials [1]. Especially, previous research InSb QDs on GaSb were formed by Stranski-Krastanov mode due to the lattice match.

In this present works we fabricated the InSb QD by droplet epitaxy. The optical properties of InSb QDs grown by droplet epitaxy have not been studied much yet. Therefore, we have investigated the optical properties of InSb QDs grown by droplet epitaxy. Fig. 1 shows the photoluminescence (PL) intensities of the InSb QDs and GaSb buffer layer as function of 1/kT. The inset figure in Fig. 1 is PL spectra of GaSb buffer layer and InSb QDs at 13 K. The activation energies of the GaSb buffer layer and InSb QDs, measured from the slope of the linear portion, are about 18.5 and 39.8 meV, respectively. These results indicate the existence of InSb QDs [2, 3]. To investigate the effect of InSb QDs on the electric field of GaSb buffer layer, the electric field changes of GaSb buffer layer were measured by photoreflectance (PR). Fig. 2 shows the electric field of GaSb buffer layer and InSb QDs as a function of excitation intensity at 13 K. The field strength changes of GaSb buffer layer with InSb QDs was found to be smaller than that of GaSb buffer layer without InSb QDs. This result indicates that the quantum confinement effect of the InSb QDs and the defects generated in the GaSb layer grown at low temperatures affect to the GaSb buffer layer. Furthermore we have conducted the temperature dependent PR.

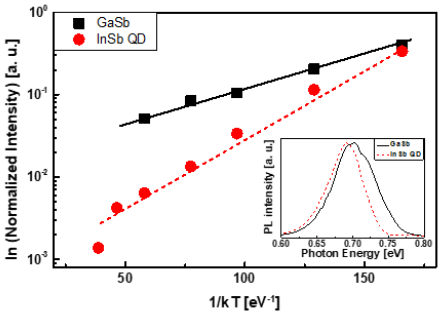


Fig. 1. PL intensities of GaSb and InSb QDs as function of reciprocal temperatures. (Inset) PL spectra of GaSb and InSb QDs at 13 K

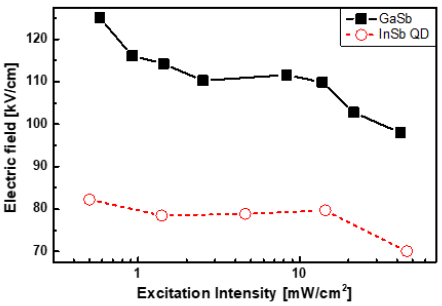


Fig. 2. The electric field of GaSb and InSb QDs as a function of excitation intensity at 13 K.

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# Demonstration of hybrid nano-architecture comprising uniaxial and coaxial InGaN/GaN MQWs on n-GaN Nanowires by MOCVD

Jung Hoon Yang, Dae-Young Um, Raju Nandi, San Kang, Jae-Kwan Sim, Suel Lee, Jun-Yong Jo, Pil-Jun Kim, Dae Han Jung, Jieun Yoo and Cheul-Ro Lee*

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We propose a novel hybrid nano-architecture which comprises both the uniaxial and coaxial multi-quantum wells on nanowires topped with a InGaN nano-cap. Recently M. Conroy *et al.* reported that stacking of quantum disks on top of NWs can result into variation of thickness and emission wavelength in increasing order.[1] Therefore, we intentionally designed n-GaN NWs with bigger diameter to realize a large InGaN nano-cap employing the inter-diffusion phenomenon of In. A hybrid nano-architecture comprising InGaN/GaN uniaxial and coaxial type MQWs with a pyramidal InGaN nano-cap was successfully grown on n-GaN NWs by MOCVD. Figure 1 shows the process flow for fabricating the hybrid nano-architecture. FE-SEM revealed high density of nanowires. HR-TEM images displayed 5 pairs of uniaxial and 6 pairs of coaxial multi-quantum wells and existence of the deliberate nano-cap. Photoluminescence spectrum was recorded for the grown structure at room temperature. The resultant emission spectrum comprised of two distinct peaks resultant to each of the mult-quantum well assembly including an emission for the nano-cap. CL mapping data revealed discrete bright field image of InGaN nano-cap and uniaxial multi-quantum well structure. Emission peaks for nano-cap and both the multi-quantum well structures were observed in CL point spectrum which in turn corroborated the PL measurement. During EDX study high In composition was found in the nano-cap area along with distinct presence of both the types of multi-quantum wells. PL and CL revealed optical properties of the InGaN nano-cap and both the types of MQWs. Photocurrent was observed to be linearly enhanced with increasing light power density. It was also shown that the photocurrent density for the hybrid nano-architecture is higher than single arrangement of uniaxial MQWs at a particular light power density.

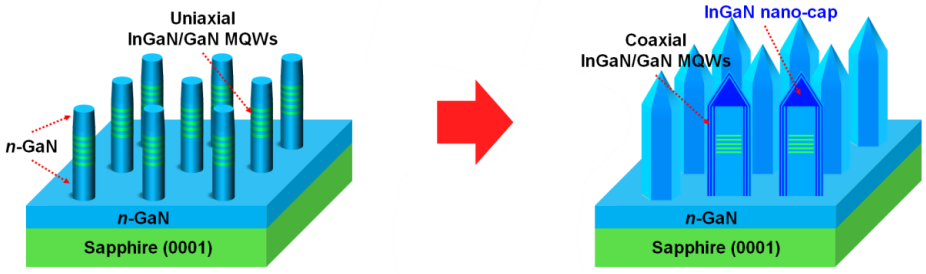


**Figure 1. Schematic diagram representing fabrication of the hybrid nano-architecture**

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# Sputtering Duration and Annealing Effects on the Structure and Local Electronic Structure of MgO Thin Films

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In present work, we report effect of sputtering duration and annealing on the structure and local electronic structure of MgO thin films. MgO thin films were grown using radio frequency (RF) sputtering method by varying sputtering duration from 25 min to 324 min (sputtering durations: 25, 36, 49, 81, 100, 144, 196, 256 and 324 min). The base pressure of sputtering chamber was $2.5\times10^{-6}$ Torr. Substrate temperature was set to 350℃. Sputtering power and Ar pressure was maintained at 40 W and 5 mTorr. Substrate to sputtering target distances was kept 5 cm. As-grown films were annealed at 400, 600 and 700℃ for 3 hrs. To get information of structure and local electronic structure of deposited films X-ray diffraction (XRD) and near edge X-ray absorption fine structure (NEXAFS) measurements were carried out at 5A MS-XRS and 10D KIST-PAL beamline, respectively in Pohang Accelerator Laboratory (PAL), Republic of Korea. Both structure and local electronic structure exhibit sputtering duration and annealing temperature dependence. At annealing temperature of 400℃, XRD patterns for these sputtering durations reveal that films are amorphous upto the sputtering duration of 256 min reveal amorphous nature. However, films exhibit polycrystalline nature at sputtering duration of 324 min for this annealing temperature. When films are annealed at 600℃, structural quality of the films improves. At this annealing temperature, films are amorphous upto sputtering duration of 144 min. Films are polycrystalline in nature for sputtering duration of 196, 256 and 324 min. Mg K-edge NEXAFS measurements reveal presence of $Mg^{2+}$ ions having co-ordination specific to the bulk MgO in the both amorphous and crystalline phase. Similarly, results obtained from O K-edge NEXAFS measurements are concurrent with that obtained from Mg K-edge measurements. In addition to this O *K*-edge NEXAFS measurements reveal presence of molecular oxygen on the surface of these films at various sputtering durations when annealed to 400℃. When annealing is performed at 600℃ and 700℃, film surface becomes free from molecular oxygen. Thus, annealing at these temperatures provides MgO thin films with improved structural and surface quality.

# Electrical observation of effective mass in a $WTe_2$ film

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The rise of graphene has naturally given rise to research interest in transition-metal dichalcogenide (TMD), which can be reduced crystal thickness below the mean free path by exfoliation method. Recently, the layered semimetal $WTe_2$ has been received a lot of attention because of the observation of a non-saturating and extremely large positive magnetoresistance. However, the underlying mechanisms of the extremely large magnetoresistance are still under debate. A first step towards understanding about $WTe_2$ is quantitative determination of physical properties.

In this research, we investigated electrical properties of distorted trigonal phase $WTe_2$ ($1T'$-$WTe_2$) crystals. We fabricated Hall bar structure using an exfoliated $WTe_2$ layers for electro- and magneto-transport measurment. We observed the extremely large magnetoresistance (XMR), transverse resistivity contributed by both electron and hole transport, and the quantum oscillation. Then, we obtained effective mass of $1T'$-$WTe_2$ from analysis of the temperature dependence of the Shubnikov–de Haas oscillation. Figure 1 shows the extracted $m^*$ value for $WTe_2$. These results can contribute to understand mechanism of the extremely large magnetoresistance.

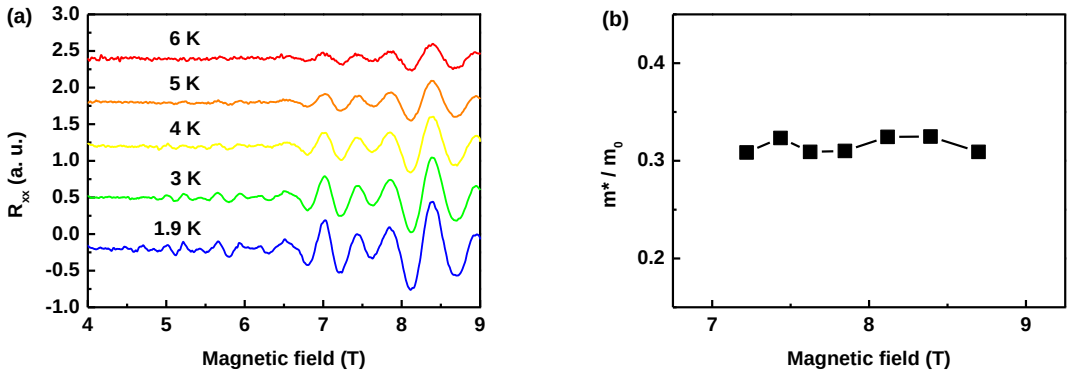


Fig. 1. (a) Temperature dependence of Shubnikov–de Haas oscillation. (b) Effective mass of $WTe_2$.

# Atomistic Simulations on Dynamics of a Magnetic Skyrmion: Role of Atomic Defects in the Breathing Mode

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Owing to the fascinating properties of the magnetic skyrmion such as topological robustness, high density, and high energy efficiency [1], it has been considered as one of the prominent candidates for future spintronic devices. It has been known that the magnetic skyrmions are topologically protected, however, it has intrinsically atomistic nature: this topological spin structure formed physically on the atomic sites in monolayer-scaled-thickness thin films. Consequently, it is inevitably influenced by the interfacial roughness and the thermal fluctuation. To study such atomistic effects on the skyrmion, a numerical method based on the atomic scale micromagnetic model is necessary. In this work, we observe effects of atomic defects on dynamics of the skyrmion, the breathing modes, by atomistic micromagnetic simulations [2]. As a model system, monolayers Co nanodisk with 60 nm diameter was used. We assumed that the Co film has simple cubic (SC) structure with the lattice constant of 2.5 Å and the interfacial Dzyaloshinskii-Moriya interaction (DMI) appears only at the bottom surface [3][4]. The DMI is considered as the tensor form of magnetic interaction between neighbor spins. The randomly formed vacancies on the surface showed the roughness of the interface as shown in Fig. 1(a). As shown in Fig. 1 (b), the breathing modes varies dramatically with the roughness. Furthermore, we found that the stable size of the skyrmion affected sensitively by the roughness.

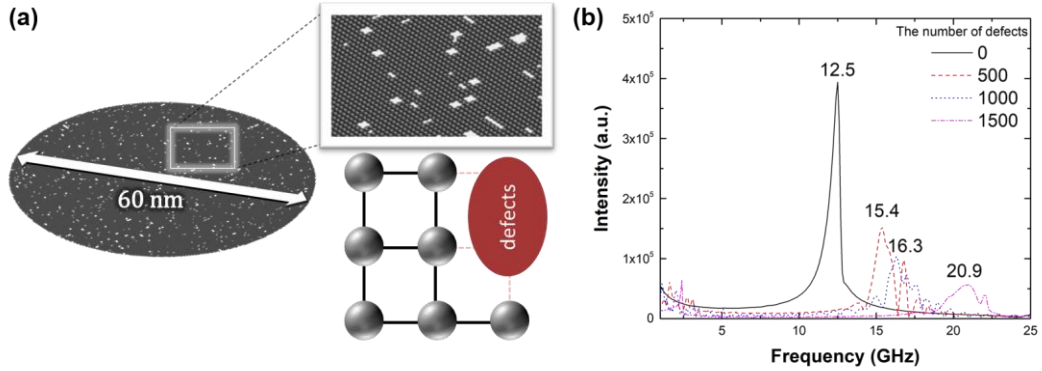


**Fig. 1. (a) Model system having 1500 atomistic defects. (b) Fast Fourier transformation (FFT) spectra for skyrmion breathing mode.**

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We perform first-principles calculation to investigate the possible magnetism on the Si(111)-$\sqrt{3} \times \sqrt{3}$ surface, which is stabilized for highly boron-doped samples. When the silicon adatom on top of a boron atom is removed to form a defect structure, three silicon dangling bonds are exposed, generating half-filled doubly degenerate energy levels in the band gap, which stabilizes a local magnetic moment of 2 $\mu_B$. When many such defect structures are adjacent to one another, they are found to align antiferromagnetically. However, we demonstrate that the ferromagnetism can be stabilized by adjusting the number of electrons in the defects, suggesting a possibility towards spintronic applications for this unique silicon surface structure.

# Antiferromagnetic Osillator Using Interfacial Spin-Orbit Coupling

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The terahertz (THz) gap (0.1 ~ 10 THz) [1] has received great attention due to the various useful applications like stand-off detection, innocuous medical diagnostics, material analysis and so on. Furthermore, THz technology will enable operation at the higher frequency than existing electronic systems, so faster devices will be realized. For these reasons, there are many scientific and engineering studies[2-4] to fill the THz gap, such as using lasers and superconductors. But, they are relatively less cost-effective because they need either lasers and transistors. Recently, antiferromagnetic(AFM) materials are emerging as one of candidates to fill the THz gap[5,6]. In the AFM, neighboring magnetic moments are arranged antiparallel, so their resonance frequency lies at the THz regime. For this reason, oscillators using antiferromanget, has been studied to generate and detect THz frequency signal.

Spin-transfer effect can induce excitation of magnetic moments in AFM and spin-Hall effect(SHE)[7] is one way to transfer spin angular momentum to the AFM magnetic moments. Recently, antiferromagnetic spin Hall nano-oscillators(AFM-SHNO) using SHE are proposed.[8,9] AFM-SHNO is cost-effective in the way that they don't need lasers nor transistors. But it requires high current density to generate THz signal.

Recent studies proposed another spin-current generation mechanism, which is different from SHE[10,11]. Spin polarization induced by conventional SHE, which is known to be induced by bulk spin-orbit coupling(SOC), is directed in one direction because charge current flow direction, spin current flow direction and spin polarization direction are always orthegonal to each other. But new mechanism based on interfacial SOC is not confined to geometric symmetry issue. In other words, spin current can have two spin polarization direction. However, the effect of two spin polarization on the AFM has been unexplored yet. We numerically study this effect based on micromagnetic simulation. We find that this effect can modify oscillating properties of antiferromagnet. In the presentation, we will discuss details of oscillating properties including critical current denstiy, oscillating frequency, frequency tunability, oscillating trajectory of antiferromagnetic moments and other oscillator's properties.

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# Fluorescence Sensor Application of the Surface Capped Colloidal ZnS:Mn Nanocrystals with L-Cysteine for the Detection of Zinc (II) Cations in Aqueous Solution

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Recently, a novel application of the water-soluble semiconductor nanocrystals as selective and sensitive photo-sensors to detect certain metal ions in an aqueous solution has gained great interest due to their significant effects on the human health [1-3]. In this study, a water-dispersible ZnS:Mn nanocrystals (NCs) were synthesized by capping the surface with L-cysteine (Cys) molecules. The obtained ZnS:Mn-Cys NC products were optically and physically characterized by corresponding spectroscopic methods. The UV-Visible absorption spectrum and PL emission spectrum of the NCs showed broad peaks around 290 nm and 580 nm, respectively. The average particle sizes measured from the obtained HR-TEM images were about 5 nm, which were also well supported by the Debye-Scherrer calculations using the XRD data. Moreover, the surface charges and the degree of aggregations of the ZnS:Mn NCs were determined by electrophoretic and hydrodynamic light scattering methods respectively, indicating formation of agglomerates in water with a negative surface charge. The negatively charged NC was applied as a photosensor for the detection of specific cation in aqueous solution. As a result, the ZnS:Mn-Cys NC showed luminescence quenching by most added metal cations; while Zn(II) ions caused a drastic enhancement of the fluorescence intensity. Finally, the kinetic mechanism study on the luminescence quenching of the NC by the addition of the copper (II) ion proposed an energy transfer through the complexation between the two oppositely charged species.

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# Electronic synapses based on silk/poly(methyl methactylate) nanocomposites

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Research into the devices by mimicking the human brain has evolved into an important role of synaptic elements for neuromorphic computing. Synapses on the basis of the perception and learning are responsible for enormous parallelism, plasticity, and computation. Recently, various investigations have been conducted to produce artificial synapses, which have a similar physical structure to the vital nervous system and can be driven with low power. Among the various types of programmable devices, memristive devices have currently emerged as one of the promising candidates to realize the function of synapses due to their simple structure and plasticity.

Electronic synaptic devices based on silk/poly(methyl methactylate) (PMMA) nanocomposites were fabricated by using a solution method. While current-voltage (I-V) curves for the devices under dual positive bias voltage sweeps show that the conductance with hysteresis gradually increased with increasing applied voltage, and those for the devices under dual negative bias voltage sweeps gradually decreased with increasing applied voltage, indicative of the characteristic electronic synapses. The silk used in the active layer of devices was composed of proteins. The proteins in the silk combined with the PMMA polymer, resulting in the achievement of electrical characteristics of the electronic synapses. The carrier transport and operating mechanisms of the electronic synapses are described on the basis of both the I-V results and the filament mechanism.

**Acknowledgement**
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**Reference**
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# Microscale patterned RGB Full-color Quantum dot Light-emitting devices

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High-resolution display is one of the main issues in advanced display industries such as virtual reality (VR), augmented reality (AR), or mixed reality (MR) as they use magnified projections. As previous fine-metal-mask (FMM) patterning methods have resolution limitations, transfer-printing or inkjet-printing methods were proposed to deliver such display resolution. However, there still exists issues regarding process cost, yield, and size-scalability in such approach. In our previous study, we have shown that Quantum Dots (QDs) can be patterned in high-resolution, large-scale with ease, using photolithography. With water-stable termination of the QD surface, the QDs are less likely to be affected by exposure to organic solvent used in photolithography.

In this study, we demonstrate high-resolution Quantum dot light-emitting devices (QD-LED) consisting of 10㎛ RGB pixels using photolithographic patterning process. In order to prevent electric breakdown from contact of the upper and lower electrodes, an insulating layer was formed by vacuum evaporation on the un-patterned portion of the QD emissive layer. As a result, we fabricate QD-LED with 3628ppi resolution that have 10 um x 10 um RGB pixels (4 um x 4 um sub pixels). This work was supported by Pioneer Research Center Program through the National Research Foundation of Korea funded by the Ministry of Science, ICT & Future Planning (NRF-2013M3C1A3065033).

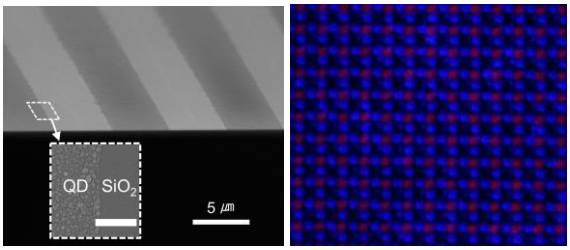


Fig 1. 5 μm line pattern of quantum dots formed by our method[1]

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# Short wave infrared field-effect phototransistor using PbS colloidal quantum dots with glutathione

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Short Wave Infrared (SWIR), spectrum invisible to human eyes, is a wavelength region feasible to attain clear sight in night or in inclement weather. To use such region, silicon and III-V compounds are commonly used for detection but have certain disadvantages: limitation of spectral response range, high material price, and difficulties in fabricating flexible or transparent device for various applications. In order to overcome such issues, we selected PbS Quantum dots (QDs) in the SWIR region to detect SWIR. Since QDs are only few tens of nanometers, they transmit light when they are thin enough, have relatively high quantum yield, and are inexpensive to develop. In this study, we used PbS QDs with PL peak center at 1550 nm, wavelength which absorption property of $H_2O$ and $CO_2$ are the lowest.
In our previous study, we showed that the QDs can be patterned using photolithography technique. Such method, however, requires QDs to have hydrophilic surface termination, whereas conventional PbS QDs have hydrophobic termination. In this study, to modify the surface of hydrophobic QDs to hydrophilic state, we exchange the surface ligand from oleic acid (OA) to Glutathione (GSH). As a result, PbS QDs that are stable in water and have negative surface charge were obtained. We also show that such ligand exchanged QDs are compatible with our previous photolithographic QD patterning method on ZnO channel layer, fabricate PbS QD based SWIR photodetector, and analyze the detection characteristics.

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# Diagnostics of long-term degradation of photovoltaic performance of organic solar cells using absorption and photo-luminescent spectroscopy

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Organic solar cells as a new type of photovoltaic devices have a variety of technological and economical advantages for industrial application in renewable energy [1]. However, there are some bottlenecks in this matter and one of them is a short lifetime of such devices. As a matter of fact, limited exploitation period of organic solar cells is the consequence of lower thermodynamic stability of organic materials in comparison with their inorganic counterparts (crystalline Si-, $A_2B_6$-based solar cells, etc.), because of the lower synthesis temperature of the first. The degradation of photovoltaic performance of organic solar cells during long exploitation periods is bring about specific changes in physicochemical properties of composite materials under intensive solar irradiation and/or aggressive environment (higher temperatures, chemical oxidation, etc.). Taking into account above-mentioned, control of the possible scales and physical mechanisms of long-term degradation of the structure and physic-chemical characteristics occurring in organic solar cells has an important scientific and practical significance.

In this presentation, absorption and photoluminescence characteristics of the individual components and the integrated structure of organic solar cells with P3HT/PCBM и P3HT/ITIC composition are studied. The mechanisms of long-term changes in physical characteristics of such devices have been investigated using comparative measurements of absorption and photoluminescence spectra in composite materials of different thickness, as well as in the integrated structure. It is shown, that the decreasing of the photoactive layer thickness leads to the increasing of absorption and photoluminescence intensities, while thickness of buffer layers has not such effect. This fact witnessed on chemical origin of long-term changes in absorption and photoluminescence spectra. Maximal changes in absorption spectra of organic solar cells of P3HT/PCBM composition were observed in the region of 370 - 480 nm, and in solar cells of on P3HT/ITIC composition - in the region of 500 - 720 nm, which indicates that long-term absorption changes are, mostly, associated with the active layer. In should be noted, that the oxidation of fullerene, including its photoinduced oxidation, can enhance transfer of electrons [2] in the cathode zone of the relevant photovoltaic device. Thus, the method of diagnostics of degradation of organic solar cells based on spectral measurements of absorption and fluorescence is proposed.

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# Comparison of characteristics for a Structured Illumination Microscopy (SIM) with a Spatial Filter

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## ABSTRACT

In this paper, the comparison of characteristics for LED source based a structured illumination microscopy (SIM) is discussed. We show that axial response is improved with a bandpass filter in structured illumination microscopy (SIM), which corresponds to highlighting a certain wavelength band in LED source. Experimentally, we obtained sectioned images taken with different bandpass filters which offer a short range of bandpass regions, and measured axial response for them. Under these test conditions, the user expect to produce clear sectioned images with lager contrast ratio from the fact that the optical sectioning strength is correlate with contrast ratio.[1,2] We demonstrate the best condition to measure samples by checking the maximum sectioning strength over a certain wavelength band using various bandpass filters in LED source.

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# Ion-intercalation assisted solvothermal synthesis and optical characterization of $MoS_2$ Quantum Dots

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A number of preparation methods for $MoS_2$ quantum dots (QDs) are reported but these methods are limited by production rate, time consumption, tedious processes or quality of the as prepared QDs. Therefore, a simple, productive and green method for large scale production of high quality $MoS_2$ QDs is still a challenge. Here we report a facile, low cost and environmentally friendly ion-intercalation assisted solvothermal route for the preparation of $MoS_2$ QDs.

In the reported method, NaOH is used as $Na^+$ ion source to intercalate and exfoliate the commercial $MoS_2$ powder (dispersed in two different solvents) into nanosheets and QDs. The reaction was carried out at a certain temperature to enhance the $Na^+$ ions intercalation between the layers. The UV-Vis absorbance spectra of the as synthesized QDs show a peak in the near UV region ($\lambda < 300$ nm) instead of the characteristic peaks for the nanosheets [1, 2]. The proposed method may further enhance the yield [3] of $MoS_2$ QDs.

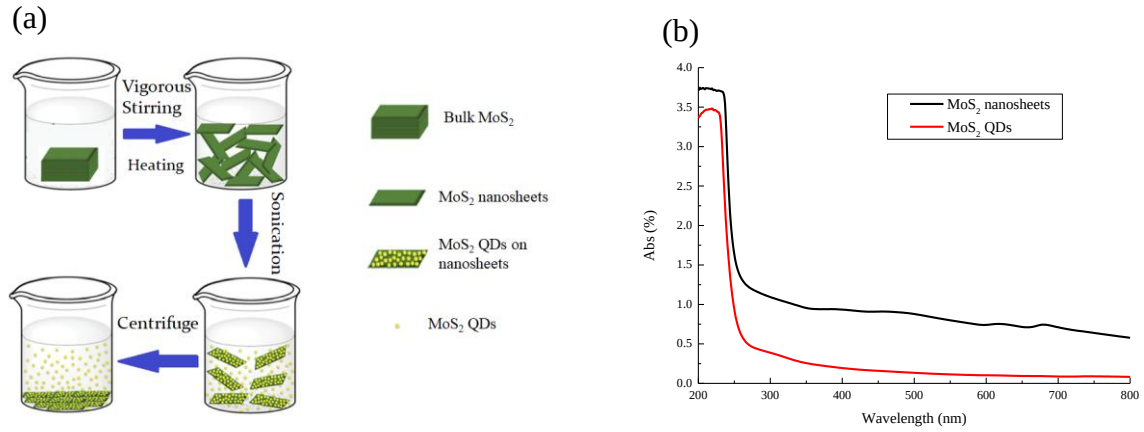


Fig. 1. (a) Synthesis route and (b) UV-Vis absorbance spectra of the prepared $MoS_2$ nanosheets and QDs

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# Characteristics of p-type Sb-doped $Cu_2O$ hole injection layer grown by RF magnetron sputtering

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Recently, various p-type materials utilized quantum dot light emitting diode cell as hole-injection layer. Among a lot of materials, $Cu_2O$ is representative p-type semi-conductor. [1] In this reason, we doped Antimony to $Cu_2O$ the well-known p-type doping material to improve amount of carrier density. We fabricated the thin film by using RF sputtering system to investigate characteristics of RF sputtered Sb-doped $Cu_2O$ (ACO) films to apply as hole injection layer for quantum dot LED. In order to optimize $O_2$ gas flow rates, the $O_2$ gas flow rates were controlled by RF magnetron sputtering system during fabricating the Sb-doped $Cu_2O$ films. We inspected the electrical, optical and structural properties of Sb-doped $Cu_2O$ film. The electrical properties of Sb-doped $Cu_2O$ (ACO) films as a hole-transport layer were analyzed by hall measurement. UV-vis equipment was utilized to ascertain the optical properties of Sb-doped $Cu_2O$ (ACO) films. We confirmed the crystallization the Sb-doped $Cu_2O$ (ACO) film by using FE-SEM. The results of FE-SEM images are able to demonstrate the crystal structure of Sb-doped $Cu_2O$ (ACO) film. The ratio of Sb doping was identified by XPS. We confirm the amount of S about 3 atomic percent f`rom the results of XPS data. Based on these results, we verified a possibility of Sb-doped $Cu_2O$ (ACO) films as the hole-injection layer for quantum dot LEDs.

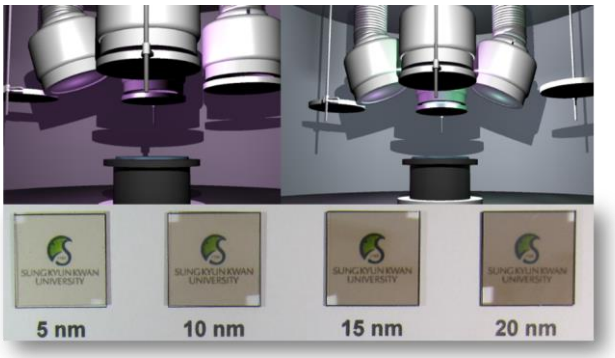


**Fig. 1** The schematic the processing to fabricate thin film of ITO and ACO without breaking the vacuum processing and the picture of ACO thin film depending on thickness

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# Sputter-processed Li-doped $Cu_2O$ as an efficient hole-injection layer (HIL) for QDLEDs

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Currently, there are a lot of study about p-type semiconductors for optovoltaics.[1]
We investigate characteristics of RF sputtered Li-doped $Cu_2O$ (LCO) films as a p-type buffer for hole-injection layer (HIL). Before applying the Li-doped $Cu_2O$ films to QDLEDs, we investigated the electrical and optical properties of Li-doped $Cu_2O$ films depending on the films thickness in this study. In order to optimize the thickness of Li-doped $Cu_2O$, the thickness was controlled by Magnetron sputter system. Hall measurement was used to confirm the p-type buffer layer conductivity of the Li-doped $Cu_2O$ films. Optical properties of the p-type buffer layer were analyzed by UV-vis equipment. Furthermore, the films were annealed by Rapid Temperature Annealing (RTA) system. The optimized Li-doped $Cu_2O$ films thickness of 20 nm presented a sheet resistance of 1.27 X $10^4$ Ohm/square and an average transmittance of 60.09 % in visible range (400 nm~800 nm), respectively. We fabricated the QDLEDs using Li-doped $Cu_2O$ films as hole-injection layer and compared with the QDLEDs without hole-injection layer. Maximum luminance and current efficiency of QDLEDs using Li-doped $Cu_2O$ films as hole-injection layer were 825 cd/$m^2$ and 0.035 cd/A, respectively. On the other hand, we confirmed electrical shorts from QDLEDs without hole-injection layer. Li-doped $Cu_2O$ films by RF sputtering at room temperature are promising hole-injection layer for high performance QDLEDs.

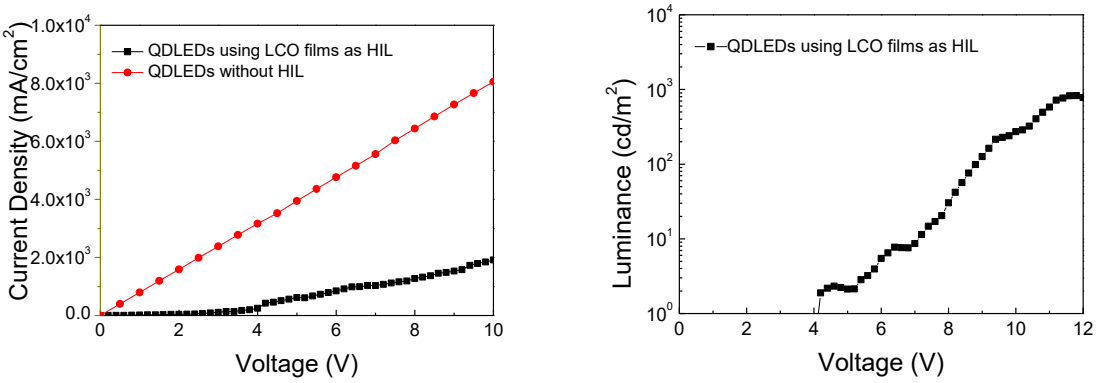


**Fig. 1** Current Density of QDLEDs using LCO films as HIL and without HIL and Luminance of QDLEDs using LCO films as HIL

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# Studying of vibration modes in $CH_3NH_3PbBr_3$ single crystals by Raman scattering

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Hybrid organic-inorganic perovskite $CH_3NH_3PbX_3$ (X= I, Cl, Br) semiconductor material has been intensely studied recently for high efficient solar cell applications. To improve the performance of photovoltaic devices, it is necessary to understand mechanism of $CH_3NH_3PbX_3$. In this report, we studied $CH_3NH_3PbBr_3$ single crystals by photoluminescence (PL) and Raman scattering spectroscopy. By monitoring temperature dependence of PL spectra from a $CH_3NH_3PbBr_3$ single crystal, we could observe distinctive PL emission lines in each structure of orthorhombic, tetragonal and cubic phases. Two emission bands at 2.27 eV and 2.10 eV were identified which are originated from free exciton recombination and coexisting orthorhombic and tetragonal phases, respectively. Raman scattering spectra at low temperature clearly showed the trend of phase transition occurring at about 140 K, 154 K, and 235 K, that is consistent with change in PL spectra. Abnormal frequency shift, changes in intensity and in FWHM of certain vibrational modes of $CH_3NH_3^+$ (MA) cation might elucidate the mechanism of structural phase transition in $CH_3NH_3PbBr_3$.

# Broadband Emission of Plasmon-coupled Quantum Dots

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The broadband PL emissions from CdSe QDs and plasmon-coupled QDs [1-3] were characterized with time-resolved and temperature-dependent spectroscopy to develop hybrid broadband LEDs. The origin of broad spectral emission includes the transitions from the band-edge and surface-trapped states. The temperature-dependent PL spectroscopy of CdSe QDs and plasmon-coupled CdSe QDs were characterized by the thermal quenching of PL intensity at the band-edge and surface-trapped states, in addition to the thermalization from the surface-trapped state to the band-edge. The observation of negligible thermal quenching of PL intensity from CdSe QDs at the band-edge implies the existence of an exciton thermalization mechanism from the surface-trapped state to the band-edge at a higher temperature. The miniscule thermal quenching at the surface-trapped states in conjunction with the appearance of thermal quenching at the band-edge for the plasmon-coupled QDs indicates the selective contribution between nonradiative decay reduction due to the plasmon-exciton coupling rate at shorter wavelengths and local field enhancement at longer wavelengths. The average PL lifetime of plasmon-coupled QDs at shorter (longer) wavelengths was shorter (longer) than bare QDs, while the PL intensity of plasmon-coupled QDs was enhanced at both shorter and longer wavelengths compared to QDs. This indicates that the selective contribution strength between nonradiative decay reduction due to the plasmon-exciton coupling rate at shorter wavelengths and local field enhancement to the average PL lifetime at longer wavelengths. Therefore, both the temperature-dependent and the time-resolved PL spectroscopy identically conclude the selective contribution strength of both plasmon-exciton coupling and large local field enhancement to the increased broadband PL intensity at different spectral regions. The unique broadband emission from plasmon-coupled CdSe QDs with InGaN blue excitation was utilized to demonstrate hybrid white LEDs with greater visual wellness beyond the off-white emission from discrete spectral combinations. Acknowledgments: The work at HU was supported by ARO W911NF-15-1-0535, NASA NNX15AQ03A, and NSF HRD-1137747 (F. S.). The work at TCU and UNT Health Science Center was supported by the NIH grant R01EB12003 (Z. G.) and NSF grant CBET-1264608 (I. G.).

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# Exploiting polar solvent vapor treatment for the organometallic halide perovskite based light emitter applications

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The research interests of organometallic halide perovskites extend to their applications in light emitting diodes due to their facile solution process and excellent optical properties such as high color purity and color tunability. For organometallic halide perovskite films, small grains can spatially confine excitons and promote radiative recombination due to their reduced diffusion lengths. For this reason, development of reliable and reproducible methods to control grain size of perovskite films is of great importance for optimizing device performances. In this work, we succeeded to control the size of perovskite grains by polar solvent treatment. The significant enhancement of photoluminescence (PL) was observed for perovskite films with polar solvent treatment. In addition, 50 nm of PL peak shift by quantum confinement was observed during this treatment. Furthermore, the origins of this dramatic improvement in PL due to grain size changes are further studied by optical characterization and density functional theory calculation.

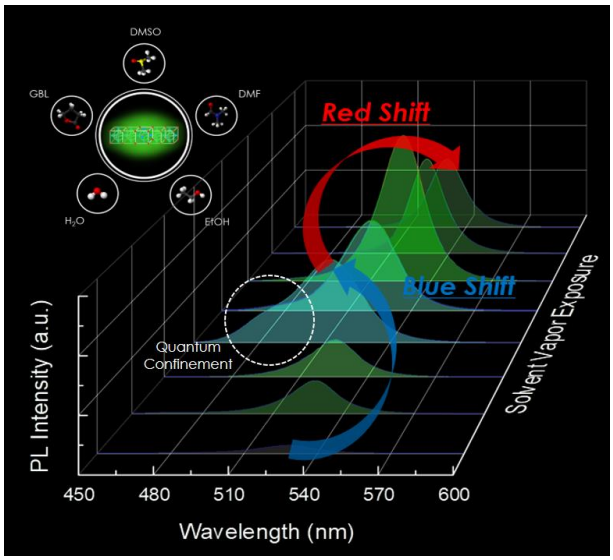


Figure 1. Photoluminescence spectra during $H_2O$ vapor exposure.

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# Absorption background and time-resolved photoluminescence of colloidal CdSe quantum dots

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Requirements for high-performance electronic and optoelectronic devices have spurred much experimental effort directed towards the understanding and exploitation of unique physical properties of colloidal quantum dots (QDs). Owing to the discrete structure of energy and density of states is mainly because of their δ-function, the restricted number of states available for carriers impairs carrier relaxation toward the ground state when the level spacing is only a few meV. Moreover, the level spacing is much larger than longitudinal-optical phonons energies due to strong confinement effects, and thus carrier-phonon scattering can only occur via the weak multi-phonon process [1,2]. In this work, the inter/extra-band optical absorption and time-resolved photoluminescence are used to study the interband relaxation and thermal redistribution of electron and hole discrete states in CdSe QDs with a range of surface properties. The size-dependent energy spacing was determined by the absorption and fluorescence spectra. We also show that the energy-level transitions play a crucial role both on the interband absorption and the decay time of the CdSe QDs.

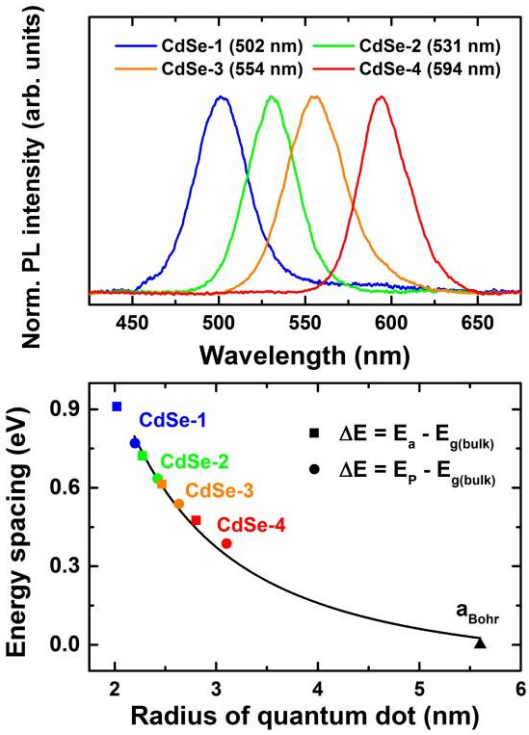


Figure 1. Fluorescence spectra and energy spacing of CdSe QDs.

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# Semi-transparent reverse structure organic solar cell with high stability and performance through electron transport layer modification

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Recently the interest in new and renewable energy has increased, and in particular solar cells are being researched and developed as alternative energy of the next generation. In the current solar cell market, bulk silicon solar cells are mainly used, but various next generation solar cells such as thin film type, organic materials, dye sensitive type, etc. are being developed. Next generation solar cells are developed in various forms based on glass or polymer substrate formed on an electrodes and The importance of conductive oxide electrodes for solar cells is also growing. Many researches on ZnO which is a transparent conductive oxide used in Electron Transporting Layer are performed. In this study, a semitransparent inverted organic solar cell element was coated with Dopamine hydrochloride by a simple spin coating method on the ZnO layer used for the Electron Transporting Layer layer. We confirmed the deformation of the ZnO ripple structure and the adjustment of the band gap and showed an efficiency of 8.208% improved by about 10% as compared with the existing element, and as a result of remeasuring 100 days later, about 80%, Which is about 11% lower than that of the decrease, confirmed the stability. Further, the device was grown by growing the area of the photoactive layer to 13.16 cm at 0.38 cm.

# Improving Magnetic Characteristics of Nano-Ferrite Particles by Controlling Particle Size for Biomedical Applications

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Nano-ferrite particles have been considered as promising agents for bio/nano-medical applications due to their advantageous characteristics [1,2]. In this study, magnetic characteristics including AC magnetically-induced heating property of $MgFe_2O_4$ nano-ferrite particles are investigated in both powder and fluids states for efficient biomedical agent applications. To obtain $MgFe_2O_4$ nano-ferrite particles with different sizes and size distributions, a ball milling process (ball diameters: 3 mm and 5 mm) is conducted within the framework of a modified sol-gel method. The $MgFe_2O_4$ nano-ferrite particles formed with 3 mm-ball milling process possess the smallest particle size and narrow size distribution. These $MgFe_2O_4$ nano-ferrite particles generate the lowest AC magnetically induced heating temperature ($T_{AC,mag.}$ $\Delta T$ = 65 ºC) in powder. However, they generate the highest $T_{AC,mag}$ ($\Delta T$ = 5.1 ºC) and SLP (Specific Loss Power, 525 W/g) in fluidic state at a low frequency ($f_{appl}$ = 110 kHz) and a magnetic field ($H_{appl}$ = 140 Oe). In addition, it is observed that hysteresis loss and relaxation loss are crucial parameters that dictate the heating mechanism of $MgFe_2O_4$ nano-ferrite particles in fluidic state. Theses parameters depend on coating conditions and dipole interaction, which in turn are closely related to particles' sizes and its distributions. Furthermore, it is found that the weaker magnetic dipole interaction in the fluidic state $MgFe_2O_4$ nano-ferrite particles enhances the relaxation loss and hysteresis loss, leading to an improvement of magnetic characteristics such as heating properties for efficient biomedical agent applications.

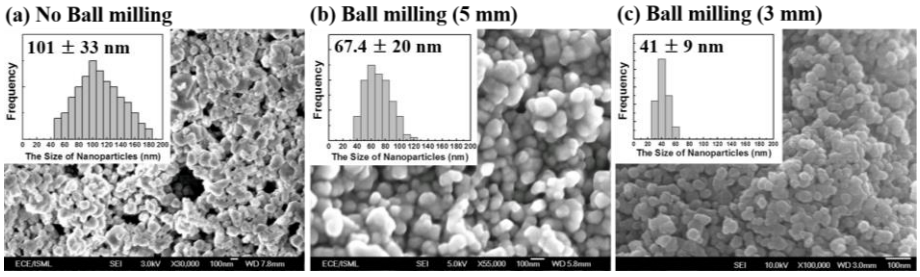


**Figure 1 The mean particle size and size distribution of $MgFe_2O_4$ nano-ferrite particles measured by FE-SEM**

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# Improvement of superhydrophobic property based on cellulose aerogel using cationic polymers

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Since the first aerogels were prepared in 1931 [1], aerogels have been utilizing in a wide variety of industrial fields. The first aerogels were produced from silica. After that, inorganic-based raw materials were mainly used in the production of aerogels. However, various organic-based aerogels with reduced fragility have been studied due to the limited properties of inorganic-based aerogels which are typically very fragile and brittle. Cellulose, a renewable organic biopolymer, is an attractive raw material for the preparation of aerogels because it has low abrasive nature and good mechanical properties as well as the flexibility and biodegradability. Therefore, the cellulose-based aerogel has the high potential to compensate the weakness of inorganic-based aerogels. However, cellulose also has the disadvantages such as moisture adsorption and quality variation when it is exposed to moisture and poor compatibility with the hydrophobic polymers. It is caused by the hygroscopic nature which is include both of hydrophilic and oleophilic. In this study, the density of cellulose aerogel was improved using the regeneration process with the mixture of PAE and vinyl acetate ethylene copolymer. The silanized cellulose aerogel was conducted with methyltrichlorosilane [2] via thermal chemical vapor deposition process without vacuum. The superhydrophobic and superoleophilic properties of cellulose aerogel were confirmed by oil absorption test. The superhydrophobic cellulose aerogel showed excellent oil absorption property with a typical weight gain ranging from 45 to 90 times of their own weight, while cellulose aerogel showed 6 times.

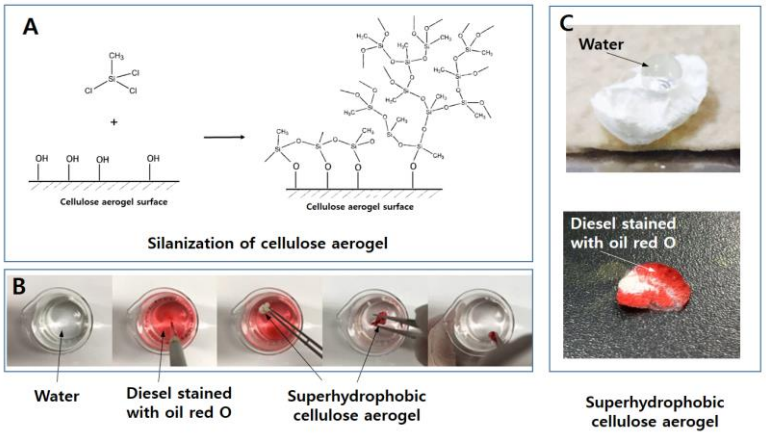


**Figure 1 Silanization of cellulose aerogel (A), and diesel stained with oil red O on top of the water apsorbed by superhydrophobic and superoleophilic cellulose aerogel (B, C)**

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# Preparation of cellulose aerogels as a biomaterial using high degree of polymerization cellulose derived from bast fibers of paper mulberry

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The use of cellulosic material is developing from the primary industrial materials such as clothing, pulp, paper, etc. to renewable energy and fabric materials like regenerated fiber and Lyocell, which makes the cellulose one of the most important materials [1]. The degree of polymerization of cellulose is significant since it is closely related to the strength of the product [2]. Because of its high polymerization degree, cellulose aerogels obtained by dissolving and regenerating bast fibers are expected to have better physical properties than the aerogels from wood fibers. In this study, cellulose with high degree of polymerization was prepared from bast fibers. The solubility of cellulose from various solvents were evaluated.

The bast fibers of paper mulberry were prepared by alkali pretreatment at 100°C for 3 hours using 1M $K_2CO_3$. Three kinds of solutions, NMMO (*N*-methylmorpholine-*N*-oxide)·$H_2O$, $Ca(SCN)_2 \cdot 6H_2O$ and 60% LiBr, were used to dissolve cellulose. 1% (w/w) cellulose sample was dissolved in the solution and stirred at 100-130°C for 30 minutes. The cellulose solutions were then cooled at room temperature, and the surface was completely hardened and washed with water for a week. Then, the hydrogels were freeze-dried. Appearance densities of cellulose aerogels were in the range of 0.016-0.025 g/cm$^3$. SEM images of cellulose aerogels showed different micro structures according to the solvents (Figure 1). Bast fibers could be completely dissolved under only NMMO solvent system without non-soluble fibers.

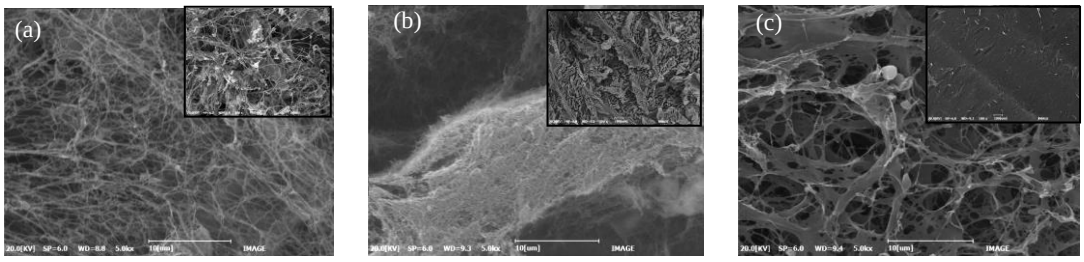


**Figure 1** SEM images (x5000) of cellulose aerogels according to the different solvent systems. (a) $Ca(SCN)_2 \cdot 6H_2O$, (b) LiBr, (c) NMMO

***Acknowledgement**: This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1D1A1B03934044).*

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# Growth of Silicon Oxide Nanowires Using Silicon-Rich Oxide Films

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Amorphous silicon oxide nanowires (NWs) are optically transparent and chemically stable making them suitable hosts for optical based sensing applications. In particular, they have great potential as biological and environmental sensing elements due to their large surface-to-volume fraction and the well-established protocols for coating silica with bioselective coatings. Amorphous silica NWs can be grown by a range of techniques. In particular, recent reports have shown that dense arrays of amorphous silicon oxide NWs can be grown by a relatively simple technique, in which nanowire growth is achieved by depositing a thin metal film on Si wafer and annealing the resulting heterostructure to temperatures close to 1100 °C in a high purity Ar or $N_2$ purging ambient.

In this study we investigate the growth of silica NWs using amorphous silicon-rich oxide ($SiO_x$) films produced by PECVD instead of Si wafer as a source material of Si precursor. Ni-coated (~15nm thickness) $SiO_x$ films with different x values were annealed at 1100 °C for 90 min in a quartz-tube furnace under $N_2$ gas significant effect on the growth of NWs. Thinner NWs are observed for increasing x-values in the range below x=1.45. These results support the notion that the diameters of the NWs are determined by a critical Si vapor concentration that can be readily modified by the x-value. The growth of the silica NWs is shown to be also achieved by a conventional vapor-liquid-solid process. The presented method provides a route to realize a simple growth of silica NWs with a low cost.

# Ultra-Sensitive Detection of Hemagglutinin by Integrated Nanotrap Sensor

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We introduce a new method for ultra-sensitive detection of antigen using on-device-percentage (ODP) of integrated nanotrap sensor. Integrated nanotrap sensor is designed for rapidly detection of low-concentration gold nanoparticles (AuNPs) based on electric field-induced trapping using dielectrophoresis. For the detection of hemagglutinin (HA) through the capture of AuNPs, we implemented a sandwich immunoassay using Au and magnetic nanoparticle probes in the solution and then washed with a magnet. The AuNP probe remains in the sample solution only when the target antigen is present. The integrated nanotrap sensor could detected the target HA by electrically trapping AuNP probes and ratio of the ODP by trapped AuNP probes showed a good correlation with the antigen concentrations. With use of our method, we could successfully quantified the HA and found that the detection limit was a few hundred attomole-level.

The 19th International Symposium on the Physics of Semiconductors and Applications (ISPSA 2018)
July 1 (Sun.) ~ 5 (Thu.), 2018 / Jeju, Korea

# Enzymatic Electrochemical Biosensor Based on Interdigitated Microgap Electrodes for Detection of Hemagglutinine

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The enzymatic electrochemical biosensor based on interdigitated microgap electrodes was developed to detect hemagglutinine(HA) of influenza A virus by dual mode chronoamperometry (CA). Sandwich-type sensor was employed for HA sensing by using the primary antibody immobilized magnetic particle (MP-$Ab^{1st}$) and secondary antibody (ALP-$Ab^{2nd}$) labeled by alkaline phosphatase (ALP). The background signal caused by free ALPs was reduced by the non-specific binding (NSB) control of ALPs and the elimination of free ALPs. The *p*-aminophenyl phosphate (*p*APP) as the substrate of ALP was added to antigen-antibody complexes after the sandwich immunoassay. After the enzyme reaction, we measured the oxidation/reduction current of the extraction solution containing aminophenol /quinoneimine by dual mode CA. It was able to detect concentrations of HA as low as 30 fM.

# Control of attachment and detachment of Gecko-inspired dry adhesive using shape memory polymer

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Today, many adhesives are used not only to stick objects but also to stick sensors to a specific part of human. In general, adhesives are made of chemical materials with sticky characteristic. So, adhesives using sticky chemical materials have a drawback which is toxic and hard to be reused becuase of remaining marks on removal. Interestingly, Gecko lizard in nature can be stuck on a a wall or window by Van der Waals forces of physical structures of foot hairs not chemical effect[1]. For this reason, studies on the fabrication of semi-permanent dry adhesives having spatula to mimic these properties have been conducted constantly[2]. However, studies on the effective detachment method of fabricated dry adhesives have not been conducted as much as adhesion studies.

In this study, we propose a easy attachment and detachment method about gecko-inspired dry adhesive by using a shape memory polymer. The shape memory polymer is polymeric smart materials that have the capability to return a deformed shape(temporary shape) to their permanent shape induced an temperature change[3]. Using this characteristic, fabricated normal pillars as permant shape using SMP are deformed as temporary shape having spatulate tip, when it is pressurized with specific temperature and cooled on the surface. This process causes the dry adhesive to attach to the surface. And deformed shape having spatulate tip is detached from the surface, when it is pulled while applying the specific temperature which becomes the normal pillar shape as permanent shape. And a thermoelectric module that can adjust a temperature expeditiously by adjusting an electric current direction is used as the temperature controller for shape memory polymer. This type of controllable detachment method can be used in the applications in which robots can be walked on windows and walls. And dry adhesives using SMP can be used a transfer system for glass or wafers.

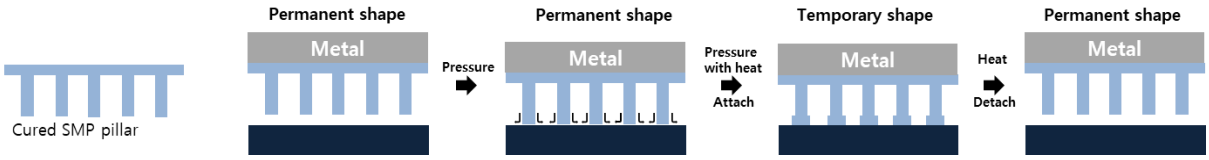


**Figure 1 Schematic image of attachment and detachment process for dry adhesive using SMP**

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# Super-resolution optical fluctuation imaging with speckle patterns illumination

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Escalating need to unveil the sub-wavelength landscape in micro-/nanomaterials and biological specimen motivated development of the numerous super-resolution optical imaging protocols in recent years[1,2]. Among these, super-resolution optical fluctuation imaging (SOFI) employs independent blinking of fluorescent emitters whose statistics encodes their location with sub-diffraction scale precision[3]. Illuminating dynamic random speckle patterns on a fluorescent sample is an alternative way of inducing blinking and relieves the need to label the sample with the blinking dyes. This extension of SOFI, so-called speckle illumination SOFI (S-SOFI), enabled SOFI to be applicable to any fluorescence imaging modalities[4]. However, as far-field speckle pattern itself has the diffraction limited spot size, speckle-induced blinking of fluorescent emitters closely spaced inside the diffraction-limited zone can be correlated. This violates one of the pivotal assumptions of SOFI calculation, which state blinking of each emitter should be mutually independent, and imposes the limitation on the level of super-resolution achievable by S-SOFI. Here, we quantitatively evaluate the artifacts inherent in S-SOFI processing by measuring the modulation transfer function before and after applying S-SOFI algorithm. To this end, computationally generated Siemens star pattern is fluctuated under exposure to the set of experimentally measured dynamic speckle patterns of varying grain size and is subject to S-SOFI processing. Any artifact induced by S-SOFI reveals itself as the difference between the original star pattern and deconvolved S-SOFI images. Observing the imaging conditions inducing aritfacts hints us on the strategies to realize an artifact-free S-SOFI protocol.

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# Linearly Polarized Photoluminescence of Anisotropically Strained c-plane GaN Grown on Stripe-Shaped Cavity-Engineered Sapphire Substrate

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The effects of anisotropic strain in GaN on optical response, structural and vibrational properties have been reported [1-2]. Most of the previously reported researches achieved the anisotropic strain by using the epitaxial structures containing non- or semi-polar epitaxial layers or substrates. We realized anisotropic in-plane strain and the resultant polarized photoluminescence (PL) of c-plane GaN on c-plane sapphire substrate by using a stripe-shaped cavity-engineered sapphire substrate (SCES), which induces anisotropic strain in the GaN grown on SCES. The fabricated SCES and GaN growth on SCES were shown in Fig. 1.

In order to investigate the anisotropic strain in GaN on the SCES, high resolution X-ray reciprocal space mapping (RSM) around asymmetric {11-24} and {-2204} and symmetric {0004} reflections was conducted. It was found that the GaN layers on the SCES was under significant anisotropic in-plane strain of -0.0140% and -0.1351% along the direction perpendicular ($x$) and parallel ($y$) to the stripe direction was measured, respectively. Figure 2 shows the polarized PL characteristics of GaN layers on the SCES. The experimental results were compared with calculated value based on $k \cdot p$ perturbation theory. It was found that the anisotropic PL was attributed to anisotropic in-plane strain. In this presentation, mechanism for the anisotropic strain of GaN layers on the SCES and the origin of polarized PL behavior will be discussed.

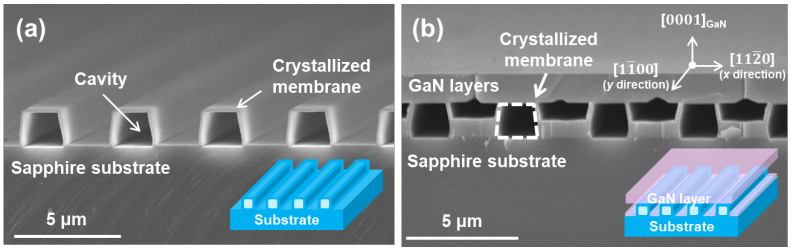


Fig. 1. Cross-section SEM images and schematic diagrams of (a) fabricated SCES with crystallized $Al_2O_3$ membranes after thermal treatment, (b) GaN grown on SCES with growth time of 90 min.

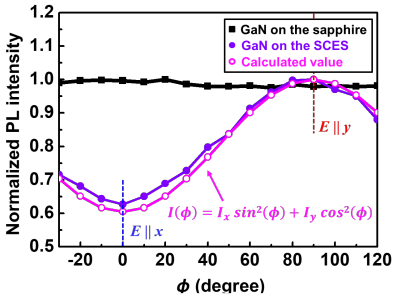


Fig. 2. Normalized PL intensities of GaN on a planar sapphire substrate and the SCES, and calculated values.

*This work was supported by the BK21 Plus Materials Division for Educating Creative Global Leaders (F15SN02D1702), South Korea.*

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# Thickness dependence of thermal conductivity of 2D materials

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We investigate thickness dependence of lattice thermal conductivities of layered materials based on Boltzmann transport equation approach and molecular dynamics simulations. For graphene, as the number of layers increases, in-plane lattice thermal conductivity decreases. On the other hand, for $MoS_2$, as the number of layers increases, in-plane lattice thermal conductivity is found to increase. The calculated in-plane lattice thermal conductivities of monolayer graphene and graphite are ≈3300 and ~2000 W/mK [1, 2], respectively, while the calculated in-plane lattice thermal conductivities of monolayer and bulk $MoS_2$ are 45.18 and 58.93 W/mK, respectively. In general, heat flows in monolayer materials are mediated dominantly by the flexural phonons, which have the longest phonon relaxation times. To better understanding the different thickness dependences, we investigate the harmonic and anharmonic interatomic force constants. The phonon dispersions, group velocities, volumetric heat capacities, and phonon relaxation times are compared for graphene and $MoS_2$. The calculated phonon relaxation times of bilayer $MoS_2$ are found to be longer than those of monolayer $MoS_2$ in some ranges of angular frequencies, which can lead to the lattice thermal conductivity enhancement.

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# Defect Mitigation for EUV Vote-Taking Lithography

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Extreme ultraviolet (EUV) lithography is one prospective technology for the fabrication of integrated chips with critical dimensions of below 10-nm. However, one of the most critical problems in the extreme ultraviolet lithography (EUVL) as a leading candidate is mask defect and repair since critical dimension (CD) becomes similar as defect size for below 10-nm CD. The defects cause local areas of undesired absorption, reflectivity or phase change, which ultimately show up as imperfections in the printed image. Phase defects may cause image anomalies which change dramatically with focus.
In this paper, the EUV vote-taking lithography for detection and repair of lithography-related defects are discussed and compared with other methodologies. These results can state that vote-taking relieves the need to have the perfect defect-free mask.

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# Fabrication of chromatic electronic textiles synthesized by conducting polymer

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Most of electronic textiles (e-textiles) were fabricated by carbon-based materials such as graphene [1,2], carbon nanotube (CNT) [3,4] and hybrids of graphene and CNTs [5,6] due to their high electrical conductivity, flexibility, and good stability. However, it is difficult to make a colored e-textiles because the carbon-based e-textiles have only black color. In this study, we produced the chromatic e-textiles synthesized with different conductive polymer such as polyaniline (PANI), polythiophene (PTh), and poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS). The chromatic e-textiles were simply fabricated by soaking the commercial cotton into the aqueous conductive polymer solution. The chromatic e-textiles were characterized by scanning electron microscopy (SEM), x-ray photoelectron spectroscopy (XPS), and fourier transform infrared (FI-IR). The electrical conductivity of chromatic e-textiles was the order of $10^{-3}$ S/cm, which is maintained even in bending.

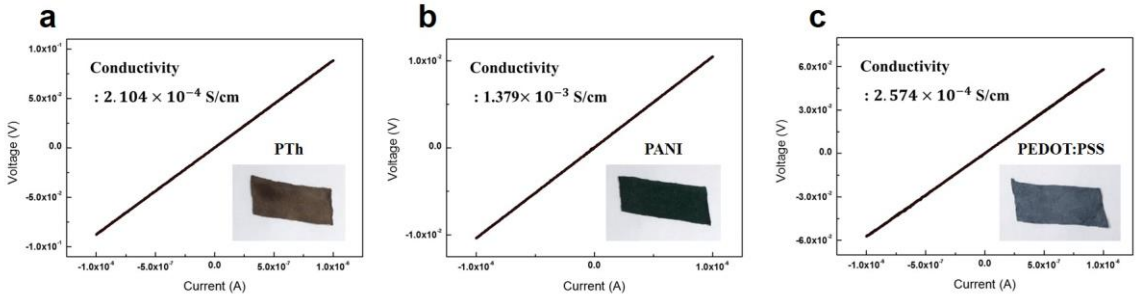


**Figure 1.** Current-Voltage characteristics of (a) PTh-coated cotton, (b) PANI-coated cotton, and (c) PEDOT:PSS-coated cotton

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# The growth of discrete GaN array with micro size using sapphire nano-membrane

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Micro-LEDs have attracted much attention due to high brightness, high pixel density and low energy consumption. In this study, we demonstrate a new, simple and cost-effective scheme combining the growth of a micro-sized GaN layer array and subsequent direct transfer of the array to a Si substrate by a mechanical lift-off.

As shown in Fig. 1, separated GaN layers of various LED chip sizes (14 μm x 14 μm and 50 μm x 50 μm) were successfully grown on a stripe-patterned sapphire nano-membrane by metalorganic chemical vapor deposition. First, photoresist (PR) pattern of a stripe with the width and the spacing of 2 μm was formed on a sapphire substrate. Then, an amorphous $Al_2O_3$ layer with thickness of 120 nm was deposited by atomic layer deposition (ALD). Then, the substrate was annealed at 1100 ºC for 2 hours to oxidize PR, leaving stripe-shaped cavities, and to crystallize the ALD alumina into sapphire membranes for the GaN growth. The stripe length and the number of arrays determine the sizes of GaN layer.

The wafer with a chip-sized GaN array was flipped over on a Si substrate and the GaN layers were successfully transferred by a mechanical lift-off process. Also, we found that the threading dislocation density of discrete GaN layers was $1.2 \times 10^8$ $cm^{-2}$, which was 40% lower than that of GaN grown on a thick sapphire substrate. In the presentation, details of the results including the growth behavior of GaN on sapphire membrane will be discussed.

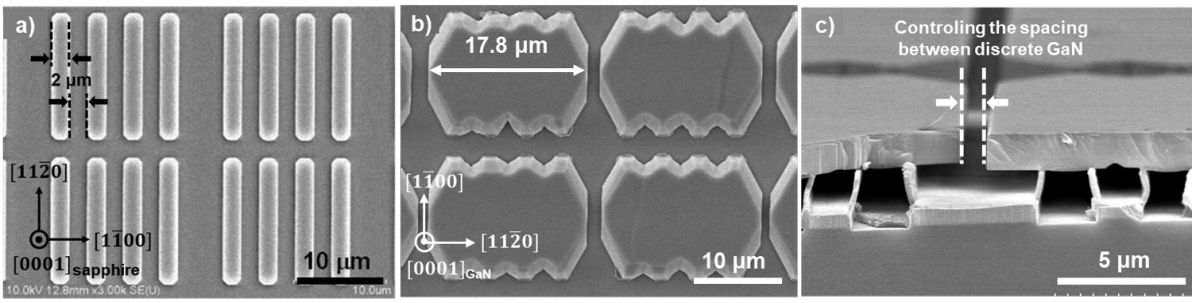


Fig.1. (a) Sapphire nano-membrane for GaN growth, (b) Plan-view and (c) bird's eye view SEM images of discrete GaN layers grown on sapphire nano-membrane for two hours.

*This work was supported by the BK21 Plus Materials Division for Educating Creative Global Leaders (F15SN02D1702), South Korea.*

# Stretchable Ag Nanowire network/PEDOT:PSS hybrid electrodes for stretchable polymer-dispersed liquid crystal-based smart windows

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Although polymer dispersed liquid crystal (PDLC)-based smart windows are very potential devices in the field of smart windows, expensive ITO electrodes are still commonly used as electrodes. In this work, we have developed a PDLC-based smart window using Ag Nanowire (NW) network/PEDOT:PSS electrodes to replace the expensive ITO electrodes. In addition, because this electrode is made on the polyurethane(PU) substrate, the PDLC-based smart window made of these electrodes is stretched up to 30% strain. The result of the bending test and stretching test of each electrode, we have proved that the Ag NW/PEDOT:PSS hybrid electrodes show the superior mechanical flexibilities than ITO electrodes. To demonstrate the potential of bar coated Ag NW/PEDOT:PSS hybrid electrodes on PU substrate, we fabricated 2.5 cm × 2 cm PDLC-based smart window on optimized Ag NW/PEDOT:PSS hybrid electrodes (40 Ohm/square, 82 % optical transmittance). The Ag NW/PEDOT:PSS hybrid electrode-based smart windows exhibited on-state transmittance (56 %) at an applied voltage of 80 V and off-state transmittance (2 %) at an non applied voltage. Therefore, successful operation of flexible and stretchable PDLC-based smart window with Ag NW/PEDOT:PSS electrodes indicates that bar coated Ag NW/PEDOT:PSS films on PU substrate are affordable, high performance, and flexible transparent electrodes for cost-effective large-area smart window and can be substituted for ITO films, which have high sheet resistance and low flexibility.

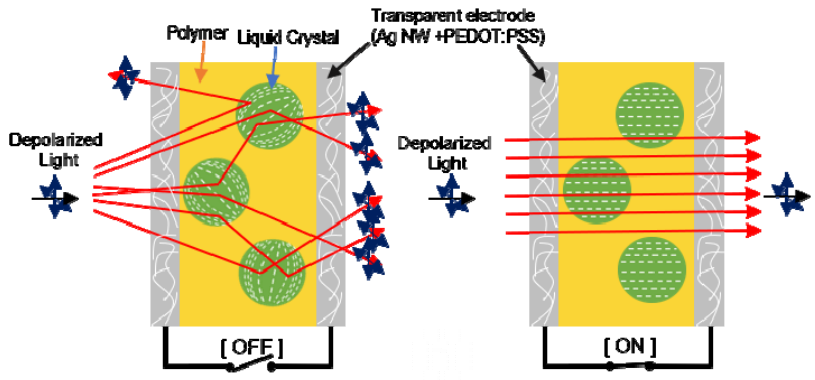


**Fig. 1** Schematic operation mechanism of PDLC-based smart windows.

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# Interfacial Reliability of Printed Ag Interconnects on Flexible Polyimide Substrate for Wearable Device Applications

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Future wearable electronic devices have increasingly expected to require fabrication technology of micro-scale active or passive components on flexible organic substrate for advanced embedded packaging technologies. Polyimide has properties of flexible, high temperature resistance, good mechanical strength, good chemical stability, and low dielectric constant. Therefore metal thin film/polyimide structure systems are commonly used as printed patterned flexible circuit. Therefore, polyimide, as a flexible substrate, has been investigated for the development of low-cost wearable electronic systems. Silver is one of the best conductor in electronic systems, but during silver metallization on polyimide substrate, silver/polyimide structure has poor interfacial adhesion. Also there is the other largest problem during developing this technology, which is long-term interfacial adhesion and reliability. Therefore, in this study, in order to understand the effect of temperature/humidity treatments on the interfacial adhesion energy between screen-printed Ag film and polyimide substrate structure were evaluated by 180° peel test. The temperature/humidity treatment was performed at 85℃/85% relative humidity for 1000hrs as an acceleration test to simulate a long-term reliability. The measured peel strength values decreased from 22.22gf/mm to 0.47gf/mm for 500hours at 85℃/85% relative humidity for the temperature/humidity treatment. X-ray photoelectron spectroscopy analysis of the peeled surfaces indicate that peeling occurs cohesively inside of the polyimide. After 500 hours of temperature/humidity treatment, there is a decrease in interfacial adhesion energy, which seems to degrade polyimide by hydrolysis reactions with water molecules.

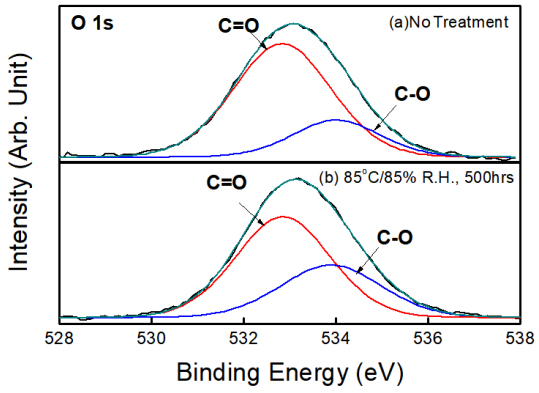


**Figure 1. Peak area fraction change in O 1s core-level XPS spectra of polyimide after temperatur e/humidity treatment for 500h.**

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# Analysis of encapsulation characteristics of aluminum zinc oxide deposited on a flexible substrate by ALD

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Transparent Conductive Oxide (TCO) has been actively developed in the fields of Organic Light Emitting Diode (OLED) and Organic Photovoltaic (OPV) because it exhibits high light transmittance and excellent electrical conductivity in the visible light region. [1] Indium Tin Oxide (ITO), one of the TCO materials, has been widely commercialized due to its low resistivity, high light transmittance and high adhesion to substrates. However, due to the recent rise in the price of indium, Aluminum Zinc Oxide (AZO) thin films have been developed to replace ITO. Since AZO has a high charge density due to the influence of $Al^{3+}$ doped with ZnO, it has an advantage of being excellent in electric conductivity and being formed on a flexible substrate due to a low temperature process.

In this study, AZO, a TCO material that can replace ITO, was fabricated and analyzed using the Atomic Layer Deposition (ALD) system. To fabricate AZO thin films, DiEthylZinc (DEZ) and $H_2O$ precursors were deposited on ZnO thin films, Trimethylaluminum (TMA) and $H_2O$ precursors were deposited on PEN films. The substrate temperature was 150° C and the purge gas was $N_2$. Purge time is 1 cycle of ZnO and $Al_2O_3$ with 0.1 s of precursor, 10 s of $N_2$ purge, 0.1 s of reactant and 10 s of $N_2$ purge. ZnO and $Al_2O_3$ were prepared at a ratio of 20:1 to form AZO. As the deposition parameters, the number of deposition of AZO was controlled. The AZO thin films deposited were measured for sheet resistance, SEM and WVTR.

As a result of the sheet resistance measurement, it was confirmed that the sheet resistance decreases as the thickness of the AZO thin film becomes smaller. As the thickness of the AZO thin film becomes thicker by the WVTR analysis, it can be applied as encapsulation preventing moisture penetration by improving the moisture permeability.

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# $Al_2O_3/SiN_x$ multilayer thin films grown by ALD and sputter deposition for encapsulation of flexible display

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Flexible organic electronics are promising candidates for next generation devices owing to lightness and free shape conversion. In order to apply the flexible electronics to the industry, a polymer plastic film is used as a substrate. However, polymer film substrates are normally poor for permeating of oxidative species such as moisture or oxygen. In the case of easily permeates moisture, the light emitting layer can't be protected and a dark spot is formed. Therefore, it is necessary to flexible barrier films for organic electronics like OLED or OPV application.

We demonstrate flexible moisture barrier film encapsulation for organic electronics using low temperatures process method. To realize the flexible barrier, the best practice is to make the barrier as multilayer structure. Low temperatures process applied the atomic layer deposition(ALD) method and sputtering method to deposit barrier films. Inorganic layers work as moisture barrier and very thin thickness provide the flexibility and planarization. To deposit the inorganic layers, TMA (TriMethyl Aluminum), $H_2O$ were used as inorganic precursors and nitrogen gas was utilized as a purging gas. We focus our attention on the effect of increasing number of interfaces on the final barrier properties. The moisture permeation characteristics of the optimized $Al_2O_3/SiN_X$ multilayer films were finally measured using MOCON's WVTR measuring instrument and WVTR values lower than the detection limit of the measuring device (less than $5.0 \times 10^{-5}$ g/m-day) were obtained.

# The actuation of paraffin-infiltrated multi-wall carbon canotube yarns

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We made hybrid yarns that were composed of CNT, as a template material, and paraffin wax, a phase change material. Heating of the yarn by the current applied melted the wax and then induced phase transition of the paraffin wax from solid to liquid. The volume change owing to the phase transition of the wax permits the hybrid yarn to function as temperature-sensitive actuator. The actuation of the yarn needs no power source. The environmental temperature changes that come across the phase change temperature of the wax can actuate the hybrid yarns.

Reference

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# Effects of annealing temperature on the UV light emission of CaO-decorated ZnO nanorods

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There have been numerous efforts to cap or decorate ZnO one-dimensional (1D) nanostructures with various materials including metal oxide semiconductors, metals and polymers, to obtain intense ultraviolet (UV) emission. However, the effects of annealing conducted after the decoration of ZnO 1D nanostructures with CaO on the intensity of the UV emitted from the nanostructures have not been reported. In this paper, we report intense UV emission from ZnO nanorods decorated with CaO. The UV emission from the nanorods decorated with CaO nanoparticles and then annealed at 400 °C was more intense than that from the pristine ZnO nanorods. The intensity of the UV emission from CaO-decorated ZnO nanorods was enhanced and the deep-level (DL) emission was suppressed completely with 400 °C annealing in an oxidizing atmosphere. In contrast, higher temperature anneals resulted in a decrease in UV emission intensity. The underlying mechanism for the enhancement of the UV emission and the complete suppression of the DL emission from the CaO-decorated ZnO nanorods by annealing at 400 °C is discussed in detail.

# Study of Mass Evaluation Methods between X-ray and Quartz Crystal Microbalance

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Printing techniques such as screen printers and dispensers are used to coat electrode material to make circuits. To test the completeness of the electrodes using a non-contact technique, their shape should be measured but this does not provide sufficient information on their electrical properties and any non-homogeneity or bubbles that may exist within the applied material. In contrast, examining a printed electrode`s mass provides information not only on its structural performance, including bubbles and non-homogeneity, but also its indirect electrical performance. However, a piezoelectric sensor or scale cannot be used to measure the mass of an already printed semiconductor element.

Thus, a non-contact mass evaluation method that uses X-rays or other techniques is required. Despite this need, there had been no research on mg level mass measurement using X-rays and Quartz crystal microbalance. This research was carried out to determine the feasibility of non-contact mass measurement at a level of 10 mg or below using an X-ray microscope and Quartz crystal microbalance.

Year).

# Lens-less Reflection Digital Holographic Microscope for Three Dimensional Measurement of Optical Component

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Development of optical tools for inspection and characterization of micro-devices are highly demanding and a challenging task. The main requirements behind development of such tools are to provide feedbacks about device performance, controlled fabrication process, and material properties for designing and simulation process to ensure the performance of device. The major requirement from the new characterization tools are: better imaging and highly accurate measurement performance for three dimensional (3D), lager field of view and high lateral resolution. Existing microscopes have limitations of short working distance, limited depth of field, and limited information recording capabilities. Conventional metrological methods are unable to meet these requirements. Thus the suitable approach has to be developed for this growing industry to ensure reliability and quality of the products and processes.

Digital holographic microscopy (DHM) has a wide range of applications, from the analysis of microelectronic mechanical systems (MEMS) to the measurement of cells. DHM can use spherical waves for recording digital holography to enlarge the object wave being reconstructed, allowing the image recorded in the charged coupled device (CCD) to be magnified. This allows the objects to be observed with more detail without the use of lenses. The novelty of the system is the incorporation of lens-less magnification with DH to provide a compact system suitable precisely to fulfill the micro device measurement requirements

In this paper we propose a compact and simple lens-less digital holographic. The lens-less magnification has achieved using a diverging beam. The study of the digital recording mechanism of holograms, and reconstruction methodology are explained. This simple microscope is based on off-axis digital holography and allows measurements in reflection geometry.

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# Direct Three Dimensional Measurement of Optical Component using Transmission Deflectometry

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Automated and precise three-dimensional (3D) shape measurement, profilometry, is an important task in quality control. However, most of the existing techniques are applied to measure objects with diffused surface.

Specular surfaces have wide applications in industrial and optical products such as lens and varnished or chrome-plated parts in automotive and aerospace areas, as well as free-form optical components. Since specular surfaces used in the industry always have complex and large areas, consideration must be given to both the improvement of measurement accuracy and the acceleration of online processing speed Therefore, developing a stable and real-time method for specular surface measurements is very essential. The research of shape measurement for specular objects is still in the early stage. Phase measuring deflectometry (PMD) has been widely studied to test specular free-form surfaces because of the advantages of non-contact operation, full-field measurement, fast acquisition, high precision and automatic data processing. PMD is based on the analysis of distorted encoding grating patterns reflected via the specular surface under test to provide a direct measurement of discrete slope variations. Phase information in the deformed fringe patterns is demodulated to obtain the slope of the measured specular surface and the 3D shape of the tested surface can then be reconstructed by integrating the gradients. The above PMD methods therefore only measure the local slope of smooth surfaces, instead of the actual 3D shape. Owing to the integration procedure, complicated specular components having isolated and/or discontinuous surfaces cannot be directly measured from phase data.

In this study, we propose a theoretical model for new direct PMD (DPMD) method that measures the full-field 3D shape of complicated specular objects and derived to directly relate an absolute phase map to depth data, instead of the slope. Computer simulations and experimental results both demonstrate the accuracy, effectiveness, of this method, DPMD.

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# Characterization of Photoresist Layer and Investigation of Dry Strip Process Through Real-time Monitored Variable Temperature Control

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Photoresist (PR) is a common block mask employed during ion implantation [1,2]. PR usually stripped out after implantation process via wet or dry strip processes. The upper layer of PR becomes carbonized during ion implantation, due to high dose ion beams delivering more than 1E15 atoms/cm2, forms a crust layer [3]. Both crust layer and ion-free bulk PR should be removed without inducing any device damages or leaving contaminations.

Dry-strip process of ion-implanted photoresist is a major challenging process due to prevent resist popping. We pre-heat the wafer at various temperatures in order to monitor the strip process steps between ion-implanted crust and bulk photoresist. It is found that the strip rate gets slower for low temperature, showing its high chemical reactive dependence. Temperature of wafer and optical emission spectrum were measured simultaneously during the strip process in real-time, in-situ.

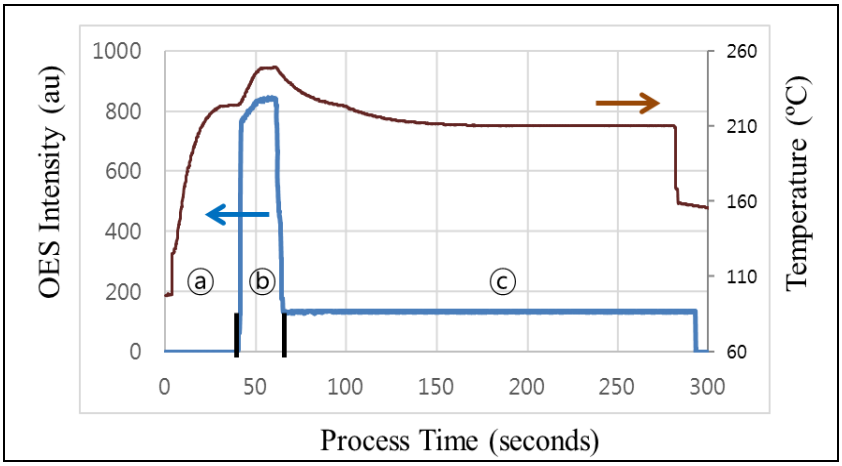


**Figure 1 Measured OES (O-H) and temperature for conventional i-line PR dry-strip process, wafer was heated at 250 °C, temperature was stabilized 90 seconds after all PR has stripped off**

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# Thermal annealing effect on nonvolatile memory characteristics of $ZnO/SiO_x$ multilayer ReRAM devices

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ReRAM(Resistive Random Access Memory) devices using metal-oxide have been extensively studied to realize next generation of a high performance nonvolatile memory. Among several materials for the memory devices, the ZnO thin film exhibited good nonvolatile memory characteristics in terms of switching speed, on-off resistance ratio, and retention. However, the thin film is stressed with increasing number of on-off resistive switching cycles, so that it is unlikely for the memory device to exhibit stable and reproducible resistive switching behavior. In order to improve the resistive switching properties of ZnO-based ReRAM, a multiple-layers structure with $ZnO/SiO_x$ multilayers has been proposed.[1] It is worthwhile to note that a resistive switching has also been observed in defective $SiO_2$ thin films, although Si is not a transition metal.[2]
In this experiment, we have demonstrated the fabrication and application of a nonvolatile ReRAM with the $ZnO/SiO_x$ multilayers. In particular, the thermal annealing effect on the nonvolatile memory characteristics was investigated. Both ZnO and $SiO_x$ thin films were deposited at room temperature using RF magnetron sputtering. The $ZnO/SiO_x$ multilayers were annealed at various temperature and time conditions under $N_2$ gas atmosphere. As a result, reproducible on-off operations with the on-off resistance ratio of $>10^2$ were obtained. Based on the results of this experiment, we will discuss the effect of thermal treatment on the nonvolatile memory characteristics.

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# Resistive switching effects of Zinc Silicate thin films for nonvolatile memory applications

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Zinc oxide (ZnO), a typical oxide semiconductor material with a wide bandgap (3.1~4 eV), has good transparency, moderate mobility, and the CMOS compatibility. In addition, ZnO thin films were widely investigated for Resistive Random Access Memory(ReRAM) applications and revealed to have the memory properties of fast switching speed, large on/off ratio of resistance, stable endurance, and long retention. Recently, a resistive switching effect has been also observed in defective $SiO_2$ thin films, although silicon is not a transition metal. Here, we consider using Zinc Silicate ($ZnSiO_3$ or $Zn_2SiO_4$) as a new material for ReRAM application. In previous experiments, we studied the optimum partial pressure-conditions of oxygen gas during the reactive sputter-deposition, and observed that the newly formed Zinc Silicate thin film has the resistive switching properties. [Fig. 1]
In this experiment, we have demonstrated the fabrication and application of a nonvolatile ReRAM with the Zinc Silicate thin film. In particular, the thermal annealing effect on the nonvolatile memory characteristics was investigated. Zinc Silicate thin film was deposited on a highly doped-Si substrate by RF-magnetron sputtering method. For the top Ag electrode, metal evaporation method was conducted with shadow mask. The highly doped-Si substrate was used for bottom electrode. The nonvolatile memory parameters were measured using HP4155C semiconductor parameter analyzer. The optimal fabrication conditions and resistive switching properties of Zinc Silicate thin films, such as, the on/off resistance ratio, endurance, retention, and switching time, will be presented.

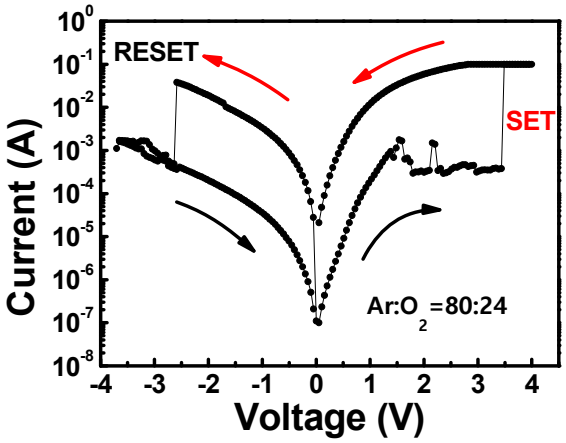


**Figure 1 Current-voltage plot of the fabricated ReRAM device**

# Study on fabrication of GaAs/AlGaAs QWIPs on Si substrates using metal wafer bonding.

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III-V compound semiconductors have been widely used in military, scientific, commercial and medical applications. GaAs-based quantum well infrared photodetectors (QWIP) have several advantages such as mature growth technology of MBE system, high uniformity, low price, etc. [1] This QWIP aims to detect infrared rays in the range of 3 to 5 μm and 8 to 14 μm. To obtain a thermal image, a focal plane array (FPA) must be integrated into Si-based readout integrated circuit (ROIC) [2]. Conventionally, indium bumps were fabricated on a GaAs-based QWIP and then a Si-based ROIC was integrated using flip-chip bonding technique [3]. Recently, a transfer technique for transferring a GaAs-based PIN photodetector onto a Si substrate using wafer bonding and epitaxial lift-off techniques has been reported [4].

The GaAs / AlGaAs QWIP was transferred onto the Si substrate by applying this method. First, at 580 degrees with the MBE system, AlAs sacrificial layer 10 nm was grown on the semi-insulating (S.I.) GaAs substrate and a 4.55 um n-type GaAs / AlGaAs QWIP was grown thereon. After cleaning surfaces of the GaAs/AlGaAs QWIP and Si substrate, 10 nm of Pt / Au was deposited by electron beam evaporator. After mesa etching and surface treatment, the QWIP was bonded to the Si substrate using the metal wafer bonding technique. And the AlAs sacrificial layer was selectively etched using HF solution to transfer the QWIP thin film onto the Si substrate. After forming electrodes on the transferred QWIP, the device process was completed through annealing at 200 degrees for 2 hours. In this paper, as-grown QWIP and transferred QWIP onto Si substrates (Si-QWIP) were compared and analyzed. At room temperature, dark current of as-grown QWIP and Si-QWIP were measured $2.6x10^3 A/cm^2$ and $3.2x10^3 A/cm^2$, respectively. Also, photoluminescence (PL) at room temperature showed a peak at 818 nm for as-grown QWIP and at 816 nm for the Si-QWIP. This is due to the formation of Fabry-Perot cavities by Pt/Au bonding layer. In addition, the spectral response of both devices was measured at 77K and 120K using FTIR. As-grown QWIP and Si-QWIP show same photoresponse at 3.5 ~ 8.5 μm and a peak was at 6.45 μm. As a result, we confirmed that the electrical and optical properties of the GaAs/AlGaAs QWIP were not changed after metal wafer bonding and epitaxial lift-off.

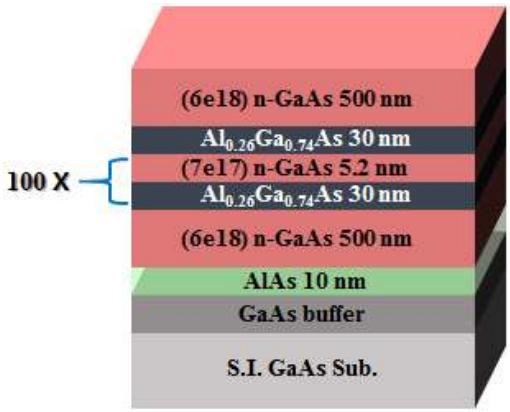


Fig.1. Structures of GaAs/AlGaAs QWIPs

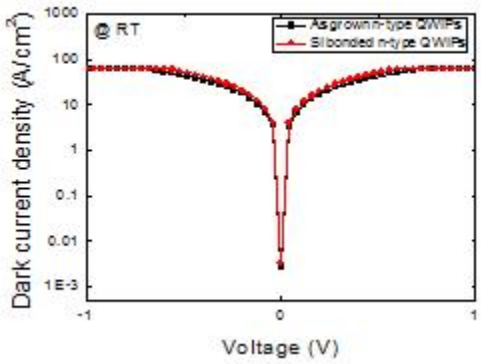


Fig.2. Dark J-V characteristic of as-grown QWIP and Si QWIP

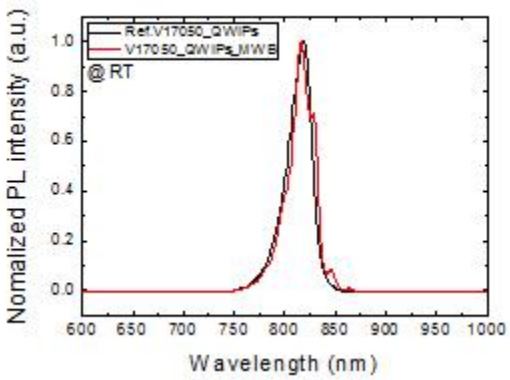


Fig.3. PL at room temperature

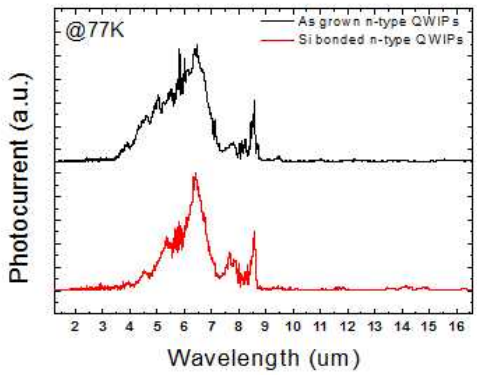


Fig.4. Spectral response of as-grown QWIP and Si-QWIP by FTIR.

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# Nano-micro ZnO structures for highly selective hydrogen gas sensor

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**Abstract**

The environmental monitoring is one of the key issues that have to be addressed in present developing world scenario. The detection of various gases (toxic or explosive) in the atmosphere has become the primary need in order to avoid any unpleasant accidents. The researchers are exclusively working on hydrogen generation and storage for clean abundant future source of energy. Hydrogen ($H_2$) gas has wide explosive concentration range (4–75 vol%), low ignition energy (0.02 mJ) and large flame propagation velocity.[1] Human senses cannot detect $H_2$ due its colorless & odorless properties.[2] There is requirement to develop high performance and low concentration detection hydrogen gas sensors.

High quality, closely packed ZnO nanorods textured micro particles were prepared using chemical method. These nano-micro structured ZnO were investigated for gas sensing properties. The nanorods texturing (diameter ~ 70 - 80 nm and height ~ 300 nm) on micro size (diameter ~ 9 nm) ZnO particles were done by introducing seed structures. The morphology was confirmed by field emission scanning electron microscope (FE-SEM) and transmission electron microscope (TEM). The structural parameters and elemental

compositions have estimated by x-ray diffraction (XRD) and energy dispersive spectrometer (EDS) respectively. Nano-micro ZnO structure have remarkable selectivity towards hydrogen ($H_2$) gas. The lowest $H_2$ detection of 2 ppm concentration was noted with response 8, whereas gas response 816 was recorded for 100 ppm at 225 °C optimized temperature with response time 180 s. The sensor has studied at different operating temperature and gas concentration along with sensor stability. The performance of present sensor was compared with reported data and found to be improved.[3,4,5]

**Keywords**: ZnO; Nanorods; microsphere; $H_2$ sensor; Selectivity

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# Development of Vanadium oxide-Based Micro-bolometer with Infrared absorbing layer

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Uncooled infrared (IR) detectors have been developed with tremendous effort in recent years due to many military and commercial applications such as thermal cameras, night vision cameras, thermal sensors, surveillance, etc. The IR detectors are generally divided into photon detectors and thermal detectors. Thermal detectors can be integrated with electronic circuits to form smaller thermal detecting devices, for example battery-operated, hand-held equipment, because they do not need any cooling system. A micro-bolometer is a temperature dependent electrical resistor where the resistance of a micro-bolometer changes according to its temperature. Infrared radiation is introduced into heat and physical property of the sensitive film changes with temperature. The changed physical property can be converted into electrical signal. That is the detection principle of micro-bolometer. Several researchers have sought to improve the bolometer performance using various materials, such as vanadium oxide, titanium oxide, yttrium barium copper oxide, Si/SiGe and amorphous silicon. The advantages of Vanadium oxide (VOx) uncooled micro-bolometer include light weight, low power consumption, room temperature operation, suitable for portable application, etc. VOx thin film has been widely used because of high temperature coefficient of resistance (TCR) and low noise. Till now, commercial VOx micro-bolometer, mainly, has TCR of 2 - 3 %/K. [1]
Here, we demonstrate optical absorption performance enhancement of micro-bolometer with infrared absorbing layer. TCR value of VOx thin film of 3.4 %/K at room temperature, which is obtained by reactive sputtering. The micro-bolometer has a detectivity of 6 x $10^8$ cmHz$^{1/2}$/W.

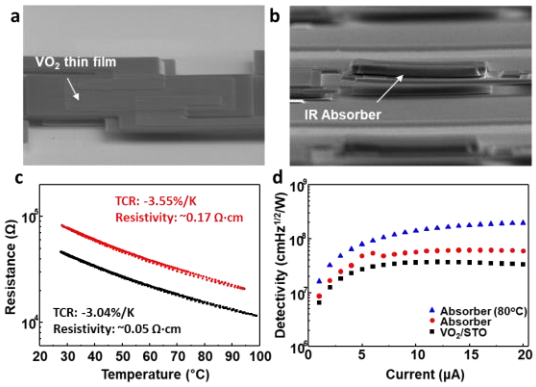


**Figure 1. (a, b) The SEM image of VO2-based micro-bolometer. (c) Temperature coefficient of resistance (TCR) and (d) detectivity of micro-bolometer device.**

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# Improved reliability of amorphous In-Ga-Zn-O TFT sensor with a bilayered active

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Amorphous indium gallium zinc oxide (a-IGZO)-based thin film transistors (TFTs) are commonly used in the display industry as switching devices. Moreover, as the demand for the overall TFTs industry increases, they have been applied in biological and chemical sensing area because of their advantages such as low temperature process, low cost, high yield, and various utilization in sensing application. [1].

The oxygen vacancy (Vo) acts as a carrier supplier in the active channel of a-IGZO and plays an important role in current flow. The a-IGZO TFTs is used for sensing application in the form of electrolyte-gated structures. The active channel of the TFT sensor is expoesed to the electrolyte solution to detect analytes directly. At this moment, however, Vo can act as a trap, which is the path through which ions or electrons in the solution can move. This occurrence generates electrical noise that can change the characteristics of the active channel; thus, it is very important to reduce such a noise in terms of the reliability and the stability of the sensor [2]. Various approaches have been proposed to overcome this critical issue, however, most of them have involved quite complex processes [3].

In this study, we report improved sensing reliability of the a-IGZO TFT with a bilayered active channel. After forming the a-IGZO active channel, passivation layers, grown another a-IGZO under higher oxygen partial pressure than that of the active channel, were deposited on the active channel to reduce the Vo-related noise. We deposited the a-IGZO passivation layer under three different oxygen partial pressure condition, $Ar/O_2$ = 18:6, 18:12, and 18:18 sccm. And we analyzed the X-ray photoelectron spectroscopy to confirm that Vo decreases as the oxygen partial pressure increases. In addition, as the Vo concentration decreases, the threshold voltage shift caused by electrical noise is reduced from 3.23 V to 0.3 V. These results show that the passivation layer of bilayered active channel with a low Vo concentration can block the path for the movement of ions or electrons from the solution. This approach has no additional process with simplicity. In addition, in the case of chemical surface treatments to attach biomolcules such as antibody, antigen, DNA, streptavidin, biotin etc, many of the oxygenated groups at the passivation layer of bilayered active channel have advantages when it comes to the utilization for sensing; hence, the sensitivity of the a-IGZO TFT sensor can be expected to improve. Details on the device performance will be presented at the conference.

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# Ionic liquid sensing properties of printed CNT:metal layers

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Ionic liquid (IL) sensing is a notable technology in terms of energy storage devices and chemical applications. [1-2] Many researches related with carbon nanomaterials (CNM) have been carried out to take an advantages of wide surface area, excellent electric conductivity, high sensitivity and catalytic action. Although the researches have been focused on the sensor technology using carbon nanomaterials and organic materials, operation stability problem should be improved to make a advanced CNM-based sensor that operates in a harsh environment such as seawater or hazardous materials. [1]

In this study, thin films using CNMs and metal powders were fabricated and applied to various ionic liquid sensing. Quartz was used as a substrate and a paste was prepared at a ratio of MW-CNT, a binder, a surfactant, and a metal powder (1:10:22:11). As show in Figure1, the size of printed area was 20 × 20 $mm^2$. The printed CNT:metal thin film was debinded at 250 ℃ to remove the organic binder. The printing precision was confirmed by confirming the transfer rate based on the size of the mask. The thickness of the printed thin film was 15 ±5μm and the resistance was 270±3kΩ.

The fabricated CNT: metal thin films showed sensitivity changes when exposed to various ionic liquids at 5V bias. In addition, the range of linear response characteristics and the minimum sensing concentration of ionic liquid were investigated and the feasibility of sensor application was examined.

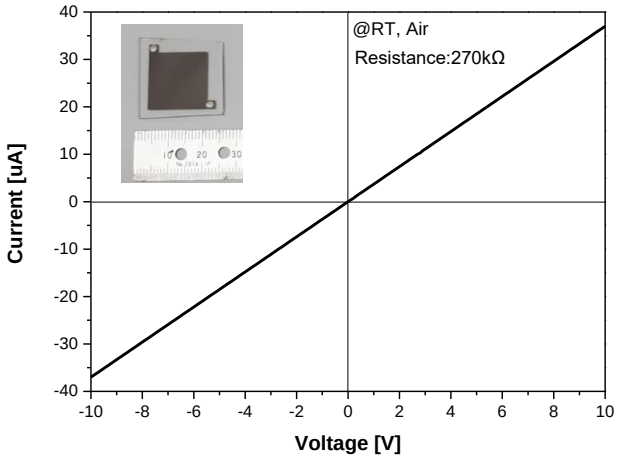


**Figure 1. I-V curve and sample image.**

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## Acknowledgement

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# Triboelectric pressure sensor based on Al wire particles

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Energy Harvesting is a technology that collects energy that can be abandoned, such as gravity energy, light energy, position energy, electromagnetic energy, and vibration energy, and turns it into electricity. The triboelectric effect is a kind of energy harvesting which collects vibrational energy, which is relatively simple in structure and has high energy transfer efficiency. In addition, flexible polymeric materials can be used for fabrication, which makes them more usable than hard materials. In addition to energy collection, the triboelectric effect can be applied to various active sensors by utilizing the characteristics of generating electricity by themselves. There are some researches that utilize the conductive sponge structure as a triboelectric active pressure sensor[1,2]. In the case of a triboelectric charge harvester utilizing the conductive sponge, a large-area process is possible, but the manufacturing process takes several steps and takes a long time. In this study, we propose a method and structure for a triboelectric charge harvester with a simple and short manufacturing time using metal wool. Metal wool is used as a positively charged material for triboelectric effect. Polymer material as a negative charge material is used as a structure for maintaining the shape of metal wool.

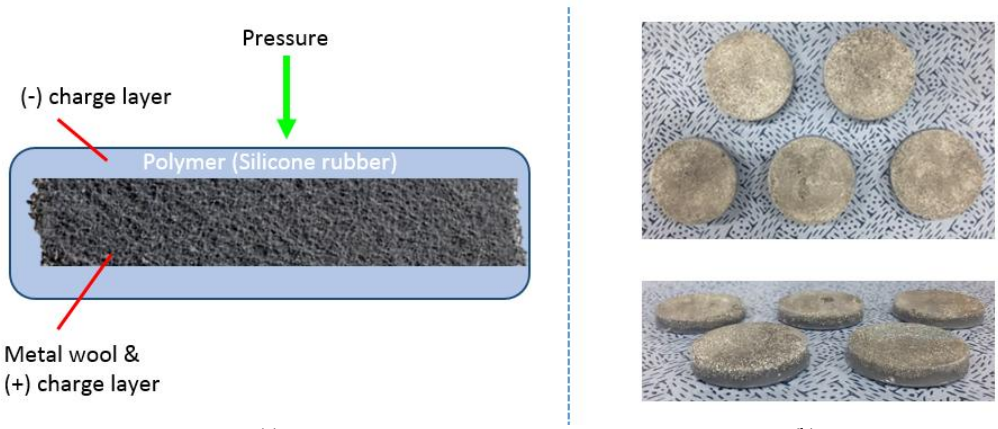


**Figure 1 (a) Structure of triboelectric pressure sensor based metal wool, (b) Proposed triboelectric active pressure sensor based metal wool**

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# Trans-linear circuits for optical beam deflection scheme toward improving the detection bandwidth of atomic force microscopy

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Optical beam deflection (OBD) scheme remains the most popular force detection system used in atomic force microscopy. With the recent development of small cantilevers, a means for measuring small deflections at high frequency has become a challenge. Minimizing noise levels of the readout unit without compromising a large bandwidth still remains a bigger problem to be addressed. For the most part, trans-impedance amplifiers have been the most adopted circuit for converting the currents from the quadrant photodiodes to voltages. Then, obtaining required sum and deflection signals were in the voltage domain. While circuits using operation amplifiers are well established and well documented, the achievable bandwidth has been so far limited to about several megahertz.

However, if the signal manipulation can be done in the current domain, the resulting electronic circuits can have many advantages including less power consumption, reduced parasitic capacitances and using less number of parts. Trans-linear circuits can be used to do current-mode arithmetic so that the bandwidth of OBD schemes for atomic force microscopy can be greatly improved. We present the initial results comparing the performance of OBD scheme using trans-linear circuits and conventional trans-impedance circuits.

**Acknowledgement**
*This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2015R1D1A1A01059003) and the Ministry of Science and ICT (2018R1A2B6008264).*

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# A dual function piezoelectric nanogenerator device based on bio-polymers

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**Abstract**

Developing a sustainable, environmental friendly and bio-compatible material in the field of self-powered sensors and energy harvesting is a major challenge. The research on development of different organic, inorganic and hybrid materials for nanogenerators and self-powered sensors, but are limited because of its toxicity and environmental issues. Nowadays fabricating a piezoelectric nanogenerator for self-powered systems is growing for an extensive range of applications from implantable devices, sensors, environmental remediation and medical devices. Herein, we have developed a dual function nanogenerator device which can acts as power source as well as a sensor device using a biocompatible polymers. This type of piezoelectric nanogenerator (PNG) driven bio-piezoelectric polymer based sensors provides a pathway towards a sustainable and greener environment in the field of self-powered sensors. In this work, we have investigated a biopolymer piezoelectric material coated on to a cotton fabric and subsequently used as an energy harvester and also a humidity sensor. As a power source the PNG device generates a maximum of 45 V/250 nA and can work as a sensor to sense various percentages of relative humidity (% RH). The sensor shows a linear sensing response with a good sensitivity in the range of 50-80 % RH. The present findings open a field of eco-friendly material towards the field of bio-medical sensor systems and technology.

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**Acknowledgement**

This work was supported by Jeju Sea Grant College Program 2018, funded by the Ministry of Oceans and Fisheries (MOF) and by the National Research Foundation of Korea (NRF) funded by the Korea Government Grant (2016R1A2B2013831).

# Ultrathin metal oxide semiconductors-based electrochemical transistors by using solution process

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Real-time health monitoring of non-invasive chronic diseases have been attracting attentions and electronic platforms based on biosensors, conformal structures, and stretchable form factors have been studied widely. Among sensing devices, electrochemical transistors enable highly sensitive detection of ultra-low level in target molecules to realize diseases detection in early stage and diverse nanomaterials have been studied.

Here, we demonstrated ultra-thin indium oxide semiconductor-based electrochemical transistors by using solution process. The thickness of indium oxide was ~4 nm and had high film density, which had high sensitivity (~60 mV $pH^{-1}$) for the pH sensing. Based on indium oxide platform, we constructed glucose sensors with immobilized glucose oxidase onto the indium oxide surface. The detecting ranges were covered within human tear's glucose level (0.1 to 1 μM). Furthermore, our conformal device structures enabled to contact on highly rough surface as well as on an artificial eye for the smart lens applications.

We also expended to small molecule detection such as dopamine and serotonin, which were consisted with dopamine sequenced aptamers to get a specific binding of the small molecule. The conformational change of the aptamers with the specific binding of the dopamine could overcome Debye screening length in physiological environments.

# Synthesis and temperature sensing behavior of $BaGd_2O_4:Er^{3+}$ green-emitting phosphors

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Temperature, which is considered as a very fundamental thermodynamic coefficient, plays an important role in various fields, such as life science, industrial production, scientific research and daily life. As a consequence, its real-time monitoring with high accuracy and high resolution is required. In recent years, the optical temperature senor based on the thermally coupled levels by utilizing the fluorescence intensity ratio (FIR) technique was considered as promising candidates to detect the temperature distribution of objects. Especially, the optical thermometric properties of $Er^{3+}$ ions were intensively studied because of its green emission arising from the thermally coupled levels of $^2H_{11/2}$ and $^4S_{3/2}$. Nevertheless, the obtained sensor sensitivities are still far away from the practical application. Therefore, more efforts should be made to further investigate the temperature sensing performance of $Er^{3+}$ ions. In this presentation, we report the preparation of $Er^{3+}$-doped $BaGd_2O_4$ phosphors by a facile Pechini type sol-gel method. The phase structure, microstructure and photoluminescence spectra of the resultant compounds were systematically analyzed. Additionally, with the aid of FIR technique, the optical thermometric properties of the synthesized phosphors were studied by analyzing the temperature-dependent green emission spectra in the temperature range of 288-483 K.

# Metallole Nanoaggregates As Explosive Sensing Materials

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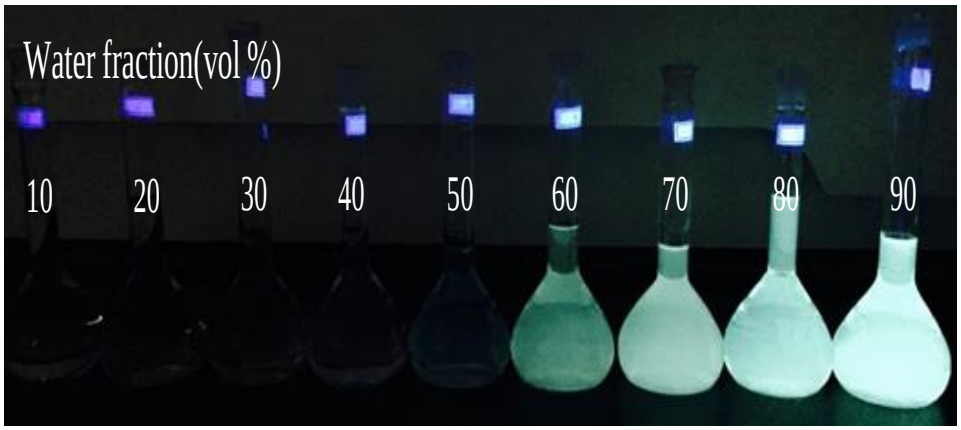
Organometallic metallole nanoaggregates containing group IV elements (M = Si, Ge, a nd Sn) were newly synthesized to investigate their photoluminescence behavior. Metallole nanoaggregates exhibit an aggregation-induced emission enhancement (AIEE). Their absolut e quantum yields (QY) and critical water concentration for onset of aggregation were measured. The size of metallole nanoaggregates were analyzed by dynamic light scattering (DLS). Fluorescence lifetimes of metallole nanoaggregates were measured. Metallole nanoaggregates were used for the detection of explosives. Detection efficiencies of the metallole nanoaggregates was measured through the quenching PL measurement by adding explosives into metallole nanoaggregates. Detection mechanism was analyzed from a Stern–Volmer plot.

Acknowledgment : This research was financially supported by the Agency for Defense Development and the National Research Foundation of Korea (NRF) funded by the Mi nistry of Education (NRF-2016R1D1A1B03933216).



# Efficient foster resonance energy transfer between semiconducting polymer and benzothiadiazole derivatives

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The efficient foster resonance energy transfer (FRET) between semiconducting polymer such as an iptycene polymer and benzothiadiazole derivatives was investigated. Iptycene polymer whose emission wavelength was 450 nm acts as an electron donor and benzothiadiazole derivatives which emits at 590 nm acts as an electron acceptor. Photoluminescence properties of iptycene polymer/benzothiadiazole – donor/acceptor were studied. Their absolute quantu m yields (QY) were measured. FRET from donor/acceptor was used for the detection of explosives. Detection efficiencies were measured through the quenching PL measurement by adding explosives into the FRET materials. Detection mechanism was analyzed from a S tern–Volmer plots.

Acknowledgment : This research was financially supported by the Agency for Defense Development and the National Research Foundation of Korea (NRF) funded by the Mi nistry of Education (NRF-2016R1D1A1B03933216).

# High-performance resistive memory devices using controllable formation of nanofilaments via tip-enhanced electric fields

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Resistive random access memory (ReRAM) is the next-generation non-volatile memory devices thanks to its fast switching speed, low power operation, and high scalability. However, the random nucleation and growth of conductive filaments (CFs) in ReRAM causes the low reliability in switching behaviors, leading to difficulties in its use.[1,2] Here, we present ReRAM with the electric fields that have been manipulated via a structured electrode in order to control the formation of CFs.

To enhance the electric fields in confined areas, metal pyramid arrays with a high-quality tip are obtained by the template-stripping method. Through finite-element modeling, we show that the magnitude of electric fields at the tip is about 7 times larger than that in the plane region. Since the tip-enhanced electric fields can facilitate the ionization of metal atoms and their migration along the electric fields, the nucleation and growth of CFs can be easily controlled. We directly observe that the CFs in ReRAM are formed only at the tip. The resulting ReRAM exhibits low and reliable SET/RESET voltages, allowing low-power operation for energy savings. Moreover, the endurance and retention time are highly improved, compared to those of the devices based on conventional geometry. All multilevel resistance states for the ReRAMs are also clearly distinguished and show narrow distributions within 1 order of magnitude, leading to reliable cell-to-cell performance for multilevel cell operation. We have high expectations on these results and those practical applications in ReRAM.

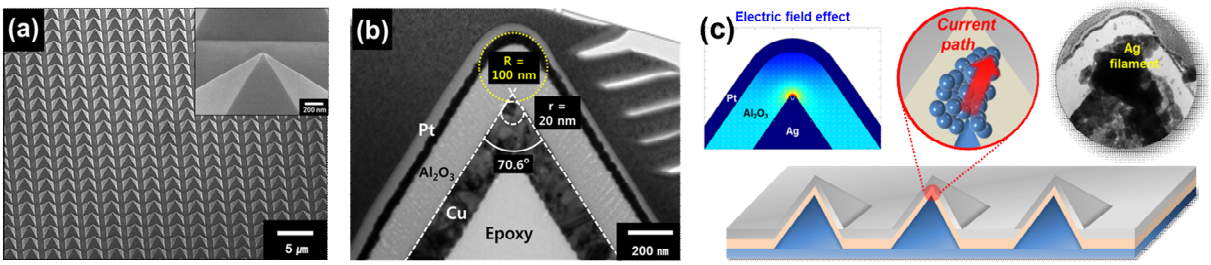


**Figure 1. a) metal pyramid arrays, b) metal pyramid ReRAM structure and c) Finite-element modeling of the electric field and the formation of controlled CFs near the tip.**

*This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2017R1D1A3B03030562)*

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# Thickness dependence of cantilever in Q-factor at Si-based NC-AFM Probe

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In this study, the cantilever thickness dependence on Q-factor of AFM probe was investigated to achieve high performance. The various concentrations of KOH solution and various shaped etching mask were used at forming the shape of a tip and sharp apex angle with anisotropic etching method. Both the tip and cantilever were formed by maskless etching process. In the tip case, the mask's edge line was set at <310> to compensate the corner under cutting. We give a deviation 2.2 um to 10 um in thickness and 135 um to 170 um in length. To investigate the thickness dependence on the Q factor, different thickness cantilevers were chosen and tested while the length was fixed in the range of 140~145 um. As a result, the Q-factor of cantilever is linearly proportional to the thickness of the cantilever (Figure 1. (b)).

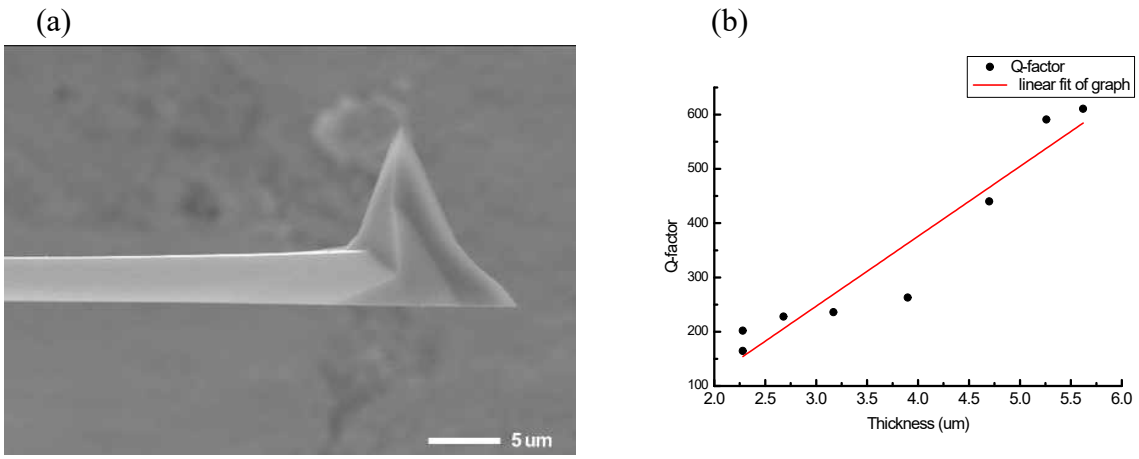


Figure 1. (a) FE-SEM image of Si-based NC-AFM. (b) Thickness-dependence on Q factor of Si-based NC-AFM.

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# Non-destructively assembled Single-walled carbon nanotube biotransistor with sub-nanomolar sensitivity

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An electrolyte-gated field-effect transistor (eFET) has attracted tremendous interest in biosensing research field owing to high sensitivity to detect sub-nanomolar concentrations of target molecules.[1,2] One-dimensional nanomaterials, such as Single-walled carbon nanotubes (SWNTs), silicon nanowires, and carbon nanofibers, have shown great potential in eFET applications due to excellent electrical/electrochemical properties and compatibility with biomaterials such as proteins and cells. In particular, SWNTs have been employed in a variety of eFET biosensors since these are highly sensitive to its local environment changes [3,4] due to low dimensionality. The current challenge with the SWNT-based eFET biosensors, however, arises from the fabrication of high-performance and large-area devices in a controllable manner. The strong tendency to form bundles exacerbates the unpredictable semiconducting properties, ultimately increasing the off-current of the eFET devices. Therefore, up-to-now, most SWNT based eFET devices showing high current on/off ratio and excellent sensitivity to target molecules were fabricated by only single or few strands of SWNT between very narrow gaps of the source and drain electrodes (less than μm). In our study, we fabricated the percolated structures of a large-scale SWNT electronic films (>25 $cm^2$) by the non-destructive assembly scheme of SWNTs using chemical and biological glues. Non-destructively assembled, percolated nanostructures provided not only a high surface area for the immobilized bioreceptor molecules such as aptamers and enzymes, but also ionic compatibility in aqueous media due to the surface charge of chemical and biological glues. The enzymes and aptamers were respectively utilized on the millimeter-scale SWNT eFETs to show the versatility of the developed biotransistor platforms. Such biotransistors can detect concentration ranges from pM to sub-mM of target molecules. We speculated that the biomimetic electronic material system with the capability of transducing biological reactions at large scale over broad dynamic range holds a great promise for biosensors, biofuels, and environmental monitoring.

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# Study on the morphology of n-GaN NWs with various TMGa flow using the MOCVD process

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We present that a novel method is developed for growing n-GaN nanowires on Si substrate using the MOCVD process. GaN NWs of high density grown using metalorganic chemical vapor deposition (MOCVD) are seldom reported. [1-3] The aim of this study was to produce GaN NWs of high density so that advanced GaN NW-based devices of larger effective area and high efficiency could be realized further. The results presented in this study succeeded to demonstrate n-GaN NWs of ultrahigh density. With the 3-step growth method, the density of pulsed NW seeds and well grown n-GaN NWs remain almost constant throughout the growth recipe; however, as expected, the height of NWs gradually increases after every step. Increase in NW density is attributed to a thin boundary layer produced during non-pulsed growth at intermediate temperature. This paper also established the effects of the flow rate of group-III precursor on the geometry and material properties of n-GaN NWs. For the 3-step growth method, the optimal growth condition was achieved with 0.4 sccm TMGa flow at the final step. it can be thought that the 3-step method is highly useful in the fabrication of the optoelectronic devices using III-nitrides NWs.

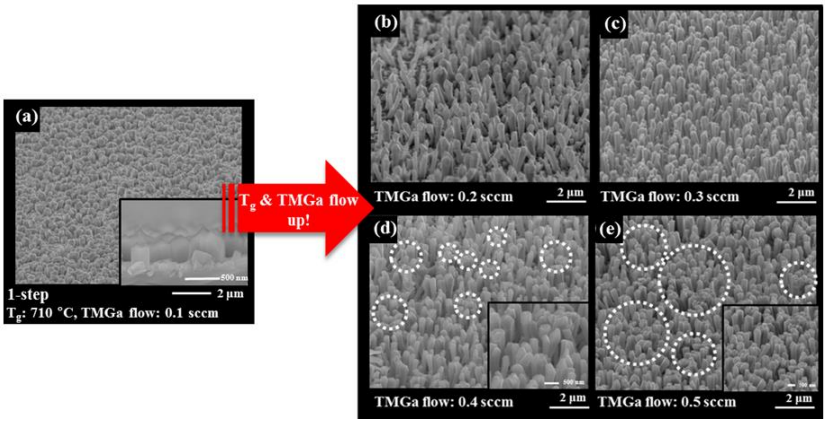


**Figure 1 FE-SEM images of (a) u-GaN seeds with optimal growth condition and n-GaN NWs at 850 °C with TMGa flow of (b) 0.2, (c) 0.3, (d) 0.4 and (e) 0.5 sccm.**

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# Optical properties of InAs/GaAs$_{1-x}$Sb$_x$ submonolayer quantum dots

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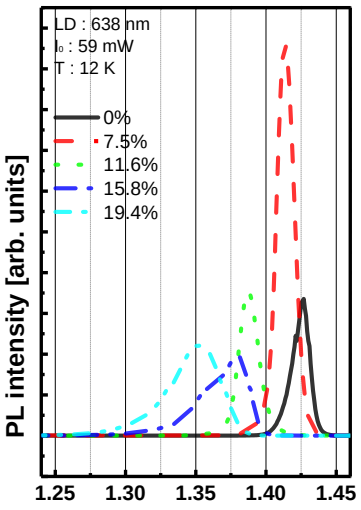
In this present works we examined photoluminescence (PL) and photoreflectance (PR) spectroscopy to investigate the optical properties of InAs/GaAs$_{1-x}$Sb$_x$ submonolayer-quantum dots (SML-QDs) with various Sb-compositions (x). Fig. 1 exhibits the low temperature PL spectra of SML-QDs with various Sb-compositions. As a reference sample, the PL emission energy of the InAs/GaAs SML-QD is 1.42 eV. However, as increasing Sb-composition of GaAsSb layer, the PL emission is redshifted due to the quantum confinement energy level shift caused by the deceasing the potential barrier height.

Moreover, the integrated PL intensities are drastically decreased when the Sb-composition increases from 7.5% to 11.6%. Because the InAs/GaAsSb band alignment becomes type-II band structure when the Sb-composition is 11.6%, the electrons and holes are separately confined in the InAs SML-QD and GaAsSb layer, respectively.

Fig. 2 shows room temperature PL and PR spectra. The PR spectra show the GaAs band-to-band and the QD transitions while PL spectra show the QD (A) and B signal which is not shown in PR spectra. The transition energy positions of the B signals are almost constant even increasing Sb-composition. To investigate the origin of the B signal, temperature and power dependent PL and PR experiments were performed additionally.



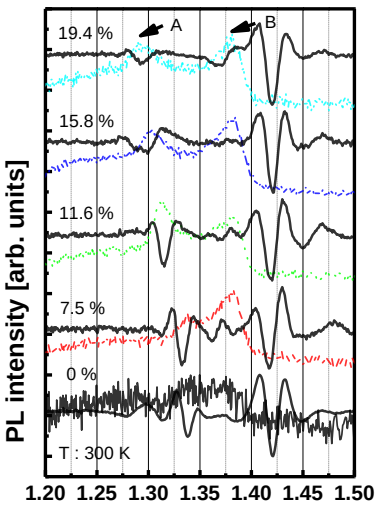




**Fig. 1. Low temperature PL spectra for InAs/GaAs1-xSbx SML-QD with various Sb compositions.**

**Fig. 2. Room temperature PL and PR spectra for InAs/GaAs$_{1-x}$Sb$_x$ SML-QD with various Sb compositions.**

# Doping inhomogeneity along single Mg-doped *p*-GaN rod studied by strong correlation among componential, electrical, and optical analyses

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GaN nano/micro sized rods have several advantages such as low dislocation density, high light extraction efficiency. These features allow the GaN rods to be used for optoelectronic devices.[1] The understanding of dopant distribution and electrical properties along the rod is important for the optoelectronic devices optimization.[2] However, doping in GaN rods suffers inhomogeneity along the rod because of a number of doping incorporation paths. Furthermore, it is challenging to utilize conventional doping measurement methods such as Hall-effect and capacitance-voltage measurement due to the one-dimensional structure of the GaN rod. Especially, *p*-doping analysis in GaN needs further studies due to the low solubility and high activation energy of *p*-type dopants.[3] Considering this complexity of p-doping, comprehensive understanding of *p*-doping in GaN rod is needed.

In this presentation, we systematically investigate the doping inhomogeneity along the single Mg-doped *p*-GaN micro-rod grown by metal-organic chemical vapor deposition by spatially resolved componential, electrical, and optical analyses. From componential analysis, time-of-flight secondary-ion-mass-spectrometry revealed the quantitative Mg doping concentration change along the axial direction of the rod. A 4-point probe measurement let us know the resistance change induced by the dopant distribution in the rod. From micro-photoluminescence experiments, spatially resolved luminescence spectra of incorporated defects were measured from green luminescence (GL). We also confirmed crystal quality and strain change along the rod induced by Mg-doping via micro-Raman measurement. Based on the correlation between the measurements results, it was confirmed that Mg concentration reduction along the axial direction of rod results in electrical resistance increase along the same direction. In addition, the GL intensity ratio sensitively change depending on the Mg concentration change along the growth direction of the rod. Furthermore, heavily doped rods shows higher resistance due to increased impurity and strain. The More detailed information will be given in the presentation.

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# Fabrication of Electrically Driven Phosphor-free White Light Emitting Diodes Based on III-nitride Three Dimensional Structures with high electrical efficiency

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White light emitting diodes (LEDs) has been attracted much interest as a new generation lighting and backlight for full-color display. Conventional white LEDs consist of blue LEDs based on InGaN/GaN active layer and yellow phosphors. However, since they make white light with only two distinct colors, they suffer from low color rendering index resulting unnatural color representation. Furthermore, they cannot achieve high enough efficiency since energy loss during color conversion is inevitable. In these reasons, there have been active studies dealing with phosphor-free white LEDs based on three dimensional structures. Chen et al. reported broad emission spectrum from a 3 dimensional structure by mixing different peak wavelength from different position [1], while Dai et al. reported large-area white LEDs with randomly distributed emitters with different emission wavelength [2]. Recently, different emission from different facets has been reported, which resulted in electrically driven phosphor-free white LEDs [3]. Despite of these merits, however, three dimensional structures based LEDs suffer from low electrical efficiency due to the absence of optimized fabrication conditions.

In this study, we developed an appropriate fabrication conditions for three dimensional structures based LEDs. The three dimensional structures were fabricated by selective are growth method on n-type GaN substrate. From precedence experiments, the top of the dielectric layer has main problem on high reverse-biased leakage current. For chip fabrication, an additional SiO2 dielectric layer has been deposited on as-grown three dimensional structures. By conventional wet etching right after spin coating a resist layer, we partially etched the dielectric layer out and exposed the upper part of the three dimensional structures. From these fabrication, we obtained highly efficient electrical properties with notably reduced reverse-biased leakage current. From these results, we could expect highly-efficient electrically driven phosphor-free white LEDs which could substitute current commercial white LEDs.

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# Terahertz Cyclotron Resonance in AlGaN/GaN Heterostructures

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Nitride compounds such as GaN have attracted significant attention for not only the opto-electronic applications [1], but also high-power electronic devices because of its large potential of the high breakdown voltage properties. Various material parameters in relation to the Nitride compounds, such as the effective mass ($m^*$) have been studied by magneto-transport and magneto-optical measurements previously. However, recent advancement of the epitaxial growth technique enables us to probe the basic material parameters more accurately.

In this study, we carried out cyclotron resonance (CR) experiments in AlGaN/GaN heterostructures at high magnetic fields in order to determine the effective mass of two-dimensional (2D) electron precisely and the contribution of the electron-phonon interaction.

Our samples were grown on sapphire substrates by the metal-organic vapor phase epitaxy method. The carrier density ($n$) was estimated from the magneto-transport experiments as $n$ = $8.5\text{x}10^{12}$ $\text{cm}^{-2}$, and the Shubnikov-de Haas oscillation was clearly observed at the integer filling factors. The quantum Hall plateaus were also observed at high magnetic field indicating to realize the high electron mobility in our samples. Consequently, it is possible to study CR in these samples because the CR conditions, $\omega_c\tau \geq 1$, can be satisfied easily.

The CR measurements were carried out at low temperatures with combining a 15 T superconducting magnet and a Fourier transform spectrometer (Bruker-Vertex 80v).

Figure 1 shows a typical CR transmission spectrum of AlGaN/GaN heterostructures at $T$ = 1.7 K. A single absorption peak was clearly observed for each magnetic field up to $B$ = 15 T. The CR spectrum can be fitted with the Lorentzian curve, and the effective mass was determined as $m^*$ = 0.24 $m_o$. Moreover, from the linewidth of the resonant spectra, the carrier mobility ($\mu$) was estimated as $\mu$ = 6,000 $\text{cm}^2/\text{Vs}$.

From the magnetic field dependence of the CR, a significant field dependence of the effective mass was observed, in particular, at high magnetic field. This could be due to the polaron effect because GaN is a polar semiconductor with large electron-phonon interaction among III-V compounds [2]. In addition, the contribution of the band non-parabolicity to the field dependence of the effective mass is smaller because of the large band-gap energy in GaN.

In this presentation, we will discuss the magnetic field dependence of the CR from the viewpoint of the electron-phonon interaction in 2D electron systems [3].

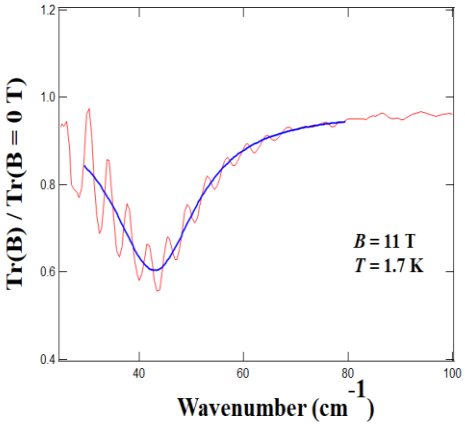


Fig. 1. CR transmission spectrum at $B$ = 11 T

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# Study of highly sensitive flexible photodetector using self-assembled SnS nanoflake and graphene

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In our study, graphene grown via chemical vapor deposition (CVD) was used as transparent electrodes, owing to their excellent electrical and thermal conductivity, transparency, and flexibility. The internal electric field established between graphene and SnS could benefit the separation of photogenerated electrons and holes without the need for any bias voltage. This is why, the fabricated photodetector exhibits a high photoresponsivity and high stability under light illumination. Tin monosulfide (SnS) nanostructures have attracted huge attention recently because of their high absorption coefficient, high photoconversion efficiencies, low energy cost, ease of deposition, and so on. Here, in this work, we report on the low-cost hydrothermal synthesis of the self-assembled SnS nanoflake-like structures in terms of performance for the photodetectors. High-performance photodetectors were fabricated using SnS nanoflakes as active layers and graphene as the lateral electrodes. The SnS photodetectors exhibited excellent photoresponse properties with a high responsivity of $1.7 \times 10^4$ A/W and have fast response and recovery times. In addition, the photodetectors exhibited long-term stability and strong dependence of photocurrent on light intensity. These excellent characteristics were attributed to the larger surface-to-volume ratio of the self-assembled SnS nanoflakes and the effective separation of the photogenerated carriers at graphene/SnS interfaces. Additionally, a flexible photodetector based on SnS nanoflakes was also fabricated on a flexible substrate that demonstrated similar photosensitive properties. Furthermore, this study also demonstrates the potential of hydrothermal-processed SnS nanoflakes for high-performance photodetectors and their application in flexible low-cost optoelectronic devices.

# Gate Modulation of the Spin-orbit Interaction in Bilayer Graphene Encapsulated by $WS_2$ films

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We designed a dual gated $WS_2$/bilayer graphene/$WS_2$ sandwich device, where the SOI is tuned by gate voltages. The strength of induced SOI in the bilayer graphene is dramatically elevated, which leads to a strong weak antilocalization (WAL) effect at low temperature. To support these results, we also examined Shubnikov-de Haas (SdH) oscillations, which give unambiguous evidence of the zero-field spin-splitting in our bilayer graphene. The spin-orbit coupling constants estimated by two different measurements (i.e., the WAL effect and SdH oscillations) show close values as a function of gate voltage, supporting the self-consistency of this study's experimental results. The gate modulation of the SOI in bilayer graphene encapsulated by $WS_2$ films establishes a novel way to explore the manipulation of spin-dependent transport through an electric field.

The dual gate enabled an effective control of the charge carrier density and transverse electric field, which broke the inversion symmetry of BLG. The dominant part of the interface-induced SOI was Rashba type, which can be confirmed by SdH oscillations. One auspicious objective was to enhance the SOI in BLG, as this may offer several possibilities including the manipulation of spin current through an electric field or the generation of a pure spin current through the Spin Hall effect.

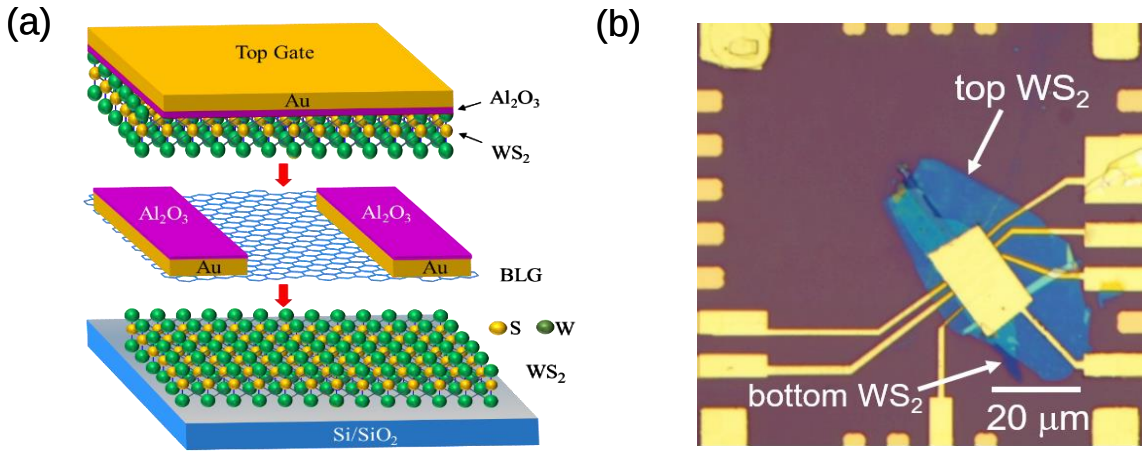


**Figure 1 (a) Schematic of bilayer graphene sandwiched between multilayer $WS_2$. (b) Opticalmicroscope i mage of the $WS_2$/BLG/$WS_2$ sandwich device.**

# Investigations of Interfaces of 2D-$MoS_2$ and 3D-GaN Heterostructures: First-principles Study

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Recently the concern with heterostructures between 2-dimensional (2D) and 3-dimensional (3D) materials has been increasing because of the designing of nanodevices using those heterostructures. There are many kinds of 2D materials such as graphene, hexagonal boron nitride (h-BN), and transition metal dichalcogenides (TMDs). Among them, TMDs, especially $MoS_2$, have good characteristics for application of semiconductor devices due to suitable bandgap, high on/off ratio, and high electron mobility. On the other hand, GaN is a 3D material showing enormous applications in high efficiency electronic and optoelectronic devices such as high electron mobility transistors and light emitting diodes. Previously, the growth of 2D $MoS_2$ directly onto the GaN surfaces has been reported [1]. From this experimental result, the $MoS_2$/GaN heterostructures were shown to electrically conduct in out-of-plane direction and across the van der Waals gap. In this regard, we have performed density functional theory calculations to study the interfaces between $MoS_2$ and GaN. Interestingly, GaN has two different types of surface terminations such as Ga-terminated (0001) and N-terminated (000-1) surfaces. We consider these two terminations to investigate the difference in their interactions with $MoS_2$. As a result, we find that the surface states disappear for the case of $MoS_2$ on Ga-terminated GaN structure, while the surface state is hybridized with MoS2 near the Fermi level for the case of N-terminated GaN configuration. In addition, we investigate the atomic and electronic properties of bilayer $MoS_2$ on GaN surface to study the layer dependence of $MoS_2$.

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# Toward Continuous Production of graphene by CVD: Key issue?

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Graphene is an atomically thin layer material with a two-dimensional honeycomb lattice. It has excellent electrical, optical, mechanical and thermal properties and is called a new material of dream at the future.
On the other hand, unfortunately, there is almost no example of real industrial applications in graphene research field. This is because the production process of graphene is expensive, takes a long time, and is not environmentally friendly.
Therefore, we have developed a process that can produce graphene at high speed and low price continuously. Although a number of previous research results have been reported, it is practically very difficult to continuously synthesize fine graphene.
In this study, we compare the results and issues in a typical chemical vapor deposition process for graphene synthesis[1] and the actual process for continuous synthesis.
We succeeded in high - speed synthesis of graphene for 1 min at 900 ℃ using liquid precursor and tried to synthesize it continuously.[2] On the other hand, in actual continuous synthesis, tension and vibration-related issues affecting the catalytic metal should not be overlooked. In addition, the continuous supply of the hydrocarbon gas during movement of catalytic substrate can form carbon black on the sample.
We tried to solve these difficult issues and explored the continuous synthesis conditions of high quality graphene.

More details will be presented in the poster presentation.

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# Electrical Detection of Inverse Spin Hall Effect in Multi-layer $WS_2$

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Applications of semiconductors in spintronics are being developed and revolutionized to fabricate nanostructures in which the spin current is injected, detected and manipulated. The manifestation of the spin Hall effect in semiconductors with a simple geometry is still a challenge to implement in spintronics. In this work, we demonstrate the distinct electrical detection of the inverse spin Hall effect in $WS_2$ multilayer crystals at temperatures ranging from 4.2 K to 300 K. The novel idea of this study is the electrical detection of the inverse spin Hall effect in $WS_2$ using an in-plane spin-polarized current, which is realized using non-ferromagnetic electrodes on the top and bottom surfaces of the $WS_2$ channel. The flow alteration of spin-polarized current results in a polarity change in the inverse spin Hall signal. By analyzing the magnitude of the inverse spin Hall effect, we estimated a long spin diffusion length of, spin Hall angle of, spin polarization of ~0.20 and alarge spin lifetime of  in $WS_2$-layered crystals at room temperature. The inverse spin Hall effect in layered, two-dimensional materials, including $WS_2$ crystals, provides a new methodology to develop low-power and fast memory devices to write, read and store information.

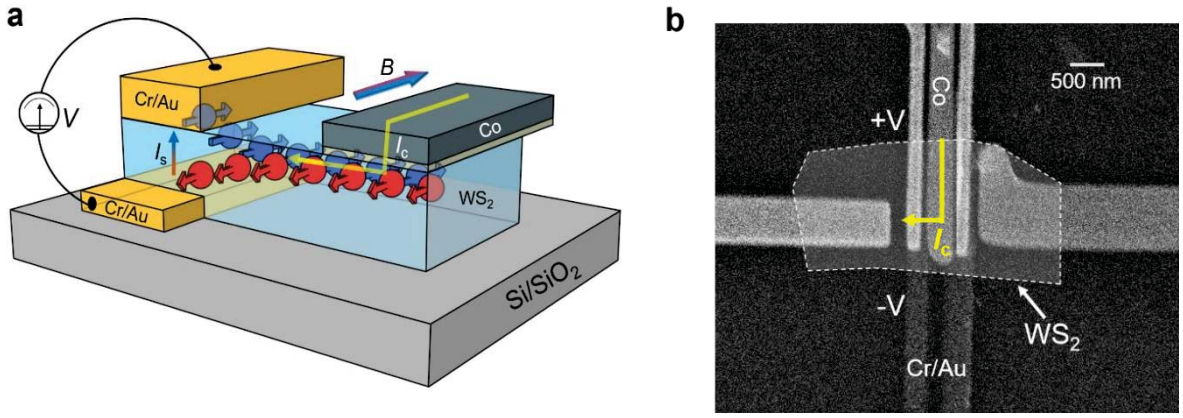


**Figure 1 Schematic, and SEM images of a $WS_2$ inverse spin Hall device with the.**

# Metal-semiconductor Contact Behaviors between $MnPS_3$ and Au using First-principles Calculations

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Since the discovery of graphene which is one of representative two-dimensional (2D) materials, various 2D materials have been actively explored due to their notable physical and chemical properties. However, magnetic van der Waals (vdW) materials have not been much investigated in 2D materials. In this connection, metal phosphorous trichalcogenides (MPTs) have drawn much attention as new 2D magnetic vdW materials: MPT consists of one transition metal (M), one phosphorous (P) and three chalcogen (X) atoms by showing the magnetic properties at room temperature with good electrical properties. Here, we focus on MPT and metal contacts for various device applications. In this study, we have performed density functional theory (DFT) calculations to investigate atomic and electronic structures of MPT on metal substrate: we consider $MnPS_3$ as 2D MPT and Au(111) as metal substrate. Details are analyzed by partial density of states (PDOS), band alignment and work function.

# Density Functional Theory Calculations of Electric-field Effect on $WS_2$/BP Heterostructures

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Recently, two-dimensional (2D) materials have been actively studied in various fields. It is known that graphene, one of the 2D materials consisting of carbon atoms, has excellent electron mobility and permeability. Despite these excellent properties of graphene, one drawback in use of graphene in the electronic devices is that electron mobility of graphene is considerably reduced when the band gap is generated. To overcome such drawback, diverse 2D semiconducting materials have been investigated, including transition metal dichalcogenides (TMDs) and black phosphorus (BP). Layered structures such as TMDs and BP show the variations in electronic structure depending on the number of layers: As the number of layers increases, their band gaps are decreased. Here, we have studied atomic and electronic structures of heterostructures between $WS_2$ and BP using density functional theory (DFT) calculations. Especially, we investigate the effect of applied electric fields on the electronic structure and band alignment of $WS_2$/BP heterostructures.

The 19th International Symposium on the Physics of Semiconductors and Applications (ISPSA 2018)
July 1 (Sun.) ~ 5 (Thu.), 2018 / Jeju, Korea

# First-principles Study of Atomic and Electronic Structure of Metal Monochalcogenides on Si(111)

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In recent years, graphene has attracted various attention from the scientific community with its excellent atomic and electronic properties. Upon this opportunity, many scientists have studied many two-dimensional (2D) materials such as transition metal dichalcogenides (TMDs) and metal monochalcogenides (MMCs) from various angles. Among various 2D materials, we consider MMCs in this study for potential applications to nanodevices. Especially, we investigate 2D/three-dimensional (3D) heterostructures of MMC/Si using density functional theory (DFT) calculations. Here, we consider gallium sulfide (GaS), gallium selenide (GaSe), and gallium telluride (GaTe) as MMC materials: GaS, GaSe, and GaTe are semiconductor with indirect band gap of 3.19, 2.10, and 1.67 eV, respectively. In terms of partial density of states (PDOS) and work function of MMC/Si heterostructures, we investigate the interaction between diverse MMC and Si(111) for device applications of their heterostructures.

# Epitaxy of ZnO microwire arrays on graphene-coated ZnO layer

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We report on ZnO microwire homo-epitaxially grown on graphene-coated ZnO sublayer with different crystal plane of *a*-plane and *c*-plane using wet chemical epitaxy method. Noticeably, ZnO overlayers were grown to be horizontally and vertically aligned microwire arrays on graphene-coated *a*-ZnO and *c*-ZnO templates, respectively, which were found to have the uniform in-plane orientation on over the entire surface of templates. Despite the presence of graphene interlayer, epitaxial relationship between overlayer and sublayer was achieved across graphene. Microstructural characteristics of ZnO overlayer/graphene/ZnO sublayer heterostructures were investigated by high-resolution transmission electron microscope (TEM) analysis, which determined the identical crystallographic orientation and lattice arrangement of ZnO overlayer and sublayer. We further demonstrated the epitaxy of ZnO using bilayer- and trilayer-graphene-coated-ZnO sublayers. These results strongly suggest that the sublayer ZnO plays a crucial role in determining the crystallographic orientation of ZnO overlayer across graphene layer. In this presentation, we will discuss the feasibility of long range single-crystalline thin film growth and the regeneration of substrate for cost-effective semiconductor fabrication process.

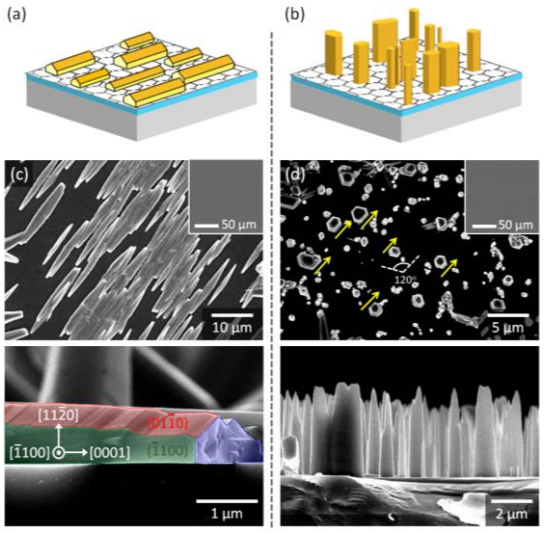


Fig. 1. Schematic illustration of ZnO overlayers on (a) MLG/*a*-ZnO/*r*-$Al_2O_3$ and MLG/*c*-ZnO/*c*-GaN templates. Plan-view (upper images) and cross-sectional (bottom images) SEM images of (c) horizontal ZnO microwire arrays on (a) MLG/*a*-ZnO and (c) vertical ZnO microwires on MLG/*c*-ZnO templates. Insets in upper images in (c-d) are plan-view SEM images of clean graphene surface before ZnO growth.

*This research was financially supported by the Basic Science Research Program (NRF-2016R1D1A1B03931518; 2010-0020207) through the NRF of Korea funded by Ministry of Education.*

# First-principles Study of Electric-field Dependence of Electronic Structure in p-Si/n-$WS_2$ Heterojunction

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The van der Waals (vdW) heterostructures using two-dimensional (2D) materials are in the limelight for various applications in electronic and optoelectronic devices. Especially, 2D transition metal dichalcogenides (TMDs) are one of key building blocks of vdW heterostructures with their attractive atomic and electronic properties. Previously, 2D-TMD/three-dimensional (3D) semiconductor vdW heterostructures such as $MoS_2$/Si [1] and $WS_2$/Si [2,3] were experimentally fabricated by representing the excellent diode-like rectification behaviors. In this point of view, we investigate the electric-field dependence of electronic structure in p-Si/n-$WS_2$ heterojunction using first-principles calculations: we explain the rectification behaviors in p-Si/n-$WS_2$ heterostructures by taking the external electric-field into account in the calculations. Furthermore, we investigate the effect of external electric field on the band alignment of p-Si/n-$WS_2$ heterostructures depending on the number of $WS_2$ layers on Si surface. Details are analyzed in terms of partial density of states (PDOS), band alignment and charge density difference.

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# Van der Waals heterojunction diode composed of $WS_2$ flake placed on p-type Si substrate

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P-N junctions represent the fundamental building blocks of most semiconductors for optoelectronic functions. This work demonstrates a technique in forming a $WS_2$/Si van der Waals junction based on mechanical exfoliation. Multilayered $WS_2$ nanoflakes were exfoliated on the surface of bulk p-type Si substrates using a polydimethylsiloxane stamp. The fabricated $WS_2$/Si p-n junctions exhibit rectifying characteristics. We studied the effect of annealing processes on the performance of $WS_2$/Si van der Waals p-n junction and demonstrated that annealing improved the electrical characteristics of a p-n junction. However, devices with vacuum annealing have an enhanced forward bias current compared with those annealed in a gaseous environment. We have also studied top gate-tunable rectification characteristics across the p-n junction interface in experiments as well as density functional theory calculations. Under various temperatures, the Zener breakdown occurred at the low reverse bias region, and its breakdown voltage exhibited a negative coefficient of temperature. Another breakdown voltage was observed, which increased with rising temperature, suggesting a positive coefficient of temperature. Therefore, such breakdown can be assigned to an avalanche breakdown. This work shows an auspicious application of two-dimensional materials placed directly on conventional bulk Si substrates.

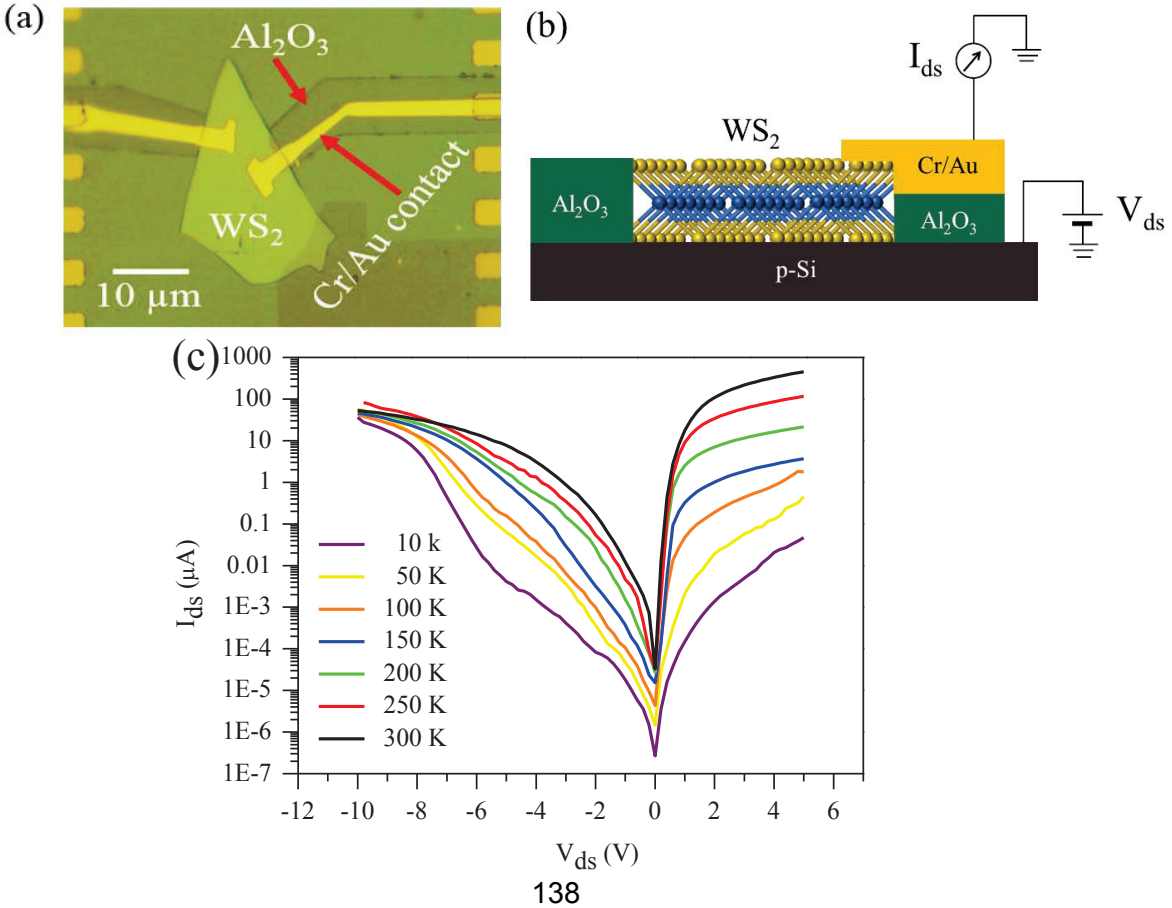

**Figure 1 (a) Optical image of device on $WS_2$ flake. Top Cr/Au electrodes are connected to the $WS_2$ flake. (b) Device schematics of $WS_2$/Si van der Waals heterojunction. (c) I-V characteristics at different temperatures in a logarithmic scale.**

# Improvement of light extraction efficiency for AlGaN-based deep UV LEDs

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The AlGaN based deep ultraviolet light emitting diodes (DUV-LEDs) are of promising application under a variety of circumstances [1]. However, there are some major obstacles responsible for their poor light extraction efficiency including anisotropic optical polarization and unreliable encapsulant materials. The former issue derives from the distinct valence band arrangement between AlN and GaN which results in TE modes emission for GaN while TM modes emission for AlN [2]. The TE mode with the electric vector perpendicular to c-axis mainly emitting from the surface of the prevailing DUV LEDs grown on c-plane while the TM mode predominantly propagating to the lateral side and hinder the light extraction. The latter issue is brought by the problems of conventional encapsulants that they can be easily destroyed by UV light and their inferior UV transmittance, these problems should lead to light failure and short-term working stability of DUV-LEDs.

In this report, strain modulation of multiple quantum wells (MQWs) and optimizing of mesa sidewall inclination angle were carried out to enhance the desirable TE mode and improve the light extraction of TM mode, respectively. The light extraction was enhanced by the increased compressive strain introduced by the underlying AlGaN template of MQWs. A 40% enhancement of light extraction coefficient was obtained by the AlGaN template with 73% Al-content comparing with the one with 55% [3]. In addition, various inclination angles of mesa sidewall are fabricated to enhance the light extraction of TM mode by modulating the propagation of the TM mode. The experiment results are further verified by theoretical analysis. It shows that inclination angel of 37.8° for the 280 nm DUV LEDs can enhancement 48% of light output power at 35 A/cm$^2$. Moreover, a novel type of graphene oxide-based fluoropolymer encapsulant was introduced to effectively improve the working stability of DUV-LEDs [4]. On the basis of the interface anchored effect of the GO-based fluoropolymer, the air voids in the interface layer of DUV-LEDs are reduced by 84%, leading to an improvement of the light output power by 15%. These results should provide some constructive methods to improve the light extraction efficiency of DUV-LEDs.

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# Effect of $SiN_x$ interlayers on the in-plane anisotropic properties of nonpolar *a*-plane AlGaN

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AlGaN-based deep ultraviolet (UV) optoelectronic devices have great potential applications in many fields such as water purification, solid-state lighting, and biochemical detection because of their low operating voltage, small size, and high efficiency[1]. However, conventional *c*-plane nitrides-based optoelectronic devices suffer from high piezoelectric and spontaneous polarizations due to the non-centro symmetry of c-axis Wurtzite crystal structure, which makes the external quantum efficiency (EQE) of the device very low[2]. Growing along one of the nonpolar directions (e.g. *a*- and *m*- directions) is expected to eliminate these effects since its polarization fields are normal to the growth direction. Moreover, nonpolar nitride also shows interesting optoelectronic properties because of the anisotropy in-plane strain caused by different lattice mismatch and expansion coefficient between the substrate and epilayer[3].

Restricted by the high density of defects, large surface fluctuations and in-plane strains, the widely application of high polarization nonpolar III-nitrides have not been achieved yet. In this report, we found that the $SiN_x$ islands can not only directly block threading dislocations during the subsequent lateral overgrowth, but partially limited the preferable growth along the [0001] direction, leading to the low densities of defects and smooth surface morphology. More importantly, the anisotropic strain relaxation and the resulting optical degree of polarization of nonpolar *a*-plane AlGaN is strongly affected by the growth time of $SiN_x$ interlayers. This research results may provide important information for the formation of high efficiency liquid crystal displays or other polarisation sensitive photodetectors.

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# NEMO5: Multi-Scale, Multi-Physics, Atomistic Modeling of Superlattice LEDs and Global Impact on nanoHUB.org

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Superlattice GaN-based Light Emitting Diodes (LEDs) are at the heart of today's commercial lighting technology. Sophisticated designs have been obtained through a variety of models and empirical experimentation. Further optimizations and critical process insights require a sophisticated quantum transport models that comprehend the electron, hole, thermal, and photon flow in a rather complex geometry. The non-equilibrium carrier transport in a complex superlattice with predictive capabilities based on full quantum transport simulations has been an unsolved challenge for decades now. We have recently introduced a multi-scale, multi-physics approach that segments the device regions into spatial domains that are close to equilibrium with significant thermalizing scattering and out of equilibrium regions which may include modest scattering [1]. This Non-Equilibrium Green Function (NEGF) partitioning approach is an expansion to the method introduced [2] to model high-bias, realistic resonant tunneling diode simulations 2 decades ago and now implemented in NEMO5. This presentation will highlight the physical concepts and the global impact of NEMO on research and education through nanoHUB.org.

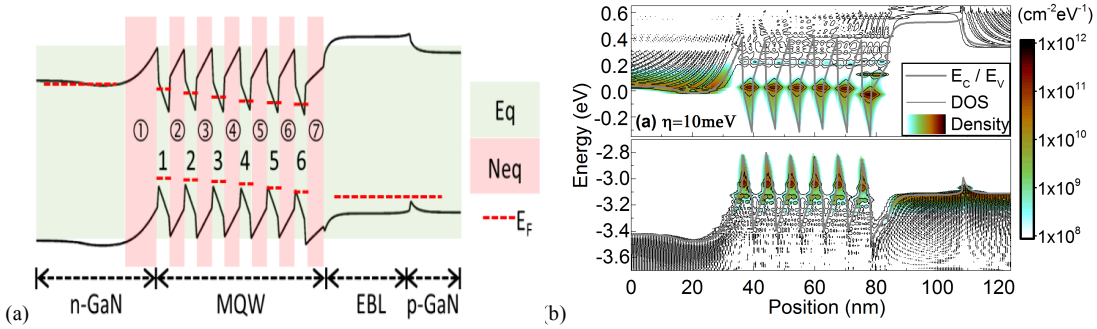


**Figure 1 LED structure that consists of an n-GaN layer; a low-doped active region made of InGaN/GaN MQW; an AlGaN electron-blocking layer and a p-GaN layer. The equilibrium (eq - green) and non-equilibrium (Neq-red) regions are marked in different colors. Each equilibrium-region has a unique quasi Fermi level, for holes and electrons as indicated by a red dashed line. The Fermi level drops across the device are depicted not to scale to emphasize that they are different from one QW to the next. The actual Fermi level drop across the 6 QWs at normal operation of 2.9V is only 25meV for electrons and 176meV for holes. (b) Energy-resolved electron, hole density of states (contour lines) filled with electrons and holes (color contours). The bulk-based conduction and valence band edges serve as a guide to the eye and only enter the calculation in the definition of the empirical scattering strength η. States in the QW are broadened due to η and coupled to each other. Figures copied from reference [1] with permission**

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# Sapphire Nano-membrane: A new platform for GaN-based devices

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Compliant substrates can share the strain associated with heteroepitaxial growth, leading to effective reduced lattice mismatch as well as better crystals with reduced defect density. A very thin sapphire membrane in the range of tens of nanometer in thickness (sapphire nano-membrane hereafter) can be a candidate for a compliant substrate for GaN growth. Sapphire nano-membranes were fabricated by solid-phase epitaxy (SPE) of amorphous alumina deposited on photoresist-patterned sapphire substrate. After the removal of photoresist pattern, suspended amorphous alumina membrane was crystallized to γ-phase alumna, then ultimately to α-phase alumna (crystalline sapphire) by SPE using underlying sapphire substrate as a seed crystal. SPE rates for both crystalline phases were carefully studied and reported [1]. The interface between GaN and 26 nm thin nano-membrane was carefully analyzed by high-resolution transmission electron microscopy. It was found that the distance between misfit dislocations were increased, implying that the lattice mismatch was effectively reduced. The reduced lattice mismatch resulted in generation of less number of misfit dislocation and threading dislocations. Cathodoluminescence measurement showed that the defect density of GaN grown on sapphire nanomembrane was lower [2], implying that sapphire nanomembrane can be used for a new substrate for high performance GaN-based devices.

We were able to obtain anisotropic photoluminescence from GaN grown on stripe-patterned sapphire nanomembrane structures. Anisotropic strain state in GaN altered the band structure of GaN, affecting the transition probability from conduction band to valence band. Experimental result and the theoretical prediction by 6x6 k-P calculation were in good agreement [3]. Sapphire nano-membranes can be further used to fabricate discrete GaN microplates on sapphire. The stripe length and the number of arrays determine the sizes of GaN microplates. In this case, die singulation process by dry etching is not necessary and it is highly expected that the external quantum efficiency of the micro-LED would not be degraded.

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# Growth and optical characterization of a three-fold symmetric III-nitride quantum dot at the apex of pyramidal structure

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The epitaxial quantum dots (QDs) with III-Nitride material are promising candidates for single photon emitter operating at room temperature. However, high degree of linear polarization induced by small anisotropy of QD makes difficult to generate polarization entangled photon pair. Considering their application for quantum information technology, the method that can fabricate symmetric III-Nitride QDs is significantly required.

In this work, we suggest the fabrication method of symmetric III-Nitride QD using three-fold symmetric GaN pyramidal structure. GaN pyramids are grown by metalorganic chemical deposition with nano-scale patterned dielectric mask. We investigated morphological evolutions of the structure with scanning electron microscopy by varying growth conditions. The three-fold symmetric structure has been formed with mixture of nitrogen and hydrogen in carrier gas. The six-fold symmetric structure have experienced degradation of symmetricity after completion of pyramidal shape, not in the three-fold symmetric case. We have applied self-limited growth mechanism to control the lateral dimension of QD (~ 20 nm) which was measured by transmission electron microscopy. The InGaN single quantum well is regrown on the self-limited top width at the apex of the pyramid. We measured low temperature micro-photoluminescence to characterize the optical properties (e.g. degree of linear polarization) of fabricated three-fold symmetric QD. As a consequence, we confirm that our method that symmetry controlling with the assistance of three-dimensional nano structure make possible to generate symmetricity controlled III-Nitride QD.

# Study of epitaxial growth and device fabrication of AlGaN-based deep ultraviolet LED

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Recently, AlGaN-based deep ultraviolet light emitting diodes (DUV-LEDs) have attracted great attentions due to its important applications such as air purification, water purification and ultraviolet phototherapy [1,2]. Despite the attractive opportunities, high-density mismatch dislocations of high Al-content AlGaN materials hinder the device performance. Meanwhile, the emitting power of the AlGaN-based LEDs undergoes an unsatisfactory non-linear increment when elevating the current. This phenomenon is known as the efficiency droop, which is a significant challenge to the improvement of the output power of AlGaN-based DUV-LEDs [3,4]. Over the past few years, this phenomenon has been studied widely, and one of the most frequently cited explanation for the efficiency droop is electron leakage from multi-quantum wells (MQWs) into the p-type layers, resulting in the poor radiative recombination in the active region [5,6].

In this work, we have proposed a new structure to mitigate efficiency droop in AlGaN-based deep UV-LEDs by optimizing the electron blocking layer (EBL) of the DUV-LED by Crosslight APSYS (Advance Physical Model of Semiconductor Devices) programs. To shed light on the mechanisms responsible for the improvement, the band diagram, optical and electrical properties of this structure were simulated by solving the Schrödinger equation, the Poisson's equation, the carrier transport equations and the current continuity equation self-consistently. Based on the structure design, the device was grown by cold-wall MOCVD system and the 3030 chips were manufactured by standard device process. The peak wavelength of the DUV-LED was 281 nm. The optical power and the driving voltage were 17 mW and 8 V at 300 mA.

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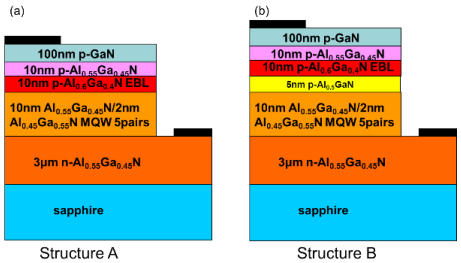


Figure 1. Schematic diagrams of different AlGaN-based deep UV-LEDs

Figure 2. Device diagram of AlGaN-based deep UV-LED

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# Microscale, Implantable Optoelectronic Devices for Optical Neural Interfaces

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**Keywords:** LEDs, Photodetectors, Optoelectronics, Biophotonics

**Abstract.** Recent progresses in the design of mechanics and materials have given birth to flexible and stretchable electronics and photonics, enabling the integration of rigid inorganic devices with soft, elastic and curved biological systems. While current flexible photonic devices are mostly based on organic materials, bio-integrated high performance inorganic optoelectronic devices will provide new insights on interactions between light and bio-systems. Here we present unconventional strategies to design and fabricate thin-film, microscale III-V based optoelectronic devices and use them in implantable systems for biomedical applications. Specifically, high performance InGaN and GaAs based LEDs and photodetectors with dimensions less than 100 um and thicknesses less than 5 um are formed by epitaxial liftoff methods. These devices are integrated with organic based substrates to realize unusual flexibility and stretchability. In addition, the organic/inorganic interfaces are studied and optimized to achieve ideal optical, electrical and thermal performance. Furthermore, the integrated microscale devices are implanted into living animals for biological signal sensing and stimulation. Specifically, LEDs are utilized to work as light sources to interact with genetically encoded neural actuators, stimulating neural activities, while photodetectors are used to monitor the fluorescence signals of light sensitive proteins, probing neural signals. Optical simulation methods are developed to understand the light propagation in deep brain tissue and optimize the device structures. Encapsulation schemes are developed to obtain prolonged device lifetime and improved biocompatibilities in living biological systems. Implanted devices are wirelessly powered and controlled by a miniaturized circuit system. These devices are implanted deeply into the mouse brain, demonstrating close loop monitoring and manipulation of neural activity in vivo. Such an integrated, deeply implanted and microscale optoelectronic system provides new insights on interactions between optical signals and neural systems.

# Optoelectronics using quantum-dots/metal-nanoparticles for transparent and soft interactive devices

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**Abstract**

This talk will focus to introduce a new type of optoelectronics based on nanomaterials, such as quantum-dots and metal nanoparticles. These kinds of optoelectronics are considered as an emerging science and technology due to the potential applications including transparent and soft interactive devices. During the presentation, the interfacial physics of quantum-dots light emitting diodes(QLEDs) will be considered as well as the fabrication process of red, greed, and blue QLEDs. In addition, a method to fabricated transparent photosensors, which can be perfectly turned on and off by a visible light, based on quantum-dots and metal nanoparticles will be discussed in detail. The measurements and analysis of interfacial electronic structure of optoelectronics based on quantum-dots will be introduced in detail as well.

**Biography**

Seong Jun Kang received his B.S., M.S. and Ph.D. degrees in Physics from Yonsei University. In 2005, He joined in University of Illinois at Urbana Champaign as a postdoctoral research associate, where he was involved in research of flexible and stretchable electronic devices based on carbon nanomaterials. In 2007, he joined Korea Research Institute of Standards and Science as a research scientist. From 2010, he joined to the Department of Advanced Materials Engineering for Information and Electronics at Kyung Hee University, where he has been an associate professor since 2014. He also worked at Columbia University (New York) in 2016. His research interests focused on transparent, flexible and stretchable electronics based on nanomaterials, such as carbon nanotube, graphene and quantum-dots. Also, he focused on the study of interfacial electronic structures between nanomaterials for the high-performance optoelectronics. Additional information of Prof. Kang can be found at his webpage of http://lant.khu.ac.kr.

# Wearable textile-driven energy harvesting device

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Wearable textile platforms have been the subject of intense focus to promote the creation of outstanding added value for textile-based applications in consumer electronics, energy harvesting, and storage. In this regard, harvesting energy from the living environment of human motions has been the focus of immense interest as one alternative option because of their considerable advantages of powering smart electronics: that is, the utilization of mechanical energy resources from a human motion is one promising way to overcome the limitations of sustainable, reliable, and maintenance-free energy sources that are abundant in our daily life. Here, we address the electrical performance of tribo-electric nanogenerators (T-TENGs) devices employing various surface engineered configuration layers coated on the conductive textiles. Control and manipulation of surface engineering represent one of key approaches in this work by using in-situ 2-step reactive ion plasma (RIE) treatments, surface embossing approach through the aid of nanowire and nanoflake frames initially prepared by hydrothermal process. Even though more technical experiments must be established in the near future, we anticipate that the use of textile yarn materials would lead to a breakthrough in textile electronics and would open up the field for a much broader range of free-form factor by weaving diverse yarns onto various 2D/3D textile networks.

# Smart and Connected Bioelectronics for Persistent Human-Machine Interfaces

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My research focuses on the fundamental and applied aspects of nanomechanics, biomolecular interactions, soft materials, and nano-microfabrication for nanoparticle biosensing and unusual electronic system development, with an emphasis on bio-interfaced translational nanoengineering.

Recently, my group opened a new research area in biomedical engineering with a novel technology: “soft, wearable electronics for health monitoring and human-machine interfaces”. We took the lead to design and develop this unique system that is based on soft biomimetic materials, stretchable mechanics designs, and hybrid system integration, aiming for advancing human health and wellness. Unlike the conventional bulky and heavy wearable devices, these innovative “skin-like” electronics are based on a completely different class of technologies that offer non-invasive, gentle lamination and comfortable wearability on the skin. Integration of multiple nano-micro sensors and actuators along with miniaturized wireless telemetry on a soft membrane provides continuous, long-term monitoring of human health and biopotentials.

In this talk, I will discuss about recent research works on soft, wearable electronics which include biomimetic materials, mechanics designs, and system integration, aiming for persistent human-machine interfaces. Specifically, I will talk about fundamental mechanics to design flexible electronics, required materials properties for soft systems, and methodologies to enable hard-soft materials integration for flexible hybrid electronics. In addition, a few examples of unobtrusive, ergonomic wearable electronics for persistent human-machine interfaces will be discussed including a drone control, human-wheelchair interface, and electronic prosthesis.

# Transient Electronics

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A remarkable feature of silicon-based integrated system is its capability to last forever without any functional and physical variation, in almost any practical purposes. Recent works demonstrate a new class of silicon electronics that has the opposite behavior -- it physically disappears in water or biofluids, in a controlled fashion, at prescribed times and with programmed rates. This ‘transient’ technology opens up completely new application opportunities for semiconductor devices in areas, such as implantable medical devices that exist for medically useful timeframes but then dissolve and disappear completely by resorption into the body. This talk summarizes recent work on ‘transient’ technology, ranging from fundamental chemistry of the key materials, to development of various components and systems for biosensors, to in vivo toxicity tests for biocompatibility.

# Electrochemical performance of Ag nanowires coated carbon cloth supported bimetallic layered double hydroxide for supercapacitor applications

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**Abstract:**

Recently, intensive research has been devoted on the development of clean and sustainable energy storage devices due to fast consumption of fossil fuels and ever-increasing energy demands. Supercapacitors (SCs), as a class of electrochemical energy storage device, have garnered considerable attention owing to their special features of high power density, fast charging-discharging ability and long lifetime. Based on charge storage mechanism, SCs are divided into electric double layered capacitors (EDLCs) and pseudocapacitors. In EDLCs, the charge is separated at an electrode/electrolyte interface and physically adsorbed on the electrode materials (activated carbon and graphene). By contrast, fast and reversible redox reactions are responsible for the storage of charge in pseudocapacitors. Transition metal hydroxides/oxides ($MnO_2$, $V_2O_5$, Ni-Co$(OH)_2$, etc.) and conducting polymers are classified as pseudocapacitor materials. Among them, nickel cobalt layered double hydroxides (NC LDHs) have received a great deal of attention due to their large interlayer structure, high redox activity and multiple oxidation states. Meanwhile, preparation of active material on carbon cloth (CC) is a prominent approach for flexible SCs. But, the CC mainly suffers from high hydrophobicity. Accordingly, we decorated silver nanowires (Ag NWs) on the surface of CC fibers (Ag@CC) via a simple dip coating method to enhance its wettability. Utilizing the electrochemical deposition, the NC LDH nanosheets were facilely coated on Ag@CC (NC LDH NSs@Ag@CC) for use as a positive electrode. The hybrid composite delivered a higher electrochemical performance compared to the one synthesized without Ag NWs. The enhancement in performance is mainly attributed to Ag NWs fencing, which not only increases the hydrophilicity of CC but also facilitates the fast charge transportation. Furthermore, an asymmetric supercapacitor (ASC) was constructed using NC LDH NSs@Ag@CC and activated carbon coated CC as positive and negative electrodes, which showed superior electrochemical performance with a maximum areal energy and power densities of 78.8 μWh $cm^{-2}$ and 12.1 mW $cm^{-2}$, respectively.

# Quasiparticle interference and impurity resonances in type II Weyl semimetal $WTe_2$

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$WTe_2$, layered transition metal dichalcogenide, is predicted to be a type-II Weyl semimetal. We present the calculated quasiparticle interference (QPI) of type II Weyl semimetal $WTe_2$ and those observed by scanning tunneling microscopy/spectroscopy (STM/STS). We perform a *T*-matrix calculation for the scattering resulting from a nonmagnetic single impurity potential by using the electronic properties from first-principles calculations, which establish clear QPI features of the surface states. The scattering on the constant-energy surface strongly depends on both momentum and spin orientation. The Weyl fermion states in $WTe_2$ emerge as topologically protected touching points of electron and hole pockets, and Fermi arcs connecting them can be visible in the spectral function on the surface. To probe the properties of surface states, we have conducted low-temperature STM/STS (at 2.7 K) on the surfaces of $WTe_2$ single crystals. We visualize the surface states of $WTe_2$ with atomic scale resolution. Clear surface states emerging from the bulk electron pocket have been identified and their connection with the bulk electronic states shows good agreement with calculations. We also show the interesting double resonance peaks in the local density of states appearing at localized impurities. The low-energy resonant peak occurs near the Weyl point above the Fermi energy and it may be closely related to the surface state of Weyl points

# Nodal line semimetals with Z2 monopole charge

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In this talk, I am going to talk about the topological properties of nodal line semimetals with Z2 monopole charge, which can be realized in PT invariant three-dimensional systems without spin-orbit coupling. Here P and T indicate the inversion and time-reversal symmetries, respectively. Due to the Z2 monopole charge, such nodal lines always exist in pairs. Here I describe the mechanism for pair-creation of Z2 nontrivial nodal lines and its linking structure, which originates from the nontrivial band topology characterized by the second Stiefel-Whitney class. I propose that an unconventional topological phase transition can be realized through pair-creation and pair-annihilation of Z2 nontrivial nodal lines.

Topological materials, including topological insulators (TIs) and topological semimetals (TSMs), have recently attracted much attention due to their exotic electronic properties and potential applications. In TSMs, the band crossing at the Fermi energy occurs at discrete points (Dirac and Weyl semimetals) or along curves (nodal line semimetals) in the reciprocal space. In nodal line semimetals, such as $Ca_3P_2$, $Cu_3PdN$, and LaN, the Dirac nodes are protected by time-reversal and inversion symmetries in the absence of spin-orbit coupling (SOC). In the presence of SOC, an additional symmetry is required to protect the nodal lines, such as non-symmorphic symmetry in ZrSiS and $IrF_4$ or mirror reflection symmetry in non-centrosymmetric $TlTaSe_2$ and $PbTaSe_2$. On the other hand, graphene, a two-dimensional (2D) honeycomb lattice of carbon, is famous for having Dirac points in the absence of SOC. The SOC opens a band gap at the Dirac point, leading to a TI phase. The TSM phase was proposed for three-dimensional (3D) carbon allotropes, such as interpenetrated graphene network, Mackay-Terrones crystal, and bco-$C_{16}$.

In this work, we report a novel 3D metallic carbon allotrope discovered using an evolutionary structure search method. We explore new carbon allotropes with $sp^2$-$sp^3$ hybridized bonds by using a computational search method [1], in which the conformational space annealing algorithm for global optimization is combined with first-principles electronic structure calculations. The new carbon phase in the monoclinic $C2/m$ space group, termed $m$-$C_8$, is characterized by five-membered rings with $sp^3$ bonding interconnected by $sp^2$-graphitic carbon networks [2]. The band structure exhibits linear dispersions around the Fermi level where the valence and conduction bands touch, similar to graphene. The linear bands are mainly derived from the $sp^2$ hybridized C atoms in graphitic sheets. Analyzing the $Z_2$ topological invariant, we identify that $m$-$C_8$ belongs to the class of topological nodal line semimetals, with a continuous nodal line piercing the 3D Brillouin zone and protected by a combination of time reversal and inversion symmetries. We also find the surface band connecting the projected nodal points on the [110] surface. Based on the analysis of X-ray diffraction spectra and enthalpy-pressure curve, we propose that $m$-$C_8$ can be present in detonation soot and a phase transition from graphite to $m$-$C_8$ can occur under compression.

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# From ab-initio calculations towards Topological Insulators nanostructures by Ion Beam Sputtering Deposition

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Topological Insulators (TI) are a recently discovered category of materials, with the term TI only being coined in 2007. They host a protected metallic state on their surface while having an insulating bulk. This state appears in the form of a spin-textured Dirac cone, where spin is locked with momentum [1]. A wide range of applications are foreseen to exist for TI materials [2]. However, more studies and experimental realization of the TI materials and tuning of the TI state must be accomplished, using scalable and industrialized fabrication techniques, prior to their wide application and usage.

The focus of this work was thus the fabrication and growth of TI thin films based on Sb-Te and Bi-Te by Ion Beam Sputtering Deposition (IBD), a top-down technique already being used in the industry [3]. Moreover, an insight into the thin films' properties and behavior was also made, through several measurements and First Principle Calculations [4].

The Sb-Te and Bi-Te thin films were sputtered in glass and Si substrates, with thicknesses ranging from few nanometers to hundreds of nanometers. The impact of the IBD parameters on the morphology, stoichiometry and structure of the thin films was deeply studied by performing XRD, XRR, Raman and SEM/EDS analysis [5]. Furthermore, the influence of the above-mentioned deposition parameters and substrate choice on the thin film transport and magnetotransport properties was also characterized. Resistivity and the Seebeck coefficient were measured as a function of temperature and the magnetoresistance for high magnetic fields and low temperatures was also obtained.

DFT calculations of bulk and thin film $Sb_2Te_3$ and $Bi_2Te_3$ were also performed using the WIEN2K software package. The transport properties of the calculated structures were calculated based on the WIEN2K outputs, through Boltzmann Transport Theory implemented in the BoltzTraP code.

In this presentation, the influence of the IBD parameters on the properties of the topological insulators sputtered thin films will be presented. An overview of how the DFT calculations can explain the behavior of the sputtered thin films is also shown.

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# Spin torque switching and magnetoresistive detection in antiferromagnets

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For a long time, there have been no efficient ways of controlling antiferromagnets. Quite a strong magnetic field was required to manipulate the magnetic moments because of a high molecular field and a small magnetic susceptibility [1]. It was also difficult to detect the orientation of the magnetic moments since the net magnetic moment is effectively zero. Nevertheless, the microscopic magnetic moments should in principle exhibit a similar spintronic effect, such as various magnetoresistance effects and the spin torque effect, as seen in ferromagnets [2,3]. In this talk, we show our recent results of the spin torque switching and magnetoresistive detection of the magnetic moments in antiferromagnets [4], leading to novel antiferromagnetic spintronic applications.

Pt 4 nm/ NiO $t_{NiO}$ nm/ Pt 4 nm multilayers were formed by magnetron sputtering. Figure 1 (a) shows the basic principle of the spin torque rotation of the antiferromagnetic moments in a Pt/ NiO/ Pt multilayer structure where the bipartite magnetic moments rotate without a cost to increasing the exchange energy. To experimentally demonstrate, we used the Hall bar structure with the measurement procedure described in Fig. 1 (b). A writing current $I_w$ flowing from the electrode 2 and 3 to the electrodes 1 and 4, as represented by write "1", rotates the magnetic moments and stabilizes them orthogonal to the direction of $I_w$. In the same manner, the other current flow of $I_w$ writes "0". The orientation of the magnetic moments is read, after each write, by the transverse resistance ($R_{Hall}$). We took advantage of the spin Hall magnetoresistance (SMR) to read out the orientation of the magnetic moments. Figure 1 (c) shows representative results of the sequential write-read operation in Pt/ NiO /Pt as well as Pt/ SiO / Pt with $I_w$ = 38 mA. The operation of write "1" results in a high resistance state and "0" in a low state, which is coherently explained by the spin torque rotation of the magnetic moments and the change of $R_{Hall}$ due to SMR.

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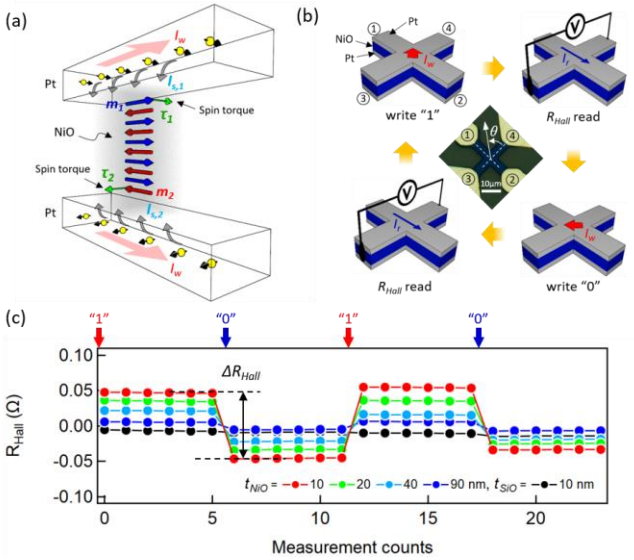


**Fig. 1 The spin torque writing scheme and the sequential write-read memory operation.**

# Antiferromagnetic domain wall dynamics in GdFeCo ferrimagnets

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Antiferromagnetic spintronics is an emerging research field which aims to utilize antiferromagnets as core elements in spintronic devices. Recent theories predicted that the antiferromagnet has a faster domain wall (DW) dynamics than ferromagnetic DWs. However, experimental investigations of antiferromagnetic DW dynamics have remained unexplored mainly because of the insensitivity of antiferromagnets to magnetic fields. Here we show that fast field-driven antiferromagnetic spin dynamics is realized in ferrimagnets at the angular momentum compensation point $T_A$. Using rare-earth–3d-transition metal ferrimagnetic compounds where net magnetic moment is nonzero at $T_A$, the field-driven DW mobility remarkably enhances up to 20 km $s^{-1}T^{-1}$. The collective coordinate approach generalized for ferrimagnets and atomistic spin model simulations show that this remarkable enhancement is a consequence of antiferromagnetic spin dynamics at $T_A$. Our finding allows us to investigate the physics of antiferromagnetic spin dynamics and highlights the importance of tuning of the angular momentum compensation point of ferrimagnets, which could be a key towards ferrimagnetic spintronics [1].

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# Theoretical study of strain-assisted synthetic anti-ferromagnetic free layer based magnetic tunnel junction switching

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Spin transfer torque magnetic random access memory (STT-MRAM) has been regarded as one of the most promising candidates for future memory devices. However, there exist well-known challenges in commercializing STT-MRAM: Firstly high on-current itself and MgO breakdown caused by the high current, and secondly it still requires innovative improvements of thermal stability. In regard to the first obstacle, the technique employing magnetostriction effect has been suggested [1, 2]. The utilizations of synthetic anti-ferromagnetic (SyAF) free layer have been reported both experimentally and theoretically, in which many expected that SyAF-based magnetic tunnel junction (SyAF-MTJ) would be a breakthrough to overcome an insufficient thermal stability [3]. In this study, we perform simulations on the MTJ with perpendicular magnetic anisotropy (PMA) structure in which the conventional free layer was substituted with SyAF. In order to reduce switching current $Pb(Zr_{0.2}Ti_{0.8})O_3$ (PZT) material with (001) surface orientation is adopted, which is adjacent to the second free layer so that it applies bi-axial stress to the interface under external voltage. We solve Landau-Lifshitz-Gilbert-Slonczewski (LLGS) equation incorporating thermal and strain fields to describe transient dynamics of magnetizations in both free layers. The simulation result shows substantial reduction in switching current and significantly enhanced switching probability by overlapping current and strain pulses.

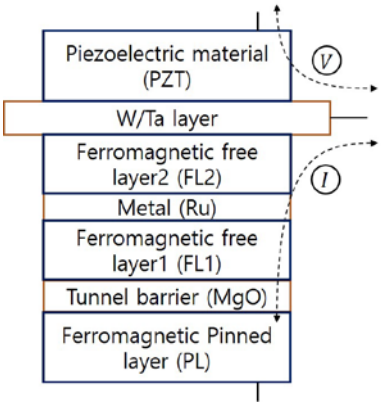


Fig. 1. Device structure of strain-assisted SyAF-MTJ

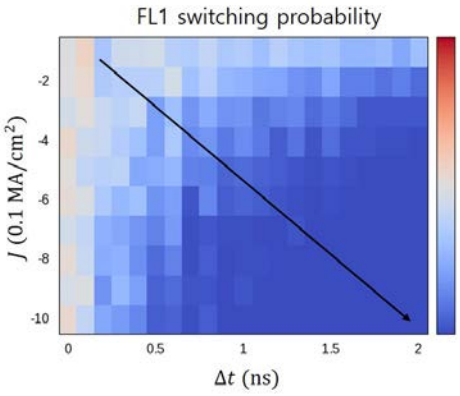


Fig. 2. Switching probability at current density as a function of the overlapping time

*This work was supported by the MOTIE (10080725) and KSRC support program for the development of the future semiconductor device*

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# Antiferromagnetic magnonic crystals with alternating Dzyaloshinskii-Moriya interaction

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The collective excitation of magnetic moments in magnetic materials is named spin-wave and quantized mode of spin waves is called magnon. The spin-wave has been extensively investigated in "magnon spintronics"[1], because spin-wave device do not involve electron transport and that allow low-power computing.

The magnonic crystal(MC) is one of metamaterial with alternating magnetic media that makes periodic potential for propagating spin-wave. Thus the MC constructs allowed bands and forbidden gaps for spin-wave [2, 3].

In this work, based on micromanetic simulation we demonstrate modulating sub-THz spin-wave band gap in antiferromagnetic magnonic crystals with alternating Dzyaloshinskii-Moriya interaction.

Figure 1 a) shows the ratio of transmitted spin-wave to incident spin-wave as a func tion of DMI constant in region 2 ($D_2$). The lines are obtained from analytical solution and symbols are numerical results. Here we find that the spin-wave transmittance cou ld be larger than 1 and all results have reasonable agreements regardless of spin-wave polarization.

Figure 1 b) shows allowed and forbidden bands for spin-wave in antiferromagnetic m agnonic crystals with alternating DMI constant. Likewise results for spin wave transmi ttance (Fig. 1. a)), the analytical solution and numerical results are well matched and the spin-wave polarization does not affect to the results. From Fig. 1. b), we find that for D2= 2 erg/cm2 the spin-wave band gap opens up to 0.1 THz.

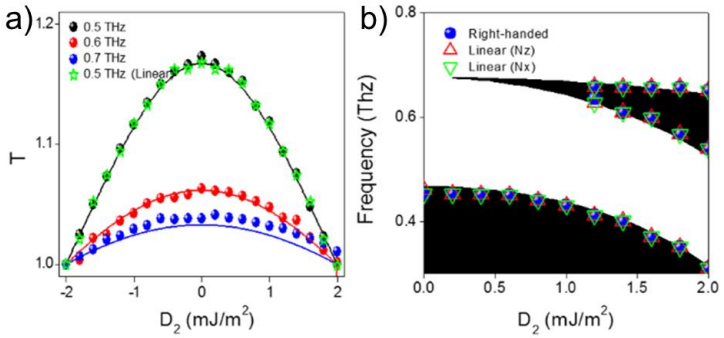


Fig. 1. a) The ratio of transmitted spin-wave at a DMI step, b) Allowed and forbidden bands for spin-wave in magnonic crystals.

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**ABSTRACT**

The recent development of strain sensor devices which can actively monitor human body motion has attracted tremendous attention, for application in various wearable electronics and human-machine interfaces. In this study, as materials for strain sensor devices, we exploit the low-cost, carbon-based, 3-dimensional (3D) printable composite dough. The dough is prepared via a chemical method based on the formation of electrostatic assemblies between 1-dimensional, amine-functionalized, multi-walled carbon nanotubes and 2-dimensional graphene oxides. The resulting composite dough has an extremely high storage modulus, which allows a vertically-stackable, 3D printing process for fabricating strain sensor devices on various dense, porous and structured substrates. The device performance parameters, including gauge factor, hysteresis, linearity, and overshooting behavior are found to be adjustable by controlling the printing process parameters. The fabricated strain sensor devices demonstrate the ability to distinguish actual human body motions. A high gauge factor of over 70 as well as other excellent device performance parameters are achievable for the printed sensor devices, and even a small strains, below 1 %, are also detectable by the fabricated sensor devices.

# Pressure sensors based on capacitor and transistor devices with printed silver nanowire buckling structures

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**Abstract**: *In this paper, pressure sensor technology based on printing-based buckling silver nanowire (Ag NW) electrodes is presented. Capacitive pressure sensor structures were used in capacitor and transistor in order to implement highly sensitive pressure sensors. The multiscale-structured buckling Ag NW electrodes were fabricated by embedding Ag NW in buckling polydimethylsiloxane (PDMS). The capacitive pressure sensitive capacitor showed high sensitivity of >3.8k Pa-1 and fast response/relaxation time of < 150ms. When a spacer is inserted in the capacitor, the sensitivity of the pressure sensitive capacitor increased to 9.9k Pa-1 and its bending stability was also further improved. If the capacitor is used as gate capacitor of a transistor, the readout signal can be changed from capacitance variation to current or voltage signals. We fabricated a pressure-sensitive transistor (PST) with semiconducting single-walled carbon nanotube (SWCNT) that operates at ultralow voltage of as low as 1V. All sensors showed high bending and cycle stabilities. We demonstrated a fingertip pressure sensor, a brachial artery pulse measurements in both flat and bent conditions, and a standalone wearable user-interface pulse monitoring system. Details of our technology will be reviewed.*

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**Presentation Preference**: Invited Paper

**Symposium Topic**: Sensors & Applications

# Fabrication and mechanoluminescence properties of CaZnOS with layer structure for visualization of stress

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Mechanoluminescent materials can convert the mechanical energy into light, making them can be widely used in stress sensor, artificial skins, skeletons, self-diagnostic systems, etc. [1, 2, 3]. Herein, we present the fabrication and mechanoluminescence properties of rare-earth ions activated CaZnOS with layer structure. It is of note that strong luminescence emission of CaZnOS:RE can be observed under a specific stress. The mechanical quenching properties of CaZnOS:RE is correlated to the non-radiative recombination originating from the electron transfer from trap to the non-radiative centers under the external stress. Considering the high luminescence efficiency, suitable emission wavelength range and high sensitivity of CaZnOS:RE, one has reason to assume that this material should gave a great potential in stress detecting system.

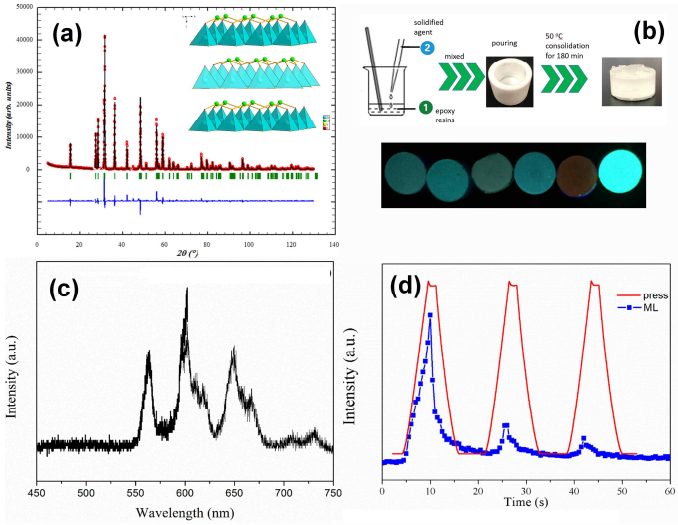


Fig. 1 The XRD and Rietveld refinement of CaZnOS (a), the fabrication and samples under UV light (b), the mechanoluminescence spectrum of CaZnOS:RE (c), the mechanoluminescence properties under several cycles (d).

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# Novel Multi-Level-Cell Resistive Random Access Memory based Reconfigurable Physical Unconable Functions

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Physical unclonable function (PUF) has been emerging as a commercialized technology in hardware security for highly secure which utilizes fabrication process variation and inherent randomness as a source of function. [1] Conventional complementary metal oxide semiconductor (CMOS) technology based PUFs have already been available on the market, but there are many obstacles to keep the system securely from various attacks due to their vulnerability toward model-and physical-attacks. [1] Therefore, to impede these attacks, various devices have been introduced so far - such as phase change memory (PCM), spin-transfer-torque magnetic random access memory (STT-MRAM), carbon-nanotube field effect transistors (CNFETs) and resistive random access memory (RRAM). [2] Especially, RRAM based PUF is a promised device due to its strong stochastic behavior and intrinsic variability characteristics. We introduce novel multi-level-cell (MLC) based reconfigurable RRAM PUF to block the physical and model attacks. Our method leads to maximize cycle-to-cycle and cell-to-cell variation to increase randomness of RRAM. As a result, our PUF not only increases the complexity in creation of challenge and response pairs but also reduces foot print dramatically. The performance of PUF was evaluated by using uniqueness, randomness and bit error rate which satisfies ideally the expected value respectively.

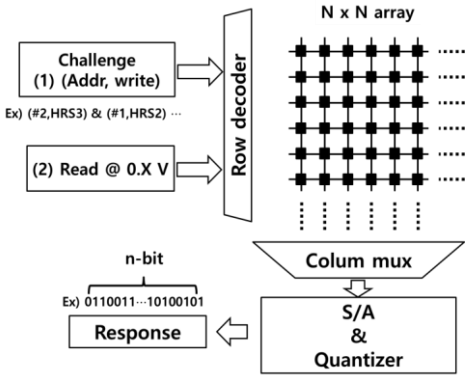


**Figure 1 Schematic of PUF**

## Acknowledgement
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# Ultrafast Graphene Light Emitters

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Graphene has emerged as a promising material for nanophotonics and optoelectronic applications due to its unique electronic and optical properties. Previous graphene based optoelectronic devices such as ultrafast and broadband photodetectors, optical modulator, and plasmonics, have shown the feasibility of ultrafast signal processing for on-chip optical communications. Among the nanophotonic components, ultrafast electrically driven nanoscale light sources are critical components in nanophotonics. However, monolithic ultrafast light sources with a small footprint remain a challenge. Previously, we demonstrated bright thermal light emission in the visible range from electrically biased suspended graphene which achieves electron temperature up to ~ 2,800 K [1] owing to graphene's high thermal stability, low heat capacity and ultrafast charge carrier dynamics. After our demonstration, graphene becomes the promising material for nanoscale light source. However, monolithic graphene based ultrafast light source remain challenge due to limited hot electrons cooling pathway bottlenecks in graphene and little is known about the intrinsic thermal modulation rate of graphene under electrical excitation. Here, I will present the demonstration of electrically driven ultrafast thermal light emitters based on hexagonal boron nitride (hBN)-encapsulated graphene that achieve light pulse generation up too 10 GHz bandwidth with a broad spectral range from the visible to near-infrared [2]. The fast response results from ultrafast charge-carrier dynamics in graphene and weak electron-acoustic phonon-mediated coupling between the electronic and lattice degree of freedom. Van der Waals heterostructure with ultraclean interface in hBN-graphene provide the strong light-matter interactions and efficient ultrafast direct electronic cooling pathway via near-field coupling by hybrid plasmon-phonon polariton modes, resulting in 460% enhancement of radiation intensity at 720 nm and 92 ps light pulse generation. Furthermore, high stability of encapsulation hBN layers allow the thermal radiation up to 2000 K under ambient condition and life-time above 4 years under vacuum. Our high-speed graphene light emitters provide a promising path for on-chip light source for ultrafast optical communications and other optoelectronic applications.

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# Electronic interferometer on GaAs/AlGaAs 2DEG

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Electronic interferometry has played a significant role in studies of the foundations of quantum physics, such as decoherence, entanglement and complementarity etc. Moreover, they are regarded as the most promising platform for probing anyonic quasi-particles in the fractional quantum Hall effect regime. Anyons are exotic excitations to obey fractional exchange statistics, which is different from that of fermions and bosons. As fabrication techniques improved and novel materials developed, interferometers were realized in numerous mesoscopic systems, such as quantum Hall systems, nanowires, carbon nanotubes, and graphene.

In this talk, I will review the basics of electronic interferometry realized on high electron mobility GaAs/AlGaAs 2-dimensional electron gas system and discuss related research topics.

# Highly Enhanced Photoresponsivity of Monolayer $WSe_2$ Photodetector with Nitrogen-doped Graphene Quantum Dots

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Monolayer (ML) transition metal dichalcogenides (TMDs) such as tungsten diselenide ($WSe_2$) are particularly interesting in the field of nanoscale optoelectronic devices because of its direct band gap, high carrier mobility and high ON/OFF ratio. However, atomically thin material layers have limited ability to absorb and emit radiation because of their low cross-sectional area.

To enhance the photoresponsivity of ML $WSe_2$, a strong light absorbing materials such as PbS quantum dots (QDs) or organolead halide perovskite were introduced. However, these materials are toxic and unstable under ambient condition because of the presence of Pb compounds or organic materials. Therefore, it is a huge challenge for finding a low cost, non-toxic and stable material to create a hybrid structure with ML $WSe_2$ to improve its optoelectronic performance.

In this work, we report a facile method for fabricating a hybrid structure that consists of ML $WSe_2$ covered with Nitrogen-doped graphene quantum dots (ML $WSe_2$/N-GQDs). The PL intensity of ML $WSe_2$ is enhanced drastically because of the reduction of the positive trion and enhancement of the neutral exciton formations through electron transfer from N-GQDs. The improved photoresponsivity in ML $WSe_2$/N-GQDs photodetector is attributed to strong light absorption and charge transfer from N-GQDs to ML $WSe_2$. The photogating effect also plays a key role in the improvement of hybrid photodetector performance. Notably, this hybrid photodetector exhibits good stability under ambient condition.

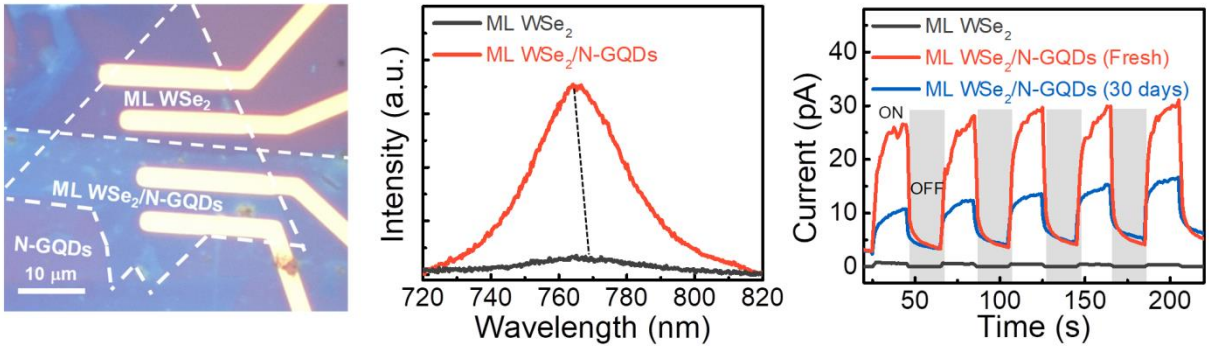


**Figure 1. a) Optical imagine and (b) Photoluminescence spectra of ML $WSe_2$ and ML $WSe_2$/N-GQDs heterostructure. c) Time-dependent photoresponse of ML $WSe_2$, ML $WSe_2$/N-GQDs fresh device and after 30 days under ambient condition.**

# Temperature induced crossing in the optical bandgap of mono and bilayer $MoS_2$ on $SiO_2$

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2D transition metal dichalcogenides material attracts great attention because of the optoelectronic properties and the van der Waals interlayer interaction that is beneficial for futuristic optical devices based heterostructure. We studied difference of MoS2 monolayer and bilayer photoluminescence behaviors. Experimentally it was observed that as the temperature increases low (~4 K) to around 300K, the monolayer PL intensity overtakes the bilayer's. Also bilayer minimum-energy peak position alter more than that of the monolayer. We calculated dipole transition probability of 1L and 2L MoS2 at the level of PBE including the spin orbit coupling (SOC). Our calculation shows that 2L-MoS2 have greater probability than 1L-MoS2 due to doubled degeneracy in 2L-MoS2. Because of the indirect transition(K to gamma) in bilayer, temperature increase can enhance the indirect emission in bilayer. Thus the peak intensity crossovers between monolayer and bilayer. On the other hand peak position variation difference originates from thermal expansion, where we incorporated the thermal expansion coefficients into our calculation by increasing the lattice size.

# Spectral Behavior of Mode-locked Quantum Dot Lasers

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The gain behavior and optical spectral characteristics of quantum dot lasers exhibit a number of unique features that are substantially different from those measured in quantum well of bulk gain media. In particular, the splitting of the ground state into two discrete subbands and the consequent appearance of two sets of modes in the optical spectra has been investigated by a number of groups [1]. Although the precise physical origin of the phenomenon is not completely clear, its impact on the dynamical behavior of a laser undere mode-locking conditions is of great interest. Depending on the biasing conditions, the laser exhibits stable mode-locking on one of the two sets of modes only or on both sets simultaneously [2]. In the latter condition, the two spectral lobes can either be locked together, generating extremely narrow pulses with a very large spectral bandwidth, or the laser can emit two pulse trains with distinct repetition rates.

In this presentation the mode-locking behavior and the lasing dynamics of quantum dot mode-locked lasers will be described. The devices were fabricated from a laser structure with a gain medium consisting of five layers of quantum dots embedded in an InGaAsP matrix emitting at a wavelength around 1550 nm. The contacts were defined to form two sections in the cavity, one a longer forward biased gain section and the other a shorter reverse biased saturable absorber. A full understanding of the pulse formation and the locking behavior is obtained through the use of a sonogram technique [3] that can unambiguously retrieve both the phase and time profiles of low energy pulses. It is found that for a certain range of biasing conditions it is possible to lock the two sets of modes together up to a separation of 15 nm between the spectral peaks. Under these conditions the generated pulses exhibit a weak red chirp with higher order components and the pulse length can be as low as 700 fs.

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# Topological valleytronics: Brought to light

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Valleys — the degenerate energy extrema in the electronic band structure of a material — have recently emerged as novel carriers of information and energy, much like charge and spin. Just like electrons with opposite spin, electrons in opposite valleys can counter-propagate along the edge of a 2D insulator without any dissipation [1]. Classical waves can possess a valley degree of freedom, too. So even though they can carry neither charge nor spin, classical systems such as sonic and photonic crystals are capable of hosting such topological valley Hall effects [1]. In this talk, I will introduce our prediction of topological valley Hall effect in bilayer graphene [1] and the recent observation of topological valley transport for electrons [2], acoustic waves [3], and electromagnetic waves [4]. In particular, I will discuss the experimental challenges in electronic systems, due to the inevitable inter-valley scattering and the lack of precise control at atomic scale, and the superior advantages in classical systems.

The discovery of counterflow in opposite valleys not only demonstrates that the valley can be a novel carrier of information and energy — particularly valuable for systems without charge and spin — but also exemplifies that the symmetry-protected band topology can be universal to both quantum and classical systems [1]. Since the laws of physics are governed by dimensionality, symmetry, and their interplay, by engineering dimensionality and symmetry, a variety of topological states of matter with fascinating properties awaits to be discovered, *e.g.*, in photonics [1]. If time permits, I will introduce our recent observation of Weyl monopoles in a 3D multi-valley artificial crystal and topological negative refraction at its surface [5].

*This work was supported by UT-Dallas Research Enhancement Fund.*

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# Semiconductor nanowire heterostructure arrays grown on two-dimensional atomic layer substrate for flexible light emitting device applications

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Flexible and wearable electronics requires soft, conductive substrates with excellent mechanical durability. Owing to excellent electrical, optical, and mechanical properties, two-dimensional atomic layer (e.g. graphene, hexagonal boron nitride, etc.) with few-atomic thickness has great potential for flexible epitaxial substrates as surrogate of conventional single crystalline substrates. In this talk, the nanoepitaxy of semiconductor nanowire arrays on graphene is presented. The critical factors leading to nucleation–growth of semiconductor on graphene without dangling bonds are discussed in terms of van der Waals epitaxy.[1] The thinnest substrate, that is mono-atom-thick graphene, is demonstrated for the epitaxy of vertical semiconductor nanowires.[2] The method for position-controlled nanoepitaxy on graphene is presented as well.[1] Finally, the nanowire light emitting diodes grown on graphene is demonstrated.[3] The challenges and opportunities of graphene or hexagonal boron nitride substrates toward future flexible optoelectronics are discussed.[4]

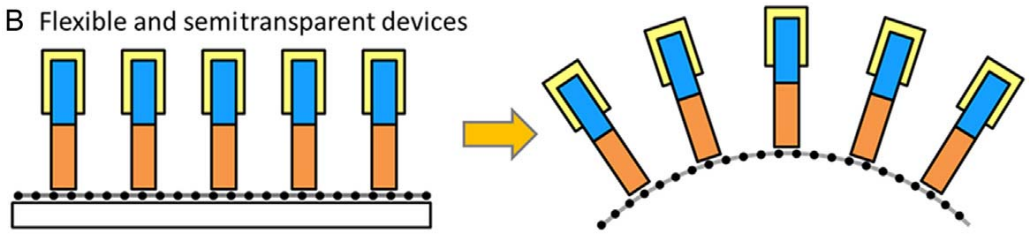


Fig. 1. Schematic illustration depicting the advantage of nanowire device arrays grown on graphene for flexible device applications

*Acknowledgement: This work was supported by the Basic Science Research Program (NRF-2016R1D1A1B03931518) of National Research Foundation and the International Cooperative R&D program (N0001819) of the Korea Institute for Advancement of Technology*

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# Control ferromagnets at room temperature without external magnetic field

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Electrically control the spin in solids is the core of spintronics. We investigated the spin Hall effect control the magnetization switching in heavy metal/ferromagnet/heavy metal multilayers and also piezo voltages control the magnetization switching of heusler ally CoFeAl.

By design the device structrue, we demonstrate a strong damping-like torque from the spin Hall effect and unmeasurable field-like torque from Rashba effect. The spin-orbit effective fields due to the spin Hall effect were investigated quantitatively and were found to be consistent with the switching effective fields after accounting for the switching current reduction due to thermal fluctuations from the current pulse[1]. The spin-orbit torque switching controllablly in above structures have to have the assistant of the external magnetic field. Without breaking the symmetry of the structure of the thin film, we realize the deterministic magnetization switching in a hybrid ferromagnetic/ferroelectric structure with Pt/Co/Ni/Co/Pt layers on PMN-PT substrate. The effective magnetic field can be reversed by changing the direction of the applied electric field on the PMN-PT substrate, which fully replaces the controllability function of the external magnetic field[2]. We also investigated the planar Hall effect devices based on the tunability of the planar Hall resistance in ferromagnetic $Co_2FeAl$ devices solely by piezo voltages. The room temperature magnetic NOT and NOR gates have been demonstrated based on the $Co_2FeAl$ planar Hall effect devices without external magnetic field[3].

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# Complementary spin logic operations

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Spintronic devices as alternatives to traditional semiconductor-based electronic devices attract considerable interest as they offer zero quiescent power, built-in memory, scalability, and reconfigurability. To realize spintronic logic gates for practical use, a complementary logic operation is essential but still missing despite a recent progress in spin-based logic devices. Here, we report the development of a complementary spin logic device using electric-field controlled spin-orbit torque (SOT) switching [1]. In heavy metal/ferromagnet/oxide structures, the critical current for SOT-induced switching of perpendicular magnetization is efficiently modulated by an electric field via voltage-controlled magnetic anisotropy (VCMA) effect in a non-volatile manner. Moreover, the polarity of the VCMA is tuned by the modification of oxidation state at the ferromagnet/oxide interface. This allows us to fabricate both “n-type” and “p-type” spin logic devices and to enable a complementary logic operation, paving the way for the development of non-volatile and reconfigurable logic devices.

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# Manipulation of domain wall motion controlled by spin-orbit torque in magnetic tunnel junctions and its synaptic behavior.

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Taking inspiration from great efficiency of the brain for parallel information processing neuromorphic computing with low-power, high density and fast operation has recently garnered considerable attention for particular tasks such as pattern recognition, which cannot be accomplished efficiently by the conventional von Neumann architecture. Several memristor devices such as resistive change memory (ReRAM) and phase change memory (PCRAM) have been suggested to act electrical synapse presenting long-term potentiation (LTP), short-term potentiation (STP), and spike timing dependent plasticity (STDP). However, these devices have not yet met the requirements for a reliable neuromorphic processing unit due to relatively large noise, high operating power and insufficient stability. Thus, spintronics devices have come under the spotlight as promising candidate for low-power, high stability and high-speed synaptic device. In particular, spin-orbit torque-based magnetization manipulation offers highly fast operation and low writing power. Therefore, we present stable synaptic behavior by spin-orbit torque-driven domain wall motion with low power operating, robust linearity and stable operation. In addition, the microscopic dynamics responsible for the various synaptic behaviors have been proposed in terms of domain wall dynamics with collective coordinate models.

# Enhanced spin-orbit torque by engineering Pt resistivity in Pt/Co/$AlO_x$ structures

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The magnetization direction in heavy-metal (HM)/ferromagnet bilayers can be electrically controlled by spin-orbit torque (SOT); however, the efficiency of the SOT which depends on the spin-orbit coupling of the HM layer or its spin-Hall angle has to be improved further for actual applications. In this study, we report a significant enhancement of the spin-Hall effect of Pt and resultant SOT in Pt/Co/$AlO_x$ structures by controlling the Pt resistivity. We observed that the effective spin-Hall angle increases about three times as the resistivity of Pt layer is increased 1.6 times by changing the Ar deposition pressure from 3 to 50 mTorr. This enhancement in effective spin-Hall angle is confirmed by the reduction in the critical current for SOT-induced magnetization switching. Furthermore, x-ray absorption spectroscopy analysis reveals a non-negligible contribution of the interfacial spin-orbit coupling to the effective spin-Hall angle. Our result, the efficient control of effective spin Hall angle by controlling the HM resistivity, paves the way to improved switching efficiency in SOT-active devices.

# An accurate analytical method of harmonic Hall voltage measurement for spin-orbit torque

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The precise analysis of the spin-orbit torque as a function of the magnetization angle can provide important information about its dominant physical origin [1, 2]. In this study, a precise method is developed to extract the spin-orbit effective fields, over a wide range of the polar magnetization angle, through an analysis of the results of harmonic Hall voltage measurements by deriving detailed analytical equations, in which both the *z*-component of the applied magnetic field and the second-order perpendicular magnetic anisotropy are taken into account [3]. The method is tested by analyzing the results of a macrospin simulation. The spin-orbit effective fields extracted from the proposed analytical method are found to be in excellent agreement with the input spin-orbit effective fields used for the macrospin simulation over the entire range of the polar magnetization angle and a wide range (0–2) of the ratio of the planar to the anomalous Hall voltage considered in this study (refer to Fig. 1). A further test of the proposed method, made by analyzing the experimental results for a stack with Pt/Co/MgO, also demonstrates the accuracy of the new analytical method.

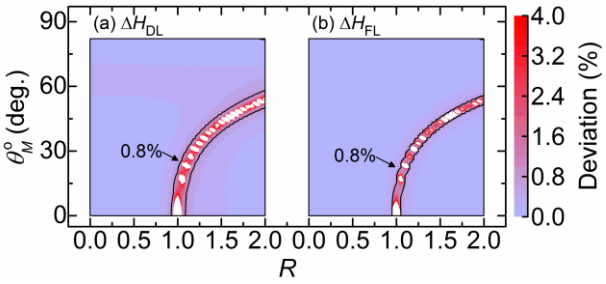


Fig. 1. Contour plots showing deviation (in %) from input values of the (a) damping-like and (b) field-like spin-orbit effective fields as a function of the polar magnetization angle ($\theta_M$°) and the ratio of the planar to the anomalous Hall voltage ($R$).

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# Capacitive Type Fingerprint Sensor for Biometrics Application

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With the growth of IoT, biometric technology such as fingerprint, voiceprint, veins, faces and iris scans is becoming very important. Among these, fingerprint sensor (FPS) is the most widely used biometric technology.[1] For the mobile application, capacitive types have been already applied to the display using Si semiconductor technology. There are two types of capacitive fingerprint sensor, mutual and self-capacitive type, depending on the driving technology as shown in figure 1 left.[2] These can be fabricated even as transparent, so it can be directly put on the display. Furthermore, flexible fingerprint sensor can be materialized on flexible substrate using printing technology as well as typical lithography technology.
We have developed transparent mutual type sensor on the glass for the application to the bezel less display, self-capacitive type fingerprint sensor based on the high mobility ITZO oxide TFT with 500 ppi resolution, and flexible sensor for the card type mobile application. For the display application, reduction of Moire is essential issue as well as the transparency. Furthermore designing of IC to obtain high S/N with reinforced cover-glass in the display are still challenging. In the case of flexible FPS fabricated using printing technology, as shown in figure 1 middle and left, planarization of each electrode increases the S/N ratio. This planarization layer also play as a hard coating layer. Hard coatings for flexible FPS secures the stability of sensor. Double layered soft-hard coating materials can enhance not only the flexibility of FPS, but also reliability for the long time use.

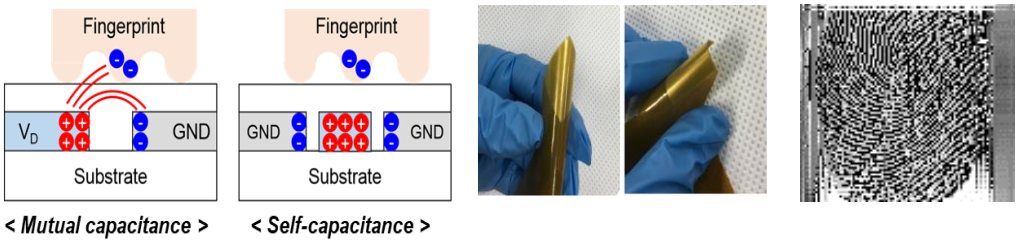


**Figure 1 Principle of mutual capacitive and self-capacitive fingerprint sensor (left), Flexible fingerprint sensor with bending stress (middle), Fingerprint image from flexible finger print sensor (right)**

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# Visco-Poroelastics: New Strategy for Ultrasensitive Electronic Skin

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Creating artificial sensor skins that shows the tactile- and chemical-sensing capability of human skin has been a big challenge in wearable sensor research. In particular, biomimetics has emerged as a burgeoning area in the field of deformable tactile sensor skins that has led innovations in material designing and device structure manipulation with the aim of imitating multimodal sensing features of human skin intelligently. Herein, inspired by the sophisticated physiological sensing mechanism of living cells, we describe a uniquely designed visco-poroelastic, iontronic pump consisting of artificial ions confined into polymeric network matrix. Novel bottom-up strategy employed here resulted into supramolecular polymer networks through non-covalent interactions between poroelastic artificial ions and viscoelastic polymer chains, which endows effective iontronic pumping under mechanical stimuli and electronic field, simultaneously. This design for visco-poroelastic, iontronic, tactile sensor skin allows for ultrasensitive mechanosensing over a wide spectrum of pressure (Pa~150kPa) beyond capabilities of human skin.

Acknowledgment
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# Effect of doping on gas sensing properties of GaN nanorods

, Reddeppa Maddaka[1], Byung-Guon Park[1] , Hoang Hai Nguyen[1], Jong-beom Lim[1], Thi Kim Phung Nguyen[1], Moon-Deock Kim[1*], Jae-Eung Oh[2], Song-Gang Kim[3]
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The effect of doping showed a great influence on optical, electrical, structural properties semiconductor. Doing tune the electronic band structure, as result it showed great influence on resistance of semiconductor [1]. GaN is one of favorable materials for toxic gas sensors due to its wide band gap, mechanical robustness, and chemical stability [2]. With increasing environmental pollution, in our daily life, human body gets exposed to various toxic gases like CO, NO, and $NH_3$. Among them the detection of nitrogen oxide (NO) is critical because $NO_2$ is a typical toxic gas that is harmful to humans as well as the environment. The high concentrations of NO in the environment cause the photochemical smog and acid rains.
The effect of Si and Mg doping on NO gas sensing properties of GaN nanorods (NRs) have been investigated. The optical, Structural, morphological properties were carried by photo luminescence spectroscopy Raman spectroscopy, scanning electron microscopy respectively. The response of gas sensor was depending on doping concentration, Si doping showed great influence on gas sensing properties. The reason for the improved sensing properties is the change of carrier concentration and creates more active sites for chemisorbed oxygen on the surface of GaN NRs. The selectivity of gas sensor was also carried out.

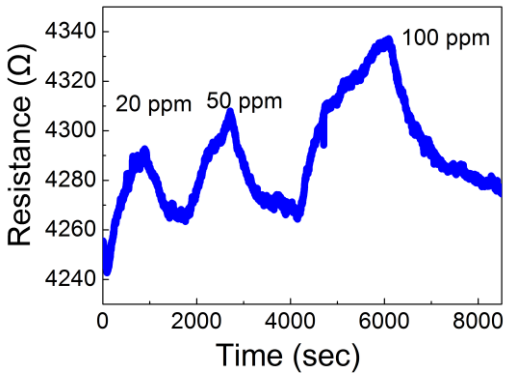


**Figure 1 Gas sensing properties of Si –doped gas sensor at three different gas concentrations (from 20 to 100 ppm**

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# Effect of hydrogen plasma treatment on downward band bending energy of InN nanorods: $NO_x$ gas sensing properties

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III-nitrides are attained tremendous interest as a prospective material for sensor applications in harsh environments due to peculiar properties like thermal stability, high carrier mobility and downward band bending at surface [1,2]. Furthermore, nanorods with downward band bending such as InN have great potential to increase sensitivity for oxidation gases such as $NO_x$ due to accumulated electrons at surface [3]. However, the sensing mechanism and optimized conditions such as accumulated carrier concentration at surface and band bending energy for InN nanorods are still unclear.

In this study, we have investigated the effect of downward band bending energy of InN nanorods on sensitivity for $NO_x$ gas by hydrogen plasma treatment. From simulation result, we have extracted downward band bending energy that was increased from 0.06 to 0.09 eV with increasing density of surface states from 1.0 $\times 10^{12}$ to 1.0 $\times 10^{13}$ $cm^{-2} \cdot eV^{-1}$ (Figure 1). Interface defect densities and downward band bending energy for InN nanorods after hydrogen plasma treatment were estimated by using current-voltage technique and X-ray photoelectron spectroscopy, respectively. The correlation between sensitivity and downward band bending in InN nanords after hydrogen plasma treatment will be discussed

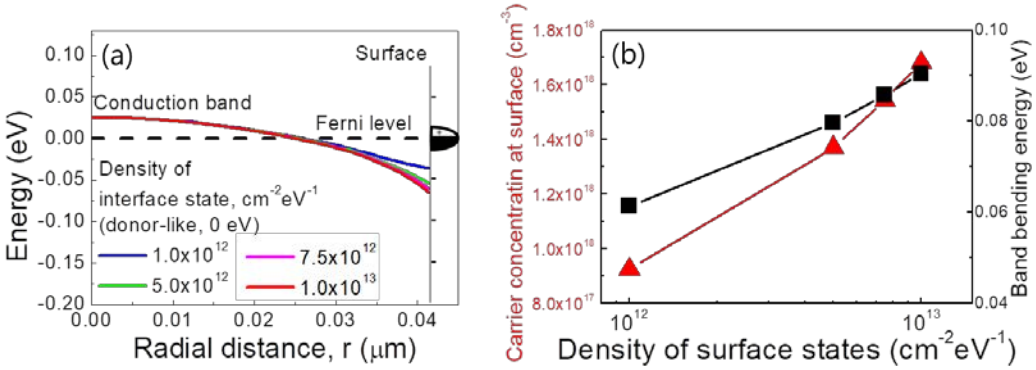


**Figure 1 (a) Downward band diagram simulation and (b) carrier concentration at surface and band bending energy for InN nanorods with different density of surface states**

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# Electronic properties of incommensurate 2D crystals

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We present a brief overview of our recent theoretical studies on electronic properties of incommensurate bilayer systems. When 2D crystals having different lattice periods are overlaid with each other, the lattice mismatch induces an interference pattern (Fig.1) and causes various unusual features to the electronic properties. Theoretically, such an incommensurate system lacks the translational symmetry and that prevents the application of the standard band theory to calculate the electronic structure. Here we develop a general theoretical scheme to describe the interlayer interaction between incommensurate crystals[1, 2], and apply the formula to various specific examples, such as twisted bilayer graphene [2,3] and graphene-hBN (hexagonal-boron-nitride) composite bilayer [4] as well as double wall carbon nanotube[5]. When the interference pattern is much longer than the atomic period, in particular, the interlayer interaction significantly modifies the energy spectrum into the nearly flat bands. [2,5] In the magnetic field, the energy spectrum exhibits a fractal structure known as the Hofstadter butterfly (Fig. 2). We also study the spontaneous lattice strain effect in the twisted bilayer graphene (TBG), where we find that the relaxed lattice forms a triangular domain structure with alternating AB and BA stacking regions. [6]

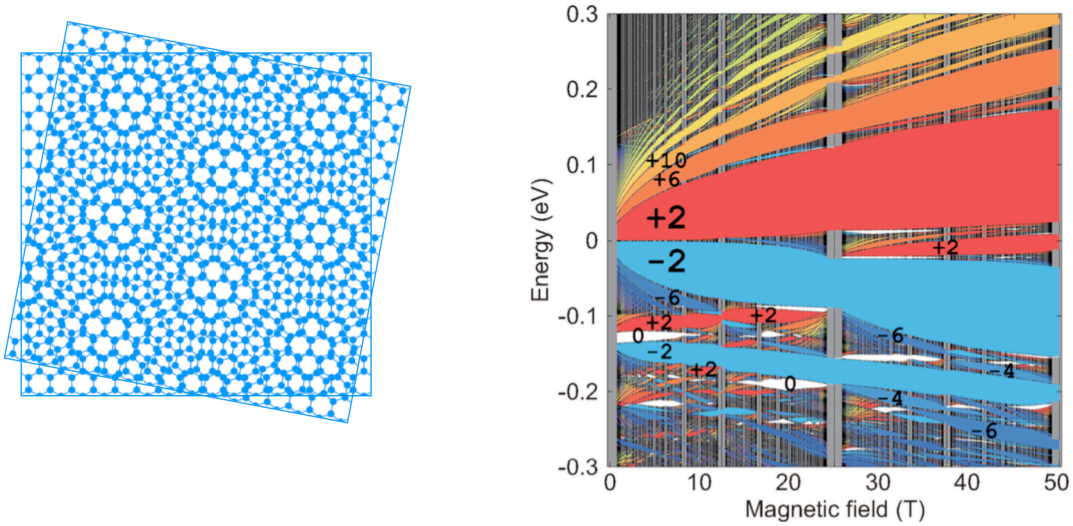


**Figure 1 (Left) Twisted bilayer graphene. (Right) Hofstadter butterfly spectrum of graphene-hBN composite bilayer [4].**

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# Integrated freestanding 2D Transition Metal Dichalcogenites

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Many expectations arise from low dimensional Transitions Metal Dichalcogenides (2D TMDs) such as MoS2, WSe2 and WS2 often presented as atomically thin semiconductors. One of the major issues lies in the integration or transfer of these 2D materials while preserving or enhancing their intrinsic luminescent or absorption properties.

To solve the above mentioned, we recently proposed a new approach called contact limited concept based on the use of nanostructured substrates [1]. Applied to Monolayer of MoS2, WSe2 and WS2 transferred on slightly tilted ZnO nanowires used here as nanostructured substrates, the limited contact concept was found to lead to stress-free monolayers as confirmed by Raman and photoluminescence analysis. This new approach will be here presented after introducing nanofabrication facilities and recent developments in large scale versatile nanostructuring of multifunctional materials and surfaces including noble metals, ZnO and Silicon [2-4]. As perspectives, the generalization of the contact limited concept to other kinds of 2D materials as well as the possibility of modifying the properties of the transferred atomically thin material by nanoscale contact engineering i.e. active substrate concept will be discussed together with the realization of a new kind of active device based on this concept.

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# Hetero-junction of 2D-van der Waals sheets and trigonal polarized oxide lattices

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Two-dimensional (2D) atomic sheets with van der Waals interaction (vdW) are potential materials for next generation applications for electronic devices. Because of atomic-scale thinness, a 2D-vdW layer is susceptible to external stimulations like charge/spin injection and polarization/magnetization control. In an integrated system with 2D-vdW layers and oxide materials, interfacial interaction is found to be very remarkable [1,2]. A trigonal oxide lattice driven by epitaxial growth of perovskite ferroelectrics on (111) crystal planes is extensively used to atomic arrangement of hetero-growth of hexagonal 2D-vdW layers [3,4]. Here, we fabricated hetero-junctions of *n*-type $MoS_2$ and *p*-type $WSe_2$ and ferroelectric $PbTiO_3$. Intriguingly, out-of-plane piezoelectric response is obtained in the $MoS_2$ layer by poling process resulted from induced dipole moments in the $MoS_2$ layer. Switching of conducting states at the atomic sheets were obtained and the resistance switching can be controlled by carrier type of the 2D-vdW layer and ferroelectric polarization states. To understand optoelectronic features, local conduction with light illumination was measured. Photo-induced carriers give variation in the transport characteristics and change of surface potential with light illumination was also attained. Hence, we can extract contribution of photo-induced carriers and we also exploited poling effect. As a result, we suggested new platforms of a variety of electronic devices by coupling 2D-vdW with ferroelectrics.

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# Ionically Switchable P-I-N diode in Perovskite Light Emitting Solar Cells

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The organohalide (OHP) perovskite PV have shown superior efficiencies already which keeps growing, while at the same time OHP perovskite LEDs are also demonstrating very high quantum efficiencies and pure colors. This raised the question of creating the dual function device, which is a light emitting solar cell: LESC that may show both good PV operation and high EQE of EL in same structural device architecture. Several approaches has been already demonstrated in order to achieve both good charge collection (for PV) and efficient charge injection (needed for LED operation). The special type of ionic ETL, such as PEI has been suggested, which has ionic conductor properties. We use a different strategy for effective "perotronic" LESC light emitting solar cell, demonstrating the possibility of the switching from PV regime to LED mode in a most conventional PV planar structure with ETL of PCBM (or C60) as shown at Fig. below. This switching is possible by using a mixed halide MAPbBr2I perovskite with band gap in visible range. By doing pre-biasing of this PV device in the low electric field with exposure to light the switching to LED mode is shown and studied. The combined effect of photoinduced segregation and light enhanced ionic migration at exposure to sun ( by cycling in PV regime ) leads to in-situ doping of the MAPbBr2I layer by its own ions: I-,Br-,MA+,H+ forming the internal p-i-n structure by in-situ ionic diffusion, induced by external bias at sun. Although the segregation effect by biasing and light soaking degrades the PV operation, it is shown to be beneficial for LED operation, which shows brighter El intensity from the segregated MAPbI3 rich regions. This approach paves the way to use the internal ionic doping, similar to ionic diffusion in light emitting electrochemical cells (LEC), in a double function perotronic devices. We will also discuss the advantages of external ionic liquid n-doping of CNT porous electrode and C60 ETL under it (seeFig.1) for improved PV operation in perovskite optoelectronics.

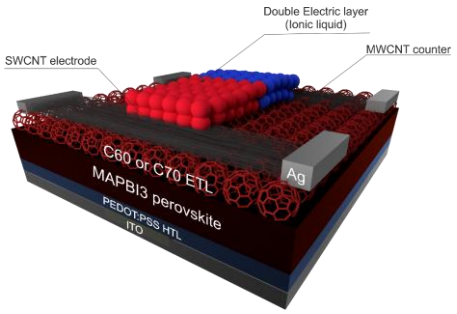


Figure 1. Device schematics of inverted planar $MAPbBr_2I$ cell with ionic gate between SWCNT cathode and MWCNT electrode

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# Extremely Small Iron-Sulfide Nanocrystals for High-Performance Na–Ion Batteries

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Na–ion batteries (NIBs) have been recognized as one of the potential alternatives to LIBs because of earth-abundant Na sources and their similar reaction mechanism to LIBs. However, research on NIBs is still at an early stage, mainly due to relatively low energy density and insufficient cyclability. Designing suitable electrode materials that satisfy high energy density and long cycling life is one of the most important issues in current NIB technology.

Na/$FeS_x$ batteries have remarkable potential applicability due to their high theoretical capacity and cost-effectiveness. However, realization of high power-capability and long-term cyclability remains a major challenge. Herein, ultrafine $Fe_7S_8$@C nanocrystals (NCs) as a promising anode material for a Na–ion battery that addresses the above two issues simultaneously is reported. An $Fe_7S_8$ core with quantum size (≈10 nm) overcomes the kinetic and thermodynamic constraints of the Na-S conversion reaction. In addition, the high degree of interconnection through carbon shells improves the electronic transport along the structure. As a result, the $Fe_7S_8$@C NCs electrode achieves excellent power capability of 550 mA h $g^{-1}$ (≈79% retention of its theoretical capacity) at a current rate of 2700 mA $g^{-1}$. Furthermore, a conformal carbon shell acts as a buffer layer to prevent severe volume change, which provides outstanding cyclability of ≈447 mAh $g^{-1}$ after 1000 cycles (≈71% retention of the initial charge capacity).

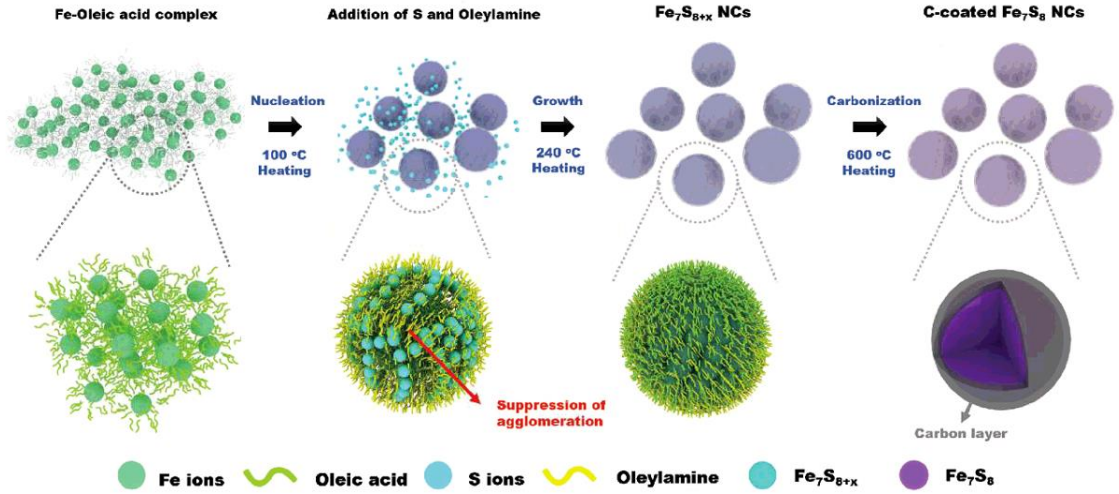


**Figure 1 Schematic of the fabrication of ultrafine $Fe_7S_8$@C NCs via one-pot colloidal synthesis.**

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# Interferometric Scattering Microscopy to Capture the Orientation of Nanometric Objects and to Visualize Subcellular Structures.

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It is of great interest to visualize nano-scale (biological) objects in both nano- and bio-science. Several ingenious methods such as fluorescence-based super-resolution microscopic techniques have been developed to meet the need. These techniques, however, bear evident limitations in measurement time, time resolution, and sample preparation as they mainly rely on fluorescence from fluorescent proteins or artificially introduced fluorescent probes. In order to circumvent such problems, a new scattering-based method named iSCAT (interferometric scattering microscopy) has been recently introduced. Since this technique relies on scattering signal from a target particle and detects interference of the signal with a constant reference, it is, in principle, not subject to the aforementioned limitations: theoretically unlimited signal-to-noise ratio to improve time resolution, practically unlimited measurement time for stably localized scatterers, and lack of photophysical and photochemical artefacts such as photo-blinking and photo-bleaching.
In this presentation, first, we would like to show our recent application of this technique to image biological cells. Interestingly, the iSCAT technique enables us to visualize subcellular structures with remarkable spatial, temporal resolutions and contrast without any labeling [1].
Second, in order to capture the orientation of nanorods as well as their positions, we utilized scattering of polarized light from anisotropic scatterers, the strength of which is a function of relative orientation of the scatterers to the direction of polarization. From this new scheme named psiSCAT (polarization selective iSCAT), we successfully demonstrate that one can capture the orientational information of anisotropic nanorods without sacrificing the bright-field image of the entire view-field, which is the case of dark-field imaging [2].
This new scattering-based microscopy technique would be also an indispensable tool in visualizing the nanoscopic material world and would shed new light on phenomena occurring in the nano-world.

*This work was supported by IBS-R023-D1.*

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# Observation of 3D magnetic structure and its control

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In a nano-patterned ferromagnetic thin film, a flux-closure domain structure such as a Landau domain is formed to reduce demagnetization energy [1]. At the center region, a magnetic singularity, a vortex core structure forms. Since its unique dynamical and static properties, it has been attracted much attention owing to their spintronic applications. Such a magnetic configuration has been considered as a simple two-dimensional (2D) singularity. However, it is intrinsically 3D structure and its 3D nature becomes dominant as increasing the thickness of the sample [2, 3]. For example, in a rectangular disk, asymmetric Bloch wall (ABW) with Néel cap is positioned between two shifted vortex cores as shown in Fig. 1. In such 3D structure, there are additional degenerate states according to clockwise (CW) or counter-clockwise (CCW) rotating sense of an ABW [2]. By utilizing magnetic transmission soft X-ray microscopy (MTXM) and micromagnetic simulations, we successfully measured the 3D flux-closure magnetic domain structure. Furthermore, even in a symmetric circular or square disk sample, it is found that ABW can be formed under an external magnetic field as well as symmetry breaking occurs in this transformation. In this presentation, we will discuss about the detailed mechanism of this ABW formation and the controllability of the rotation sense of ABW.

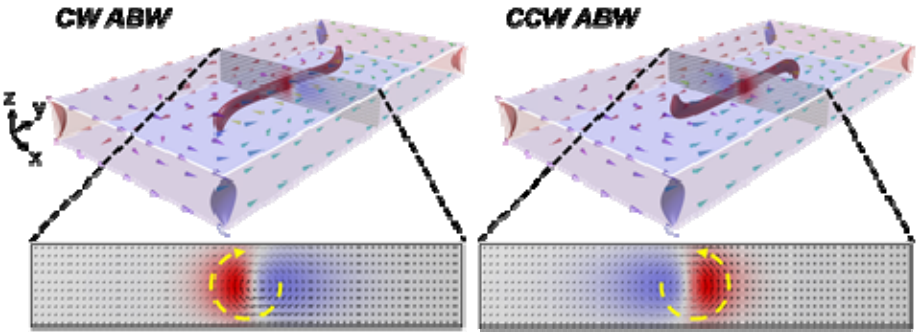


**Figure 1 The simulated images for two degenerate states of the asymmetry Bloch wall (ABW) (top) and their magnetization configuration on the cross section area of the center region (bottom). The red surface indicates the volume where Mz/Ms > 0.8.**

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# Effect of Isovalent Doping on the Magnetic Properties of ZnMnO Diluted Magnetic Semiconductors

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ZnO-based diluted magnetic semiconductors (DMS) is a promising candidate for realizing a ferromagnetic semiconductor with a Curie temperature $T_C$ exceeding room temperature [1]. However, the magnetic properties of ZnO doped by transition metal, reported so far by different research groups are quite contradictory. Some groups observed high-temperature ferromagnetism in low-temperature-grown bulks and thin films of ZnO doped by Mn [2] whereas others have observed paramagnetic or even spin-glass behaviors [3]. ZnO suffer from a low solubility of the magnetic ions and also from a low concentration of free carriers holes and isovalent alloying can improve this problem. The alloying of ZnO with MgO and ZnS have a strong influence on the energy gap, structural, optical and electrical properties of the synthesized material.

In this work we have studied the effect on the magnetic properties of ZnMnO DMS the isovalent doping with Mg and S, respectively. The thin films of ZnMnO alloys with different concentrations of the magnesium and sulfur dopants were grown by using ultrasonic spray pyrolysis. Since, the isovalent doping does not introduce the free charge carriers, the films were additionally doped by nitrogen as an acceptor dopant.

The doping of the ZnMnO (5% of Mn) with the concentration of Mg up to 10% shows the increasing of the Curie temperature from 75 K to 104K. However, the further increasing of the Mg concentration leads to the formation of the second phase magnetic precipitates.

Whereas, the doping of ZnMnO (5% of Mn) with the sulfur increases the Curie temperature higher than room temperature and the saturated magnetization increases with increasing of the sulfur concentration. This might be explained by increasing of the concentration of free carriers (holes), which are mediated the magnetic exchange interaction between the magnetic ions. The increase of free carrier concentration is connected with decreasing of ionization energy of nitrogen acceptors due to the bowing effect in sulfur doped ZnO.

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# Unidirectional Magnetoresistance in CoGd-ferrimagnet/Pt-heavy Metal Bilayers Across the Magnetization Compensation Point

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Ferrimagnets have received much attention because those materials can bring a bridge between ferromagnet-and antiferromagnet-based spintronics. For example, the ultrafast antiferromagnetic domain wall dynamics was achieved at the angular momentum compensation point of the CoFeGd ferrimagnet [1]. However, it has been less studied for the spin dependent transport properties of ferrimagnets. The recently discovered unidirectional magnetoresistance (UMR) can serve as an excellent probe to investigate them [2-4].

In this presentation, we discuss the UMR in CoGd/Pt bilayers with various composition of CoGd alloys. Interestingly, the sign reversal of the UMR is observed across the magnetization compensation point, which is evidenced by comparing $Co_{90}Gd_{10}$ 10/Pt 5 (nm) and $Co_{70}Gd_{30}$ 10/Pt 5 (nm) bilayers as shown in Fig. 1. This result indicates that the spin dependent electrical conduction is mainly determined by sub-Co atoms in CoGd ferrimagnets.

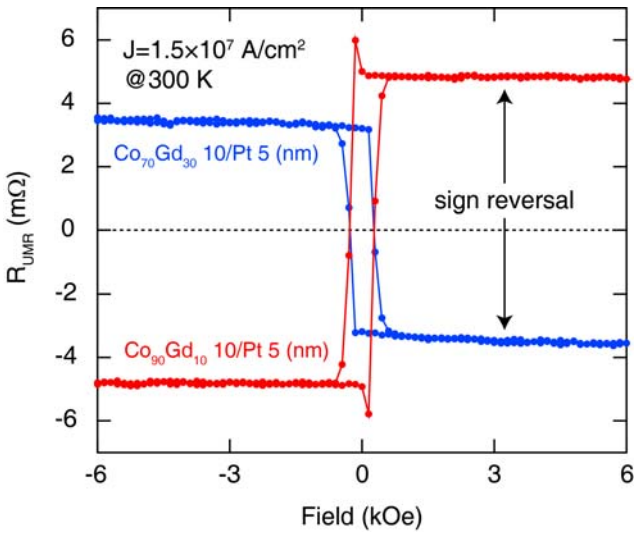


Fig. 1. The sign reversal of the UMR between $Co_{90}Gd_{10}$/Pt (red) and $Co_{70}Gd_{30}$/Pt (blue) bilayers.

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# Asymmetric Hall effect induced by canted state in epitaxial Co/Pt

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Spin orbit torques (SOT) driven by spin Hall and interfacial effects have been broadly investigated to understand the underlying mechanism and to achieve desirable spintronic devices [1]. Recent reports suggest that spin transport and spin dephasing mechanism depend on the crystal structure of the heavy metal [2], therefore one can expect that SOT also shows a dependence on the crystal structure of the heavy metal (HM) layer in HM/ferromagnetic metal structures. In this report, we investigate the harmonic Hall voltage in epitaxial and polycrystal Pt/Co bilayers with perpendicular magnetic anisotropy. We find that an antisymmetric contribution to the Hall effect is present additional to the conventional anomalous and planar Hall effects when Pt is epitaxial. The understanding of this additional signal is crucial in the SOT characterization in epitaxially grown metallic systems.

Perpendicularly magnetized Co on poly crystal Pt (Co/Pt(P)) and epitaxial Pt (Co/Pt(S)) were deposited on MgO (100) and MgO (111) substrates, respectively. The 1st harmonic Hall voltage $V_{harm}$ with an in-plane field sweep is typically driven by the anomalous Hall effect as well as the planar Hall effect (PHE). For Co/Pt(P), $V_{harm}$ behaves symmetric to the sign of the in-plane magnetic field (Fig. (a)) as typically obtained in literature [3]. However, in the case of Co/Pt(S), we could observe a significant antisymmetric component in addition to conventional symmetric signal (Fig. (b)). When we separate $V_{harm}$ into symmetric $\Delta V_S$ and asymmetric component $\Delta V_A$, we find that $\Delta V_S$ shows $\sin 2\varphi$ dependence as expected from the PHE. On the other hand, $\Delta V_A$ is proportional to $\cos\varphi$, which results from the crystal symmetry (Fig. (c), (d)) [4].

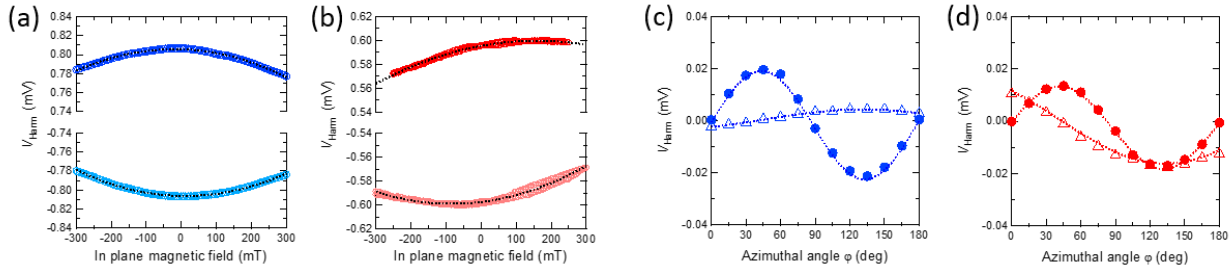


Fig. (a) $V_{harm}$ at $\varphi = 0°$for Co/Pt (P). (b) $V_{harm}$ at $\varphi = 0°$ for Co/Pt (S). (c) and (d) corresponds to $\varphi$ angle dependence of $\Delta V_S$(dot) and $\Delta V_A$(triangle) in $V_{harm}$ of Co/Pt (P) and Co/Pt (S).

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# Transverse spin Nernst magnetoresistance in heavy metal/ferromagnet bilayer

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Electric generation of spin current via spin Hall effect (SHE) is of great interest as it allows an efficient manipulation of magnetization in spintronic devices. Theoretically, pure spin current can be also created by a temperature gradient, which is known as spin Nernst effect (SNE). Here, we report an experimental evidence of the SNE by investigating spin Nernst effect-induced transverse magnetoresistance in ferromagnet (FM)/non-magnetic heavy metal (HM) bilayers [1]. Similar to spin Hall magnetoresistance that originates from SHE-induced spin current and inverse SHE of the reflected spin current, the spin Nernst magnetoresistance (SNMR) originates from SNE-induced spin current in HM and subsequent reflection of the spin current at the FM/HM interface (Fig. 1a). Thus, the magnitude of the SNMR is determined by heat-to-spin conversion efficiency or spin Nernst angle ($\theta_{SN}$) and spin Hall angle ($\theta_{SH}$).

Using focused laser heating, we induce temperature gradients on the HM/CoFeB samples as illustrate in Fig. 1b, where HM is Pt or W. When the laser is illuminated at the center (edge) of the sample, a vertical (lateral) temperature gradient $\Delta T_z$ ($\Delta T_x$) is generated. Upon illumination at the center, generating only $\Delta T_z$ while $\Delta T_x$ cancels out, the thermoelectric signals shows a clear $cos\theta$ dependence. This signal originates from the longitudinal spin Seebeck effect and/or anomalous Nernst effect (Top penal of Figs. 1c-e). On the other hand, as the laser moves toward the edge, generating non-zero $\Delta T_x$, additional angle-dependent thermoelectric signal ($\sim sin2\theta$) appears and it depends on HM and its spin Hall angle (Middle and bottom of Figs. 1c-e). Furthermore, using the HM thickness dependence of the SNMR in W and Pt structures, we estimate their $\theta_{SN}$, which have comparable magnitudes to the $\theta_{SH}$, but opposite signs. Our result of the SNE-induced spin current opens up an alternative way to generate the spin current and control the magnetization direction in spintronic devices.

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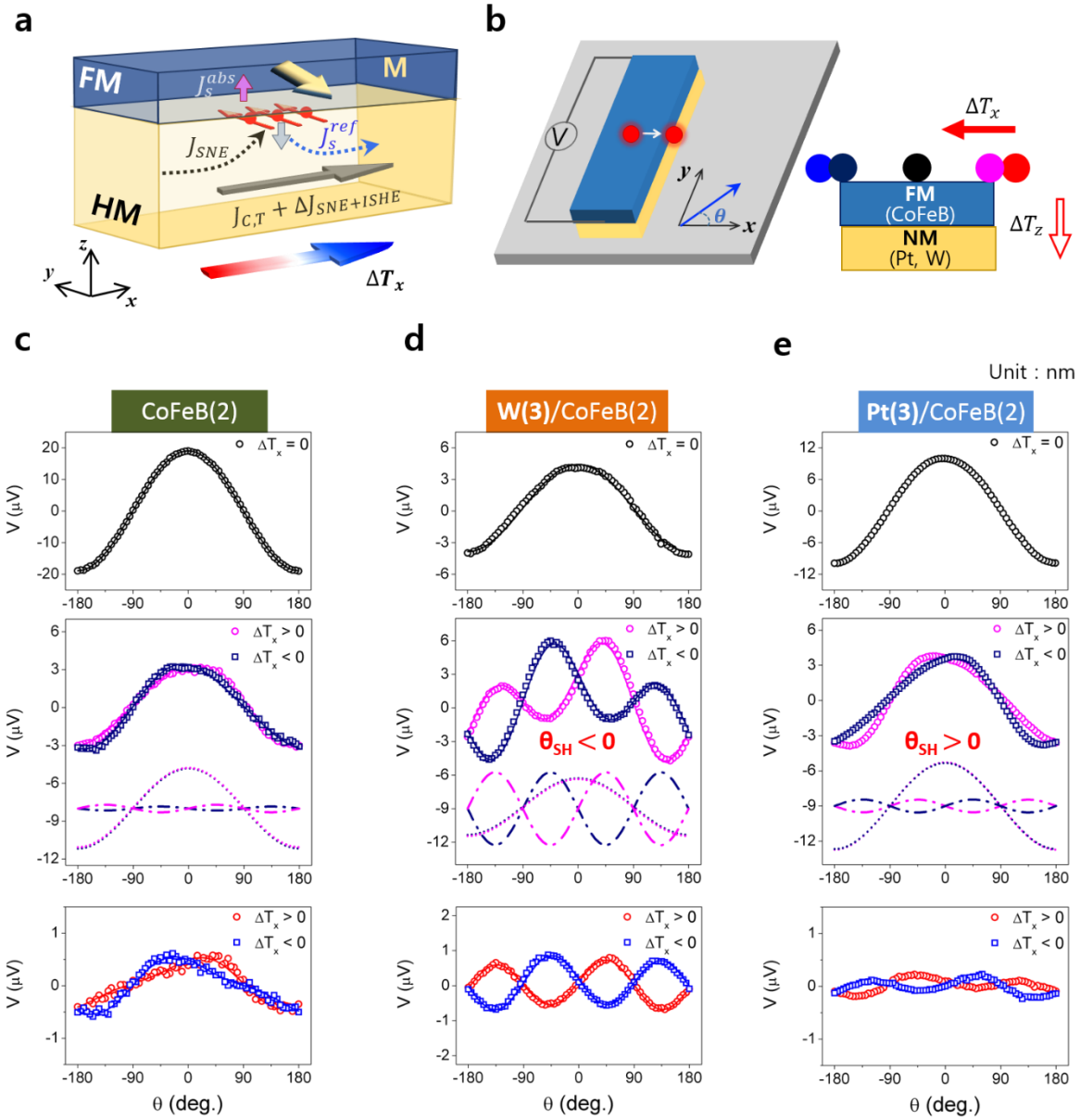


Figure 1. **a**, Schematics for spin Nernst magnetoresistance combined spin Nernst effect and inverse spin Hall effect. **b**, Schematics of measurement under different laser positions on sample structure. Spin thermoelectric signals in **c**, CoFeB, **d**, W/CoFeB, and **e**, Pt/CoFeB, for different laser locations, at the center (top panel), edge (middle panel), and just outside of the structure (bottom panel).

# Optical Properties of All-Inorganic Perovskite Nanocrystals

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All-inorganic cesium lead halide perovskite nanocrystals (CsPbX3 NCs, X = Cl, Br, I) have attracted much attention recently due to their high photoluminescence quantum yields (50-90%) and narrow emission bands with wide tunability. They combine the advantages of perovskites and quantum dots creating an exceptional material for low-cost optoelectronic and photovoltaic devices. Conducting low-voltage electron energy loss spectroscopy (EELS) on individual NCs, we provide novel insights regarding three important aspects of their microscopic behavior: (i) we explicitly demonstrate the relation between NC size and shape with their bandgap, and that the effective coupling between proximal NCs causes band structure modifications [1]; (ii) the synthesis of CsPbX3 NCs inevitably yields simultaneous formation of other nanostructures, insulating Cs4PbBr6 nano-hexagons and hybrid nano-spheres [2]; and (iii) drop-casted NCs merge spontaneously at room conditions by seamless stitching of aligned NCs, it can be accelerated by humidity and mild-temperature treatments, while arrested with electron beam irradiation [3]. Further, by using high-resolution induced absorption and emission spectroscopies, we obtain detailed information on carrier dynamics in perovskite NCs [4], their water-resistant encapsulation [5], and on energy exchange within their ensembles [6]. Finally, we will report on the on-going quest of carrier multiplication in these materials.

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# Van der Waals interfaces for optoelectronics in 2D semiconductors

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Recently emerged transition metal dichalcogenides (TMdCs) as atomically thin-layered semiconductors are one of strong contenders for leading next generation semiconductor technology, particularly in soft electronics, together with its counterparts of metallic graphene and insulating hexagonal-boron nitride, which are the basic components for active channel, electrode, and gate insulator for FETs. As an important building block for practical device applications of TMdCs, van der Waals (vdW) *p-n* junctions have been intensively highlighted. The homojunction *p-n* diode is an ideal platform compared to the heterojunction in terms of diode characteristics, *e.g.* more efficient current rectification and photovoltaic response, since the interface of homojunctions with continuous band alignments possess smaller carrier trap sites than that of the heterojunctions. Nevertheless, only vertical vdW heterojunction devices have been realized, since explicitly converting the carrier type in the same material has not been realized in two-dimensional (2D) TMdCs. Here, we demonstrate $MoSe_2$ *p-n* diode with vdW homojunction by stacking the undoped (*n*-type) and the Nb-doped (*p*-type) semiconducting $MoSe_2$ synthesized by chemical vapor transport for Nb substitutional doping. The *p-n* diode reveals an ideality factor (~1.0) and a high external quantum efficiency (~52%) which increases in response to light intensity due to negligible recombination rate at the clean homojunction interface [1]. While interlayer Coulomb interaction mediated by vdW coupling has been extensively studied for carrier recombination processes in diode transport, its correlation with interlayer tunneling transport has not been elucidated. Here, we report a contrast between tunneling and drift photocurrents tailored by the interlayer coupling strength in $MoSe_2/MoS_2$ heterobilayers (HBs). Interfacial coupling modulated by thermal annealing was identified by interlayer phonon coupling in Raman spectra and the emerging interlayer exciton peak in photoluminescence spectra. In strongly coupled HBs, positive photocurrent was observed owing to inelastic band-to-band tunneling assisted by interlayer excitons that prevailed over exciton recombination. By contrast, weakly coupled HBs exhibited a negative photovoltaic diode behavior, manifested as a drift current without interlayer excitonic emission. Our studies shed light on tailoring carrier transport for numerous vdW optoelectronic devices [2].

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# Raman spectroscopy of van der Waals heterostructures

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After the successful isolation of graphene [1], research on two dimensional (2D) layered crystals has grown considerably because of their unusual physical properties. Such unusual properties have triggered excitement and anticipation to produce emerging optical and electronic devices made of 2D crystals [2]. Beyond 2D layered crystals themselves, one can envision new properties and phenomena arising from the stacking of 2D crystals, heterostructures made layer by layer [3]. Vertical stacks of 2D crystals, also called van der Waals heterostructures, have been made in a precisely chosen sequence. However, studies of the impact of the interaction of between 2D crystals on their physical properties are still needed, and are of paramount importance for the design of any potential applications. In this talk, I will present recent results for superlattice phonons of various 2D heterostructures studied by Raman spectroscopy.

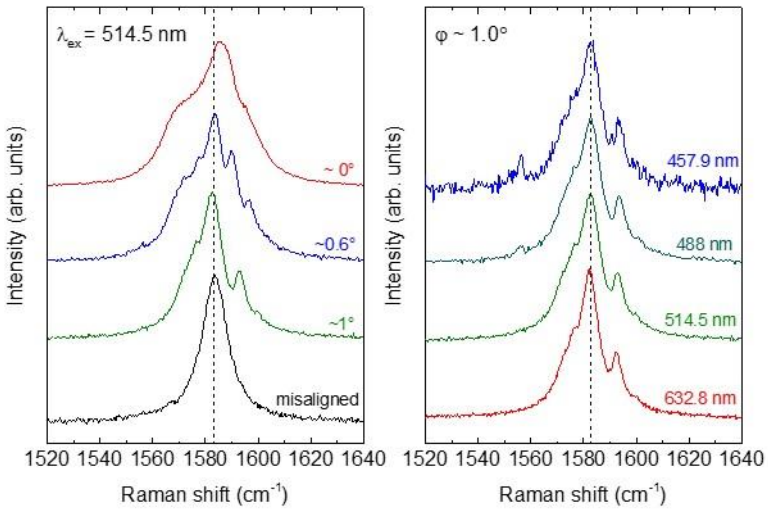


**Figure 1** The Raman G peaks of graphene/hBN heterostructures with different stacking angles (left). The Raman G peaks of graphene/hBN heterostructures with different laser excitation wavelengths (right).

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# Anomalous optoelectronic properties of hybrid halide perovskites as probed by wavelength-dependent nonlinear optical spectroscopy

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Although emerged from the field of photovoltaics, organic-inorganic hybrid halide perovskites have also shown great promise for other optoelectronic applications such as light-emitting diodes, radiation detectors, lasing, thermoelectricity, nonlinear optics, etc. While device architecture is a critical factor in terms of technology evolution, the basic understanding of light-matter interaction in the perovskites is unarguably important for furthering their optoelectronic performance. In this talk, we will talk about two anomalous properties recently observed from this emerging material class as probed by wavelength-dependent nonlinear optical spectroscopy. Specifically, we will present intriguing results on 1) selective enhancement of third-order optical nonlinearity in two-dimensional layered lead iodide perovskites [1] and 2) the bandgap anomaly associated with above-bandgap emission in three-dimensional all-inorganic lead bromide perovskites [2]. The observed anomaly may be universal to the halide perovskites, which can be utilized for realizing novel hybrid nonlinear optical applications with high efficiency and high selectivity.

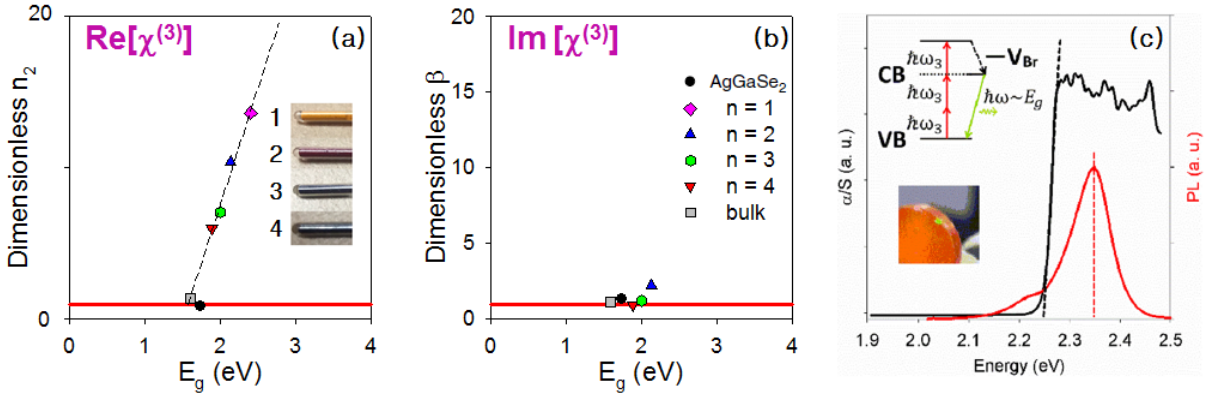


**Fig. 1: Impact of quantum confinement on the (a) real part and (b) imaginary part of third-order optical nonlinearity in the 2D perovskite series. (c) Bandgap mismatch observed from $CsPbBr_3$ single crystal.**

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# Tin rich Perovskite solar cell with optimal band gap

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The optical bandgap of the conventional lead-based perovskite is around 1.5 eV. Although its efficiency has reached 22.7%, it is not the most suitable band gap for photovoltaic semiconductors according to shockley-Queisserd theory. The absorption loss of near-infrared photon, makes the SQ limit efficiency of this semiconductors only 30%. while a large number of lead in this perovskite material also raises the environmental concerns. In response to these problems, we propose to construct a new type of perovskite by tin-lead co-doping method. By adjusting the ratio of tin and lead, the optimal optical bandgap (1.2-1.3eV) can be obtained and the SQ limit efficiency can reach the maximized value of 33%.

In this talk, I will talk about our recent progress of Tin rich perovskite solar cell, the efficiency has reached over 17.5%, and the defect passivation mechanism has been investigated with advanced optical spectroscopy.

# Tip-Enhanced Raman Spectroscopy (TERS)

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Tip-enhanced Raman spectroscopy (TERS) has been an advanced scanning probe microscope (SPM) technique for obtaining chemical information from surface in nanometer scale since it was invented in 2000 [1-2]. In TERS experiment, the tip has to act not only as a local Raman enhancer but also as a topographic imaging probe. Therefore, the modification of probes must be the key problem in order to provide high resolution optical and topographic image, simultaneously.

However, one of the major stumbling blocks holding back its wide application is a difficulty in preparing reliable TERS-tips. Previous TERS experiment relied on several types of TERS-tips such as metallic thin film-coated atomic force microscope (AFM) tips, chemically etched thin metallic wire, and metallic nanoparticles attached at the end of SPM probes [3]. Those tips often exhibit unpredictable performance as a TERS probe, and it is still extremely difficult to exactly tune the properties of the tips for a specific TERS application. In case of metal-coated tip, it is hard to obtain reproducible tip-enhancement because metal-coating relies on random nucleation and island formation process on the surface of Si AFM probe. In chemically etched metal wire, it suffers the well-known rolling-up problem during dithering operation, typically by tuning fork, for force-distance feedback. In case of nanoparticle probes, nanoparticle suffers from mechanical deformation, and the linker molecules used to fix the nanoparticles at the end of the AFM probe can easily cause false signals during the TERS experiments. Furthermore, one has to go through time-consuming tedious picking-up process at the end of the AFM probe to fabricate individual probes.

In this talk, a brief review on TERS in terms of principle, applications and current status will be presented [4].

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# Large-scale assembly of 2D atomic layers and their applications in opto-electronics and energy storages

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Recent advances in atomically thin two-dimensional transition metal dichalcogenides (2D TMDs) have led to a variety of promising technologies for nanoelectronics, photonics, sensing, energy storage, and opto-electronics, to name a few. The TMDs are finding niche applications for next-generation electronics and optoelectronics devices rely on ultimate atomic thicknesses [1]. Albeit several challenges in developing scalable and defect-free TMDs on desired substrates, new growth techniques compatible with traditional and unconventional substrates have been developed to meet the ever-increasing demand of high quality and controllability for practical applications. This talk will present two important subjects; (1) Synthesis of scalable 2D TMDs and their alloys for engineering energy bandgap - especially our recent development of uniform and scalable single-layer TMDs by two-step CVD method followed by a laser thinning process will be presented. Excitons' behavior based on composition and layer dependent photoluminescence analysis will be highlighted [2-4]. (2) 2D $MoS_2$ protective layer for Li-metal anodes in Li-S batteries - we observe stable Li electrodeposition and the suppression of dendrite nucleation sites from the 2D $MoS_2$ coated Li-metal. The deposition and dissolution process of a symmetric $MoS_2$ coated Li-metal cell operates at a current density of 10 mA $cm^{-2}$ with low voltage hysteresis, and a three-fold improvement in cycle-life than using bare Li-metal. In a Li-S full cell configuration, we obtain a specific energy density of ~600 Wh $kg^{-1}$ and a Coulombic efficiency of ~98% for over 1200 cycles at 0.5 C. Our approach can lead to the realization of high energy density and safe Li-metal based batteries [5]. The large-scale synthesis of 2D TMDs and their tunable optical properties and atomic layer passivation of 2D $MoS_2$ on Li-metal could empower a great deal of flexibility in designing atomically thin optoelectronic devices and future Li-metal based rechargeable batteries.

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# Photo-doping of graphene enhanced by stable perovskite and hole transfer layer

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Recently, researchers in many fields have focused their study on graphene as a potential candidate material for the channel of the field effect transistors (FET) due to its extraordinary carrier mobility [1]. Furthermore, graphene is a popular plasmonic material due to its unique electrodynamic response [2].

Particularly, it has been suggested to use graphene-based FET (GFET) devices as a photo-transistors for photo-sensing applications [3]. However, despite of the extraordinary mobility of carriers in graphene, the responsivity of the devices – the most important characteristic of photo-detectors – is lower than that of the III-V compound semiconductor-based photo-detectors, stemming from the fundamentally limited light absorption efficiency in graphene of just 2.3%. Some researchers suggest to improve the light absorption efficiency in GFETs by introducing quantum dots, perovskite, and other sensitizers, demonstrating significantly improved responsivity due to the photo-doping effect in graphene [4].

In this study, we introduce additional layers of $MoO_3$, PEDOT:PSS, and $MAPbI_3$ into the GFET structure in order to improve hydrophilicity, band energy alignment, [5] and light absorption efficiency respectively. Our devices demonstrate improved normalized responsivity as compared to previous works. In addition, we consider an increment of the photocurrent over the dark current value to quantify the photo-doping efficiency in saturated photocurrent regime, which shows a 20% increase of photo-doping efficiency within hole-doped regime comparing to previously reported results. Our results are important for further development of photo-doped graphene-based devices operating in saturated photocurrent regime.

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# Self-energy and quasiparticle spectral function in black phosphorene

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We theoretically calculate, for black phosphorene, the electron self-energy and quasiparticle spectral function by taking into the account electron-electron interactions in the leading order dynamically screened Coulomb interaction. The anisotropic semiconducting black phosphorene has a unique characteristic properties which prompted envisioned applications ranging from field effect transistors to thermoelectric devices. The low energy dispersion is quadratic with very different effective masses for the charge carriers along armchair and zigzag directions. Apart from the anisotropy, the electron-electron interaction is one of the fundamental interactions that affects the electrical, thermal, thermoelectric, and superconducting properties. These properties are strongly associated with the behavior of the quasiparticles in the system. The qualitative as well as quantitative study of these quasiparticles is necessary to understand of the properties. We present the electron self-energy, quasiparticle spectral function, and band velocity renormalization in black phosphorene in the presence of electron-electron interaction using the GW approximation. These results provide the basis for understanding quasiparticles in the black phosphorene. The renormalization due to the Coulomb interaction on the single-particle properties are very substantial and different than the usual 2D case.

# A new phosphorus allotrope with tunable direct band gap and high mobility

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Since black phosphorus was successfully exfoliated to a few layers in 2014, it has attracted much attention as an emerging material in nanoelectronics and nanophotonics due to its high carrier mobility and moderate band gap. Black phosphorus has shown topological phase transitions controlled by hydrostatic pressure and alkali metal doping, enriching non-trivial topological materials. Besides black phosphorus, phosphorus exists in various allotropes such as red, white, and violet phosphorus. Recently, blue phosphorus, one of the theoretically predicted P allotropes, has been successfully synthesized on the gold substrate. The realization of blue phosphorus motivates our work to search for new P phases that might provide better and more interesting characteristics than black phosphorus.

Here we report the prediction of a new P allotrope, called green phosphorus, using a combined approach of global optimization with density functional theory calculations [1]. Similar to black phosphorus, green phosphorus has a layered structure consisting of zigzag and armchair ridges. Since the interlayer interaction is comparable to that of black phosphorus, green phosphorus should be exfoliated to a monolayer phosphorus, termed green phosphorene. When the film thickness decreases from bulk to monolayer, the band gap increases from 0.7 to 2.4 eV, without altering the direct band gap nature. We calculate the optical and transport properties and find that green phosphorene has high *n*-type carrier mobility and exhibits strong anisotropy along zigzag and armchair directions, which is suitable for novel device applications like black phosphorene. We discuss the effects of temperature and substrate on the stability of green phosphorene and provide a possible route to synthesizing green phosphorene on corrugated metal surfaces.

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# Selective growth of monolayer-bilayer graphene patterns on oxygen and Ar plasma pre-treated Cu surface.

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Next generation graphene required controllability of the number of layers in particular areas and fast synthesis for advanced and miniaturized devices. Nanoscale kink structure on Cu surface facilitates faster growth rate due to high dense graphene nucleation sites that influenced by high surface free energy morphology [1]. Rapid coverage of Cu surface controls the diffusion of carbon adatoms through the Cu-graphene interface for the formation of bilayer patches. Further, any existence of oxygen on the catalytic surface can reduce the graphene nucleation density, but higher adsorption tendency of carbon adatoms because kink structure facilitates the formation of a bilayer structure, which is due to the availability of carbon adatoms in Cu-graphene interface by the entrapping and owing to enough space for diffusion. Both argon and oxygen plasma treatments facilities formation of surface kink structure while oxygen plasma introduced oxygen-rich kink structure. The photolithography technique was used for the selective treatment of different plasmas before faster graphene growth (less than 1 min) with the shorter pre-annealing process at 1000 ºC, as shown in Fig. (a).

The synthesized graphene film shows 96.21% transmittance at 550 nm wavelength. Synthesized graphene pattern confirms its ability to synthesize uniform graphene pattern in the large area, as shown in Fig. (b). Further, the present technique can be extended to form graphene-non-graphene (discrete pattern) and multilayer (more than two layers)-bi-layer graphene structure by controlling plasma treatment and CVD growth process.

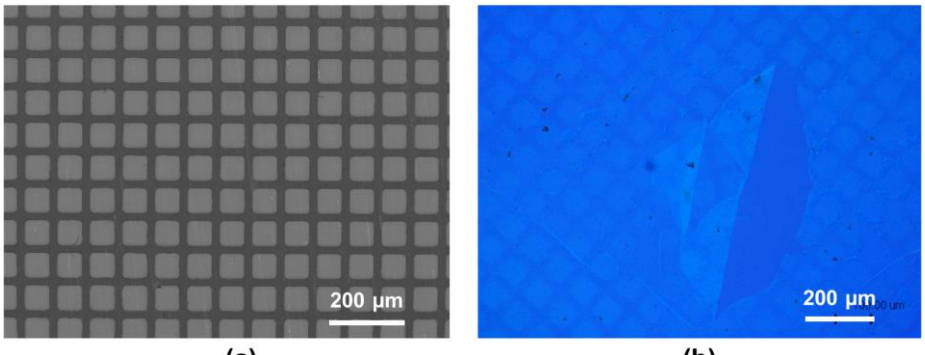


**Figure (a) FE-SEM image of different plasma treated Cu surface (Ar and $O_2$ plasma treated surfaces are shown in dark and light colors, respectively). (b) Synthesized monolayer-bi-layer graphene pattern on $SiO_2$/Si substrate.**

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# Microwatt silicon thin-films thermoelectric harvesters

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It is expected that the blooming of the so-called Internet-of-Things (IoT) will depend on the availability of inexpensive, reliable and compact energy harvesters. Thermoelectricity features key advantages of reliability and is complementary to other sources but it's efficiency is intrinsically limited to a few percent around room temperature and usually relies on harmful materials. Two decades of research on low-dimensionality materials have shown the potential of quantum dots, nanowires, thin-films [1] or nano-composite materials towards reduced thermal conductivities and increased thermoelectric efficiency. It has been advocated that silicon thin-films, patterned through a so-called phonon engineering approach [2] could reach competitive thermoelectric power densities [3]. In this talk, we will discuss the merits of this approach in terms of heat gradient management in the converter. We will show our latest results on the design, simulation, fabrication and characterization [4] of micro-scale, phonon engineered silicon thin-films thermoelectric converters [5].

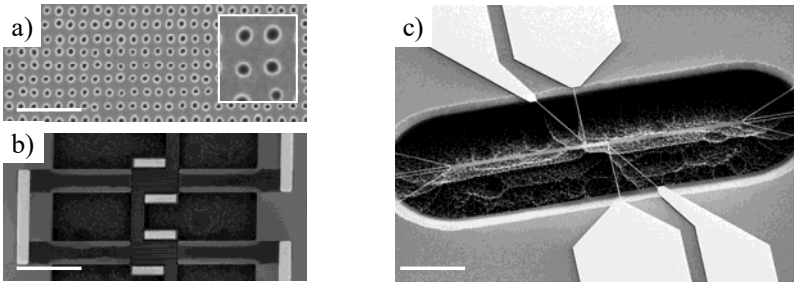


Fig. 1. a) Detail of a phonon engineering pattern (scale 250 nm). b) Two thin-film thermopiles (scale 10 µm). c) Integrated thermoelectric characterization platform. (scale 60 µm).

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# Silicon thermoelectric devices

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Thermoelectric device interconverts thermal gradient and electricity for power generation or cooling. Traditionally, $Bi_2Te_3$ semiconductor has been widely used as thermoelectric material. On the contrary, silicon has been considered as the impropriate material due to high thermal conductivity property. However, recent research revealed the possibility of silicon as thermoelectric material by incorporating nanotechnology.

In this work, silicon manufacturing process based top-down approach is adopted to implement the n-/p-leg included silicon thermoelectric device. The 50 nm width n- and p-type silicon nanowires (SiNWs) are manufactured using a conventional photolithography and ion implantation methods on 8 inch silicon wafer. For the evaluation of the Seebeck coefficients of the silicon nanowires, heaters and temperature sensors embedded test pattern is fabricated. Also, bulk structured silicide/silicon samples are manufactured for massive power generation applications. The highest Seebeck coefficients are -170 μV/K and 153 μV/K and the highest power factors are 2.77 $mW/mK^2$ and 0.65 $mW/mK^2$ for n- and p-type SiNWs, respectively. For silicide/silicon bulk sample, Seebeck coefficients are higher than 200 μV/K.

# Inorganic 2-D Transition Metal Dichalcogenides Charge Transport Layers for $MAPbI_3$ Perovskite Solar Cells

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Perovskite solar cells (PSCs) have attracted huge attention because of the excellent optoelectronic properties of perovskite such as long carrier diffusion lengths and low trap density. Despite their attractive properties, PSCs have a problem with decreasing device performance due to degradation of perovskite materials [1]. Although many efforts to prevent degradation have been attempted, PSCs still suffer from stability issue. Generally, PSCs are composed of transparent conductive oxides (TCO), electron and hole transport layer, perovskite layer and electrode [2]. The materials and interfaces of each part are important for high efficiency and long stability of PSCs [3]. In particular, some organic materials conventionally used as a charge transport layer have hygroscopic and unstable properties. So they can accelerate the degradation process in PSCs structure [4]. To prevent this internal degradation, the other stable materials are required to replace them. Here, we suggest the stable charge transport materials for PSCs using Transition metal dichalcogenides (TMDs), and will discuss device performance and charge transporting mechanism of TMDs-based PSCs.

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# Photo-induced alteration of band bending in perovskite halide photovoltaic materials

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Organic-inorganic lead perovskite halide is one of the most promising materials for solar cells owing to the remarkable efficiency increase from its superior photovoltaic properties. Fundamental understanding of the band arrangement and the charge transport mechanism is important for advancing the use in high performance optoelectronic applications. We investigated the local electrical properties and surface potential distributions of lead and tin perovskite halide materials via conductive atomic force microscopy and Kelvin probe force microscopy, respectively. Furthermore, optical excitation under illumination using three light sources with different wavelengths onto the samples also supported the different nature between them. We particularly focused on the potential variations which are strongly dependent on grain boundaries and intra-grains. We expect the investigation on the movement of carriers in the perovskite thin films will have a positive effect to complement the lack of perovskite solar cells by improving the electrical quality characteristics, such as the carrier collection and recombination.

# Raman Spectroscopy of Antiferromagnetic Ordering in 2-Dimensional Materials

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Recent discovery of ferromagnetism in atomically thin materials [1,2] ignited much interest in magnetism in 2 dimensions in general. However, antiferromagnetic ordering is much more difficult to study than ferromagnetism because of the lack of net magnetism. Conventional tools for bulk materials such as neutron scattering cannot be used for atomically thin samples due to the small volume. Raman spectroscopy has proven to be a powerful tool to detect antiferromagnetic ordering by monitoring the zone-folding due to the antiferromagnetic order [3,4] or the signal from two magnon scattering. In this talk, I will review recent progress in the study of antiferromagnetism in 2 dimensions using Raman spectroscopy. $FePS_3$ exhibits an Ising-type antiferromagnetic ordering down to the monolayer limit, in good agreement with the Onsager solution for 2-dimensional order-disorder transition. The transition temperature remains almost independent of the thickness from bulk to the monolayer limit, indicating that the weak interlayer interaction has little effect on the antiferromagnetic ordering. [4] On the other hand, $NiPS_3$, an XXZ-type antiferromagnet in bulk, exhibits antiferromagnetic ordering down to 2 layers, but the magnetic ordering is suppressed in the monolayer limit. [5]

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# Structural phase transition and superconductivity in $MoTe_2$

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Structural phase engineering in polymorphic transition metal dichalcogenides (TMDs) has received much attention in recent years. Most researches have been studied with hexagonal phases, similar with the phase of graphene, but other phases have not yet been explored because people believed that other phases emerge inhomogeneously in limited areas. Here, I introduce the current research on phase engineering in $MoTe_2$ single crystals, which are successfully synthesized with three different structural phases ; hexagonal, monoclinic and orthorhombic structure. We found that $MoTe_2$ exhibits intriguing structural phase transitions; from hexagonal to monoclinic, and from monoclinic to orthorhombic structure. These structural phase transitions undergo via temperature, strain, carrier doping and Te vacancy, and result in the electronic phase transitions from semiconducting to semimetallic phase as well as from trivial semimetallic to superconducting phase in $MoTe_2$. This phase engineering including crystal and electronic structure provides a new route for cultivating rich electronic states, such as superconductivity, Weyl semimetallic and topological insulating states, in 2D van der Waals materials.

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# Probing defect dynamics in monolayer $MoS_2$ via noise nanospectroscopy

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**Abstract:** Monolayer molybdenum disulfide ($MoS_2$) has received intense interest as a strong candidate for next-generation electronics. However, the observed electrical properties of monolayer $MoS_2$ exhibit several anomalies: reported mobilities are unexpectedly low, < 150 $cm^2V^{-1}s^{-1}$; samples are universally observed to have n-type characteristics; and contact resistances are large, regardless of contact metal work function. All these anomalies have been attributed to the presence of defects, but the mechanism behind this link has been elusive. Here we report the ionization dynamics of sulfur monovacancy defects in monolayer $MoS_2$ probed via noise nanospectroscopy, realized by combining noise-current analysis with atomic force microscopy (AFM). Due to the nanoscale dimension of the in situ channel defined by the tip size, we probe a few monovacancy defects at a time. Monovacancy defects exhibit switching between three distinct ionization configurations, corresponding to charge states 0, -1, and -2. The most probable charge configurations are 0 and -1, providing a plausible mechanism to explain the unexpectedly low mobility, large contact resistance, and universally observed n-type characteristics of $MoS_2$ monolayers.
**Key words:** $MoS_2$, TMDs, defects, low frequency noise

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# Theory and Applications of Plasmon Enhanced Luminescence Upconversion

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This talk presents the latest progress in plasmonic nanostructures for enhanced luminescence upconversion and their applications in novel cancer therapy. Luminescence upconversion is a highly efficiency frequency conversion process based on interactions between optically active ions or molecules. Upconversion can be achieved efficiently even with low-intensity, incoherent light, enabling new applications such as biomedical imaging. Despite being much more efficient than nonlinear susceptibility based frequency conversion process, efficiency needs to be further improved for broad applications. Surface plasmon is ideal for this purpose. Surface plasmon can enhance all components of upconversion – absorption, energy transfer and emission. In this talk, we will first present the quantum electrodynamics framework describing the quantum processes involved in luminescence upconversion and how they might be impacted by surface plasmon [1]. We will then present a systematic spectroscopy study revealing how each process is impacted by the surface plasmon [2,3]. In addition to the fundamental study, we have designed a metal-insulator-metal (MIM) structure which exhibits strong field enhancement leading to over 1000-fold enhancement in luminescence upconversion (Fig. 1a and b). The MIMs are dispersed in water and used for imaging of bladder cancer cells (Fig. 1c). We observed the same level of brightness with 1000 times lower concentrations compared with the standard upconversion nanoparticle based imaging. Finally, we developed a multifunctional nanocluster composed of gold nanorod, upconversion nanoparticle and antibody targeting human bladder cancer cells. With the multifunctional nanoclusters, we then demonstrated highly targeted cancer therapy based on thermal ablation and optoporation.

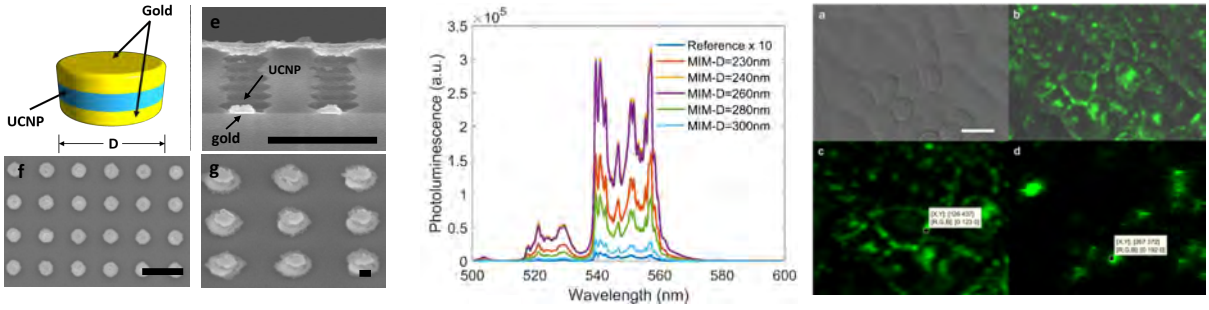


**Fig. 1.** (a) Schematic of MIM structure and SEM images showing various steps of MIM fabrication, (b) Photoluminescence spectra of upconverted luminescence from MIM, which shows over 1000-fold enhancement, and (c) Top panel shows the brightfield and upconversion imaging of bladder cancer cells and the bottom panel shows upconversion imaging with upconversion nanoparticles and MIMs.

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# Mid-infrared tunable plasmonics in graphene

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Graphene is an interesting material for mid-infrared active nanophotonics. Recent studies have shown that the effective optical index of graphene depends on the local Fermi level, which can be varied greatly via electrostatic gating techniques. More interestingly, the low carrier concentration and the atomic thinness of graphene allows for highly confined plasmonic modes whose properties are also widely tunable as a function of doping density. We showed that these plasmonic modes can play a dominant role in controlling the optical properties of periodically patterned graphene at mid-infrared frequencies. We showed that the energy-momentum dispersion relation of graphene plasmons are fundamentally different from the conventional noble metal surface plasmons and that the wavelength of graphene plasmons is more than 100 times shorter than the free space wavelength. As a consequence of such extreme field confinement, we further demonstrated that graphene plasmons strongly interact with substrate phonons, forming hybrid modes called surface phonon plasmon polaritons. By placing a reflector to block transmission channels and engineering the spacing between the reflector and the graphene resonators, we demonstrated that the absorption in a single layer of graphene resonators can be dynamically tuned from 0 to 25% by electrostatic gating. We also showed that the absorption modulation by graphene resonators can be 2.67 fold enhanced by incorporating EOT(extra-ordinary transmission) metallic resonant restructures. By further advancing the idea of overlapping various scales of resonances in a narrow spectral and spatial window, we recently demonstrated that it is possible to achieve perfect mid-infrared absorption modulation based on graphene plasmonic metasurfaces. Finally, Kirchhoff's law of thermal radiation, which states the absorptivity and the emissivity of an object are equal, also allows for dynamic control of thermal radiation from heated graphene plasmonic nanoresonators. These tunable plasmonic modes offered by graphene and other 2D materials provide new opportunities to create electo-optically active devices with novel functionalities that have thus far been impossible to be realized by using conventional media.

# Efficiency enhancement in Flexible Photovoltaic Cell via Plasmonic Metal Nanoparticles

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In the present energy-crises scenario the world is looking for alternating green energy resources. Solar photons are one of the best promising clean/green energy out of the available conventional energy sources. Solar cell technology is outspread in three generation families, out of which, third generation is aimed to economical flexible thin-films efficient solar cells. Making device in a constrain dimensions led to the lower solar photon absorption due to enhanced transmission results to low efficiency. To address this problem, plasmonics is the promising tool to enhance the light absorption via different absorption and scattering events. In this work, we discuss the development of plasmonic nanostructure with efficient control over the morphology via radiation induced process. Metallic nanoparticles are the simplest plasmonic nanostructures which offered the enhanced localized surface plasmonic resonance response in a visible to infrared electromagnetic spectrum region. Due to this phenomena, these plasmonic sites becomes trap for the solar photons via absorption and scattering which led to the enhanced path length and results in the better efficiency of cell. Synchrotron X-rays[1,2], swift heavy ion (SHI) beam, and microwave irradiation techniques has been optimized for the fabrication of plasmonic nanostructure to better control over the reaction-mechanism and eliminate the production of secondary products. The incorporation of plasmonic nanostructure in the active layer of solar cell tailors the optical properties for enhanced light absorption of the cell and hence higher efficiency. Plasmonic metal nanoparticles are also investigated via synchrotron radiations to understand the electronic structure and charge transport phenomena's. The main objective of the research is to develop flexible photovoltaic cell incorporating plasmonic nanostructure for enhanced optical properties. The work involves the development of one pot synthesis protocol for plasmonic (isotropic and anisotropic) nanoparticles under irradiation with microwave, swift heavy ion (SHI) and synchrotron X-rays. Precise techniques is developed for *in-situ* synthesis and characterization of NPs under synchrotron X-rays[1,2]. As per literature available, no one has investigated the metal nanoparticles incorporated photovoltaic cell by synchrotron X-ray techniques. This research work leads to the novel flexible plasmonic photovoltaic cell. Collectively, this work includes novel synthesis protocol for plasmonic NPs, flexible plasmonic characterization techniques for NPs as well as photovoltaic cell.

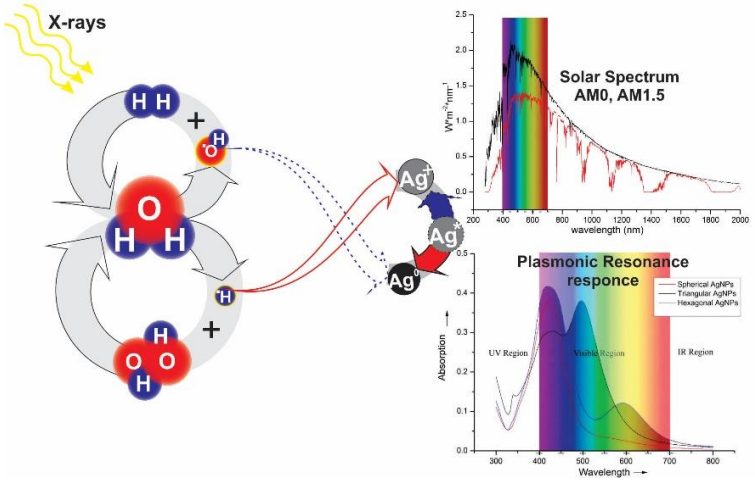


**Figure 1: Radiation induced synthesis of plasmonic nanostructures and its optical response relative to solar spectrum.**

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**Keywords:** photovoltaics; plasmonics; metal nanoparticle; synchrotron radiation research; swift heavy ion irradiation.

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# Polariton Condensates in Spatially Modulated Excitation

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Exciton polariton (polariton) is the result of strong coupling between quantum well exciton and cavity photon in semiconductor microcavity. Polariton is a bosonic quasi particle that can become bosonic condensate, called a polariton condensate. Spatial distributions of polariton condensates are determined by the beam shape of excitation laser because laser spots are considered as repulsive potential.[1] Depending on the laser beam shape, polariton condensates can experience parabolic potentials and their wavefunctions have the distribution of Hermite-Gaussian functions.[2] Here, we created two-dimensional Hermite-Gaussian (2DHG) distributions of polariton condensates using beam-shaping technique. We measured spectral-resolved real space image of photoluminescence (PL) in GaAs-based semiconductor microcavity. According to the pumping power and pumping shape, the occupations of 2DHG states are changed. Thus, we show a possibility of controlling the wavefunction of polariton condensates by beam-shaping technique. It will be great potential for studying polariton simulator,[2] macroscopic quantum phenomena, condensed matter physics, and semiconductor BEC.

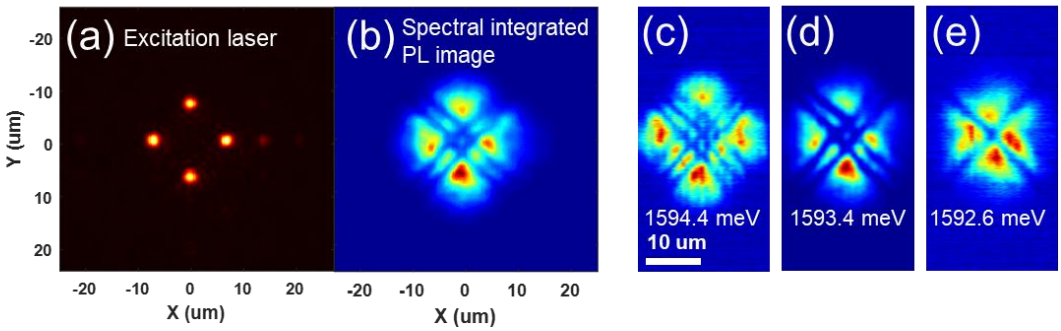


**Figure 1 (a) Real space image of excitation laser. (b) Real space image of Spectral integrated PL of polariton condensates when the beam shape of excitation is (a) situation. (c), (d), (e) are spectral resolved real space images. Energy of each images are 1594.4 meV, 1593.4 meV, and 1592.6 meV respectively.**

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# Title: The Andreev reflection at the junction of graphene quantum Hall state and superconductor

Abstract: Tremendous effort is currently underway toward generating and manipulating Majorana fermions by coupling a superconductor (SC) either to a topological insulator or to a semiconductor with strong spin orbit coupling. The coupling of a quantum Hall (QH) state and a superconductor (SC) has been proposed as a novel route for creating even more exotic topological entities, such as non-abelian Majorana, parafermion or Fibbonacci particles. As a step toward that goal, we demonstrate in this letter Andreev reflection (AR) at the junction of a QH state in a single layer graphene (SLG) and a two dimensional (2D) NbSe2 superconductor. This system allows us to study Andreev effect up to magnetic fields as high as B = 10T when graphene consists of well resolved Landau levels. We see characteristic signatures of Andreev reflection, such as: enhanced conductance inside the superconducting gap; oscillations in the conductance as a function of the magnetic field or the back gate voltage; and also an anomalous finite-temperature peak located precisely at the Dirac point, which provides a compelling evidence for inter-band Andreev reflection. Our observations are well supported by detailed numerical simulations, which offer additional insight into the role of the edge states in coupling superconductor and QH state. This study paves the way for investigating analogous Andreev reflection in a fractional quantum Hall system coupled to a superconductor.

# Monolayer $MoS_2$ on Sub-100-nm $SiO_2$/Si: Interface-Interference-Mediated Absorption Enhancement

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2D atomically thin semiconductor $MoS_2$ has attracted great research interest due to its unique optical, electrical, and mechanical properties. Optical measurements of $MoS_2$ are very useful for identification of the layer thickness and characterization of material qualities. Improved optical absorption of the $MoS_2$ layers is also crucial for optoelectronic applications. To enhance the light-matter interaction, researchers have tried several approaches, using plasmonic metal nanostructures, Fabry-Perot-type cavities, and photonic nanostructures. In this work, we investigated optical spectral responses of the $MoS_2$ monolayers on $SiO_2$/Si substrates with very thin $SiO_2$ layers (thickness of $SiO_2$ = 40 ~ 130 nm). The incident light undergoes phase changes upon reflection and transmission at the highly absorbing $MoS_2$/$SiO_2$ and $MoS_2$/air interfaces. In addition to the interface phase changes, those induced by the propagation of light in the $SiO_2$ layer can cause interference. As a result, the optical properties of the $MoS_2$ monolayers significantly depend on the $SiO_2$ layer thickness. The interface phase change is insensitive to the wavelength and incident angle of the light. Therefore the $MoS_2$ monolayers on sub-100 nm $SiO_2$/Si substrates can exhibit broadband omnidirectional absorption enhancement. As expected, the measured Raman and optical reflection spectra of the $MoS_2$ monolayers varied considerably depending on the $SiO_2$ thickness, while changing the thickness from 40 to 130 nm. The Raman peak intensity of the $MoS_2$ monolayer on the substrate with an 80-nm-thick $SiO_2$ layer was four times larger than those with 40- and 130-nm-thick $SiO_2$ layers, indicating a significant difference in the absorption at the excitation wavelength. All the measured reflection and Raman spectra of the $MoS_2$ monolayers could be well explained by the optical calculation results. This work showed that the use of sub-100-nm-thick $SiO_2$/Si substrates could provide us a simple means to enable broadband omnidirectional optical absorption enhancement of 2D $MoS_2$ monolayers.

# Coherence and indistinguishability of single photons emitted from nitrogen impurity centers in GaAs

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Nitrogen isoelectronic impurities in III-V compound semiconductors have been attracting considerable attention as a novel solid-state single photon source [1]. These luminescence centers show sharp and bright luminescence peaks below the bandgap energy, and are useful as single photon sources with very small inhomogeneity. Such a property may be advantageous for interfering photons from spatially remote photon sources, which is important for some particular applications including quantum repeater, and is difficult to achieve with semiconductor quantum dots (QDs) because of unavoidable size distribution of QDs. In fact, single photon emission with well-defined energy has been demonstrated for nitrogen impurity centers in GaP [2] and GaAs [3]. Nitrogen impurities in GaAs are more important for indistinguishable photon generation, because it has a higher radiative decay rate [4], which is favorable for satisfying the Fourier-transform limited coherence time.

We measured the coherence time of nitrogen centers in GaAs by interferometric measurements of photoluminescence from individual centers, and also examined the indistinguishability of successively emitted two photons from a center [5]. Nitrogen impurities were doped within a two-dimensional layer by the so-called δ-doping techni que during metalorganic chemical vapor deposition growth. We found that the coheren ce time under above-gap excitation reached to 380 ps at 2 K, comparable to that of t he QDs. The indistinguishability was measured as 0.25 by using the Hong-Ou-Mandel setup. Four-wave mixing (FWM) technique is known as an alternative method to obtain the coherence time that is not affected by slow spectral diffusion process. We have successfully observed FWM signal from ensemble of N-related luminescence centers in a δ-doped layer by using a highly sensitive heterodyne-detected two-pulse FWM. The signal showed exponential decay with a decay time of about 60 ps at 2 K.

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# Integration of quantum light sources on a Si chip

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Integration of quantum light on a chip is very important to achieve scalable, integrated quantum photonic devices. Solid-state quantum emitters can generate single photons with high efficiency, while silicon photonic circuits can manipulate them in an integrated device structure. Combining these two material platforms, therefore, enable us to utilize the advantages of both systems and make feasible integrated quantum photonic devices. We demonstrate hybrid integration of solid-state quantum dots to a silicon photonic device by using a pick-and-place technique as shown in Fig.1. We employ InAs/InP quantum dots generating single photons at telecom wavelengths[1], and thus they are compatible with Si chips. We also perform Hanbury-Brown and Twiss experiments on the silicon chip with integrated quantum emitters[2]. The result shows the possibility of integrated quantum photonic devices on a Si circuit.

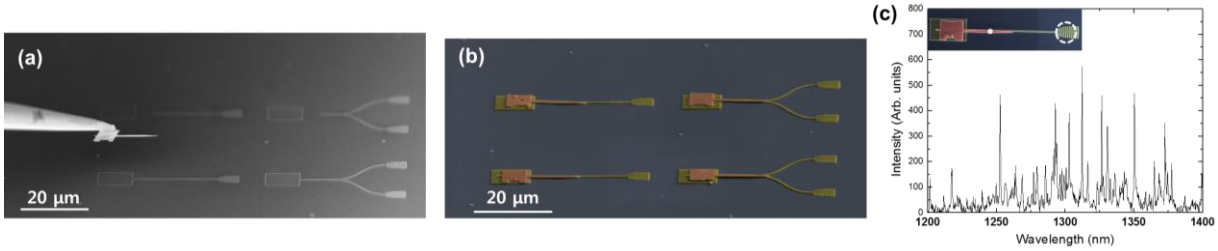


Fig. 1 (a-b) Pick-and-place procedure with a microprobe tip combined with a focused ion beam and scanning electron microscope. (c) Photoluminescence spectrum of the coupled quantum dots on a Si waveguide.

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# III-Nitride Nanowire based Piezoelectric Generators for supplying nomad microelectronic devices

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To address the worldwide challenge dealing with the development of autonomous micro-devices for sensing, monitoring and nomad electronics, new competitive ultra-compact and integrable electrical energy sources are required. These sources must generate sufficient power to supply the micro-devices without increasing their size and weight.
The III-Nitride nanowires (NWs) based piezo-generators have emerged as excellent candidates to fabricate novel power sources. Thanks to their superior mechanical properties, higher sensitivity to applied force and higher piezoelectric response over conventional 2D films and bulk materials, the NWs have the potential to fundamentally improve the electrical generator performances.
We demonstrate the fabrication of piezo-generators integrating vertical arrays of GaN NWs. Based on a systematic multi-scale analysis, going from single wire properties to macroscopic device fabrication and characterization, we establish for GaN NWs the relationship between the material properties and the piezo-generation [1-3]. Thank to this fine understanding of the piezo-conversion mechanisms, we propose an efficient piezo-generator design.
The piezo-conversion of individual MBE-grown p-doped GaN NWs in a dense array is assessed by atomic force microscopy equipped with Resiscope module yielding an average output voltage of 228 ± 120 mV and a maximum value of 350 mV generated per NW. In the case of p-doped GaN NWs, the piezo-generation is achieved when a positive piezo-potential is created inside the nanostructures, i.e. when the NWs are submitted to a compressive deformation. The establishment of the piezo-generation mechanism in our GaN NWs gained from AFM analyses is applied to design piezo-generators operated under compressive strain. The devices integrate NW arrays of several square millimeters in size and deliver a maximum power density of 12.7 mW/cm$^3$ [4]. This value settles the new state of the art for piezo-generators based on GaN NWs and more generally on Nitride NWs. These results offer promising prospects for the use of GaN NWs for high-efficiency ultra-compact energy harvesters, since the generated power density is already interesting for real world applications such as remote wireless transceivers.

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# Facile synthesis of metal oxide nanostructures with versatile morphologies for high-performance supercapacitors

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**Abstract:**

Recently, supercapacitors have considered as a very promising candidate for energy storage devices owing to their advantages of high power density, fast charge-discharge cycles and long cycling lifetime. In comparison with lithium-ion batteries, the energy density of supercapacitors is relatively low to store sufficient energy. This limits their practical applications of supercapacitors in energy storage system. Without reducing the power density and cycling lifetime, the improvement of energy density is a strategic idea to meet the future energy requirements. Usually, the energy density can be enhanced by maximizing the specific capacitance and cell potential in supercapacitors because it is proportional to the specific capacitance and the square of cell voltage. An effective method for increasing the capacitance is to develop novel electrode materials, e.g., transition metal oxides, conductive polymers, etc. with versatile morphologies, large surface area and excellent electrochemical activity. On the other hand, the strategy of asymmetric supercapacitors design with various positive and negative electrode materials is a promising approach to widen the operating potential window of total cell. Accordingly, the fabrication of novel nanostructured materials and asymmetric supercapacitors design could bring in a step change in the enhancement of energy density. In this presentation, we synthesized facilely the metal oxide (NiO, CoO, $Mn_2O$, etc.) nanostructures with versatile morphologies on various substrates for supercapacitor applications. Also, asymmetric supercapacitors were fabricated using the synthesized nanostructures as a positive electrode and activated carbon as a negative electrode, respectively. Then, the CV, GCD, EIS and cycling characteristics were measured to evaluate the electrochemical properties of the fabricated supercapacitors. From these results, the hybrid electrode materials are expected to be useful for high-performance supercapacitor applications.

# Battery-free Electronic Smart Toys: A Step toward the Commercialization of Sustainable Triboelectric Nanogenerators

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Future toys are designed in a way to interact and entertain with the kids. Such kind of toys needs a power source, generally, a battery which needs to replace very frequently, thus increasing the maintenance cost of the toy. Recently an innovative biomechanical energy harvester called Triboelectric Nanogenerator (TENG) [1] was introduced as an eco-friendly approach to scavenge the waste energy. Here, we present a novel method which can be a step to commercialize the TENG device by incorporating the biocompatible TENG with the traditional toys to develop battery-free smart toys. This robust, eco-friendly and cost-effective approach to harnessing the biomechanical energy is successfully utilized to transform a conventional toy into a smart toy. By using this innovative idea, we developed a smart puzzle (SP-TENG) [2], smart clapping toy (SCT-TENG) and a smart duck toy (SDT-TENG) using bio-compactable materials. We systematically studied the electrical performance of all the three devices. This approach transforms a traditional toy into a battery-free interactive smart toy, and it also creates an opportunity to commercialize TENG-based smart gadgets.

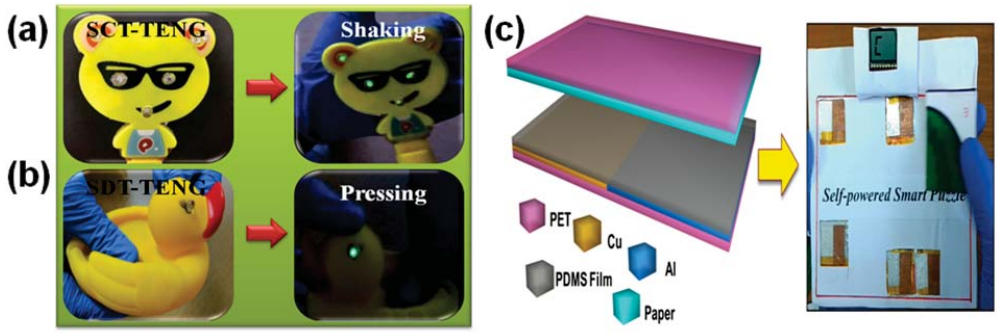


**Figure 1. Working model of (a) Smart clapping Toy-TENG, (b) Smart Duck Toy-TENG and (c) Self-powered smart-puzzle.**

## Acknowledgments

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# Synthesis and Characterization of Multiple Cation Rb(MAFA) Perovskite Single Crystals

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Hybrid perovskite single crystals have attracted considerable attention as promising optoelectronic materials owing to their high absorption coefficients, low trap density, and long electron-hole diffusion lengths. Despite their unique properties, monovalent cation (MA or FA) perovskite single crystal suffer from long-term stability due to low moisture resistance or phase transition at room temperature [1]. Recently, incorporation of inorganic cation such as cesium (Cs) has been found to improve moisture- and thermal-stability with better device performance [2]. Rubidium (Rb) is another possible alternative cation, which has slightly smaller atomic size than Cs. However, so far very few studies have reported on Rb-based perovskite thin films [3-5], not single crystals. Here, we first synthesized Rb incorporated perovskite single crystals by inverse temperature crystallization method. X-ray diffraction and UV-Vis absorption spectroscopy were carried out to investigate structural and optical properties, and finally, electrical properties were also characterized upon the addition of Rb.

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# Interplay between lattices, topology, and orbitals in two-dimensional crystals

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In this talk, I will discuss my recent theoretical works on possible phase transitions from quantum spin Hall insulating (QSHI) states to superconducting and charge density waves states in a transition metal dichalcogenide (TMD), 1T' phase MoTe2 and WTe2 as a function of doping. A new charge density wave phase with a non-symmorphic lattice symmetry in those TMDs can realize the Dirac metallic phase with a partially filled band and a reentrant QSHI state with fully filled bands, respectively. I will also discuss a peculiar interplay between the orbital degrees of freedom in transition metals and the lattice symmetry in realizing the Mott insulating state in 1T phase TMDs and will show a possible topological effects originating from the orbital orderings.

# Device Performance of $MoS_2$ Field Effect Transistor Depending on Junction Structure and Channel Thickness

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Although semiconducting transition metal dichalcogenides (s-TMDs) exhibit superior optical and electrical characteristics comparing to Si, their applications for the digital electronics requires the deep understanding on their transport properties. In this presentation, we will discuss device performance of $MoS_2$ field effect transistor (FET)s, which are affected by the junction structure and channel thickness. The effect of metal contacts to the top and edge of monolayer $MoS_2$ were studied. The device shows the temperature-dependent ideality factor and Schottky barrier height (SBH), both which originate from charge puddles, defects, and grains in $MoS_2$. In addition, the degree of SBH inhomogeneities varies depending on the junction structure. In addition, the effect of channel thickness is studied using double-gated thick $MoS_2$ FETs. At 300 K, the dual and independent controls of top and bottom gate field give rise to the spatial division of conduction channel. Two separate channels simultaneously exist near the top and bottom gate dielectrics, whose existence is supported by a different threshold voltage ($V_{TH}$) and the field effect mobility ($\mu_{FE}$). The segregation of carrier transport between top and bottom channel is attributed to the electrostatic screening of the gate field and the interlayer resistance of $MoS_2$. When, the temperature is below than 100 K, a transport behavior by a single channel is detected, which results from the increased interlayer resistance at low temperature that shuts the conduction in a vertical direction toward the bottom gate electrode.

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# Hexagonal-BN (*h*-BN) as an ideal substrate for $MoS_2$ electronics.

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As the thickness becomes thinner, the importance of supporting dielectric increases in two-dimensional (2D) electronics because of the close proximity between channel and interfacial layer. Recently, a hexagonal boron nitride (*h*-BN) thin film has been suggested as an exceptional substrates for 2D electronic systems due to its inert and free of dangling bond surface for transition metal dichalcogenides materials (TMDs) and their heterostructures with graphene. However, the underlying mechanism of *h*-BN effect on electron excess doping, interface trap density, and Schottky barrier height (SBH) is little known. In this presentation, we demonstrate various beneficial aspects of *h*-BN over a conventional silicon-dioxide ($SiO_2$) substrate for 2D carrier transport *via* temperature (*T*)-dependent conductance behavior and low-frequency noise analysis, which allows us to have a clear insight of the Coulomb scattering mechanism in $MoS_2$ channel in the presence of *h*-BN buffer layer on $SiO_2$ insulating layer. The inserted *h*-BN substrate, which enables to mask the undesired effects of fixed oxide charges in $SiO_2$, not only enhances electron excess doping concentration and carrier mobility but also suppresses interface trap density and SBH [1-2]. These improvements aid to successfully identify the main noise source in the channel, which is the trapping–detrapping process at gate dielectrics rather than the charged impurities localized at the channel, as confirmed by fitting the noise features to the carrier number and correlated mobility fluctuation model.

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# Development and Key Technologies of GaN-on-Si LEDs

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Continuous development of lighting technology has been driving us to explore the innovation in the growth of InGaN-based epitaxial structures on a cost-competitive silicon substrate. The sapphire substrate has been one of most popular and also successful choice for the growth of blue light-emitting diodes (LEDs). However, relative high cost and unavailability of large diameter of sapphire substrate is considered to one of serious technical hurdles, consequently limiting the widespread adoption of LEDs. Silicon substrate fulfills most of criteria of substrate for the cost reduction of LEDs in terms of mass production while sapphire might not. Despite prominent advantages of silicon substrate, however, growing high quality of GaN or InGaN on a silicon substrate is extremely challenging due to the mechanical crack, high defect density, and difficulty of bow control of LED wafer [1,2]. In this presentation, how to address and resolve the fundamental issues of GaN/Si technology will be discussed. In addition, its perspective for future LED chips and possible application using GaN-on-Si technology will be envisioned as well.

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# Highly Compliant Guided-Mode Resonance 1D and 2D Gratings for Sensing Applications

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We report the theory, design, fabrication, and characterization of highly-compliant polymer-based guided-mode resonance (GMR) grating devices for sensing applications. GMR devices have been widely researched in recent years for their applications in telecommunications and biosensing. The vast majority of GMR-based sensors are fabricated and characterized on rigid transparent substrates, and are designed to respond to changes in the optical properties of their surrounding media. While useful in a number of conventional sensing configurations, the applications of rigid gratings for mechanical sensing are extremely limited. To enable a GMR sensor to respond to mechanical stimuli, both the grating and its substrate must be compliant, a property inherent to the devices presented herein.

Both 1D and 2D physically flexible GMR devices were designed and fabricated in such a manner that subwavelength titanium dioxide ($TiO_2$) gratings embedded at the surface of highly compliant polydimethylsiloxane (PDMS) structures. A 1D membrane-embedded GMR grating (Fig. 1b) was demonstrated for local measurement of microfluidic channel pressure. The results, which show excellent agreement between simulation and experiment, display an average sensitivity of 10.6 nm/kPa over the sensor range, with relative changes in pressure as low as 50 Pa being detectable [1]. A 2D asymmetric slab-embedded GMR grating was also demonstrated (Fig. 1c) for simultaneous measurement of biaxial strain detection. Along the long-period axis, the resonant wavelength shifts with a sensitivity of 4.8 nm/%ε over a range of 5% strain [2].

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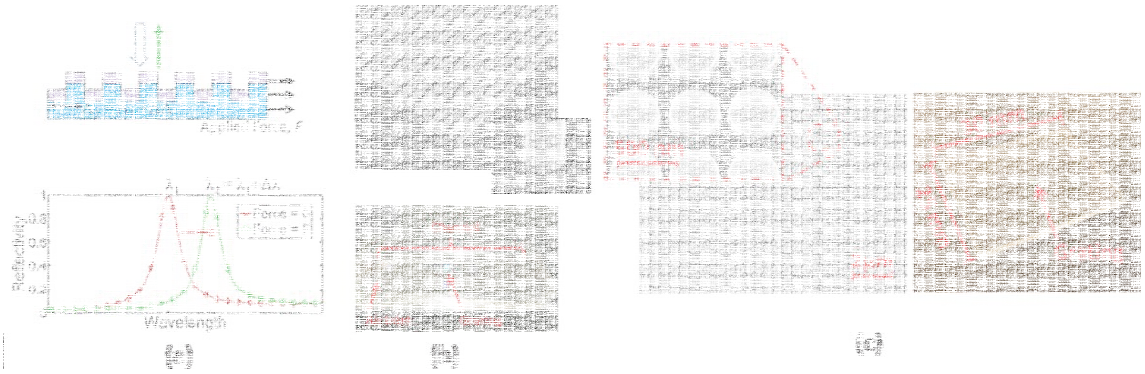


**Figure 1. (a) Working principle of GMR, (b) 1D grating pressure sensor, (c) 2D grating 2D strain sensor.**

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# Experimental verification of high-performance linear polarizer using stacked 1D subwavelength gratings

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Infrared (IR) polarimetric imaging has attracted much attention due to various applications such as remote sensing, military surveillance and industrial monitoring [1]. However, a single layer of 1-dimensional (1D) grating to be conventionally integrated with IR focal plane array device intrinsically has the limited extinction ratio (defined as the ratio of TM transmission to TE transmission) and TM transmission efficiency due to the large impedance mismatch between incoming medium and 1D metal grating. Here, we investigate experimentally and theoretically new design, stacked 1D subwavelength gratings, with a superior linear polarization extinction, which is based on the Fabry-Perot (FP) cavity formed by two layers of 1D subwavelength grating and operates in the mid-wave IR range. The structure of stacked 1D gratings consists of two identical metal gratings, separated by a dielectric film (spacer) as shown in Fig. 1(a). The thickness of the spacer layer, $t_{BCB}$ = 0.25 μm was determined in consideration of the linear polarization performance using a multiple-layer model [2] and a finite integration technique based simulation [3] as shown in Figs. 1(b) and 1(c). TM transmission efficiency of stacked 1D gratings is improved as compared with a single 1D grating, which results from the FP cavity resonance between two 1D grating layers, where FP phase condition ($\gamma$) at λ = 4.2 μm is found to be -2π as indicated in Fig. 1(c). As a result, the polarization performance of a single 1D grating and stacked 1D gratings was characterized by means of InAs/GaSb type-II superlattice (T2SL) based MWIR camera as displayed in Fig. 1(d).

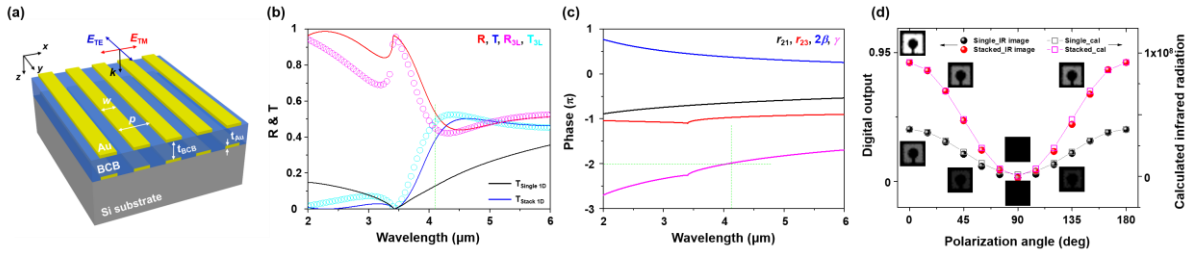


**Figure 1** (a) Schematic of the stacked 1D gratings with geometric parameters. (b) The transmission and reflection (CST simulation and multiple-layer model). (c) The amplitude and phase terms in FP phase condition equation ($r_{21}$, $r_{23}$, $2\beta$, $\gamma$). (d) T2SL based IR camera output and calculated IR intensity through fabricated samples.

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**Direct Observation of Quantum Tunneling Charge Transfers between Molecules and Semiconductors for SERS**

We present large enhancement of the Raman scattering intensity from molecules adsorbed on one-dimensional ZnO semiconductor nanostructures, without involving any noble metals. By using semiconductor structures as host materials, we could safely exclude plasmonic resonance as a Raman enhancement mechanism. Instead, we found that chemical enhancement due to charge transfer is mainly responsible for intensity increase. To further study charge transfer mechanism, we used combinations of four host nanostructured materials ($HfO_2$, $Al_2O_3$, ZnO, GaN) and three different molecules (4-Mpy, 4-Mba, 4-Atp), where the relevant energy levels vary. As a result, we observed that the Raman intensity enhancement occurs only selectively for a specific kind of substrate and a kind of molecules pair. We also found that there exist a preferential direction of charge transfer between substrate and adsorbed molecules. Our results suggest that optimal pairs for Raman enhancement can be found, and the enhancement can further be optimized for selective sensing, for example.

# Spin qubits in silicon MOS quantum dots

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Spin qubits in silicon are excellent candidates for scalable quantum information processing [1] due to their long coherence times and the enormous investment in silicon CMOS technology. By modifying the gate-electrode patterning of a silicon MOS (SiMOS) transistor, one can conveniently configure such circuits into gate-defined quantum dot devices [2]. With further adjustment of the gate structure and potential bias, a single electron can be isolated within the quantum dot [3] and via integration of a nearby charge sensor [4] one can realise a single electron-spin silicon qubit. Such qubits can have long spin lifetimes T1 = 2 s, with controllable conduction-band valley splitting via electric field tuning that removes the problem of spin-valley mixing in silicon [5]. These qubits can be further improved by using isotopically enriched Si-28 substrates, leading to control fidelities exceeding 99%, driven by an on-chip electron spin resonance (ESR) microwave line [6]. Multi-qubit systems can be realised by placing two quantum dots adjacent to each other [7], where qubits are individually addressed using ESR and Stark shift tuning, while two-qubit operations use a simple gate control that turns the exchange coupling on and off.

In this talk I will present the design, fabrication, and measurements of the SiMOS qubits developed at UNSW, including the key results discussed above. In addition, I will present our recent results on single- and two-qubit operation, including experiments on fidelity benchmarking and newly observed spin-orbit physics in silicon quantum dots. Finally, I will discuss a path to realise a large-scale 2D array SiMOS qubits [8].

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# The Quantum Dot Hybrid Qubit: A Spin Qubit with Tunable Coupling to Electric Fields

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In order to achieve high-speed operation of semiconductor spin qubits, a strong control knob for qubit manipulation is essential. Increasingly, that control knob is a gate voltage coupling to the spin qubit through spin orbit coupling, which itself is often engineered in silicon through the use of micromagnets and the large magnetic field gradients they produce. I will discuss an alternative approach to coupling gate voltages to spins in silicon: using three electron spins in two quantum dots as a single qubit, a configuration called the quantum dot hybrid qubit (QDHQ) [1,2]. I will show recent results that demonstrate how changing the operating conditions for this qubit enables control of the coupling of the spin state to the noise environment [3]. Such tunability can be used, for example, to turn down the coupling to preserve coherence and to turn up the coupling when desired for qubit manipulation. The time scale for making such changes is very short, so that they can be implemented in real time during qubit operation.

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# Holonomic quantum control of geometric spin qubits in diamond

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Realization of fast fault-tolerant quantum gates on a single spin is the core requirement for solid-state quantum-information processing. As a polarized light shows geometric interference, a spin coherence is geometrically controlled with light via the spin-orbit interaction or directly with microwave. We show that a geometric spin in a degenerate subspace of a spin-1 electronic system in the nitrogen vacancy center in diamond allows implementation of optical non-adiabatic holonomic quantum gates. The geometric spin under quasi-resonant light exposure undergoes a cyclic evolution in the spin-orbit space, and acquires a geometric phase or holonomy that results in rotations about an arbitrary axis by any angle defined by the light polarization and detuning, enabling universal holonomic quantum gates with a single operation. We demonstrate the complete Pauli quantum gates using the geometric spin preparation and readout techniques for the quantum process tomography [1]. On the other hand, in the case of polarized microwave, the geometric spin undergoes a cyclic evolution in the partial space of the spin triplet states via the magnetic field component of the microwave to acquire the geometric phase, which becomes the relative phase in the degenerate logical qubit. We demonstrate the universal quantum holonomic gates using the electron and nitrogen nuclear spins in an NV center via the hyperfine interaction. The optical holonomic quantum gates open the way towards holonomic quantum computers and repeaters.

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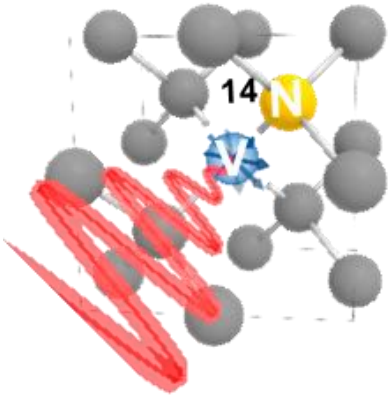


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# Current antiresonance in spin-orbit coupled double quantum dots

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The coherent control of spin states with ac-driving fields is important for spin-based qubits. At the same time, the spin-orbit-interaction enables electrical control of spin qubits [1], therefore understanding the role of the spin-orbit-interaction is useful. In semiconductor quantum dots spin resonance effects can be detected via electrical transport measurements [1].

In this work, we consider a double dot in the spin blockade regime and focus on the coupled two-spin states. The resulting states in a static magnetic field are mixed (hybridized) because of the spin-orbit-interaction. Under the application of an oscillating electric field the electrical current flowing through the double dot displays spin resonance effects. By employing a Floquet-Markov open-system approach we calculate the current as a function of the frequency and power of the driving field. For a specific frequency range we predict an interference pattern (antiresonance) in the current as a result of a three-level dynamics. We compute the current in the weak and strong driving regimes and find a rather high sensitivity. We clarify the role of the spin-orbit strength, energy detuning, and g-factor difference. Our findings can be tested with standard electrical transport measurements [1, 2, 3].

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# Functional Designs of Si Photovoltaics and Transparent Photoelectrics

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A photoelectric device converts the incident light into the electrical energy or vice versa. At a certain amount of incoming light, tailoring of the front side is crucial to reduce the light reflection at a surface and thus simultaneously enlarges the photon energy driven into the light-reactive materials.

Practically, however, the geometry tailoring of light-absorber readily causes recombination losses, which is inevitable concern for the most nanoscale patterned photo-electric devices. Researchers reported 'zero' (or near zero) reflector by using various nanoscale entities. However, up to date, this state-of-the-art nanoscale zero reflector is not much effective to improve the practical solar cell performances. This is because of the over weighted design for optical aspects of nanoscale structured solar cells. It also clearly suggests that there exists a discrepancy between the optical advantage and the electrical performances.

We may think how we can realize the optical benefits of light management into electrically improved performances. This important issue can be resolved by using a conductive transparent material as multi-functional purpose. As an example, we can apply transparent layer, such as, indium-tin-oxide (ITO) or aluminum-doped ZnO (AZO) or nanowires[1,2][3], for the refractive-index matching entity or structures[4]. These transparent conducting materials may spontaneously reduce the electrical recombination loss by contributing the transport of photo-generated carriers.

Different from the conventional use of 'dark' solar cells, the transparent solar cells would provide vivid benefits by through the intrinsic feature of 'invisible' to human eyes.

Could transparent solar cells work as the invisible power generator? Is it possible, in order to satisfy the on-site energy production, to install the transparent solar cell into the window of buildings and vehicles without recognizing the existence of energy harvesting entities?

We demonstrate the wide energy bandgap materials for visible light transmittance and UV photon absorption for power generation. All-transparent solar cell was achieved by the heterojunction of metal oxide layers. By using the solid-state sputtering method, transparent heterojunction (p-type NiO/n-type ZnO) was realized [5][6]. A unit cell gave the record-high conversion efficiency of 6% with the enormous current density (2.7 mA/cm2) and open circuit voltage of 532 mV.

The remarkable transparent solar power is mainly attributed to the absolute UV

absorption to induce the substantial excitonic effect for ZnO/NiO heterojunction. For integration, the transparent solar cell units were fabricated on a glass substrate to demonstrate the module of unit solar cells. Using the 3 × 3 unit cell solar module, a significant output voltage (> 2 V) was achieved to confirm the excellent connection manipulation of transparent solar cell units. By putting the transparent solar cells on buildings and vehicles, the electric power is spontaneously supplied from the Sun power but human eyes have no visible scarification. Transparent solar cells would provide a route for on-site energy generation. In addition, the semitransparent metal oxide solar cell is also an effective way to solar-driven hydrogen production [7].

We may also apply the emerging 2D materials [8][9]for high-performing photoelectric applications, by through the large-area production and direct embedment on the desired spots.

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# Ultra-thin and Single Crystal Si and Ge Wafers for Next Generation Photovoltaics

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Ultra-thin and single crystal Si and Ge wafers are attractive since it can lower materials cost and also provide additional functionality, such as flexibility, in photovoltaics. Previously, ultra-thin and single crystal semiconductor films often are grown using costly epitaxy process. Here, I'll present a novel epi-free process to fabricate thin and single crystal Si and Ge films in a wafer-scale at low cost. Firstly, I'll talk about a spalling process to fabricate single crystal Si foils in 2-inch diameter. The spalling process can exfoliate a Si foil when a biaxial strain induced from a thick Ni layer on a Si wafer. By controlling thicknesses of Ni overlayer, we successfully fabricate single crystal Si foils with controlled thicknesses from sub 2 to 50 μm. Secondly, I'll talk about a novel epi-free process to fabricate 300 nm-thick single crystal Si films. This process relies on the morphology evolution of vertically aligned nanoporous Si upon high temperature annealing. Influence of process parameters will be presented in detail.

# Influence of Si intermixing on optical properties of Ge-on-Si

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We present the activation energy change of direct transition from germanium(Ge)-on-silicon(Si). For a comparative study we performed temperature dependent photoluminescence measurement on as-deposited and thermally annealed Ge-on-Si. A significant change of activation energy could be observed by comparing the intensity of each sample. Thermally annealed Ge-on-Si exhibited higher activation energy than that of as-deposited Ge-on-Si. This can be attributed to increased bandgap energy between L valley band edge and Γ valley valence band. We also report a significant observation of Δ valley related emission. As Δ valley lies about 70 meV[1] above the Γ valley, electron can be also thermally activated to the Δ valley in Ge. Our temperature dependent study clearly shows the photoluminescence spectra that consists of L, Γ, and Δ related peaks and the thermal activation phenomena from L to the other valleys. This research will provide an in-depth understanding of Ge luminescence properties as a promising light source material.

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# Toward the performance enhancement of semitransparent ultra-thin CIGSe solar cells

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Ultra-thin CIGSe solar cells (absorber layer thickness < 500 nm) gather interests not only because they can reduce the material-related cost but also they enable a semitransparent daylighting window or a bifacial configuration in BIPV applications. Decreasing the CIGSe absorber thickness from ~2.5 μm to < 500 nm can be a way to bring the cost of photovoltaic generated electricity in the close proximity to the cost of grid parity since the material-related cost of a usual CIGSe solar cell module is estimated to reach almost the half of manufacturing cost [1] and especially cutting down the usage of indium and gallium can be even more significant due to their scarceness. However, decreasing the absorber thickness while maintaining high conversion efficiency is a difficult task due to the increase of the back surface recombination and shunt conductance, which deteriorate the device performance. In addition, the formation of unwanted $GaO_x$ interfacial phase in between CIGSe and oxide can aggravate solar cell performance [2].
To study and resolve the issued problems, semitransparent ultra-thin CIGSe solar cell on ITO (Indium Tin Oxide) glass is fabricated by using one-stage co-evaporation with modifications on rear interface. Major changes are made in post-deposition treatment (PDT) of ultra-thin CIGSe, bandgap engineering of absorber layer, and insertion of hall transfer layer (HTL) in between absorber layer and ITO glass. Those modified rear interface and other variations are investigated independently by fabricating semitransparent solar cells and by analyzing interfaces and solar cell parameters. The effects of rear-side modifications and the related solar cell performances will be discussed in detail.

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# Nanorod Array Structure through Nano-mold Process for AVR Display

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The purpose of this study is to produce the three-dimensional structure with the application of nano-mold process. The three-dimensional structure and growth will be more appropriately provided through nano manufacturing process using mask patterning and etching process. Uniformity and reproducibility of nano-mold process in this study enables multiple wavelengths unlike conventional single-wavelength light emitting diodes. This study will show the characteristics of various wavelengths beyond blue and green through newly developed nano-mold and its nanorod array. This research will also prove the feasibility of the white light emitting diode without phosphor as multiple wavelength in a single chip can be realized. This kind of study about the light emitting diode with nano structure has been actively conducted to develop the next generation display for augmented and virtual reality (AVR) and wearable devices. [1,2]
This study is aimed at forming the nano-mold applied with semiconductor's manufacturing process, suggesting the new characteristics of nano structure by the way of realizing the light emitting diode of three-dimensional structure by this mold.

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# Towards Highly Efficient Photoelectrolysis Systems: InGaN-based Nanowires on Conductive Substrates

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Solar hydrogen generation using InGaN-based nanomaterials is recently attracting much attention due to their chemical stability and tunable band gap that can cover the entire visible solar spectrum and improve the solar light harvesting efficiency [1]. However, the commercial applications of these systems are hindered by the low solar-to-hydrogen (STH) energy conversion efficiency. This can be partially attributed to the lack of compatible and highly conductive substrates, which are indispensable for the efficient separation and the rapid transport of the photo-generated charge carriers to the desired water redox interfaces [2]. The growth of InGaN-based nanowires usually involved single crystalline substrates, such as semi-insulating sapphire and semi-conducting Si, which cannot fulfil the conductivity requirements. Therefore, the growth of InGaN-based nanowires on substrates made of conventional metals can provide new opportunities for enhancing the photo-generated charge carrier transport that can significantly improve the STH efficiency.

Motivated by the inert nature of wide bandgap and wide compositional tunability of group-III nitride, as well as the feasible single crystal growth of nitride-based nanowires on scalable Si substrate, we first investigated the combination of both nitride nanowires with Si substrate in the presence of a metallic interlayer. Enhanced stability as well as reduced interfacial transfer resistance were achieved after the insertion of a 300 nm Ti interlayer at the interface between InGaN nanowires and Si-substrate. Flexible and substrate-free InGaN-based nanowires membrane photoanodes were also fabricated through liftoff and transfer techniques, where excess charge carriers are efficiently extracted from the InGaN-based nanowires through a proper ohmic contact formed with a high electrical conductivity metal stack membrane. Finally, InGaN-based nanowires were grown on an all-metal stack substrate (TiN/Ti/Mo) for a better electron transfer process [2]. In addition, we have applied a bifunctional ultrathin thiol-based organic surface treatment using 1,2-ethanedithiol (EDT), in which sulfur atoms protected the surface from oxidation. This treatment has dual functions, it passivates the surface (by the removal of dangling bonds) and creates ligands for linking Ir-metal ions as oxygen evolution centers on top of the semiconductor. This treatment resulted in a photo-catalyst that achieved 3.5% STH efficiency, in pure water (pH~7, buffer solution) under simulated one-sun (AM1.5G) illumination and without electrical bias. Over the tested period, a steady increase of the gas evolution rate was observed from which a turnover frequency of 0.23 $s^{-1}$ was calculated.

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# Towards GaN Hybrid Heterostructure Photoanodes for Photoelectrochemical Water Splitting Devices

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Gallium nitride (GaN) is one of the recently known photoanode for photoelectrochemical water splitting due to its tunable band gap and favorable band edge positions. However, the unavoidable surface defects in GaN induces surface Fermi level pinning and surface band bending which severely reduces its PEC conversion efficiency. Constructing hybrid heterostructure is the key to approaching better charge separation efficiency and light harvesting ability for PEC water splitting devices. Considering the fact, we have demonstrated the fabrication of hybrid GaN/ZnO, ZnS/GaN and GaN/MWCNTs/CoPi heterostructures by combining metal organic chemical vapour deposition, hydrothermal and atomic layer deposition methods. The as synthesized heterostructures are extensively characterized to investigate their physicochemical properties using FESEM, FE-TEM, XRD, XPS and Raman spectroscopy. After confirming the heterostructure formation, the thin film electrodes are further utilized as a photoanode for PEC water oxidation which showed superior PEC activity at (0V vs. Pt electrode), compared to pure GaN photoanode (Fig. 1). The superior PEC activity of hybrid heterostructures can be attributed to the co-catalytic effect of ZnS, ZnO, CoPi as well as intriguing physicochemical and electrical properties of MWCNTs. The possible PEC water splitting mechanisms have been investigated to describe the improved PEC performances of hybrid devices. It is apparent that the enhanced PEC performance of heterostructure is due to reduced electron and holes recombination, high electrode/electrolyte contact area and rapid electron transportation. These results highlight promising techniques to fabricate hybrid photoelectrodes for solar energy conversion devices.

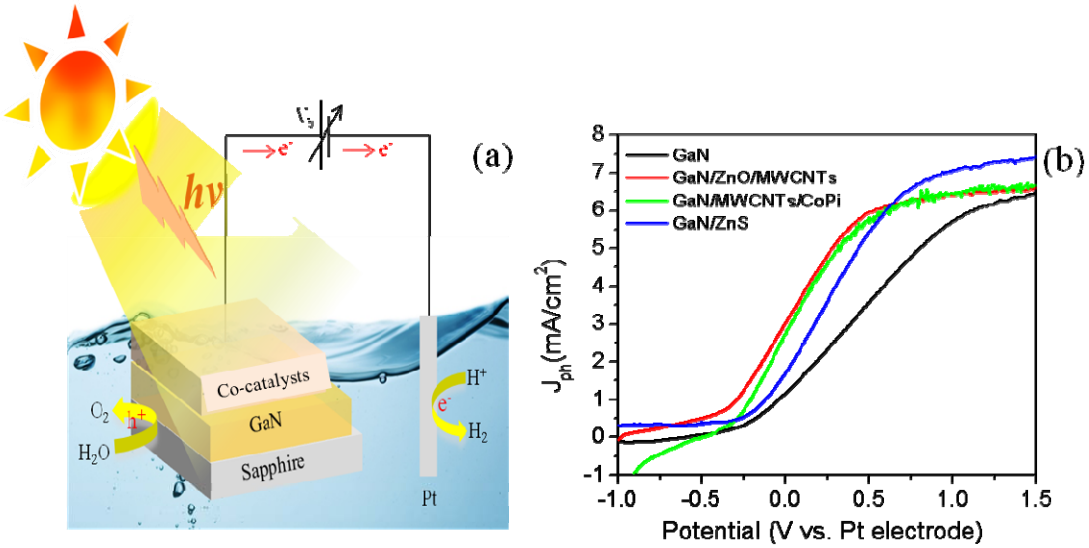


**Figure 1. (a) Schematic representation of PEC water splitting process (b) J-V curves of GaN hybrid heterostructure photoanodes under illumination**

# Graphene based active metadevices

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Recently, progress has been made over a class of new ultrathin structured surfaces [1] – so called metasurfaces, which can control the wavefront of the transmitted or reflected beam, and thus tailor the wave propagation in customer defined manner. A metasurface consists of arrays of artificial atoms with individually engineered optical properties. Unfortunately, however, very feature that makes these devices so useful, structurally dependent optical properties, also limits their potential for dynamically manipulating electromagnetic waves as micro/nano objects are difficult to modify post fabrication.

We present our recent progress in developing active metasurfaces which can control optical properties such as polarization [2], anomalous refraction, and focusing [3] by integrating graphene layer onto metamaterials with different functional unit cells. Benefitting from the electrically controllable optical properties, the developed graphene based meta-devices are expected to provide a myriad of important applications such as polarization controllers, ultrathin lenses and ultrasensitive sensors.

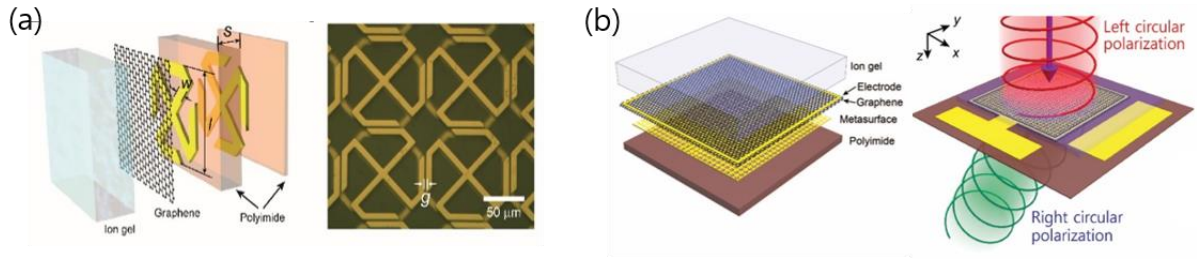


**Figure 1 (a) Graphene chiral metamaterials, (b) Graphene metasurfaces**

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# Extended whispering gallery polariton condensate from GaN single hexagonal wire at room temperature

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Exciton cavity polaritons (polaritons) offer hybrid state of excitons and photons, which is interactive quasi-particles providing a special solid-state system for exploration of bosonic statistics. Particularly, the polaritons in wide bandgap semiconductors such as GaN and ZnO can be observed even at room temperature due to strong oscillator strength and large exciton binding energy. Nevertheless, two-dimensional cavity fabrication of high-quality distributed Bragg reflectors [1,2] is still challenging due to the large lattice misfit and low refractive index contrast between AlN and GaN.

Here, we propose robust one-dimensional polariton system operating at room temperature. A selectively grown single GaN hexagonal microwire grown for symmetry control can generate high-qualified whispering gallery modes without any complicated fabrications. One-dimensional polaritons result from strong coupling between robust three-dimensional free excitons in GaN wire and one-dimensional whispering gallery photons. Exploiting large spatial overlap between photons and exciton, we firstly observe single mode one-dimensional polariton condensate with quasi-equilibrium to lattice temperature. Large Rabi splitting induced by large spatial overlap between excitons and photons can assist the thermalization of polaritons with enhanced scattering of polaritons for the condensate. We manipulate the ballistic propagation of the condensate along c-axis by tightly focused laser. This small footprint wire platform could be utilized for a wide range of interesting applications with robust polariton.

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# Adaptive multispectral detection using IR transmission spectra through quasi-3D circular coaxial aperture array

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In recent years, the physical phenomenon of a metal hole grid structure has been demonstrated to have a high potential for use as multispectral sensing elements or couplers of infrared (IR) imagers. This surface plasmon (SP) resonance structure is suitable for integration with low performance IR detectors such as quantum dots and quantum well based detectors due to a sufficient coupling strength to active layer via local field engineering, thereby enabling spectral responsivity modifications to implement the IR retina concept (algorithmic spectrometry) [1]. In contrast, SP structure is inadequate to modify the spectral responsivity spectrum of type-II superlattice, InSb and MCT based detectors due to their strong light absorption of the active layer. For this reason, we focused our attention on arrays of more complex unit cells offering additional degrees of freedom for controlling and optimizing the spectral responsivity of high performance IR detectors such as a subwavelength annular aperture (AA) array, first proposed by Baida [2]. The use of such structure has several advantages over SP structure in terms of enhanced transmission compared with that through comparable diameter hole array, the ability to control the transmission peak wavelength and angular insensitive response. However, the fabrication of AA structure for the IR region of interest (3-12 μm) is required to use electron beam lithography or interference lithography in order to create the narrow gap in AA structure, which gives rise to a generally low throughput or complicated fabrication process [3], respectively. To get one step closer to useful application (i.e. the need of large-area patterning capability), we designed an alternative, easy-to-fabricate quasi 3-dimensional (3D) circular coaxial aperture (CCA) array, which is capable of adding a minimal amount of additional effort to conventional detector fabrication flows, more specifically, we used a process based on standard photolithography to fabricate a large-area, uniform, low-cost quasi 3D CCA array as illustrated in Fig. 1.

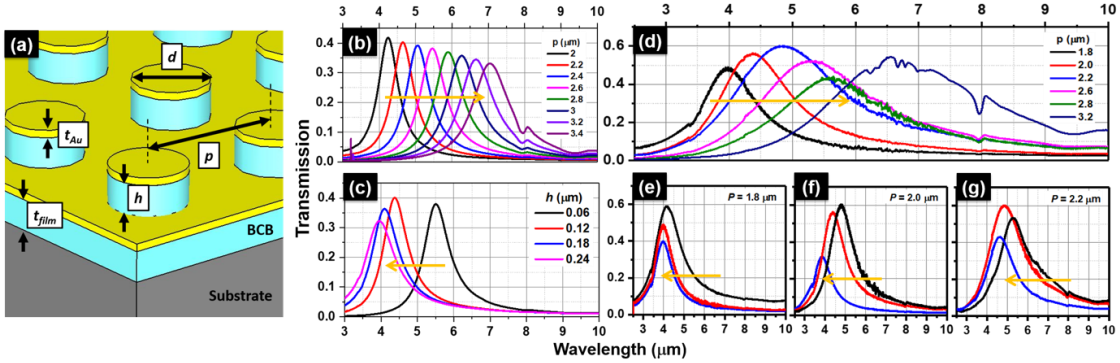


Fig. 1. (a) Illustration of CCA. (b, c) FDTD-simulated and (d-g) FTIR-measured transmission of fabricated CCA samples with various pitches ranging from 2 to 3.4 μm (upper) and post-height (lower). The orange arrow indicates the peak shift as *p* and *h* are increased.

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# Coherent quantum control and magnetism on atoms on surfaces

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Magnetometry having both high magnetic field sensitivity (energy resolution) and nanoscale spatial resolution has been of great interest and an important goal for applications in diverse fields covering physics, chemistry, material science, and biomedical science. The scanning tunneling microscope (STM) has been one of the most versatile tools for atomic-scale imaging, manipulation, and tunneling spectroscopy.

Here, we successfully combine electron spin resonance (ESR) and STM, coherently driving spin resonance of individual iron (Fe) atoms on surfaces (MgO/Ag(100)). A radio-frequency electric field (~20 GHz), applied at the tunneling junction, modulates the spin state of the Fe atoms. The spin resonance signal is detected by a spin-polarized tunneling current. The ESR signals from individual Fe atoms differ by a few GHz (~10 μeV) while the ESR linewidth is in the range of only a few MHz (~10 neV). Such a high energy resolution enables us to distinguish spin distributions down to single-atom level and to investigate weak magnetic interactions.

When we placed two Fe atoms close together with controlled atom manipulation, we found that the ESR signal from each Fe atom splits into doublet, of which separation depends on the distance between two atoms. Our measurements show $r^{-3.024\pm0.026}$ distance-dependent splitting, in excellent agreement of magnetic dipole-dipole interaction. We utilized this precisely measured dipolar interaction to determine the location and magnetic moment of unknown spin centers with sub-angstrom and one hundredth of Bohr magneton precision.

Our ESR-STM may promise the STM as a new and unique platform for a quantum sensor, investigating spin-labeled molecular structures and a quantum information processor, modeling quantum magnetism.

# High-fidelity and scale-up of quantum gates in spin-based quantum computing with quantum dots

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Qubit number and error rate are both key parameters to characterize the ability of quantum computing, but to upgrade them is still a challenge in spin-based systems. The underlying physics for the error rate is dephasing due to coupling to the environment noise, magnetic or electrical for the case of spin qubits with quantum dots (QDs). I will first discuss the spin dephasing measured for Si QDs and how to suppress it to raise the gate fidelity exceeding the threshold of fault tolerant computation. On the other hand, for the scale-up Si QDs can be used as a promising platform. Indeed intensive effort of developing Si integration circuit technologies and making CMOS-based QDs is going on. I will review the current development progress of Si-based qubit systems.

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# Generation of bright single photon and entangled photon pair using semiconductor quantum dot

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Single self-assembled quantum dot (QD) is an ideal system as an “on-demand” single photon source, due to its unique characteristics of exciton levels and near-100% quantum efficiency. With this promise there have been numerous reports on high-brightness, high-purity, and high-coherence single photons during last 20 years. Recently, research focus in this system is shifting to generation of entangled photon pair (EPP) due to its importance in perfectly secure long distance quantum secure communications and other quantum information applications. Biexciton-exciton cascade process in its exciton can provide “on-demand” EPP, which is equivalent to EPP generation in an atom. In this presentation, we will introduce recent progress on EPP generation using a self-assembled QD and design rules for efficient EPP generation, together with our recent progress.

# Coherent single photon emission with small inhomogeneous broadening from an InGaN single quantum-dot in a nano-pyramid

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Singe photon emitter based on semiconductor have been received much attention for quantum information processing due to electrical driven operation and compatibility with photonic structure. Especially, there is intense research interest in III-Nitride semiconductor quantum dot (QD) due to possibility of room-temperature operation and high degree of polarization.[1-5] However, large lattice mismatch between III-Nitride and substrate causes built-in electric field as well as crystal defect. These induce inhomogeneous linewidth broadening via spectral diffusion, which impedes the coherence properties of single photon.

In this work, we suggest single InGaN quantum dot in GaN nano-pyramid structure to reduce inhomogeneous linewidth broadening. The nano-pyramid structure provides suppressed built-in electric field and superb crystal quality. In addition, we observed small height QD with 2 nm thickness, which can reduced a permanent dipole moment. Based on these properties, It significantly suppress the electronic fluctuation nearby QD, which leads to improved coherent single photon with small inhomogeneous linewidth broadening. The result proposes an advanced growth geometry to bypass inhomogeneous linewidth broadening, and ultimately overcome well-known obstacles for quantum information processing.

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# Band Gap dependent on temperature in Epitaxial Films of Perovskite $Ba_{1-x}La_xSnO_3$

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$Ba_{1-x}La_xSnO_3$ (BLSO) is a perovskite-based transparent conducting oxide. In BLSO (0-0.06%) epitaxial films grown on MgO substrates, we have investigated the temperature dependence of the band gap. and measured the band gap by using visible-ultraviolet spectrophotometry. We detected a band gap increasing from 3.5eV to 4.2 eV as the doping concentration increases.

# Highly efficient phosphor-free warm white light emitting diodes based on InGaN/GaN ring structures fabricated by selective area growth and wet etching

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The GaN-based lighting-emitting diodes (LEDs) have attracted a lot of attention as a lighting source due to the direct band gap energy covering the full visible range, as well as their good thermal, chemical, and mechanical stabilities. In spite of those merits, the GaN-based lighting-emitting diodes suffer from low efficiency issue at long wavelength range from green to red. This is a main reason why blue LEDs with relatively higher efficiency were used as the source of white LEDs by combining yellow emitting phosphor. Commercial white LEDs still have problems such as low color rendering index (CRI) and high correlated color temperature (CCT). Recently, because the CCT and the CRI are becoming the most important factor of white light for smart lighting application, the new kinds of phosphor are required for red component to obtain white light with low CCT ( < 4,500 K) and high CRI (Ra>75). However, the red phosphors are rare-earth elements, and using phosphors lead to degradation problems with decreased luminous efficiency, result in unintentional change of light color. In order to avoid problems related with phosphors, many group have recently attempted to fabricate three-dimensional (3D) structure of GaN to solve disadvantage of present white LEDs. Even though many research group have reported significant results, they still suffer from the low efficiency problem in long visible spectral range.

In this work, we introduce a method for the fabrication of the new 3D structure by bottom-up growth with KOH chemical wet etching. This combined method reduces a polarization field with a strain relaxation and forms the inversed semi-polar facet with high indium composition in 3D structure. We performed cathodoluminescence and photoluminescence experiments to characterized optical properties of the QWs on formed etched structure.

Conclusively, the phosphor-free white LEDs are successfully demonstrated with the high luminescence efficiency under current injection.

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# Characterization of $InAs_{0.81}Sb_{0.19}$ based Mid-Infrared photovoltaic detectors with $In_{0.2}Al_{0.8}Sb$ barrier layer grown on GaAs substrate

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In this paper, $InAs_{0.81}Sb_{0.19}$-based hetero-junction photovoltaic detector (HJPD) with $In_{0.2}Al_{0.8}Sb$ barrier layer was grown on GaAs substrates. By using technology computer aided design (TCAD), a design of a barrier layer that can achieve nearly zero valance band offsets was accomplished. A high quality $InAs_{0.81}Sb_{0.19}$ epitaxial layer was obtained with relatively low threading dislocation density (TDD), calculated from high-resolution X-ray diffraction (XRD) measurement. This layer showed a Hall mobility of 15,000 $cm^2/V \cdot s$, which is the highest mobility among InAsSb layers with around Sb composition of 20%grown on GaAs substrate. Temperature dependence of dark current, photocurrent response and responsivity were measured and analyzed for fabricated HJPD. HJPD showed the clear photocurrent response having long cutoff wavelength of 5.35 μm at room temperature. It was observed that the dark current of HJPDs is dominated by diffusion limited current at temperatures ranging from 200K to room temperature from the dark current analysis [1]. Peak responsivity of HJPD exhibited the 1.18 A/W and 15 mA/W for 83K and room temperature under zero bias condition even without anti-reflection coating (ARC). From these results, we believe that HJPDs could be an appropriate PD device for future compact and low power dissipation mid-infrared on-chip sensors and imaging devices [2].

*This work was supported by KIST Institutional Program of Flag-ship (2E28180); National Research Foundation of Korea (NRF-2017M1A2A2048904);*

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# Temperature-dependent and time-resolved photoluminescence of multilayer CdTe/ZnTe quantum dots

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Semiconductor quantum dots (QDs) with large nonlinear optical response, ultrafast signal switching, quantum efficiency and higher temperature stability are important in future photonic devices, optical data storage, and optical computing [1]. QDs are formed as a consequence of strain relaxation of layer to layers which usually encountered the problem of non-uniformity and the difficulty to control the dot size and density. It raises the important issue of control the size, density and uniformity because the optical properties of the QD-based photonic devices depend on the size, density and uniformity of QDs. It was demonstrated that the control of growth parameters, the reorganization of the surface into islands by post-growth thermal annealing, the capping layer, and effect of different substrates could successfully manipulate the size, density and uniformity of QDs [2]. In addition, due to the intermixing effects into layer-by-layer assembly of QDs, which result in enhanced electron-hole (e-h) wave-function overlap, providing an additional tool to understanding of carrier dynamics and the relaxation processes in quantum-confined nanostructures. In this work, we investigate the temperature dependent photoluminescence (PL) and time-resolved PL spectra for the multilayer CdTe/ZnTe QDs to understand their carrier dynamics. We demonstrate that the continuum states of intermixing layers/wetting layers cause the enhance confinement of carriers in CdTe QDs.

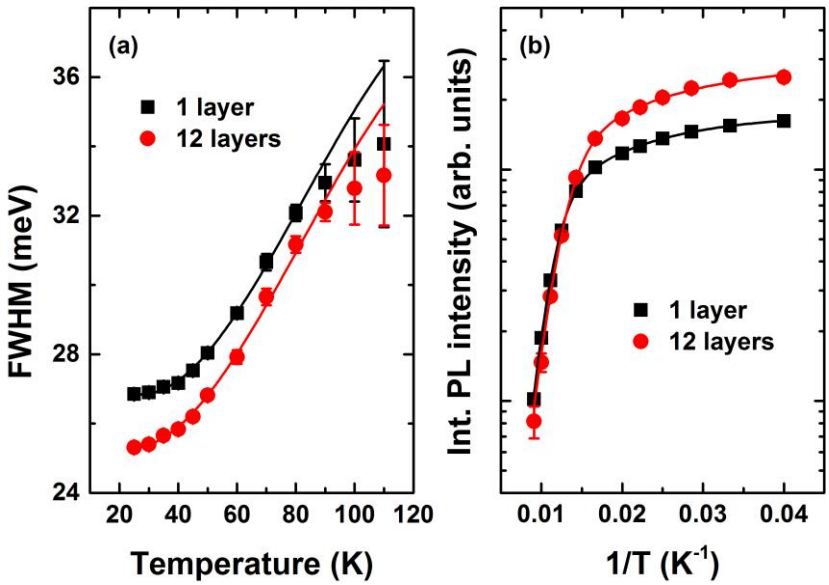


Figure 1. (a) Measured (symbols) and calculated (solid lines) of the FWHM, and (b) Integrated PL intensities as a function of reciprocal temperature for stacked CdTe/ZnTe QDs.

## References

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# Crystal structure and electrical properties modulation of Al-doped $HfZrO_2$ thin films by ALD

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As the size of semiconductor device is scaled down, electronic components such as gate oxide, DRAM capacitor are more important for high-k materials. Among the variety high-k materials, The oxide thin films based on Zr and Hf can be realized crystal structure such as monoclinic, tetragonal and cubic by deposition condition and phase stabilizer doping. Especially, when having tetragonal phase, it is known to have high dielectric constant about 40. In addition, it has relatively wide band gap and is highly compatible with Si integration technology. So, the high-k materials based Zr and Hf are applied actual device.[1] Recently, $HfZrO_2$ films exhibits ferroelectric and anti-ferroelectric properties by Zr content. Many researches have been carried out for application to ferroelectric devices.[2] However, A lot of study on the electric characteristic of phase transition by doping in thin films based ZrO2 and $HfO_2$ has been carry out but change of the dielectric properties by doping in binary oxide films based $HfZrO_2$ film is insufficient compared to availability.

In this paper, We researched structure, electric properties and ferroelectric characteristic of the $HfZrO_2$ thin films doped by controlling Al content. Also, the Al dopant was doped two method(supercycle and sequential cycle) by using PEALD. Then, the characteristics of Al doped $HfZrO_2$ films were measured by ellipsometer, XRD, XPS and semiconductor parameter analyzer.

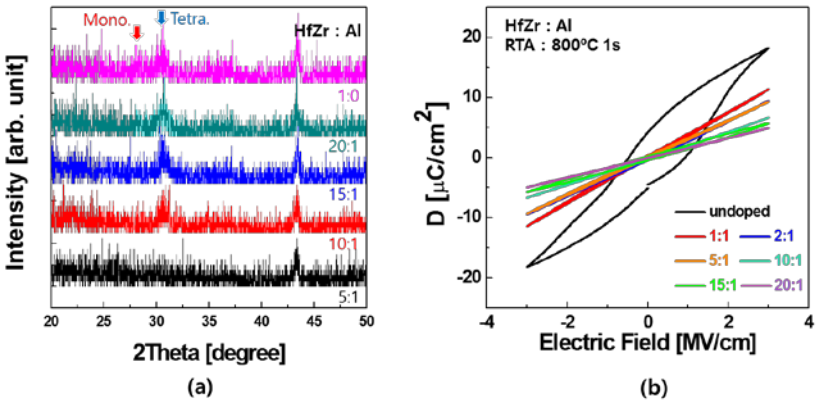


**Figure 1. (a) XRD patterns and (b) Displacement properties of by Al doped $HfZrO_2$ thin films**

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# Properties of ZnO:Tb Thin Films Deposited on Quartz Substrates by Magnetron Sputtering

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Recently, wide band gap semiconductors, such as ZnO, $ZnAl_2O_4$, and $ZnGa_2O_4$ have attracted much interest as possible transparent conducting oxide materials. In particular, the wide band gap structures are widely investigated as promising materials for reflective optical coatings in optoelectronic applications. In this work, we report the effects of deposition temperature on the properties of ZnO:Tb thin films deposited on quartz substrates by radio-frequency magnetron sputtering. The optimization of deposition temperature under the sputtering deposition is essential for the development of high-quality ZnO-based thin films and devices. A ZnO:Tb target was synthesized by using a solid-state reaction method with ZnO (99.99%) and $Tb_4O_7$ (99.9%). All of the ZnO:Tb films showed a significant dependence on the growth temperature. For the thin film deposited at deposition temperature of 100 $^oC$, the optical transmittance spectra indicate an average transmittance of 87% at 600 nm. As the growth temperature increases, the optical transmittance shows a significant decreasing tendency. The optical band gap was determined by using the Tauc's model and parabolic relation, and its value was found to be 3.3 eV for the thin film deposited at 100 $^oC$. These results can be explained by the correlation with the microstructure of the films. The optimization of the deposition temperature may provide a way to control the optical band gap energy.

# Photoluminescence Properties of Eu-doped $CaNb_2O_6$ Thin Films Grown by Radio-Frequency Magnetron Sputtering

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Recently, niobate materials have attracted considerable interest because their remarkable properties make them suitable for a wide range of applications in catalysis, sensors, displays, and solid-state lighting. In particular, calcium niobate ($CaNb_2O_6$) deserves attention in the phosphor field, due to its high optical absorption in the ultraviolet region, excellent chemical stability, and strong blue luminescence. Europium doped calcium niobate ($CaNb_2O_6:Eu^{3+}$) thin films were deposited on quartz using a radio-frequency magnetron sputtering technique at different growth temperatures in the range of 100–400 °C. The films grown at different deposition temperatures showed different microstructural and optical properties. The structural characterization indicated that the phosphor films were preferentially (311) oriented. The surface morphology of the thin films exhibited spherical-shaped crystallite grains with an average diameter of 40 nm, and agglomerated islands were observed at a growth temperature of 400 °C. Increased growth temperature resulted in an increase in both the transmittance and photoluminescence intensity, arising from better crystallinity. The emission spectra of the films under excitation at 265 nm showed five dominant emission peaks centered at 541, 597, 618, 656, and 707 nm. The maximum intensity in orange-reddish emission at 618 nm was observed for the phosphor thin film deposited at 400 °C. These results suggest that the $CaNb_2O_6:Eu^{3+}$ thin film is a promising candidate for use as a red-emitting phosphor thin film for displays and photonic device applications.

# Effect of Deposition Temperature on the Properties of Tb-doped $SrMoO_4$ Thin Films Deposited on Quartz Substrates

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$Tb^{3+}$-doped $SrMoO_4$ phosphor thin films were deposited by radio-frequency magnetron sputtering at different growth temperatures. The X-ray diffraction spectra revealed a tetragonal $SrMoO_4$ structure with the main peak occurring at the (112) plane, regardless of the growth temperature. The average crystalline particle size was determined to be 110 nm using scanning electron microscopy, and cobble-like shapes were observed for all the thin films. The highest average transmittance of 87.2% in the wavelength range of 400–1100 nm was observed for the thin film deposited at a growth temperature of 100 °C, where the optical band gap energy was found to be 4.38 eV. The emission spectra of $SrMoO_4$:$Tb^{3+}$ phosphor thin films under excitation at 273 nm exhibited a major emission band at 549 nm and four weak emission bands at 469, 493, 591, and 625 nm. The strongest emission was green at 549 nm arising from the $^5D_4 \rightarrow {}^7F_5$ magnetic dipole transition. The intensity of the magnetic dipole transition is greater than that of the $^5D_4 \rightarrow {}^7F_6$ (493 nm) electrical dipole transition, indicating that the $Tb^{3+}$ ions in the host lattice occupy sites without inversion symmetry. These results suggest that the optimum green emission can be realized by modulating the growth temperature.

# Performance Improvement of GaAs/AlGaAs QWIP on Si substrate by $CF_4$ Plasma Treatment

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Infrared detectors have been applied in various fields[1]. A typical infrared detector is an MCT. But it is poor in uniformity, difficult to grow, expensive. Conversely, Quantum well infrared detectors(QWIPs) have the advantage of relatively low cost, high uniformity, high yield[2]. these characteristics show that we offer an alternative for monolithic integration with readout integrated circuits(ROIC). In order to obtain images by conventional methods, infrared focal plane arrays(FPAs) were fabricated and the process was integrated with ROIC using indium bumps. However, the indium bump has a disadvantage in that the manufacturing process is complicated and additionally requires an epoxy process and a chemical-mechanical polishing(CMP) process[3]. In recent study, we have solved this problem by using metal wafer bonding (MWB) and epitaxial lift-off (ELO)[4]. In addition, we have succeeded in developing infrared detectors with improved responsivity by using $CF_4$ plasma treatment. We compared the performance of as grown QWIPs and QWIPs on Si samples before comparing the effects of plasma and confirmed the variations with various plasma conditions. In order to examine the performance of the developed device, we confirmed through Fourier transform infrared (FT-IR), photoluminescence(PL) and I-V characteristics. We performed plasma treatment with reactive ion etching(RIE) under the following conditions. Figure 1. (a) shows that the largest PL value is measured at 180 seconds, which shows that the responsivity of QW is increased. In Figure 1. (b), The PL peak intensity increases from 60 to 180 seconds, It means operating temperature, responsivity, detectivity are all enhanced.

Plasma Condition

| Gas | Pressure | Temperature | RF Power | Time |
|---|---|---|---|---|
| CF4 | 50 mtorr | 300K | 50W | 60/120/180/240s |

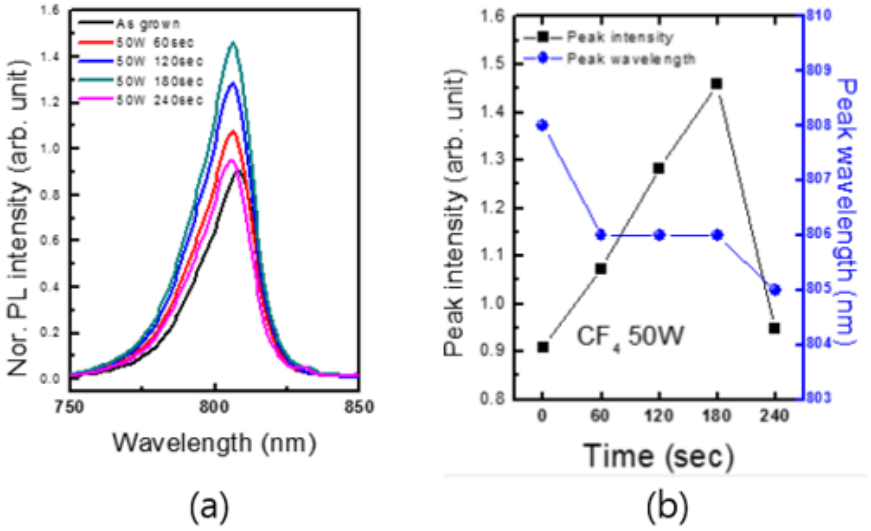


**Figure 1. (a) Result of PL(photoluminescence) according to various conditions (b) Changes in intensity and wavelength with plasma exposure time**

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# Investigation of GaInP/GaAs QW structure Heterojunction Solar Cells

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Various efforts have been made to improve spectral response of photovoltaic cells. The highest current conversion efficiency have achieved in III-V compound semiconductor multi-junction (MJ) photovoltaic(PV) cells in which several *pn* junctions with different bandgap semiconductor materials are stacked to cover different spectrum [1]. As different approach, quantum wells (QWs) or quantum dots (QDs) having different bandgap can be inserted in absorption layer. The open circuit voltage($V_{oc}$) is determined by smaller energy bandgap($E_g$) material when two different bandgap materials are used and is approximately 0.6 $E_g$ of the smaller bandgap material. However, if QW or QD materials are inserted in absorption layer of PV cell, it is possible to increase absorption spectrum with less decrease in $V_{oc}$. In this report, we have proposed a simple GaInP/GaAs QW heterojunction structure which is lattice matched to GaAs substrate and fabricated solar cells. The characteristics of the QW structure solar cells were compared with single heterojunction structure solar cells. The short-circuit current density was increased and the $V_{oc}$ was reduced from 1.44V to 1.35V which is much less than the 0.6 of GaAs $E_g$.

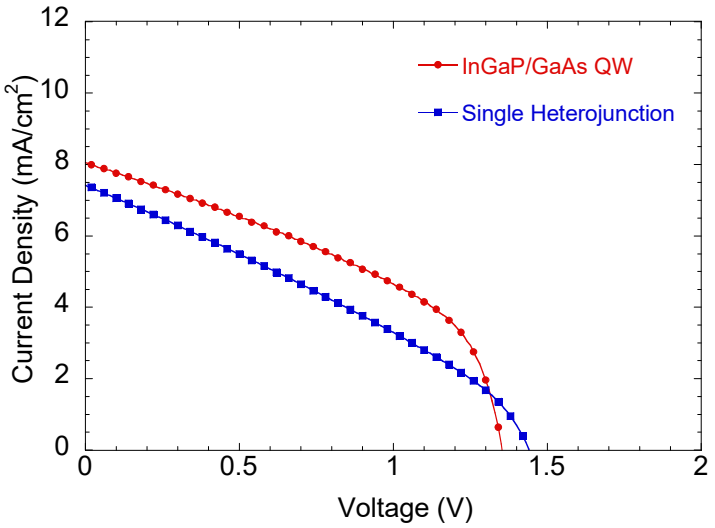


Fig. 1. Comparison of current density-voltage characteristics between a GaInP/GaAs QW heterojunction and a single GaInP/AlGaInP heterojungtion cells for 5mm×5mm area

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# E-mode GaN HEMT devices and PA MMICs for 5G mobile handsets

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As the data rates of information in mobile systems increases, the need for 5G systems has increased. In order to transmit more data, the operating frequency is higher than 4G systems. 28GHz, one of the high frequency bands proposed as global standards by Korea, was chosen for 5G systems. The GaN high electron mobility transistor (HEMT) device used in the high output power amplifier is basically a normally-on device, but a normally-off device is required for use in handsets of 5G systems.
An enhanced-mode (E-mode) AlGaN/GaN HEMT was developed by using ETRI GaN HEMT process. We designed and fabricated E-mode HEMTs and characterized device performance. To shift the threshold voltage of HEMTs we applied the $Al_2O_3$ insulator to the gate structure and adopted the gate recess technique. The large signal modeling of GaN HEMT devices was extracted using Angelov-GaN model by IC-CAP program. The PA MMIC is designed in two stages for higher gain and four transistors (4 x 50 um) are connected in parallel at the final stage for output power.
The simulations of power amplifier show a maximum output power of 30 dBm (1 W), a power gain of 15 dB and PAE (Power Added Efficiency) of 25 % at frequencies of 26 and 30 GHz. The chip size of the PA MMIC is 2.8 mm x 2.8 mm.

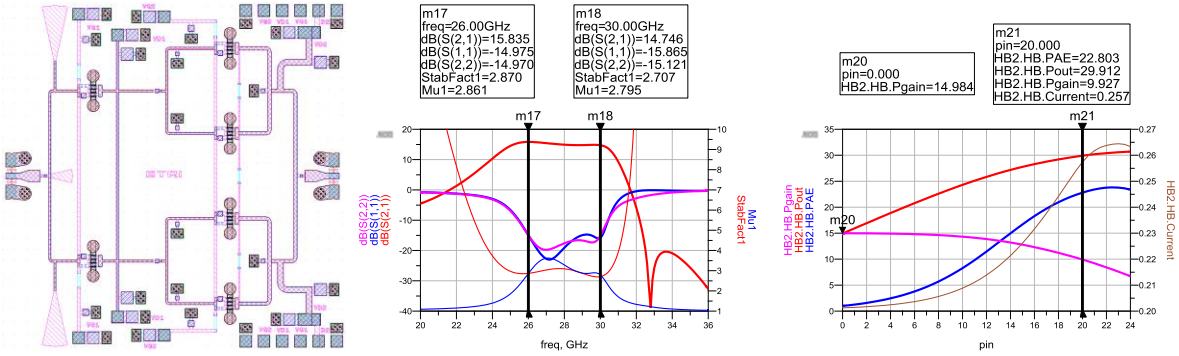


**Figure 1 Layout of PA (left), frequency response(S-parameter)(middle), power results(right)**

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# Annealing of Sn doped ZnO thin films grown by radio frequency powder sputtering

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We report the post-annealing effect of Sn doped ZnO (ZnO:Sn) thin film grown on sapphire(001) substrate. During thermal annealing in a vacuum atmosphere, ZnO:Sn thin film is transformed into a porous thin film. Possible mechanism is presented based on X-ray diffraction, scanning electron microscopy, and energy dispersive X-ray analyses. The Sn atoms acting as a catalyst dissociate the Zn-O bond and subsequently the Zn and O atoms are vaporized, leading to the formation of pores in the ZnO:Sn thin film. Pore size varies from 30 to 200 nm. We also found that Sn atoms segregate to form SnO or $SnO_2$ phases.

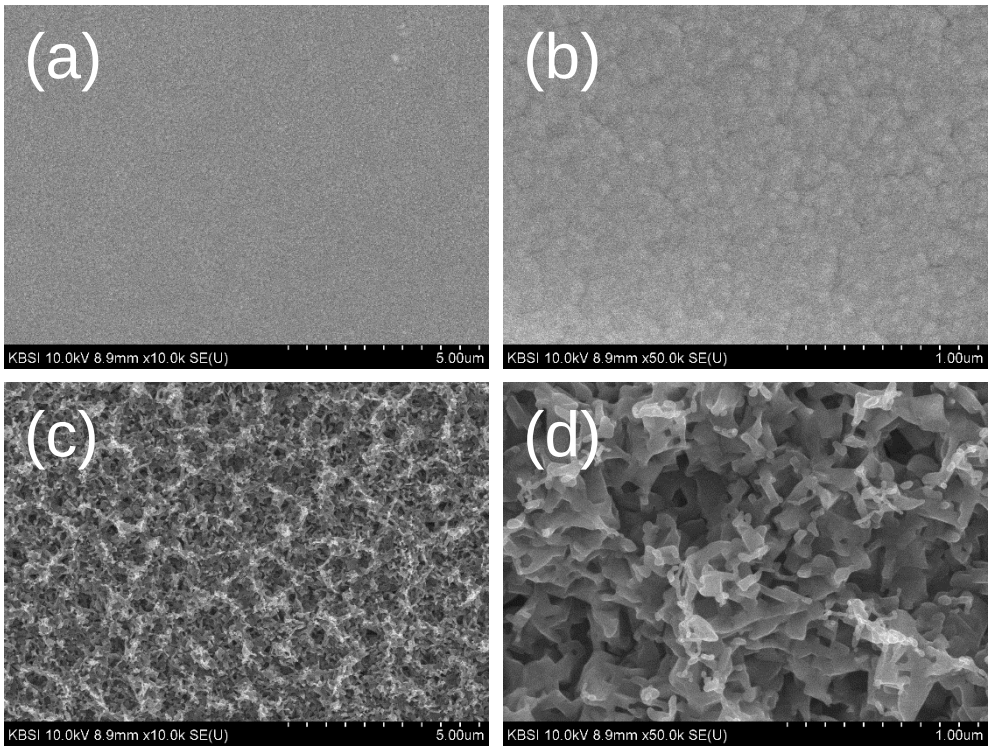


Figure 1. SEM images of the (a),(b) as-grown sample and the (c),(d) annealed sample at a temperature of 950 °C.

*This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) through SRC (NRF-2015R1A5A1009962) and basic science research program (2015R1D1A3A01020547).*

## Reference

[1] H. R. Lee *et al.* to be submitted (2018).

# Direct conversion of β-$Ga_2O_3$ thin films to β-$Ga_2O_3$ nanowires by annealing in a hydrogen atmosphere

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We report the annealing process of Au/β-$Ga_2O_3$ thin films in a hydrogen atmosphere leading to the growth of β-$Ga_2O_3$ nanowires (NWs). Annealing in a hydrogen atmosphere results in the evaporation of β-$Ga_2O_3$ thin films, which are subsequently converted to β-$Ga_2O_3$ NWs through the vapor-liquid-solid (VLS) process assisted by Au nanocrystals. The VLS growth starts at 600 °C and progresses with increase in the annealing temperature to 800 °C. β-$Ga_2O_3$ NWs are formed on the surface of the host β-$Ga_2O_3$ thin films, resulting in the formation of a homogeneous β-$Ga_2O_3$ NW/β-$Ga_2O_3$ thin film structure. Based on structural analyses using X-ray diffraction, scanning electron microscopy, and transmission electron microscopy, a possible mechanism for the growth of β-$Ga_2O_3$ NWs is presented.

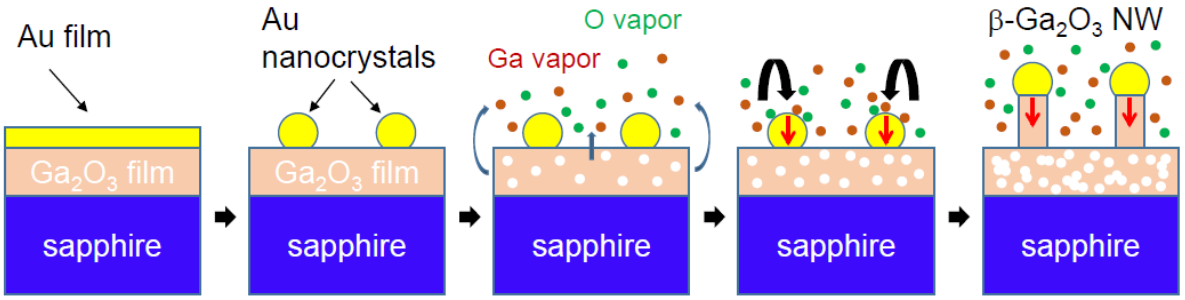


Figure 1. Schematic of the possible mechanism for direct conversion of the β-$Ga_2O_3$ thin film into the β-$Ga_2O_3$ NW in a hydrogen reduction atmosphere. The NW growth takes place via the VLS process assisted by Au nanocrystal seeds [1].

*This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) through SRC (NRF-2015R1A5A1009962) and basic science research program (2015R1D1A3A01020547).*

## Reference

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# Hydrothermal process of hydroxyapatite nano-structures

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Hydroxyapatite (HA) nano-structures were successfully deposited on sapphire(0001) and Ti substrates by hydrothermal process. Dependence of pH variation on the morphology of HA nano-structures was examined. HA nano-flowers were observed on sapphire(0001) substrates, while nano-beams were formed on Ti substrates. This is attributed to the crystallographic orientation and surface roughness of substrates. Details of the growth mechanism was discussed.

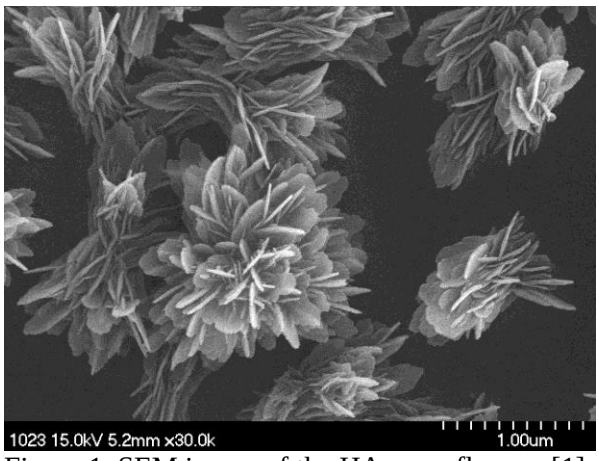

Figure 1. SEM image of the HA nano-flowers [1].

*This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIT) through SRC (NRF-2015R1A5A1009962) and basic science research program (2015R1D1A3A01020547).*

## Reference

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# Inductively Coupled Plasma Dry Etch and Wet Treatments for The Improvement of Surface Roughness of β-$Ga_2O_3$

Hoon-Ki Lee[1], Sakhone Pharkphoumy[1], Daeyoon Baek[1], Hyun Gwon Park[1], Chel-Jong Choi[1], Sang-Sik Choi[2], Deok-Ho Cho[2], Dae-Woo Jeon[3], Kyu-Hwan Shim[1,2]*

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The inductively coupled plasma (ICP) process combined with wet chemical treatment using sulfuric acid-hydrogen peroxide mixture (SPM) or tetramethyl ammonium hydroxide (TMAH) solution was employed to achieve the high-density dry etching of undoped or Sn-doped single crystalline β-$Ga_2O_3$. The ICP dry etching was performed using gas mixtures of $Cl_2$ and $BCl_3$ ($Cl_2/BCl_3$ =40/30 sccm) with a bias power of 400 W and an inductive power of 700 W. The ICP process led to an increase in the values of root mean square (RMS) roughness for both undoped and Sn-doped single crystalline β-$Ga_2O_3$ wafers due to the formation of post-etch polymer residue associated with by-product during plasma etching process. The additional SPM treatment was effective in the removal of ICP etch residue for both samples, resulting in the decrease in their RMS roughness. The values of RMS roughness of undoped and Sn-doped β-$Ga_2O_3$ samples were measured to be 4.5 and 3.6 nm, respectively. However, these values were higher than those measured from as-received samples. Namely, the removal of the plasma-induced physical damage by SPM treatment was insignificant. A further improvement of dry-etched surface uniformity was achieved using post-TMAH treatment. For instance, the RMS roughness of both samples with ICP process coupled with TMAH treatment decreased, of which values were 2.8 and 0.9 nm, respectively. This implies that TMAH treatment dissolved the damaged layer caused by ICP process and simultaneously removed ICP-induced polymer residue. Namely, post-TMAH treatment was essential to minimize surface roughening, which frequently occurs during ICP process.

# Effect of S passivation using aqueous and alcoholic ammonium sulfide ($(NH_4)_2S$) solutions on the specific contact resistivity of Ni contact to InAs-capped $In_{0.56}Ga_{0.47}As$ epilayer

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We have investigated the effect of S passivation using aqueous and alcoholic ammonium sulfide solutions ($(NH_4)_2S$) on the specific contact resistivity of Ni contact to InAs -capped $In_{0.56}Ga_{0.47}As$ epilayer. Prior, the Ni deposition using DC sputtering system, the samples were surface-treated using diluted $(NH_4)_2S$ solutions by water and isopropyl alcohol in the ratio of 1:100 by volume for 100 sec at room temperature. The specific contact resistivity of Ni contact to InAs-capped $In_{0.56}Ga_{0.47}As$ epilayer with the surface treatment using aqueous and alcoholic $(NH_4)_2S$ solutions was measured to be $1.06 \times 10^{-7}$ and $4.09 \times 10^{-9}$ $\Omega cm^2$, respectively. From X-ray photoelectron-spectroscopy (XPS) analysis, As-S/As-In bonding ratios were calculated to be 3.1 and 0.8 for the InAs surfaces chemically treated by alcoholic and aqueous $(NH_4)_2S$ solutions, respectively. This implies that alcoholic $(NH_4)_2S$ treatment was more effective in the S passivation of InAs-capped $In_{0.56}Ga_{0.47}As$ epilayer than aqueous $(NH_4)_2S$ one. Superior S passivation by the surface treatment using alcoholic $(NH_4)_2S$ solution was also confirmed by the electrostatic force microscopy (EFM) examinations, showing that alcoholic $(NH_4)_2S$-treated surface showed more homogenous distribution of electrostatic potential than aqueous $(NH_4)_2S$-treated one.

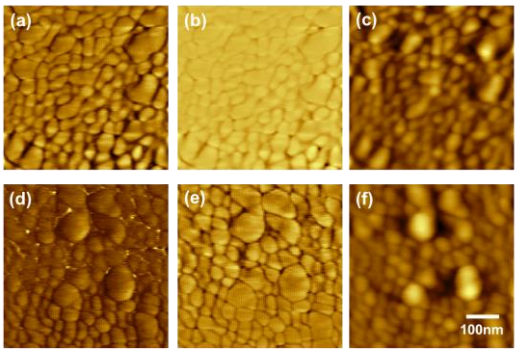


Figure. (a, d) surface potential, (b, e) phase shift, and (c, f) topography images taken from InAs-capped $In_{0.56}Ga_{0.47}As$ epilayers with aqueous (a – c) and alcoholic (d – e) $(NH_4)_2S$ treatments using EFM examinations.

# Effect of the hydrogen diffusion on Electrical performance and Reliability of IGZO based TFT with dual dielectric layers

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Transparent amorphous oxide semiconductors which exhibit high mobility, excellent uniformity, good transparency and applicability for the low-temperature process have potential to serve as active layer in TFTs. In recent years, research on the oxide semiconductor has been concentrated and finally it has settled on the industrialization. However, a complete understanding of the stable and high performance characteristics on the amorphous oxide semiconductor is important to ensure the success of future electronics application that leverage this technology. In this study, we investigated the effect of the oxygen and hydrogen concentration in the oxide semiconductor TFTs. Samples were fabricated on an undoped Si wafer. The Mo electrodes were used both as gate and source/drain electrodes, which were deposited by sputtering and patterned by lithography and wet etching. A dual dielectric layers was composed of SiOx/SiNx layers by plasma-enhanced chemical vapor deposition (PECVD). A 50 nm a-IGZO film was sputtered by RF sputtering at 100 $^{o}$C temperature using IGZO target (In:Ga:Zn=1:1:1 atomic ratio) and then post annealed at various temperatures for 1 hour to improve the contact and stability of transistors. To determine the possible correlation between hydrogen diffusion and TFT performance, the chemical composition and concentration profiles of hydrogen(H), indium(In), gallium(Ga), and zinc oxide(ZnO) were analyzed using X-ray photoelectron spectroscopy (XPS) and secondary-ion mass spectroscopy characterization (SIMS).

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# Electrical characteristics of nano SOI FET for 1 transistor memory

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Silicon on insulator FET memory cells have been fabricated with 28nm node technology and the device structure consists of double gates and undoped floating body, covered partially by the control gate and positively charged polysilicon gate with a $P^+$ anode and an $N^+$ cathode[1]. The operation principle of the device is using energy band modulation by the front and back gate bias. Without any voltage applied, the PIN diode structure has a carrier injection barrier on both side of the 7nm thick floating body on very thin buried oxide (10nm). Anode voltage ($V_A$) is high enough to lower the injection barrier of holes, and holes are injected and flow from $P^+$ anode to $N^+$ cathode, which reduces the electron injection barrier and electrons flow from cathode to anode. This positive feedback provides nearly zero swing slope in the I-V characteristics owing to vertical turn on. In this study, DC and AC transient memory characteristics are presented. In fig 1, the DC characteristics show sharp switching from '0' state to '1' state and hysteresis curves. The on/off current ratio is over $10^7$. The width of the memory window increases as the front gate voltage is increased. The memory operation process is shown in fig 2 with writing and reading '0' and '1' state (W0-R-W1-R bias process) by voltage pulses. The writing process of the device is storing carriers in the SOI channel due to the floating body. By lowering the front gate voltage, the carriers in the body channel is removed, writing the '0' state. With lowered front gate voltage and anode voltage pulse, the carriers are injected to the body channel which is writing the '1' state. The reading process is giving a short anode voltage pulse to sense the current of the device. In '1' state, the current is high due to carriers stored in the body channel. On the other hand, there is no carriers stored in the body channel at '0' state hence very low current is observed.

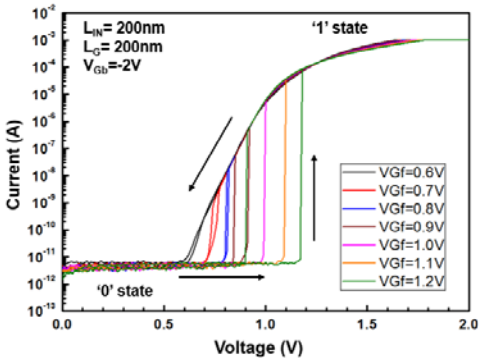


Fig. 1. I-V curve of $Z^2$-FET

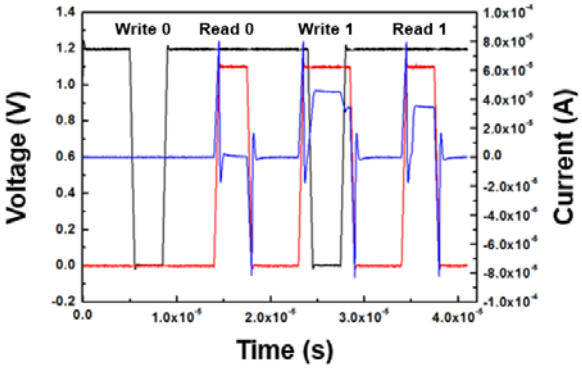


Fig. 2. Memory operation of $Z^2$-FET

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# Material design with lattice distortion for phase-change memory

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For over a decade, phase-change memory (PCM) has been investigated as a next-generation device component, which stores data with reversible phase transition between crystalline and amorphous phases by controlling electrical pulses. PCM can be applied to new memory with fast operation speed, long retention, and low power consumption.

The distortion of atomic structure is one of key factors to design the novel phase-change materials for fast electrical switching. The material of Ge-Sb-Te system was designed with control of vacancy and distortion with change of composition[1]. As alternative way to control the distortion, we suggest the method to add dopants in phase-change materials. Sb atoms in $In_3SbTe_2$ (IST) are partially substituted by Bi dopants[2]. As a result, the phase transition from crystalline to amorphous phases for reset operation became faster than the pure material.

To find an ideal dopant that maximizes the effect of the distortion, we calculated the enthalpy change and distortion angle by 29 elements doping through computational high-throughput screening (HTS) method. Yttrium are suggested as one of proper dopants, and the characteristics of Y-doped IST (YIST) has been investigated. The crystal structure of IST is distorted with substitutional Y at In site. The changed inter-planar angles can be observed using TEM, and these values are matched with the maximum range of inter-planar angles calculated by density functional theory (DFT). Molecular dynamics calculation shows that the IST becomes considerably stabilized by Y dopant, and the distorted YIST are melted more quickly than the IST. Using the YIST, PCM devices are fabricated and electrical performance shows that the devices are operated with faster switching and lower power than GST and IST PCMs, which will be benefit for 3D XPoint memory with fast speed, long retention, and low power consumption.

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# Wet chemical etching of p-n-p-n structure for two-terminal vertical DRAM

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Dynamic random-access memory (DRAM) has been employed broadly with its fast operation speed and low power consumption. Conventional DRAM consists of 1 transistor and 1 capacitor, which acts as storage of charges. However, it faces critical challenges including scaling down, and integration because of the existence of capacitor. Many attempts have been tried to solve it such as modifying structures from 2-D to 3-D shaped, which stacked or trench-capacitor, or amending high-k dielectric materials to store sufficient charges at least 25fF/cell. It seems that these approaches have worked well to overcome scaling down, but it would be confronted limitations in the future. The 1T-capacitorless structure could be fundamental alternative of conventional DRAM. The thyristor consists of n++ cathode/p+ base/n+ base/p++ anode, would be a candidate. After introducing the concept of a thin capacitively coupled thyristor [1], various researches related with T-RAM have been reported with its fast speed, high $I_{on}/I_{off}$ ratio, great integration density [2-4]. To be operated as memory device, proper thickness and doping concentration of each layers are required. From the precise simulation to be obtained as optimized these factors, thyristor which epitaxially grown above silicon wafer was prepared.

In this work, we fabricate the two-terminal vertical DRAM by using KOH wet chemical etching to epitaxial wafer with p-n-p-n structures. KOH solutions could be used for anisotropic wet etching, and it depends upon orientation to crystalline planes, so it produces vertical side walls. The etched depth with respect to time is measured by atomic force microscopy, and then etch rate is introduced. SEM images are acquired to check the interface and surface condition. Electrical properties of memory characteristics including bi-stable I-V feature related with etching time are also presented. We obtain average latch-up voltage from 2V to 2.5V, and latch-down voltage from 0.5V to 1V. Also, it shows the $I_{on}/I_{off}$ ratio around $10^4$ to $10^5$.

*This work was supported by KSRC (Korea Semiconductor Research Consortium) support program for the development of the future semiconductor device.*

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# Luminescent Properties and Morphology of Porous Silicon Nanowires

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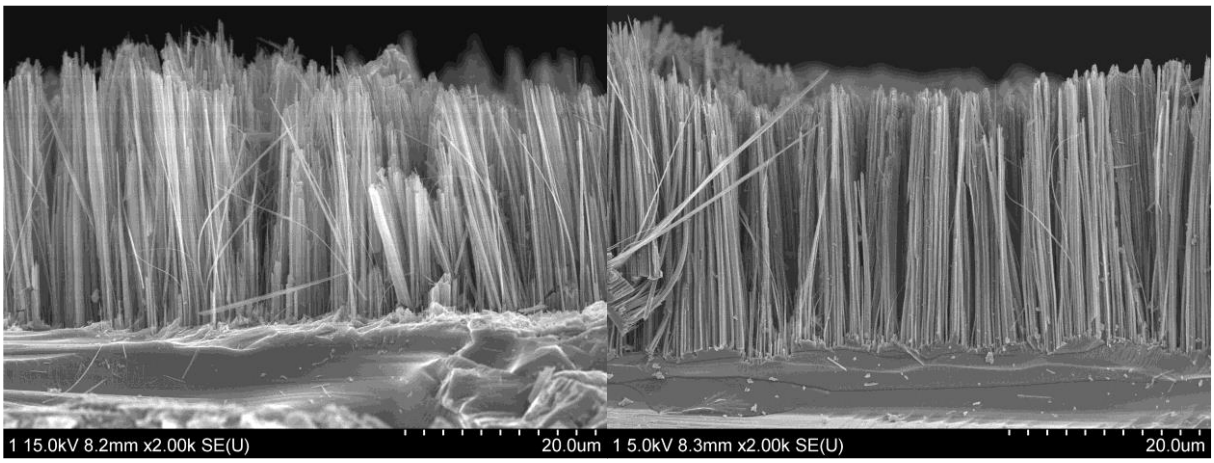
We report the fabrication of porous silicon (PS) nanowires through a metal-assisted chemical etching in a solution of hydrofluoric acid and hydrogen peroxide. The morphology and luminescence properties of PS nanowires were characterized by scanning electron microscopy, transmission electron microscopy, and luminescence spectroscopy. The SEM image of PS nanowires indicates that PS nanowires are formed uniformly over the whole silicon wafer and shows the porous structures. TEM image of the PS nanowires whose porous diameters are less than 5 nm showed a selected area electron diffraction (SAED) pattern but a lattice fringe indicating that they are crystalline sponge-like porous structure.

Acknowledgment : This research was financially supported by the Agency for Defense Development and the National Research Foundation of Korea (NRF) funded by the Mi nistry of Education (NRF-2016R1D1A1B03933216).



# Fabrication of microholes in silicon wafers by wet-chemical etching

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Microholes exploit the coupled interactions of light and matter to achieve unique properties [1-3]. In particular, metallic microhole structures exhibit strong resonances when illuminated with ultraviolet, visible, or near-infrared light in the vicinity of their surface plasmon polariton frequencies. However, techniques employed to fabricate microholes (e.g., focused ion beam, soft lithography, nanoimprint lithography, X-ray lithography, and reactive ion etching) are time consuming and require expensive equipment and professional staff. In the present experiments, we developed a method to create microholes by wet-chemical etching a Si substrate. The etching shape and crystalline structure of the samples were investigated by FE-SEM, atomic diagram and lattice structures.

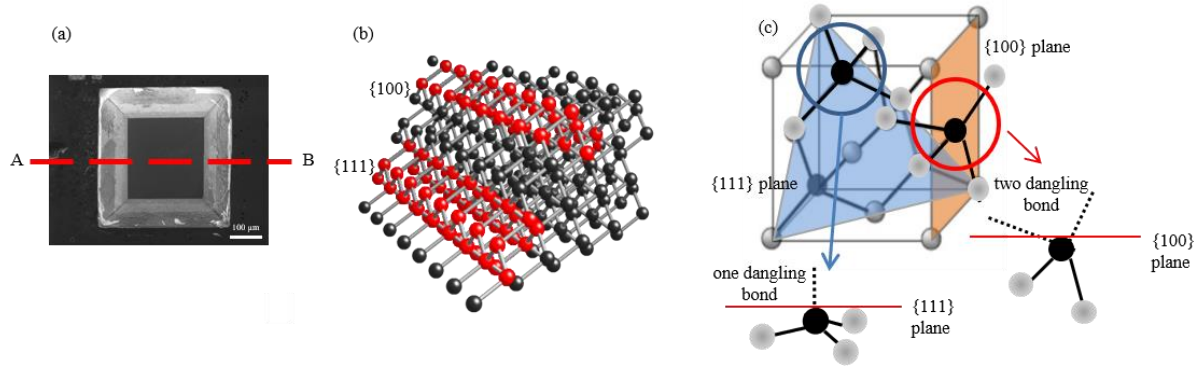


**Figure 1 (a) FE-SEM image of Si(100) etched for 4 h at 70 ℃. (b) Three-dimensional atomic schematic diagram of Si(100). (c) {100} and {111} plane lattices of a diamond structure.**

Figure 1 (a) shows a top-view FE-SEM image of a Si(100) sample etched for 4 h at 70 ℃, and Fig. 1 (b) outlines the three-dimensional atomic structure of Si. Figure 1 (c) shows the diamond structure, which is adopted by Si crystals, and the shape of the lattice when it is cut along the {100} and {111} planes, which have two and one dangling bonds, respectively.

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July 1 (Sun.) ~ 5 (Thu.), 2018 / Jeju, Korea

# Phosphorus Out-diffusion in $n^+/p$ Shallow Junctions of Ge Epilayer Grown on Si Substrate Formed Using $PH_3$ Plasma Immersion Ion Implantation (PIII)

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$n^+/p$ shallow junctions of Ge epilayer grown on Si Substrate were formed using $PH_3$ plasma immersion ion implantation (PIII) combined with rapid thermal annealing (RTA) process. 120 nm-thick p-type Ge films with a carrier concentration of $10^{17}$ $cm^{-3}$ were epitaxially grown on p-type Si substrates using rapid thermal chemical vapor deposition (RTCVD) system. $PH_3$ PIII was performed with an energy of 2 kV for 5 min at room temperature, followed by RTA processes in the temperatures ranging from 400 to 600 °C for 1 min in flowing $N_2$ ambient. Hall measurement and four point-probe systems were employed to investigate the electrical properties of samples. Hall measurement showed that PIII combined with RTA process led to the transition of p- to n-type carrier conduction of Ge epilayer, implying the formation of $n^+/p$ shallow junction. However, in the entire RTA temperature range, their sheet resistance was higher than that of as-grown p-type Ge epilayer. This could be associated with the out-diffusion of implanted phosphorus (Ph) atoms in Ge epilayer occurring during RTA process. Such a Ph out-diffusion behavior was confirmed by the annealing time dependency of the sheet resistance. Namely, the sheet resistances of Ge epilayer with PIII coupled with RTA process above 500 °C for 10 min were close to that of as-grown p-type Ge epilayer. Moreover, Hall measurements showed that these samples exhibited p-type carrier conduction. In other word, implanted Ph atoms were mostly out-diffused during prolonged RTA process. The results demonstrated here strongly suggests that the introduction of capping layer to prevent the out-diffusion of Ph atoms is essential to form highly doped $n^+/p$ shallow junctions of Ge epilayer.

# Optical Properties of Single-Crystal $PdSe_2$

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We measured the transmittance of $PdSe_2$ in the UV-Vis-NIR regions and obtained the absorbance. The bulk $PdSe_2$ reveals evidence of an indirect gap at around 0.4 eV at room temperature. We measured the polarized transmittance in the ab plane of $PdSe_2$ and performed spectroscopic ellipsometry measurements in the visible region. From our ellipsometry data, we extracted the optical constants of $PdSe_2$ and the absorption coefficient from the extinction coefficient. Our data reveal weak optical anisotropy in $PdSe_2$ in the ab plane.

# Quasiparticle interference (QPI) in twisted bilayer graphene

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We calculate the effect of quasiparticle interference (QPI) on the spatial variations of the local density of states in twisted graphene in the neighborhood of an isolated impurity. A number of characteristic behaviors of interference are identified in the Fourier transformed spectrum of scanning tunneling microscope (STM), which can map the energy dependent local density of states (LDOS) by measuring the position dependence of the current /voltage characteristics. Combining the powerful technique, STM, the QPI features may be analyzed to reveal information about the momentum space structure of the electronic states [2] of twisted bilayer graphene. Twisted bilayer graphene, in which the lattice mismatch between neighboring layers gives rise to an additional potential modulation, creates novel electronic features distinct from graphene. Its most fascinating aspect is the Fermi velocity decreases with decreasing the twist angle between the two layers [3]. We investigate quasiparticle interference in twisted bilayer graphene in two frameworks: the tight-binding model and the effective continuum model based on the Dirac equation. We use the T-matrix approximation to analyze the effect of a localized impurity on the local density of states in twisted bilayer graphene. We also calculate the dependence of QPI on the twisted angle. Combing the experimental data from STM measurements for various energies and twisted angles, our calculated QPI results provide the scattering information of twisted bilayer graphene.

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# Spatially resolved Raman spectroscopy of monolayer graphene domains

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We report spatially resolved Raman results of domain boundaries, defects, strains, and strain fluctuations in monolayer graphene films. Raman imaging is an efficient probe to identify spatial variations of D, G, and 2D peaks that provide useful information on the graphene domain structures. For example, Raman images of the spectrally integrated intensities of the D and G peaks ($I_D$ and $I_G$) revealed individual domain boundaries and their corresponding sizes. In particular, Raman images of $I_D/I_G$ and $I_{2D}/I_G$ ratios and spectral widths of 2D peaks ($\Gamma_{2D}$) showed that the domain boundaries consisted of the overlapped graphene. Interestingly, the $I_D$ image showed that defect density was significantly increased within the domains for the graphene with large domain size. The correlation analysis between the G and 2D peak energies revealed that biaxial tensile strain was more developed in the graphene with large domain size. In addition, the $\Gamma_{2D}$ images showed that strain fluctuations were more pronounced in the graphene with large domain size. Therefore, we conclude that the electrical performance of graphene can be significantly affected by not only domain sizes but also defects, strains, and strain fluctuations.

*This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) (Grant No. 2016R1D1A1B03935270) funded by the Ministry of Education.*

# Improving conductivity of graphene/silver nanowire hybrids by plasma treatment

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Graphene-silver nanowire (AgNW) hybrids are considered as a potential replacement for the conventional ITO electrodes owing to its transparency, high conductivity, and, most importantly, the flexibility. However, the conductivity of these hybrids could still be improved. Polyvinylpyrrolidone (PVP) coating around AgNW weakens the contact between wire to wire and wire to graphene and undoped CVD synthesized graphene has higher sheet resistance owing to its polycrystalline nature and the presence of defects. Post processing treatments such as high temperature annealing, acetone washing, and plasma etching can remove PVP coating and thus increase the conductivity of silver network. Chemical or physical doping of polycrystalline graphene can further enhance its conductivity [1,2]

In order to enhance the conductivity of the hybrids, a post processing treatment with low power nitrogen plasma was utilized. Over 34% reduction in sheet resistance was obtained within 45s of plasma treatment at 20W of power, as shown in Fig. 1.This reduction of sheet resistance is comparatively higher than that of annealing on the hybrid for 30 min at $180^0$C, which is 3.6% .The highest figure of merit (FOM) for the hybrid was 234, which is higher than that of AgNW electrode alone.

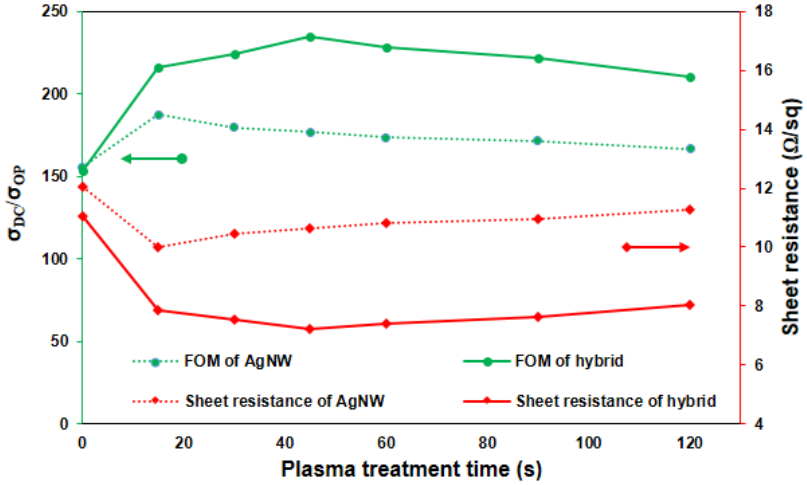


**Fig. 1. Variation of FOM and sheet resistance of the hybrid and AgNW electrode alone with plasma treatment time**

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# Ag nanowires-doped-graphene/Si-quantum-dot heterojunction optoelectronic devices

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Recently, graphene/Si heterojunction devices have attracted considerable attention due to the outstanding properties of graphene, such as perfect transparency and high carrier mobility.[1] Even though Si is a principal material in the semiconductor industries, it is of limited use in optoelectronic device applications due to the small- and indirect-bandgap.[2] To solve this problem, many researchers have employed Si quantum dots (SQDs) in optoelectronic devices based on quantum confinement effect. Here, we report excellent properties of SQDs-based solar cell and photodetectors (PDs) by employing Ag nanowires (NWs)-doped-graphene as a transparent conductive electrodes (TCE). Typical photovoltaic parameters of the solar cells, such as open circuit voltage, short circuit current, fill factor, and power conversion efficiency (PCE) are greatly improved by employing Ag NWs-doped-graphene TCEs. In particular, the PCE shows a maximum of 16.2%. The PDs show photocurrent/dark current (on/off) ratio of $10^5$ at 0 V bias, meaning "self-powered". Other typical PD parameters such as responsivity, external quantum efficiency (EQE), detectivity, and linear dynamic range are 0.32 – 0.65 $AW^{-1}$, ~ 85 %, ~ 4.5 x $10^{12}$ cm $Hz^{1/2}W^{-1}$, and 83 dB in the range of 500 to 900 nm, respectively. These results suggest that the Ag NWs-doped graphene/SQDs heterojunctions are very promising for their applications in optoelectronic devices.

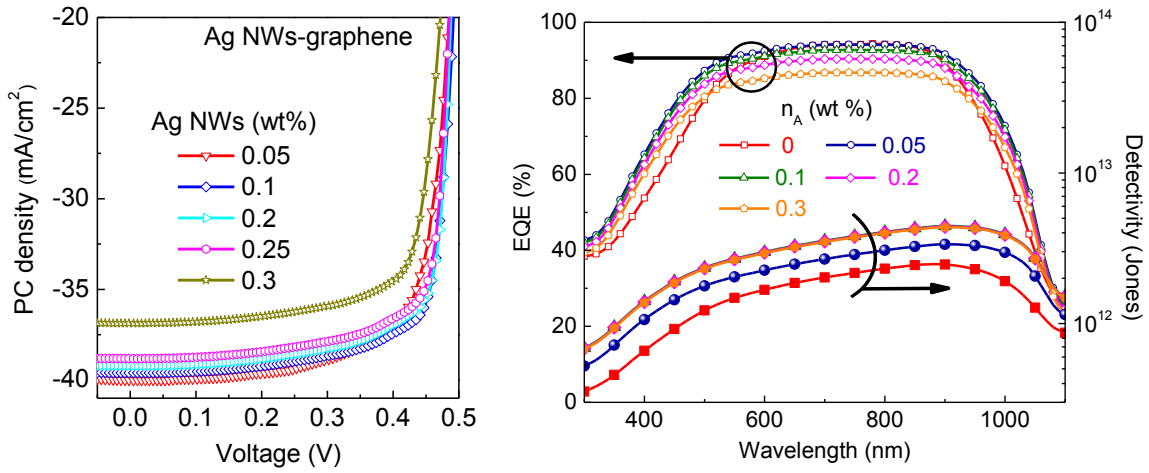


**Figure 1 Photocurrent density-voltage curves of solar cells for various doping concentrations (left), Spectral EQE/detectivity of PDs for various doping concentration (right)**

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# Two Color Two Photon Excited Photoluminescence of Graphene-Rhodamine 6G-Graphene Sandwich System

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Recently, graphene has been introduced as a good chemically-enhanced Raman scattering (CERS) enhancer through the carrier transfer due to the lacking in the band gap.[1,2] In this work, we chose a highly fluorescent rhodamine 6G molecule and studied the ultrafast carrier dynamics of graphene/R6G/graphene sandwich systems to detail the nature of charge transfer between R6G and graphene. We observed the ultrafast dynamics from R6G molecules (absorption: ~ 530 nm) resulting from two color (pump: 750~850 nm, probe: 1040 nm) two photon fluorescence (TCTPF). A timely-matched pump & probe injection allowed the enhanced TCTPF from graphene/R6G/graphene sandwich structure while the signatures of the electron transfers are developed by delaying the probe. The defect sites of the graphene played critical roles in transferring carriers between graphene and R6G molecules. The ultrafast dynamics probed in the lower wavelength region (400~450 nm) shows a faster (<10 ps decay constant) electron-electron scattering than the higher wavelength region (600~650 nm) from R6G/Gr. Interestingly, the usage of high power pump illumination (>20 mW) allowed the remaining of electrons to the defect sites for a longer time period (>100 ps).

*This work is supported by basic research programs (18-BT-01) DGIST funded by the Ministry of Science of Korea.*

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# Fermi energy pinning and bending of *n*-type $MoS_2$ and *p*-type $WSe_2$ thin layer on ferroelectric *c*-domains of $LiNbO_3$

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Emerging properties of transition metal dichalcogenides (TMDCs) with ferroelectric (FE) materials are a promising combination showing high performance in electronic properties [1]. The dipolar nature of the TMDCs and FEs provide a new platform to applications of non-volatile memory field-effect transistors (FETs). In this study, a few $MoS_2$ and $WSe_2$ thin layers on *c*-cut $LiNbO_3$ (LNO) single crystals were prepared. Polarization states in LNO crystals can give variation in electrical performance in *n*-type $MoS_2$ layers and *p*-type $WSe_2$ layers. The $MoS_2$/$WSe_2$-LNO heterosturctures were characterized by scanning probe microscopy. Electrical transport measurement was conducted by conductive-atomic force microscopy. Kelvin probe force microscopy was used to investigate variation in surface potential depending on the thickness of $MoS_2$ layers and $WSe_2$ layers. During the measurement, some of the samples were illuminated with a laser light to elucidate the surface band bending. In addition, electrical performance of $MoS_2$ layers and $WSe_2$ layers was varied depending on the polarization state of LNO. Therefore, we can control the electrical characteristics of $MoS_2$ layers and $WSe_2$ layers by controlling the ferroelectric characteristics.

[1] H. J. Jin, W. Y. Yoon, and W. Jo "Virtual out-of-plane piezoelectric response in $MoS_2$ layers controlled by ferroelectric polarization", *ACS Applied Materials and Interfaces* **10**, 1334 (2018).

# Enhanced electrical performance of Si-In-Zn-O thin film transistor by employing graphene as a capping layer

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Amorphous oxide semiconductors have been studied widely as active layers for high-performance active-matrix transistors.[1] Recently, the electrical performance in amorphous Si-Zn-Sn-O thin film transistors (TFTs) was enhanced by employing a metal capping layer and simulating current conduction mechanism.[2] Here, we report a-Si-In-Zn-O (a-SIZO) TFTs by using graphene as a capping layer for further enhancing the electrical properties, as shown in Fig. 1. The channel of the a-SIZO TFTs are first fabricated by photolithography patterning method and wet etching process. The width/length of the channel are 250/50 μm, respectively. Graphene layer is subsequently transferred to the patterned a-SIZO on $SiO_2$/Si substrate. Ti/Al films of 10/50 nm thicknesses for source, drain, and MC layers are deposited on graphene/a-SIZO/$SiO_2$/Si substrates through shadow mask during evaporation. The graphene layer is then etched by reactive ion etching using $O_2$ plasma. To minimize the damage to the a-SIZO active region, RF power, gas pressure, and gas flow rate are properly controlled. The properties of the TFTs with graphene capping layers are analyzed by electrical measurements and simulation. These and further details of the results are discussed based on possible physical mechanisms.

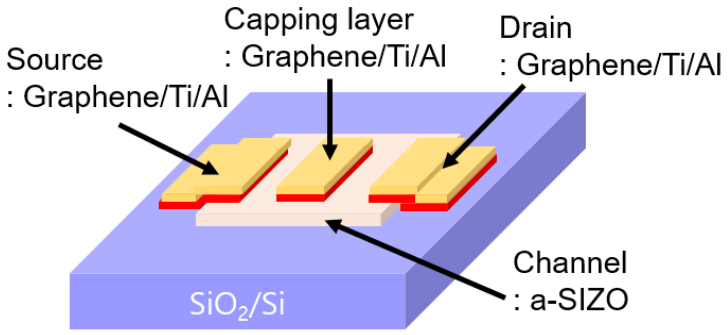


**Figure 1 Schematic illustration of a-SIZO TFT with graphene capping layer.**

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# Studying the Temperature Dependence of Optical Characteristics of monolayer $MoSe_2$ by Spectroscopic Ellipsometry

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Recently, a numerous number of the two-dimensional (2D) materials of transition metal dichalcogenides (TMDCs) are paid more attention because of their tunable bandgap. Molybdenum diselenide ($MoSe_2$) is well known as one of TMDCs that has a potential substitute for silicon or organic semiconductors in high-tech transistors, sensors, and photodetectors. The systematic study on dielectric function of $MoSe_2$ depending on temperature is indispensable for designing and understanding device application.

In this work, monolayer $MoSe_2$ is formed by selenization of $MoO_3$ which is fabricated on a sapphire substrate by using pulsed-laser sputtering. The dielectric function of 2D $MoSe_2$ was measured in 0.74 - 6.42 eV energy range at temperatures from 31 to 300 K by spectroscopy ellipsometry. In Fig. 1, the existence of eight critical points (CPs) (*A*, *B*, *C*, and $E_{I\text{-}V}$) is clearly seen at 31 K and some of which are newly observed peaks. Especially, a tightly bound negative trion peak appeared as a result of greatly enhanced Coulomb interactions in monolayer $MoSe_2$, arising from reduced dielectric screening in 2D structures. The blue shift and enhancement of critical points (CPs) at low temperature are observed, which are understood by the reduction of lattice constant and electron-phonon interaction. We believe that these results facilitate improved monolayer studies and refinements of the devices based on 2D $MoSe_2$.

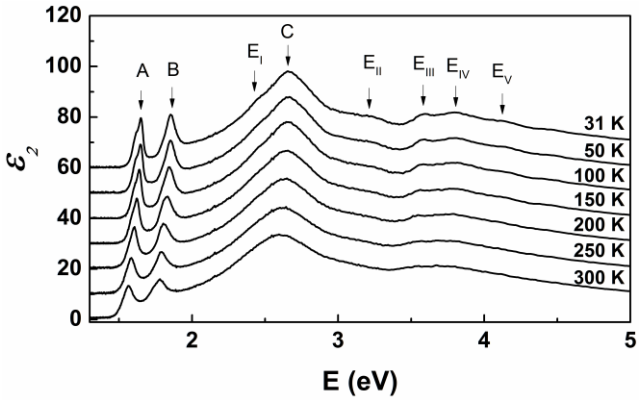


Fig. 1 Imaginary parts of $\varepsilon$ of monolayer $MoSe_2$ for temperatures from 31 to 300 K.

# Self-guided Growth of sub-millimeter-long Vanadium Dioxide Nanowires Driven by Directional Ostwald Ripening

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The large-scale assembly of nanowires with controlled orientation on various surfaces still remains as one challenge preventing their integration from practical devices. Here, we present a simple, general approach based on spontaneous conversion of thin film to nanowires in the reducing environment, which makes it possible to grow highly crystalline vanadium dioxide nanowires with extremely narrow size and length distributions. The assembly of the nanowires was driven by directional Ostwald Ripening process, that is, the transport of liquid droplets became directional by designing the oxide substrate to be V-grooved. This simple change made the nanowires sub-millimeter long and align at the bottom of the V-grooves. The nanowires were also found to be have uniform metal-insulator transition properties. Through this approach, we could fabricate $VO_2$ nanowire arrays to detect the magnitude of strain with highly sensitivity and high accuracy by chemical transfer method on the PDMS substrate. It is believed that it is a new concept to the synthesis of a lot of nanowires systems simply and generally.

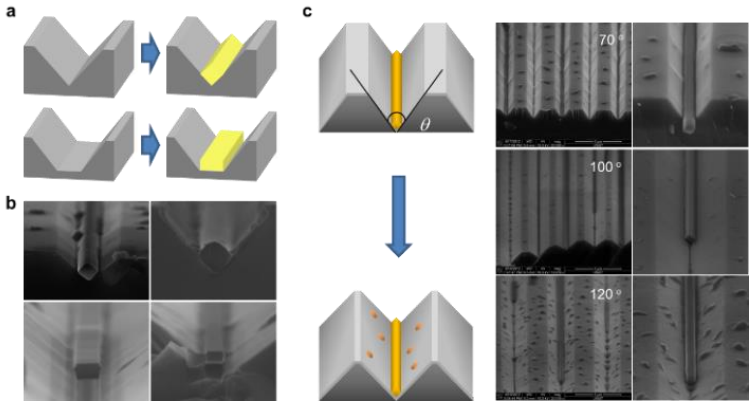


**Figure 1. (a) Cross-section schematic and (b) SEM image of $VO_2$ nanowires with controlled morphology. (c) The SEM image of $VO_2$ nanowires according to V groove angle.**

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# Ultrafast dynamics of center-of-mass exciton confinement states in a single CdTe/CdMnTe heterostructure

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Size control is often used to control the energy levels of nanostructures. In the case of strong confinement, the energy levels are dominated by confinement size. However, as the ratio of the exciton Bohr radius become comparable to the confinement size, the Coulomb interaction becomes as important as the confinement energy. In particular, when a heterostructure becomes considerably thick, the exciton confinement states need to be considered in the center-of-mass coordinate. Although the novel center-of-mass-exciton (CMX) confinement states can be verified by narrow level spacing (a few meV), the confinement nature is unknown whether it is the case of 2-dimensional or 3-dimensional confinement. Temperature dependence of radiative decay time enables to evaluate confinement dimensionality in terms of effective density of states. In this work, we have investigated the dimensionality nature of the CMX confinement states by using temperature dependence of radiative decay time. Also, its ultrafast intra-relaxation among the fine confinement levels were observed by excitation-correlation technique.

A single CdTe/CdMnTe heterostructure was used, where the exciton-Bohr radius (CdTe) (~ 6 nm) is far small compared to the well width (~ 144 nm) as the large exciton binding energy (~ 10 meV) in comparison to the confinement energy of electron (~ 1 meV) and hole (~ 0.2 meV). The CMX confinement states were calculated theoretically and compared with the observed photoluminescence spectrum [1~3], whereby the fine energy levels of CMX states were identified up to N=18 state. As shown in Fig.1, temperature dependence of radiative decay time was also obtained by time-resolved photoluminescence and integrated photoluminescence spectrum. Temperature dependence of the emission energy, radiative decay time, and spectral linewidth suggest that our CMX states are likely localized up to ~ 12 K. However, as temperature is increased, the localization effect is gradually suppressed and a linear temperature dependence appears up to 35 K. In this case, the released CMX states can be considered a 2 dimensional exciton [4]. Also, we observe the intra-relaxation among the fine confinement levels occurs within ~ 100 ps.

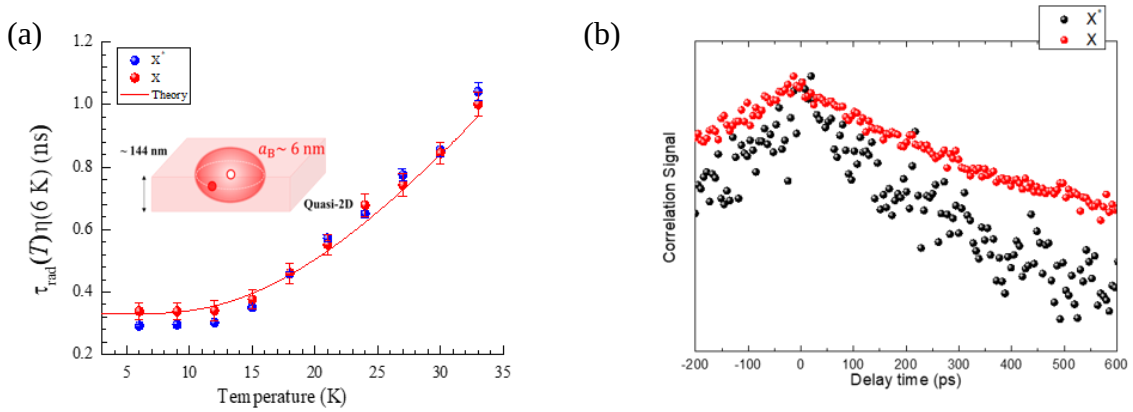

**Figure 1 (a) Radiative decay time of the ground (X) and excited (X*) CMX confinement states for temperature. (b) Correlation Signal of the ground (X) and excited (X*) CMX confinement states for delay time**

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# $MoS_2$/Si 2D-3D Semiconductor Heterojunction Photodiodes Fabricated by High-Working Pressure Plasma-Enhanced Chemical Vapor Deposition

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There have been intensive research efforts to fabricate 2D $MoS_2$-based optoelectronic devices, since $MoS_2$ has sizable band gap (1.2 ~ 1.8 eV) and large absorption coefficients at visible wavelength range. 3D semiconductors, such as Si, GaAs, and GaN, have advantages of various reliable device technologies and well-established fabrication processes in mass-production level. 2D-3D hybrid semiconductor heterojunctions have attracted great attention since they possess benefits of both 2D emergent materials and 3D conventional semiconductors. In this work, we fabricated trilayer-$MoS_2$/p-type Si heterojunctions using a high-working pressure plasma-enhanced chemical vapor deposition technique and carried out dark and light current-voltage (*I-V*) measurements of them. Dark *I-V* characteristics of the $MoS_2$/Si heterojunctions showed rectifying behaviors. The temperature dependent *I-V* measurements and analyses based on 3D *p-n* junction diode models helped us to understand the carrier transport mechanism of the $MoS_2$/Si heterojunctions. Under illumination of a green light (wavelength: 532 nm), the heterojunction exhibited negligibly small and large photocurrent in forward and reverse bias, respectively. The photocurrent did not much depend on the magnitude of the reverse bias voltage. The measured photocurrent was linearly proportional to the laser power, indicating that trapping and detrapping of the photo-generated carriers at defect states could not significantly suppress the collection of photo-carriers. The heterojunction also showed fast photoresponse: the photocurrent dropped only about 30% while increasing the operation frequency from 100 to 3900 Hz. All these results suggested that our plasma-enhanced growth technique could produce high quality $MoS_2$/Si 2D-3D heterojunctions for optoelectronic applications.

# Spatially resolved Raman thermometry of graphene/hBN heterostructure

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We report a heat dissipation study of an electrically biased 2D graphene/hexagonal boron nitride (hBN) field-effect transistor (FET) structure using *in situ* Raman spectroscopy. To study the heat generation and dissipation in the graphene/hBN FET, we performed spatially resolved Raman scattering over the entire graphene channel (length: 26 μm, width: 6 μm). In situ Raman spectra revealed that the $E_{2g}$ phonon energy of the hBN layer shifted downward with increasing bias voltage, indicating that temperature of the FET channel increased. Average temperatures of the hBN substrate underneath the graphene channel were 43 (48) and 76 (92) ºC at $V_{sd}$ = 10 (−10) and 15 (−15) V, respectively. The temperature values of the hBN of the biased FET were consistent with analytical calculations, except for the case of $V_{sd}$ = −15 V at which the measured average value was higher than the calculated one. It suggested that local doping effect might occur owing to a locally high electric field under a high bias.

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# Characteristics of defect-assisted carrier lifetime in tungsten diselenide single crystal

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Next-generation integrated circuits will require newer materials as well as building block for homojunction to meet essential requirement of logic devices. Fortunately, their criteria are expected to be filled by an abundance of atomically thin two-dimensional materials. Tungsten diselenide($WSe_2$) crystal has been widely known by the community as p-type semiconducting transition metal dichalcogenides. It has been used as p-n junction diode and inverter. Although many studies have reported the ambipolar characteristics of $WSe_2$, the true p-type transport by effective p-doping have rarely been published. Thus, challenges such as controllable and reliable doping method to turn electrical and optical property of the materials are remained so far. To date significant efforts on surface charge transfer doping method has been reported. This surface functionalization relies on molecular attachment of various chemical solutions [1-3].

In this work, the possibility of substitutional doping scheme with niobium dopant in $WSe_2$ is investigated. The material is characterized by dynamic secondary ion mass spectrometry, Raman spectroscopy, and X-ray photoelectron spectroscopy for confirming the impact of niobium impurity. We find a Fermi level shift toward lower half band gap that results non-degenerate doping level exceeding to $10^{17}$-$10^{18}$ $cm^{-3}$ of hole concentration. By applying Zerbst-type method to the transient data enables to systemically characterize generation lifetime and surface generation velocity of $WSe_2$ with Nb dopant. We also measured that carrier lifetime for the bulk form of $WSe_2$ is commonly in 0.5~0.1 μs range and proportionally scaled by thickness regardless of doping effect.

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# ZnO Nanosheet Growth By Oxygen Plasma Exposure of Zn Films

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Zinc oxide (ZnO) semiconductor has various favorable properties, including good transparency, high electron mobility, a wide band gap, and strong blue luminescence. In particular, nanostructured ZnO offers additional advantages over those of bulk ZnO due to a large surface area-to-volume ratio. Moreover, ZnO sheets are very useful for coating secondary materials, extending their functionality to other areas of application, such as biological and environmental sensing elements and dye-sensitized solar cells (DSSCs). As a consequence, a variety of techniques has been suggested for the growth of ZnO nanostructures. The suggested techniques can be broadly classified into two methods: solution and gas-based synthesis. The former is generally carried out below 300 ℃ but requires several processing steps while the latter is carried out at high temperatures ranging from 500 to 1500 ℃, in which special substrates are required. For nanostructured ZnO to have a potential for further advanced applications such as for DSSCs, therefore, alternative techniques for fabricating nanostructured ZnO at low temperatures should be developed. In this work, we report the synthesis of ZnO nanosheets by oxygen plasma chemical annealing of Zn sheets at low temperatures over 280 ℃. In this way, ZnO nanosheets with well-defined crystallinity were found to have been formed, and to have had a porous structure with a reduced *n*-type character. These results demonstrate that the present method is a promising technique for fabricating ZnO nanosheets on arbitrary substrates.

# Controlled growth of large-area and high-quality molybdenum disulfide

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Transition metal dichalcogenides (TMDCs) are well-known layered materials with sizab le bandgaps, which can be changed from bulk to layered forms (indirect to direct tran sitions) to yield unique physical properties. These could be employed in future semico nducting devices as a supplement to silicon-based technology. In particular, molybdenu m disulfide ($MoS_2$) has attracted much research interest due to its interesting electroni c and optical properties when in layered and nanostructure forms. Transition metal dic halcogenides (TMDCs) are well-known layered materials with sizable bandgaps, which can be changed from bulk to layered forms (indirect to direct transitions) to yield un ique physical properties. These could be employed in future semiconducting devices as a supplement to silicon-based technology. In particular, $MoS_2$ has attracted much rese arch interest due to its interesting electronic and optical properties when in layered an d nanostructure forms. Various approaches have been developed to obtain electronics-g rade layered MoS2, such as exfoliation from bulk material, chemical vapor deposition (CVD), atomic layer deposition and metal-organic CVD.[1,2] In particular, CVD is attr active for low-cost and scaled-up production. However, $MoS_2$ grown by CVD usually forms triangular flakes with low surface coverage and random size, orientation and po sition. For their fabrication and eventual application in electronic devices, it is highly desirable to grow continuous and large-scale $MoS_2$ thin films with control over the lo cation, size, and shape of its features. We describe a method for synthesizing large-are a and uniform $MoS_2$ films with control over the size and layer number at predetermin ed locations, using a step-edge mediated growth technique with simple lithography. Co ntrolling various growth parameters such as temperature and pressure enables the synth esis of high quality, crystalline, monolayer MoS2, with electrical and optical properties that are comparable to those of exfoliated MoS2. In addition, MoS2 is deposited on various substrate. This approach to precise control of the size and orientation of MoS 2 atomic layers can open a path toward scalable production of high quality devices ba sed on MoS2 for applications in flexible displays.

*This work was supported by This work was supported by the National Research Foundation (NRF) grant funded by the Republic of Korea government (NRF-2016R1D1A1B01013847) and by "Human Resources Program in Energy Technology" of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea government. (No. 20174030201620)*

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**Ferroelectric oxide-dichalcogenide heterostructural memristors**

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Two-dimensional atomic sheets such as transition metal dichalcogenides (TMDC) are potential materials for next generation applications for electronic devices. In particular, TMDC can be utilized to control interfaces relatively easily in the heterostructured system with oxides because of its low dimensionality showing small thickness of atomic scale [1, 2]. Semiconducting TMDC can behave as trigger for controlling the electrical properties in the heterostructure system. In this study, we utilized *n*-type $MoS_2$ and *p*-type $WSe_2$ as semiconducting materials. We utilized ferroelectric $PbTiO_3$ thin films deposited by pulsed laser deposition and inserted each TMDC layers to control interfacial charge carrier configuration. We used conductive-atomic force microscopy (C-AFM) to obtain switching of conducting states at the atomic sheets. Because of opposite carrier type in the $MoS_2$ and $WSe_2$ layers, switching characteristics can be reversed. It indicates that carriers in each TMDC layers induces switching behavior in the heterostructured system by introducing movable carrier at the interface analogous to the role of oxygen vacancies in memristive system with metal oxide layers [3]. In addition, photocurrent was also obtained by using C-AFM with light illumination. Contribution of photo-induced carriers give variation in the transport characteristics and change of surface potential with light illumination was also obtained by using Kelvin probe force microscopy. Therefore, we can extract contribution of photo-induced carriers. As a result, we suggested new design of memristive system by introducing the atomic sheets in oxide ferroelectric thin films which can be applied as photovoltaic memory devices.

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# Electrical and magnetic properties of in-plane graphene/graphene oxide/graphene junction devices

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In the past decade, the study of graphene has been tremendously conducted due to its phenomenal physical and electromagnetic properties such as high flexibility, high thermal conductivity, high electron mobility, and long spin diffusion length. Especially, long spin life-time and spin diffusion length of graphene have been extensively investigated for its potential application to spintronics. However, very low spin-injection efficiency (~1%) of graphene is an obstacle to realize spintronic devices based on graphene. Recently, it has been reported to overcome this problem by inserting a material which has a similar hexagonal lattice constant of graphene such as Ni (111) between the ferromagnet electrode and graphene.[1]

In this study, we fabricated in-plane graphene (G)/graphene oxide (GO)/G junction structures in which GO was formed by atomic force microscopy (AFM) lithographic technique by applying various voltages through a conductive AFM tip. AFM lithography is one of the shortcuts to fabricate nano-sized GO by minimizing damage and contamination of graphene surface, which can be easily produced during the conventional process of fabricating device.[2] We examined back-gating effect on the carrier transport of this in-plane G/GO/G device under constant magnetic field. We also investigated magnetoresistance behavior in the G/GO/G structure at different back gate voltages.

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# Nonlinear Optical Susceptibility of $WS_2$ Atomic Layer

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The transition-metal dichalcogenide atomic layer has enormous scientific merits and technical applications. The technical applications of third-order nonlinearity in TMDC atomic layer include passive Q-switch, mode-locking, optical power limiting, and quantum imaging and sensing. The third-order nonlinear optical properties can be characterized with Z-scan, four-wave mixing, self-phase modulation, etc. The nonlinear absorption and nonlinear refraction of tungsten disulfide ($WS_2$) nanoflakes with ~1-4 atomic layers in aqueous solution were characterized with a Z-scan technique and a box-car averager. The excitation source was a ~6 ns laser with 10 Hz repetition rate, and energy of ~2.33 eV. One photon excitation was located between A and B exciton absorption peaks which are assigned to the optical transition at the K/K' valley of the first Brillouin zone. The energy splitting at the lowest conduction band at K/K' valley of the first Brillouin zone is negligible due to the weak spin-orbital coupling, while the energy splitting at the highest valence band at K/K' valley of the first Brillouin zone is significant due to the strong spin-orbital coupling. The energy splitting at the highest valence band was around ~0.43 eV. The A exciton absorption peak (~1.99 eV) of WS2 atomic layers is assigned to the transition from the highest energy level in the valence band to the lowest conduction band. The B exciton absorption peak (~2.43 eV) of WS2 atomic layers is assigned to the transition from the $2^{nd}$ highest energy level in the valence band to the lowest conduction band. The exciton binding energy, which is the difference between electronic band gap and optical band gap, of a $WS_2$ monolayer is ~0.71 eV for around K valley of the first Brillouin zone. The large binding energy is due to the significant reduction of dielectric screening on the Coulomb interactions in the 2D atomic layer semiconductor and the tightly bounded exciton with the strong Coulomb interaction. Considering the large exciton binding energy of $WS_2$ nanoflakes, the A and B excitons of $WS_2$ nanoflakes with ~1-4 atomic layers could be excited to the deep conduction band by a two-step excitation through the optical band and by two-photon excitation through the virtual state or the broad optical band, respectively. The C (~2.7 eV) and D (~3.54 eV) exciton absorption peaks of $WS_2$ atomic layers are attributable to the band nesting at the regions where conduction and valence bands are parallel to each other in energy, around $\Gamma$-$\Lambda$ and $\Gamma$-M points, respectively. The C and D excitons could be also excited to the optical band or conduction band with two-photon through a virtual state. One-photon excitation could be also allowed through the indirect transition from $\Gamma$ to $\Lambda$ for the 2-4 layers which could lead to the negative nonlinearity of saturable absorption. However, an open Z-scan revealed that the $WS_2$ nanoflakes with ~1-4 atomic layers have a positive nonlinearity with reverse saturable absorption for the excitation energy and applied intensity. The nonlinear absorption coefficient of the $WS_2$ atomic layer was estimated to be ~ $6.2 \times 10^{-8}$ m/W. The positive nonlinear absorption indicates that the excited absorption cross-section of the $WS_2$ atomic layer is bigger than that of the ground state for the nonlinear excitation channel with a photon energy at ~2.33 eV. A closed Z-scan revealed the nonlinear refraction coefficient to be ~ $-3.8 \times 10^{-15}$ $m^2/W$ which is a negative nonlinearity or defocusing characteristics of $WS_2$ atomic layers. The modulus third-order nonlinear susceptibility of $WS_2$ nanoflake in aqueous solution was estimated to be ~ $2.93 \times 10^{-17}$ $m^2/V^2$.
Acknowledgment: This work is supported by ARO W911NF-15-1-0535, NSF HRD-1137747, and NASA NNX15AQ03A.

# A Single Atomic Defect in $MoS_2$ Monolayer

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The transition metal dichalcogenide (TMDC) atomic monolayer has unique material, electronic, and optical characteristics of time-reversal symmetry, spatial inversion asymmetry, anisotropic piezoelectricity, and direct transition at K/K' valley in the first Brillouin zone with optical polarization chirality. A defect-mediated molybdenum disulfide ($MoS_2$) in a supercell of 5×5 unit cells presented piezoelectricity enhancement, bandstructure modification, and formation of new energy level due to a single atom shift of molybdenum or sulfide along the armchair or zigzag direction [1]. The singe atom shift in the supercell exhibited new energy levels inside the forbidden band, not in the conduction or valence band. The induced energy levels for a molybdenum atom shift along the armchair direction are relatively deeper than that for a sulfide atom shift along the same direction. The total energy of the supercell with a single atom shift revealed that the single atom shift along the zigzag direction has better structural stability than the single atom shift along the armchair direction. The single atom shift in the supercell also modified the piezoelectricity. The piezoelectricity occurs in the inversion asymmetric crystal that converts mechanical deformational force to electricity. The crystal structure of 2D molybdenum disulfide monolayer or odd layers has an inversion asymmetry. The molybdenum disulfide monolayer has an intrinsic piezoelectricity [2, 3]. The intrinsic piezoelectric coefficient ($e_{11}$) of $MoS_2$ monolayer is ~290 pC/m [3]. However, a single atom shift in the supercell of molybdenum disulfide monolayer is obviously a new material system which exhibits its own piezoelectric property. The piezoelectric coefficient of $e_{11}$ in the molybdenum disulfide supercell of 5×5 unit cells is significantly increased by 18% as a single molybdenum shifts 20% along the armchair direction which is attributable the large ionic Coulomb interaction. A single atom shift in molybdenum disulfide supercell modified piezoelectric coefficients which change the electronic and ionic polarizations and output voltage. Additional macroscopic strain to the material system of a supercell with a single atom shift also changes the output voltage. The parallel and series connections of devices provide higher electric voltage and current [4] for piezoelectricity, heart rate monitoring, etc. The defect-mediated $MoS_2$ monolayer paves the way for realization of piezoelectricity enhancement, energy level formation in the forbidden band, bandstructure modification with Fermi level shift, change of ionic Coulomb interaction, and modification of real and imaginary dielectric constants. Acknowledgement: This work is supported by ARO W911NF-15-1-0535, NSF HRD-1137747, and NASA NNX15AQ03A.

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# van der Waals Heterostructure Atomic Layers

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Transition metal dichalcogenide (TMDC) atomic layers are of great interest for the applications of nano electromechanical system (NEMS), biomedical devices for monitoring muscle dynamics and arterial repetition rates, mechanical energy harvesting, and piezoelectronic sensing [1,2]. The 2D TMDCs with an odd number layers are asymmetric, while those with an even number of layers are centrosymmetric. The orientation of crystal layer is critical for piezoelectricity [3, 4] because the atomic layer exhibits anisotropic angular symmetry of second-order nonlinear polarization in response to applied electric field [1]. The symmetry of the atomic layer is broken along the armchair direction, while it is preserved along the zigzag direction [1, 5]. The 2D heterostructure of $WSe_2/MoS_2$ atomic layers has unique piezoelectric characteristics which depend on the number of atomic layers, stacking types, and interlayer interaction size. The van der Waals heterostructure of p- and n-type TMDC atomic layers with different work functions forms a type-II staggered gap alignment. The large band offset of conduction band minimum and valence band maximum between p-type $WSe_2$ and n-type $MoS_2$ atomic layers leads to the large electric polarization and piezoelectricity. The output voltages for a $MoS_2/WSe_2$ partial vertical heterostructure with a size of 3.0 nm × 1.5 nm were 0.137 V and 0.183 V for 4% and 8% tensile strains, respectively. The output voltage of AB-stacking $MoS_2/WSe_2$ heterostructure was larger than that of AA-stacking heterostructure for 4% tensile strain due to the contribution of intrinsic piezoelectricity and the symmetric condition in out-of-plane. The AB-stacking has the lower formation energy and better structural stability compared to AA-stacking. The interlayer interaction size modified the magnitude and polarity of output voltage. The intrinsic interlayer distance between 1L-$MoS_2$ and 1L-$WSe_2$was 3.135 Å. The output voltage of full vertical heterostructure with 1L-$MoS_2$ and 1L-$WSe_2$ was 0.239 V for 8% tensile strain, while that of full vertical heterostructure with 2L-$MoS_2$ and 2L-$WSe_2$ was 0.193 V for the same strain. The large output voltage of nanoscale partial or full vertical heterostructure was the unique piezoelectric property of 2D $WSe_2/MoS_2$ atomic layers with a large band offset. A series connection of multiple nanoscale piezoelectric devices will significantly increase the output voltage that will enable the realization of nanoelectromechanical systems (NEMS) with TMDC heterostructure atomic layers. Acknowledgements: This work at HU is supported by ARO W911NF-15-1-0535, NSF HRD-1137747, and NASA NNX15AQ03A.

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# Solution-processed Two-dimensional Layered Perovskite Semiconductor $(C_6H_5CH_2CH_2NH_3)MnCl_4$ Thin Films

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Two-dimensional layered organic-inorganic halide perovskite semiconductors (2d-OIHPs) with chemical formula $A_2BX_4$ (A: organic cation such as $C_6H_5$ $(CH_2)_n$ $NH_3^+$, B: divalent metal cation such as $Pb^{2+}$, $Sn^{2+}$, $Cu^{2+}$, $Mn^{2+}$, X: halogen anion such as $I^-$, $Cl^-$, $Br^-$) offer a wide variety of novel functionality such as solar cells and optoelectronic devices and magnetism. Structural flexibility of organic layer makes it possible to prepare single crystal-like 2d-OIHP thin films using solution-based processes such as spin coating and dipping technique (intercalation). [1] Great care should be taken for choosing the kind of solvent depending on spin coating or dip coating. Specifically, intercalation method prefers nonpolar solvent to polar solvent because polar solvent causes charge screening and inhibits the hydrogen bond formation between ammonium group and halogen cation during intercalation.[2] Meanwhile, in case of spin coating, solvent is required to dissolve not only organic but also inorganic precursors without any chemical precipitates. Therefore, solubility should be considered with first priority. It has been well-known that the solubility is proportional to the dielectric constant of the solvent. [3,4] We prepared $(C_6H_5(CH_2)_2NH_3)_2MnCl_4$ (abbreviated as Mn-PEA) thin films on top of Si wafer using spin coating technique with a total of nine polar and nonpolar solvents as follows: (1) Dichloromethan (polar, aprotic) and (2) Acetone(polar, aprotic) and (3) Methanol (polar, protic) and (4) Isopropanol (polar, protic) (5) Acetonitrile (polar, aprotic) and (6) Hexane(nonpolar) and (7) Benzene(nonpolar) and (8) Diethylether(nonpolar) and (9) Chloroform(nonpolar). It should be pointed out that the other preparation parameters such as solution volume/concentration and substrate and spin coating speed and spinning time are fixed the same. It is found that a mixed solvent of MeOH and iPOH (volume ratio 2:1) is most preferable for large scale uniform and single crystallized Mn-PEA thin films.

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# A graphene photodetector with bandgap opening using gate control.

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Graphene is expected to be suitable for use as an optical device because of its wide bandwidth approaching 500GHz, high cutoff frequency of ~60GHz, and mobility of ~$10^5$$cm^2$/Vs. Despite the excellent performance of the graphene, it is difficult to use the graphene in the optical device due to the gapless band structure. The photodetector of this study is a FET structure using graphene as an active layer and a metal back electrode as a metal electrode, a local top gate, a source and a drain. Graphene synthesized by CVD method transferred to Si wafer and used as active layer and, heavily p-doped Si used global back gate. Local top gate were defined by e-beam lithography and deposited by Ti/Au thermal evaporation. When a bias is applied to the top gate to invert the carrier type of the active layer, a p-n junction where generated photocurrent is formed at the gate edge. To solve gapless of graphene, method graphene nanoribbon and making defect at graphene is not perfect yet because of which may degrade carrier mobility of graphene. Accordingly we adopted method can handle problem to gapless of graphene. The research solve gapless of graphene and do not degrade high carrier mobility merit of graphene thus can be applied to high speed photodetector for optical computing, optical communication, etc.

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# Patterning of graphene for high-speed photodetectors

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Two-dimensional materials have attracted strong interest for their fascinating electronic properties and have shown many advantages in optoelectronic applications. Among two-dimensional materials, graphene has demonstrated promising applications in various types of photodetectors from terahertz to ultraviolet, due to its ultrahigh carrier mobility and light absorption in broad wavelength range.
However, weak light absorption and the absence of a gain mechanism that can generate multiple charge carriers from one incident photon have limited the responsivity of graphene based photodetectors. Here we demonstrate a new method of graphene patterning for high speed photodetectors. We fabricate and characterize dual-gate structure transistor, which creates a p-n junction at gate edges. Optical microscopy, Raman spectroscopy and atomic force microscopy (AFM) were used to determine optimal etching conditions that eliminate graphene etching residues. The device offers a broad spectral bandwidth and compatibility with CMOS technologies.

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# Oxygen migration in graphene electrode based memory

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Graphene is an atomically thin sheet of carbon atoms with a low sheet resistance[1]. In the past, graphene has used in various memory devices, including ferroelectric[2], resistive[3-8], phase change memories[9]. In this paper, We fabricated $HfO_2$-based-RRAM, and verified that graphene can be used as electrodes by using Raman raster scanning.
Resistive RAM forms CF(conductive filament) depending on the movement of oxygen ions, and there are SET and RESET processes. During SET, the oxygen ions are inserted in electrode. During RESET, the oxygen ions are pushed back into Metal-Oxide. Observing the movement of the 2D peak of graphene, we found that graphene acts as an oxygen reservoir[10,11],and that it is inert because the characteristic of Raman did not change.[12]
Also, we compared the characteristic of the devices that use graphene with TiN as the oxygen reservoir, applying voltages with opposite polarity. In case of TiN as the oxygen reservoir, TiN form conical electric field because the thickness is much thicker than graphene. Therefore, CFs of TiN-electrodes-RRAM are the larger. Also, the TiOxN1-x layer can work as a diffusion barrier and introduce additional resistance and voltage drop across the electrode. On the other hand, the oxygen functions as a dopant in graphene and lower the sheet resistance. These opposite effects may result in a more conductive LRS and HRS compared to TiN-electrode-RRAM.

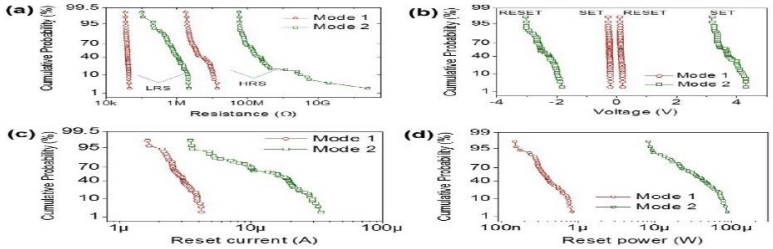


**Figure 1 (a) Resistance distribution for Mode1(graphene) and Mode2(TiN). (b) Set and Reset voltage distribution for Mode1(graphene) and Mode2(TiN). (c) Reset current distribution for Mode1(graphene) and Mode2(TiN). (d) Reset power distribution for Mode1(graphene) and Mode2(TiN).**

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# Ultraclean interface of vertically assembled 2D heterostructures with conformal contact on arbitrary substrates as high performing electrocatalysts

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Though epitaxial growth of heterostructures offers the most favorable means of achieving a single unit of material with unhindered novel electrochemical, electronic, optical or magnetic properties, the synthesis of two or more materials with disparate atomic configuration and ranges of thermal stability remains challenging.[1] Top-down manipulation (transfer) of individual layers into desired heterostructures often results in impurity traps and structural uncertainties, which negatively impacts on material performance.[2] Here we demonstrate conformal contact of vertically assembled 2D-heterostructures (2DHs) with ultraclean interfaces on arbitrary substrates as high-performing electrocatalysts.

To attain conformal contact between the target substrate, polyethylene (PMAX) was used as a viscoelastic support layer, to effectively aid in transfer of assembled 2DHs onto substrates of various surfaces, achieving complete wetting. The viscoelastic nature of PMAX enables it to be used as a pick and lift template, with which various materials on varying growth substrates are picked and attached with conformal contact to target substrates without traps of impurities. Wafer-scale assembly of 10 layers of monolayer CVD graphene was achieved, which elaborates the scalability of our top-down approach. Resultant $MoS_2$/Graphene electrocatalysts assembled on various substrates demonstrated higher hydrogen evolution reaction (HER) activity and stability in acidic medium. Our results pave the way for large scale assembly of heterostructures of diverse functionality toward unlimited applications.

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# Visualization of graphene defect and number of graphene layers on Cu foil by selective-ALD process

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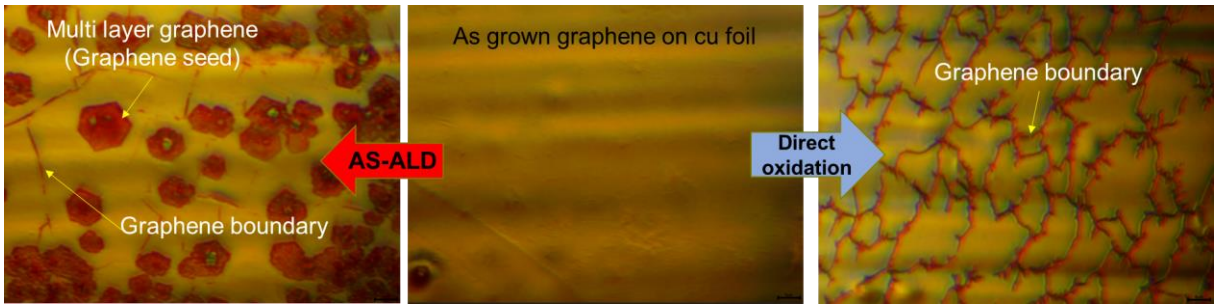
Graphene has very thin and transparent properties, making it difficult to evaluate the number of layer using the optical microscope. Therefore, Raman spectroscopy is commonly used to determine the number of layers of CVD graphene on Cu foil. Recently, visualization of graphene defect such as grain boundary, ripple, crack, and void through copper oxidation has been introduced by Duong, but the visualization of graphene layers is impossible[1]. In this study, we have investigated the graphene defect and number of graphene layers on Cu foil by area selective-atomic layer depostion(AS-ALD) process.




Optically visualization of various of graphene defects

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# Heteroepitaxial growth of 2D layered crystals with semiconductor-semimetal junction

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In recent years, transition metal chalcogenides (TMCs), with 2D crystal structure having various semiconductor properties, have been widely studied, due to their high carrier mobility and excellent quantum efficiency. Also, there is considerable interest in studies of TMCs heterojunction devices compound of different kind of 2D materials which can be controlled the electronic band structure and electronic properties. Among the various synthesis methods, the chemical vapor deposition has been proposed as the most feasible method for producing a two-dimensional heterojunction by sequential growth of different kind of 2D material. And then, the synthesis and characterization of various TMCs heterojunctions using $MoS_2$, $WS_2$, $MoSe_2$ and $WSe_2$ single crystals have been realized [1]. However, these kind of studies on heteroepitaxy using 2D materials have been restricted to a group of materials having the same space group of P63/mmc. First, therefore, we synthesized the $Bi_2Te_3$ layered crystals, with space group of R-3m, by conventional CVD [2]. And then, we investigated the heterostructure growth between $Bi_2Te_3$ and $MoS_2$, which are having different space group. Moreover, it is known that $Bi_2Te_3$ is a semimetallic material with a narrow bandgap of about 0.17 eV. Therefore, we will discuss the transport and optical properties of a two-dimensional semiconductor-semimetal heterojunction of $Bi_2Te_3$ and $MoS_2$ nano crystals.

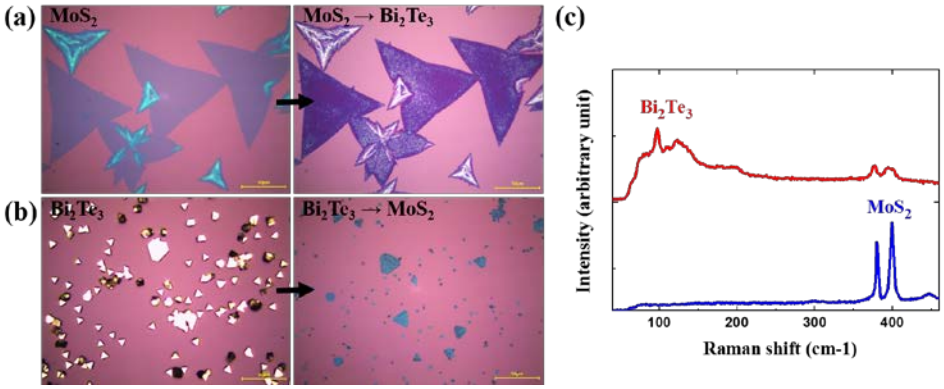


**Fig 1. (a) OM image of $MoS_2$→$Bi_2Te_3$ and $Bi_2Te_3$→$MoS_2$ heterostructures grown by CVD, (b) It is Raman spectroscopy**

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# Boron nitride as a stress-relaxation layer for high performance light-emitting diodes

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Most of the energy of the light-emitting diodes (LEDs) is emitted by the heat. The heat degrades the reliability of the LED and adversely affects the electrical and optical properties of the LED. Recently, low-dimensional nanomaterials including graphene, carbon nanotubes (CNTs), and hexagonal-boron nitride (h-BN) as a buffer layer for high quality GaN layers on the sapphire substrate have attracted considerable interest owing to their excellent physical properties such as high thermal conductivity, chemical and thermal stabilities, and mechanical flexibility. However, direct epitaxial growth of GaN films on graphene or h-BN is difficult due to low surface energy of graphene or h-BN caused by the absence of dangling bonds toward c-plane.
In this work, the boron nitride nanotubes (BNNTs) were introduced as an intermediate layer for the epitaxial overgrowth of GaN films on the sapphire substrate without an additional fabrication process or layers. GaN-based LEDs fabricated using this approach showed significant enhancement in the internal quantum efficiency and electroluminescence intensity compared to conventional LEDs grown on sapphire. Moreover, reduced efficiency droop and surface temperature at high injection currents were improved due to excellent physical properties of BNNTs.

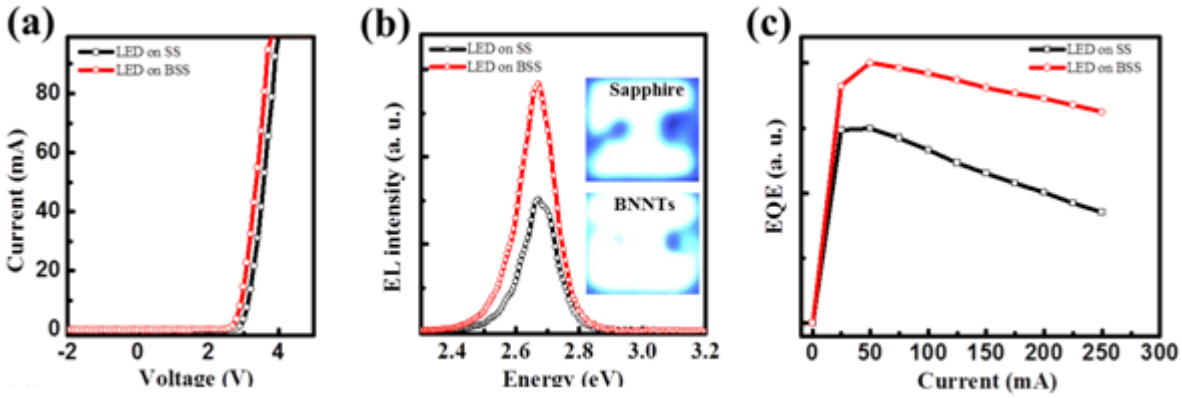


Fig. 1. (a) Current-voltage (I-V) curves, (b) EL spectra at an injection current of 20 mA, and (c) EQE of the LED grown on sapphire and BNNTs/sapphire properties of BNNTs.

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# Spectroscopic study of metal-tetraphenylporphyrin on two-dimensional layered materials

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Two-dimensional (2D) layered materials, exhibiting a flat surface a strong candidate for both fundamental Raman enhancement studies and its extension for practical application requirements. Here, we explore the Raman and fluorescence enhancement effects of the metal-tetraphenylporphyrin (TPP) molecules on graphene and $MoSe_2$. We attribute the enhancement behaviors to the charge transfer interaction between the 2D materials and the adsorbates. The Raman enhancement factors on the two flat substrates exhibit dissimilarly due to the corresponding charge transfer ability resulting from the electronic structures. The charge transfer interaction can be explained by the adsorption probability from Langmuir's model.

# Flexible perovskite photodiodes by employing $AuCl_3$-doped multilayer-graphene transparent conductive electrodes

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Recently, photodetectors (PDs) available in the ultraviolet, visible, and infrared range have attracted substantial attention due to their broad applications. Among the various materials, organic-inorganic hybrid perovskites are attractive for PDs due to the excellent material properties.[1] Most of the perovskites-based PDs have been fabricated by using ITO as a transparent conductive electrodes (TCE), but the ITO TCE is not suitable for flexible PDs because of its brittle and fragile properties. Graphene TCE is very useful for flexible applications as an alternative to ITO due to the excellent properties such as transparency, conductivity, flexibility, and chemical stability.[2] Here, we first report flexible perovskite photodiodes using gold (III) chloride ($AuCl_3$)-doped multilayer-graphene TCEs. The doping effect is more effective at number of layers ($L_n$) = 1 and 2 than at $L_n$ = 3 and 4, as analyzed by Raman scattering and sheet resistance. Typical photodiode parameters such as external quantum efficiency (EQE), detectivity, and linear dynamic range show best values of ~0.4 $AW^{-1}$, ~ 80 %, ~ 6 x $10^{12}$ cm $Hz^{1/2}/W$, and 96 dB, respectively at $L_n$ = 2. These results are comparable to those of the previously-reported ITO-based perovskite PDs. In addition, the flexible $AuCl_3$-doped graphene/perovskite photodiodes show excellent bending stabilities. These results suggest that the $AuCl_3$-doped graphene/perovskite photodiodes are very promising for their applications in foldable/bendable fields of optoelectronics.

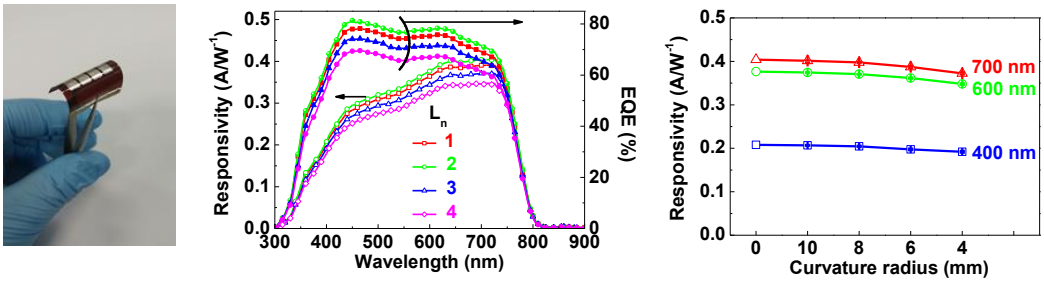


**Figure 1 Real image of a typical photodiode (left), spectral responsivity/EQE (middle) for various $L_n$, and wavelength-dependent responsivity as functions of bending radius for $L_n$ = 2 (right).**

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**Chemical enhancement mechanism studied by non-plasmonic Surface enhanced Raman Spectroscopy (SERS)**

Surface enhanced Raman spectroscopy (SERS) has been intensively studied during the past decades for its enormous enhancement of signal near the nanoscale metallic surfaces. There are two mechanisms of SERS, electromagnetic and chemical enhancement mechanism. The former involves surface plasmonic resonance and the latter involves charge transfer between substrates and analytes. Despite intensive research efforts, chemical enhancement remains elusive mainly due to the relatively complex enhancing factors and inconsistent experimental results. We used high-quality ZnO nanostructures/graphene substrates to provide an ideal SERS environment and to understand the charge transfer (CT) mechanisms of SERS which has no interference from strong surface plasmonic effect. We report the optimal conditions for CT processes that is found to be directional. We also present the characteristic length scale of charge transfer by introducing atomically thin $HfO_2$ layers between substrates and analytes and by monitoring SERS signals as a function of spacing between the molecules and the semiconductor surface.

# Improved LED performance by core/shell InGaN/GaN-multi-quantum-well nanowires non-catalytically-grown on SiO2 templates/Si

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The Nitride-based nanowires (NWs) have several advantages, such as flexibility in choosing a substrate, easy fabrication, large light-emitting area, no internal electric field, enhanced light extraction, and reduced defects by strain relief, that are useful for enhancing the efficiency of light-emitting diodes (LEDs). Here, we report how crucial the formation properties of the InGaN active layer are for enhancing the efficiency of core-shell InGaN/GaN multi-quantum-well (MQW)-NW LEDs that are selectively grown on oxide templates with perfectly-circular hole patterns. The nanostructures are analyzed for two types of LEDs, one containing defect-free MQW active layer and the other containing MQW layer with defects by using high-resolution transmission electron microscopy. The I-V curve of the defect-free LED shows a rectifying behavior with an on/off ratio of ~109, typical of a diode, and the off-state leakage current of the LED with defects is much larger than that of the defect-free LED, resulting in brighter electroluminescence from the latter device. These results suggest that well-defined nonpolar InGaN/GaN MQW-NWs can be utilized for the realization of high-performance LEDs.

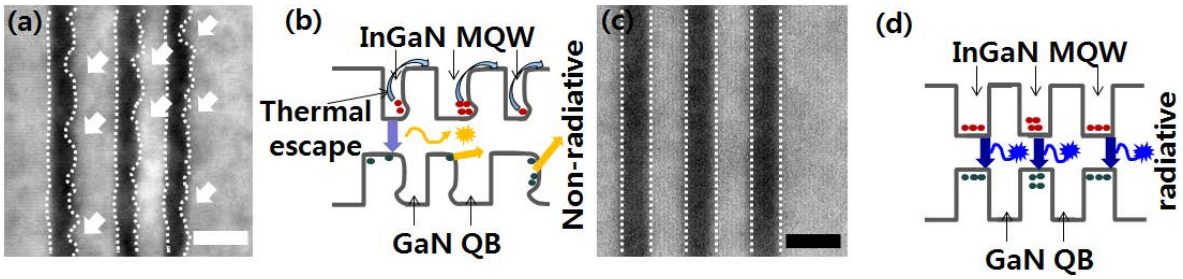


**Figure 1 (a) HRTEM image showing a magnified middle part of the defective MQWs in the NW. The scale bar 5 nm. (b) A schematic of the MQWs active layer showing its non-uniform formation. (c) HRTEM image showing a magnified middle part of the defect-free MQWs in the NW. (b) A schematic of the MQWs active layer showing its uniform formation.**

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# An Optimization of Electrochemical Etching Conditions for Gold Nanotips Fabrication

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Near-field scanning optical microscope(NSOM) is developed in order to observe electric field near the surface of the sample. Metal tip or optical fiber tip, which is a part of NSOM, is used to induce evanescent field from near to far field. To improve resolution of scattering type NSOM, gold nano tip was fabricated using electrochemical etching method, and optimized condition for the fabrication of tip with smaller diameter was studied. The electrochemical etching method has advantages such as low cost, short fabrication time [1].

Hydrochloric acid (HCl) is widely used as etchant in electrochemical etching process. By applying alternating or direct current into a gold wire, oxidation reaction is induced to gold wire. In these process, the meniscus of the solution around the gold wire make gold tip of sharp apex. The tip diameter can be controlled by varying those conditions as amplitude of voltage, duty cycle, HCl:ethanol ratio, platinum ring depth [2]. In this experiment, we optimized a fabrication of gold nano tip through changing each variable condition, Each diameter of fabricated tips through variable condition were observed using a scanning electron microscope(SEM).

This study confirmed that amplitude of voltage applied in gold wire and platinum ring gives significant difference to tip diameter (Fig.1). By chaning the duty cycle in etching process, we show that stable probe fabrication requires sufficient supply of electric voltage. We also show that the platinum ring depth does not give significant difference to diameter, instead improving success rate. Finally, we varied hydrogen ion concentration by adding ethanol into solution, and found that ratio between HCl and ethanol of 3 to 1 gives the smallest diameter of the tip. It was estimated that the character and surface shape of nanoscale can be measured using scattering type NSOM with gold nano tip with less than 50nm diameter.

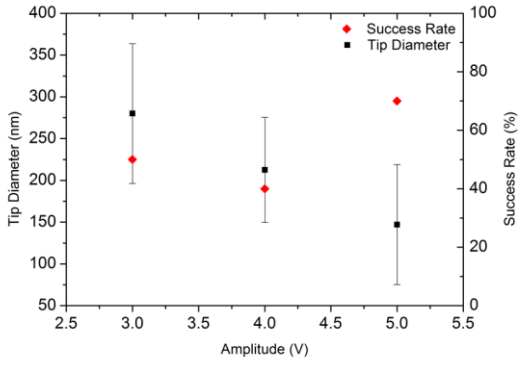


**Figure 1 Standard deviation and success rate graph for diameter of gold nano tips corresponding to the variable amplitude of voltage**

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# Light Transmission through Ultrasmall Nanohole with Plasmonic Groove Structure

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Current developments on individual nanostructures such as nanoparticle, nanorods, 2-dimensional nanostructures reaches their physical dimension down to few tens of nanometers or even down to few nanometers. Such remarkable achievement in fabrication technology demands challenging effort in measurement and analysis technology, especially regarding optical observation technique breaking diffraction limits having ~λ/2, where λ~500 nm is wavelength of light in visible frequency. Surface plasmon polariton excitation and related electromagnetic field radiation near the metallic subwavelength structure has been proven to assist both transmission enhancement and narrowing of emission direction of transmitted light, using 250 nm-diameter nanohole and bull's eye grating [1]. We have fabricated ultrasmall nanohole, reaching few nanometer diameter to observe whether such beaming is still available.

We have performed a simulation of electric field distribution based on a finite-difference time domain (FDTD) methods. Shown in Fig. 1(a) is a transmission spectra measured at 1 μm (black squared line in Fig. 1(a)) and 10 μm (red circled line in Fig. 1(a)) apart from structure. Interestingly, two distinct peak is seen near 500 nm and 680 nm, one near 500 nm shows almost negligible changes in intensity when monitoring distance from the sample increases, while the other near 680 nm shows considerable decreases. a top-view of electric field distribution observed at 10 μm apart from the structure shows quite good beaming properties of transmitted light, as shown in Fig. 1(b); a distinct circular distribution at the emission center. This strongly indicate that a certain wavelength, where resonant surface plasmon polariton is excited, high degree of beaming is available even in the ultrasmall nanohole down to 10 nm[2].

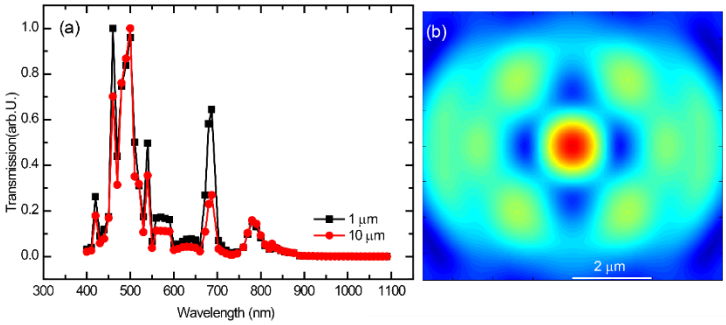


Fig. 1 (a) A simulated spectra for nanohole with bull's eye structure observed at 1 μm (black squared line) and 10 μm (red circled line) far from the structure. (b) to-view image of electric field observed at 10 μm apart from the structure.

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# The Characteristics of the cylindrical, rotating, magnetron-sputtered ITO films as the function of the film thickness on the electrical, optical and structural properties

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The ITO films, deposited by using conventional sputtering system with planar cathode, have been used in optoelectronic devices as a transparent conducting electrodes due to their high optical transmittance and low resistivity. But the target usage of planar type cathode is 20~30 %, which increases the fabrication cost of the ITO films. Cylindrical rotating magnetron sputtering (CRMS) system has been a great attention of the researcher because of the high target usage over 80 %, which can lead to decrease of the fabrication of the ITO films.

We investigated the optical, electrical and structural properties of five-generation, in-line type, CRMS-grown ITO films as the function of the film thickness. The sheet resistance and resistivity of the CRMS-grown ITO films decrease as the thickness of the ITO films from 2.19 × $10^{-4}$ Ω-cm to 1.58 × $10^{-4}$ Ohm-cm and from 42.14 $cm^2$/V-s to 39.97 $cm^2$/V-s, respectively. As the thickness of the ITO films increase, the transmittance in the near infrared region decreases due to increase in the interference phenomena [14]. As shown in the XRD peaks, the preferred orientation changed from the (222) plane to the (400) plane as the thickness of the ITO films increased. The orientation changed is attributed to the stability of the (400) plane against resputtering during the CRMS process. Based on surface field emission scanning electron microscopy, and cross-sectional transmission electron microscopy, we can suggest the proper mechanism to explain the preferred orientation changed and effects of the film thickness on the characteristics of the CRMS-grown ITO films.

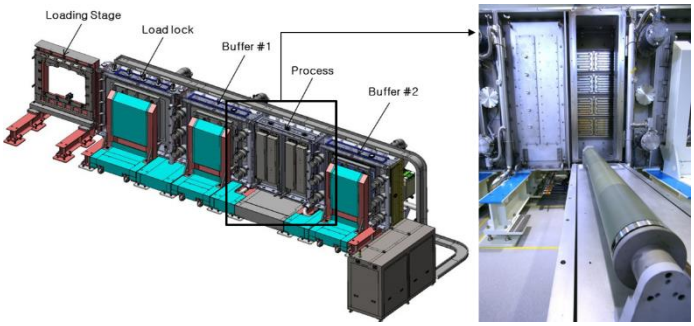


**Fig. 1. (a) Illustration of a 5-generation, in-line, CRMS system for the deposition of ITO films. (left), An ITO cylindrical target on a rotational cathode in the process chamber. (right)**

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# Full color LED matrix array based on micro blue LED with color conversion layer

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Micro light emitting diodes (micro LEDs) have been interested because they are suitable candidate for next generation display such as flexible and virtual reality display. [1] When compared to organic LEDs or liquid crystal displays, inorganic LED have many advantages such as low power consumptions, high brightness, short response time and long lifetime.

Although inorganic LEDs have many advantages, it is still challenging to realize a full color red-green-blue (R,G,B) color controllable light source from one chip because an epitaxially grown inorganic LEDs are only has monochromatic light emission. To fabricate full color display, transfer technique of R, G, B LEDs is needed. However, transfer technology can occur defect in pixel and misalignment. So, an innovation solution for achieving a high resolution full color micro LED display is needed.

In this work, we fabricated full color LED matrix array based on micro blue LED with color conversion layer. For full color LED matrix array, 33 × 33 GaN based blue LED array with 60×90 $\mu m^2$ are fabricated on sapphire substrate. For red and green color with blue LEDs, nanoorganic down converting materials instead of phosphor are used. To deposit the nanoorganic down converting materials materials on emission area of blue LEDs, nanoorganic down converting materials are mixed with photocurrable acrylic resin. The conversion efficiency and characteristic of display will be discussed.

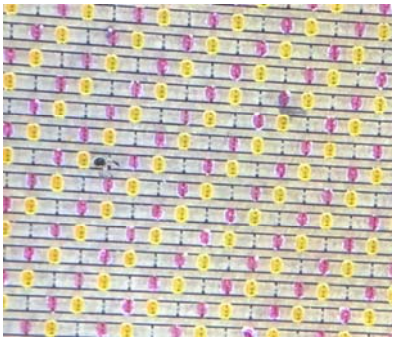

Fig. 1. 33 × 33 LED matrix array with nanoorganic down converting materials

*This study was supported by the National Research Foundation (NRF-2016R1D1A1B01013847 and NRF-2015R1D1A1A01059987) of Korea*

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# Transfer and control of orbital angular momentum on exciton-polariton quantum fluid

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Microcavity Exciton-polariton (Polariton) is bosonic quasi-particle arising from strong coupling between cavity photon and quantum well exciton. This hybrid state of half matter and half photon can transit to macroscopic coherent state very close to Bose-Ei nstein condensate in non-equilibrium. Manipulating quantized orbital angular momentum can explore fundamental dynamics of quantum fluid and contribute to quantum technol ogy for example, information processing and sensing in polaritons, cold atoms, superfl uid helium, other solid state, optics and photonics systems. In this study, we transferdi rectly optical orbital angular momentum (OAM) to polariton superfluid through effectiv e Fourier optics and photo-luminescence technique. Quantized vortices were easily gen erated and manipulated from polaritonic potential and flow guided by transferring optic al OAM in out-of-equilibrium polariton condensate.

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# Modulation of Effective Permittivity and Surface Plasmon Propagation by Using Electron Beam Exposure

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The patterned semiconductors and metal structures have been developed in diverse applications in nano electronics and photonics. The efficiency and reliability of these devices may depend on the impurities on the surface of devices. Usually, the contaminations and impurities come from the fabrication processes such as a carbon contamination from a crucible or the vacuum chambers in the metal deposition process. Furthermore, residual chemical compounds like photoresists in the patterning process critically affect the functionality of the devices. To avoid such surface contamination effects, we proposed the surface cleaning with energetic particle bombardment in scanning electron microscope (SEM) apparatus. Particularly, the plasmonic nano structures which has plasmonic resonances from the relation between dielectric constants of two materials (metal/dielectric) strongly rely on the properties of impurities on the metal surface. It is expected that the dielectric properties can be changed if the gold surface were cleaned by using electron beam exposure. In this research, the electron beam was irradiated on the carbon contaminated gold nano slit array during 15 minutes to eliminate the contaminated carbons on the gold surface. We observe that the propagation length of the surface plasmon is affected in the exposed area due to the change of the effective permittivity by electron beam exposure.

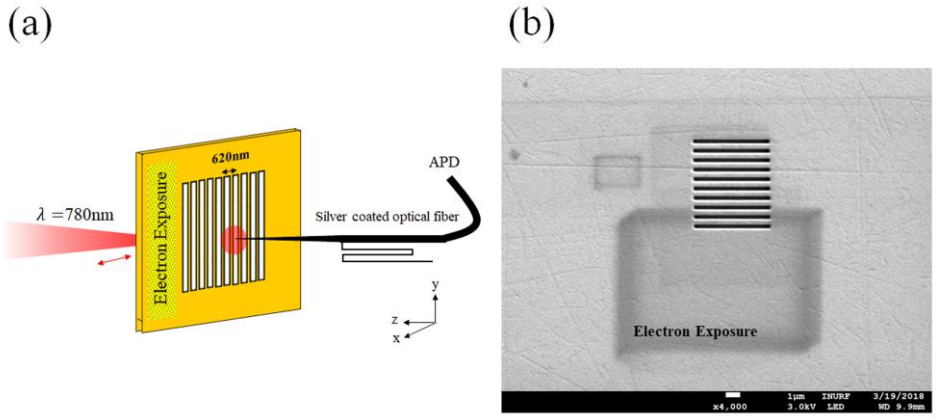


Figure 1. (a) Schematic of experimental setup of NSOM. (b) SEM image of gold slit array after 15minutes electron beam exposure.

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# Thickness dependence of cantilever in Q-factor at Si-based NC-AFM Probe

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In this study, the cantilever thickness dependence on Q-factor of AFM probe was investigated to achieve high performance. The various concentrations of KOH solution and various shaped etching mask were used at forming the shape of a tip and sharp apex angle with anisotropic etching method. Both the tip and cantilever were formed by maskless etching process. In the tip case, the mask's edge line was set at <310> to compensate the corner under cutting. We give a deviation 2.2 um to 10 um in thickness and 135 um to 170 um in length. To investigate the thickness dependence on the Q factor, different thickness cantilevers were chosen and tested while the length was fixed in the range of 140~145 um. As a result, the Q-factor of cantilever is linearly proportional to the thickness of the cantilever (Figure 1. (b)).

(a) (b)

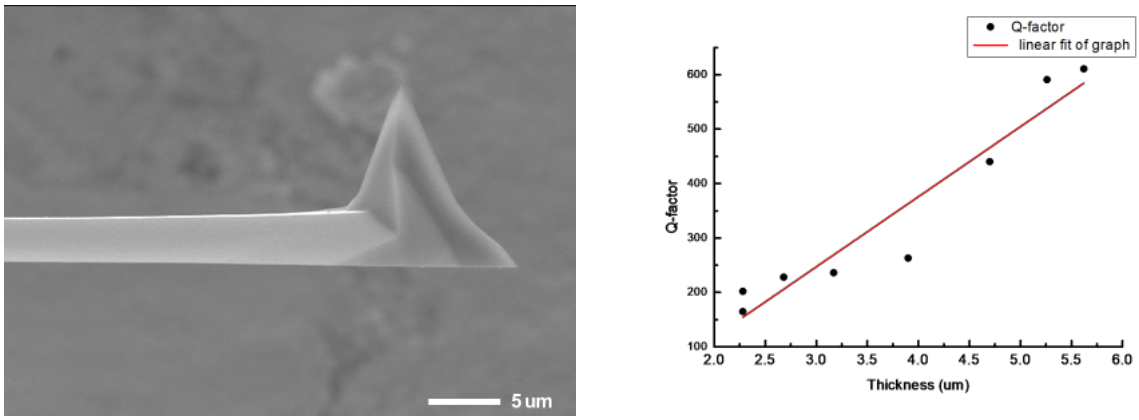


Figure 1. (a) FE-SEM image of Si-based NC-AFM. (b) Thickness-dependence on Q factor of Si-based NC-AFM.

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# Third Harmonic Generation in Purified Single-walled Carbon Nanotubes

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Single-walled carbon nanotubes (SWCNT) with few nm diameters are the important new nano-scale functional materials. Since its discovery in early 90s,[1] carbon nanotubes (CNT) have been the important new nano-scale functional materials due to their stable chemical structure, yet relatively strong interaction with irradiated optical field or applied electric field. Nonlinear optical properties, such as the third-harmonic generation (THG), of SWCNT could be one of the key elements in developing new nano-scale devices, providing the parameters for theoretical models in energy level structures and optical characteristics for actualization of CNT based photonic devices. To be realized as an actual device, the effective nonlinear optical response to intense laser light is needed to be studied for understanding the basic physics and electronic/optical functionalities. Using the intense femtosecond laser pulses in near infrared (1270 nm), we observed relatively strong third harmonic generation (THG) in visible region as shown in FIG 1. Our THG signal was wholly originated only from SWCNT without any effect from the substrate, and strong enough to be measured with a simple portable spectrometer without using a complicate gated lock-in amplifier technique as reported in literature.[2-4] The observed THG obeys the third-order power law up to 70 μJ of irradiated laser pulse energy, which corresponds to the peak intensity of few tens of GW/cm$^2$ (FIG 2). The pulsewidth and the repetition rate of the laser were 140 fs and 1 kHz, respectively. The power dependence of THG, in addition to the peak wavelength, assures that our result truly represents a third-order nonlinear optical process. We expect the nonlinear optical characteristics of SWCNT would be one of the key elements in developing CNT based nano devices such as optical display, sensors, detectors, etc.

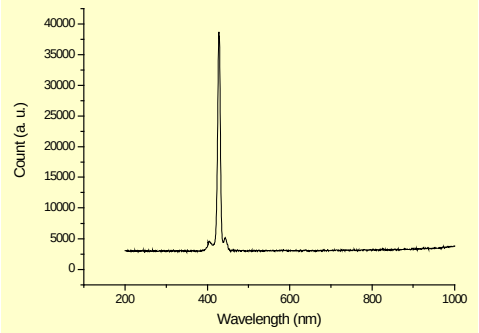


**FIG 1 .** Observed THG from a bulk tablet of SWCNT.

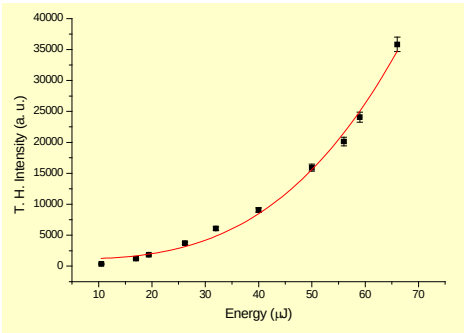


**FIG 2 .** Power dependence of THG from SWCNT.

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# FDTD analysis of local electric field enhancement by nanoholes of varying shape and size in metal with different thickness

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Surface plasmons have attracted considerable research interest [1] owing to recent advances in nano-scale metal engineering: e.g., nanoparticle clusters, nano optical fibres, nanorings, nanorods, nanoshells, and nanoholes. When light interacts with a metal structure smaller than its wavelength, surface plasmons occur by the collective oscillation of free electrons in the metal [2]. We therefore hope to be able to control surface plasmon properties by adjusting the size and shape of metal structures, which can sensitively influence the properties of a confined local electric field. To study the surface plasmon phenomena with finite-difference time-domain(FDTD) simulation, we designed three-dimensional thin metal nanostructures with cylindrical or reversed trapezoidal nanoholes, and considered the structural factors affecting transmission and reflection for local electric field enhancement (e.g., nanohole diameter and metal film thickness).

We used the FDTD method to simulate different wavelengths interacting with thin metal films of various thickness containing RTH and CH structures of varying sizes. The local electric field enhancement of RTH is stronger than that of CH. Regardless of the shape of the hole, the local electric field enhancement becomes stronger as the hole becomes smaller. To confine and enhance the applied light in nanostructures requires an appropriate thickness to overcome the reduction of incoming light, considering its penetration depth in the metal. Electric field enhancement combined with metal nanostructures could be usefully applied in plasmon biosensors or surface-enhanced spectroscopy.

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# Vertically grown $BaTiO_3$ nanotube arrays for piezoelectric energy harvester

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Recent progress in the field of flexible electronics technology has accelerated the possibility of its practical uses in various real-life applications, including smart mobile device, healthcare device, the Internet of Things (IoT), and wearable device. Among the many kinds of flexible devices, the self-powered systems have been attracted great attention because they could guarantee sustainable, long-lasting, and remote use of devices without additional energy storage systems. Especially, for the stable and permanent operation of flexible electronic devices without restraints, it is essential to develop a high-output flexible energy harvester that can efficiently convert electrical energy from mechanical energy source.[1,3]
Herein, we will describe the well aligned $BaTiO_3$ nanotube (NT) arrays on a thin Ti foil were adopted for use in piezoelectric energy harvesting device that scavenges electricity from mechanical energy. $BaTiO_3$ NTs were grown onto a Ti substrate by a simple anodization process and a facile hydrothermal process. A $BaTiO_3$ single NT selected from NT arrays was transferred onto a flexible substrate to characterize the piezoelectric output performance of the individual $BaTiO_3$ NT. We also fabricated the $BaTiO_3$ NT arrays-based piezoelectric energy harvester and characterized the harvested output signals under mechanical deformations.

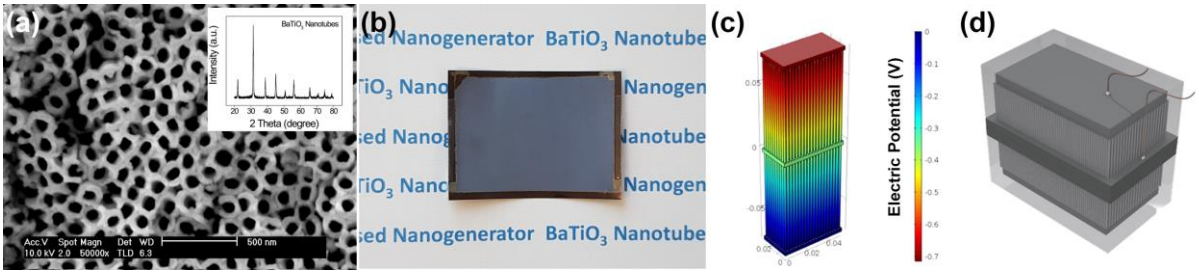


**Figure 1.** (a) A SEM image and XRD result of $BaTiO_3$ NT arrays. (b) Vertically grown $BaTiO_3$ NT arrays on a Ti substrate. (c,d) Multiphysics simulation result (c) and scheme (c) of $BaTiO_3$ NT arrays-based flexible energy harvesting device.

*This work was supported by National Research Foundation (NRF) of Korea grant funded by the Korea government (MSIT) (No.2016R1C1B1006456).*

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# Hydrogen Storage using Phyllostachys bambusoides-based Porous Blue Carbon

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Hydrogen has been considered as the ideal energy carrier of the future due to its eco-friendly property, unlimited amount of quantity, and regional delocalization. To use hydrogen as an energy source, high hydrogen storage capacity is indispensable. Lots of materials for hydrogen storage have been reported. Among them, carbon-based materials such as carbon nanotube, graphene, and graphene oxide have recently been focused. Here we report the possibility of carbonized bamboo as a hydrogen storage structure because they have basically porous organic structure. The bamboos were treated at 800 ℃, 900 ℃, 1000 ℃ and 1100 ℃ for 24 hours. The pore size and hydrogen storage capacity of each sample was measured by $N_2$ and $H_2$ gas sorption up to 1.0 bar at 77 K. Hydrogen storage capacity is maximized when the sample treated at 900 ℃, which reaches over 1 wt.% at 1 bar/77K. The results showed that the bamboo, one of the blue carbons, has the possibility to be a hydrogen storage material.

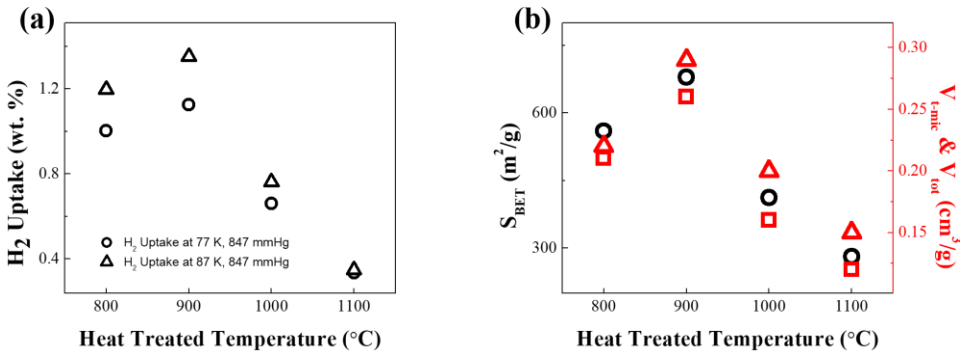


**Figure 1.** Characteristic of BET result (a) Comparison between $H_2$ uptake at 77 K and 87 K, in 847 mmHg by samples (b) Comparison between BET-plot($S_{BET}$) and t-plot($V_{t\text{-}mic}$ and $V_{tot}$)

*This work was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2017R1A6A1A06015181 and NRF-2017R1A1A1A05000789).*

# Optical transitions of MAPbBr3 organic-inorganic perovskite crystals under high magnetic fields

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Despite the vast investigations of applications on solar cell devices, there are numerous unknown basic properties of methyl-ammonium (MA) lead halides perovskite materials. In this regard, we investigate optical transitions of such crystals in high magnetic fields to 19 T. We fabricate $MAPbCl_{3-x}Br_x$ (x=0, 0.5, 1 and 3) crystals by using conventional solution methods. For the photoluminescence measurements under magnetic fields, we use a 19 T cryocooled superconducting magnet and a 60 T pulsed magnet. Samples show strong temperature dependency while cooling from room temperature to the liquid helium temperature. We will discuss magnetic field dependency of the optical transitions including the reduced mass and exciton diamagnetic shifts.

# Titanium Dioxide Photonic crystals enhance the power-conversion efficiency for Perovskite Solar Cells.

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We report Perovskite solar cell with a high-quality three dimensional Photonic crystal nanostructure embossed in the mesoporous titanium oxide layer. We have developed the mesoporous layer with embossed pattern to enhance the optical properties via the patterning procedure including fabrication of well-designed PDMS master mold with nano-scale patterns and pressure imprinting/stamping PDMS with various imprinted nano-scale structures in the mesoporous $TiO_2$ layer. The effect of photonic crystal with round-shaped of various size show that enhanced optical absorption. The current density is greatly improved while the open-circuit voltage of the cell maintain. As a result, power conversion efficiency was greatly improved.

***Keywords: Photonic crystal, self-assembly, photovoltaics, Perovskite solar cell***

# Electrospinning synthesis of $Li_7La_3Zr_2O_{12}$ nanowires and the optimum calcination temperature with the formation of cubic phase for all solid-state lithium ion batteries

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$Li_7La_3Zr_2O_{12}$ is a garnet-type material that has two stable phases: the tetragonal phase and the cubic phase. Theoretically, the cubic phase has a high bulk (grain) Li ionic conductivity of ~$10^{-3}$ S $cm^{-1}$ which is available for application, compared to ~$10^{-6}$ S $cm^{-1}$ for the tetragonal $Li_7La_3Zr_2O_{12}$ phase.[1,2] In this study, the optimum calcination temperature of $Li_7La_3Zr_2O_{12}$ solid electrolyte powder using electrospinning with garnet structure were determined for the formation of stable cubic phase. The synthesized $Li_7La_3Zr_2O_{12}$ solid electrolytes were characterized by X-ray diffraction(XRD), scanning emission microscopy(SEM) and electrochemical impedance spectroscopy(EIS).

*This study was supported by the granted financial resource from the Ministry of Trade program of the Industry & Energy, Republic of Korea (G02N03620000901).*

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# Core-shell structured $Li[Ni_{1-x}(Ni_{0.85}Co_{0.1}Al_{0.05})_x]O_2$ cathode material for superior cycling performance lithium ion batteries

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## Abstract

$LiNiO_2$ have attracted much interest as lithium storage materials for rechargeable lithium batteries because of their high capacity and low cost. [1] However, there is problem that rapid capacity loss, mostly due to surface degradation arising from the presence of highly reactive $Ni^{4+}$ in the delithiated state. [2] In order to improve the cycle performance of the $LiNiO_2$, we synthesized the core-shell structure of $LiNiO_2$ (core) and $LiNi_{0.85}Co_{0.1}Al_{0.05}O_2$ (shell). It was demonstrated that this core-shell cathode material, despite being very close to $LiNiO_2$ in composition, exhibited excellent cycling performance and high discharge capacity. The result of energy-dispersive X-ray spectroscopy (EDS) line analysis showed that the core precursor and the shell layer were successfully synthesized as two phases.

*This study was supported by the granted financial resource from the Ministry of Trade program of the Industry & Energy, Republic of Korea (G02N03620000901).*

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# A Scalable, Flexible and Transparent GaN Based Heterojunction Piezoelectric Nanogenerator for Energy Harvesting

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Flexible and transparent piezoelectric nanogenerators (PNGs), which can harvest energy from mechanical actuators in the surrounding environment, have attracted great interest as energy sources to power-up smart clothing, micro/nano systems, and portable electronic gadgets. Due to non-centrosymmetric crystal structure, bio-compatibility, and mechanical robustness of GaN, it is a promising candidate to fabricate PNGs. In order to fabricate highly efficient GaN based PNGs, the suppression of internal screening of piezoelectric charges by free carriers was addressed by forming the p-n homojunction of GaN using electrochemical etching but output voltages and current were limited to 4.2 V and 150 nA, respectively [1].

The suppression of internal screening was enhanced by forming heterojunction of NiO/GaN thin films (TF) PNG using electrochemical lift-off technique. The piezoelectric output was measured using several actuation sources such as air flow, finger forces for bending, vibrations, and cyclic stretching-releasing agitation mechanism driven by a linear motor. The piezoelectric output voltages and current of 30 V and 1.43 μA were obtained. The stability was degraded after 800 cycles.

In order to fabricate malleable PNG, c-axis GaN nanowires were grown upto 15 μm long with 50 nm diameter. Then PDMS was coated and the matrix embedded with c-axis GaN nanowires was transferred onto a flexible PET substrate followed by p-type NiO deposition. The piezoelectric properties were investigated as a function of GaN nanowires length, demonstrating the peak output of 21 V and 253 nA. The stability of the device was also evaluated for 28,000 cycles, the performance was found very stable due to malleability of the design. Such high piezoelectric output was attributed to the suppression of free carrier screening and junction screening.

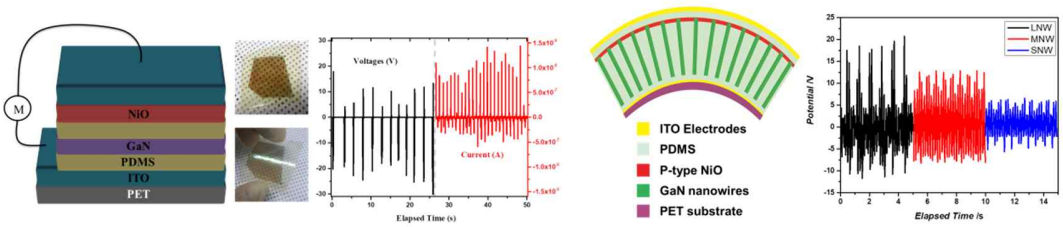


Figure 1 NiO/GaN TF PNG (left), c-axis GaN nanowires based PNG (right)

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# Introduction to Semiconductor Processing: Fabrication and Characterization of *p-n* Junction Silicon Solar Cells

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We describe an upper-division undergraduate physics laboratory experiment that integrates the fabrication and characterization of a *p-n* junction in silicon. Under standard illumination, this *p-n* junction exhibits the photovoltaic effect as well as the typical diode rectification behavior when measured in the dark [1]. This experiment introduces students to the physics of solar photovoltaics from the perspective of participating in the fabrication process. Procedures, experimental strategies and typical student measurement results are presented. This low-cost, engaging, and effective lab can be adapted to undergraduate physics courses at various institutes. The techniques provide students with an important educational experience regarding the process by which electronic devices are manufactured as well as critical skill development for future scientific careers [2].

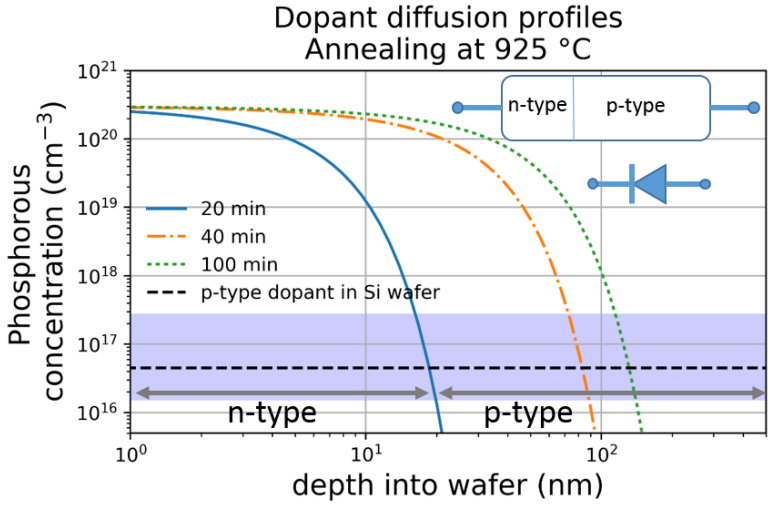


*Figure 1. Increasing the annealing time for Phosphorous-coated Si wafer at 925 °C deepens the n-type region in the wafer. The dashed line represents the threshold level for the p-type dopant, with the uncertainty region shaded, measured by four-probe, from the original Boron-doped Silicon wafer. We indicate the n- and p-type regions for a 20 min anneal below the plotted curves. Conventional forward bias current flow for a diode is in the direction from p- to n-type, whereas for the solar cell under illumination current flows in the opposite direction.*

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# Effect of structure properties and ionic conductivity of perovskite-type $Li_{0.34}La_{0.56}TiO_3$ electrolyte produced by ultrasonic atomizing method for all-solid-state lithium batteries

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**Abstract**

Inorganic lithium solid state electrolytes have been considered as candidates to substitute the organic liquid electrolytes in lithium batteries. However, their low conductivity is the bottleneck of their practical applications [1]. In this paper, ceramic electrolytes based on perovskite-type $Li_{0.34}La_{0.56}TiO_3$ was synthesized by ultrasonic atomizer. XRD(x-ray diffraction), SEM(scanning electron microscope), DSC(differential scanning calorimetry) and EIS(electrochemical impedance spectroscopy) were used to characterize their composition, microstructure and ionic conductivity. The results showed that the total ionic conductivity was enhanced to achieve about $10^{-6}$ S/cm at 25 ℃ due to the uniform particle size.

*This study was supported by the granted financial resource from the Ministry of Trade program of the Industry & Energy, Republic of Korea (G02N03620000901).*

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# Transparent and flexible IZTO films by plasma damage-free linear facing target sputtering for the top cathode of flexible perovskite solar cells

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We report characteristics of flexible and transparent indium zinc tin oxide (IZTO) films prepared by a linear facing target sputtering system with a ladder type magnet arrangement is a promising low-temperature and more advanced plasma damage-free sputtering method to use as transparent top cathode for flexible perovskite solar cells (FPSCs). As-deposited IZTO films (100 nm) showed a low sheet resistance ($R_{sh}$) and a high optical transmittance (T) even though it was prepared at room temperature. In addition, mechanical flexibility of the optimized IZTO films were examined using lab-designed outer and inner bending test systems. Until outer bending radius of 5 mm and inner bending radius of 3 mm, the IZTO films showed constant a resistance change indicating good flexibility of the IZTO films. Dynamic outer and inner bending fatigue tests of the IZTO films showed no change in resistance ($\Delta R$) after 10,000 bending cycles, demonstrating the flexibility of the IZTO/PET. This suggests that LFTS is a promising low temperature and plasma damage free sputtering technology for preparing high-quality IZTO top cathodes for PSCs and flexible FPSCs at room temperature.

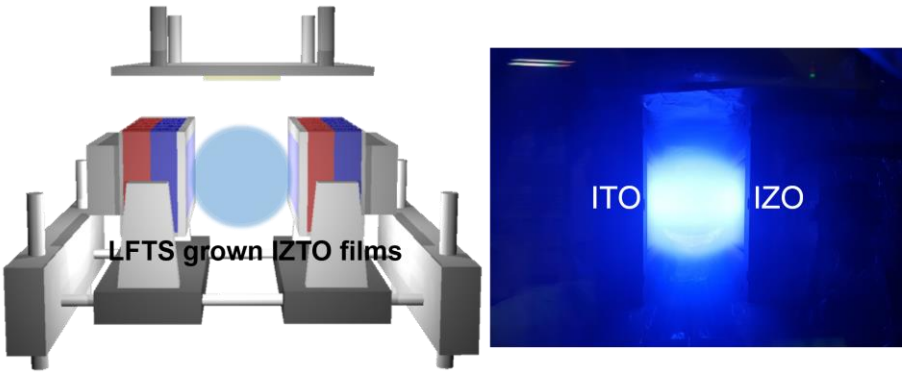


**Fig. 1** Schematics of linear facing target sputtering system(left), Argon plasma formed between ITO and IZO targets effectively confined high-density plasma(right)

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# Synthesis of nanostructured spinel $LiNi_{0.5}Mn_{1.5}O_{4-x}F_x$ as cathode material using electrospinning for lithium-ion battery

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Spinel $LiNi_{0.5}Mn_{1.5}O_4$ has attracted much interest as promising high voltage cathode materials due to its advantages of large reversible capacity, low cost and high energy density [1]. However, $LiNi_{0.5}Mn_{1.5}O_4$ cathode materials have poor rate stability, especially at elevated temperatures, due to the electrolyte degradation at high working voltage and $Mn^{2+}$ dissolution resulting from the disproportionation reaction of $Mn^{3+}$ ions [2]. Thus, this study aims to improve the rate stability by the partial substitution of fluorine for oxygen in $LiNi_{0.5}Mn_{1.5}O_4$ structure. Also, substitution of fluorine can be inhibition formation of $Mn^{2+}$ and improved structure stability. $LiNi_{0.5}Mn_{1.5}O_{4-x}F_x$ nanofibers were successfully prepared by electrospinning. We are characterized by X-ray diffraction (XRD), field emission scanning electron microscope (FE-SEM) and electrochemical measurement of the $LiNi_{0.5}Mn_{1.5}O_{4-x}F_x$ electrodes. As a result, $LiNi_{0.5}Mn_{1.5}O_{4-x}F_x$ show improved the structural stability and the electrochemical performance by fluorine with strong binding energy for oxygen.

*This was supported by Korea National University of Transportation in 2018 and the granted financial resource from the Ministry of Trade program of the Industry & Energy, Republic of Korea (G02N03620000901).*

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# Barium Doped $Li[Ni_{0.30}Co_{0.25}Mn_{0.45}]O_2$ cathode materials for Li-Ion Secondary Batteries

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## Abstract

Ni-rich system $Li[Ni_{1-x-y}Co_xMn_y]O_2$ of lithium secondary battery cathode material keep a high discharge capacity. However, by the Ni content increases, there is a problem that the electrochemical properties and stability of the structure are reduced [1]. In order to solve these problems, research for positive ion doping is performed. The one of the cathode material, barium-doped $Li(Ni_{0.3-x}Ba_xCo_{0.25}Mn_{0.45})O_2$ (x=0.05), was synthesized by the precursor, $Ni_{0.30}Co_{0.25}Mn_{0.45}(OH)_2$, from the co-precipitation method. The barium doped materials have studied the structural and electrochemical properties. The barium doping expanded the pathway for $Li^+$ to intercalate and deintercalate [2]. Also, it was improved that the structural stability and restraining the increase of charge transfer resistance of cathode during cycling [3]. As a result, synthesized cathode material Increased stability of the layered structure was observed by SEM(scanning electron microscope) and XRD(x-ray diffraction) and charge transfer resistance is lowered by EIS(electrochemical impedance spectroscopy).

Keyword: cathode material, barium doping, co-precipitation

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### Acknowledgments

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# Copper molybdenum sulfide: a novel pseudocapacitive electrode material for electrochemical energy storage device

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**Abstract:**

Currently, research interests on layered transition-metal chalcogenides (TMCs) were expanded from the binary compounds to ternary or multiple-valued counterparts, due to their richer electronic structures and diverse chemical compositions. In this work, copper molybdenum sulfide ($Cu_2MoS_4$) nanoparticles were prepared via a one-pot hydrothermal method and examined as an advanced electrode material for supercapacitor. Physico-chemical characterizations such as X-ray diffraction, laser Raman, field emission scanning electron microscope, and X-ray photoelectron spectroscopy analyses revealed the formation of I-phase $Cu_2MoS_4$. [1,2] Electrochemical studies using cyclic voltammetry (CV), charge-discharge (CD), and electrochemical impedance spectroscopic (EIS) methods revealed the pseudocapacitive nature of charge-storage via ion intercalation/de-intercalation has been occurred in $Cu_2MoS_4$ electrode. The $Cu_2MoS_4$ electrode delivered a specific capacitance of 127 F $g^{-1}$ obtained from the CD measured using a constant current density of 1.5 mA $cm^{-2}$. Further, $Cu_2MoS_4$ symmetric supercapacitor (SSC) device delivered a specific capacitance of 28.25 F $g^{-1}$ at a current density of 0.25 mA $cm^{-2}$ with excellent rate capability. The device acquired a high energy and power density of 3.92 Wh $kg^{-1}$ and 1250 W $kg^{-1}$, respectively. The experimental results indicate the potential application of $Cu_2MoS_4$ nanoparticles as a novel electrode material for energy storage devices.

**KEYWORDS:** Copper molybdenum sulfide, Energy storage, Pseudocapacitance, Supercapacitor, Electrochemical impedance spectroscopy.

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# Cost-Effective Yarn Based Piezoelectric Nanogenerator Using $Bi_4Ti_3O_{12}$ For Energy Conversion Applications

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**Abstract:**

Highly crystalline, Aurivillius phase perovskite structure-based bismuth titanate nanoparticles ($Bi_4Ti_3O_{12}$ NPs) was synthesized by simple sol-gel technique for effective conversion of mechanical energy into useful electrical energy. The XRD pattern of $Bi_4Ti_3O_{12}$ confirms the orthorhombic crystalline phase and the calculated average crystallite size, micro strain was 17.5 nm and 1.98 x $10^{-3}$, respectively. The dynamic symmetry and atomic vibrations of $Bi_4Ti_3O_{12}$ was evaluated by Raman pattern and major active modes confirm the presence of piezoelectric orthorhombic crystalline phase. The functional group analysis was done by FT-IR spectra and the peaks at 585 $cm^{-1}$ and 817 $cm^{-1}$ corresponds to Bi-O and Ti-O stretching vibrations of $Bi_4Ti_3O_{12}$ lattice. Both XRD and Raman patterns data is well matched and suggest that $Bi_4Ti_3O_{12}$ is a potential candidate for piezoelectric nanogenerator (PNG) and self-powered sensor applications. Piezoelectric potential distribution was experimentally demonstrated by fabricating yarn-based PNG using $Bi_4Ti_3O_{12}$ film and powered up low power consumed commercial light emitting diodes and liquid crystal display. The device generates V=60 V and $I_{sc}$=0.4 μA with the power density of 18.5 $mW/m^2$. The proposed device further demonstrated for self-powered breath sensor application. The efficient piezoelectric material, cost-effective process, eco-friendly nature of PNG and its energy conversion will partially solve energy crisis and possible to control the global warming and carbon emission.

**Keywords**: Piezoelectric nanogenerator, $Bi_4Ti_3O_{12}$, energy conversion, low power electronic devices, sol-gel technique

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# Development of high performance solid state self-charging supercapacitor

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Self-charging power cell (SCPC) received much attention for harvesting and storing energy in an integrated device, which paves the way for developing maintenance free autonomous power systems for various electronic devices. In this work, a new type of SCPC device is fabricated comprising 2D molybdenum diselenide ($MoSe_2$) as an energy storing electrode with PVDF-co-HFP/$TEABF_4$ ion gelled PVDF/$NaNbO_3$ as the piezopolymer electrolyte. The fabricated SCPC delivers a specific capacitance of 18.93 mF $cm^{-2}$ with a specific energy of 37.90 mJ $cm^{-2}$ at a specific power density of 268.91 µW $cm^{-2}$ obtained at a constant discharge current of 0.5 mA. The $MoSe_2$ SCPC device can be self-charged with the aid of mechanical deformation induced using the applied compressive force, thus making it harvest and store energy. The $MoSe_2$ SCPC device can be charged up to a maximum of 708 mV under a compressive force of 30 N in 100 s, and the mechanism of charge-storage is discussed in detail. The experimental findings of this work demonstrate the high efficiency of the fabricated $MoSe_2$ SCPC device, which can provide new insights for developing sustainable power sources for the next generation wearable electronic applications.

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# Photoactive Piezoelectric Energy Harvester Driven by $A_VB_{VI}C_{VII}$ Class of Ferroelectric-Semiconductor Compound (SbSI)

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Ferroelectric-semiconductor, Antimony Sulfoiodide (SbSI) embedded PMMA matrix turns to be an excellent material for the piezoelectric energy harvester as well as photodetector. SbSI micro-rods synthesized via solid state reaction (SSR) technique exhibits (001) axis orientation, activating the ferroelectric active sites of the orthorhombic crystalline phases. In addition, the dipole alignment of SbSI was enhanced through electrical poling (1 kV) maintained at different time intervals (15 min – 180 min). The piezoelectric nanogenerator developed using SbSI/PMMA composition delivers an electrical characteristic of ~ 4 V (voltage) and 150 nA (current) when demonstrated under a liner mechanical force acting at the rate of 2 N. Further, the feasibility of photonic sensing properties of the composite film is determined under the illumination of visible and near IR (NIR) light sources that promises the ability of SbSI as an effective photodetector.[1,2] Owing to its ferroelectric and optical characteristics a new class of piezoelectric energy harvester has been developed for its effective utilization in powering the Vis/NIR based photodetector. The experimental report validates the capability of SbSI as an emerging class of material for the rising piezoelectric-photonic technologies.

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# Enhancement of PVDF β -phase through Biocompatible Amino acid for Energy Harvesting Application: Flexible Ferroelectric Nanogenerator

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Highly ferroelectric and biocompatible PVDF composite films were fabricated by solution casting technique. The class of amino acids, Glycine was used as an additive that was incorporated in to an organic ferroelectric PVDF polymer matrix. Compared to other inorganic and some carbon-based materials, glycine is biocompatible in nature. The influence of glycine leads to the improvement of electroactive β-phase of the fabricated PVDF composite film. The significance of the loading content was analyzed with different weight ratios such as 5, 10, 15 and 20 wt.%. The enhancement of the β-phase nucleation is due to the strong interaction between the proteinogenic amino acid and the PVDF chains which was confirmed through various physical characterizations. Further, the electroactive films were used to fabricate the biocompatible ferroelectric nanogenerator (BFNG) devices for harvesting mechanical energy. The as-fabricated devices were subjected to electrical performance analysis such as load resistance, instantaneous power density calculation, stability, LED lit up and LCD display. This study will be helpful in harnessing the mechanical energy in a biocompatible way.

**Keywords:** ferroelectric, biocompatible, glycine, poly (vinylidene fluoride), nanogenerator, electroactive β-phase.

**Acknowledgement**:

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# Free-standing, Flexible conducting carbyne: A novel electrode material for supercapacitor applications

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## Abstract

A new freestanding flexible carbyne film is prepared via one-step chemical reaction of the dehydrofluorination process and examined its electrochemical properties for supercapacitor application. The chemical bonding nature of carbyne is examined using Fourier-transform infrared spectroscopy(FT-IR) it revealed the presence of C≡C and C=C stretching vibration in the obtained carbyne film. Laser Raman spectroscopy confirms the carbyne contains both the sp and $sp^2$ hybridized carbon. The surface morphology of carbyne is analyzed using Long Term Emission Scanning Electron Microscope (TESCAN).The electrochemical properties of prepared carbyne film are examined using cyclic voltammetry (CV), and galvanostatic charge-discharge analysis(CD) The cyclic voltammetry(CV) profile shows the quasi-rectangular type behavior which suggests the presence of electrochemical double layer capacitance (EDLC) and Faradaic capacitance in carbyne.The galvanostatic charge-discharge analysis (CD) shows the symmetric charging and discharging curve over the potential of -1.0 to 0.0 at various current range from (0.2 µA to 1 µA) which further confirms the EDLC behavior. Moreover, the long-term cyclic stability tests confirmed excellent capacitance retention of about 92.2% for the free-standing conducting carbyne (FSCC) electrode. These studies suggested the potential applications of carbyne as an electrode material for supercapacitor application.

**Keywords:** Freestanding conducting carbyne, Energy storage, Dehydrofluorination and sp & $sp^2$ hybridized carbon.

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# Superionic Lithium Ion Pathways Formed on the Surface of $Li_3V_2(PO_4)_3$/C Cathode Materials for High Power Li Ion Battery

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Lithium rechargeable batteries have emerged as the overwhelming choice for portable power sources in the modern world, due to their high energy density and sustainable chemical architecture after long-term repeated use.[1,2] However, serious concerns are now being raised regarding the practicality of lithium rechargeable batteries for electric vehicles, electric power storage systems, smart grids, etc. These large-scale appliances need tremendously high energy density and excellent thermal stability at elevated temperatures, but the current lithium rechargeable battery systems cannot totally fulfill all of these requirements because of the limited energy/power density of the current cathode materials.

NASICON-type $Li_3V_2(PO_4)_3$ (LVP) is favored among these materials due to its high theoretical capacity (197 mA h $g^{-1}$ when all three Li atoms are reversibly transferred) and average redox voltage (4.0 V vs. $Li^+$/Li). However, several drawbacks still exist that prevent the use of LVP as a commercial cathode material, including its poor kinetic properties caused by its intrinsic low electronic (2 x $10^{-8}$ S $cm^{-1}$) and ionic ($10^{-9}$ to $10^{-10}$ $cm^2$ $s^{-1}$) conductivity.[3,4]

We report a new discovery for enhancing Li ion transport at the surface of $Li_3V_2(PO_4)_3$ particles through super-ionic pathways built along an ionic conductor. The $Li_3V_{1.95}Zr_{0.05}(PO_4)_3$/C composite has much higher initial discharge capacity, superior rate-capability, and excellent cycling performance when compared with pristine $Li_3V_2(PO_4)_3$/C. This is partly due to the occupation of vanadium sites by $Zr^{4+}$ ions in the $Li_3V_2(PO_4)_3$ host crystals and facile Li ion migration through a $LiZr_2(PO_4)_3$-like secondary phase that forms on the surface of the $Li_3V_{1.95}Zr_{0.05}(PO_4)_3$ particles.

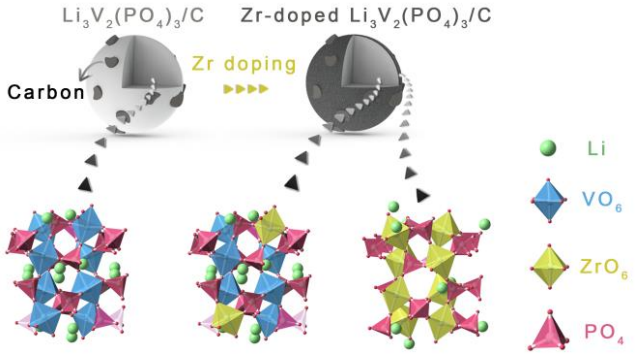


**Figure 1 Schematic illustration of the Zr-incorporated $Li_3V_2(PO_4)_3$/C composite merged with a NASICON-$LiZr_2(PO_4)_3$ secondary phase**

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# Effects of Hydrogen on the synthesis of highly porous $V_2O_5$ as a template for Hydrogen Evolution Reaction Electrocatalyst

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Hydrogen production through electrochemical water splitting has attracted growing interest as a future energy carrier because of its clean and renewable sources. Over the years the development of two-dimensional (2D) layered materials as electrocatalyst have taken a center stage because of their peculiar and rich electronic properties such as high electrical conductivity, large area, high performance and wider applications on the nanoscale.[1,2] Chemical vapor deposition (CVD) synthesis has the advantage of synthesizing high quality binder free electrocatalyst with potential scalability. This strategy for direct growth of active material on current collector makes the whole hydrogen generation process more direct, time and cost efficient.

As a semi-conductor, 2D $V_2O_5$ has the potential to act as an electrode for energy storage and catalysis due to its high porous nature.[3] The highly porous nature of $V_2O_5$ nano rods can enhance electrolyte contact. Thus it can serve as a good template for hosting hydrogen evolution reaction electrocatalyst .A one step direct synthesis of 2D layered material on $V_2O_5$ template can serve as a good electrode for Hydrogen evolution reaction. Preliminary synthesis of $V_2O_5$ with varied hydrogen concentration (reducing agent) shows morphological changes from 2D nano rods to a whisker morphology which we envisage can have a positive influence on the activity of the electrocatalyst hosted on this templates.

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# Effect of Electrode Structure on Concentration Type III-V Solar Cell

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The light-gathering type solar cell receives a lot of sunlight corresponding to 500 times or more of one Sun and generates a large amount of current. Therefore, the electrode on the light receiving surface of the solar cell should have a thick thickness so that it can cope with a large current. In order to form a thicker light-receiving surface electrode, an Au plating method using an electrolyte which can be obtained at a lower cost is used instead of an Au plating method. The distribution of the electrodes is obtained by covering the light receiving surface to obtain a loss, but since the sheet resistance required for electrons to reach the electrode must be reduced, a proper gap is produced. In this study, the efficiency of the solar cell was investigated by changing the electrode structure of the light receiving part of the concentrating solar cell. Au, Ag, Ni, etc were investigated as an electrode forming material and its shape was investigated according to the inclination angle of the mesa structure. The InGaP/GaAs double junction solar cell was used for the solar cell. Finally, it was confirmed that the optimum electrode structure irradiated had an efficiency improvement of about 2 ~ 3%.

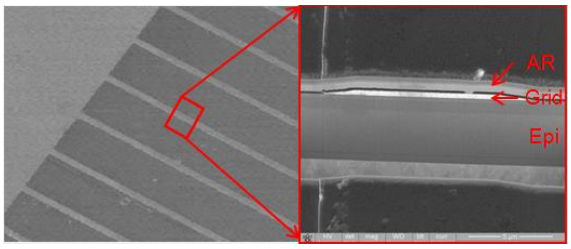


Fig. 1. Electrode Formation by E-beam deposition

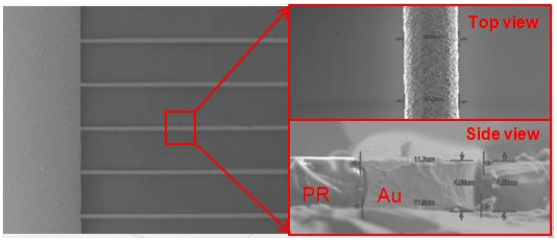


Fig. 2. Electrode Formation by Electro plating

# Flexible Temperature Sensor for Real-time Monitoring of Individual Medicinal Products as a Cold Chain System

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Recently, Flexible electronic sensors have been developed for healthcare applications where temperature sensing is considered as the most fundamental measurements for monitoring the patient's health. There are some limitations for monitoring the quality of clinical products in real-time and ensuring the reliability of products in various environments. The medicinal products such as vaccines, human blood and polio are required to store at the recommended temperature for maintaining the quality and reliability during transportation. In addition, for ensuring the potency of the vaccine and human blood, these should be kept from 2 ℃ to 8 ℃. Any change in thermal environment may cause a damage to the products, so, it is important to continuous monitor the thermal activity of the individual medicinal products and provide a traceability for ensuring the potency of the products during transportation.

Herein, the multichannel temperature sensor has been fabricated on the solution-based polyimide (SPI) with sensing layer of Platinum (Pt) for reliable electrical and mechanical properties. The thermal sensing of the proposed temperature sensor has been observed in the range of -5 ℃ to 15 ℃ and the results shows a higher thermal stability and linear response at various temperature. In addition, the temperature sensor has been designed in such a way which can be easily attached to any surface of medicinal products. The flexible temperature sensor does not show any significant degradation at various bending cycles of 100, 500, 1000, 5000, and 10000. A wireless real-time monitoring system has been introduced for continuous monitoring of clinical products separately in the ice box at the temperature range of -5 ℃ to 15 ℃. The wireless data acquisition of temperature sensor has been acquired by the Bluetooth device and external circuitry has also been developed to amplify the signal for accurate measurements of temperature measurement. To be conclude, we believe that our flexible sensor will be beneficial for the scientific community and the human life.

*This research was supported in part by the National Research Foundation of Korea.*

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# 2D layered structure $MoS_2$ and highly applicability to be $NO_2$ gas sensor

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After a discovery of graphene, researches had adored its outstanding properties including high mechanical strength and high conductivity. But graphene exhibits zero bandgap so there is a limitation to be used as a semiconductor material. Similarly, 2D materials such as $MoS_2$, $WS_2$ and $MoSe_2$ have layer by layer stacking structure consisting of atomic sheets with great materials properties. Above all, $MoS_2$ is a representative 2D material which can be easily synthesized by powder vapor transport (PVT) and chemical vapor deposition (CVD). $MoS_2$ is applied to various fields like bioelectronics, ultra-sensitive sensors and actuators.

$NO_2$ is one of toxic gases and even small amount lower than 1 ppm $NO_2$ can cause serious diseases. In order to be used as an active matrix for $NO_2$ gas sensors, the material must exhibit high sensitivity to $NO_2$ and $MoS_2$ could have good sensitivity to very small amounts of $NO_2$ because of S vacancies [1]. Mo/S atomic ratio in the $MoS_2$ surface is from 1.7 to 1.8. The ratio is high enough to influence reaction between $NO_2$ and $MoS_2$ during process so we should consider S vacancies as active sites. Through the S vacancies on the surface of the CVD grown $MoS_2$, a strong dipole of $NO_2$ generates an attractive force which induces a sub-state in the energy gap near the valance band to induce the off current to increase as a function of $NO_2$ concentration [2].

In this work, $MoS_2$ is used for $NO_2$ gas sensor with high sensitivity. All the electrical measurements and gas-sensing characterizations of devices proceeded in a closed vacuum chamber at room temperature. $NO_2$ gas flew into $MoS_2$ channel directly as a form of a gas sprayer type so that we could observe how gas reacted with surface of gas sensor and how the reaction affected to the electrical characteristics of $MoS_2$. The desired concentration and fluxes of $NO_2$ gas were obtained by mass flow controllers (MFCs) from mixing $N_2$ diluted 2000 ppm $NO_2$ gas and 99.999 % $N_2$ gas. The gas reactivity ($R$) were determined as $I_{gas}/I_0$ at a certain gate bias.

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# Sticky PDMS patch with nature-inspired patterns for detection of Electrophysiological signal by “transfer and paste” approach

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Non-invasive electrophysiological signals provide body information which can be utilized in human machine interaction (HMI) and biomedical field. Previously, the reported flexible sensors show promising applications in various fields that include prosthetic hands in robotics, controlling in home electronics. Recently, nature inspired structures have motivated and demonstrated for various applications like stretchable supercapacitor inspired by kirigami, and nanopile interlocking system from root system of plants. further, filamentary serpentine shaped designs have been widely reported for the fabrication of stretchable sensors through elastomeric substrates for conformable and strain relief. Accordingly, combining the nature inspired structures with well-known serpentine designs will enhance the structure sustainability under complex stress environments.

Herein, we have introduced a novel high areal coverage structure adopted from nature for electrophysiological measuring electrodes that are stretchable along uniaxially, diagonally, and z-axis. Additionally, PDMS layer with soft, sticky, and permeable to water have been considered to avoid irritation while longer usage. In more detail, the novel structure was transferred onto modified PDMS substrate by using water-soluble tape. The experimental results suggest that the sensor designs inspired by nature can be mounted on compliant substrates and able to measure EMG, ECG, EOG and EEG. Overall, the design offers a chance of developing a new format of stretchable and flexible electronics.