Saudi Arabia-Korea Joint Photonics Workshop on Semiconductor Nanostructures and Applications

Dates: February 16, 2020
Venue: King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

Session I: Seminar to Electrical Engineering community at KAUST

Growth, Characterization of Semiconductor Nanostructures
(12:00 noon - 12:45 pm)

Chair: Prof. Boon S. Ooi

Session I Program:

Speaker	Institute	Time	Title
Sang-Wan Ryu	CNU	12:00 noon~ 12:45 pm	Ultrafast carrier dynamics of semi-polar (11-20) InGaN/GaN core-shell quantum wells grown on *m*-plane GaN nanowires

12:50 ~ 1:20 pm: Presenter's lunch at Building 9, Level 2, Room 2322, Hall 1

Opening Ceremony (1:20 - 1:30 pm)

Prof. Boon S. Ooi (KAUST)

Session II: Growth, Characterization of Semiconductor Nanostructures
(1:30 ~ 3:15 pm)

Chair: Prof. Young-Min Song (Republic of Korea)

Session II Program:

Speaker	Institute	Time	Title
Boon S. Ooi	KAUST	1:30 - 1:45 pm	Research overview of Photonics Laboratory: Optical wireless communications and optical fiber sensing
Young-Min Song	GIST	1:45 - 2:15 pm	Recent advances in flexible optoelectronics and heat management strategy
Kazuhiro Ohkawa	KAUST	2:15 - 2:45 pm	MOVPE growth of InGaN and its application to red LEDs
Xiaohang Li	KAUST	2:45 - 3:15 pm	Polarization-inspired III-nitride Research

Refreshment Break (3:15 - 3:30 pm)

Session III: Applications of Semiconductor Nanostructures
(3:30 - 4:30 pm)

Chair: Prof. Boon S. Ooi (Saudi Arabia)

Session III Program:

Speaker	Institute	Time	Title
Aadil Waseem	CNU	3:30 - 3:50 pm	Effect of crystal orientation of pristine and GaN/V_2O_5 core-shell nanowires on piezoelectric nanogenerators
Jung-Wook Min	KAUST	3:50 - 4:10 pm	Heterogeneous integration of GaN/perovskite semiconductors for optoelectronic devices
Tien Khee Ng	KAUST	4:10 - 4:30 pm	Hybrid integration of semiconductors for optical wireless communication

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Closing Ceremony (4:30 - 5:00 pm)

Prof. Boon S. Ooi & Prof. Sang-Wan Ryu

Ultrafast carrier dynamics of semi-polar (11-20) InGaN/GaN core-shell quantum wells grown on m-plane GaN nanowires

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Abstract: GaN-based light-emitting diodes (LEDs) on sapphire are known to exhibit high efficiency and long lifetime. In order to fabricate the cost-effective LEDs on larger scale, the most efficient approach is the growth of scalable and high crystal quality GaN nanowires on amorphous substrate, preferably glass. We have demonstrated the growth of GaN nanowire-based LEDs using metal-organic chemical vapor deposition on an amorphous glass substrate. Additionally, the InGaN/GaN multiple quantum well shells are conformally grown on semipolar $\{11\bar{2}2\}$ growth facet of m-axial GaN core nanowires and resulted in reduced quantum confined Stark effect. The photoluminescence spectroscopy of the GaN core nanowire-ensemble reveals a very high crystal quality due to the dominant emission from the band-to-band transition and absence of a characteristic yellow luminescence. Furthermore, the temperature-dependent PL of the nanowire ensemble exhibits a very high internal quantum efficiency of 76.1%. Therefore, the ultrashort radiative lifetime of the carriers was in the range between 19 ps and 54 ps. These results emphasize the potential of our approach to grow high-crystal quality GaN nanowires on amorphous substrates for large scale production and various optical applications such as LEDs, solar cells, and photodetectors.

Biography: Sang-Wan Ryu received the B.S., M.S., and Ph.D. degrees in physics from Seoul National University, Seoul, Korea, in 1992, 1994, and 1998, respectively. After graduation, he joined the University of Southern California, Los Angeles, in a post-doctoral position till 2000 where he worked on a long-wavelength VCSEL. During 2000-2004, he worked with the Electronics and Telecommunication Research Institute, Taejon, Korea, and researched on optical devices for fiber communication. Then he moved to the Department of Physics, Chonnam National University, Gwangju, Korea, in 2004, and has been continuing his research on growth and characterization of novel semiconductor materials, nano-fabrication, and the applications for optical, electrical, and energy devices.

Optical wireless communications and optical fiber sensing

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Abstract: Investigations in photonics and optoelectronics have resulted many utilities in consumer electronics and photonic integration circuits. In the advent of internet-of-things, the fields are contributing to ever important applications in low-latency and large bandwidth wireless communication as well as far-reaching and robust optical sensing. In this talk, we will briefly discuss the current activities in Photonics Laboratory in these applications.

Biography: Boon S. Ooi received the B.Eng. and Ph.D. degrees in electronics and electrical engineering from the University of Glasgow, Glasgow, U.K. He is a Professor of Electrical Engineering with the King Abdullah University of Science and Technology, Thuwal, Saudi Arabia. He has served on the technical program committee or organizing committee of IEDM, OFC, CLEO, ISLC and IPC. He is currently an Associate Editor for Optics Express, IEEE Photonics Journal and SPIE Journal of Nanophotonics. He is a Fellow of OSA, SPIE, and IOP (U.K.). He is also an elected Fellow of the U.S. National Academy of Inventors (NAI).

Recent advances in flexible optoelectronics and heat management strategy

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Abstract: Recent advances in materials and fabrication techniques enable construction of high-performance optoelectronic devices that can flex, bend, fold and stretch, with ability to accommodate large (<<1%) strain deformation, reversibly and in a purely elastic fashion. Such systems open up new engineering opportunities in bio-inspired device design and in intimate, multifunctional interfaces to biology. This talk summarizes two examples of flexible optoelectronics: (1) hemispherical digital imagers that incorporate essential design features found in the arthropod eye and (2) tiny light emitting diodes (LEDs) and photodetectors (PDs) for oximetry. For practical applications of such devices, this talk introduces recent advances in thermal management based on radiative cooling.

References:

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5. G. J. Lee, Y. J. Kim, H. M. Kim, Y. J. Yoo, Y. M. Song, Colored, Daytime Radiative Coolers with Thin-Film Resonators for Aesthetic Purposes, Adv. Opt. Mater. 1800707 (2018)
6. H. H. Jung et al., Thin Metallic Heat Sink for Interfacial Thermal management in Biointegrated Optoelectronic Devices, Adv. Mater. Technol. 1800159 (2018)

Biography: Young Min Song received a M.S. and Ph.D. in Information and Communications from the Gwangju Institute of Science and Technology (GIST) in 2006 and 2011, respectively, after a B.S. degree in Biomedical Engineering from the Yonsei University in 2004. From 2011 to 2013, he was a postdoctoral research associate in the Department of Materials Science and Engineering at the University of Illinois at Urbana–Champaign. He is currently an associate professor in the School of Electrical Engineering and Computer Science at the GIST. Dr. Young Min Song's research interests include advanced optoelectronic devices/systems, multifunctional nanophotonics, and optical healthcare systems. He has published 96 peer-reviewed research articles including Nature, Science, and Nature Communications. His Google Scholar profile acknowledges over 4900 citations and an h-index of 28.

MOVPE growth of InGaN and its application to red LEDs

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Abstract: The development of three primary colors (RGB) InGaN LEDs will be the key technology to realize monolithic full-color lighting and displays shortly. We have developed micro-flow channel MOVPE that can grow high-In-content InGaN at raised temperatures of 60-100°C compared to conventional MOVPEs. Simulations of the micro-flow channel method show increases in the gas-phase concentrations of decomposed molecules from TMIn and NH_3 precursors. Higher concentrations have made it possible to achieve the raised growth temperatures. Alternatively, more In-content InGaN layers were grown at specific temperatures. For example, a typical growth temperature of 600-nm InGaN LED structures is about 710°C, but we have achieved a temperature of 810°C for such InGaN by using the micro-flow channel MOVPE and the strain control. It was confirmed that the quantum efficiency of InGaN QWs by the micro-flow channel method is higher than that of InGaN by the conventional way in the longer wavelength region than green. Red (≥ 620 nm) InGaN-based LEDs which were grown by the micro-flow channel MOVPE will be reported.

Biography: Kazuhiro Ohkawa is a professor at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. He belongs to Electrical Engineering of KAUST and is the principal investigator of Energy Conversion Devices and Material (ECO Devices) laboratory. Also, he is a Fellow of the Japan Society of Applied Physics. He received Ph. D. degree from the University of Tokyo, Japan. He worked for Panasonic as a senior research staff, University of Bremen (Germany) as a professor, and Tokyo University of Science. He is appointed a Lifelong Honorary Professor from Bremen State, Germany. He was a visiting professor at Xiamen University, China. His research interests are the study of wide bandgap materials and the development of their efficient LEDs, lasers, and photocatalyst.

Polarization-inspired III-nitride research

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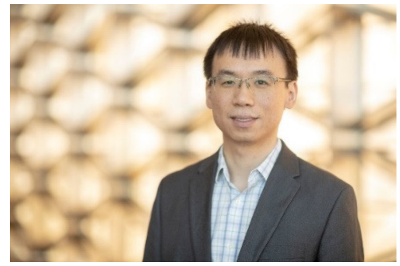

Abstract: Polarization is one of the most intriguing and important material properties for III-nitride semiconductors, for instance, leading to the invention of GaN HEMT and countless works of improving LED and laser performance. Over 120,000 polarization-related papers have been published in the past. However, there is still a great lack of understanding about new research opportunities related to polarization. Our group have been the first to study polarization properties of III-nitride ternary alloys using the modern hexagonal reference. As a result, we are able to discover numerous new structures that are significant for future device research. Furthermore, we have employed polarization engineering to invent the first UV-LED without electron blocking layer, the first III-N/III-O HEMT, the first GaN QW deep UV laser, the first 3D device band diagram for III-N optical devices. This talk will elaborate those efforts.

Biography: Xiaohang Li is a faculty member of Electrical Engineering and Applied Physics and the PI of Advanced Semiconductor Lab at KAUST. Prior to joining KAUST, he received Ph.D. from Georgia Institute of Technology. His broad research interest includes important aspects of III-N and III-O wide bandgap semiconductor research: MOCVD growth, characterization, devices, physics, software, and hardware for UV and visible optical and electronic devices. He has published > 70 peer-reviewed journal papers and given > 80 invited/plenary talks and seminars and has > 20 pending and issued patents. He is an Associated Editor of the OSA Photonics Research and a reviewer of numerous journals including Nature Photonics.

He is the recipient of several prestigious awards including Harold M. Manasevit Young Investigator Award from American Association for Crystal Growth, SPIE D. J. Lovell Scholarship, Edison Prize from the Edison Innovation Foundation, IEEE Photonics Graduate Student Fellowship. He is a selected participant of McKinsey Insight Program and BCG Bridge Program. Based on polarization and machine learning research, his group has created the cloud-based software *Polarization Toolbox* which has been used by hundreds of researchers from > 60 universities, institutions, and companies around the world.

Effect of crystal orientation of pristine and GaN/V_2O_5 core-shell nanowires on piezoelectric nanogenerators

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Abstract: The application of pristine and core-shell GaN nanowires (NWs) was extensively studied in piezoelectricity. The single crystallinity and flexibility of GaN NWs enhance their applicability in self–powered electronics. However, the existence of free carriers even in undoped GaN degrades the piezoelectric performance. In order to fabricate the NW based flexible PNGs, pristine and GaN/V2O5 core-shell NWs of controlled crystallographic orientations were utilized. Catalyst-assisted c- and m-axis GaN NWs were grown on c-plane GaN thin film using MOCVD regardless of the catalyst size and choice of substrate. The orientation of the NWs was controlled by changing the NH3 flow rate and reactor pressure. The V2O5 with controlled resistivity was conformally deposited on the NWs using RF magnetron sputter to suppress the internal screening effect. The flexible PNGs were then fabricated by sequentially transferring PDMS embedded NWs from c–plane GaN TF to flexible PET substrates using doctor blading technique. A stability test was performed for one hour to verify the feasibility of using NW based flexible PNGs for real life applications. The high stability of PNGs was attributed to flexibility and high crystallinity of the GaN NWs. However, the maximum output voltage (27 V) and current (850 nA) were exhibited by the PNG based on c–axis GaN/V2O5 core-shell NWs. The V2O5 shell with controlled resistivity overall enhanced the piezoelectric performance.

Keywords: GaN, nanowires, piezoelectricity, V2O5, core-shell

Biography: Aadil Waseem received his M.Sc. degree from Federal Urdu University of Arts, Science, and Technology, Pakistan. He is currently pursuing his M.S-PhD. degree in Department of Physics, Chonnam National University, South Korea. His current research is focused on the fabrication and characterization of gallium nitride (GaN) based nanostructures using MOCVD. He has expertise to grow n- and p-doped GaN thin films, GaN nanowires with controlled crystallographic orientations, and to fabricate nanoporous GaN. These GaN based nanostructures are being utilized in fabrication of piezoelectric nanogenerators and light.

Heterogeneous integration of GaN/perovskite semiconductors for optoelectronic devices

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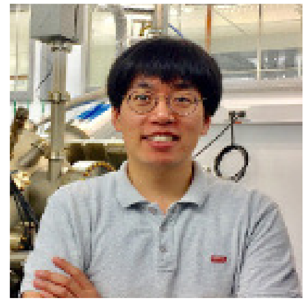

Abstract: High-density and well-aligned self-catalyst III-nitride nanowires are defect- and strain-free by nature. These characteristics make them suitable for next-generation light-emitting and photovoltaic/photocatalytic devices on a non-conventional platform such as poly-crystalline metals or even non-crystalline amorphous substrates. In this talk, catalyst- and mask-free GaN nanowires ensemble were grown by plasma-assisted molecular beam epitaxy (PA-MBE) under nitrogen-rich condition on an amorphous substrate. We introduced the GaN nanowires as a new electron transport layer (ETL) for methylammonium lead iodide ($MAPbI_3$) perovskite solar cells (PSCs). Prior to optoelectronic device realization, we conducted the fundamental studies including diffusion-induced growth mechanism. On bare fused silica substrate, without any buffer layer, hundreds-of-nanometer scale grains of GaN nanowires were examined by SEM and interfaces were investigated by TEM. Despite the poly-crystalline properties of coalescent columnar GaN layer, each grain showed the preferential orientation along the *c*-axis growth direction.

To provide conductivity and transparency on amorphous fused silica as a thermally durable substrate, transparent conductive oxide (TCO) layers were deposited by RF magnetron sputtering method. Nanowires were grown on indium tin oxide (ITO) and fluorine-doped tin oxide (FTO) interlayer, respectively, and their optical, structural and electrical characteristics of each Si-doped n-type GaN nanowires were also investigated. For the solar cell device application, n-GaN nanowires were used as a new ETL on TCO/silica template for the PCSs. As compared to conventional ETLs of ZnO, TiO_x, and Al_2O_3, n-GaN nanowires also showed high electron mobility and UV-light blocking characteristics. To optimize n-GaN nanowires for effective carrier transporting characteristics, systematic silicon doping concentration was studied by Mott-Schottky measurements. Moreover, finite-difference time-domain (FDTD) simulation confirmed that the roughened GaN/$MAPbI_3$ interface is helpful for photon recycling. We obtained the best PSC device performance with 19.60 mA/cm^2 short-circuit current (J_{sc}), 1.078 V open circuit voltage (V_{oc}), 74.2% fill factor (*FF*), and photo conversion efficiency (PCE) performance of 15.67% for PSC. These achievements can open a new pathway for the heterogeneous integration of III-nitride and perovskite semiconductors and substrate-independent epitaxy.

Biography: Jung-Wook Min is currently a research scientist in Photonics Laboratory at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. He received his PhD in applied physics from Gwangju Institute of Science and Technology (GIST), Republic of Korea in 2016, and joined Ooi-group at KAUST as a postdoctoral fellow in 2017. His research mainly focuses on the plasma-assisted molecular beam epitaxy growth of group-III-nitrides and its heterogeneous integration with other material systems for optoelectronic device applications.

Hybrid integration of semiconductors for optical wireless communication

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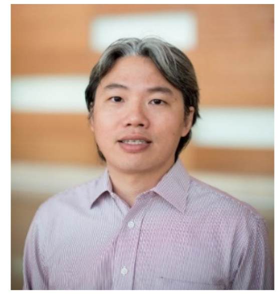

Abstract: Semiconductors are pervasive in consumer electronics and optoelectronics, and the related optical devices are deemed disruptive that Nobel Prize in Physics in 2014 was awarded to the inventors of blue light-emitting diodes (LEDs), which "has enabled bright and energy-saving white light sources". While AlInGaN-based lasers and LEDs, and silicon-based photodetectors are currently matured, unconventional usage based on the semiconductors have demonstrated their further potential, including solar-hydrogen generation, indoor-horticulture and data internet. By combining the optical characteristics of robust AlGaInN-based semiconductor with high quantum-yield photon-conversion semiconductor, and tailor design the components into the desired form and shape, the potential for solving technological challenges in smart cities are boundless. In this talk, we will discuss our progress in InGaN/GaN-quantum-well based photodetector and integrated perovskite/silicon semiconductor photodetector in realizing applications in ultraviolet-to-visible light wireless optical communication.

References:

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Biography: Dr. Tien Khee Ng is currently a senior research scientist with Photonics Laboratory at King Abdullah University of Science and Technology (KAUST), Saudi Arabia. He was a co-principal-investigator responsible for innovation in Molecular-Beam-Epitaxy-grown nanostructures devices and in laser devices for the Technology-Innovation-Center on Solid-state Lighting at KAUST (sponsored by KACST, the national agency for science and technology). His research primarily focusses on the development of semiconductors and devices for efficient optoelectronic devices, optical communication, and energy harvesting. He is a senior member of IEEE and The Optical Society (OSA), as well as members of the SPIE and the Institute of Physics.