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Editorial

Nanostructure physics and materials science at center for integrated nanostructure physics

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This special issue introduces major research in uniquely defined nanostructures of 0D, 1D, and 2D, to explore unprecedented physics and chemistry at Center for Integrated Nanostructure Physics (CINAP), Institute for Basic Science (IBS), located at Sungkyunkwan University (SKKU). SKKU is one of the most comprehensive, research-oriented, and globalized universities in Korea. The name 'Sungkyunkwan' originates from Academy of Sciences in Chosun dynasty in 1398, and therefore, the university has the longest history in Korea. The building 'Sungkyunkwan Myungryundang' is still preserved as a National Treasure #141 located in Seoul campus (Fig. 1). The natural science campus was transferred to city of Suwon in 1978, which is also known for the locations of Samsung headquarter and numerous related industries including Samsung Electronics, Samsung Semiconductors, and Samsung Advanced Institute of Technology. SKKU is a private university supported financially by a global company, Samsung group, although it was managed by the Confucius scholars until 1995. SKKU with two campuses in Seoul with humanities and arts and in Suwon with natural sciences is a comprehensive university and has about 20,000 undergraduate students, 8000 graduate students, 1400 tenured faculty members, and 3700 postdoctoral fellows and research professors. In 2015 QS World University Rankings, SKKU was ranked 118th worldwide and Joong Ang Daily newspaper ranked number 1 among private and comprehensive universities in Korea.

IBS was launched by Korean government under the newly established constitutional Law of Promoting Basic Sciences in 2012, to promote the basic science in Korea and eventually develop disruptive technology that could revolutionize the Korea industry in the long run. The idea is to establish IBS headquarter in Daejon, and select pioneering individual directors in basic research fields in mathematics, physics, chemistry, biology, geology, and medical sciences in which each center can be spread over the country, and provide them research environments such that they can compose research groups as they wish and allow freedom of performing researches with sufficient amount of research fund for a long term. IBS follows the spirit of Max Planck Institute in Germany. Started in 2012, 27 Directors including 5 foreign scientists have been selected so far with several steps of in-depth evaluation systems from various fields of basic sciences.

Our center, Center for Integrated Nanostructure Physics (CINAP), was launched in 2012 located at Suwon, Natural Science Campus of SKKU. The annual budget started with nearly 10 million US dollars at the beginning, although this may fluctuate slightly year by year. The program is guaranteed to sustain for ten years to ensure stable research environment with unique evaluation system focusing on conceptual new findings and technical breakthroughs in science. In July 2015, SKKU set up a new independent building assigned for the CINAP with a total area of about 9000 m^2. N-Center was constructed within the Natural Science Campus, which is a prestigious opportunity to promote the basic science at SKKU (Fig. 2). The new building has a clean room, a dry room, vibration-free anti-sound TEM and STM rooms, the world's best-level optical laboratory capable of all carrier-dynamics experiments with versatile equipment (such as a pump-probe system with IR-visible range, a transient absorption spectroscopy, and a time-resolved photoluminescence with IR/visible laser sources, two AFM-NSOM-confocal Raman-PL correlation systems (NT-MDT)), two STMs at high vacuum/low temperature, the electrical characterization facilities (including two PPMS with 50 mK/9 T and 2 K/14 T and several ambient and vacuum probe stations), numerous comprehensive CVD systems (for the synthesis of graphene, h-BN, and various TMD materials). Two TEMs (including STEM) are expected to be installed on April and June 2016. All the instruments are installed in the open space without compartment so as to be shared more robustly with the help of super-users assigned for each system. Public on-line scheduling for the access to each machine is available and still continuing for full access of all the systems. The mission to finish the setup of infra-structure within the first three years is nearly accomplished with the great help from SKKU. Currently, CINAP consists of one Director, one Associate Director, one Group Leader, 12 cooperative professors, 33 research fellows, and 73 doctoral students. Research fellows are hired from all over the world, including USA, UK, France, Netherlands, China, and India. They are co-working and collaborating freely with anyone in the Center depending on their research subjects.

Understanding how the nanostructured-materials such as quantum dots, nanowires, nanotubes, graphene, and potential 2D

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Fig. 1. Sungkyunkwan Myungryundang was the highest education institute in Chosun dynasty.

Fig. 2. Landscape of the N-Center with CINAP located in the front wing.

layered materials are grown from self-assembly of atoms and molecules and their fascinating new phys-ics remain as one of the unconquered frontier sciences. The low dimensional materials can be easily hybridized to reveal multifunctional performance, which has never been realized in conventional approaches. Nevertheless, growth control of nanostructures and design of such hybrid structures are very challenging and often difficult to attain intuition from physical point of view. Recent progresses in ideal two-dimensional layered structures such as graphene, boron nitride, metal oxide, transition metal dichalcogenides (TMDs), and their hybridization with zero- and/or one-dimensional nanostructures has opened new exciting research areas in tunneling phenomena, enhanced carrier mobility, exciton dynamics, charge injection/extraction spectroscopy, and thermoelectric effect. Because of the complexity of low dimensional systems, most researches in nanostructure materials cannot be done in a small laboratory scale and require interdisciplinary collaboration from various disciplines of physics, chemistry, materials science and engineering. The research topics under investigation at CINAP at current stage is summarized the schematic, Fig. 3.

This Special Issue offers four review articles and six new research articles, with the focus on 2D material synthesis of TMDs, hexagonal boron nitrides (h-BN), BiTe alloy, graphene quantum dots, and graphene/carbon nanotubes (CNTs) hybrid structures for fundamental sciences and applications in the energy, optoelectronics, and thermoelectrics. Although the research theme of the CINAP focuses on fundamental sciences of various materials, it sometimes extends its realm towards demonstration of such concepts to applications of, for example, oxygen reduction reaction, multifunctional carbon nanotube sheet and yarn. Although these cannot cover all our researches in the CINAP, they still represent and give a taste what we are working on. One of the hot issues in TMDs is the unusual optical properties that reveal direct bandgap in monolayer but indirect bandgap in bulk and large exciton binding energies due to reduced charge screening. Unfortunately, these can be easily altered due to several external factors such as strain, dielectric of the surrounding medium, and electrical/optical/chemical doping. These studies are extensively reviewed here. Another important class of materials is highly conductive graphene and its counterpart highly insulating h-BN layer, which can used for an ideal substrate for gate dielectric due to the minimum charge scattering and flatness. Here, direct synthesis of graphene/h-BN heterointerface is reviewed comprehensively. Since graphene quantum dots have potential in many applications to energy harvesting and catalysts, various synthesis methods have been proposed. There are still some issues in reproducibility and controlling the size and functional groups, which will be discussed in the review here. A review is also provided in high thermoelectric performance of Bi-Te alloy *via* defect engineering strategy. We have three new research articles on 2D synthesis and three application-related works with graphene and carbon nanotubes. Choice of substrate is one critical parameter for growth of 2D materials. In addition to oxide substrates, transition metal substrate is another candidate for this purpose in particular due to its catalytic reaction to decompose precursors at the substrate. Gold foil is used to demonstrate high quality WS_2 growth and advantages and issues compared to other substrates are further discussed. The role of promoter, introduced in the growth of MOS_2 by chemical vapor deposition, is also elucidated *via* photoluminescence

Fig. 3. Research topics under investigation at CINAP.

measurements. Thick h-BN is another important material in electronic devices. Large-area thick h-BN film is synthesized with a borazine precursor in plasma-enhanced chemical vapor deposition. Monolayer h-BN is used as a buffer layer for thick h-BN film growth with improved uniformity and smooth surface. For applications, multilayer graphene is proposed to be useful for Pirani gauge and gas sensors due to sensitive pressure dependent convective heat transfer and differentiability for the gas species. 3D hierarchical graphene/CNTs building blocks are used to demonstrate high oxygen reduction reaction due to easy ion accessibility and efficient catalytic activity by the N-terminated graphene and carbon nanotubes. Finally, CNT sheets and yarns, and their composites have been fabricated to demonstrate their structures to be useful for electro-mechanical actuation.

The goal of this Special Issue is to provide a glimpse of what kinds of researches are under investigation in the CINAP and furthermore to stimulate multidisciplinary collaborations with other scientists outside the CINAP, although this Special Issue covers only little of what is undertaken at the CINAP. We sincerely hope that this Special Issue will inspire the readers to pay attention to the currently growing ongoing research breakthroughs at the CINAP and furthermore promote collaborations between CINAP and global institutions.

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Young Hee Lee. Professor Lee is the director of the Center for Integrated Nanostructure Physics (CINAP), Institute for Basic Science (IBS) at Sungkyunkwan University (SKKU). Prof. Lee has been a full professor of the Physics Department at SKKU, since 2001. Prior to joining SKKU in 2001, Prof. Lee was a full professor in the Physics Department at Chonbuk National University since 1986. Prof. Lee obtained his Ph. D at Kent State University in 1986. He serves as an Associate Editor of Energy Storage Materials and Europhysics Letters, and an Editorial board for Scientific Report. He was awarded the first SKKU fellow in 2004 at SKKU, Science award from Korean Physical Society, 2005, Lee Hsun Research Award, Chinese Academy of Sciences, 2007, and Presidential Award in Science and Education, 2008 and also nominated as a National Scholar by MOE, 2006 and recently got Sudang prize. He has been a member of Korean Academy of Science and Technology since 2007. Prof. Lee's work has focused on understanding the fundamental properties of nanostructures in 0D, 1D, 2D and their hybrid heterostructures, design and synthesis of various heterostructures to implement unique physical and chemical properties. His research covers carrier dynamics, carrier multiplication, hot carrier solar cell, thermoelectrics, quantum mechanical tunneling phenomena, nanocarbon-based soft electronics, and energy harvesting.

Woo Seok Choi. Professor Choi received his B.S. and Ph.D. degree in physics from Seoul National University in 2004 and 2010, respectively. From 2010, he worked as a postdoctoral research associate in the Oak Ridge National Laboratory, USA. Since 2013, he has been a professor in Department of Physics, Sungkyunkwan University. He received Bombi Award from the Korean Physical Society in 2014 and TJ Park Science Fellowship by POSCO TJ Park Foundation in 2015. His research interest lies in the field of emergent properties in complex oxide heterostructures.