2DMAT2022
2nd Global Summit and Expo on Graphene and 2D Materials
August 22-24, 2022          Edinburgh, Scotland

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Dear Colleagues,

It is a great pleasure to announce that The Scientistt will host the 2nd Global Summit and Expo on Graphene and 2D Materials (2DMAT2022) in Edinburgh, Scotland during August 22-24, 2022.

The 2DMAT2022 is the vital platform for exchanging recent achievements and discussing future facilities in Graphene and 2D Materials.

The 2DMAT2022 will be a 3 days event that means to gather the key players of the Graphene and 2D Materials Community and related sectors. This event is launched with the aims to become an established event, attracting global participants, intent on sharing, exchanging and exploring new avenues of graphene-related scientific and commercial developments.

A wide-ranging scientific program consisting of plenary lectures, keynote lectures, Invited lectures, parallel sessions, as well as poster sessions for young scientists covering all topics in grapheme and 2D materials will be scheduled. This conference provides a wonderful opportunity for you to enhance your knowledge about the newest interdisciplinary approaches in Graphene and 2D Materials technologies. Moreover, the conference offers a valuable platform to create new contacts in the field, by providing valuable networking time for you to meet great personnel in the field.

We look forward to seeing you at 2DMAT2022 in Edinburgh, Scotland
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Waterborne Exfoliated Nanocarbons and 2D Materials

Abstract
Polymerized ionic liquids (PIL) have enabled a new stimuli-responsive materials and some of these are finding innovative applications as thermodynamically stable dispersions and as dispersing aids with tunable solubilities. Such PIL based on imidazolium functional groups provide particularly good binding to nanocarbon sp2-surfaces. This binding emanates from overlap of imidazolium π-bonds with partially empty π-orbitals on surfaces. Excellent solubility, dispersibility, and interactions with continuous-phase solvents, such as water, are obtained because of the hygroscopic nature of imidazolium anion pairs. An outstanding practical attribute of such dispersing aids is that they can be adsorbed onto nanocarbon surfaces from solution and suspension, making the costs of such stabilizers and associated processing competitive with existing polymeric stabilizer costs. In addition, when adsorbed, these PIL provide osmotic-brush protection that works efficiently over wide indifferent-salt concentrations in addition to providing selective tunability. This tunability makes possible selective destabilization using small concentrations of select anions that is also reversible.

These PIL are illustrated to be excellent stabilizers for SWCNT (single-wall carbon nanotubes), MWCNT (multiwall carbon nanotubes), hydrothermal carbon, and graphene in water. This stabilization emanates from osmotic sphere effects that have provided means to prepare the most concentrated aqueous dispersions of MWCNT (17% w/w) and graphene (6.4% w/w) reported to date via liquid phase exfoliation in water.

Simple sedimentation and coating in a shear-field produce (MWCNT and graphene) functional electrodes suitable for conventional applications in addition to supercapacitor electrodes. Such dispersions also facilitate making particularly noteworthy advanced materials including: stimuli-responsive dispersions that can be manufactured using water but can be phase-transferred for composite formulation; thermally conductive hydrothermal carbon coatings (25 W/m/K); thermally conductive graphene coatings in the mid-diamond range (0.5 - 3 kW/m/K); rheo-optical (amorphous-nematic) transitions in graphene dispersions induced by couette shear fields; alternative coating methods derived from stimuli-responsiveness of imidazolium-anion exchange; and transformational electrode structures produced by electrospinning of MWCNT and graphene. Such a 2D heterostructured coated electrode derived from aqueous polyvinyl alcohol (0D) and MWCNT (1D) yield high surface area (0D+1D=2D) meso-networks.

Figure 1. SEM of 0.5:1:0.5 polyvinyl alcohol:MWCNT:NL coating.
Biography.
Professor Dr John Texter has worked for 44 years in industrial small particle and coating technologies (Strider Research Corporation; Eastman Kodak Company) and has been Professor of Polymer and Coating Technology for 19 years (Eastern Michigan University). He has been Editor-in-Chief of the Journal of Dispersion Science and Technology and Associate Editor of the Journal of Nanoparticle Research. He earned his degrees at Lehigh University, where he studied at the Zettlemoyer Center for Surface and Coatings Research. He is an experienced lecturer, inventor, technical project manager, and organizer, with over 250 publications including five books and 47 issued US patents. He has served as Chairman of the Division of Colloid and Surface Chemistry of the American Chemical Society, Chair of the Chemistry at Interfaces Gordon Research Conference, Chair of the Chemistry of Supramolecules and Assemblies Gordon Research Conference, and organizer of many international symposia. He is a Fellow of the American Chemical Society, the American Physical Society, and the Society for Imaging Science and Technology and has received numerous other honors for his innovation and service to Kodak and the profession.
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Graphene and Graphene-Based Nanocomposites: Mechanics and Mechanisms of Deformation and Fracture

Abstract
The deformation and fracture behaviour of one-atom-thick mechanically exfoliated graphene has been studied in detail. Monolayer graphene flakes with different lengths, widths and shapes were successfully prepared by mechanical exfoliation and deposited onto poly(methyl methacrylate) (PMMA) beams. Through in-situ Raman mapping at different strain levels, the distributions of strain over the graphene flakes were determined from the shift of the graphene Raman 2D band. The strength dropped to less than ∼10 GPa for large flakes, much lower than the reported value of 130 GPa, thought to be due to the presence of defects [1]. The evolution and propagation of cracks in exfoliated monolayer graphene single crystals and their associated stress fields have also been studied using Raman spectroscopy as a strain sensor. Such stress fields are found to extend over several microns, and their analysis leads to the fracture behavior of graphene being interpreted using linear elastic fracture mechanics [2]. It is shown that propagation of a sharp crack along the zigzag direction occurs at a critical stress intensity factor Kc ~4.0 MPa m1/2, similar to the findings of theoretical simulations.

Polymer nanocomposites reinforced with carbon-based fillers are gaining increasing interest for a number of applications due to their excellent properties [3]. This presentation will summarize the current literature status on the mechanical properties of composites reinforced with graphene- and identify the parameters that clearly affect the mechanical properties of the final materials such as the effective length, thickness and modulus of the reinforcement. It will also shown how Raman spectroscopy can be utilized for the understanding of the stress transfer efficiency from the matrix to the reinforcement. Importantly, it will be demonstrated clearly that continuum micromechanics that was initially developed for continuous composites is still applicable at the nanoscale for graphene [4].

Keywords
Graphene, Deformation, Fracture, Nanocomposites, Deformation mechanisms

References
Biography
Professor Young studied Natural Sciences at the University of Cambridge and gained his PhD in 1973. He became Professor of Polymer Science and Technology in Manchester in 1986, and the founding Head of the School of Materials in the newly-formed University of Manchester in 2004. Professor Young is a Fellow of Royal Society (2013), Royal Academy of Engineering (2006) and Academy of Europe (2015). He has introduced a number of revolutionary techniques that have given a completely new insight into the micromechanics of deformation in fibres and composites. Over recent years he has extended this approach to the mechanics of deformation of graphene and other 2D materials in nanocomposites. His contribution in research has been recognised through the awards of the Griffith Medal (2002), Leslie Holliday Prize (2011), Swinburne Medal and Prize (2012) and Platinum Medal (2019) from the Institute of Materials, Minerals and Mining.
Van der Waals Nanostructures for Advanced Electronics and Biomedicine

Abstract
I will review several unique van der Waals nanostructures for electronics and biomedical applications in this plenary talk. These nanostructures are based on van der Waals adsorption of molecular-scale materials on the surfaces or inside boron nitride nanotubes (BNNTs). BNNTs are electrically insulating and optically transparent [1, 2]. The unique properties of BNNTs have enabled the formation of single-electron transistors (SETs) without semiconductors [3]. We have also demonstrated the formation of 2D gold with tunable optical band gaps [4], field-effect transistors (FETs) by Tellurium (Te) atomic chains inside BNNTs [5], and high-brightness fluorophores that could be 1000X brighter than existing dyes [6, 7]. The synthesis, characterization, and applications of these van der Waals nanostructures will be discussed in the meeting.

Keywords
van der Waals, transistors, boron nitride nanotubes, atomic chains, fluorophores

References

Biography
Dr. Yoke Khin Yap is a professor of physics, director of the applied physics graduate program, and an honorable University Professor at Michigan Technological University (MTU). He earned his Ph.D. in 1999 from Osaka University as sponsored as a Monbusho scholar. He was a postdoctoral fellow of the Japan Society for the Promotion of Science before his appointment at MTU. His research interest focuses on synthesizing nanoscale van der Waals materials and their applications in electronics, energy harvesting, and biomedicine. Professor Yap was honored with the National Science Foundation CAREER Award in 2005. He was a Charter member of the users’ executive committee of the Center for Nanophase Materials Sciences at Oak Ridge National Laboratory from 2005 to 2007 and the first elected user group chair in 2008. Professor Yap received the Bhakta Rath
Research Award in 2011, was honored as an Osaka University Global Alumni Fellow in 2015, and received the MTU Research Award in 2018.
Keynote Forum
Day-1
Dae Joon Kang¹.*

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Universal Transfer Technique of 2-Dimensional Materials and Patterned Nanostructures by a Capillary Exfoliation Method Using Salmon DNA

Abstract

We present here a new water-based capillary peeling technique that allows 2-dimensional (2D) materials as well as patterned nanostructures to be efficiently detached from a host substrate and float freely on a water surface, facilitating the subsequent transfer process to any target substrates. We have investigated the parametric conditions required for successful exfoliation with our capillary exfoliation route (the peeling yield is close to 100%) to enable easy and controllable exfoliation for a facile fabrication of nanodevices. To verify the compatibility of our capillary exfoliation method with various device fabrication techniques, we have also demonstrated the successful transfer of 2D materials to various substrates with non-flat surfaces and fabricated back-gated FETs with remarkable charge mobility values using the 2D films thus transferred.

Keywords

transfer of 2D materials/nanostructures, solvation, salmon DNA, capillary-peeling

Biography

Professor Dae Joon Kang is with Sungkyunkwan University in Korea. He is the head of the Graduate School of Physics Department and director of the Brain Korea 21 Four Research and Education Division of the department. His main research interests are in non-conventional pattern replication technique based on electrohydrodynamic lithography, and physics and application of 2-dimensional materials. He has published more than 250 SCI peer reviewed journal articles in the field of nanophysics and nanotechnology. (H-index:50)
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Chemically-Functionalized MXene Based Triboelectric Nanogenerators: Environmental Stability and Versatility of MXene

Abstract
The limited choice of materials for triboelectric contact pairs and their low stability to the humid environment hinder the research and further development of triboelectric nanogenerators (TENGs). Two-dimensional (2D) transition metal carbides (Ti\textsubscript{3}C\textsubscript{2}T\textsubscript{x}, MXene) have attracted much attention due to their potential application in TENGs. However, the poor stability of MXene-based TENGs to oxidation and humidity is a major obstacle that affects device performance during prolonged use. Here, we report a simple approach to surface functionalization through a silylation reaction to stabilize MXene against humidity and make MXene more versatile for TENGs. Functionalization of MXene with hydrophobic silane molecules, aminopropyl-triethoxy silanes and fluoroctyl silanes, not only stabilizes MXene against humidity but also makes it more useful as a triboelectric material.

Keywords
MXene; Chemical functionalization; Stability against humidity; triboelectric nanogenerators, aminopropyl-triethoxy silanes and fluoroctyl silanes

Biography
Professor Dae Joon Kang is with Sungkyunkwan University in Korea. He is the head of the Graduate School of Physics Department and director of the Brain Korea 21 Four Research and Education Division of the department. His main research interests are in non-conventional pattern replication technique based on electrohydrodynamic lithography, and physics and application of 2-dimensional materials. He has published more than 250 SCI peer reviewed journal articles in the field of nanophysics and nanotechnology. (H-index:50)
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**Growth of Single-Crystal Hexagonal Boron Nitride by Chemical Vapor Deposition**

**Abstract**  
Large-area single-crystal monolayers of two dimensional (2D) materials such as graphene, hexagonal boron nitride (hBN) and transition metal dichalcogenides have been successfully grown. Among them, hBN has been demonstrated to be the “ideal” dielectric substrate for 2D materials-based field effect transistors (FETs) – offering the potential for extending Moore’s law. Although hBN thicker than a monolayer is more desirable as substrate for 2D semiconductors, the growth of highly uniform and single-crystal few- or multi-layer hBN has not yet been demonstrated. Here we report the epitaxial growth of wafer-scale single-crystal tri-layer hBN by a chemical vapour deposition method. Uniformly aligned tri-layer hBN islands are found to grow on a 2 cm × 5 cm single-crystal Ni (111) at early stage of growth and finally to coalesce into a single-crystal film. Cross-sectional transmission electron microscopy (TEM) results show that a Ni23B6 interlayer is formed (during cooling) between the single-crystal tri-layer hBN film and Ni (111) substrate by boron dissolved in Ni (111) and that there is epitaxial relationship between tri-layer hBN and Ni23B6 and between Ni23B6 and Ni (111). We further find that the tri-layer hBN film acts as a protective layer that remains intact during catalytic evolution of hydrogen – suggesting continuous and uniform single-crystal tri-layer hBN in large area. This tri-layer hBN transferred onto the SiO2 (300 nm)/Si wafer acts as a dielectric layer to reduce electron doping from the SiO2 substrate in MoS2 FETs. Our results demonstrate that it is possible to achieve high quality multi-layered hBN over large areas by CVD – opening up new pathways for making it a ubiquitous substrate for 2D semiconductors and other purposes.
Functionalization improves performance of graphene devices

Abstract
Recently, it was clearly demonstrated, that functionalization of graphene dramatically enhance potential for application of this material. However, so far realized strategies do not typically allow to control the functionalization process in terms of localization of the functional groups and mutual interactions with the graphene. Mastering of these processes will pave the way to precisely control electronic structure of graphene and thus enable more advanced applications. Here, we will propose some strategies, which enable controlling and tailoring the functionalization process. It will be also shown how tailored functionalization can be applied to optimize function of supercapacitor in graphene /PANI composite and to realize fast, ultrasensitive and broadband 2D detector.

Keywords
Graphene, functionalization, devices, spectroscopy

References

Biography
Prof. Martin Kalbac graduated in inorganic chemistry from Charles University, Prague, Czech Republic, (1998), where he also received his Ph.D. degree in 2002 and has been habilitated in the field of inorganic chemistry (2019). Since 2001 he has worked at the J. Heyrovsky Institute of Physical Chemistry of the Academy of Sciences of the Czech Republic. Currently, he is a vice-director of the institute and the head of the Department of Low dimensional Systems. His research interests include carbon nanotubes, 2D materials, Raman spectroscopy and spectroelectrochemistry, isotope engineering of carbon nanostructures and sensorics.
Moon-Ho Jo$^{1,2,3,*}$

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Tuning mosaic textures of van der Waals monolayer semiconductors by vicinal epitaxy

Abstract
Atomically thin van der Waals (vdW) semiconductors can be a new set of condensed matter with emergent phenomena, particularly when they can be atomically molded to form artificial lattices, where electronic and atomic motions are tightly confined within in two-dimensional layers [1-4]. In this talk, we discuss our recent developments of epitaxial molding of vdW monolayer crystals by vdW atomic heteroepitaxy, particularly on tuning mosaic textures by vicinal vdW epitaxy. Such tunable mosaic textures include geometrical bi-crystals and single-crystals, involving interesting forms of the extended-defects within the host lattice. We show that such lattice discontinuities can be manipulated in a deterministic manner by vicinal vdW epitaxy, to turn the host semiconductor lattice into another one with diverse novel properties [5-7].

Keywords
van der Waals semiconductors, vicinal epitaxy, mosaic crystals

References

Biography
Prof. Moon-Ho Jo is Director of Center for Van der Waals Quantum Solids, Institute for Basic Science (IBS) and Mueunjae Chair Professor of Dept. of Materials Science and Engineering, Pohang University of Science and Technology (POSTECH). Moon-Ho Jo received his Ph.D. in Materials
Science at University of Cambridge (2001), with a dissertation on electron-spin tunneling in half-metallic manganites. He joined the faculty of the Department of Materials Science and Engineering at POSTECH in 2004 after a postdoctoral fellowship in Department of Chemistry/Physics at Harvard University. He was appointed Fellow of The Korea Academy of Science and Technology in 2015. His current research interests include (1) atomic scale heteroepitaxial growth of semiconductors and strongly correlated materials, (2) light-matter interactions at atomically thin materials, as well as (3) electron transport and laser transport spectroscopy in atomic scale materials.
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Low-voltage transistors and diodes; Extending the road beyond CMOS

Abstract
The continuous transistor down-scaling has been the key to the successful development of the current information technology. However, with Moore’s law reaching its limits the development of alternative transistor architectures is urgently needed. Transistors require at least 60 mV switching voltage for each 10-fold current increase, i.e. sub threshold swing (SS) 60 mV/dec. Alternative tunnel field-effect transistors (TFETs) are widely studied to achieve a sub-thermionic SS and high I60 (current where SS becomes 60 mV/dec). Hetero junction (HJ) TFETs bear promise to deliver high I60, but experimental results do not meet theoretical expectations due to interface problems in the HJs constructed from different materials. Here, we report a natural HJ-TFET with spatially varying layer thickness in black phosphorus (BP) without interface problems. We achieved record-low average SS over 4 decades of current, SSave_4dec ≈ 22.9 mV/dec with record-high I60 (= 19.5 μA/μm), paving the way for the application in low power switches. Low-power transistors, such as tunnel field-effect transistors (TFETs), negative-capacitance field-effect transistors (NC-FETs), and Dirac-source field-effect transistors (DS-FETs), have been realised to break the thermionic limit of the subthreshold swing (SS). However, a low power diode rectifier, which breaks the thermionic limit of an ideality factor (η) of 1 at room temperature, has not been proposed yet. In this study, we have realized a DS diode, which exhibits a steep slope characteristic curve, by utilising the linear density of states (DOSs) of graphene. For the developed DS diode, η < 1 for more than two decades of drain current with a minimum value of 0.76, and the rectifying ratio is large (> 105). The realisation of a DS diode paves the way for the development of low-power electronic circuits.
Invited Forum
Day-1
Evolutions of Dirac Fermions in Monatomic layers

Abstract
Two-dimensional (2D) monatomic layers containing Dirac fermions have recently attracted intensive research attentions for pursuing fundamental science and developing quantum devices. Research on free-standing graphene layers has revolutionized our nanotechnology and it has also triggered following works to develop novel atomic layers [1]. When valence and conduction bands cross each other in an extended line or a closed loop, a quantum state of the Dirac nodal line (DNL) emerges and induces intriguing physical properties. Monatomic layers with DNL fermions have now become one of the focusing topics in the field.

Recently, we designed and synthesized an atomic layer of hydrogen borides (HB) or “borophane” that is topological semimetal with DNL fermions [2-4]. The novel layer is composed of a boron framework with five- and seven-membered rings. The DNLs are topologically protected by the local chemical bonding and non-symmorphic symmetry [2]. The three-center two-electron bonds in the HB sheets restrict the electronic system to be insulator (gapped) or semimetal (gapless) with a nodal loop at the Fermi level. Two types of electronic structures are distinguished by a Z2 index. The topological prediction was confirmed by band calculation using the density functional theory. By the ion-exchange reaction method [3], we synthesized such borophane layers. Then, we examined the electronic structures by measurements of X-ray spectroscopy and confirmed the gapless electronic structure of DNL. The topological sheet of HB is a free-standing conducting layer with 21% weight of graphene. Moreover, the carrier density is 100 times larger than that of graphene. The novel 2D boron is promising for industrial applications and for academic research of quantum transport phenomena [5].

Keywords
Borophane, Dirac nodal loop, Dirac fermion

References
A Universal Approach for Room-temperature Printing and Coating of Two-dimensional Materials

Abstract
We here introduce a new approach for the formulation of 2D materials into printable or coatable inks for the fabrication of functional devices [1]. In a traditional ink formulation additives are introduced in large concentrations to address processing challenges, but they drastically degrade the electronic properties of the materials. For additive removal, a high-temperature post-deposition treatment can be used, but this complicates the fabrication process and limits the choice of materials (i.e., no heat-sensitive materials). The unique properties of 2D materials offer the possibility to formulate additive-free inks in which the roles of the additives are taken over by van der Waals (vdW) interactions. The approach is universal and is demonstrated with a number of 2D materials. In this new class of inks, solvents are dispersed within the interconnected network of 2D materials, increasing the possible choice of solvents over traditional inks where dispersibility-related issues limit the selection. Furthermore, flow behavior of the inks and mechanical properties of the resultant films are mainly controlled by the inter-flake vdW attractions and can be largely controlled via concentration and choice of solvent. The structure of the vdW inks, their rheological properties, and film-formation behavior are discussed in detail. A method for large-scale production of inks for all major high-throughput printing and coating is introduced. In a first application we demonstrate a Thin Film Transistor fully printed from 2D materials, with no additional heat treatment and competitive performance.

Keywords
2D materials, ink, room temperature printing, printed electronics

References
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2D Atomic Sheets based Non-volatile 6G Switches

Abstract
Various atomically thin two-dimensional materials such as transitional metal dichalcogenides and hexagonal boron nitride have shown to exhibit non-volatile resistive switching (NVRS) phenomenon. Previously, non-volatile analog switches base on monolayer MoS2 were demonstrated up to 50 GHz and subsequently, non-volatile monolayer hBN switches were operated across the 5G spectrum with an experimental data-rate of 8.5 Gbit s⁻¹.[1,2] Crystalline 2D materials enable low insertion loss and high isolation radio-frequency (RF) switches due to its strong layered structure. In terms of energy efficiency, sub-nanosecond pulse switching, operating voltages, and high data-rate operation, 2D materials based analog switches outperformed other emerging RF switches such as MEMS, PCM, and RRAM. We report the high-performance non-volatile analog switches made of monolayer MoS2 that operate at sixth-generation (6G) communication frequencies. An eye-diagram and a constellation diagram with different modulation formats and a data transmission rate of up to 100 Gbit s⁻¹ is shown. Notably, the operating frequencies are approximately 10 times higher than previously reported RF switch operating frequencies. These findings show that non-volatile MoS2 switches can be an appealing component for rapidly expanding 6G communication systems and related ubiquitous applications.

Keywords
MoS2, memristor, Non-volatile, RF switch, 6G

References

Biography
Myungsoo Kim is an assistant professor of Electrical Engineering at the Ulsan National Institute of Science and Technology (UNIST). His research focuses on advanced nanomaterials, their characteristics, and device applications. He received his M.S. and Ph.D. degrees in Electrical and Computer Engineering at the University of Texas at Austin in 2019 and 2020, respectively. He earned his B.S. degree in Electrical and Computer Engineering at Sungkyunkwan University in 2016. He previously worked as an R&D Device Characterization Engineer at Micron Technology before joining UNIST.
Ravindra Pandey

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Interface driven properties of 2D materials

Abstract
The discovery of graphene has inspired extensive interest in two-dimensional (2D) materials due to their unique properties. Graphene-based hybrid structures are being considered for novel applications at the nanoscale. These structures contain different types of interfaces, including metal-semiconductor and semiconductor-semiconductor interfaces. In this talk, we will highlight the role of interfaces in establishing the mechanical, optical, and electronic properties of 2D materials and their heterostructures employing state-of-the-art first-principles methods. Examples will be given in the areas of two-terminal electronic device, graphene/polymer composites, and van der Waals heterostructures to show that a fundamental understanding of the interface interactions is crucial in advancing applications of such atomically thin 2D materials.


Biography
Ravindra Pandey is Professor and Chair of Physics at the Michigan Technological University, Houghton, USA. Pandey received his education at Hari Singh Gaur University, Sagar, National Physical Laboratory, Delhi, Atomic Energy Research Laboratory, Harwell, UK, and University of Manitoba, Winnipeg, Canada. He has participated in multi-disciplinary efforts (theoretical and experimental) to build the programs in novel nanostructures with industrial and national laboratories. He also has co-organized and participated in several international conferences in Materials Physics and Nanoscale Science. Pandey is a Fellow of the American Physical Society.
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Engineering 2D Materials for Optoelectronic Applications

Abstract
The discovery of graphene had stimulated the interests of the scientific community towards two-dimensional 2D materials. Although the enhanced carrier mobility observed in graphene is highly desirable for electronic applications, the lack of intrinsic bandgap led to the exploration of alternative 2D materials with semiconducting properties for optoelectronic applications. However, scalable large-area synthesis and material/device engineering processes are necessary to fully unlock the viability of these 2D materials for practical applications.

In this work, we explore the properties of 2D MoO3 and black phosphorus for optoelectronic applications in the ultraviolet-visible and mid-wave infrared range, respectively. We demonstrate large-area synthesis of non-stoichiometric 2D MoO3 at a millimeter scale.[1] Using the as-synthesized MoOx, we show photodetectors in the UV-Vis range and electroactive UV filters.[2] On the other hand, we use mechanically exfoliated black phosphorus for photodetection in the MWIR range. We employ mechanical strain to tune the bandgap and thereby extend the photodetection/emission cut-off wavelength.[3] Furthermore, we show the viability of optical cavities structures,[4] and nanoresonators[5] for enhancing the responsivity of the photodetectors.

Keywords
2D MoO3, Black Phosphorus, photodetectors,

References
Invited Forum
Day-2
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**Improvement of graphene surface for the elaboration composite materials with copper matrix with improved physical properties**

**Abstract**

Copper (Cu) is a widely used material in many fields like electronics, telecommunications, and transport due to its excellent electrical and thermal conductivity, its corrosion resistance or its malleability which makes it an easy machinable material. However, in the field of electrical application, the density of current through electrical connection can generate a high heat dissipation by Joule effect. This dissipation of energy causes a rise of temperature which can affect user safety (risk of fire) as well as a great waste of energy. To avoid these effects, the improvement of the electrical and thermal conductivity of the bulk Cu is necessary. For that purpose, the chosen solution is linked with the addition of graphene reinforcement inside the Cu matrix. Indeed, graphene (G), a 2D material extracted from graphite that consists of a monoatomic carbon sheet, appears to have extraordinarily physical properties, particularly concerning the exceptional mobility and density of its electron.

The development of this type of Cu/G composite material is carried out in three stages using powder metallurgy process. The first and the more important one, consists in improving the interface between the matrix and the reinforcement because of the non-chemical reactivity between Cu and carbon. For that reason, covalent functionalization treatment using acid, nitrogen plasma, and supercritical ammoniac is used to dope the G materials and/or incorporate different surface chemical function. Then, Cu salt is used to grow Cu nano-dots, chemically linked with G, to obtain optimum properties transfer. The second step is a mixing step which is carried out using a mixer using acoustic vibrations. This method allows rapid and homogeneous mixing with a very low amount of G to avoid agglomeration. And finally, a final densification step by uniaxial pressing allows us to force the alignment of our G reinforcement inside the Cu matrix. After this final step a hot-rolling mill or extrusion post-treatment can be used to enhance alignment of the G materials and therefore the composite properties. Physical properties of Cu/G materials are measured and correlated with processing conditions.
Photophysics of Mixed-Dimensional van der Waals Heterostructures

Abstract

Mixed-dimensional van der Waals (vdW) heterostructures present opportunities for creating hybrid materials with extraordinary optoelectronic properties not observed in the constituent semiconductors. By combining 2D semiconductors with materials of different dimensionalities, such as 0D or 1D small organic molecules or conjugated polymers, mixed-dimensional heterostructures benefit from the advantageous properties of their constituent components. This enables potential scalability of vdW heterojunctions by taking advantage of more well-established technologies, such as organic optoelectronics, to fabricate large-area heterostructures.

To determine the effectiveness of mixed-dimensional heterostructures, it is important to understand the nature of charge and energy transfer processes across the semiconductor interface at fundamental timescales. In this talk, I will discuss our recent findings on photophysical processes within three different vdW heterostructures: 1) conjugated polymer/MoS2 organic/2D heterostructures [1]; 2) polymer:fullerene/MoS2 organic/2D heterostructures in the presence of a plasmonic metasurface [2]; and 3) ReS2/MoSe2 type-II 2D/2D heterostructures [3]. In the organic/2D heterostructures investigated, ultrafast charge transfer from MoS2 to the conjugated polymers occurred within 9 ps, and in some cases, in under 120 fs. The charge generation yield was improved by over a factor of 6 at ultrafast time scales in the presence of a plasmonic metasurface. In the ReS2/MoSe2 heterostructure, we show that resonant energy transfer dominates over charge transfer from ReS2 to MoSe2, even without a charge-blocking interlayer. I will discuss our on-going and future work on incorporating large-area 2D semiconductors into high-efficiency organic photovoltaics.

Keywords
mixed-dimensional heterostructures; charge transfer; energy transfer; ultrafast phenomena; organic semiconductors; photovoltaics

References
Two-Dimensional MoS$_2$ Gas Sensor Prepared by Liquid Phase Exfoliation

Abstract
Among the most famous, inexpensive and successfully marketed gas sensors are chemoresistors (i.e., resistive gas sensors) employing metal oxides as gas sensitive films. In addition, metal oxides are highly sensitive to a wide spectrum of gases of interest. Despite all these advantages, they generally require being operated high above room temperature (power consuming), show poor selectivity and suffer from long-term stability issues. However, two dimensional materials like Graphene and TMDs present outstanding electrical, optical, and chemical properties. They are promising for developing a new generation of low-power gas nano-sensors with high sensitivity, short response and recovery times, low detection limit, high selectivity and good stability at room temperature [1]–[3]. Nowadays, different methods of preparation are possible to obtain two-dimensional (2D) nanomaterials. Liquid phase exfoliation (LPE) is an efficient method for achieving (2D) nanomaterials. This method offers a simple and efficient method for the large-scale production of 2D materials in solution at low cost [4]–[6].

In this work, we will present some primary results of MoS2 gas sensor prepared by liquid phase exfoliation and operated at room temperature and at 50 oC. Two approaches were used to prepare the exfoliated 2D materials, which included bath sonication and probe sonication showing different gas response. The structural and chemical characteristics were investigated by FESEM, XRD and Raman spectroscopy. Chemoresistive gas sensors were fabricated and explored for the detection of different toxic gases such as NO2, NH3 and H2. Highly sensitive and stable MoS2 sensors operating at room temperature for detecting NO2 were prepared via bath sonication. Sensor response to 40 – 800 ppb NO2 gas was 2% - 31 % at room temperature and 11 % - 45 % at 50oC. Selectivity and moisture cross-sensitivity will be discussed as well.

Keywords
2D materials, MoS$_2$, liquid phase exfoliation, chemoresistance, gas sensors

References
Biography

Dr. Dalal Fadil is currently postdoctoral researcher at universitat Rovira I Virgili in Tarragona in Spain. She has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101025770 for multidisciplinary research project in filed of two-dimensional (2D) nanomaterials for gas sensing applications. Dr. Dalal Fadil obtained her PhD in field of Micro-Nanoelectronics from University of Caen in France. Then, she was Assistant Professor at university of Rouen in France and her research activities was about reliability and failure analysis of HEMT-GaN. After that, she was selected as postdoctoral fellow at university of Texas at El Paso in USA where she started working with Professor Kaul to synthesize and characterize 2D nanomaterials for optoelectronic devices. In 2016, she joined IEMN-Lille in France and has participated to EU-Project GRAPHENE FLAGSHIP for emerging technology in nanofabrication and characterization of Graphene HF-FETs.
Towards chirality control of graphene nanoribbons embedded in hexagonal boron nitride

Abstract
The integrated in-plane growth of graphene nanoribbons (GNRs) and hexagonal boron nitride (h-BN) could provide a promising route to achieve integrated circuitry of atomic thickness.[1] However, fabrication of edge-specific GNRs in the lattice of h-BN still remains a significant challenge. Here we developed a two-step growth method and successfully achieved sub-5-nm-wide zigzag and armchair GNRs embedded in h-BN. Further transport measurements reveal that the sub-7-nm-wide zigzag GNRs exhibit openings of the bandgap inversely proportional to their width, while narrow armchair GNRs exhibit some fluctuation in the bandgap-width relationship. An obvious conductance peak is observed in the transfer curves of 8- to 10-nm-wide zigzag GNRs, while it is absent in most armchair GNRs. Zigzag GNRs exhibit a small magnetic conductance, while armchair GNRs have much higher magnetic conductance values. This integrated lateral growth of edge-specific GNRs in h-BN provides a promising route to achieve intricate nanoscale circuits.

Fig.1 a, Synthetic strategy to orient GNRs with crystallographic edge orientations. b, c, The typical transfer curves of an ~5-nm-wide armchair GNR sample (b) and an ~8.9-nm-wide zigzag GNR sample (c) at different temperatures.

Keywords
Graphene nanoribbons, boron nitride, 2D materials

References

Biography
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2D MXenes for electrochemical energy storage

Abstract
2D transition metal carbides, carbonitrides and nitrides, also known as MXenes, are synthesized by selectively removing the A atom layer from the parent MAX phase using an etchant such as aqueous fluoride-containing acidic solutions [1]. MXenes have shown great potential in electrochemical energy storage devices due to their electronic, mechanical and optical properties. Herein, we will present our strategies for optimizing the electrochemical performance of Ti-based MXenes in both aqueous and non-aqueous systems. In sulfuric acid electrolytes, Ti₃C₂Tx MXene hydrogel electrodes demonstrated a high volumetric capacitance of 1500 F cm⁻³ and 350 F g⁻¹ for the gravimetric capacitance, exceeding those of conventional carbon materials [2]. The charge storage mechanism of the Ti₃C₂Tx electrodes in the acidic electrolyte was further studied by combining experimental and simulation approaches. It was demonstrated that the presence of H₂O molecules in-between the MXene layers plays a critical role in the pseudocapacitive behavior, providing a pathway for proton transportation to activate the redox reaction of the Ti atoms [3]. Differently, the electrochemical performances of HF-containing MXene electrodes were limited in non-aqueous systems. It is crucial to increase MXenes capacitance in non-aqueous electrolytes since non-aqueous systems can offer a larger voltage window (> 2.5 V), thus lead to high energy density. Interestingly, we proposed a new Lewis acidic etching synthesis route for preparing F-free, Cl-containing MXenes. The obtained Ti₃C₂Tx MXene delivers a Li-ion storage capacity up to 738 C g⁻¹ (at a potential range of 2.8 V) with high-rate performance and pseudocapacitive-like electrochemical signature in a carbonate LiPF₆-based electrolyte, offers new opportunities for MXene materials for future energy storage applications [4]. Finally, we further proposed a one-pot method to prepare MXenes from elemental precursors [5]. The obtained Ti₂CTₓ MXene exhibits lithiation capacity values of approximately 280 mAh g⁻¹ and 160 mAh g⁻¹ at specific currents of 0.1 A g⁻¹ and 2 A g⁻¹, respectively.

References
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Nano Energy Applications Using 2D TMD FETs and Diodes

Abstract
Transition metal dichacogenides (TMDs) and black phosphorus (BP) are those and many of field effect transistors (FETs) have thus been reported using such 2D materials. But practical device applications towards energy devices are few to find. Here, photovoltaic and RF energy harvestings are presented, based on thin and thick 2D-layered MoS2, MoSe2, and h-BN for semiconducting active materials and capacitors. In particular, figures shown below are about photovoltaic applications involved with Perovskite cell and MoS2 FET circuits. [1] Besides, we are also about to present van der Waals crystal radio using Pt/MoSe2 Schottky diode and h- BN capacitor circuits [2,3].

Figure. a) Cross section scheme of one package device where n-MoTe2 and perovskite PV cell are back- to-back bonded. b) Photographic top image of the package device. c) and d) Light intensity-dependent I-V curves of the PV cell under red illumination for high and low intensity regimes, respectively. e) and f) Dynamics of light intensity-dependent Vout of the package device under periodic red LED illumination (1 Hz) for high and low intensity regimes, respectively. g) and h) Dynamics of light intensity-dependent Iout of the inset circuit under periodic red LED illumination (1 Hz) for high and low intensity regimes, respectively.

References
Van der Waals epitaxy of two-dimensional transition metal dichalcogenides

Abstract
Transition metal dichalcogenides (TMDs) constitute a class of quantum materials that have gathered a tremendous interest from the solid-state physics community focusing on two-dimensional (2D) materials. They hold promises for numerous applications in photonics and electronics [1] owing to their large exciton binding energies and a transition from an indirect to a direct band gap in the monolayer limit [2]. They also exhibit a strong spin-orbit coupling which is promising for spintronic applications [3].

Until recently, most studies on TMDs have been performed on micrometer-sized flakes mechanically exfoliated from bulk samples [4]. Extensive efforts are beginning to enable the growth of wafer-scale TMD single-crystal films [5]. The absence of lattice matched substrates and the high reactivity of chalcogen atoms prevent the epitaxial growth of monolayers using molecular beam epitaxy (MBE) on usual substrates (Si, Ge, GaAs…). In this presentation, I will discuss our strategy to achieve the growth of single crystalline TMD monolayers by vdW epitaxy [6]. In this regime, the substrate exhibit a van der Waals surface like graphene, mica or Se-passivated GaAs to limit the substrate-epilayer interaction. In a second part, I will present the vdW epitaxy of two TMDs with high spin-orbit coupling on graphene: PtSe2 for the study of spin-charge interconversion phenomena and WSe2 for the study of the valley Nernst effect [7]. Finally, I will demonstrate the clear advantages of MBE and vdW epitaxy to grow well-controlled 2D ferromagnets: Fe5GeTe2 with high Curie temperature close to room [8] and Cr1+dTe2 with tunable magnetic properties by proximity effects and adjusting the stoichiometry d.

Keywords
Transition metal dichalcogenides, molecular beam epitaxy, spintronics, valleytronics, 2D magnetism

References
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Helicity-resolved cryomagnetic spectroscopies on van der Waals materials

Abstract
The Raman (Ra) and photoluminescence (PL) micro-spectroscopies are eminent tools for exploring electronic, optical, and spin phenomena in two-dimensional materials (2DMs) and their heterostructures [1 - 4]. By employing light with intrinsic helicity, valley physics in various 2DMs can be addressed. Also, the Ra spectroscopy enables the investigation of the magnetic order and quantum phenomena in van der Waals magnets thanks to the spin-lattice coupling [5]. Recently, we have also demonstrated that helicity-resolved Ra/PL microscopy carried under the applied magnetic field is an excellent tool for mapping the magnetization reversal and magnetic domains in various 2D magnets and their heterostructures. In this talk, selected results of the helicity-resolved cryomagnetic spectro-microscopies on the prominent 2DMs will be presented.

Keywords
Raman spectroscopy, photoluminescence, chiral light, spin-lattice coupling

References

Biography
JKV is a full professor at the Faculty of Mathematics and Physics at Charles University, Prague. She graduated from Charles University with MSc. In “Chemistry” in 2003 and Ph.D. in “Condensed Matter Physics and Materials Research” in 2007. After her postdoctoral stays at Hasselt University, Belgium, and National Institute for Materials Science, Tsukuba, Japan, she worked as the head of the department in the Institute of Physics, Czech Academy of Sciences (2011–2017). Her current research interests cover the experimental physics of low-dimensional materials, focusing on advanced magnetometry techniques, cryomagnetic optical and nuclear spectroscopies. Her work has been funded by ~15 projects as PI (~3.5 MEUR), including the prestigious ERC Starting grant (2016). She published ~160 papers, presented ~30 invited/plenary talks, and received multiple recognitions, e.g., Scopus/Elsevier Award (2010), Otto Wichterle Award (2014), F. Behounek Award for promotion and popularization of Czech science in the European Research Area (2019).
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Defect engineering and impurity doping of graphene

Abstract
Heteroatom implantation has been a remarkably successful technique for manipulating electronic properties of semiconductor materials, contributing to the success of modern information technology. However, to do this for 2D materials, one needs to find the delicate balance between being able to displace atoms from the target material while at same time stopping the incoming ion [1]. This leads to low energies (for graphene, some tens of eV) and narrow energy distributions, that are not typically available using conventional ion implanters. An additional problem is the limit imposed by momentum and energy conservation, which (with the simplified assumption of head-on collision) even fundamentally limits ion implantation of graphene to elements between Li and Ti. Nevertheless, some success has been made for light elements such as B and N [2], P [3], and even Ge [4]. Moreover, even in the case of successful implantation, the samples suffer from surface contamination. In this contribution, we describe how all of these issues can be overcome combining vacancy-mediated heteroatom implantation [5] with efficient sample cleaning through laser heating [6] in a vacuum system shared with an atomic-resolution scanning transmission electron microscope that is used for automatic atomic-scale characterization of the samples [6] both before as well as after ion implantation. Our approach relies on defect-engineering of graphene with low-energy Ar irradiation that creates single and double vacancies into graphene (and is interesting itself [6]) and subsequent thermal and/or e-beam evaporation of the impurity species onto the sample. Equivalently, irradiation can be carried out first with higher energy ions to create vacancies that are subsequently filled with lower energy ions, as we recently demonstrated with gold [7]. Overall, this approach holds a great promise for achieving true control over the atomic-structure of graphene and other 2D materials.

Funding from Austrian Science Fund (FWF) through projects I 3181, M 2595 and P 31605, and computational resources through the Vienna Scientific Cluster are gratefully acknowledged.

Keywords
graphene, defect-engineering, implantation, heteroatoms, transmission electron microscopy

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Large-area single crystal 2D materials growth

Abstract
Two-dimensional (2D) materials including graphene, hexagonal boron nitride and transition metal dichalcogenide have been highlighted due to unusual intrinsic physical and chemical properties such as high exciton binding energy and large magnetic resistance, which allows unprecedented applications. To realize the intrinsic material properties and industrial applications, wafer-scaled single-crystal 2D films are highly required. Here, we present the recent progress of single-crystal growth for 2D materials in a wafer scale via the self-collimation on liquid substrate and the epitaxial growth on atomic sawtooth surface [1,2]. The detailed growth mechanism is discussed accordingly.

Keywords
transition metal dichalcogenides, chemical vapor deposition, single-crystal

References

Biography
Ki Kang Kim is an Associate Professor in the Department of Energy Science, Sungkyunkwan University (SKKU). He received his Ph.D in Physics from SKKU, Korea, under the supervision of Prof. Young Hee Lee. He held a post-doctoral position at SKKU and Massachusetts Institute of Technology, USA for 4 years and as Assistant/Associate Professor at Donggu University, Korea for 7 years. He is one of the pioneers in the growth of 2D materials. His group in SKKU and collaborators are currently working on developing novel synthesis techniques for diverse 2D materials and their various emerging applications.
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Magnetic and Electronic Properties of the Two-Dimensional Transition Metal Dihalides

Abstract
Two-dimensional (2D) van der Waals materials were found to possess many interesting properties that triggered surge of research activity and brought about numerous proposals of applications in electronics and optoelectronics [1, 2]. Magnetic ordering found in some of the 2D materials allows to test theoretical models of two-dimensional magnetic systems and appends functionality to the perspective devices, based on the materials [3]. In this talk I will present results of experimental investigation of a new family of magnetic 2D materials: Transition Metal Dihalides (TMDH). These materials have chemical composition MX$_2$, where M stands for 3d-transition metal ion and X is one of the halogens (Cl, Br). Bulk properties of these materials were summarized in the review [4]. I will discuss in-situ growth of the TMDHs thin films and its thickness-dependent properties with special emphasis on the structural, electronic and magnetic properties of the single-layers. These results will include Scanning Tunneling Microscopy (STM), X-ray Photoelectron Spectroscopy (XPS) and X-ray Absorption Spectroscopy (XAS/XMCD) obtained in our laboratory and in various synchrotron facilities. Part of these results was recently published in the paper [5].

Keywords
2D Van der Waals materials, magnetic and electronic properties of semiconductors

References
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The interlayer exciton state in MoS$_2$/WSe$_2$ van-der-Waals heterostructures

Abstract

Following the isolation of monolayered Graphene, the family of two-dimensional materials has immensely expanded to include materials of varied electronic, optical, and magnetic properties. An important group of such materials are the semiconducting transition metal dichalcogenides (TMDCs), of the from MX$_2$ (M= Mo, W, X=S, Se, Te). In their monolayer limit these are direct band-gap semiconductors showing pronounced light absorption and emission, dominated by strongly bound exciton states – correlated electron-hole pairs. These arise from the enhanced Coulomb interaction between electrons, stemming from the low dimensionality and the reduced dielectric screening around these monolayers. Thus, any electro-optical application of such materials requires a thorough consideration of excitonic effects, motivating their fundamental study.

TMDC heterobilayers, where two TMDC monolayers are stacked on top of each other, host unique and useful exciton states – the interlayer excitons[1]. This charge separation leads to an attractively extended lifetime, much longer than those of monolayer excitons, and for energy tunability using electric fields. Moreover, interlayer excitons are sensitive to the structure of the interlayer interface, featuring the effects of moiré patterns.

In this talk, I will discuss the recent explorations of the interlayer excitons in the heterobilayer of MoS2 and WSe2. There, the large band offset leads to an interlayer exciton light emission in the infrared spectrum, around 1200 nm, compatible with Si-photonics technologies[3]. I will focus on its signatures in momentum-space, observed using a unique time-resolved momentum-microscopy setup[4]single-photon emission and other quantum-information applications. Yet, despite extensive optical spectroscopic investigations, critical information about their size, valley configuration and the influence of the moiré potential remains unknown. Here, we captured images of the time- and momentum-resolved distribution of both the electron and the hole that bind to form the ILX in a WSe$_2$/MoS$_2$ heterostructure. We thereby obtain a direct measurement of the interlayer exciton diameter of ~5.4 nm, comparable to the moiré unit-cell length of 6.1 nm. Surprisingly, this large ILX is well localized within the moiré cell to a region of only 1.8 nm - smaller than the size of the exciton itself. This high degree of localization of the interlayer exciton is backed by Bethe-Salpeter equation calculations and demonstrates that the ILX can be localized within small moiré unit cells. Unlike large moiré cells, these are uniform over large regions, thus allowing the formation of extended arrays of localized excitations for quantum technology, [5].
These measurements allowed us to visualize, for the first time since the term 'exciton' was coined, the distribution of both the electron and hole states that constitute this exciton. From these distributions we deduced the exciton structure over all its defining coordinates: the relative electron-hole separation defining the interlayer exciton size, and their center-of-mass coordinate which evidences its localization. We show that it is localized by the moiré pattern of the heterobilayer, despite being comparable in size to the relatively small moiré period. As such, this will open the door to use such moiré patterns, which are uniform over large areas (as opposed to moiré patterns with larger periods that suffer from inhomogeneities), as platforms for arrays of confined quantum-emitters. I will conclude with the future opportunities this measurement technique stores in the ILX context.

References:
Giant valley Zeeman coupling in the NbS2 surface monolayer of V1/3NbS2

Abstract
One of the most striking properties of the transition-metal dichalcogenides (TMDs) is a locking of their quasiparticle spin to a valley pseudospin. This results from strong spin-orbit coupling and is enabled by global or local inversion symmetry breaking [1,2], providing a route to stabilise novel physical properties such as Ising superconductivity [3,4], and potentially facilitating new computing schemes via `valletronics' [1]. Tuning of the resulting spin splittings is thus strongly desired. To date, this has been achieved via externally-applied magnetic fields [5] and by proximity coupling in van der Waals heterostructures [6], but only modest changes of the intrinsic spin-orbit splitting have been realised. Here, we investigate a monolayer-like NbS2 layer at the surface of the V-intercalated TMD V1/3NbS2 using spatially- and angle-resolved photoemission spectroscopy (m-ARPES). Our measurements and corresponding density-functional calculations reveal that this intrinsic van der Waals heterostructure supports a giant valley Zeeman interaction exceeding 50 meV, of comparable magnitude to the intrinsic spin-orbit mediated splittings. Our findings thus indicate how magnetism is mediated via the itinerant states in this nominally local-moment system, and reveal new routes to utilise this to gain control over valley spin splittings in transition-metal dichalcogenides and related materials.

Keywords
proximity, spin-valley locking, magnetic, transition-metal dichalcogenide

References
Two-Dimensional Germanananes and silicene as Self powered Photodetector and sensors

Abstract
Recently, monoelemental two-dimensional (2D) materials such as germanene and silicene, also known as “xenes”, have attracted great scientific and technological interest due to their enormous potential applications in optoelectronics and sensing. Here, we have successfully exfoliated layer hydrogen terminated germanene and silicene composition (Ge-H, Ge0.75Si0.25H and Ge0.5Si0.5H) from alloyed Ca(Si 1-xGex)2. The monoelemental photoelectrochemical (PEC) device demonstrated self-powered broadband photodetection in the range of 385 to 940 nm with an unprecedented sensitivity of 1.7 mA/W under the illumination of 420 nm LED light. In addition, 2D germanene and silicene exhibited superior sensing capability for organic vapors with ultrafast response and recovery time less than 1 s. Finally, the photocatalytic activity in the form of hydrogen evolution reaction was investigated due to the suitable band alignment and catalytic activity. This novel material with the mentioned fascinating phenomenon will pave the way to practical future applications in optoelectronics and sensing.
Interferometric Second-Harmonic Generation in Two-Dimensional Heterocrystals

Abstract
Optical second-harmonic generation (SHG) is not only a powerful structural tool owing to its sensitivity toward crystallographic symmetry, but also a coherent probe because of its instantaneous but non-dissipative response. Two-dimensional (2D) transition metal dichalcogenides (TMDs) are excellent media for SHG because of their strong excitonic resonances in the NIR and visible range. Their atom-thick sheet-like geometry lifts the requirement of phase matching for SHG and also allows novel properties to be designed via artificial stacking. In this talk, we will present our recent findings on SHG interference occurring in 2D TMD heterocrystals with a thickness of ~1 nm. All 2D crystal samples were prepared by mechanical exfoliation and studied with a polarized and interferometric micro-spectroscopy setup powered by a tunable femtosecond Ti-sapphire laser. Using spectral phase interferometry, we directly showed that SHG in heterobilayers of MoS2/WS2 is governed by optical interference between two coherent SH fields that are phase-delayed differently in each crystal. We also quantified the frequency-dependent phase difference between the two, which agreed with polarization-resolved data and first-principles calculations on complex susceptibility. The second part of the talk will be focused on the remarkable modulation of SHG intensity and phase induced by van der Waals-like interlayer interactions in MoSe2/WS2. We will discuss their possible causes and future plans to elucidate the origin. The second-harmonic analogue of Young’s double-slit interference shown in this work demonstrates the potential of custom-designed parametric generation by atom-thick nonlinear optical materials.

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**2D materials as a base for large area light detectors**

**Abstract**

Transition metal dichalcogenides (TMDCs) have emerged as highly promising semiconducting materials for optoelectronic devices. Currently, as an important step forward, 2D based heterostructures are in the focus of interest, in order to achieve higher efficiencies or to provide additional functionality. However, many device concepts are based on exfoliated crystals, resulting in only µm-sized prototypes, or require transfer processes with undefined process artefacts. Metalorganic chemical vapor deposition (MOCVD) has proven to allow for the fabrication of TMDCs [1] and TMDC heterostructures up to wafer-scale [2]. In our contribution, we present light detectors in the mm² scale, based on directly grown 2D layers by MOCVD without transfer steps.

We show that in detectors based on a heterostructure consisting of MoS2 and WS2 monolayers, a striking increase of quantum efficiency is obtained (Fig.1). The responsivity and gain of a WS2/MoS2–based photodetector are 5 orders of magnitude higher than in photodetectors based on single MoS2 or WS2. [2]

For MoS2/Graphene based photodetectors we present an analysis technique using pulsed light sources, which separates long-time effects like desorption of surface adsorbates from the short-time photo-generation of carriers within the heterostructure. We show that with decreasing adsorbate density, the graphene in the heterostructure switches from p-type to n-type. These findings open interesting perspectives for photodetectors that are sensitive to the environment.
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Defective Metal Nitrides as Efficient Hybridization Matrices to Explore High-Performance Electrocatalysts

Abstract
In this study, a novel synthetic strategy to create crystal vacancies was developed by enhancing the interfacial electronic coupling between hybridized species. According to density functional theory calculations and systematic spectroscopic analyses, there occurs a localized charge transfer from the surface nitrogen vacancies of holey TiN nanotube to Ni-Fe-layered double hydroxide (LDH) and the resulting strong interfacial electronic coupling leads to the further stabilization of nitrogen vacancy in holey TiN. In comparison with pristine Ni-Fe-LDH and non-holey TiN-LDH nanohybrid, the holey TiN-LDH nanohybrid exhibits much higher electrocatalytic activity for oxygen evolution reaction (OER) and better electrode performance for Li-O2 batteries. The unusually high efficacy of vacancy introduction in improving electrocatalyst/electrode functionality originates from the enhancement of interfacial electronic coupling, the increase of electrochemical active surface area, and the improvement of electrocatalysis kinetics and charge transfer property.

Keywords
Metal nitride; Defect; Hybridization; Electrocatalyst; Matrices

References

Biography
Xiaoyan Jin is currently a research professor in the Department of Materials Science and Engineering at Yonsei University under Prof. Seong-Ju Hwang. She received a B.S. degree in chemistry (2012) from Yanbian University (China) and a Ph.D. degree in inorganic chemistry (2018) from Ewha Womans University (Korea). Her research focuses on synthesis and characterization of layered metal oxides, layered double hydroxides, and metal chalcogenides, and their applications in electrocatalyst, supercapacitor, photocatalyst, and Na/Li-ion batteries.
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Self-assembled peptides functionalizing graphene field-effect transistors for detection of odor molecules

Abstract
Various biosensors using graphene field effect transistor (GFET) have been studied widely and demonstrated their potentials with a high sensitivity. However, there is a still challenge to establish a selective detection of relatively small molecules which are volatile and insoluble in aqueous solutions. Engineered peptides are known to form self-assembled structures on the graphene surface[1] based on their amino acid sequence, and have demonstrated their potential as a scaffold domain for biosensors[2]. In this study, we utilized
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Ternary Transistor using p-MoTe$_2$/n-MoS$_2$ Heterostack Channel toward Quaternary NAND Logic

Abstract
Applications of two dimensional (2D) semiconductors have been much oriented to various electron devices, which now include multivalue field effect transistors (FETs). The 2D channel multivalue FETs are fascinating. Several n-channel devices are thus reported along with few p-channel devices, while studies to achieve both n- and p-channel multivalue FETs are hardly found. Here, both of n- and p-channel multivalue FETs are fabricated by using p-MoTe$_2$/n-MoS$_2$ heterostack channel architecture, where either p- or n-channel ternary value FET is reproducible by switching the stacking order of p- and n-channel layer. The main ternary value mechanism originates from resonant tunnel injection and channel inversion which take place during device operation. For n-channel multivalue device applications, quaternary NAND logic circuit is demonstrated by integrating two ternary n-channel FETs as a state-of-the-art in 2D electronics. As a p-channel device application, complementary ternary inverter is fabricated by integrating multivalue p-channel and plain n-channel FET.

Keywords
MoTe$_2$, MoS$_2$, Heterostack, Ternary Transistor, Quaternary NAND logic

Biography
Seongil Im, applied physicist and device engineer, achieved Ph.D. from UC at Berkeley in 1994 and worked as research fellow at CALTECH from 1995 till 1996. He joined the department of Physics at Yonsei University as associate professor in 1999. Currently, he is the Director of van der Waals Materials Research Center (vdWMRC) at Yonsei University.

Sam Park and Han Joo Lee are Ph.D. candidates in Yonsei University.
Electrical characteristic Schottky Diode and MESFET using β-Ga2O3 with RF Measurement

Abstract
In order to have a larger Breakdown voltage than conventional Radio Frequency (RF) devices, devices using Ga2o3 with ultra-wide bandgap are attracting attention. Also, Ga2O3 exists in nature in various phases. In particular, β-Ga2O3 has semiconductor properties that can be doped and behaves like a two-dimensional (2D) material. Based on the characteristics of the material, the basic device characteristics of Schottky diode and field-effect transistor (FET), which are the basic units constituting the RF circuit, and characteristics in the RF environment will be discussed. After designing the FET with a Gate-All-Around Metal-Semiconductor Field effect transistor (GAA-MESFET) structure to achieve a higher transconductance value than that of the conventional Metal-Oxide-Semiconductor Field effect transistor (MOSFET), examine the RF characteristics and suggest the structural limitation. Furthermore, it confirms that the solution to the chronic contact resistance problem in 2D materials is still applicable to the β-Ga2O3 devices.

Keywords
β-Ga2O3, RF, Schottky diode, FET, Contact

Biography
Hyun-Jung Kim is a M.S. student in the Department of Physics at Yonsei University, Republic of Korea. He received his B.S. degree from Korea Advanced Institute of Science and Technology in the Department of Electrical engineering in 2020. His current research interest includes oxide electronic devices characterization.

Sungjae Hong is a Ph.D. candidate in the Department of Physics at Yonsei University, Republic of Korea. His current research is focused on 2D heterostructure device applications.

Seongil Im, applied physicist and device engineer, achieved Ph.D. from UC at Berkeley in 1994 and worked as research fellow at CALTECH from 1995 till 1996. He joined the department of Physics at Yonsei University as associate professor in 1999. Currently, he is the Director of van der Waals Materials Research Center (vdWMRC) at Yonsei.
Two-Dimensional WSe2/MoS2 p−n Heterojunction-Based Transparent Photovoltaic Cell

Abstract
As a means to overcome the limitation of installation space and to promote the utilization of the solar cell in various applications, a transparent thin-film solar cell has been studied by many researchers. To achieve a transparent solar cell, the choice of materials which are transparent enough and showing the photovoltaic property at the same time is the key. Here, we suggest a two-dimensional (2D) p−n heterojunction of WSe2/MoS2 and an indium tin oxide electrode to fabricate a transparent thin-film photo-voltaic cell. Because of advantages that 2D materials possess, a highly transparent (∼80%) solar cell with considerable efficiency was achieved. Furthermore, by introducing a transparent passivation layer composed of a fluoropolymer, the photovoltaic performance was much improved. With the passivation layer, our WSe2/MoS2 transparent photovoltaic cell reached an efficiency of ∼10%. A comparison of photovoltaic parameters before and after applying passivation and analysis on the origin of such differences are also discussed. Our result exhibits a great potential of the van der Waals p−n heterojunction of 2D semiconductors to be utilized for an active layer of a highly transparent and lightweight thin-film solar cell.

Biography
Prof. Jang-Yeon Kwon is an associate professor of School of Integrated Technology at Yonsei University, Korea. He got his M.S. and Ph.D. degrees in material science and engineering at Seoul National University in Korea in 1999 and 2002, respectively. He has been a Principal Researcher at Samsung Advanced Institute of Technology from 2002 to 2010. He was in charge of research and development of AMOLED display with oxide semiconductors.

Prof. Kwon’s research background is in advanced functional devices focused on applied nano and macro scale materials of semiconductor, such as oxide TFTs and 2D materials like TMDs. He pursues fundamental studies on new material and its applications of TFT, biosensor and photo-electronic device.

Prof. Kwon has published more than 100 SCI journal papers, and has delivered more than 120 international conference presentations. In addition, he has been grated 55 patents including 23 US patents
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Assessment of Broadband Shielding Effectiveness of Graphene Composite Panels for Protective Enclosures

Abstract
The paper investigates the shielding effectiveness (SE) of a metallic enclosure with a multilayer composite cover over a wide frequency range, from near-field magnetic shielding (1 Hz – 1 MHz) to far-field electromagnetic shielding (4 GHz – 14 GHz). Two enclosures are considered: a conductive enclosure made of aluminum (Al) and a magnetic enclosure made of steel. The multilayer composite is a trilayer combining a thin conductive layer of graphene and a thin magnetic layer of a Fe-Ni alloy on both sides of a fiberglass epoxy composite plate. To determine the SE of these enclosures in both low-frequency and high-frequency approaches, two experimental setups and two numerical models are developed. The use of the composite cover, instead of the metallic one, gives a similar level of SE in the far-field and a higher specific SE in the near-field from 1 Hz to 2 kHz. Such quantitative analysis is the first step to design practical enclosures entirely covered with composite panels to face EMC constraints in embedded systems. This work focused only on the enclosure cover, thus in near future, the behavior of an entire enclosure constituted with the trilayer composite should be performed. Also, the mid-range frequency extending from 1 MHz to 4 GHz has not been addressed due to limitations of the experimental setups.

Keywords
Composite, Enclosure, Far-field, Near-field, Shielding effectiveness
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Wireless RF Energy Harvesting Through van der Waals Semiconductor Crystal Radio

Abstract
Two-dimensional (2D) semiconductor-based devices are mostly using in-plane direction current in their device architecture, so that those might fully utilize the 2D-based novelty as ultrathin electron devices beyond the conventional 3D ones. Those ultrathin 2D devices, however, would unavoidably meet high contact resistance issue, which often prevents high-frequency switching. Here, thick 2D-layered crystals are chosen for a meaningful vertical device, which alleviates the contact resistance issue using a large contact area. By choosing a thick n-type MoSe2 crystal, we have fabricated 10 MHz working Pt/n-MoSe2 Schottky diodes with Ohmic metal contacts of Au, Ti/Au, and MoTi/Au. These diodes are then monolithically integrated with a capacitor of ~20 nm-thick h-BN or 50 nm-thick ALD Al2O3. This way, van der Waals (vdW) crystal radios are successfully fabricated for a wireless RF energy harvesting. In terms of crystal radio device performance, the best results come from Pt/n-MoSe2 Schottky diode with MoTi contact and h-BN capacitor combination. This superiority is attributed to the excellent Ohmic behavior of MoTi alloy contact. Interestingly, when AM demodulation experiments are conducted with 1 MHz carrier frequency/audio frequency-mixed signals, the vdW crystal radio demonstrates good output DC voltage envelope, which allows loud music/audio sound.

Keywords
crystal radio, MoSe2 Schottky diode, h-BN capacitor, MoTi contact, wireless

Biography
Livia Janice Widiapradja is currently pursuing her Ph.D. degree at the Department of Physics, Yonsei University. She received her B.S. degree in 2016 from Institut Teknologi Bandung, Indonesia, majoring in Physics as well. Her current research is focusing on the electronic devices involving 2D materials.
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Electrical-Measurement-Based Band Gap Estimation of 2D Semiconductor using FET with Thin Graphite Contact

Abstract
The most wide-used way to measure the bandgap of two-dimensional (2D) semiconductors is photoluminescence (PL). However, as the thickness of 2D semiconductor goes thicker than 5L, PL measurement becomes ineffective and inaccurate because the optical transition nature of 2D semiconductor changes from direct to indirect. Here, a different way to extract the bandgap of multilayer 2D van der Waals semiconductors is suggested; based on electrical measurement using field-effect transistor (FET). Thin graphite is used as source/drain contact to multilayer van der Waals channels in FET to retain ambipolar behavior and tune Schottky barrier. By the temperature-dependent transfer curve characteristics of graphene contact 2D FETs, 2D van der Waals semiconductors’ bandgaps finally extracted.

Keywords
Graphene, Bandgap measurement, FET, Contact, Ambipolar

Biography
Sungjae Hong is a Ph.D. candidate in the Department of Physics at Yonsei University, Republic of Korea. He received his B.S. degree from Yonsei University in the Department of Physics in 2018. His current research is mainly focused on electronic devices exploiting transition metal dichalcogenides.

Sam Park is a Ph.D. candidate in the Department of Physics at Yonsei University, Republic of Korea. His current research is focused on 2D heterostructure device applications.

Seongil Im, applied physicist and device engineer, achieved Ph.D. from UC at Berkeley in 1994 and worked as research fellow at CALTECH from 1995 till 1996. He joined the department of Physics at Yonsei University as associate professor in 1999. Currently, he is the Director of van der Waals Materials Research Center (vdWMRC) at Yonsei.
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An Important Role of Crystal Defect in Hybridization Matrix for Exploring Efficient Hybrid Supercapacitor Electrodes

Abstract
In this study, an efficient synthetic route to high-performance supercapacitor electrodes is developed by employing conductive holey TiN nanosheet (NS) with anion defects as a hybridization matrix for layered double hydroxide (LDH) NSs. The strongly-coupled nanohybrids of holey TiN-LDH can be synthesized by the crystal growth of LDH NSs on the surface of holey TiN NSs via the hydrothermal reaction. According to the extended X-ray absorption fine structure and micro-Raman analyses, the holey TiN NS has coordinatively unsaturated Ti sites, which is effective in achieving a strong electronic coupling with LDH NS. The obtained nanohybrid exhibits much better supercapacitor performance than the pristine LDH NS. The beneficial effect of holey TiN NS incorporation on the electrode performance of LDH NS is attributable to the enhanced redox activity, increased porosity, and increased charge transfer kinetics. The present study underscores that the defect control of conductive hybridization matrix can provide an effective way of optimizing the supercapacitor functionality of hybrid materials via an enhanced interfacial electronic coupling.

Keywords
Defect engineering; Holey structure; 2D nanosheet; Hybridization

References

Biography
Yeon Hu Park received a B.S. degree in Plant and Environmental New Resources (2021) from Kyung Hee University. He is currently a Combined M.S & Ph.D student in the Department of Materials Science and Engineering at Yonsei University under Prof. Seong-Ju Hwang. His research focuses on synthesis and characterization of the 2D inorganic nanosheets and their applications in energy-related applications.
Virtual Presentations
Anupama B. Kaul
PACCAR Professor of Engineering; Materials Science and Engineering and Electrical Engineering
University of North Texas

Selenides and perovskites for optical sensing and energy harnessing applications

Abstract
The excitonic and multibody interactions in some semiconducting two-dimensional (2D) crystallites, their strain-dependent properties and pristine atomically flat interfaces, coupled with the ability to solution-process these materials, offer a rich playground to unveil fundamental physical mechanisms for exciting and innovative devices. Amongst these, the transition metal dichalcogenides (TMDCs), such as tungsten diselenide (WSe2) and niobium diselenide (NbSe2) are finding promise in nanoelectronics, optoelectronics, sensors and quantum photonics. I will discuss our efforts in studying the light-matter interactions in halide-grown monolayer and fewlayer 2D semiconducting WSe2 to unveil multibody interactions towards quantum platforms. Heterostructures of 2D-2D semiconductors or 0D-2D ensembles also offer an intriguing prospect to enhance the light matter interactions in these systems to new levels. Our efforts in the solution-based synthesis of 2D materials has also enabled us to realize a rich plethora of flexible and bendable sensing devices. Here, additive manufacturing approaches are used including with organo-halide 2D perovskites, where we will describe their exceptional light absorption properties towards photoabsorbers and photovoltaics applications.
Materials Science
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Rational Design of Nanostructured and Functionalized 2D Materials for Advanced Nanoelectronics and Energy Storage devices

The nanostructured and functionalized 2D could bring versatile properties, thus opening a new possibility for advanced energy storage materials or high-performance nanoelectronics. In this talk, in the first part, I will report a dual-functional anode modifier as lithium deposition host and artificial solid electrolyte interphase (ASEI) that is prepared by the fluorinated graphene(FG) with a unique 3D structure, from which the coating film forms extra lithium storage interspace and enhances the mechanical strength, leading to higher stability even in full cell device. This study provided a new strategy for improving the strength of ASEI by introducing graphene ball as a structure supporting extra lithium transport tunnels realizing the potential of LMBs. [1] In the second part, I will present the self-aligned fluorinated graphene/polymer composites as a multifunctional coating for durable electronics passivation. The results show the highly enhanced thermal stability, ion/gas penetration resistance, and extremely high breakdown electrical field of 28 kV/cm, which can be applied in future advanced electronics passivation. [2] In this final part, we present, for the first time, the in-situ cleaning and selective functionalization of 2D black phosphorus (BP), where the selective functionalization and passivation not only enhanced stability in the air but also highly improve the electrical properties of the BP field-effect transistor (FET), with the high on-current and enhanced carrier mobility and on/off ratio. Also, the BP as functional active layers for artificial synapse memristors will be demonstrated.

References
Mixed 1T-2H MoS₂ Nanoflakes Electrodes For Li-ion Supercapacitors

Abstract
Molybdenum disulfide (MoS2) is a layered transition-metal dichalcogenide which has attracted great interest as material for energy conversion and storage. MoS2 exists in three different polymorphs that are the stable 2H, the meta-stable 1T and 3R with the possibility of obtaining 2D nanostructures.

Herein, we report the characterization of a few-layer hybrid material containing both metallic 1T and semiconducting 2H phases (1T-2H MoS₂ nanoflakes) obtained by a hydrothermal synthesis. Morphological and structural characterization’s results are presented and compared to commercially available 2H-MoS2 powder. The thermal conversion of the 1T-2H MoS₂ into fully 2H MoS₂ is studied by means of X-ray Photoelectron Spectroscopy to quantify the relative amount of 1T and 2H phase and maintaining the same morphology. This conversion allows to appreciate the superior properties of the 1T-2H mixed phases as electrode material in Li-ion supercapacitors. In order to enhance the capacitive proprieties of the mixed phases, the 1T-2H nanoflakes were finely alternated to reduced graphene oxide (rGO) sheets by obtaining a tridimensional matrix of rGO-MoS₂ (aerogel). This co-synthesis allowed to increase the cycling life and stability of aqueous supercapacitors and ensured a good stability at high temperature.

Keywords
MoS2, supercapacitor, TMD

References

Biography
Dr. Mara Serrapede is currently a postdoctoral collaborator in Istituto Italiano di Tecnologia based in Torino where she works on the topic electrochemical energy conversion and storage. She holds a BS and MS from the University of Torino and in the 2014 she was awarded of her Ph.D. in electrochemistry from the University of Southampton, UK, where she worked on palladium hydride microelectrodes and scanning electrochemical microscopy. In the last years, first in
Politecnico di Torino and then in IIT, she has focused on the characterization of materials and electrolytes for supercapacitors and hybrid devices in standard and ash environments.
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Graphene Coatings: A Novel Approach to Corrosion Resistance

Abstract
Corrosion and its mitigation costs dearly (any developed economy loses 3-4% of GDP due to corrosion, which translates to ~$250b to annual loss USA). In spite of traditional approaches of corrosion mitigation (e.g., use of corrosion resistance alloys such as stainless steels and coatings), loss of infrastructure due to corrosion continues to be a vexing problem. So, it is technologically as well as commercially attractive to explore disruptive approaches for durable corrosion resistance.

Graphene has triggered unprecedented research excitement for its exceptional characteristics. The most relevant properties of graphene as corrosion resistance barrier are its remarkable chemical inertness, impermeability and toughness, i.e., the requirements of an ideal surface barrier coating for corrosion resistance. However, the extent of corrosion resistance has been found to vary considerably in different studies. The author’s group has demonstrated an ultra-thin graphene coating to improve corrosion resistance of copper by two orders of magnitude in an aggressive chloride solution (i.e., similar to sea-water). In contrast, other reports suggest the graphene coating to actually enhance corrosion rate of copper, particularly during extended exposures. Authors group has investigated the reasons for such contrast in corrosion resistance due to graphene coating as reported by different researchers. On the basis of the findings, author’s group has succeeded in demonstration of durable corrosion resistance as result of development of suitable graphene coating. The presentation will also assess the challenges in developing corrosion resistant graphene coating on most common engineering alloys, such as mild steel, and presents results demonstrating circumvention of these challenges.

Biography
Professor Raman Singh’s expertise includes: Alloy Nano/Microstructure-Corrosion Relationship, Stress Corrosion Cracking (SCC), Corrosion/SCC of Biomaterials, Corrosion Mitigation by Novel Material (e.g., Graphene), Advanced and Environmentally Friendly Coatings, High Temperature Corrosion. He has supervised 50 PhD students. He has published over 225 peer-reviewed international journal publications, 15 books/book chapters and over 100 reviewed conference publications. His professional responsibilities include editor-in-chief of two journals, Fellow ASM International and Engineers Australia, over 40 keynote/plenary talks at international conferences (besides numerous invited talks), leadership (as chairperson) of a few international conferences.
Multifunctional rGO-based nanocomposites

Abstract
Multifunctional coatings for high-performance electronics are highly keen in a plethora of applications, with 2D materials nanostructures ruling unique advanced functional electronic, mechanical, and optical properties. We will report studies on reduced graphene oxide (rGO) nanoplatelets wrapped by polymers, suitable for layer-by-layer (LbL) assemblies. Molecular dynamic simulations helped us to comprehend molecular interactions between polymers and rGOs forming stable aqueous suspensions [1]. We have explored the size effect of the rGO nanoplatelets in distinct LbL assemblies for a fine-tuning of the charge transport, easily going from a 2D conduction mechanism along the pathway where the rGOs are deposited to a 3D interlayer transport endowing high charge carrier mobility ($\mu \sim 236 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$) [2–4]. More recently, we have started studies on self-healing, conductive LbL composites looking for attractive multifunctional coatings for high-performance electronic interfaces. Some composites presented unusual electrical phenomena not observed on individual materials, and the strong anisotropy present in one of them was explored in a field-effect device displaying ambipolar charge transport, with field-effect mobility of 4.0 cm$^2$ V$–1$ s$–1$ [5]. It was a simple, efficient idea to tailor transistors where the film acts simultaneously as the insulator and channel, avoiding a lattice mismatch at the dielectric/semiconductor interface and paving the way for further developments.

Keywords
reduced graphene oxide, layer-by-layer, field effect, high-mobility, self-healing

References


Biography
Antonio Riul Jr is currently an Associate Professor at the Department of Applied Physics, “Gleb Wataghin” Institute of Physics, University of Campinas (UNICAMP), São Paulo State, Brazil. He researches nanostructured films from self-assembled multilayers for the nano-engineering of interfaces using tunable materials. He also works with impedance measurements in e-tongue devices, exploring the 3D printing technique to integrate e-tongue systems into microfluidic devices. Nowadays, he is focusing on multifunctional coatings formed by self-healing, conductive nanocomposites.
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Development of CVD growth of high-quality 2D materials and their heterostructure

Abstract
Catalytic chemical vapor deposition (CVD) is a promising technique for the fabrication of scalable, continuous two-dimensional (2D) atomic films, especially monolayer crystals and exclusive heterostructures. However, the CVD-grown samples still contain multiple crystal defects compared to those prepared by mechanical exfoliation from bulk crystals. For example, CVD-grown 2D materials generally have multiple orientations on the catalyst surface. It is therefore challenging to grow both high-quality monolayer single crystals and heterostructures with uniform interlayer angles.

We have been working on the controllable growth of 2D crystals and their heterostructures. In this presentation, we report recent progress including (i) catalyst-selective growth of single-orientation and wrinkle-free hexagonal crystalline boron nitride (hBN) [1]. (ii) one-pot synthesis of centimeter-scale hBN/graphene bilayers with convergent interlayer angles [2], followed by (iii) theoretical understanding of the growth mechanism of 2D heterostructures [3, 4].

Keywords
CVD, graphene, hBN, 2D heterostructure

References

Biography
Dr. Shengnan Wang is currently a senior research scientist in NTT Basic Research Laboratories, Nippon Telegraph and Telephone Corporation, Japan. She received her Ph.D. in Physics studying the electronic properties of graphene from National Center for Nanoscience and Technology, China in 2012. After her Ph. D course, she joined NTT Basic Research Laboratories in 2012 as a researcher, in 2017 as a research scientist, and in 2020 as a senior research scientist. Her current researches focus on the large-scale growth and characterizations of 2D materials and their heterostructures.
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Interface-/Defect-Engineered Nanosheet-Based Hybrid Materials with Diverse Energy Functionalities

Abstract
Highly anisotropic 2D nanosheets of layered inorganic solids (layered metal oxides, layered double hydroxides, layered metal chalcogenides, layered metal carbides, and graphene) attract intense research interest because of their versatile roles in multifunctional nanohybrids applicable for renewable energy technologies. The monolayered 2D nanosheets of inorganic solids can be synthesized by soft-chemical exfoliation reaction of the pristine layered materials. A great diversity in the chemical compositions, crystal structures, and defect structures of inorganic nanosheets provides this class of materials with a wide spectrum of physical properties and functionalities. The inorganic nanosheets can be used as powerful building blocks for exploring high performance hybrid electrodes and catalysts with the help of interface and defect engineering. These materials can play a role as active components, additives, and substrates for improving the energy performance of hybridized species. In this talk, several practical examples of interface-/defect-engineered 2D inorganic nanosheet-based hybrid materials with electrode/catalyst functionalities will be presented together with the discussion about the relationship between chemical bonding nature and functionalities.

References
Controlling the electronic structure and related optical properties in van der Waals heterointerfaces: 2D semiconductor and functional organic molecules

Abstract
Recently, Van der Waals heterointerfaces consist of two-dimensional (2D) materials and functional organic molecules which have been intensively studied in order to enhance their optoelectrical properties.\cite{1} If the functional organic molecules are appropriately designed, this enables manipulation of the electronic structure and optical properties of 2D materials.\cite{2}

In this contribution, we demonstrate the controlling of the electronic structure of 2D materials by using the model functional organic molecules. The type of energy level alignment, which generally can be classified as straddling type-I and staggered type-II, will be controlled significantly at the heterointerfaces. Those are evidenced by the measurement of the angle-resolved and X-ray photoelectron spectroscopy.

In addition, how the manipulated energy level alignment by functional organic molecules influences the optical properties was investigated by time-resolved PL and transient absorption spectroscopy. Our findings reveal that the type of energy level alignment at the heterointerfaces determines interface carrier dynamics. (i) For type-I alignment, “resonance energy transfer, i.e., electron–hole pair transfer” is dominated, and (ii) For type-II, the “direct excited charge transfer.” These results help not only to understand interfacial physical phenomena, but also help design optimized optoelectrical applications.

Keywords
Photoelectron spectroscopy, 2D semiconductors, functional molecule

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Biography
Dr. Soohyung Park received his Ph. D. degree in physics from Yonsei University (Korea) in 2017. As a post-doc researcher, he then moved to Berlin (Germany) the Helmholtz Zentrum Berlin (HZB), and Humboldt University. Beginning in 2019, he has moved to the Korea Institute of Science and
Technology (KIST), Advanced Analysis Center (AAC) as a junior research team leader. Currently, we are focusing on the electronic structure of the interesting nanomaterial such as two-dimensional materials, perovskite, and functional molecules by using ultraviolet/X-ray photoelectron spectroscopy.
Hydrogen boride sheets and boron monosulfide sheets

As new two-dimensional metal-free materials, we have reported boron monosulfide (BS) sheets [1] and hydrogen boride (HB) sheets [2]. The BS sheets are crystalline semiconductor and its bandgap was found to be tuned to a desired value by controlling the number of stacked 2D BS nanosheet [1]. HB sheets are composed of boron and hydrogen at a 1:1 stoichiometric ratio, which can be formed by an ion-exchange reaction between protons and magnesium cations in magnesium diboride with exfoliation.[2] In the HB sheets, boron atoms form a hexagonal 2D network, in which hydrogen atoms are bound to boron by three-center-two-electron bonds (B–H–B) and two-center-two-electron bonds (B–H).[3] Experimental studies have clarified that HB sheets exhibit solid acid catalytic activity,[4, 5] metal ion reducibility,[6, 7] semimetal electronic properties,[8] gas-sensor applicability,[3] and a light-responsive hydrogen release function.[9] Furthermore, theoretical studies have revealed intriguing electronic,[10] optical, and thermal properties,[11, 12] as well as possible applications of HB sheets as rechargeable Li/Na ion battery electrodes,[13] hydrogen release,[14] reversible hydrogen storage,[15] current limiting, photodetectors, individual identification of amino acids, and anodes for rechargeable potassium-ion batteries with a high capacity, low voltage, and desirable rate performance. In this talk, the synthesis, evaluation, and application of HB and BS sheets will be presented.

Keywords
Boron monosulfide, Hydrogen boride, Borophene, Borophane

References

**Biography**

Takahiro Kondo received Doctor of Philosophy in Engineering from University of Tsukuba at 2003. His research focuses on creating new materials, technologies, sciences, and concepts to solve energy, environment and resource problems.

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