GRAPHENE FLAGSHIP

Korean Graphene Society
한국그래핀학회

The 7th Graphene Flagship EU-Korea Workshop on Graphene and related 2D materials

Eurostars Grand Hotel, Munich (DE)

5 September 2022

Workshop report

Contents

Overview

The 7th EU-Korea Workshop on Graphene and Related Materials was held on 5 September 2022 in Munich at the Eurostar Grand Hotel conference room. This workshop aimed at fostering exchange of experiences, practices and ideas related to the current and emerging topics associated with graphene and 2D related materials for electronics, opto-electronics quantum devices and sensing and to maintain active the interactions with overseas partners.

This was a follow up of four most successful workshops already organised, the first workshop was held in Busan (Republic of Korea) in 2015, the second in Copenhagen (Denmark) in 2016, the third in Jeju Island (Republic of Korea) in 2017, the fourth in San Sebastian (Spain) in 2018, the fifth in Seoul (Republic of Korea) in 2019 and the sixth online in 2021. The meeting was jointly prepared and co-chaired by Korean and European researchers.

Workshop chairs: Prof. Jari Kinaret (Sweden) and Prof. Hyeon Suk Shin (Republic of Korea)

Program chairs: Prof. Paolo Samori (France) and Prof. Tae-Woo Lee (Republic of Korea)

The workshop was attended by 21 participants, coming mainly from academic institutions but also from industry. Twelve speakers gave a talk, six from each side, to present scientific activities and topics investigated by the different research groups. The two groups of organizers provided the selection of the scientific speakers. The presentations stimulated questions and discussions.

The workshop was opened by the respective chairs who welcomed all participants and set the scene introducing the aim of this event.

Common challenges and opportunities for collaborations

The workshop covered topics related to production, characterisation, tuning of properties and applications. Below is an overview of the topics addressed during the workshop:

- Highly purified and ordered graphene oxide liquid crystals (GOLC), applications in elastomeric composites for medical applications.
- Chemical functionalization as tool for 2D materials properties tunability and generation of multifunctional coatings, foams and nanocomposites with improved performances in electronics, sensing and energy.
- Surfactant-monolayer assisted interfacial synthesis (SMAIS) method for promoting programmable assembly of precursor monomers on water surface and subsequent controlled 2D polymerisation.
- Engineering of the 2D crystal symmetry in Van der Waals heterostructures for the control of electrical properties (e.g. electric polarisation).
- Next generation batteries, including i) In Li-ion capacitors to avoid having metal plating; ii) Na-ion batteries using CVD graphene intercalated with Na; iii) Li-S batteries with sulphur in C-matrix as the cathode such as fluorinated rGO glass fiber; iv) Al batteries or Al ion capacitor using spray-coated few layer graphene as a cathode; v) Na-air batteries or rather Na-O_2.
- Progress in 3D printing of TMDs- and 2D material-based inks for manufacturing 3D printed micro-devices (e.g. micro-supercapacitors).
- Graphene fabrication and integration in the microelectronics process flows through the 2D experimental pilot line (2D-EPL).
- Spectroscopy and microscopy techniques for advanced characterisation of 2D materials composition, mechanical and electrical properties, including Coherent Raman Scattering spectroscopy, Angle-resolved photoemission spectroscopy, Interlayer coupling spectroscopy, Transmission Electron Microscopy, Deep-ultraviolet optical imaging and spectroscopy.

Relevant research areas of common interest amongst all the participants were confirmed in the fundamental characterisation and understanding of 2D material characteristic and the structure-properties relationships. With regards to graphene and related 2D materials applications, common areas of interest included energy and medical applications.

At the end of the meeting, there was clear interest to continue the series of workshops by organising the next workshop in 2023 in Korea as a side event of NanoKorea 2023 or in Europe as a side event of other main EU conferences (i.e. EuroNanoForum, Graphene Week 2023). Discussions also addressed the end of the Graphene Flagship in the current format and the new format as one CSA and several RIA/IA projects. Concern has been expressed about the lack of a dedicated budget for the continuation of this activity on the EU side under Horizon Europe. It has been finally agreed to move forward with the organisation of the 2023 workshop and to investigate the possibility to organise it close to the Japan-EU workshop to decrease the carbon footprint of the travelling delegates.

Programme

Indicated time corresponds to the Central European Summer Time (CEST) zone (Paris, Brussels time)

September 04th, 2022		
19:00	**Workshop welcome dinner at Augustiner Keller**	
September 05th, 2022		
08:30 – 09:00	**Networking breakfast**	
09:00 – 09:40	**Welcome and introduction** Jari Kinaret, Hyeon Suk Shin, Paolo Samorì and Kwanpyo Kim	
Session1 *Chair:* Paolo Samorì		
09:40 – 10:05	*Sang Ouk Kim, Korea Advanced Institute of Science and Technology*	Graphene Oxide Liquid Crystal for Real–World Graphene Applications
10:05 – 10:30	*Patrik Johansson, Chalmers University of Technology*	Next generation batteries - graphene an enabler?
10:30 – 10:50	**Coffee break**	
Session2 *Chair:* Kwanpyo Kim		
10:50 – 11:15	*Keun Su Kim, Yonsei University*	Pseudogap in a surface-doped puckered honeycomb crystal
11:15 – 11:40	*Cecilia Mattevi, Imperial College London*	3D Printed Zinc Ion Batteries for Wearable Electronics
11:40 – 12:05	*Heejun Yang, Korea Advanced Institute of Science and Technology*	Van der Waals Heterostructures for Orbital Gating-Based Phototransistors and Electronic Spectroscopy
12:05 – 13:30	**Lunch**	
Session3 *Chair:* Xinliang Feng		
13:30 – 13:55	*Sanna Arpiainen, VTT*	Wafer-scale graphene processing and integration on CMOS

13:55 – 14:20	*Kwanpyo Kim, Yonsei University*	Strong anisotropy of black phosphorus visualized by electron microscopy
14:20 – 14:45	*Paolo Samorì, University of Strasbourg*	Boosting charge injection and charge transport in 2D transistors
14:45 – 15:10	*Hyobin Yoo, Sogang University*	Operando TEM investigation on domain dynamics in 2-D ferroelectric materials
15:10 – 15:30	**Coffee break**	
Session4 *Chair:* Hyeon Suk Shin		
15:30 – 15:55	*Xinliang Feng, TU Dresden*	Organic 2D Membranes
15:55 – 16:20	*Jonghwan Kim, Pohang University of Science and Technology*	Probing deep-ultraviolet optoelectronic processes in hexagonal boron nitride
16:20 – 16:45	*Andrea C. Ferrari, University of Cambridge*	Layered Quantum Materials: Characterization and Applications
16:45 – 17:30	**Final discussion** Moderators: Paolo Samorì & Kwanpyo Kim	
18:30 – 20:30	**Graphene Week 2022 Welcome Reception at Munich House of Artists**	

List of speakers and participants

Title	Last name	First name	Institution	Country
Prof.	Kim	Kwanpyo	Yonsei University	Republic of Korea
Prof.	Kim	Sang Ouk	Korea Advanced Institute of Science and Technology	Republic of Korea
Prof.	Kim	Keun Su	Yonsei University	Republic of Korea
Prof.	Kim	Jonghwan	Pohang University of Science and Technology	Republic of Korea
Prof.	Shin	Hyeon Suk	UNIST	Republic of Korea
Prof.	Yang	Heejun	Korea Advanced Institute of Science and Technology	Republic of Korea
Prof.	Yoo	Hyobin	Sogang University	Republic of Korea
Dr	Arpiainen	Sanna	VTT	Finland
Prof.	Feng	Xinliang	TU Dresden	Germany
Prof.	Ferrari	Andrea C.	University of Cambridge	United Kingdom
Prof.	Johansson	Patrik	Chalmers University of Technology	Sweden
Prof.	Kinaret	Jari	Chalmers University of Technology	Sweden
Dr	Mattevi	Cecilia	Imperial College London	United Kingdom
Prof.	Samorì	Paolo	University of Strasbourg	France
Prof.	Roche	Stephan	ICREA and ICN2	Spain
Mr.	Fernández Serra	Enrique	CNM	Spain
Dr.	Diamante	Letizia	Cambridge Graphene Centre	United Kingdom
Dr.	Vacchi	Isabella Anna	European Science Foundation	France

BOOK OF ABSTRACTS

Chemically Modified Graphene for Real-World Applications: Graphene Oxide Liquid Crystal & Single Atom Catalyst

Sang Ouk Kim

National Creative Research Initiative (CRI) Center for Multi-dimensional Directed Nanoscale Assembly, Department of Materials Science & Engineering, KAIST, Republic of Korea

Short biography:

Prof. Sang Ouk Kim attained his Ph.D. in 2000 from the Department of Chemical Engineering at KAIST and joined the Department of Materials Science & Engineering of KAIST as a professor in 2004. His main research interest is the directed self-assembly of soft materials, including block copolymers and 2D nanomaterials such as graphene oxide aiming at the practical utilization of the resultant nanostructures for electronics, energy, environmental and biological applications. Noticeably, he has pioneered the extension of molecular level self-assembly principle, previously mostly associated to biomolecules or polymers, for the general material fabrication methodologies based on various nanomaterials with molecular level precision. One of the prof. Kim's well-known research achievements is the world-first discovery of graphene oxide liquid crystal. Since this original contribution, graphene based material fabrication has been rapidly advanced and approaching real-world applications in the form of 1D fibres, 2D films, and 3D nanoassmbled structures. Significantly, graphene oxide liquid crystal offers a valuable precursor state for the mass-production of sub-5 layer level high quality graphene powders. His contribution in materials research has been widely appreciated by prestigious honours, including the youngest fellow of the Korea Academy of Science and Technology (2020), Highly Cited Researcher from Clarivate Analytics (2018), the KAIST Grand Prize for Academic Excellence (2015) and Presidential Young Scientist Award (2013). He is currently serving as an associate editor of the prestigious academic journal, Energy Storage Materials, published by Elsevier as well as editorial advisors or committee members Accounts of Materials Research (ACS), Small Methods (Wiley), ACS Applied Materials & Interfaces (ACS), Molecular Systems Design & Engineering (RSC) and so on. To date, He has published more than 265 SCI Journal papers and 100 patens relevant to nanomaterials & 2D materials science. Based on the Google Scholar statistics, Prof. Kim's H-index is 83 and the total citation is more than 25000.

Abstract:

Graphene Oxide Liquid Crystal (GOLC) is an emerging 2D carbon based soft material, which exhibits nematic type colloidal discotic liquid crystallinity with the orientational ordering of graphene oxide flakes in good solvents, including water. Since our first discovery of GOLC in aqueous dispersion at 2009, this interesting mesophase has been utilized over world-wide for many different application fields, such as liquid crystalline graphene fiber spinning, highly ordered graphene membrane/film production, prototype liquid crystal display and so on. Interestingly, GOLC also allow us a valuable opportunity for the highly ordered molecular scale assembly of functional nanoscale structures. This presentation will introduce our current status of GOLC research particularly focusing on the nanoscale assembly of functional nanostructures, including highly oriented 1D fibers, 2D films and 3D nanoporous structures. Besides, relevant research works associated to the nanoscale assembly and chemical modification of various low dimensional materials, including 1D carbon nanotubes, 2D TMDs and MXene, will be presented particularly aiming at energy and environmental applications. In the last part of presentation, our first discovery of single atom catalyst will be introduced also, including other relevant research efforts exploiting the customized heteroelement doping of graphene based structures.

Next generation batteries - graphene an enabler?

Patrik Johansson
Department of Physics, Chalmers University of Technology, 41296 Göteborg, SWEDEN
ALISTORE-European Research Institute, FR CNRS 3104, 80039 Amiens, FRANCE

Short biography:

Patrik Johansson is Full Professor in Physics at Chalmers University of Technology, Sweden, where he leads a group of ca. 12 PhD students and postdocs. He was recently awarded a 10 years Distinguished Professor Grant (ca. 4.5 M€) from the Swedish Research Council for Next Generation Batteries. He is also co-director of ALISTORE-ERI, one of Europe's largest industry-academia networks within the field of modern batteries, as well as vice-director of the Graphene Flagship, one of Europe's largest joint research efforts all categories. His research efforts continuously aim at combining thorough understanding of new materials at the molecular scale with proper battery concept development and real battery performance – with a special interest being all kinds of electrolytes. He is currently active in several large H2020 battery projects, such as BIG-MAP and DESTINY. Most notably, his team won the Open Innovation Contest on Energy Storage arranged by BASF in 2015 for his new ideas on Al-battery technology (100 k€). He has published over 200 papers and a few patents, he co-founded Compular AB and holds commission of trust positions both for research councils, centra and institutes, as well as publishers and scientific journals.

Abstract:

The push for improved energy storage is today omnipresent and high up on also political agendas as readily available and clean energy affect all of our society profoundly through climate change, resources and sustainable development, energy security, nomadic work life, etc.

While lithium-ion batteries (LIBs) clearly have delivered beyond all expectations, to the extent that mobile phones and laptops are commodities and electric vehicles penetrate the market at ever-increasing rates, there are, however, still issues with cost, energy and power density, life-length, resources, safety, etc. All of this is also to be re-valued when we for example look at large-scale storage of renewable variable energy from solar and wind. This is one reason why various next generation batteries (NGBs) are being heavily researched at the moment.

Depending on who you ask NGBs encompasses both improved LIBs as well as conceptually different ones such as sodium-ion batteries (SIBs), lithium-sulfur batteries (Li-S), metal-air batteries, and multivalent chemistry-based batteries (Mg^{2+}/Ca^{2+}/Al^{3+}). Each NGB has its own set of promises and challenges – and some can (possibly) be remedied by introducing graphene.

In the world of batteries graphene itself has been used to improve the storage capacity, foremost of LIBs, but even more so different derivatives have been used such as rGO, grafted materials, 3D-sponges, etc. – not to mention other 2D-materials such as MXenes – for a variety of purposes and NGBs. Here I will present a *smörgåsbord* of some of the advances made for NGBs.

Pseudogap in a surface-doped puckered honeycomb crystal

Keun Su Kim
Department of Physics, Yonsei University, Republic of Korea

Short biography:

Keun Su Kim is an associate professor in the Department of Physics, Yonsei University, South Korea. He earned his PhD from Yonsei University, and undertook postdoctoral research in Lawrence Berkeley National Lab, United States. From 2013, He started his assistant professorship in Pohang University of Science and Technology (POSTECH) and move to Yonsei University in 2017. He has studied the electronic band structure of low-dimensional quantum materials, such as black phosphorus, by means of angle-resolved photoemission spectroscopy (ARPES).

Abstract:

Two-dimensional (2D) quantum materials have continued to attract broad interest in the field of condensed-matter physics. One of the exciting opportunities with these materials is the tunable band structure with surface doping. The in situ deposition of alkali metals can be used to tune the band gap of black phosphorus over the energy range even greater than its intrinsic band gap [1]. This can also be used not only to deliberately induce the topological phase transition to the 2D Dirac semimetal protected by spacetime inversion symmetry [2], but also to systematically trace the evolution of pseudospin order (quantum phases) across the band inversion [3]. In this talk, I will focus on our most recent discovery of intriguing band renormalizations and pseudogap by the effect of short-range order of alkali metals on black phosphorus [4]. Using angle-resolved photoemission spectroscopy (ARPES), we found that the simple quadratic band dispersion of doped black phosphorus bends back towards zero wavenumber, which can be explained by the Anderson-McMillan band dispersion of liquid metals proposed in the 1960s. This is a natural consequence of resonance scattering by the potential of dopant ions with a liquid-like short-range order. The depth of scattering potential tuned by different kinds of alkali metal (Na, K, Rb, and Cs) allows us to classify the pseudogap of p-wave and d-wave resonance.

1. J. Kim et al., Science 349, 723 (2015).
2. J. Kim et al., Phys. Rev. Lett. 119, 226801 (2017).
3. S. W. Jung, S. H. Ryu et al., Nature Mater. 19, 277 (2020).
4. S. H. Ryu, M. Huh, D. Y. Park et al., Nature 596, 68 (2021).

3D Printed Zinc Ion Batteries for Wearable Electronics

Cecilia Mattevi
Imperial College London, United Kingdom

Short biography:

Dr.**Cecilia Mattevi** is a Reader and Royal Society University Research Fellow in the Department of Materials at Imperial College London. Dr Cecilia Mattevi received her Laurea degree in Materials Science and a PhD in Materials Science from the University of Padua. After a postdoctoral appointment at Rutgers University, Cecilia joined the Materials Department at Imperial College London, becoming a Junior Research Fellow in 2010. Cecilia is a Fellow of the Royal Society of Chemistry and her research interest focuses on the precise synthesis of 2D materials and their three-dimensional structuring in the form of miniaturized devices to address pressing challenges in energy storage, energy conversion and nanoelectronics.

Abstract:

Rechargeable Zinc Ion Batteries (ZIBs) based on aqueous electrolytes are promising beyond-lithium energy storage systems. They feature large volumetric capacity, outstanding safety and they are low cost. The use of Earth-abundant, non-hazardous electrode materials and water-based electrolytes makes ZIBs ideal power sources to meet the growing energy demand of wearable and portable electronics. Nonetheless, the rechargeable zinc ion batteries are still limited by significant technological challenges, primarily associated with the low electrochemical reversibility of such systems.

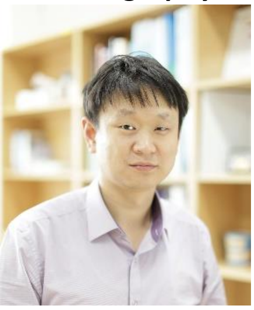
The structural re-design of the electrode architectures is an effective strategy to prolong the cycle life of ZIBs, reducing the local current density at the interface with the electrolyte and promoting a uniform and reversible zinc plating. 3D Printing is a sustainable manufacturing process that can be employed to fabricate electrodes with customized design, via the layer-by-layer deposition of suitable inks. The rationally-designed structure of 3D Printed electrodes provides enhanced electrochemical stability and superior specific capacity, ensuring uninterrupted charge transport pathways and fast charge transfer inside the device.

Here, we present the fabrication of interdigitated Zinc Ion Batteries entirely via the 3D Printing of aqueous ink formulations, specifically tailored for the anode, cathode and gel electrolyte deposition. We electrochemically characterize the battery and we demonstrate that it can to power commercial wearable devices. We identify that the 3D architecture of the electrodes is an important parameter to increase the reversibility of the printed battery, and investigate the degradation processes and electrochemical failure through post-mortem characterization.

Van der Waals Heterostructures for Orbital Gating-Based Phototransistors and Electronic Spectroscopy

Heejun Yang
Department of Physics, KAIST, Republic of Korea

Short biography:



Heejun Yang received B.S. in physics from KAIST in 2003 and a joint Ph.D. in physics from Seoul National University (Korea) and University Paris-Sud XI (France). He was awarded the IUPAP Young Scientist Prize in Semiconductor Physics 2018 for his outstanding contribution to novel interface devices based on structural, electronic, and quantum-state control with van der Waals layered materials. His Ph.D. subject was on graphene by scanning tunneling microscopy and spectroscopy (STM/STS), and he experienced industrial device studies in Samsung Electronics from 2010 to 2012. Then, he conducted his research on graphene spintronics in Albert Fert's (2007 Novel laureate) group in CNRS/Thales as a postdoc from 2012 to 2014.

With his research background on molecular and nanometer-scale studies (in Seoul and Paris) and electric and spintronic device physics (in Samsung and CNRS/Thales), he moved to Sungkyunkwan University (2014~2021) and KAIST (2021~) and started original device studies with phase engineering of low-dimensional materials. He has proposed novel and conceptual interface devices such as 'Graphene Barristor' and 'Ohmic homojunction contact between semiconductor channel and metal electrodes'.

Abstract:

Each atomic layer in van der Waals heterostructures possesses a distinct electronic band structure that can be manipulated for unique device operations. The subtle but critical band coupling between the atomic layers, varied by the momentum of electrons and external electric fields in device operation, has not yet been presented or applied to designing original devices with the full potential of van der Waals heterostructures. In this talk, I will introduce interlayer coupling spectroscopy at the device-scale based on the negligible quantum capacitance of two-dimensional semiconductors in lattice-orientation-tuned, resonant tunneling transistors (Figure below). The effective band structures of the mono-, bi-, and quadrilayer of MoS2 and WSe2, modulated by the orientation- and external electric field-dependent interlayer coupling in device operations, could be demonstrated by the new conceptual spectroscopy overcoming the limitations of the former optical, photoemission, and tunneling spectroscopy [1]. Based on the vertical heterojunction, single-defect resonant transistors [2], and novel orbital-gating phototransistors [3] could be developed.

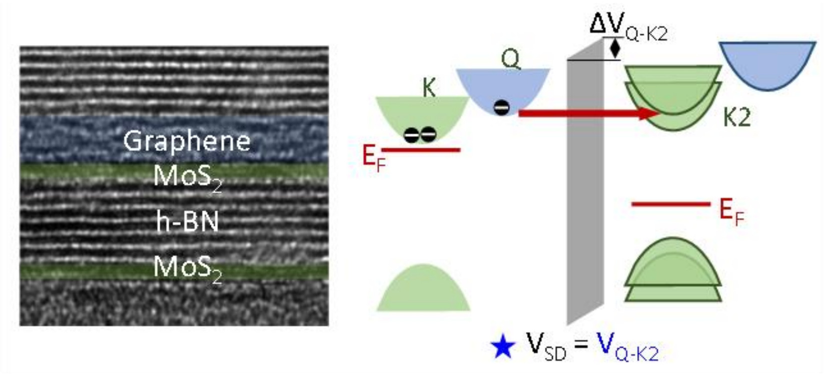


Figure. Resonant tunneling spectroscopy via orientation-tuned van der Waals layers

[1] Resonant tunneling spectroscopy to probe the giant Stark effect in atomically-thin materials, Advanced Materials 32, 1906942 (2020)
[2] Robust Quantum Oscillation of Dirac Fermions in a Single-Defect Resonant Transistor, ACS Nano 15, 20013 (2021)
[3] Orbital gating driven by giant Stark effect in tunneling phototransistors, Advanced Materials 34, 2106625 (2022)

Wafer-scale graphene processing and integration on CMOS

Sanna Arpiainen
VTT, Finland

Short biography:

Dr. Sanna Arpiainen team leader in Nanosystems team at VTT Microelectronics and quantum technology. She coordinates the graphene and 2D materials research and commercial offering at VTT, with special focus on CVD graphene based applications in biosensing, photonics and electronics. She made her PhD on graphene and photonic crystal integration on microelectronics processes for Aalto University in 2015. Her background is in optical MEMS, photonics integration, nanotechnology and materials research. She is the PI of several national and international research projects on graphene sensors, photonics and integration.

Abstract:

Graphene is now strongly emerging from the research phase towards industrial applications also in the microelectronics field, including photonics, sensing and electronics. The largest bottleneck in this process has been the scalability and reliability of the graphene fabrication and integration with the microelectronics process flows, in which respect the recent years have provided significant progress. The industrialization is now being further speeded up with the 2D experimental pilot line (2D-EPL) project recently launched by EC as a new initiative in the Graphene Flagship.

The most relevant key control characteristics (KCCs) related to graphene-based device stability are doping, contact resistance and mobility. Statistical analysis on large data sets achieved from wafer scale production batches allows accessing the effect of different process variations on both the optimization and the reliability and stability of the KCCs. For example, by optimizing pre-transfer surface topography – including surface roughness, step profile & step heights – the contact resistance of bottom contacted GFETs can be reduced significantly. [1]. The reliable low resistance contacts are critical for graphene field-effect transistors (GFETs), as a large contact resistance restrains drain current, thereby preventing a high ‘on’ current and high-frequency operation [2].

A repeatable and scalable fabrication process is also required for the detailed study of THz detector responsivity models and performance optimization. The repeatability of the process allows fabricating the detectors with various geometry and designs, but similar graphene electrical parameters, such as Dirac voltage shift and charge carrier mobility. This in turn supports the THz detector design optimization for the given intrinsic GFET parameters. [3]

In biosensing, the high sensitivity of the graphene transducers is combined with bioreceptors to provide a response specific to the desired bioanalytes, and the quantitativity generally requires both statistics and carefully selected set of receptors for internal calibration and referencing. CMOS integration of the graphene sensors now provides keys to address the challenges in statistical variability of the sensor response and provides means for truly quantitative on-chip bioanalysis with the multiplexed bioassays. [4]

References

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[2] A. Allain et al. “Electrical contacts to two-dimensional semiconductors.” Nature materials vol. 14 no. 12: 1195-205 (2015).
[3] A. Generalov et al., “Wafer scale graphene fabrication towards THz detector arrays”, Graphene Week 2022.
[4] M. Soikkeli et al., “Wafer-scale graphene field effect transistor CMOS integration for biosensing applications” unpublished.

Strong anisotropy of black phosphorus visualized by electron microscopy

Kwanpyo Kim
Department of Physics, Yonsei University, Republic of Korea

Short biography:

Dr. Kwanpyo Kim is an associate professor at the Department of Physics in Yonsei University, Korea. He finished his undergraduate from Seoul National University, Korea in 2006 and completed his PhD in Physics at the University of California, Berkeley in 2012. He worked as a postdoctoral research fellow at Stanford University from 2012 to 2014. Before moving to Yonsei Univeristy, he worked in the Department of Physics of Ulsan National Institute of Science and Technology (UNIST), Korea from 2014 to 2018. His research is focused on atomic-scale characterizations and manipulation of various 2D materials and their electronic applications. He has published more than 75 refereed articles.

Abstract:

Black phosphorus (BP), a mono-elemental layered crystal composed of phosphorus, is a promising building block for optoelectronics. BP also possesses unique puckered structures, which leads to high in-plane anisotropic properties. In this talk, I will present applications of transmission electron microscopy (TEM) to investigate the anisotropic mechanical, chemical, and electric properties of BP and its heterostructure with other van der Waals components. In particular, the anisotropic etching behavior of phosphorene and controlled assembly on BP's surface via anisotropic surface diffusion will be discussed.

First, we utilize in situ TEM experiments to study the anisotropic etching behavior of BP at room temperature and elevated temperatures [1,2]. In particular, we identify unique reconstruction at the zigzag edge in bilayer phosphorene. Through first-principles calculations and TEM image analysis under various tilting and defocus conditions, we find that bilayer ZZ edges undergo edge reconstruction to self-passivated edge configurations. We also demonstrate the fabrication of bilayer phosphorene nanoribbons with atomically-sharp closed ZZ edges. Second, we report the assembly of metals and organic crystals on BP's surface. TEM and X-ray photoelectron spectroscopy confirm that atomically sharp van der Waals metal−BP interfaces are formed with an exceptional rotational alignment for Au, Ag, and Bi cases through guided assembly on the BP surface [3]. The observed formation of the high-quality metal film can be attributed to the high anisotropy in surface diffusion. The ordered assembly of organic molecules, C60, on BP can be utilized for mixed-dimensional van der Waals transistors with superior electrical and optical tunabilities [4].

References

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[3] Y. Lee, H.-g. Kim, T. K. Yun, J. C. Kim, S. Lee, S. J. Yang, M. Jang, D. Kim, H. Ryu, G.- H. Lee, S. Im, H. Y. Jeong, H.J. Choi, and K. Kim, Chem. Mater., 33, 3593 (2021).
[4] T. K. Yun, Y. Lee, M. J. Kim, J. Park, D. Kang, S. Kim, Y. J. Choi, Y. Yi, B. Shong, J. H. Cho, and K. Kim, Small, 18, 2105916 (2021).

Boosting charge injection and charge transport in 2D transistors

Paolo Samorì
University of Strasbourg, France

Short biography:

Paolo Samorì is Distinguished Professor at the Université de Strasbourg, Director of the Institut de Science et d'Ingénierie Supramoléculaires (ISIS) and Director of the Nanochemistry Laboratory. He is Foreign Member of the Royal Flemish Academy of Belgium for Science and the Arts (KVAB), Fellow of the Royal Society of Chemistry (FRSC), Fellow of the European Academy of Sciences (EURASC), Member of the Academia Europaea, Member of the European Academy of Sciences and Arts, Fellow of International Engineering and Technology Institute (IETI), Socio corrispondente, Sezione di Scienze Matematiche, Fisiche e Naturali ; Accademia Nazionale di Scienze Lettere e Arti di Modena, Fellow of the Materials Research Society (MRS), Fellow of the University of Strasbourg Institute for Advanced Study (USIAS), Senior Member of the Institut Universitaire de France (IUF).

He has obtained a Laurea (master's degree) in Industrial Chemistry at University of Bologna in 1995. In 2000, he has received his PhD in Chemistry from the Humboldt University of Berlin (Prof. J. P. Rabe). Before joining ISIS, he has been permanent research scientist at Istituto per la Sintesi Organica e la Fotoreattività of the Consiglio Nazionale delle Ricerche of Bologna. He has published 400+ papers on nanochemistry, supramolecular sciences, materials chemistry, and scanning probe microscopies with a specific focus on graphene and other 2D materials as well as functional organic/polymeric and hybrid nanomaterials for application in optoelectronics, energy and sensing. He has been awarded numerous prestigious prizes, including the E-MRS Graduate Student Award (1998), the MRS Graduate Student Award (2000), the IUPAC Prize for Young Chemists (2001), the Vincenzo Caglioti Award (2006), the Nicolò Copernico Award (2009), the Guy Ourisson Prize (2010), the ERC Starting Grant (2010), the CNRS Silver Medal (2012), the Catalán-Sabatier Prize (2017), the Grignard-Wittig Lectureship (2017), the ERC Proof of Concept Grant (2017), the RSC Surfaces and Interfaces Award (2018), the Blaise Pascal Medal in Materials Science (2018), the Pierre Süe Prize (2018), the ERC Advanced Grant (2019), the "Étoiles de l'Europe" Prize (2019), the ERC Proof of Concept Grant (2020) and the RSC/SCF Joint Lectureship in Chemical Sciences (2020).

He is Associate Editor of *Nanoscale* and *Nanoscale Advances* (RSC) and Member of the Advisory Boards of *Advanced Materials*, *Small*, *ChemNanoMat*, *ChemPhysChem*, *ChemPlusChem*, *ChemSystemsChem* and *SmartMat* (Wiley-VCH), *Chemical Society Reviews, Nanoscale Horizons*, *Chemical Communications* and *Journal of Materials Chemistry* (RSC), *ACS Nano* and *ACS Omega* (ACS), and *BMC Materials* (Springer Nature).

Abstract:

The fabrication of high-performance (opto-)electronic devices based on 2D channel materials requires the optimization of both charge injection at electrode–semiconductor interfaces and the charge transport through the 2D semiconductor. Chemical functionalization offers key advantages to boost both these fundamental physical proesses for efficient opto-electronic technologies.[1]

In my lecture I will review our recent findings on the chemical functionalization to engineer:

(1) Chemically functionalized electrodes integrated in top-contact field-effect MoS2 transistors by contact engineering through the dry transfer of self-assembled monolayers pre-modified electrodes. Charge injection was optimized by using ad hoc thiolated molecules with controlled dipole moments, thereby boosting the device performance. When asymmetrically functionalized electrodes were employed, Schottky diodes with a high rectification ratio could be realized. [2]

(2) Covalently functionalized solution-processed TMDs (MoS2, WS2 and ReS2) with bi-dentate semiconducting molecules enabled to simultaneously heal sulfur vacancies in metal disulfides and

covalently bridge adjacent flakes, by promoting percolation pathways for charge transport, yielding a significant enhancement of the transistor characteristics.[3]

Our modular strategies relying on the combination of 2D material with molecules offer a simple route to generate multifunctional coatings, foams and nanocomposites with pre-programmed properties to address key global challenges in electronics, sensing and energy applications.

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Operando TEM investigation on domain dynamics in 2-D ferroelectric materials

Hyobin Yoo
Department of Physics, Sogang University, Republic of Korea

Short biography:

Hyobin Yoo received his B.S. (2010) and Ph.D. (2016) in Materials Science and Engineering from Seoul National University. His graduate study in the groups of Prof. Miyoung Kim and Prof. Gyu-Chul Yi at Seoul National University consisted of investigating the atomic structures of compound semiconductor materials using transmission electron microscopy. He was a post-doctoral fellow in the group of Prof. Philip Kim in the Department of Physics at Harvard University where he studied the correlation between quantum electronic transport and atomic structures of 2-D van der Waals heterostructures. He joined the Department of Physics at Sogang University as a junior faculty member in 2020.

Abstract:

Control of interlayer stacking angle in two-dimensional (2-D) van der Waals (vdW) heterostructure enables one to engineer the crystal symmetry to imprint novel functionality. By stacking two layers of transition metal dichalcogenides (TMD) with designed twist angle, one can break the inversion symmetry and thereby develop vertical electric polarization. The direction of the electric polarization can be switched electrically, suggesting that the twisted bilayer TMD can host ferroelectricity. Such ferroelectricity reported in twisted bilayer vdW system is distinguished from conventional ferroelectrics in that the lateral sliding of the constituent layers induces vertical electric polarizations. Due to the reduced dimension, the ferroelectric domains do not require forward growth along the third dimension, suggesting unconventional 2-D domain dynamics under an applied electric field.
Here we employ operando transmission electron microscopy (TEM) to investigate the domain dynamics in 2-D vdW ferroelectrics. Operando TEM technique enables one to examine the structural change in the environment that mimics the device operating condition. On a thin SiN based TEM compatible platform, we fabricated double capacitor structure on 2D vdW ferroelectrics. Electrical gating in double capacitor structure and real time observation of structural change in a simultaneous manner provides an insight onto the switching mechanism of the 2-D vdW ferroelectrics.

Organic 2D Membranes

Xinliang Feng
Center for Advancing Electronics Dresden & Faculty of Chemistry and Food Chemistry, Technische Universitaet Dresden, Max Planck Institute of Microstructure Physics, Germany,

Short biography:

Prof. Feng is the head of the Chair of Molecular Functional Materials at Technische Universität Dresden, and a director at the Max-Planck Institute of Microstructure Physics. He has published more than 670 research articles which have attracted around 85000 citations with H-index of 145 (Google Scholar).

He has been awarded several prestigious prizes such as IUPAC Prize for Young Chemists (2009), European Research Council (ERC) Starting Grant Award (2012), Journal of Materials Chemistry Lectureship Award (2013), ChemComm Emerging Investigator Lectureship (2014), Fellow of the Royal Society of Chemistry (FRSC, 2014), Highly Cited Researcher (Thomson Reuters, 2014-2021), Small Young Innovator Award (2017), Hamburg Science Award (2017), EU-40 Materials Prize (2018), ERC Consolidator Grant Award (2018). He is a member of the European Academy of Sciences (2019), member of the Academia Europaea (2019), and member of the Germany's Academy of Science and Engineering (acatech, 2021). He is an Advisory Board Member for Advanced Materials, Chemical Science, Journal of Materials Chemistry A, ChemNanoMat, Energy Storage Materials, Small Methods, Chemistry -An Asian Journal, Trends in Chemistry, etc. He is the Head of ESF Young Research Group "Graphene Center Dresden", Working Package Leader of WP Functional Foams & Coatings for European Commission's pilot project "Graphene Flagship", and spokesperson for the DFG Collaborative Research Center for the Chemistry of Synthetic 2D Materials (2020-).

Abstract:

Organic 2D materials are an underdeveloped field that can offer tremendous opportunities for exploring exotic physical and chemical properties and phenomena. In this talk, we will present our recent efforts in bottom-up synthetic approaches towards novel organic 2D membranes with structural control at the atomic/molecular level and beyond. We will highlight on-water surface synthesis as a powerful synthetic platform for organic 2D polymers by exploiting surface confinement and enhanced chemical reactivity and selectivity. We will particularly present a surfactant-monolayer assisted interfacial synthesis (SMAIS) method that is highly efficient to promote programmable assembly of precursor monomers on the water surface and subsequent 2D polymerization in a controlled manner. The unique 2D crystal structures with possible tailoring of molecular building blocks and linkage spacers, tunable pore sizes and thicknesses, as well as impressive electronic structures, make them highly promising for a range of applications in electronics, optoelectronics, spintronics, energy storage and membranes. We will particularly discuss the aspects related to 2D membrane applications in view of selective ion transport phenomenon.

Probing deep-ultraviolet optoelectronic processes in hexagonal boron nitride

Jonghwan Kim
Department of Materials Science and Engineering, Pohang University of Science and Technology, Republic of Korea

Short biography:

Jonghwan Kim, Ph. D., is interested in novel quantum phenomena emerging in low-dimension nanomaterials for fascinating optical science and optoelectronics. He has obtained Ph.D. in Physics at UC Berkeley in 2015 with the focus on ultrafast optical spectroscopy/microscopy, high quality 2D material preparation and nano-device fabrication. In POSTECH, as an assistant professor started from 2017, he has been constructing an interdisciplinary research team at the department of materials science and engineering to connect the bridge between fundamental physics and advanced material engineering.

Abstract:

Hexagonal boron nitride (hBN) is a van der Waals (vdW) semiconductor with a wide bandgap of ~ 5.96 eV. Despite the indirect bandgap characteristics of hBN, charge carriers excited by high energy electrons or photons efficiently emit luminescence at deep-ultraviolet (DUV) frequencies via strong electron-phonon interaction. In this work, we probe optoelectronic processes at a band edge in hBN by means of optical imaging and spectroscopy at deep ultraviolet frequencies. Our laser excitation spectroscopy shows that strong radiative recombination and carrier excitation processes originate from the pristine structure and the stacking faults in hBN. We further demonstrate prominent electroluminescence and photocurrent generation from hBN by fabricating vdW heterostructures with graphene electrodes. Our work provides a pathway toward efficient DUV light emitting and detection devices based on hBN.

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Andrea C. Ferrari
University of Cambridge, United Kingdom

Short biography:

Andrea Ferrari is Professor of nanotechnology at the University of Cambridge and a Fellow of Pembroke College. He founded and directs the Cambridge Graphene Centre and the EPSRC Centre for Doctoral Training in Graphene Technology. He chairs the management panel and is the Science and Technology Officer of the European Graphene Flagship. He is a Fellow of the Royal Academy of Engineering, the American Physical Society, the Materials Research Society, the Institute of Physics, the Optical Society, the Royal Society of Chemistry, The European Academy of Sciences, the Academia Europaea, and he received numerous awards, such as the Royal Society Brian Mercer Award for Innovation, the Royal Society Wolfson Research Merit Award, the Marie Curie Excellence Award, the Philip Leverhulme Prize, The EU-40 Materials Prize

Abstract:

Layered Materials (LMs) have potential for quantum technologies, as scalable sources of single photon emitters (SPEs)[1,2]. LM heterostructures can be built with tuneable properties depending on the constituent materials and their relative crystallographic orientation[3,4]. Quantum emitters in LMs hold potential in terms of scalability, miniaturization, integration. Generation of quantum emission from the recombination of indirect excitons in heterostructures made of different LMs is a path with enormous potential. I will discuss how LM combinations can be used to generate SPEs and confinement of interlayer excitons[5].

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