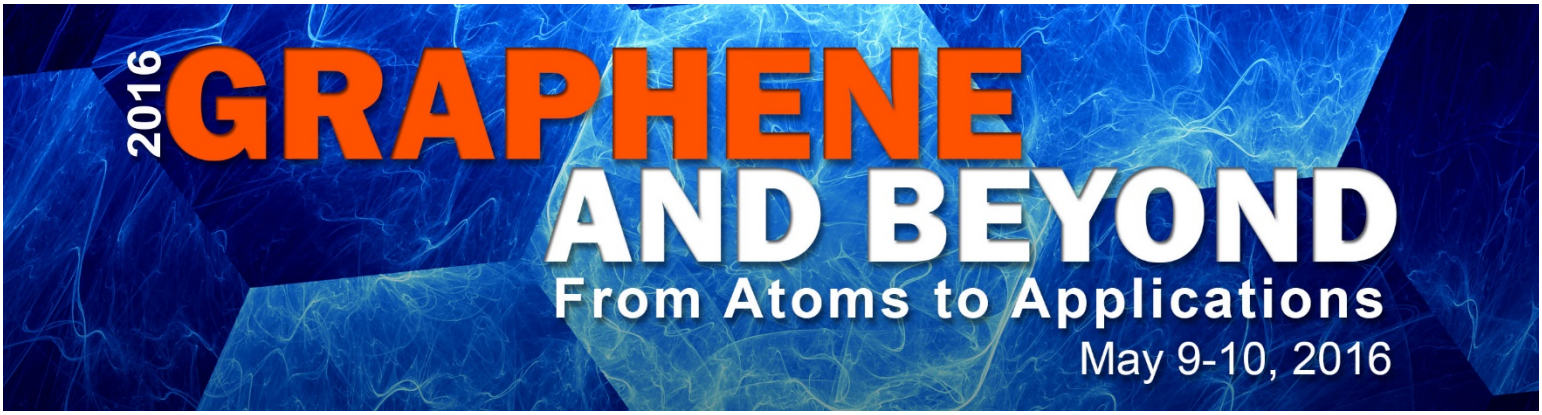

Presenters

Keynote Speaker

Luigi Colombo, Texas Instruments

Invited Speakers

Manish Chhowalla, Rutgers University
Ali Javey, University of California-Berkeley
Brian LeRoy, University of Arizona
Nicholas J. Borys, Molecular Foundry
Alexey Chernikov, Columbia University
Hui Zhao, University of Kansas
Xiaoxiang Xi, Penn State University
Jiwoong Park, Cornell University
Mark C. Hersam, Northwestern University
Raymond Schaak, Penn State University
Kai Xiao, Oak Ridge National Laboratory
Joshua Robinson, Penn State University
Susan Fullerton, University of Pittsburgh
Marija Drndic, University of Pennsylvania
James C. M. Hwang, Lehigh University
Stephen McDonnell, University of Virginia
Hongtao Yuan, Stanford University

Keynote Speaker

Two-Dimensional Materials: An Industry Perspective

Luigi Colombo
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Abstract: The isolation of graphene, now over a decade ago, has given rise to the revitalization of many two-dimensional materials (2DM). The 2DM materials under investigation, in addition to graphene, include hexagonal boron nitride (h-BN), semiconducting, metallic, and superconducting transition metal dichalcogenides (TMD). Graphene has received a lot of attention because of its superior physical and chemical properties but because of its semi-metallic behavior it has limited use for electronic applications. Transition metal dichalcogenide materials on the other hand provide what neither graphene nor h-BN can, intermediate bandgaps that can be used to create new heterostructure devices. Hexagonal boron nitride on the other hand is an insulator and has demonstrated to be an excellent dielectric for graphene devices and perhaps it will be for TMDs as well, however growth of high quality uniform thin films remains elusive. A number of devices structures using TMDs are currently under evaluation, some of the devices are based on tunneling which can be used to lower the voltage and power dissipation of the logic gate. However, growth of TMDs and h-BN presents significant challenges that are very different from those of existing cubic elemental and compound semiconductors. The TMD and h-BN materials growth technology is very immature and requires significant resources to achieve properties required for future electronic devices. In this presentation I will provide an overview of the current status of graphene, h-BN and TMD materials, and compare these technologies to existing compound semiconductors. In addition, I will discuss critical aspects of chalcogenide thin film growth that need to be addressed in order to achieve high quality TMD heterostructures.

Invited Speaker

Importance of Contact Resistance in Catalysis and Electronics based on 2DTransition Metal Dichalcogenides

Professor Manish Chhowalla
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Abstract: Two-dimensional transition metal dichalcogenides (2D TMDs) — whose generalized formula is MX_2, where M is a transition metal of groups 4–7 and X is a chalcogen — consist of over 40 compounds. Complex metal TMDs assume the 1T phase where the transition metal atom coordination is octahedral. The 2H phase is stable in semiconducting TMDs where the coordination of metal atoms is trigonal prismatic. High performance of electronic and opto-electronic devices have been demonstrated with semiconducting TMDs while interesting condensed matter effects such as charge density waves and superconductivity have been observed in bulk metallic 1T phase TMDs. However, stability issues have hampered the study of interesting phenomena in two-dimensional 1T phase TMDs. Recently there has been a surge of activity in developing methodology to reversibly convert 2D 2H phase TMDs to 1T phase. In contrast with typical phase transformation conditions involving pressure and temperature, phase conversion in TMDs involves transformation by chemistry at room temperature and pressure. Using this method, we are able to convert 2H phase 2D TMDs to the 1T phase or locally pattern the 1T phase on 2H phase 2D TMDs. The chemically converted 1T phase 2D TMDs exhibit interesting properties that are being exploited for catalysis for hydrogen evolution reaction, source and drain electrodes in high performance field effect transistors, and as electrodes for energy storage. In this contribution, I will demonstrate that it is the decrease in contact resistance that is crucially important in improving the performance of FETs with phase engineered electrodes as well as 1T phase catalysts for hydrogen evolution reaction.

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Invited Speaker

2D Layered Semiconductors: From Material Properties to Device Applications

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Conexant Systems Distinguished Professor
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Abstract: Two-dimensional (2-D) semiconductors exhibit excellent device characteristics, as well as novel optical, electrical, and optoelectronic characteristics. In this talk, I will present recent advancements in defect passivation, contact engineering, surface charge transfer doping, and heterostructure electronic and optoelectronic devices of layered chalcogenides. Recently, a defect repair/passivation technique has been developed using a simple solution treatment that allows for observation of near-unity quantum yield in monolayer MoS2. The work presents the first demonstration of an optoelectronically perfect monolayer. Forming Ohmic contacts for both electrons and holes is necessary in order to exploit the performance limits of enabled devices while shedding light on the intrinsic properties of a material system. In this regard, I will discuss different strategies, including the use of surface charge transfer doping at the contacts to thin down the Schottky barriers, thereby, enabling efficient injection of electrons or holes. Thus, high performance n- and p-FETs with various 2D materials have been demonstrated. Additionally, I will discuss the use of layered chalcogenides for various heterostructure optoelectronic and electronic device applications, exploiting charge transfer at the van der Waals heterojunctions. I will also present progress towards achieving tunnel transistors using layered semiconductors.

Invited Speaker

Imaging and Spectroscopy of Van der Waals Heterostructures

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Abstract: The ability to create arbitrary stacking configurations of layered two-dimensional materials opens the way to the creation of designer band structures in these materials. Graphene on hexagonal boron nitride (hBN) is an example of such a van der Waals heterostructure where the electronic properties of the composite material can be different from either individual material. These van der Waals heterostructures can be formed using a wide variety of layered materials including from transition metal dichalcogenides, graphene and topological insulators. This talk will mostly focus on devices consisting of graphene coupled to other layered materials. The lattice mismatch and twist angle between the layers produces a moiré pattern and affects their electronic properties. For graphene on hBN, the long wavelength moiré pattern creates a new set of superlattice Dirac points. In addition, applying pressure leads to changes in the preferred stacking configuration and favors a commensurate stacking. In graphene on transition metal dichalcogenides, the interaction between the materials leads to the presence of new states in graphene and the ability to tune the band offsets. Lastly, we will discuss results for transition metal dichalcogenides where we observe a large spin-splitting and a spinvalley-layer coupling.

Invited Speaker

The Anatomies of Excitons and Structurally-Dependent Photophysics in Monolayer-MoS_2

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Abstract: The tightly bound exciton complexes of monolayer-MoS2 and other two-dimensional transition metal dichalcogenide semiconductors constitute a new class of nanoscale electronic excitations. While it is tempting to assume that these states are analogous to excitons in conventional two-dimensional quantum wells, the atomically thin width, piezoelectricity, many-body interactions and intricate band structure of monolayer-MoS2 combine to produce a unique collection of unanticipated phenomena that defy such simplifications. Exploiting their strong light-matter interactions, a broad arsenal of near-field and conventional optical microscopy and spectroscopy tools has been used to explore and develop a better understanding of this rich suite of photoexcitations. Signatures of conventional two-dimensional excitons (i.e., a Rydberg-like progression of bound states leading to a continuum of free carrier excitations) are identified in sub-gap optical excitation resonances but are additionally augmented by an unexpected manifold of above-gap resonances from higher-energy states in an altogether different region of the Brillouin zone. Moreover, spatially mapping the efficiency, transient dynamics and energetics of the excitonic photoluminescence has uncovered a striking diversity of photophysics in these two-dimensional systems. Single flakes of synthetic monolayer-MoS2 are found to be composed of distinct regions with remarkably unique optoelectronic traits. The physical origins of these disparate regions, which include disordered peripheral edges, interiors patterned with nanoscale charge puddles, and defective grain boundaries, can be traced to both external stimuli as well as the temporal dynamics of the growth process, and overall, highlight the potential of using two-dimensional transition metal dichalcogenides as a canvas in which specific excitonic functionalities can be patterned.

Invited Speaker

Tuning Many-Body Interactions in 2D Semiconductors

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Abstract: Since the discovery of graphene, a single sheet of carbon atoms, research focused on two-dimensional (2D) materials evolved rapidly due the availability of atomically thin, thermally stable, high-quality crystals with intriguing physical properties. The 2D materials naturally inherit major traits associated with systems of reduced dimensionality: strongly enhanced Coulomb interactions, efficient light-matter coupling, and sensitivity to the environment. In particular, the considerable strength of the Coulomb forces between the charge carriers introduces a rich variety of many-body phenomena. In the class of 2D semiconductors this leads to the emergence of strongly bound electron-hole quasi-particles, such as excitons, trions, and biexcitons, with unusually high binding energies and efficient light absorption.

In this talk, I will focus on the excitonic properties of 2D semiconductors, as exemplified in recent works on atomically thin transition metal dichalcogenides. The observation of exciton binding energies on the order of many 100's of meV and the marked deviation of the electron-hole attraction from the conventional Coulomb law will be discussed. The results reflect both strong carrier confinement and the distinctive nature of dielectric screening in atomically thin materials. I will further describe how non-equilibrium conditions such as strong photo-excitation and electrical doping can profoundly alter the many-body interactions in these systems.

Invited Speaker

Ultrafast Electron Transport in and between 2D Materials

Hui Zhao
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Abstract: I will present our recent experimental studies on electron transport in and between monolayer semiconductors by using ultrafast laser techniques. Two regimes of the electron transport in 2D materials will be discussed. First, we used a transient absorption microscope to study diffusive motion of photocarriers in various 2D materials, such as black phosphorus and transition metal dichalcogenides (TMDs). Second, we injected ballistic charge currents in a TMD by using a coherent control technique, and time resolved the sub-nanometer and sub-picosecond ballistic motion of electrons and holes. In the second topic, we studied interlayer transport of electrons in different types of van der Waals heterostructures. First, we found that in heterostructures formed by monolayer TMD and graphene, excitons injected in TMD can efficiently transfer to graphene on a sub-picosecond time scale. Second, in heterostructures formed by two different TMD monolayers, type-II band alignments facilitate ultrafast charge separation and formation of long-lived charge transfer excitons. Finally, we fabricated 3-layer and 4-layer TMD stuctures with laddered band alignments, and time resolved the electron transfer across these single atomic layers and van der Waals interfaces between them.

Invited Speaker

Collective Electronic States in Two-Dimensional Metallic NbSe2

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Abstract: Atomically thin van der Waals materials have emerged as a frontier for both fundamental physics and device applications. Although novel single-particle and excitonic properties have been extensively studied, the collective electron phenomena in these materials remain less well understood. In this talk, we will discuss superconductivity and charge-density-wave (CDW) order in atomically thin group-V transition metal dichalcogenide NbSe2 down to the monolayer limit [1,2]. Electrical transport measurements show that the superconducting transition temperature decreases monotonically with reducing the layer thickness. The temperature dependent Raman scattering, on the other hand, shows enhanced CDW order as the sample thickness reduces. While the former can be understood mainly as the result of reduced interlayer Cooper pairing, the latter arises from the enhanced electron-phonon coupling in atomically thin samples. Magnetotransport measurements further reveal the effect of spin-momentum locking, a consequence of broken inversion symmetry and strong spin-orbit coupling in monolayer NbSe2, on Cooper pairing and the in-plane upper critical fields. We will also discuss our recent progress on electrical tuning of the superconductivity and CDW in this 2D metal.

[1] X. Xi et al. Nature Nanotech. 10, 765 (2015).
[2] X. Xi et al. Nature Phys. 12, 139 (2016).

Invited Speaker

Coloring, Stitching, and Twisting for Atomically Thin Circuitry

Jiwoong Park
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Abstract: 2D layered materials are like color papers: they can be glued, stacked, cut and folded to form integrated devices with atomic thickness. In this talk, I will discuss how different 2D materials can be grown with distinct electrical and optical properties (coloring), how they can be connected laterally to form pattered circuits (stitching) and how their interaction with light can be designed by controlling the interlayer rotation and the valley degree of freedom (twisting).

Invited Speaker

Fundamentals and Applications of Two-Dimensional Nanoelectronic Heterostructures

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Abstract: Two-dimensional materials have emerged as promising candidates for next-generation electronic and optoelectronic applications. As is common for new materials, much of the early work has focused on measuring and optimizing intrinsic properties on small samples (e.g., micromechanically exfoliated flakes) under idealized conditions (e.g., vacuum and/or cryogenic temperature environments). However, real-world devices and systems inevitably require large-area samples that are integrated with dielectrics, contacts, and other semiconductors at standard temperature and pressure conditions. These requirements are particularly challenging to realize for two-dimensional materials since their properties are highly sensitive to surface chemistry, defects, and the surrounding environment. This talk will thus explore methods for improving the uniformity of solution-processed two-dimensional materials with an eye toward realizing scalable processing of large-area thin-films. For example, density gradient ultracentrifugation allows the solution-based isolation of transition metal dichalcogenides (e.g., MoS_2, WS_2, $MoSe_2$, and WSe_2) and boron nitride with homogeneous thickness down to the single-layer level. Similarly, two-dimensional black phosphorus is isolated in solution with the resulting flakes showing field-effect transistor mobilities and on/off ratios that are comparable to micromechanically exfoliated flakes. In addition to solution processing, this talk will also report on the integration of two-dimensional materials with dielectrics and other semiconductors. In particular, atomic layer deposition of dielectrics on two-dimensional black phosphorus suppresses ambient degradation, thereby preserving electronic properties in field-effect transistors at atmospheric pressure conditions. Finally, gate-tunable p-n heterojunction diodes with Type I and Type II band alignments are demonstrated by integrating n-type single-layer MoS_2 with p-type semiconducting single-walled carbon nanotubes and pentacene, respectively.

Bio: Mark C. Hersam is the Walter P. Murphy Professor of Materials Science and Engineering and Director of the Materials Research Center at Northwestern University. He also holds faculty appointments in the Departments of Chemistry, Applied Physics, Medicine, and Electrical Engineering and Computer Science. He earned a B.S. in Electrical Engineering from the

University of Illinois at Urbana-Champaign (UIUC) in 1996, M.Phil. in Physics from the University of Cambridge in 1997, and a Ph.D. in Electrical Engineering from UIUC in 2000. His research interests include nanofabrication, scanning probe microscopy, semiconductor surfaces, and nanoelectronic materials. As a faculty member, Dr. Hersam has received several awards including the NSF CAREER Award, Beckman Young Investigator Award, ARO Young Investigator Award, ONR Young Investigator Award, Sloan Research Fellowship, Presidential Early Career Award for Scientists and Engineers, TMS Robert Lansing Hardy Award, AVS Peter Mark Award, MRS Outstanding Young Investigator Award, MacArthur Fellowship, and six Teacher of the Year Awards. Dr. Hersam is the co-founder of NanoIntegris, which is a commercial supplier of high performance nanoelectronic materials. Dr. Hersam is a Fellow of MRS, AVS, APS, AAAS, SPIE, and IEEE, and also serves as Associate Editor of *ACS Nano*.

Invited Speaker

Colloidal Nanostructures of Two-Dimensional Metal Chalcogenides

Raymond Schaak
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Abstract: Two-dimensional (2-D) metal chalcogenides offer a wide range of interesting and useful functions, including high catalytic activity for key chemical transformations that underpin energy conversion and storage, light harvesting capabilities for solar cells, and unique thickness-dependent electronic and optical properties. We have been studying several model systems to learn how 2-D metal chalcogenide nanostructures form in solution and how their structures, morphologies, and properties can be controlled and tuned. For example, solution routes to the monochalcogenides GeSe, GeS, SnSe yield single-crystal 2-D nanosheets that are a useful platform for studying fundamental aspects of how such systems nucleate and grow. Similar solution routes to $MoSe_2$ and $MoTe_2$ dichalcogenide nanostructures provide access to unique nanosheet-derived morphologies with interesting structural and optical characteristics.

Invited Speaker

Isoelectronic Doping of $MoSe_2$ Monolayers for 2D Heterostructures

Xufan Li, Ming-Wie Lin, Masoud Mahjouri-Samani, Alexander A. Puretzky, Juan C. Idrobo, Christopher M. Rouleau, David B. Geohegan, and Kai Xiao*

Kai Xiao
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Abstract: Atomically thin two-dimensional (2D) materials and their heterostructures exhibit highly unusual behaviors. In this work, the isoelectronic doped (W and S) $MoSe_2$ monolayer crystals were synthesized by chemical vapor deposition (CVD) and pulse laser deposition (PLD). We investigated the effect of isoelectronic dopants on the bandgap and optoelectronic properties of monolayer of $MoSe_2$ crystals. We find that the electronic properties of atomically thin 2D $MoSe_2$ crystal can be modified significantly thorough controlled W doping, which lead to the p-type semiconducting properties after doping from n-type of $MoSe_2$. Atomic-resolution annular dark field imaging revealed that the dopant atoms (W or S) substitute Mo or Se to form alloys and are randomly distributed in the hexagonal lattice. The vertical and lateral 2D heterostructures by controlled assembly and doping will be discussed. Our results show that the 2D heterostructures exhibit high persistent photoconductivity and excellent gate-tunable rectification behavior, which have the potential to deliver innovative applications in ultra-thin and flexible solar-energy devices and in micro- and nano-electronics.

Acknowledgement: Synthesis science sponsored by the Materials Science and Engineering Division, Office of Basic Energy Sciences, U.S. Department of Energy. Characterization science performed at the Center for Nanophase Materials Sciences, which is a DOE Office of Sciences User Facility.

Invited Speaker

Growth in the Flatland: It's All About the Substrate

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Corning Faculty Fellow, Materials Science and Engineering
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Co-Director, NSF-I/UCRC Center for Atomically Thin Multifunctional Coatings (ATOMIC)
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Abstract: The last decade has seen nearly exponential growth in the science and technology of two-dimensional materials. Beyond graphene, there is a huge variety of layered materials that range in properties from insulating to superconducting. Furthermore, heterogeneous stacking of 2D materials also allows for additional "dimensionality" for band structure engineering. Of particular interest are the layered chalcogenides, which range from superconductors to wide-bandgap semiconductors. One area that has not been given much focus in recent years, however, is how the substrate can control our ability to achieve the 2D layers with desired properties. In this talk, I will provide an overview of our understanding of how the substrate impacts 2D layer growth, doping, and transport.

Acknowledgement: This work is supported by a variety of sponsors including NSF, ARO, DTRA, DARPA, and AFRL.

Invited Speaker

Nanoionic Two-Dimensional Memory

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Abstract: A new approach to memory will be presented that relies on the electrostatic gating of 2D crystals using lithium ions. When Li^+ is near the channel, image charge is induced in the channel resulting in a low resistance (1) state, and when the Li^+ is moved away from the channel via field-effect, the channel is switched to the high resistance (0) state. The device design requires the development of a 2D electrolyte, crown ether phthalocyanine (CoCrPc) and LiClO4, which provides energetically favorable sites to create the two states. Density functional theory calculations by Prof. KJ Cho's group at the U. of Texas at Dallas indicate that induced charge on the 2D crystal will modulate the energy barrier encountered by the ions, making fast switching (~ 1 ns) and long retention (> 1 year) possible. Unlike resistive random access memory (RRAM), where conductive filaments are formed and broken, this memory concept relies on the physisorption of ions to the 2D crystal and there is no charge exchange. We have demonstrated the solution-phase deposition of an ordered monolayer of CoCrPc on graphene. After Li^+ is introduced, programming measurements on graphene FETs show n-type doping with sheet carrier densities of ~ 4×10^{12} cm^{-2}. The doping is reversible, and the two states can be retained – even in the absence of a liquid solvent. The initial response is slower than predicted, and efforts are currently underway to understand the material properties that are limiting the switching speed. Guided by DFT calculations, MoS_2 is being explored to replace graphene.

Acknowledgement: This work was supported in part by the Center for Low Energy Systems Technology (LEAST), one of six SRC STARnet Centers, sponsored by MARCO and DARPA, and NSF grant #ECCS-GOALI-1408425.

Invited Speaker

2D Materials Nanosculpting and Bio-Applications

Marija Drndic
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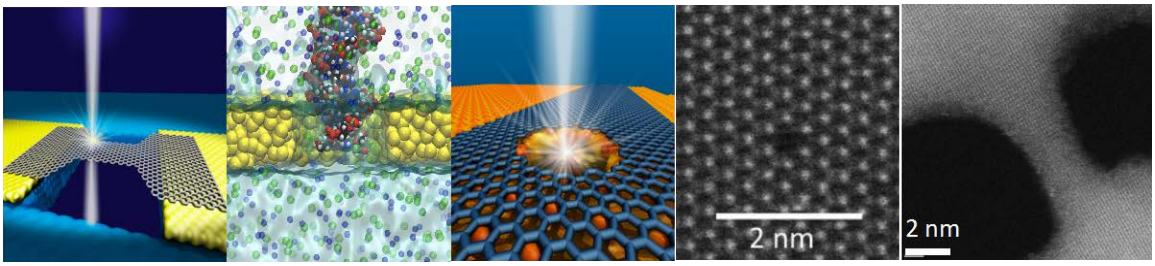
Abstract: Electron beams constitute powerful tools to shape materials with atomic resolution inside a transmission electron microscope (TEM). I will describe experiments where we push the limits of device size to atomic scale in 2D materials beyond graphene (MoS_2, WS_2, $MoTe_2$, black phosphorous) and expand their function and precision, while addressing fundamental questions about structure and properties at nanometer and atomic scales. Experiments are performed *in situ* and *ex situ TEM*. *In situ TEM* experiments include fabrication of nanoribbons from novel two-dimensional materials down to sub-nm widths. *Ex situ TEM* experiments include the ultrafast, all-electronic detection and analysis of biomolecules by driving them through tiny holes – or nanopores – in thin membranes, including the efforts towards mapping a human genome under 10 min. As molecules are driven through nanopores in solution, they block the ion current flow resulting in current reductions from which molecule's physical and chemical properties are inferred. DNA, proteins, microRNA and other biomolecules can be analyzed. The temporal, spatial resolution and sensitivity in these experiments have been improved over the last few years thanks to advanced materials, device designs and new electronics.



From left to right: illustrations of nanoribbon sculpting with the electron beam; passage of a DNA molecule through a nanopore; illustration of nanopore drilling with an electron beam inside of the TEM; one-atom-large nanopore in a MoS_2 sheet; armchair few-layer black phosphorous nanoribbon sculpted in the AC-TEM.

References: Rodriguez-Manzo *et al.*, ACS Nano 9 (6), 6555, 2015; Qi *et al.*, ACS Nano 9(4), 3510, 2015; Balan *et al.*, Nano Letters 14 (12), 7215, 2015; Drndic, Nature Nanotechnology 9, 743, 2014; Qi *et al.*, Nano Letters 14 (8), 4238, 2014; Rosenstein *et al.*, Nature Methods, 9 (5), 487, 2012.

Invited Speaker

Phosphorene FETs – Promising Transistors Based on a Few Layers of Phosphorus Atoms

James C. M. Hwang
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Abstract: This talk will review the emergence and progress within the past couple years of field-effect transistors (FETs) based on phosphorene, which is a new elemental two-dimensional atomic-layer material similar to graphene. However, unlike graphene, phosphorene has an intrinsic, direct and sizable bandgap making it a semiconductor instead of a semimetal. Yet, unlike in other two-dimensional semiconductors such as molybdenum disulfide, the carrier mobility in phosphrene is higher than that in single-crystal silicon. In a very short time, back-gated phosphorene FETs evolved into top-gated FETs, gate length was reduced to the sub-micron range, passivation by high-*k* dielectric or hexagonal boron nitride was demonstrated with temporal, thermal and mechanical stability, ohmic contact was achieved down to cryogenic temperatures, and cutoff frequency was pushed above 10 GHz. These and other attractive characteristics of phosphorene promise the phosphorene FET to be a viable candidate for current-generation thin-film electronics, as well as future-generation ultra-thin-body low-power-consumption high-speed and high-frequency transistors.

Bio: Dr. James Hwang is Professor of Electrical Engineering at Lehigh University. He graduated with a B.S. degree in Physics from National Taiwan University in 1970, and completed M.S. (1973) and Ph.D. (1976) studies in Materials Science at Cornell University. After twelve years of industrial experience at IBM, AT&T, GE, and GAIN, he joined Lehigh in 1988. He cofounded GAIN and QED; the latter became a public company (IQE). Most recently, he was a Program Officer for GHz-THz Electronics at the Air Force Office of Scientific Research. He is a Life Fellow of the Institute of Electrical and Electronic Engineers. He has published more than 300 refereed technical papers with an h-index of 36 according to Google Scholar. He has been granted eight U. S. patents. His current research interests include electrical biosensing at the cellular and molecular levels, two-dimensional atomic-layer materials and devices, and radio-frequency micro-electromechanical systems.

Invited Speaker

The Integration of 2D Materials Into Nanoelectronic Devices: The Impact of Defects and Interfaces

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Abstract: 2D materials, which include graphene, hexagonal boron nitride, and a plethora of transition metal dichalcogenide combinations, have electronic structures exhibiting metallic, semiconducting, and insulating properties. This promises devices with scalability to the atomic limit combined with tunable bandgaps that can be direct or indirect and defect free interfaces. Realizing this promise has not proved trivial. The inert surfaces do not provide ideal substrate for industry standard chemistry based processing techniques such as atomic layer deposition. Monolayer residues resulting from processes such as photolithography can impact device performance. Metal depositions can result in the formation of unexpected interface compounds that can dominate the contact behavior. The metal--semiconductor contact is also found to be highly sensitive to the deposition conditions such as pressure and deposition rate. Presented will be a summary of our work on identifying and overcoming these challenges with a focus on the metal--semiconductor interface.

Invited Speaker

Generation and Electric Control of Spin-Coupled Valley Current in WSe_2

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Abstract: Recent efforts on two dimensional atomic layer materials, aiming at novel electronic properties and quantum phenomena beyond graphene, have attracted much attention for potential electronics/spintronics applications. Compared to the weak spin-orbit-interaction (SOI) in graphene, layered transition-metal chalcogenides MX_2 (M = Mo, W; X = S, Se, Te) have heavy 4d/5d elements with strong atomic SOI, providing a unique way to extend functionalities of novel spintronics and valleytronics devices based on valleytronics physics by considering the valley degree of freedom in MX_2 dichalcogenides. For example, in WSe_2, with a layered honeycomb lattice and two inequivalent valleys in the ***k***-space electronic structure in the hexagonal Brillion zone, due to the large separation of valleys in ***k***-space and the resulting suppression of intervalley scattering, the valley index can be used in analogy to the spin in spintronics, opening a new research direction called 'valleytronics'. Such a valley polarization achieved via valley-selective circular dichroism has been predicted theoretically and demonstrated with optical experiments in those MX_2 systems.

However, despite this exciting progress, the following two important issues in MX_2 valleytronics community remain elusive: 1) The most current understanding of their electronic structures is based on either theoretical investigations or indirect experimental techniques (e.g. optical measurements), leaving the detailed band structures elusive, especially the valley location (the band maxima/minima) in the BZ have not been experimentally confirmed yet. Therefore a direct detection for band dispersion becomes of great importance for valleytronics especially for those cleaved ultrathin mono- and bi-layer flakes hosting most of recently-reported exotic phenomena in the 2D limit. 2) The generation of a valley/spin current by the valley polarization in MX_2 remains elusive and a great challenge. A spin/valley current in MX_2 compounds caused by such a valley polarization has never been observed, nor its electric-field control.

In this talk, we will present the basic electronic structure of representative MX_2, obtained by angular resolution photoemission spectroscopy (ARPES), and investigate both the variation of the band minima/maxima (the valley locations) between these compounds and their band evolution from bulk to the monolayer limit. After having a systematic understanding of the band structure, we will demonstrate, within an electric-double-layer transistor based on WSe_2, the manipulation of a spin-coupled valley photocurrent whose direction and magnitude depend on the degree of circular polarization of the incident radiation and can be further greatly modulated with an external electric field. Such room temperature generation and electric control of valley/spin photocurrent provides a new property of electrons in MX_2 systems, thereby enabling new degrees of control for quantum-confined spintronics devices.

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