2D Materials

Room A216 - Session 2D+EM+MN+NS-WeA

2D Device Physics and Applications

Moderator: Ivan Oleynik, University of South Florida

2:20pm **2D+EM+MN+NS-WeA1 Monolayer Electronics and Optoelectronics - Advances, Opportunities and Challenges**, ***Ali Javey,*** University of California at Berkeley **INVITED**

Two-dimensional semiconductors exhibit excellent device characteristics, as well as novel optical, electrical, and optoelectronic characteristics. In this talk, I will present our recent advancements in surface passivation, contact engineering, surface charge transfer doping, and heterostructure devices of layered chalcogenides. We have developed a passivation technique that allows for observation of near-unity photoluminescence quantum yield in monolayer semiconductors. I will discuss the mechanism by which non-radiative recombination can be fully removed in monolayers. The work presents the first demonstration of an optoelectronically perfect monolayer, and highlights one of their unique properties. Finally, I will discuss an AC carrier injection mechanism to enable bright light emitting devices using monolayers, overcoming the problem of Schottky contacts.

3:00pm **2D+EM+MN+NS-WeA3 Investigation on Graphene Band-gap Engineering for Graphene Transistors Applications**, ***Benfdila Arezki,*** University M. Mammeri Tizi-Ouzou, Algeria

Graphene transistors are considered to be the successor's basic element for the next generation of advanced integrated circuits. However, graphene material suffers from the absence of bandgap to behave as semiconductor. The present paper deals with the investigation on the bandgap engineering approach aiming an increase of the switching characteristics of the graphene transistors.

The main obstacle for graphene transistor is the material zero bandgap that worsens the switching characteristics of the GFETs. Several techniques have been proposed to open a bandgap in graphene, among these engineering techniques, we can cite the Substrate induced bandgap, Bandgap engineering using h-BN/Ni (111). It is known that in theory a maximum of 0.50 to 0.53 eV can be obtained. Such bandgaps are observed on Graphene Bi-Layer (GBL) sheets grown on silicon carbide (SiC).

Other methods are the substitutional doping (SD), Nitrogen doping (NB). In any case graphene engineering should be considered in chemistry and physics view points. A high selective hydrogenation of graphene grown by lithography under the form of nanoruban showed a very interesting result of 0.7 eV. This process is part of selective chemical graphene functionalization techniques (SCGF).

In this paper we will deal with the graphene nanoruban and the opening of a bandgap capable of inducing an appreciable switching current ratio of at least $I_{ON}/I_{OFF}>10^6$.

The Graphene Nano Ribbon (GNR) structure used in the form of GNRFET for logic circuits and RF devices combines the high field, high mobility and the possibility of opening a bandgap. The higher carrier mobility of graphene is the basis of all electrical characteristics of graphene transistors.

In this paper we have used a semi-classical device model including the band to band tunneling that is described in Ref[8] to emphasize on the bandgap engineering. Device performances are studied based on the current-voltage characteristics with respective bandgap width variations. I_{OFF} current estimated and the performance ratio deduced.

3:20pm **2D+EM+MN+NS-WeA4 Fully Inkjet Printed, High Photo-responsive, 2D WSe_2-Graphene Based Flexible Photodetector**, *R.F. Hossain, A.B. Kaul,* ***Avra Bandyopadhyay,*** University of North Texas

Tungsten di-selenide (WSe_2), a classic representative of two dimensional (2D) layered materials has recently drawn much attention due to its unique optoelectronic properties, offering a potential platform to construct hetero-structure photodetector (PD) for ultrafast optoelectronic devices on low-cost, flexible substrates [1,2]. As WSe_2 exhibits a weak van der Waals interlayer bonding, one of the approaches to obtain 2D WSe_2 is through top-down liquid phase exfoliation (LPE), where the bulk crystal is dispersed in a solvent through appropriate sonication and centrifugation conditions [1]. In this work, we report on the synthesis of WSe_2 via LPE and the first-ever assembly of an all inkjet printed WSe_2-graphene hetero-structure PD on flexible polyimide film, where the WSe_2 acted as a photo-active semiconductor and graphene was the carrier collector. The inkjet printed PD was photo-responsive to broadband incoming radiation in the visible regime, and exhibited a high photoresponsivity R ~ 0.70 A/W, and detectivity D ~ 3×10^{10} Jones. The strain-dependent measurements were conducted with bending for different curvatures, indicating the feasibility of such devices for large format arrays printed on flexible substrates. The capacitance-frequency (*C-f*) measurements were performed to investigate the trap states. In conclusion, this unique all inkjet printed 2D hetero-junction photodetector formed on flexible and conformable substrate was successfully shown to be highly photo-responsive to a wide range of light intensities and strain levels, making it a promising prospect for scalable flexible electronic and optoelectronic devices and circuitry.

References:

[1] Kelly, A. G., Hallam, T., Backes, C., Harvey, A., Esmaeily, A. S., Godwin, I., ... & Kinge, S. (2017). All-printed thin-film transistors from networks of liquid-exfoliated nanosheets. Science, 356(6333), 69-73.

[2] Pradhan, N. R., Ludwig, J., Lu, Z., Rhodes, D., Bishop, M. M., Thirunavukkuarasu, K., ... & Balicas, L. (2015). High photoresponsivity and short photoresponse times in few-layered WSe2 transistors. ACS applied materials & interfaces, 7(22), 12080-12088.

4:20pm **2D+EM+MN+NS-WeA7 Chemical Vapor Sensing with Transition Metal Dichalcogenides via Photoluminescence Modulation**, ***Aubrey T. Hanbicki,*** *P.M. Campbell, S.V. Sivaram,* U.S. Naval Research Laboratory*; A.J. Kusterbeck,* Nova Research, Inc.*; V.K. Nguyen, R.A. McGill, K.M. McCreary, B.T. Jonker, E.D. Cobas, F.K. Perkins,* U.S. Naval Research Laboratory*; A.L. Friedman,* Laboratory for Physical Sciences

Two-dimensional transition metal dichalcogenides (TMDs) such as MoS_2 and $MoSe_2$ are promising materials for chemical vapor sensing applications. Their potential includes straightforward fabrication, readily available materials, and good selectivity, sensitivity, and speed of response. We previously showed [1] that monolayer TMDs are sensitive to and selective for vapors of strong electron donors and/or strong electron acceptors in concentrations as low as 1 part per million (ppm). Another attractive aspect is that TMDs have been shown to detect chemical vapors and gases in several ways, for instance via changes in electrical conductance or photoluminescence (PL) [2]. Sensors commonly have been fabricated based on the chemiresistive device properties, but here we will discuss our recent studies implementing TMD sensors using the PL as the core element of the sensor. We show that the PL intensity of monolayer CVD-grown WS_2 can rapidly (<< 1sec) detect triethylamine (TEA), a decomposition byproduct of the VX series of nerve agents, in concentrations <<1 ppm. The optical response is similar to the electrical response of other TMDs previously shown [1]. We shall discuss the mechanisms determining the size and shape of the optical responses. We envision suites of different TMDs using both optical and conductance sensing to rapidly and selectively detect chemical agents.

This research was performed while S.V.S held a National Research Council fellowship at NRL. This work was supported by core programs at NRL.

References

[1] A.L. Friedman et al., Sci. Reports 7, 3836 (2017)

[2] P.M. Campbell et al., Appl. Phys. Lett. 113, 163106 (2018)

4:40pm **2D+EM+MN+NS-WeA8 Effective and Robust Graphene Immunoligical Sensors Functionalized through Non-covalent Ninding of Antibody-Conjugated Tripodal Compound**, *A. Hugo,* CEA-LETI, France*; C. Sun,* Northwestern University*; M. Kumar,* CEA-LETI, France*; R. Othmen, J. Renard, V. Bouchiat,* CNRS-Institut Néel, France*; J. Mann,* Northwestern University*; J.M. Parpia, H.G. Craighead,* Cornell University*; P. Mailley,* CEA-LETI, France*; W.R. Dichtel,* Northwestern University*; T. ALAVA,* ***Sebastian Hentz,*** CEA-LETI, France

Electrical detection is a very robust technique to transduce the adsorption of charged protein to a biological selective layer (i.e. biosensing). Electrolyte gated field effect transistors (EGFET) integrating graphene monolayers as the transducing element have shown outstanding electrical sensitivity in liquid compared to silicon and diamond based EGFET. In order to build graphene EGFET as effective biosensing unit it is important to attach at its surface a functional layers of biological molecules that will carry the task of enforcing specific detection of compound. Protein are widely used as specific bioreceptor for sensor biological functionalization yet it has been shown that protein lose their function when simply adsorbed on graphene. Covalent binding being out of the way for 2D dimensional crystals such as graphene (for the inherent deterioration of mechanical and electrical properties) we have shown that custom made tripodal compound attaching the graphene basal plane through Pi-stacking of aromatic moieties could be used to attach specific biomolecules to graphene while maintaining their biological function hence their specificity.

In this report we present an optimized fabrication process for graphene EGFET that includes patterning and passivation of electrical contact. The devices reproducibly show state of the art electrical performances. We demonstrate that the process can be simply transferred to different host substrates to integrate graphene EGFET ubiquitously on Silicon, glass or printed circuit board with similar performances. Finally, we implemented biological functionalization of the sensors by attaching streptavidin to the sensor thanks to the non-covalent tripodal compound. We report consistent changes in the Dirac peak of graphene due to the adsorption of tripodal compound and streptavidin as well as the binding of biotin, specifically bound to streptavidin. We show the detection to be specific and reproducible.

5:00pm **2D+EM+MN+NS-WeA9 Electronic Properties of Ultra-Thin Na_3Bi: A Platform for a Topological Transistor**, ***Mark Edmonds,*** Monash University, Australia **INVITED**

Na_3Bi in bulk form represents a zero-bandgap topological Dirac semimetal (TDS), but when confined to few-layers is predicted to be a quantum spin Hall insulator with bulk bandgap of 300 meV.[1] Furthermore, application of an electric field to few-layer Na_3Bi has been predicted to induce a topological phase transition from conventional to topological insulator.[2]

I will discuss our efforts to grow epitaxial few-layer Na_3Bi via molecular beam epitaxy, and probe its electronic structure and response to an electric field using scanning probe microscopy/spectroscopy and angle-resolved photoelectron spectroscopy. We demonstrate that monolayer and bilayer Na_3Bi are wide bandgap quantum spin Hall insulators (E_G>300 meV) that can be tuned with an electric field to semi-metallic, and at higher electric fields re-opened as a conventional insulator.[3] This is the first experimental demonstration of such an electric field tuned topological phase transition in any material. Finally, I will discuss our most recent efforts to perform transport measurements on few-layer Na_3Bi at doping levels corresponding to bulk conduction and edge conduction, with and without an applied magnetic field.

References

[1] C. Niu et al., Phys. Rev. B (2017) 95, 075404

[2] H. Pan et al., Scientific Reports (2015) 5, 14639

[3] J. Collins et al., Nature 564, 390 (2018)

6:00pm **2D+EM+MN+NS-WeA12 Negative Fermi-level Pinning Effect Induced by Graphene Interlayer in Metal/Graphene/Semiconductor Junction**, *H.H. Yoon, W. Song,* Ulsan National Institute of Science and Technology (UNIST), Republic of Korea*; S. Jung,* SK Hynix, Republic of Korea*; J. Kim,* Ulsan National Institute of Science and Technology (UNIST)*; K. Mo, G. Choi, H.Y. Jeong, J.H. Lee,* ***Kibog Park,*** Ulsan National Institute of Science and Technology (UNIST), Republic of Korea

We report the direct observation revealing that the electric dipole layer originating from the off-centric distribution of interacting electrons at metal/graphene interface can induce the negative Fermi-level pinning effect in metal/graphene/semiconductor junction made on a semiconductor substrate containing regions with low interface-trap density. The graphene interlayer takes a role of diffusion barrier preventing the atomic intermixing at interface and preserving the low interface-trap density region. The change of electrostatic potential across the metal/graphene interface due to the interaction dipole layer and the doping of graphene is found to cause the negative Fermi-level pinning effect, supported by the Schottky barrier decreasing as metal work-function increasing. In case of metal/graphene/GaAs junction, the local small patches with very thin or no native oxide layer are considered to be responsible for the negative Fermi-level pinning. In the prevailing region with normal native oxides surrounding the small patches, the Fermi-level pinning appears to be strong. Meanwhile, the negative Fermi-level pinning is found to occur globally in metal/graphene/SiC junction where the SiC substrate is known to produce a low density of interface traps. This work provides an experimental method to form Schottky and Ohmic-like contacts simultaneously on a semiconductor substrate covered partially with graphene by using identical metal electrodes.

Author Index

Bold page numbers indicate presenter