PCSI

Room Keauhou II - Session PCSI-SuA

2D Surfaces I

Moderator: Emanuel Tutuc, University of Texas at Austin

3:45pm **PCSI-SuA-1 Generating Valley Current and Magnetoelectricity in MoS_2, *Jieun Lee,*** Ajou University, Korea **INVITED**

Atomically thin crystals, such as monolayer transition metal dichalcogenides (TMDs), provide a new platform to investigate the electrons in low dimensional solid state systems. In these materials, two inequivalent energy band extrema occur at the edges of the Brillouin zone, known as valleys, which serve as a binary degree of freedom of electrons similar like spins [1]. The unique control of valley pseudospins by optical and electrical means are not only fundamentally interesting, but may also find applications in valley-based electronics and optoelectronics [2,3].

In this talk, we discuss methods to manipulate the valley polarization in 2D TMD materials. First, we describe the observation of the valley Hall effect in monolayer molybdenum disulfide (MoS_2), in which the valley current is generated transverse to the charge current. We use optical techniques to directly image the valley polarization accumulated at the edges of MoS_2 channel with spatial resolution [4]. We will also discuss the possibility to tune the valley Hall conductivity by controlling the crystal's inversion symmetry in bilayer. Second, we apply strain to monolayer MoS_2 to break the crystal's 3-fold rotational symmetry which leads to the generation of valley magnetoelectricity [5]. The observed valley magnetization switches the sign when the in-plane bias direction flips and the magnitude scales with the amount of channel current. We discuss the dependence of the observed magnetization on bias, gate, strain direction, and external magnetic fields.

[1] D. Xiao, W. Yao and Q. Niu, Phys. Rev. Lett. 99, 236809 (2007).

[2] J.R. Schaibley, H. Yu and G. Clark, et al., Nat. Rev. Mater. 1, 16055 (2016).

[3] K.F. Mak and J. Shan, Nat. Photon. 10, 216 (2016).

[4] J. Lee, K.F. Mak and J. Shan, Nat. Nanotech. 11, 421 (2016).

[5] J. Lee, Z. Wang, H. Xie, K.F. Mak and J. Shan, Nat. Mater. 16, 887 (2017).

4:15pm **PCSI-SuA-7 Diffusion of Silver and Nickel into Few-Layer MoS_2 and Its Effect on Contact Resistance, *Timothy Walter,*** *A Domask, M Abraham,* The Pennsylvania State University*; B Kabius,* Materials Research Institute*; K Cooley, S Mohney,* The Pennsylvania State University

MoS_2 is attractive for a variety of nanoelectronic devices due to its ability to maintain desirable semiconducting properties at the single layer limit [1]. Understanding the behavior of metal/MoS_2 interfaces is important for developing low-resistance contacts for scaled transistors and other emerging applications of MoS_2. Our recently published work on Ag/MoS_2 contacts shows that after annealing in Ar at 250 and 300 °C, the contact resistance R_C is reduced from 0.8–3.5 kΩ·μm to 0.2–0.7 kΩ·μm, likely due to the incorporation of Ag donors between layers of MoS_2 [2]. This result is very good relative to the state-of-the-art. More recently, we have verified using transmission electron microscopy and electron energy loss spectroscopy that Ag diffuses into MoS_2 at low levels.

Now we have discovered that Ni also diffuses into MoS_2 — without altering its structure — after annealing in Ar at a temperature as low as 200 °C. Therefore, we fabricated Ni-based contacts to MoS_2 and characterized them before and after annealing. However, annealing caused an increase in R_C in every Ni-contacted device. As deposited, R_C varied from 2.5–8.0 kΩ·μm, but it increased by 50% after annealing at 200 °C, and increased by 650% after annealing at 300 °C. While Ag acts as a donor when intercalated in MoS_2 [3], Ni might not. Our further efforts towards understanding the effects of diffusion of Ag, Ni, and possibly other transition metals into MoS_2 may ultimately guide us in achieving even lower contact resistances.

[1] K. F. Mak *et al*., Phys. Rev. Lett. **105**, 136805(2010).

[2] M. Abraham and S. E. Mohney, J. Appl. Phys. **122**, 115306 (2017).

[3] D. M. Guzman *et al*., J. Appl. Phys. **121**, 055703(2017).

4:20pm **PCSI-SuA-8 Ultra-thin van der Waals Heterostructure: How Thin can a Diode be?, *Mahfujur Rahaman,*** *A Mukharjee,* Chemnitz University of Technology, Germany*; S Gemming,* Institute for Ion beam Physics and Materials Research, Germany*; D Zahn,* Chemnitz University of Technology, Germany

With the advent of atomically thin van der Waals materials, it is now possible to combine p and n doped 2D semiconductors to realize p-n junctions at their ultimate thickness. [1-3] Due to the lack of a depletion width in atomically thin van der Waals materials, however they are conceptually different compared to conventional diode. [4]Here, we demonstrated strong rectification behaviour for a p-n junction made of bilayer n-type MoS_2 and ultrathin (10 nm) p-type GaSe with a rectification ratio of 10^4. The threshold voltage is determined to be 0.57 V. The I – V characteristics under illumination using below band gap excitation reveals a marked photovoltaic effect suggesting efficient exciton dissociation due to the presence of an electric field at the interface. The below band gap excitation also suggests the presence of accessible states in the forbidden gap of MoS_2. To validate our experimental observations we also performed DFT calculations on such heterostructure. Our theoretical findings indicate that the electronic band structure of bilayer MoS_2 is modified by the interaction with GaSe. This interaction creates accessible states in the forbidden gap of MoS_2 and may explain the below band gap excitation and the rectification behaviour of the p-n junction.

1. Lee, C.-H.; Lee, G.-H.; van der Zande, A. M.; Chen, W.; Li, Y.; Han, M.; Cui, X.; Arefe, G.; Nuckolls, C.; Heinz, T. F.; Guo, J.; Hone, J.; Kim, P. *Nat Nano* **2014,***9* (9), 676-681.

2. Huang, C.; Wu, S.; Sanchez, A. M.; Peters, J. J. P.; Beanland, R.; Ross, J. S.; Rivera, P.; Yao, W.; Cobden, D. H.; Xu, X.; *Nat Mater* **2014,***13* (12), 1096-1101.

3. Ross, J. S.; Klement, P.; Jones, A. M.; Ghimire, N. J.; Yan, J.; Mandrus, D. G.; Taniguchi, T.; Watanabe, K.; Kitamura, K.; Yao, W.; Cobden, D. H.; Xu, X.; *Nat Nano* **2014,***9* (4), 268-272.

4. Li, H.-M.; Lee, D.; Qu, D.; Liu, X.; Ryu, J.; Seabaugh, A.; Yoo, W. J.; *Nature Communications* **2015,***6*, 6564.

4:25pm **PCSI-SuA-9 Surface Modification of SiC by Plasma Oxidation to Form Graphene/SiC Structure with Low Pit Density, *Kenta Arima,*** *R Ito, O Minami, K Hosoo, Y Sano, K Kawai,* Osaka University, Japan

The sublimation of Si atoms from a SiC surface by annealing in UHV is a familiar method for the epitaxial growth of graphene. However, a problem is the pitted morphology of the graphene/SiC(0001) structure after simple annealing above 1100°C in UHV. It is well known that, prior to graphene growth above 1100°C, a buffer layer is formed at around 1000°C. The pitted morphology is probably caused by the insufficient amount of liberated carbon atoms on the SiC surface to form a uniform buffer layer because the rapid sublimation of Si atoms occurs on an area not covered by a buffer layer, causing the formation of pits. Thus, the control of the carbon concentration at the monolayer level on an initial SiC surface is important.

We have found a new chemical route to achieve this, which is the plasma oxidation of a SiC surface near room temperature followed by HF etching. This is referred to as the plasma-assisted process hereafter. We took the change in O1s XPS spectra caused by the plasma-assisted process. It indicated that the initial untreated SiC surface is terminated by OH species, which are the origin of the hydrophilic property of the surface. In contrast, after the plasma-assisted process, a shoulder peak corresponding to C-O bonds appeared in the O1s spectrum. Taken together with the C1s spectrum, we consider that a mixture of C-C and C-O bonds exists, which agrees with the slightly hydrophobic property of the treated SiC surface. We speculate that carbon species composed of C-C and C-O bonds accumulated at the SiO_2/SiC interface during plasma oxidation near room temperature. When the SiO_2 layer was stripped off by subsequent HF etching, additional carbon species with a thickness of 1-2 monolayers appeared on the SiC surface. When this surface was annealed at 1100°C for 30 min in UHV, a graphene/SiC structure with a low pit density was obtained, which is completely different from the structure on the untreated SiC surface. This is probably because the additional carbon species produced by the plasma-assisted process contribute to the formation of a uniform buffer layer, which suppresses random Si sublimation at elevated temperatures of above 1000°C.

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[2] K. Arima et al., Meeting Abstracts of 230th ECS Meeting, 2062 (2016).

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