PCSI
Room Redondo - Session PCSI-WeA2
Graphene

Moderator: Cedric Robert, LPCNO, CNRS INSA Toulouse

4:20pm **PCSI-WeA2-29 Diodic Transport in Graphene Moiré Systems**, ***Jia Li***, Brown University **INVITED**

The discovery of magic-angle graphene moiré systems has unlocked a wide variety of intriguing emergent phenomena. Inside the nearly dispersionless band structures, the combination of isospin symmetry breaking and strong correlation gives rise to an intricate landscape of emergent quantum phases, such as superconductivity and orbital ferromagnetism. The subtle interplay between the flat moiré band and strong Coulomb interaction provides an ideal venue for exploring novel electronic orders. For instance, a recent experiment reported a prominent zero-field superconducting diode effect in twisted trilayer graphene, revealing a new type of symmetry breaking order [1]. The nonreciprocal superconducting transport behavior, evidenced by the direction-dependence in the critical current points towards spontaneous breaking of both parity and time-reversal symmetry in the superconducting state, which motivates our search for a parity-breaking electronic order in metallic states of graphene-based moiré systems.

Such an electronic order can be identified based on highly nonreciprocal, diode-like current-voltage characteristics throughout the moiré flatband, which exhibits a one-fold or three-fold symmetric angular dependence as a function of the azimuth direction of current flow (Figure 1). We show that this parity-breaking order can be described as a valley-polarized loop current state, which is highly tunable with magnetic field, current flow, and field-effect doping. Our findings point towards the universal presence of valley-polarized isospin order and rotational symmetry breaking across the moiré flatband, with important implications for understanding intertwined and competing orders, such as ferromagnetism, nematicity, and superconductivity, in graphene-based moiré systems.

[1] Lin, J-X. et al. Zero-field superconducting diode effect in small-twist-angle trilayer graphene. Nature Physics, in press (2022).

5:00pm **PCSI-WeA2-37 UPGRADED: Proximity-Induced Superconductivity in Epitaxial Topological Insulator/Graphene/Gallium Heterostructures**, ***Cequn Li***, Pennsylvania State University

A topological insulator/superconductor heterostructure may support a novel superconductor called a topological superconductor through the proximity effect. In this work [1], we synthesize high-quality, large area $(Bi,Sb)_2Te_3$ (BST)/graphene (Gr)/gallium (Ga) heterostructures with atomically sharp hetero-interfaces combining confinement heteroepitaxy and molecular beam epitaxy (Fig. 1a). Atomically thin Ga film superconducts at T_c~4 K, and the growth of $(Bi,Sb)_2Te_3$ preserves its superconductivity extremely well. A lithography-free, van der Waals tunnel junction is developed to perform transport tunneling spectroscopy. Our results show a robust, proximity-induced superconducting gap formed in the Dirac surface states of 5-10 quintuple-layer BST/Gr/Ga heterostructures (Fig. 1b). This novel synthesis approach opens up new avenues for the understanding of topological superconductivity and the realization of topological quantum computing. This work is supported by the Penn State Materials Research Science and Engineering Center under award NSF-DMR 2011839.

5:20pm **PCSI-WeA2-41 Stabilizing Phosphorus Oxides at Confined Heterointerfaces**, ***Jiayun Liang***, *Z. Al Balushi,* University of California at Berkeley

A clean interface is crucial to obtain complex heterostructures with pre-determined properties. Intercalation, a polymer-free method to realizing vertical stacks with a clean interface, remained challenging for large intercalants. In this work, we reported the intercalation of P_2O_5 via chemical reactions at the graphene-Ge (110) heterointerface. Strong P and O signals from energy dispersive X-ray spectroscopy (EDS) were detected underneath the graphene layer on the cross-section of the graphene-Ge (110) heterointerface. A two-step mechanism for the intercalation process was that P_2O_5 decomposed into small fragments (i.e., P, O). These small fragments intercalated through graphene, reacted, and formed P_2O_5 at the graphene-Ge (110) interface. The P_2O_5 intercalated not only tunning the electronic structure of graphene on top with charge transfer but also converting metal (e.g., Ga) to its phosphate form. This study offers an important opportunity for advancing the understanding of mechanism for unstable large molecule intercalation at the graphene-substrate heterointerface.

5:25pm **PCSI-WeA2-42 Origin of Rectangular-like Lattice on Nanographene in STM Images Unveiled by First-Principles Calculations**, ***Junhuan Li***, *K. Inagaki, R. Sun, K. Yamamura, K. Arima,* Osaka University, Japan

We performed atomic-scale scanning tunneling microscopy (STM) of a cleaved highly oriented pyrolytic graphite [1]. Together with a $(\sqrt{3}\times\sqrt{3})R30°$ phase (Fig. 1(c)), a unique rectangular-like lattice (Fig. 1(d)) was resolved on a graphene nanosheet at a sample bias (V_s) of -0.05 V. To clarify the origin of this rectangular lattice, we conducted first-principles calculations [2] based on density functional theory and obtained simulated STM images of armchair-edged graphene nanoribbons (AGNRs) with different widths. In terms of the ribbon width (Fig. 2(a)), W is defined as the number of dimer lines across the ribbon width [3]. To avoid inaccuracies in the Fermi level, we used the sum of the electron density of orbitals in $[\varepsilon_{HOMO}+eV_s, \varepsilon_{HOMO}]$ for a negative sample bias, where ε_{HOMO} indicates the energy level of the highest occupied molecular orbitals (HOMO). The band structure was magnified in Fig. 2(c). V_1 and V_2 denote different energy levels at k=0. Fig. 2(d) shows simulated STM images at both sample bias of V_1 and V_2. At the lower sample bias (V_1), we find a rectangular superstructure similar to our experimental results [1]. The other image at V_2 indicates the ring-like shapes within the AGNR, which is in good agreement with the hexagonal lattice of graphene.

5:30pm **PCSI-WeA2-43 Valley-Controlled Even-Denominator Fractional Quantum Hall Effect in Bernal-Stacked Bilayer Graphene**, ***Ke Huang***, *H. Fu,* Department of Physics, The Pennsylvania State University*; D. Reifsnyder Hickey,* Department of Chemistry, The Pennsylvania State University*; N. Alem,* Department of Materials Science and Engineering, The Pennsylvania State University*; X. Lin,* International Center for Quantum Materials, Peking University, China*; K. Watanabe,* Research Center for Functional Materials, National Institute for Materials Science, Japan*; T. Taniguchi,* International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Japan*; J. Zhu,* Department of Physics, The Pennsylvania State University

The braiding statistics of non-abelian anyons is the foundation for topological quantum computation. The even-denominator fractional quantum Hall (FQH) effect in a two-dimensional electron system is expected to host such quasi-particles. In Bernal-stacked bilayer graphene (BLG), even-denominator FQH states at filling factors ν = -5/2, -1/2, 3/2 and 7/2 have been observed. In this presentation, I'll discuss our observation of a new even-denominator state at filling factor ν = 5/2 in samples of unprecedented quality and by manipulating the valley isospin degrees of freedom in BLG using a perpendicular electric field. We show that the 5/2 state is spontaneously polarized in the limit of zero valley Zeeman splitting. Theory proposes three possible topological orders for the even-denominator states, i.e. the Moore-Read Pfaffian, its particle-hole conjugate the anti-Pfaffian, and a particle-hole symmetry state. Both the Pfaffian and the anti-Pfaffian break the particle-hole symmetry. They are predicted to have different FQH daughter states. We observe the daughter states of the Pfaffian near ν =3/2, 7/2 and of the anti-Pfaffian near ν = 5/2 and -1/2. These results provide new information on the rich physics of the FQH effect.

Author Index

Bold page numbers indicate presenter