Substrate driven electronic reconstruction in bilayer graphene

Aalok Tiwari[1], Sandy Adhitia Ekahana[1,2], Souvik Sasmal[1], Liangtao Peng[5], Pratik Saud[1], Syeda Faiza Rubab Sherazi[3], Ravi Kumar Bandapelli[1], Duy Le[3], Rahul Rao[4], I-Hsuan Kao[1], Chris Jozwiak[2], Eli Rotenberg[2], Aaron Bostwick[2], Talat S Rahman[3], Simranjeet Singh[1], Shaffique Adam[5] and Jyoti Katoch[1,*]

[1]Department of Physics, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, United States

[2]Advanced Light Source, E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States

[3]Department of Physics, University of Central Florida, Orlando, Florida 32816, United States

[4]Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433, United States

[5]Department of Physics, Washington University in St. Louis, St. Louis, Missouri 63130, USA

*Corresponding author: jkatoch@andrew.cmu.edu

The electronic and optical properties of two-dimensional van der Waals material systems are intimately tied to stacking configuration and sublattice arrangement. Interface engineering through substrate interactions, layer alignment and twist angle, offers a powerful route to design and manipulate electronic correlations. In this talk, I will use angle-resolved photoemission spectroscopy with micron sized spatial resolution (microARPES) to present direct evidence that substrate interactions and twist angle can dramatically modify the electronic band structure of bilayer graphene (BG). First, I will discuss our result of tuning the electronic structure of BG when interfaced with two distinct van der Waals substrates: hexagonal boron nitride (hBN), a wide-gap semiconductor, and α-$RuCl_3$, a Mott insulator, on the same sample. In the pristine heterostructure, differential charge transfer in the BG/hBN and BG/$RuCl_3$ regions induces spatially modulated doping, forming an atomically sharp lateral p–p† junction. We observe a flattened valence band tip in BG on hBN, while BG on $RuCl_3$ exhibits strong hole doping. Upon electron doping via alkali-metal deposition, we access the conduction band in the heterostructure and observe that BG on hBN develops a ~0.4 eV band gap, while BG on $RuCl_3$ retains robust semimetallic in-gap states. These findings establish that substrate interactions modify BG's intrinsic ground state. Next, I will explore what occurs when graphene or BG is aligned with hBN at 0° or 30° along the high-symmetry Γ–K direction. At specific alignments, we observe flat bands away from the Fermi level whose dispersion is tunable via perpendicular electric field and strongly dependent on graphene–hBN relative orientation. These results demonstrate that substrate selection and layer alignment together provide a powerful basis for achieving correlated electronic phases in graphene-based heterostructures, opening pathways toward functional quantum devices in interface-tunable van der Waals systems.

References:

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