Graphene Focus Topic
Room: Brazos - Session GR+AS+TF+MI-ThA

Graphene: Surface Characterization
Moderator: P. Sutter, Brookhaven National Laboratory

2:00pm **GR+AS+TF+MI-ThA1 Scanning Tunneling Microscopy and Spectroscopy of Impurities on a Gated Graphene Device**, ***R.T. Decker***, *V.W. Brar, M.H. Solowan, Y.C. Wang, A. Zettl, M.F. Crommie*, University of California Berkeley **INVITED**

Understanding the scattering properties of electrons in graphene is important for controlling the behavior of different graphene nanostructure-based devices. Here we report a scanning tunneling microscopy (STM) and spectroscopy (STS) study of impurities on a single monolayer of graphene. In our experiments the graphene is placed on a layer of insulating SiO_2 that sits above a doped silicon back-gate electrode. We will discuss our observations of the electronic local density of states of impurities, as well as how these properties respond to electrical gating of the graphene monolayer with respect to the silicon back-gate electrode.

In particular, we will show that the combination of the back-gate voltage and the STM tip-gating effect allows the controlled ionization of the impurity when the resonance sweeps through the Fermi energy. The influence of this induced Coulomb potential on the electrons in graphene in the vicinity of the impurity will be discussed.

2:40pm **GR+AS+TF+MI-ThA3 Graphene Defect States in a Magnetic Field Studied by Scanning Tunneling Spectroscopy**, ***K.D. Kubista***, *D.L. Miller, M. Ruan, W.A. de Heer, P.N. First,* Georgia Institute of Technology, *G.M. Rutter, J.A. Stroscio*, National Institute of Standards and Technology

We present tunneling differential conductance (*dI/dV*) spectra and 2D conductance maps acquired over both positive and negative defects in magnetic fields up to 8 T. The measurements were performed on multilayer epitaxial graphene using scanning tunneling microscopy and spectroscopy at 4 K under ultrahigh vacuum conditions. Landau level drift states are found to follow the local potential (determined independently at near-zero magnetic field), but near a negatively-charged defect a bound (or quasibound) state originates from the $n = -1$ Landau Level. The defect state Stark shifts and finally ionizes under the influence of the STM tip electric field.

3:00pm **GR+AS+TF+MI-ThA4 Atomic-Scale Maps of Quantum Hall States in Epitaxial Graphene**, ***D.L. Miller***, *K.D. Kubista,* Georgia Institute of Technology, *G.M. Rutter,* National Institute of Standards and Technology, *M. Ruan, W.A. de Heer, P.N. First*, Georgia Institute of Technology, *J.A. Stroscio*, National Institute of Standards and Technology

When a perpendicular magnetic field is applied to a graphene sheet, the resulting eigenenergies (Landau Levels or LLs) have a nonlinear energy distribution that includes a four-fold degenerate zero-energy state (LL_0). Maps of the energy-resolved local density of states (LDOS) acquired via cryogenic scanning tunneling spectroscopy (STS) provide atomic-scale imaging of the LL spatial distribution. Focusing on LL_0, we use STS maps to image the *localized* and *extended* quantum Hall states. Unexpectedly, we find atomic-scale variations of the LDOS above a critical magnetic field. We attribute this to an energy gap in LL_0 and show how it depends on the local A-B lattice symmetry. The gap is observed only within patches of at least a few magnetic lengths in size, which forces the splitting to “turn off” below the critical field. This behavior implies a breaking of the local sublattice symmetry imposed by moiré layer stacking.

3:40pm **GR+AS+TF+MI-ThA6 Imperfect Graphene: Point Defects, Edges, Dislocations and Grain Boundaries**, ***O.V. Yazyev***, University of California, Berkeley **INVITED**

In two dimensions, properties of materials can be heavily affected by defects. In this talk, I will review our recent efforts directed towards understanding various types of structural irregularities in graphene.

Firstly, I will present the results of theoretical studies of the magnetism induced by point defects and edges in graphene and graphite. We show that in graphene single-atom defects such as vacancies and hydrogen chemisorption induce the spin-polarized defect states [1, 2]. The coupling between the magnetic moments is either ferromagnetic or antiferromagnetic, depending on whether the defects correspond to the same or to different sublattices of the graphene lattice, respectively. These results are able to clarify some experimental observations of high-temperature ferromagnetism in proton-irradiated graphite. Similarly, zigzag edges of graphene are predicted to induce spin-polarized edge states which can serve as a basis for novel spintronic devices. We address the question of the spin correlation length at finite temperatures in this one-dimensional magnetic system and establish the limitations of the proposed spintronic devices [3].

Then, I will talk about our latest results on dislocations and grain boundaries in graphene [4], topological defects which are still not well understood despites the growing number of experimental observations. We introduce a general approach for constructing dislocations in graphene characterized by arbitrary Burgers vectors as well as grain boundaries, covering the whole range of possible misorientation angles. By using ab initio calculations we investigate thermodynamic, electronic and transport properties of grain boundaries, finding energetically favorable large-angle symmetric configurations, strong tendency towards out-of-plane deformation in the small-angle regimes, pronounced effects on the electronic structure, and two distinct behaviors in the electronic transport [5] - either perfect reflection or high transparency for low-energy charge carriers depending on the grain boundary structure. Our results show that dislocations and grain boundaries are important intrinsic defects in graphene which may be used for engineering graphene-based functional devices.

[1] O. V. Yazyev and L. Helm, Phys. Rev. B 75, 125408 (2007).

[2] O. V. Yazyev, Phys. Rev. Lett. 101, 037203 (2008).

[3] O. V. Yazyev and M. I. Katsnelson, Phys. Rev. Lett. 100, 047209 (2008).

[4] O. V. Yazyev and S. G. Louie, arXiv:1004.2031 (2010).

[5] O. V. Yazyev and S. G. Louie, submitted.

4:20pm **GR+AS+TF+MI-ThA8 Spectroscopic Ellipsometry for Thickness Measurement and Optical Dispersion Modeling of CVD-Grown Graphene**, *F.J. Nelson, V.K. Kamineni,* ***A.C. Diebold***, The University at Albany-SUNY

Graphene has attracted much research over the past several years due to its electrical and mechanical properties. It is a prime candidate for electronic and optoelectronic devices, yet much of the research has utilized the exfoliation, or "scotch-tape" technique of sample preparation. More scalable growth methods have been investigated, such as the thermal decomposition of SiC, and the resulting graphene films have properties dependent on their fabrication parameters. One potentially scalable technique is that of hydrocarbon gas-based CVD onto metallic substrates. Here, we report on the ellipsometric measurement of Few-Layer-Graphene (FLG) grown on copper foils and subsequently transferred to a different substrate (i.e. glass). One of the challenges with development of a dispersion model for FLG is that the CVD graphene has many "grains" inside the measured area while previous reports of exfoliated graphene were done on single crystal samples. The work explores finding an average thickness, as well as the optical dispersion modeling, of the graphene layers on different substrates, such as SiO2/Si and glass slides.

Authors Index

Bold page numbers indicate the presenter