

MAR13-2012-020255

Abstract for an Invited Paper  
for the MAR13 Meeting of  
the American Physical Society

### **Single-layer behavior and its breakdown in twisted graphene layers<sup>1</sup>**

ADINA LUICAN-MAYER, Argonne National Laboratory

Stacking order plays a major role in the electronic properties of graphene layers because hopping between carbon atoms in neighboring layers is a key ingredient in their band structure. Twisting the layers away from the equilibrium Bernal stacking, which produces the superstructures known as Moiré patterns in scanning tunneling microscopy, decreases the overlap between atoms in adjacent layers and therefore significantly alters their electronic properties. Using scanning tunneling microscopy and spectroscopy, we obtained direct evidence for the electronic structure of twisted graphene layers.<sup>2</sup> The samples were membranes of CVD grown graphene and graphite crystals which contain areas with various twist angles. In topographic images the regions where layers are twisted away from Bernal stacking exhibit Moiré patterns with periods which depend on the twist angle. We find that the density of states on the twisted layers develops two Van Hove singularities that symmetrically flank the Dirac point at an energy that depends on the twist angle. High magnetic field scanning tunneling microscopy and Landau level spectroscopy of twisted graphene layers reveal that for twist angles exceeding  $\sim 3$  degrees the low energy carriers exhibit Landau level spectra characteristic of massless Dirac fermions. Above 20 degrees the layers effectively decouple and the electronic properties are indistinguishable from those in single-layer graphene, while for smaller angles we observe a slowdown of the carrier velocity which is strongly angle dependent.<sup>3</sup> These results are compared with theoretical predictions.

<sup>1</sup>DOE-FG02-99ER45742, NSF DMR 1207108, Alcatel-Lucent

<sup>2</sup>G. Li, A. Luican, J.M. B. Lopes dos Santos, A. H. Castro Neto, A. Reina, J. Kong and E.Y. Andrei, Nature Physics 6, 109 (2010).

<sup>3</sup>Luican, G. Li, A. Reina, J. Kong, R. R. Nair, K. S. Novoselov, A. K. Geim, E.Y. Andrei, Phys. Rev. Lett. 106, 126802 (2011).