Spin Phase Transition in Bilayer Graphene at Charge Neutrality

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Introduction

The most celebrated property of the quantum spin Hall effect is the presence of spin-polarized counter-propagating edge states. This novel edge state configuration has also been predicted to occur in graphene when spin-split electron and hole-like Landau levels are forced to cross at the edge of the sample. In particular, a quantum spin hall analogue has been predicted at charge neutrality in bilayer graphene if the ground state is a spin ferromagnet. Because in-plane magnetic field couples directly to the spin degree of freedom and the interlayer asymmetry created by oppositely biased top and back gates couples to the valley degree of freedom, the ground state of bilayer graphene can be experimentally tuned.

Experimental

Hexagonal-boron-nitride-encapsulated bilayer graphene devices were fabricated using a mechanical transfer process. Samples were patterned into a Hall bar using conventional electron beam lithography techniques, and contacted with electrical leads consisting of a Cr/Pd/Au metal stack. Four-terminal transport measurements were performed using standard low-frequency lock-in techniques. Displacement field was controlled by simultaneously changing top and back gates, and in-plane magnetic field was controlled by rotating the sample. All measurements were performed in a 31 Tesla resistive magnet with the sample mounted in a 3He cryostat (sample in vapor) at an approximate 300 mK base temperature.

Results and Discussion

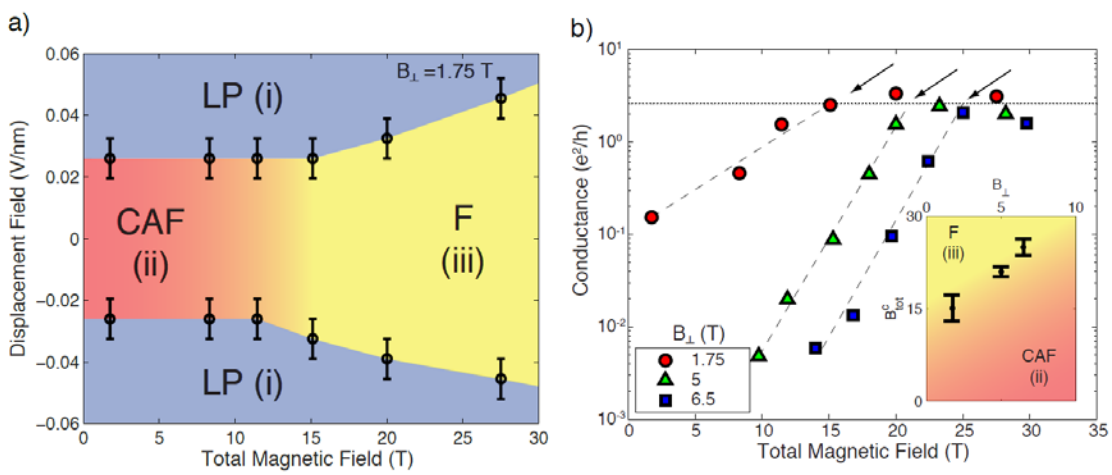

Figure 1

By altering both the electric displacement field across the sample and the in-plane magnetic field at a fixed perpendicular magnetic field, we can tune the spin and pseudospin anisotropies and control the ordering of the $\nu = 0$ state. **Figure 1a** shows the phase diagram we observe. At high displacement field, the ground state is an insulating layer polarized phase. At low displacement field and low in-plane field, the ground state is an insulating canted antiferromagnet. As in-plane field is increased, the ground state transitions to a ferromagnet. **Figure 1b** shows that as this transition happens, the conductance increases exponentially with total field. At some finite total field, the conductance reaches a final value of ~$4e^2/h$. This is in agreement with predictions that the ferromagnet ground state should have gapless counter-propagating spin polarized edge states. This edge configuration is analogous to the quantum spin Hall effect.

References

[1] Maher, P. *et al*., accepted to Nature Physics (2012).