Magnetotransport and Capacitance of Proximally-Gated Monolayer Graphene

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Introduction

The quantum spin Hall (QSH) state is a fascinating state of matter in which the electronic transport is quantized and current is carried by two pairs of counter-propagating, spin-polarized edge modes. So far, the QSH effect has only been observed in an exotic type of semiconductor quantum well [1], but in an alternative proposal, an exact analog of the QSH state has been proposed to exist in graphene for the half-filled zero-energy Landau level (i.e. at filling factor ν=0) [2]. This occurs for sufficiently large Zeeman energy (i.e. total magnetic field), but unambiguous demonstration of this state has been hindered by lattice-scale Coulomb interactions, which tip the scales in favor of valley polarization in the ν=0 state rather than spin polarization [3]. This results in an insulating state at ν=0 whose charge gap increases with perpendicular magnetic field rather than the conducting state characteristic of the QSH effect. Here, we investigate whether we can induce the QSH by reducing the Coulomb interactions via a proximal screening electrode while simultaneously increasing the Zeeman energy.

Experimental

We use tilted-field magnetotransport and magnetocapacitance to study the interplay of the Coulomb and Zeeman energy scales in the edge transport and bulk properties of monolayer graphene. Our samples are graphene-thin hexagonal boron nitride (hBN)-graphite vertical heterostructures, prepared using a co-lamination technique [4]. We obtained the data shown below in the helium-3 cryostat in Cell 9 in July 2012.

Results and Discussion

We observe a striking increase in the two-terminal conductivity at the charge neutrality point (ν=0) as we increase the total magnetic field (and thereby the Zeeman energy) while keeping the perpendicular field constant (Fig. 1, top). In simultaneous measurements of the capacitance, we do not see a comparable reduction in the gap at ν=0 (Fig. 1, bottom). This provides evidence that the insulator-conductor transition at ν=0 is due to the formation of conducting channels at the edge of the sample while the bulk remains gapped.

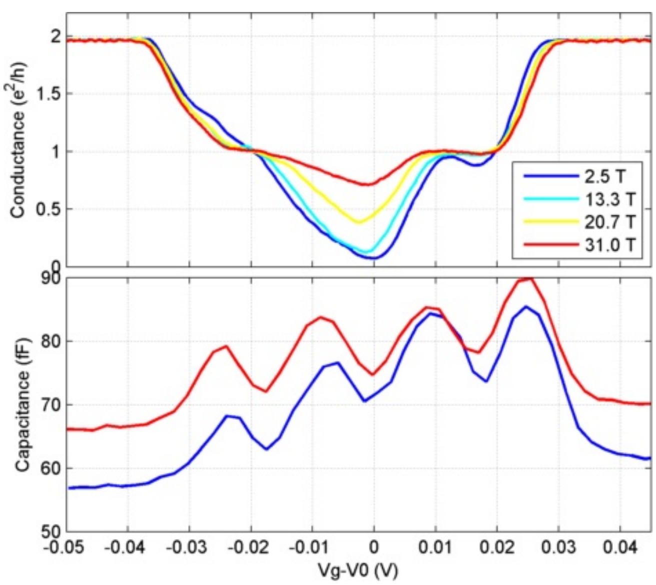

Figure 1. (Top) Conductance and (bottom) capacitance of graphene-BN-graphite vertical heterostructure for fixed perpendicular field of 2.5T, as a function of adjusted gate voltage Vg. The legend indicates the total magnetic field for each curve. A significant change in the conductance can be seen at the charge neutrality point ($Vg-V_0 = 0$) for increasing total field, whereas the change in the capacitance is much less significant.

Conclusions

The data of **Figure 1** provide tantalizing hints that we are close to observing the QSH effect in monolayer graphene. Definitive evidence of the QSH would be observation of a conductance of $2e^2/h$ at ν=0, for which we require cleaner samples, a larger total magnetic field, or, ideally, both. We hope to satisfy these requirements during our January 2013 time in the 45T Hybrid (Cell 15).

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References

1. König, M. *et al. Science* **318**, 766 –770 (2007).
2. Abanin, D. A., Lee, P. A. & Levitov, L. S. *Phys. Rev. Lett.* **96**, 176803 (2006).
3. Young, A. F. *et al. Nature Physics* **8**, 550–556 (2012).
4. Dean, C. R. *et al. Nat Nano* **5**, 722–726 (2010).