Towards the Quantum Spin Hall Effect in Graphene

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Introduction

Thin film bismuth selenide samples—the original target of the proposal--were not ready in time for the assigned high field run. Instead, we brought high quality graphene samples.

In monolayer graphene, a unique kind of quantum Spin Hall state was predicted at charge neutrality for sufficiently large values of the Zeeman energy [1]. However, in normal graphene devices, either disorder or short ranged electron-electron interactions drive the system to an antiferromagnetic order instead. We've engineered devices in which disorder is very low, and electron interactions are partially screened, to make observation of this state possible. At MIT, we were able to approach the transition to this interesting state, but its full saturation remained out of reach. We brought several high quality graphene samples to see if the transition might occur at high fields, >25 tesla, for the accessible parameter range.

Experimental

We studied electronic transport in our screened graphene devices 3He cryostat in magnet cell 9. We used the sample rotator probe, outfitted with several coax lines. The coaxial lines were intended for doing capacitance measurements, but the samples died before we could obtain high field capacitance data. We did however manage to obtain high field transport data, from which interesting new physics has emerged. Figure 1 shows the two terminal conductance at fixed magnetic field B=2.5T perpendicular to the graphene, at three values of total magnetic field. While there is very little dependence of the conductance on in-plane field for filling factors $|\nu|>1$, a striking transition from insulator to metal is observed near charge neutrality. Two additional, higher peaks in conduction are observed symmetrically positioned about charge neutrality.

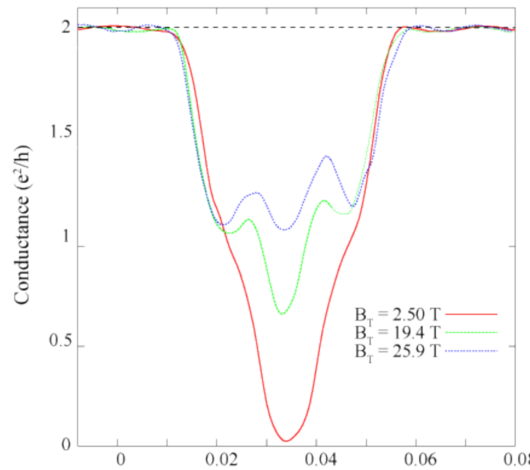

Figure 1: Two terminal conductance of a graphene flake at $B_\perp$=2.5 Tesla. T=300 mK. At charge neutrality, the sample undergoes a transition from insulator to metal as a function of in-plane field.

Results and Discussion

The observation of a insulator metal transition is roughly in line with existing theory. These theories stipulate that the conduction is due to the formation of counter-propagating spin polarized edge states. However, the failure to saturate the transition, and the large gap between expected conductance of 2e^2/h and the observation suggest that cleaner samples, or higher fields, are needed to fully induce the ferromagnetic phase. More interesting are the peak features, which are unexpected. We speculate that these features may be associated with the not-completely helical edge states characteristic of the intermediate canted antiferromagnetic phase [2], which is thought to precede the onset of the fully spin polarized quantum spin Hall phase. However, a theory of the high field state of graphene at small but finite doping is not available.

Conclusions

This magnet time resulted in a glimpse of the exciting new physics of the high field quantum spin hall effect in graphene. In particular this magnet time resulted in the first observation of the peaks which we take to be signatures of the edge states of the canted antiferromagnetic phase. We hope this result will engender discussion in the theoretical community. In several trips to NHMFL since, we have elaborated on this measurement, and are now writing it up for submission to *Nature*.

References

[1] Abanin, D.A., Phys. Rev. Lett. **96** 176803-176807 (2006).
[2] Kharitonov, M.Yu. Phys. Rev. B **86**, 075450 (2012).