Detailed Study of the Quantum Hall Effect and Quantum Hall to Insulator Transition in Ultra-Low Carrier Density Topological Insulator Films

Salehi, M. (Rutgers U., MSE); Rosen, I.T. (Stanford U., Physics); Goldhaber-Gordon (Stanford U., Physics) and Oh, S. (Rutgers U., Physics)

Introduction

By utilizing a compatible buffer layer and proper interface engineering, we report the lowest ever carrier density in a topological insulator (TI) system (carrier density as low as 1.0×10^{11} cm^{-2}) in MBE-grown transition metal-doped Sb_2Te_3 thin films.

Experimental

In our 2018 visits we measured the following: 1: Ultralow carrier-density Sb_2Te_3 films (*p*- and *n*-type) using the 45T hybrid magnet. 2: The best ungated sample in more detail as well as several top-gated Sb_2Te_3 films using the 35T resistive magnet.

Results and Discussion

Such low carrier density enabled us to observe the topological surface state-originated quantum Hall effect (QHE), for both p- and n-type samples, at much lower fields (as low as ~5.5T; without gating). More importantly, for the first time in a TI system, we observed the quantum Hall to insulator transition (QIT) at higher fields. The insulator phase could either be a coherent excitonic super fluid or a Hall insulator. Additionally, we could tune the carrier density from p to n-type with gate-voltage application (Fig.2). Furthermore, upon investigating the scaling behavior of the QIT at the critical point, we found that the critical exponents are different from those of the QIT in conventional 2D electron gases, implying that these transitions belong to different universality classes. Moreover, the flow lines of the conductivity tensor for an ungated 8QL sample is shown in Fig.3. The manuscript for this work has been submitted[1].

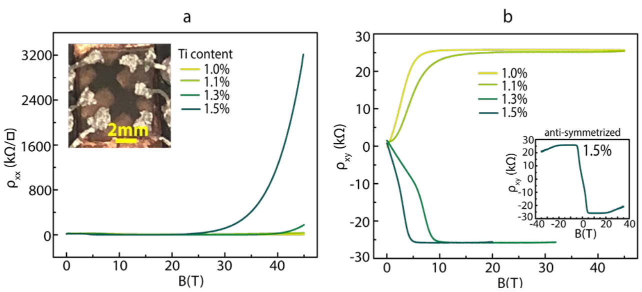

Figure1. a, ρ_{xx} and **b,** ρ_{xy} for Sb_2Te_3 films with various doping concentrations as a function of magnetic field from 0 to 45 T.

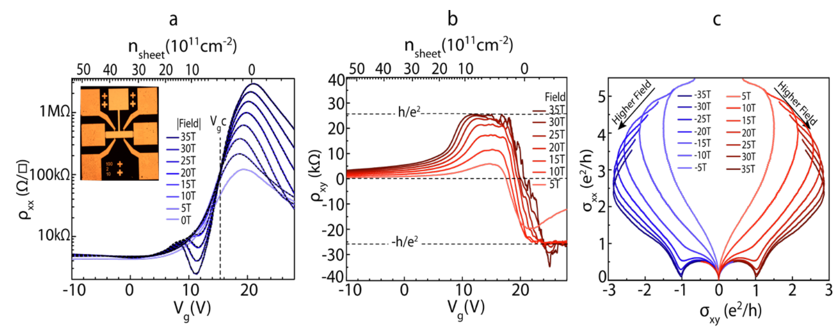

Figure2. a, ρ_{xx} and **b,** ρ_{xy} of a top-gated device as a function of gate voltage (-10 V ≤ V_g ≤ 28 V) for different fields from 0 to 35 T at 300 mK show a well-defined p-type QHE and an incipient n-type QHE. **c,** The parametric flow of the conductivity tensor (σ_{xx} vs. σ_{xy}) of the same sample. Each line represents a gate sweep at a constant field.

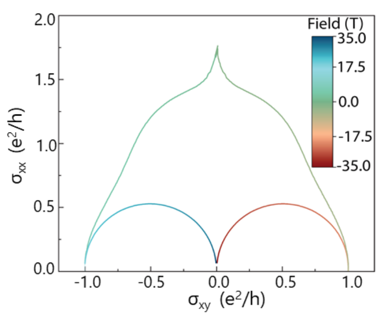

Figure 3. The conductivity tensor flow of an 8QL sample for |B| ≤ 35 T. The points ($\pm e^2/h$,0), (0,0), and ($\pm 0.5e^2/h$, $0.5e^2/h$) correspond to the QH state, the insulator phase, and the transition between these two phases, respectively. The cusp around zero field indicates weak anti-localization

Conclusions

In summary, these ultra-low carrier density TI films enabled us to explore an extreme quantum limit and the zeroth Landau level in TIs which previously were inaccessible. Further, these films can serve as a promising test-bed for high-temperature quantum anomalous Hall effect and other magneto-topological effects when combined with proper magnetic coupling schemes.

Acknowledgements

The NHMFL is supported by NSF/DMR-1157490/1644779 and the State of Florida. Film growth and transport measurements are supported by the Gordon and Betty Moore Foundation’s EPiQS Initiative (GBMF4418) and NSF (EFMA-1542798). Device fabrication and measurement of gated devices are supported by DOE (DE-AC02-76SF00515).

References

1. Salehi M., *et al.* Quantum-Hall to insulator transition in ultra-low-carrier-density topological insulator films. *Submitted*.