Observation of Topological Surface State Quantum Hall Effect in an Intrinsic Three-Dimensional Topological Insulator

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Introduction

A three-dimensional (3D) topological insulator (TI) is a novel quantum matter system with a gapped insulating bulk and a conducting surface hosting topologically-protected gapless surface states, where charge carriers are spin-helical massless Dirac fermions [1]. One of the most iconic electronic transport signatures predicted for such topological surface states (TSS) is a well-defined half-integer quantum Hall effect (QHE) in a magnetic field, where the surface Hall conductivities become quantized in units of $(1/2)e^2/h$ (e being the electron charge, h the Planck constant) concomitant with vanishing resistance.

In this work, we report observations of well-developed TSS QHE in $BiSbTeSe_2$ (BSTS), an intrinsic TI material where the bulk is highly insulating with negligible conductance [2].

Experimental

BSTS single crystal were synthesized in Purdue and then fabricated into bulk or thin flake devices for transport measurements, which were mostly performed in cell 9 with base temperature down to 350 mK and magnetic fields up to 31 T.

Results and Discussion

At low temperatures and high magnetic fields perpendicular to the top and bottom surfaces, we observe well-developed integer quantized Hall plateaus, where the two parallel surfaces each contribute a half integer e^2/h quantized Hall (QH) conductance, accompanied by vanishing longitudinal resistance. When the bottom surface is gated to match the top surface in carrier density, only odd integer QH plateaus are observed, representing a half-integer QHE of two degenerate Dirac gases.

Conclusions

Our intrinsic TI with TSS exhibiting half-integer QHE provides an excellent platform to pursue a plethora of exotic physics and novel device applications predicted for TIs, ranging from magnetic monopoles and Majorana particles to dissipationless electronics and fault-tolerant quantum computers.

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References

[1] Hasan, M.Z. & Kane, C.L., *Rev. Mod. Phys.*, **82,** 3045-3066 (2010).
[2] Xu, Y., *et al*., *Nature Physics*, **10**, 956-963 (2014).

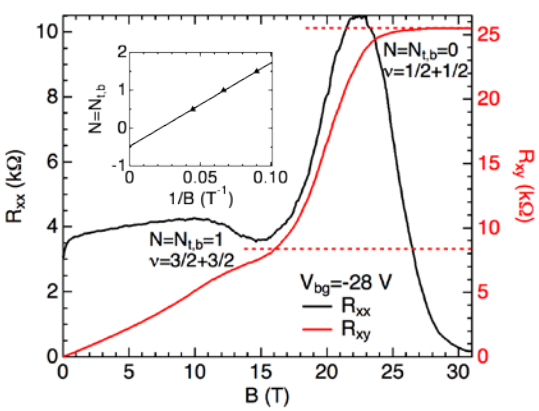

Fig.1 Magnetic field (B) dependence of R_{xx} and R_{xy} measured when top and bottom surfaces have the same carrier density. Inset shows the corresponding Landau level (LL) fan diagram. A linear fit gives intercept -0.5 on the N-axis, which supports Dirac fermion.

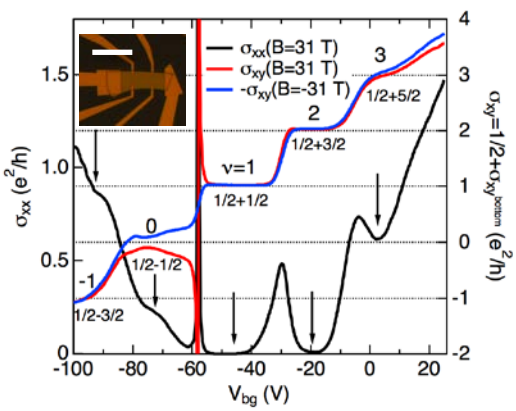

Fig.2 Extracted 2D longitudinal and Hall conductivities (σ_{xx} and σ_{xy} at 31 T along with $-\sigma_{xy}$ at -31T), in units of e^2/h. σ_{xy} shows well-developed integer QH plateaus where total filling factor equals 1/2 (from top surface) plus a half integer (from bottom surface). Inset shows a typical optical image of device on SiO_2/Si substrate with scale bar 25 μm.