Tunable two-species Dirac fermions and quantum Hall effect in dual-gated three-dimensional topological insulators

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Topological insulators (TI) are a novel class of quantum matter with a gapped insulating bulk yet gapless spin helical Dirac fermions. Recently [1], we have shown surface-dominated conductance in an intrinsic 3D TI, $BiSbTeSe_2$ (BSTS), even close to room temperature for thin samples. In high magnetic field and low temperature, thin-flake samples exhibits well-developed quantum Hall effect (QHE), where the two parallel surfaces each contribute a half-integer e^2/h quantized Hall resistance, accompanied by vanishing longitudinal resistance. Such "half-integer" QHE is a hallmark of massless Dirac fermions.

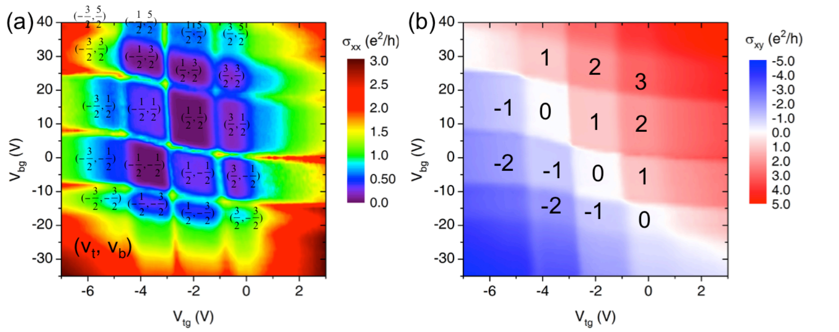
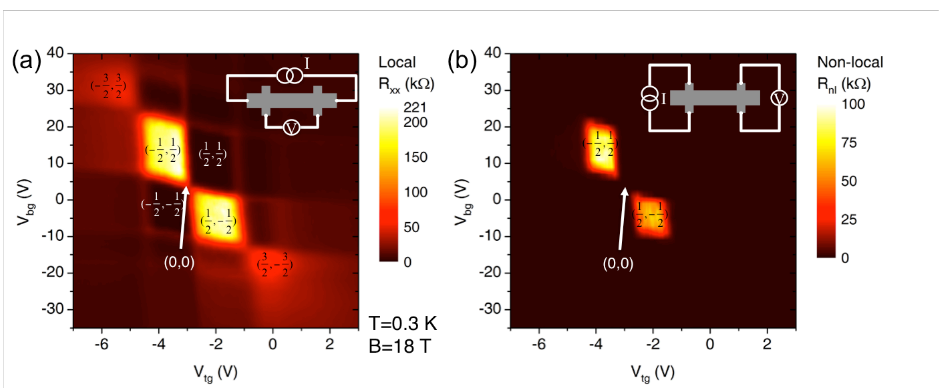


Figure 1. (a) Longitudinal resistivity σ_{xx} and (b) Hall resistivity σ_{xy}, shown as 2D color maps, as functions of topgate voltage V_{tg} and backgate voltage V_{bg} at B=18 T and T=0.3 K, with (v_t, v_b) labeling (top, bottom) surface half-integer filling factor of corresponding QH state. The integer in (b) labels the total filling factor v of each state.

Further [2], we performed local and non-local electrical and magnetotransport measurements in dual-gated BSTS thin film TI devices, with conduction dominated by the spatially separated top and bottom surfaces, each hosting a single species of Dirac fermions with independent gate control over the carrier type and density. We observe many intriguing quantum transport phenomena in such a fully-tunable two-species topological Dirac gas, including a zero-magnetic-field minimum conductivity of ~$4e^2/h$ at the double Dirac point, a series of ambipolar two-component "half-integer" Dirac quantum Hall states (see Fig. 1) and an electron-hole total filling factor v=0 state (with a zero-Hall plateau), exhibiting dissipationless (chiral) and dissipative (non-chiral) edge conduction respectively (Fig. 2). Such a system paves the way to explore rich physics ranging from topological magnetoelectric effects to exciton condensation.

Figure 2. Comparing (a) Local resistance R_{xx} and (b) non-local resistance R_{nl}, as functions of V_{tg} and V_{bg} at B=18 T and T=0.3 K. Inset is the corresponding measurement setup. At (v_t, v_b)=(1/2,-1/2) or (-1/2,1/2), there's an intriguing v=0 state, characterized by zero Hall plateau and simultaneously large local and nonlocal resistance.



[1] Yang Xu *et al.*, Nature Physics 10, 956 (2014).
[2] Yang Xu, Ireneusz Miotkowski and Yong P. Chen, submitted to Nature Communications (2015).

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