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\textsubscript{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.

Further [2], we performed local and non-local electrical and magneto-transport 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 $\sim 4e^2/h$ 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 $\nu=0$ 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 1. (a) Longitudinal resistivity $\sigma_{xx}$ and (b) Hall resistivity $\sigma_{xy}$, 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 $(\nu_t, \nu_b)$ labeling (top, bottom) surface half-integer filling factor of corresponding QH state. The integer in (b) labels the total filling factor $\nu$ of each state.

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 $(\nu_t, \nu_b)=(1/2, -1/2)$ or $(-1/2, 1/2)$, there’s an intriguing $\nu=0$ state, characterized by zero Hall plateau and simultaneously large local and nonlocal resistance.


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