Electron transport in 3D topological insulators

The three dimensional topological insulator (3D TI) is a new class of materials having metallic surface states while the bulk is insulating. The surface states have gapless Dirac dispersions with novel properties such as momentum-spin locking. Moreover, coupling the surface states to an s-wave superconductor is predicted to produce so-called Majorana fermions, which may be applicable to fault-tolerant topological quantum computations. However, many basic properties of 3D TI materials should be explored before any application could be developed. In this talk, I will discuss my transport experiments on Bi_2Se_3, a 3D TI having large bulk bandgap of 0.3eV and a single surface state. Thin (10~15nm) Bi_2Se_3 films and nanowires are mechanically exfoliated to fabricate gate tunable transport devices. Electrolyte gating and/or molecular doping methods are used to tune the chemical potential into the bulk bandgap through the Dirac point [1-3]. Electronic transport measurements reveal an ambipolar metallic electronic transport in the topological surface of an insulating bulk [1]. I will show that the surfaces of thin, low-doped Bi_2Se_3 ($<10^{17}$ cm^{-3}) crystals are strongly electrostatically coupled, and a gate electrode can completely remove bulk charge carriers and bring both surfaces through the Dirac point simultaneously. Next, I will discuss my measurements of dc Josephson effects in TI-superconductor junctions [2]. I will compare my results with three-dimensional quantum transport simulations and show that the supercurrent is largely carried by surface states regardless of disorders. The results clarify key open issues regarding the nature of supercurrents in topological insulators. Finally, I will discuss my recent experiments on electron transport in 3D TI nanowires. TI nanowires with an insulating bulk can be described as a hollow metallic cylinder, showing Aharonov-Bohm oscillations upon magnetic flux threaded through the axis. Angular-momentum quantization in TI nanowires allows only half integer angular-momenta due to a Berry phase π and induces a surface gap at zero magnetic fields. When half quantum magnetic flux ($\Phi_0/2$) through the nanowire axis cancels the Berry phase, a gapless Dirac-mode is predicted to appear. Hence, by measuring the magnetoconductance of TI nanowire near the Dirac point, a Berry phase of curved TI surfaces can be detected. The conductance at the Dirac point is expected to have a minimum at $\Phi = 0$ and a maximum ($\sim e^2/h$) at $\Phi = \Phi_0/2$ while oscillating with a period of Φ_0 [3]. I will discuss my four-probe magnetoconductance measurements in a TI (Bi_2Se_3) nanowire while the gate voltage is tuned through the Dirac point. My measurement of Aharonov-Bohm effects near the Dirac point shows the first evidence of 1D gapless Dirac-mode and a Berry phase in a TI nanowire.

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[2] **Sungjae Cho**, Brian Dellabetta, Alina Yang, John Schneeloch, Zhijun Xu, Tonica Valla, Genda Gu, Matthew J. Gilbert, Nadya Mason, *Nature Communication* 4, 1689 (2013)

[3] **Sungjae Cho***, Brian Dellabetta, Alina Yang, John Schneeloch, Zhijun Xu, Genda Gu, Matthew J. Gilbert, Nadya Mason* *Nature Communication* 6, 7634 (2015)