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Direct detection of topological surface conductance via four-probe spectroscopy

Saban M. HUS[1], Corentin DURAND[1], X.-G. ZHANG[1,2], Chuanxu MA[1], Michael A. MCGUIRE[1], Yong P. CHEN[3] and An-Ping LI[1]

[1] *Oak Ridge National Laboratory, USA*
[2] *University of Florida, USA*
[3] *Purdue University, USA*

apli@ornl.gov

Topological insulator (TI), with characteristic topological surface states, has emerged as a new state of matter with rich potentials for both fundamental physics and device applications. In TI materials, the existence of metallic surface states with massless Dirac dispersion and a simultaneous bulk insulating behavior is the hallmark of a TI state. Separating 2D surface conductance from often unavoidable and more dominating 3D bulk contributions, however, has always been a challenge in transport experiments. Four-probe spectroscopy measurement with variable probe distances is the method of choice for studying materials where both surface and bulk contributions to electrical conduction are present [1]. The common practice is to assume two decoupled conduction channels corresponding to the 2D conductance of surface states and the 3D conductance of bulk, and deduce the dominant conduction mechanism through the dependence of the conductance with probe spacing. Such an assumption would only be valid if the potential profile across the surface were identical for both 2D and 3D conduction. However, in TIs the 2D and 3D conduction channels are usually coupled due to the ubiquitous vacancies and anti-site defects in the bulk, making it often difficult to cleanly decouple the two channels.

Here we report a new method to account for both surface and bulk conduction mechanisms by solving the simultaneous current continuity equations for both 2D and 3D, allowing cross “channel” current at every point along the surface. This enables the extraction of the conductivities from both conduction channels of a TI crystal based on a set of spectroscopy measurements using the 4-probe scanning tunneling microscopy [2]. Using this method, we demonstrate the separation of 2D and 3D conduction in topological insulators by comparing the conductance scaling of Bi_2Se_3, Bi_2Te_2Se, and Sb-doped Bi_2Se_3 with that of a pure 2D conductance of graphene on SiC substrate. We also quantitatively show the effect of surface doping carriers on the 2D conductance enhancement in topological insulators. The method offers an approach to understanding not just the topological insulators but also the 2D to 3D crossover of conductance in other complex systems [3].

[1] A-P Li et al., Adv. Funct. Mater. 23 (2013), p. 2509.
[2] C Durand et al., Nano Lett., 16 (2016), ASAP. DOI: 10.1021/acs.nanolett.5b04425.
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