Berry-phase-controlled weak antilocalization and Josephson effects in HgTe topological insulator materials

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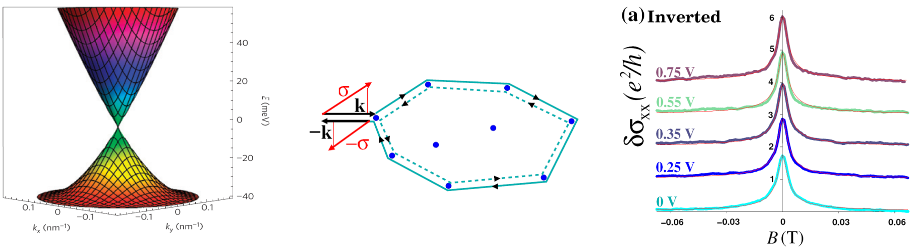
This work is focused on transport phenomena in topological insulators (TIs). Unlike conventional insulators, these novel nanomaterials exhibit nontrivial conduction properties originating from metallic-like boundary (edge or surface) states. The boundary states have a Dirac-cone energy bands (see Fig., left) characterized by nontrivial Berry phases. In this contribution, we demonstrate, both theoretically and experimentally, that the band Berry phases lead to unusual transport phenomena in HgTe TI materials:

(i) Weak antilocalization in HgTe nanostripes. As well known, in low-dimensional conventional systems electronic states tend to be localized by static disorder (e.g. due to impurities). Remarkably, this never happens in TI materials because the Berry phases hinder constructive quantum interference in the random disorder potential (see Fig., center). Moreover, we find that HgTe quantum wells exhibit weak antilocalization observable via a positive magnetoresistance. It is extremely strong in quasi-1D diffusive nanostripes with inverted band ordering and only weakly depends on the Rashba spin-orbit splitting, persisting even for zero splitting (see Fig., right). We propose a theoretical model that explains our findings in terms of the band Berry phases of single-valley Dirac fermions [1,2].



(ii) Zero-bias anomaly and topological midgap states in Josephson junctions. We also investigated transport in HgTe TIs with superconducting contacts. We observe and theoretically explain a zero-bias anomaly (pronounced resistance drop) resulting from Andreev reflection and the induced superconductivity on the TI surface [3]. Furthermore, in the TI Josephson junctions the Berry phase leads to topological midgap Andreev bound states [4] which are intimately related to Majorana fermions. We suggest schemes to detect these topological states in transport measurements.

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