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Electrical control of spin in topological insulators

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All-electrical manipulation of electron spin in solids becomes a central issue of quantum information processing and quantum computing. The many previous proposals are based on spin-orbit interactions in semiconductors. Topological insulator, a strong spin-orbit coupling system, make it possible to control the spin transport electrically. Recent calculations proved that external electric fields can drive a HgTe quantum well from normal band insulator phase to topological insulator phase [1]. Since the topological edge states are robust against local perturbation, the controlling of edge states using local fields is a challenging task. We demonstrate that a p-n junction created electrically in HgTe quantum wells with inverted band structure exhibits interesting intraband and interband tunneling processes. We find a perfect intraband transmission for electrons injected perpendicularly to the interface of the p-n junction. The opacity and transparency of electrons through the p-n junction can be tuned by changing the incidence angle, the Fermi energy and the strength of the Rashba spin-orbit interaction (RSOI). The occurrence of a conductance plateau due to the formation of topological edge states in a quasi-one-dimensional p-n junction can be switched on and off by tuning the gate voltage. The spin orientation can be substantially rotated when the samples exhibit a moderately strong RSOI [2]. An electrical switching of the edge-state transport can also be realized using quantum point contacts in quantum spin Hall bars. The switch-on/off of the edge channel is caused by the finite size effect of the quantum point contact and therefore can be manipulated by tuning the voltage applied on the split gate [3,4]. The magnetic ions doped on the surface of 3D TI can be correlated through the helical electrons. The RKKY interaction mediated by the helical Dirac electrons consists of the Heisenberg-like, Ising-like, and Dzyaloshinskii-Moriya (DM)-like terms, which can be tuned by changing the gate voltage. It provides us a new way to control surface magnetism electrically. The gap opened by doped magnetic ions can lead to a short-range Bloembergen-Rowland interaction. The competition among the Heisenberg, Ising, and DM terms leads to rich spin configurations and an anomalous Hall effect on different lattices [4]. There are many proposals for quantum computation scheme are based on the spin in semiconductor quantum dots. Topological insulator quantum dots display a very different behavior with that of conventional semiconductor quantum dots [5]. In sharp contrast to conventional semiconductor quantum dots, the quantum states in the gap of the HgTe QD are fully spin-polarized and show ring-like density distributions near the boundary of the QD and optically dark. The persistent charge currents and magnetic moments, i.e., the Aharonov-Bohm effect, can be observed in such a QD structure. This feature offers us a practical way to detect these exotic ring-like edge states by using the SQUID technique.

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