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Magneto-Electric Effect in Three-Dimensional Topological Insulators from Surface Magnetic Disorder and Ferromagnetic Thin Film

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Topologically nontrivial gapped phases can be characterized by the bulk topological indices and the surface gapless modes. The topological magneto-electric (ME) effect is a novel manifestation of the bulk-surface correspondence in which the bulk magnetization is generated by a circulating quantized Hall current flowing at the surface of topological insulators. To realize the topological ME effect, there are two difficulties: (a) one needs to attach an insulating ferromagnetic layer with the magnetization normal to the surface all pointing out or in. (b) The Fermi energy must be tuned accurately within the small gap of the surface Dirac spectrum opened by the exchange interaction. In this talk we discuss the anomalous quantized Hall current on the surface of a magnetically doped topological insulator, basing on the two-dimensional surface Dirac Hamiltonian with magnetic disorder. The scaling analysis indicates that, in sharp contrast to the time-reversal-invariant cases, the all surface states tend to be localized while the Hall conductivity is quantized no matter whether the Fermi level resides within or out of the surface gap. This resolves problem(b). Furthermore it is shown that this also resolves problem (a) with the simultaneous application of magnetic and electric fields parallel or antiparallel to each other. By this method, doped local spins can be controlled by the bulk energy which can overcome the magnetic anisotropy and Zeeman splitting at the surface. We also comment on the generalization of the topological responses to the case of topological superconductors and superfluids. This work was done in collaboration with Naoto Nagaosa, Shinsei Ryu, and Akira Furusaki. K. Nomura and N. Nagaosa, Phys. Rev. Lett. 106, 166802 (2011); K. Nomura, S. Ryu, A. Furusaki, N. Nagaosa, arXiv:1108.5054.