Numerical Modeling of Nanoconstrictions in Two-Dimensional Topological Insulators

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Even though the experimental observation of the quantum spin Hall effect was reported for 2D non-magnetic topological insulators, the quantization accuracy of conductance is rather unsatisfactory. Therefore, it is important to determine the reasons for the imperfect quantization through studying the properties of the edge states depending on the structure design and disorder. Motivated by experimental studies of quantum point contacts, which follow previous studies [1], we investigate theoretically transport properties of HgTe/(Hg,Cd)Te quantum wells by using scattering matrix formalism. We perform calculations for three different classes of shapes of the point contacts and various sizes of them in each of the classes. We determine the parameters of the constriction for which the conductance begins to decrease from the quantized value, i.e., conditions under which the topological protection ceases to operate. These parameters show a strong dependence on the position of the Fermi level inside the bulk band gap. We also study the impact of uncorrelated and correlated disorder on the conductance in the case of a stripe geometry. The dependence of the wavefunction decay length on the disorder strength and the Fermi energy is established. We map the simulation results onto the experimental results and tell to what extent alloy fluctuations in the barrier and residual impurities in the well may account for breaking of the topological protection, if a weak time-symmetry breaking mechanism is allowed. We also investigate multiple quantum point contacts arranged in series in order to form interferometers. We show how by adjusting the magnetic field flux through the samples one can control the probability of transmission through the interferometer and how its properties change depending on the geometry of the contacts and the disorder in the sample.
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