Nonlocal transport near charge neutrality point in two-dimensional topological insulator

A.Rahim,[1] A.D.Levin,[1] G.M.Gusev,[1] Z.D.Kvon,[2,3], E.B Olshanetsky,[2] N.N.Mikhailov,[2] and S.A.Dvoretsky,[2]

[1]*Instituto de Física da Universidade de São Paulo, 135960-170, São Paulo, SP, Brazil*
[2]*Institute of Semiconductor Physics, Novosibirsk 630090, Russia*
[3]*Novosibirsk State University, Novosibirsk, 630090, Russia*

The two-dimensional (2D) topological insulator (quantum spin Hall insulator) is characterized by a bulk energy gap and boundary modes that are robust to nonmagnetic impurity scattering. The 2D quantum spin Hall insulator (QSHI) have been realized in HgTeCdTe quantum well with a width $W > 6.3nm$. Indeed, the presence of the edge state transport in the absence of magnetic field has been recently demonstrated both in the ballistic [1] and diffusive cases [2] in HgTe quantum wells. This novel state is driven by the intrinsic spin-orbit interaction, which leads to the formation of the helical edge modes with opposite spin polarization counter-propagating at a given edge. The resistance of samples longer than 1μm might be much higher than $h/2e^2$ due to the presence of the spin dephasing (electron spin flip backscattering on each boundary). Mechanisms of the back scattering are new and appealing task for theoreticians and is a matter of ongoing debate. An unambiguous way to prove the presence of edge state transport mechanism in a 2DTI are the nonlocal electrical measurements. The application of the current between a pair of the probes creates a net current along the sample edge, and can be detected by another pair of the voltage probes away from the dissipative bulk current path. It has been demonstrated that the resistance of HgTe quantum wells reveals a sharp peak, when the gate voltage induces an additional charge density, altering the quantum wells from an n-type conductor to a p-type conductor via a QSHI state[1, 2]. These behaviours resemble the ambipolar field effect observed in graphene [3].

The mechanism responsible for the observed peak in the local and nonlocal resistances near the charge neutrality point (CNP) in HgTe quantum wells relies on the combination of the edge state and bulk transport contributions with the backscattering within one edge as well as bulk-edge coupling both taken into account. When the gate voltage is swept through the CNP the local and nonlocal transport coefficients arise from the edge state contribution at CNP and short-circuiting of the edge transport by bulk contribution away from CNP.

In this paper we report on the observation and a systematic investigation of a local and nonlocal transport in HgTe quantum wells with inverted band structure corresponding to the QSHI phase. The measurements were performed in the different devices. The device A consists of three $4\mu m$ wide consecutive segments of different length $(2, 8, 32\mu m)$, and 7 voltage probes. The device B was fabricated with a lithographic length $6\mu m$ and width $5\mu m$. We provide details on the model taking into account the edge and bulk contribution to the total current. In the full edge + bulk transport model the density dependence of the local and nonlocal transport coefficients arises from bulk conductivity short circuiting the edge current away from the charge neutrality point. The model reproduces the key features of the data, in particular the density dependencies of the local and nonlocal resistivity.

[1] M. Konig et al, Science 318, 766 (2007)
[2] G.M.Gusev, Z. D. Kvon, O.A.Shegai, N. N. Mikhailov, S. A. Dvoretsky and J. C. Portal, Phys. Rev. B 84, 121202(R), (2011)
[3] S. Das Sarma, Shaffique Adam, E. H. Hwang, Enrico Rossi, Rev. Mod. Phys., 83, 407 (2011)