Giant Zeeman-splitting induced Spin Hall Effect in Dirac Fermions system in HgTe quantum wells

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We report the observation of a giant nonlocal effect in Dirac point of a single valley gapless Dirac fermions system in HgTe quantum wells (QW) with the thickness d = 6.6 nm closed to the critical one corresponding to a transition from the direct to inverted band structure. We attribute this nonlocality to Zeeman splitting induced spin-Hall effect recently observed in graphene [1,2]. Unlike graphene the found nonlocality expands on macroscopic scale of several hundreds microns due to very long spin relaxation length.

The samples studied were the Hall bars with a width of 50 μm and a distance of 100 μm and 350 μm between voltage probes were fabricated by means of photolithography on the basis of (013)-oriented HgTe quantum wells with thickness 6.6 nm. As were shown recently in cyclotron resonance and weak localization experiments [3,4] in such kind of QW the system of single valley gapless 2D Dirac fermions is realized. Next, the ohmic contacts were prepared by annealing of indium. After that a double dielectric layer consisting of 100 nm SiO_2 and 200 nm Si_3N_4 was deposited at temperature 100°C. Then TiAu metallic gate was evaporated on the top of structure. The final device represented field effect transistor in which the conductivity of 2D electron system in HgTe QW was be able to change by applying the gate voltage V_g. The measurements of local and nonlocal resistance in the described samples were carried out in the temperature range 1.5 K – 10 K in a magnetic field up to 2 T by means of a standard Lock-in detection technique at frequencies 6–32 Hz with the excitation currents 1–100 nA through the sample. The main results are as follows:

1. At temperature range 1.5 – 25 K and in magnetic field range 0.3 – 1 T the nonlocal transport response (nonlocal resistance $\mathbf{R_{nonloc}}$) was observed at Dirac point of all studied samples while no nonlocal signal was seen out of its vicinity. Magnetic field dependence of nonlocal response has the threshold character with $B_{th} \approx 0.3$ T then at it saturates at B ≈ 0.5 T and does not change up to 1 T. As the temperature increases $\mathbf{R_{nonloc}}$ falls as $\mathbf{R_{nonloc} \approx T^{-1}}$.

2. At 1.5 K and B = 1 T nonlocality has the giant magnitude. The nonlocal resistance $\mathbf{R_{nonloc}}$ is in fact equals to local resistivity $\boldsymbol{\rho_{xx}}$ when the distance between current probes and potential ones is 100 μm. The increasing of this distance up to 350 μm leads to strong exponential fall of $\mathbf{R_{nonloc}}$.

3. Qualitatively the found nonlocality is very similar to that observed recently in graphene [1.2] and according to the theory developed in [2] can attribute to Zeeman splitting induced spin-Hall effect in Dirac point of the system studied. It means that giant nonlocal response reflects "giant" value of spin-Hall coefficient close to 1 as in graphene, which is 10^3 times bigger than in ordinary spin-Hall effect. But in comparison with graphene in our case nonlocality expands on much longer distance (several hundreds microns). We suggest that it is due to much higher Zeeman splitting in HgTe-based Dirac system than in graphene.

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