Surface States in HgTe Quantum Well and Interface-Roughness Scattering.

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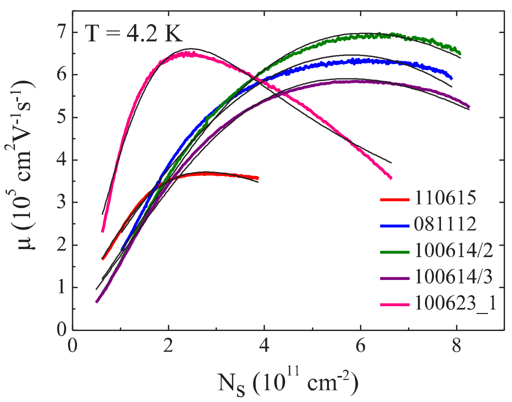

Fig.1 Experimental and calculated (thick black lines) mobility $\mu(N_s)$ curves versus electron concentration at $T = 4.2$ K. Orientation of the sample 100623_1 is (100), of others – (013).

At the present time HgTe quantum well (QW) is one of the most intensively investigated subject of two-dimensional electron system (2DES) physics. First of all it is caused by the unique energy spectrum of 2DES in HgTe QW which is possible due to strong relativistic effects and consequently spin-orbit interaction. Due to it in recent years some new sorts of low-dimensional electron systems, such as 2D topological insulator, 2D semimetal, 2D Dirac fermions, have been realized.

This work is devoted to experimental and theoretical investigation of interface-roughness electron scattering in wide ($d = 18$-22 nm, d is a well width) HgTe QW with the inverted energy spectrum. The research was done by study the mobility μ dependence on electron concentration N_s at low temperature; corresponding curves for several samples are shown in Fig. 1. Qualitative behavior of all $\mu(N_s)$ curves is seen to be identic: at low N_s the mobility increases, then it attains a maximum of $(4\text{-}7)\cdot 10^5$ cm^2 / Vs and after that starts to decrease. Such behavior denotes two scattering mechanisms: impurity scattering, dominating at low N_s, and interface-roughness scattering which is the main at large N_s. To describe the first one, common expressions were used; while the typical theory of interface-roughness scattering was not well suited. The reason was an insufficient scattering amplification with concentration increase for appearance the mobility maximum within presented concentration range. The matter is that according to the typical theory, scattering increase is caused by a wave function maximum shift towards a well interface, in its turn caused by a well deformation at a nonzero gate voltage. However the well depth of the describing systems is large enough (about 0.5 eV) that its shape varies slightly at the gate voltages used in the experiment. Hence the theory of interface-roughness scattering, taking into account an electron wave function alteration with concentration increase predicted in articles [1, 2], was developed. According to named papers at $k < \pi/d$ (k is an electron wave vector) the wave function is in a conventional manner localized near the well center, while at $k > \pi/d$ its maximum shifts towards one of the well heterointerface, and the shift direction depends on the sign of the vector product of electron momentum and its spin. That is to say the wide HgTe QW at large concentrations is a topological insulator equivalent to the three-dimensional one but having a quantum well as a volume rather than 3D crystal. Predicted electron localization near interfaces results in a greater amplification of electron scattering by roughnesses than it happens in an ordinary case; corresponding curves, calculated according to this theory and shown in Fig. 1 by thin black lines, are seen to describe experimental ones quite well. Therefore the conclusion of a surface states existence in wide ($d \approx 20$ nm) HgTe quantum well at large electron concentration and hence realization of topological insulator based on the well, as described above, was done. Also it is worth to be mentioned that used as parameters values of roughness height ($h \approx 1.5$ Å - is of the order of an interplanar spacing) and lateral size (10 - 20 nm) have the same order as ones of QW based on AlGaAs / GaAs heterojunction [3].

References

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