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On the Peculiarities of Galvanomagnetic Effects in High Magnetic Fields in Twisting Bicrystals of the 3D Topological Insulator $Bi_{1-x}Sb_x$ ($0.07 \le x \le 0.2$)

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Abstract—Galvanomagnetic effects in twisting bicrystals of $Bi_{1-x}Sb_x$ alloys ($0.07 \le x \le 0.2$) at low temperatures and in magnetic fields up to 40 T are studied. It is found that, at small crystallite misorientation angles, the semiconductor–semimetal transition is induced in the central layer (~60-nm-thick) and two adjacent layers (each ~20-nm-thick) of the interface at different values of ultraquantum magnetic field. Bicrystals with large misorientation angles, being located in strong magnetic fields, exhibit quantum oscillations of the magnetoresistance and the Hall effect, thus indicating that the density of states is higher and charge carriers are heavier in the adjacent layers of the interfaces than in the crystallites. Our results show also that twisting bicrystals contain regions with different densities of quantum electronic states, which are determined by the crystallite misorientation angle and magnetic-field strength.

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1. INTRODUCTION

Narrow-gap semiconductor alloys $Bi_{1-x}Sb_x$ ($0.07 < x < 0.15$) are the first (see [1–4]) theoretically predicted and experimentally found three-dimensional (3D) topological insulators (TIs). They are characterized by an inverted (with respect to Bi) ordering of energy extrema near the points L of the Brillouin zone; an indirect energy gap between the minima of L electrons and maximum of T holes; asymmetric Dirac surface states [5]; and spin-polarized states, which link the valence and conduction bands in a nontrivial topological form [6].

Galvanomagnetic phenomena are attractive for studying the characteristics of charge carriers in ultraquantum magnetic fields for inducing electronic phase transitions of the semiconductor–semimetal type, semimetal–semiconductor type [7–9], etc.

In this paper, we report the results of studying bicrystals of $Bi_{1-x}Sb_x$ alloys ($0.07 < x < 0.15$) in very strong magnetic fields. The study is aimed at revealing the specific features of the interaction of charge carriers in systems of different dimensions, including the boundary of a quasi-two-dimensional superconductor and a 3D TI [10].

2. EXPERIMENTAL

Twisting bicrystals were obtained by the floating-zone method using the double-seed technique. The experimental samples were rectangular bars 1 × 2 × 4 mm in size, with a ratio of the interface volume to the total bicrystal volume of $\sim 10^{-4}$. The sample composition was monitored by scanning electron microscopy (SEM) and optical emission spectrometry using a Jobin-Yvon JY-38-S spectrometer. We investigated two groups of twisting bicrystals (see Fig. 1): samples with a small misorientation angle (SMA, $\theta_1 < 9°$) and samples with a large misorientation angle (LMA, $\theta_1 > 12°$). The width of the interface layers (ILs) was estimated to be ~100 nm using the SEM data and the magnetic-field values at which quantum oscillations begin to manifest themselves.

The bicrystal crystallites were 3D TIs, whereas the interfaces of $Bi_{1-x}Sb_x$ bicrystals ($0.07 < x < 0.15$) at $T_{onset} \le 35$ K exhibited one or two superconducting transitions [11, 12] (see Fig. 2). At one resistive transition, characteristic of LMA samples, the critical temperature T_c was ~3.7–4.6 K (for different bicrystals), and the hysteresis loops were the same as for weak ferromagnets (Fig. 2b, inset). At the same time, the hysteresis loops for most of the SMA bicrystals with two