QUANTUM OSCILLATIONS OF MAGNETORESISTANCE AND SIZE EFFECTS IN $Bi_{1-x}Sb_x$ TOPOLOGICAL INSULATOR SEMICONDUCTOR WIRES

OSCILAŢII CUANTICE ALE MAGNETOREZISTENŢEI ŞI EFECTE DIMENSIONALE IN FIRE SEMICONDUCTOARE ALE IZOLATORILOR TOPOLOGICI $Bi_{1-x}Sb_x$

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Currently, $Bi_{1-x}Sb_x$ alloys in the semiconductor concentration range in the form of low-dimensional structures (films, wires) are the subject of extensive research, because, on the one hand, they exhibit the properties of topological insulators (TIs) [1] and, on the other hand, small effective masses and long free paths of charge carriers contribute to the occurrence of size effects at larger diameters and higher temperatures than those in pure bismuth [2].

This paper describes results of studying the electron transport, Shubnikov–de Haas (SdH) oscillations, and manifestations of classical and quantum size effects in longitudinal(LMR) and transverse magnetic fields of $Bi_{0.83}Sb_{0.17}$ alloy TI semiconductor wires in a wide range of temperatures, magnetic fields, and wire diameters.

Glass-insulated $Bi_{0.83}Sb_{0.17}$ wires with a thickness of 75 nm to 1 μm were prepared by liquid-phase casting in accordance with the Ulitovsky method [3]. The samples had a strictly cylindrical shape and the (1011) orientation along the wire axis.

Figure 1 shows temperature dependences of the resistance $R_T/R_{300}(T)$ of wires with the different diameters in a temperature range of 4.2–300 K. The $R_{4.2}/R_{300}$ resistance of the wires at 4.2 K increases with an increase in the diameter (inset in Fig.1). The "semiconductor" and "metallic" behaviors of the $R_T/R_{300}(T)$ dependences are separated by an

R_{max} maximum, the position of which linearly depends on wire diameter d, namely, a transition from the semiconductor to metallic behavior, which represents the effect of surface states characteristic of TIs. The energy gap ΔE value calculated from the $\rho_T = \rho_0 * \exp(\Delta E/2k_0T)$ dependences is shown in Fig. 1b. For wires with d = 1000 nm, ΔE = 21 meV, which is consistent with the values obtained for bulk $Bi_{1-x}Sb_x$ samples [4]. With a decrease in the wire diameter, ΔE increases in 2 times in accordance with the following law: $\Delta E \sim 1/d$ (Fig. 1b) and it indicates that the cause of the increase in the ΔE energy gap is the quantum size effect [2], as in pure Bi wires [3].

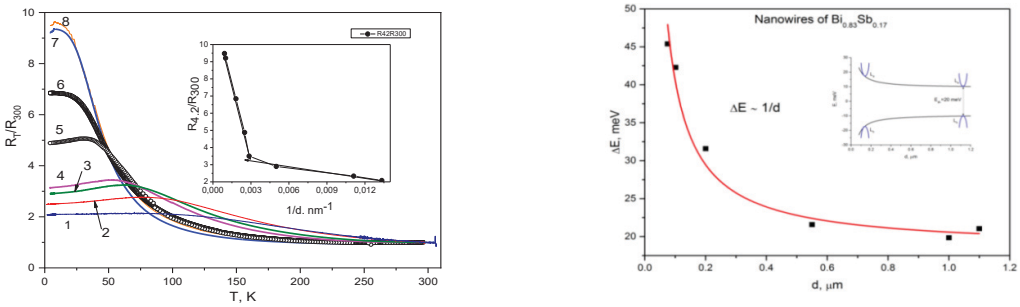


Fig. 1. (a) Temperature dependences of resistance $R_T/R_{300}(T)$ of $Bi_{0.83}Sb_{0.17}$ wires with the diameters (in nm): d = (*1*) 75 , (*2*) 100 , (*3*) 200, (*4*) 350, (*5*) 450, (*6*) 550, (*7*) 900, and (*8*) 1100 nm. Inset: $R_{4.2}/R_{300}(1/d)$ dependence; (b) dependence of energy gap ΔE on wire diameter d

The transverse and longitudinal magnetoresistance $R_н/R_0(H)$, SdH oscillations on $dR/dH(H)$, and their angular dependences in magnetic fields of up to 14 T were studied. The LMR ($H//I$) has a maximum that depends on wire diameter d, $H_{max} = p_F\ c$ /ed, this indicates the occurrence of a galvano-magnetic size effect. The Fermi momentum component p_F perpendicular to the magnetic induction vector H exceeds the values for pure Bi by a factor of 5. The dependences of quantum number $n(H^{-1})$ of SdH oscillations for three directions of the magnetic field are shown in the inset of Fig. 2b.

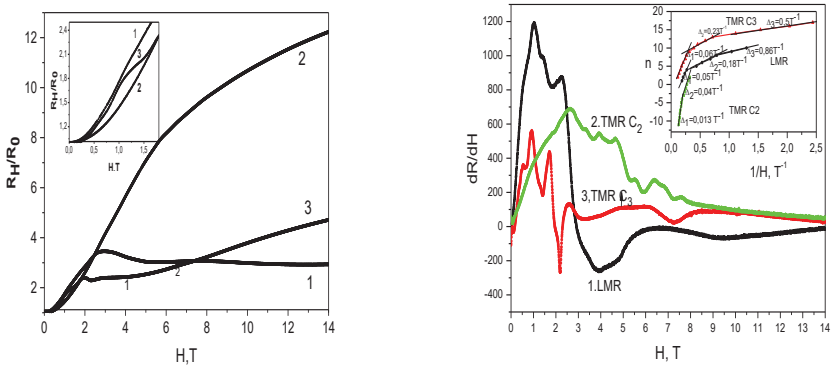


Fig. 2. (a) Field dependences $R_H/R_0(H)$ at $H \parallel I$ (*1*) and $H \perp I$ ($H \parallel C_{2)}$ (*2*) and $H \perp I$, ($H \parallel C_{3)}$, (*3*) $Bi_{0.83}Sb_{0.17}$ wire with d = 200 nm at 4.2 K:, inset - initial of the curves up to 2 T; (b) $dR/dH(H)$ of curves (*1*)–(*3*); the inset -the dependence of quantum number n of SdH oscillations on H^{-1}

In magnetic fields (2 T < H), the SdH oscillation frequency is F = 2 T at $H \parallel I$. In magnetic fields (H > 3 T), the maximum frequency is F = 18–20 T for both $H \parallel C_2$ and $H \parallel C_3$. (Fig.2b inset) Comparison of the SdH oscillation periods with bulk $Bi_{0.91}Sb_{0.09}$ samples [4] shows a significant difference in the periods for all directions of the magnetic field. The $\Delta(H^{-1}) < 0.5\ T^{-1}$ values for the bulk samples were obtained only at $H \parallel C_3$. [4].At a deviation of a magnetic field from direction H ⅢI ,-H_{max} on R (H) shift in area of strong magnetic fields as H_{max}~1/cos α for wires with d =100nm (fig.3a,insert) and linearly increases in 1,7 times at wires with d = 75nm (inset fig.3b,above). Magnetoresistance in a point of maximum ($R_H/R_{0(max)}$) linearly decreases at wires with d = 100nm and nonmonotonic at wires with d = 75nm (inset fig3,at the left.)

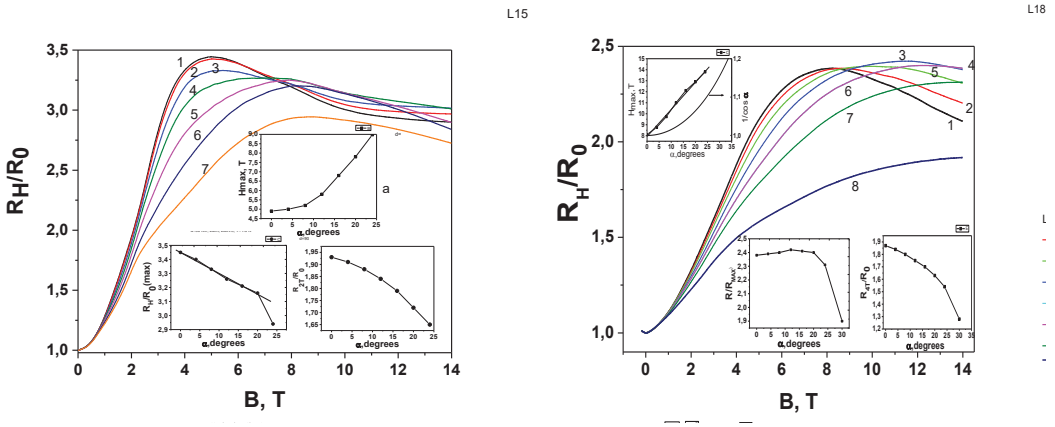


Fig. 3. Angular dependences $R_H/R_0(H)$ at magnetic field from $H \parallel I$, (a)-d= 100 nm, (b) d=75 nm, 1 α=0°,2- α =4°, 3- α=8°,4. α=12°, 5. α=16°, 6. α=20° 7. α=24° ,insets (a,b) - $H_{max}(\alpha)$- above. $(R_H/R_0)_{max}(\alpha)$- at the left, $R_{2T}/R_0(H)(\alpha)$ -on the right

This significant difference in the SdH oscillation frequency values occurrence of the quantum size effect, the "metallic" behavior of conductivity is attributed to surface states characteristic of topological insulators , anomalies and differences in the angular dependences of the LMR of the wires with the different diameters can be associated with the features of the manifestation of surface states in low-dimensional 1D TI structures; it suggests that there is a relationship between the surface and bulk states; as in 2D TI systems (films), it is reasonable to expect new effects that have not been observed earlier in other systems.

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This work was financially supported by the State Program of the Ministry of Education and Research of the Republic of Moldova (project no. 20.80009.5007.02) and the following American foundations: NSF through STC CIQM 1231319, the Boeing Company, and the Keck Foundation.