PECULIARITY OF SEMICONDUCTOR-SEMI METAL TRANSITION IN MAGNETIC FIELD IN BICRYSTALS OF Bi_{1-x}Sb_{x} (0,08 ≤ x ≤ 0,12) ALLOYS

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ABSTRACT: The magnetoresistance of single crystals and bicrystals of Bi_{1-x}Sb_{x} (0,08 ≤ x ≤ 0,12) alloys in stationary (up to 14 T) and pulsed (up to 30 T) magnetic fields was investigated. It was found that the semiconductor-semimetal transition in macroblocks and internal boundary of bicrystals is induced at different values of magnetic field due to a rotation of the Fermi surface at the internal boundary.

I. INTRODUCTION

The internal boundary (IB) between two macroblocks in bicrystals is of a special interest as an object for studying different physical problems. One of them is the influence of disturb spatial homogeneity in the samples on semiconductor-semimetal (SC-SM) transition in ultraquantum magnetic fields.

For the first time the SC-SM transition has been observed by N.Brandt et al. [1] in single crystals of narrow-gap semiconducting Bi_{1-x}Sb_{x} (0.08 ≤ x ≤ 0.15) alloys. It was found, that at B||C3 magnetoresistance ρ(B) sharply decreases after the certain critical value of magnetic field B_c and dependence ρ(T) typical for metals appears. The SC-SM transition in magnetic fields was explained by a band edge displacement [2], when the spin splitting of the energy levels of charge carriers exceeds the orbital splitting (γ = Δε_s/Δε_{orb} > 1).

In this paper the magnetoresistance of Bi_{1-x}Sb_{x} (0.08 ≤ x ≤ 0.12) bicrystals is investigated for studying the peculiarities of SC-SM transition conditioned by the presence of IB.

II. EXPERIMENTAL METHODS

Single crystals and bicrystals of Bi_{1-x}Sb_{x} (0,08 ≤ x ≤ 0,12) semiconducting alloys were obtained by the zone recrystallization method using a double seed technique. The samples for measurements were prepared in the parallelepiped form. We have investigated the small angle bicrystals in which the angles between the axes C_3 of crystallites (the disorientation angles θ) were in the range 1° ≤ θ ≤ 9° (Fig.1, inset (a)). The crystallites were unwound by an angle 2° ≤ φ ≤ 4° with respect to each other around the normal to the internal boundary. The width of IB of bicrystals was 140nm ≤ L ≤ 200nm. The composition of the samples was controlled by X–ray methods.

The measurements in stationary (up to 14 T) and pulsed (up to 30 T) magnetic fields were carried out in the International Laboratory of High Magnetic Fields and Low Temperatures (Wroclaw, Poland).

III. RESULTS AND DISCUSSION

The following dependences of resistance ρ(B) in single crystals and bicrystals of Bi_{1-x}Sb_{x} (0,08 ≤ x ≤ 0,12) alloys (n-type of conductivity in semiconductive state) at 4,2 K were observed. The Shubnikov-de Haas oscillations were distinctly observed at field B < 1T. Ultraquantum limit of the magnetic field (B ≈ 1T) was achieved both in single crystals and in bicrystals. In ultraquantum magnetic fields magnetoresistance ρ(B) of single crystals has a maximum at B||C_3, and then it sharply decreases (Fig.1). Presence of this maximum is caused by the transition in the
semimetallic state in high magnetic field [1] ($L_{\sigma}$ and $T_{d5}$ extrema are overlapped). Magnetoresistance of bicrystals at $B \parallel IB$ ($B \parallel C_3$ in macroblocks) increases in the beginning, then passes the first

maximum (at $B_{c1}$ value similar to that in single crystals), weakly falls down to a certain value, increases again and passes the second maximum (at value $B_{c2}$ slightly depending on $\theta$ and $\varphi$). The measurements in stationary and pulsed magnetic fields show that $\rho(B)$ at $B > B_{c2}$ falls down to 30 T.

Note, that the single crystals and the bicrystals of Bi$_{1-x}$Sb$_x$ ($0.08 \leq x \leq 0.12$) alloys were obtained in the same technology conditions (single crystals were cut from macroblocks of bicrystals). X-ray investigations do not reveal difference between compositions of macroblocks and IB of bicrystals. The positions of magnetoresistance maximum for single crystals and the first maximum for bicrystals (SC-SM transition in macroblocks) coincide. Only the concentration of electrons in
bicrystals (semiconductive state) is a few more than in single crystals. For example, in bicrystal of alloy with $x = 0.08$ the electron concentration is more $\sim 9\%$.

The insignificant surplus of electron concentration in internal boundary region (probably due to the presence of unsaturated bands at IB) can not produce a significant delay of SC-SM transition in magnetic field, because the Fermi level of electrons in IB is only $\sim (8-10)\%$ higher than in macroblocks. Therefore we assumed that the second maximum on the magnetic field dependences of the bicrystal resistance is determined by IB transition in the semimetallic state, i.e. the change of spin splitting factor $\gamma$ takes place.

The change of spin-orbital splitting characteristics at the orientation of the magnetic field parallel to IB can be connected with the rotation of the Fermi surface of $L_{a}$-electrons on crystallite interface [3] ($\sim 74^\circ$ relatively the position in macroblocks). As a result of the Fermi surface rotation spin splitting factor $\gamma$ for $L_{a}$-electrons at $B \parallel IB$ becomes close to 1, i.e. the position of Landau sublevel $0^\circ$ (the bottom of the conduction band) in ultraquantum limit is not changed, and SC-SM transition takes place in higher magnetic field. On the other hand, for magnetic field directions at $B \parallel C_3$ in single crystals (as well as in macroblocks of bicrystal) of Bi$_{1-x}$Sb$_{x}$ ($0.08 \leq x \leq 0.12$) alloys electron $\gamma$-factor is higher than 1 ($\Delta\epsilon_a > \Delta\epsilon_{orb}$) and SC-SM transition takes place in smaller fields. This fact is in a good agreement with the results [4], where it was shown that spin splitting of electrons is significantly greater than orbital splitting at the same orientation of magnetic field ($B \parallel C_3$).

Thus, it was established that SC-SM transition is induced in macroblocks and internal boundary at different values of the magnetic field due to the rotation of the Fermi surface of $L_{a}$-electrons at the crystallite interface.

IV. CONCLUSIONS

In result of the magnetoresistance investigation of Bi$_{1-x}$Sb$_{x}$ ($0.08 \leq x \leq 0.12$) bicrystals it was found, that the semiconductor-semimetal transition in ultraquantum magnetic fields takes place twice. The first transition (in macroblocks) is analogous to that in single crystals. The second transition (at the internal boundary) is observed in higher magnetic fields and is conditioned by the Fermi surface rotation at the internal boundary of bicrystals.

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REFERENCES