M. Lifshitz phase transitions in the n-type lloy $Bi_{0.924}Sb_{0.076}$ under tension

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A new method of producing strong elastic tensile strains (~1%) in the n-type alloy $Bi_{0.924}Sb_{0.076}$ used to observe the transition from a three-ellipsoid to a single-ellipsoid Fermi surface when stretched along the binary axis and to a two-ellipsoid surface when stretched along the bisector axis.

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The Lifshitz phase transitions,[1] which are accompanied by a qualitative change in the pology of the Fermi surface, were observed under hydrostatic compression in a large number of bstances. In the case of uniaxial deformations, owing to the low elastic limit of most metals and the impossibility of producing sufficiently strong deformations, a change in the topology of the ɜrmi surface was observed only for Zn whiskers[2] at 0.35% elongation. Recently developed ethods of obtaining strong elastic compression strains[3,4] and tension strains,[5] reaching 1% in ılk crystals, greatly extend the possibilities of investigating the I.M. Lifshitz phase transitions ıder uniaxial deformations.

A detailed investigation of the energy spectrum of Bi under compression[6,7] and tension[5,6,8] by ese methods has shown that if the strains are perpendicular to the crystal trigonal axis the ɜctronic extrema at the points L of phase space are no longer equivalent, so that the electron

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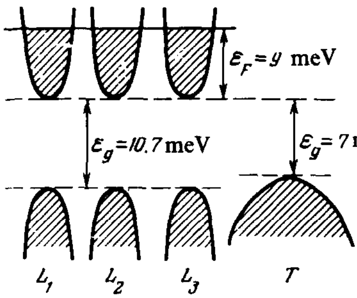

FIG. 1. Arrangement of the electron and hole extrem of n-type $Bi_{0.924}Sb_{0.076}$ near the Fermi level.

"ellipsoids" of the Fermi surface of Bi vary in different manners with changing load: the volume one of the ellipsoids increases and that of the two others decreases in the case of compression alor the bisector axis C_1 and tension along the binary axis C_2, whereas two ellipsoids increase and o decreases if the tension is along C_1 and the compression along C_2. It is obvious that in the case sufficiently strong deformations ($\gtrsim 1\%$ [5,7]) in these directions a qualitative change should tal place in the Fermi surface of Bi, which should turn into a single ellipsoid in the former case ar two ellipsoids in the latter.

Inasmuch the deformations needed to observe the expected phase transition of Bi exceed 1% the object of the investigation was chosen to be the alloy $Bi_{0.924}Sb_{0.076}$ doped with $10^{-4}\%$ of Te, which the Fermi energy of the electrons is much lower than that of Bi. The main characteristics the energy spectrum of this alloy[9,10] are shown in Fig. 1. The small Te additive to this alloy lea to a filling of the electronic extrema in L. The presence of a sufficiently large gap between tl extrema in L and T gives grounds for expecting the total number of the electrons to rema unchanged after the deformation, and that the change of the volumes of the ellipsoids is d exclusively to the transfer of carriers from some extrema (no longer equivalent) L_i to others.

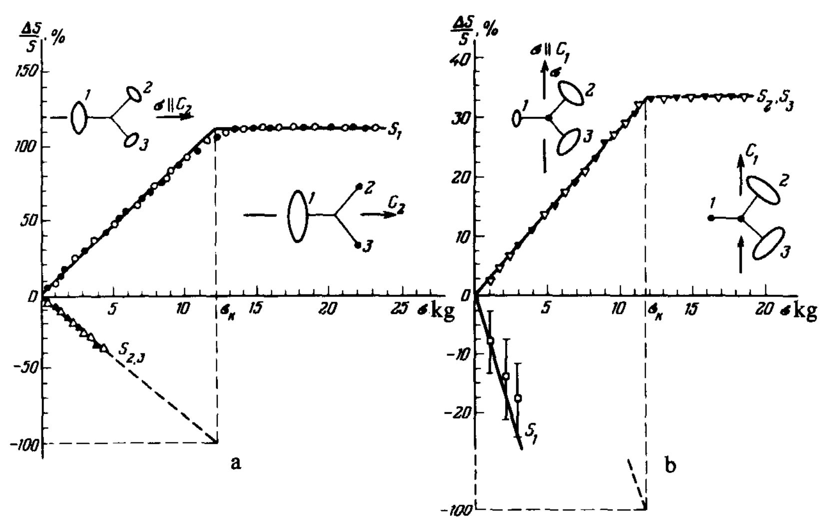

FIG. 2. Dependence of the extremal sections of the Fermi surface of n-type $Bi_{0.924}Sb_{0.076}$ on t load at $\sigma \| C_2$ (a) and $\sigma \| C_2$ (b): sample 1: ○——$85 \leqslant \phi \leqslant 0°$, Δ—$0° \leqslant \phi \leqslant 10°$, sample ○——$85 \leqslant \phi \leqslant 0°$, Δ—$0° \leqslant \phi \leqslant 10°$, sample 3: Δ——$10° \leqslant \phi \leqslant 10°$, $80° \leqslant \phi \leqslant 100°$, ○—$H \| C_2$, sample Δ——$10° \leqslant \phi \leqslant 10°$, $80° \leqslant \phi \leqslant 100°$.

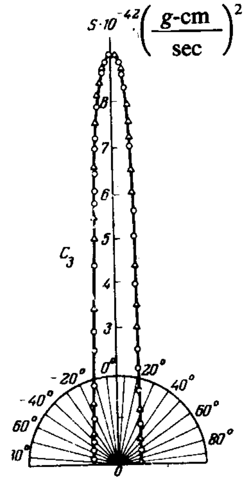

FIG. 3. Angular dependence of the extremal sections in the trigonal-bisector plane for the single-ellipsoid Fermi surface of the n-type alloy $Bi_{0.924}Sb_{0.076}$ at 12.5 kg$\leqslant\sigma\leqslant$25 kg: ○—sample 1, Δ—sample 2. Solid line—ellipse drawn through the extremal sections.

Since direct observation of the vanishing of the individual parts of the Fermi surface under eformation with the aid of the Shubnikov–de Haas effect is impossible, owing to the sharp ecrease of the oscillations from the decreasing groups of carriers, the I.M. Lifshitz phase transions that are accompanied by topological changes of this kind are more conveniently detected by ıe accompanying change of the rate of increase of the other parts of the Fermi surface. From this oint of view, the n-type alloy $Bi_{0.294}Sb_{0.076}$ is a more convenient object for a distinct observation of ıe expected phase transition than pure Bi, in which the vanishing of individual electronic extrema ıkes place against the background of varying overlaps of the bands in L and T.

The samples were stretched in the apparatus described in[5] in the direction of the binary or isector axis, up to a strain $\epsilon_{xx}\sim0.6\%$ in the tension direction and $\epsilon_{yy}\sim0.4\%$ in the perpendicular irection. The strains were determined at room temperature with the aid of FKPA-1 small-base ɔil strain resistors and amounted to $\epsilon_{xx}\approx0.025\%$ kg^{-1} and $\epsilon_{yy}\approx-0.15\%$ kg^{-1}. The change of the nergy spectrum under tension was investigated with the aid of the Shubnikov–de Haas effect by ıe usual modulation method in the temperature interval 1.9–4.2 K and in magnetic fields up to 45 Oe at loads up to 23 kg.

The dependences of the extremal sections of the Fermi surface on the values of σ were ıvestigated in a wide range of angles ϕ with the magnetic field oriented in the trigonal-bisector $\sigma\|C_2$) and trigonal-binary ($\sigma\|C_1$) planes. ϕ was reckoned from the trigonal axis C_3 of the sample. he measurements were made on four different samples. All the observed cross sections of each lipsoids vary with load in like fashion as shown in Fig. 2. The figures show also the schematic rangement of the electron ellipsoids of the Fermi surface in the basal plane and indicates the ıaracter of their variation in the course of dilatation.

It is obvious that the increase of ellipsoid 1 in the case $\sigma\|C_2$ and of ellipsoids 2 and 3 at $\sigma\|C_1$ ontinues until the electronic extrema of L_i, which correspond to decreasing ellipsoids, rise above he Fermi level. At that instant, at $\sigma_k=12\pm0.3$ kg, it follows from Figs. 2a and 2b that in both ases the decreasing ellipsoids vanish, and the increase of the remaining ellipsoids ceases because he influx of the carriers is stopped. Thus, in the n-type alloy $Bi_{0.924}Sb_{0.076}$ at values $\sigma_k\|C_2$ ($\epsilon_{xx}\approx0.3\%$; $\epsilon_{yy}\approx-0.2\%$) an electronic phase transition takes place from a three-ellipsoid ɔ a single-ellipsoid equal-energy surface, and at $\sigma_k\|C_1$ a transition takes place from three-ellipsoid ɔ a two-ellipsoid surface (Figs. 2a and 2b).

It should be noted that the amplitudes of the oscillations of the magnetoresistance due to t increasing parts of the Fermi surface increases to $\sigma \sim \sigma_k$, after which it remains constant. T maximum changes of the volumes of the ellipsoids, namely $V_\sigma/V_0 \approx 3$ when the single-ellipso surface is produced and $V_\sigma/V_0 \approx 1.5$ when a two-ellipsoid surface is produced, indicate that all t existing carriers are transferred to the electronic extrema that remain below the Fermi level.

By obtaining a single-ellipsoid Fermi surface we were able to determine its parameters wi high accuracy. For the obtained single-ellipsoid surface, oscillations of the magnetoresistance a observed at all directions of the magnetic field in the trigonal-bisector plane. This has made possible to determine directly, for the first time ever, the principal intersections of the Ferı surface with this plane: $S_{\min} = (0.52 \pm 0.02) \times 10^{-42}$ (g cm/sec)^2 and $S_{\text{int}} = (9.0 \pm 0.2) \times 10$ (g cm/sec)^2 (Fig. 3). The cyclotron effective masses on the principal sections are m^*_{i} $/m_0 = 0.092 \pm 0.004$ and $m^*_{\min}/m_0 = 0.0059 \pm 0.0006$. The mass anisotropy is $m^*_{\text{int}}/m_0 = 15$ somewhat less than the section anisotropy $S_{\text{int}}/S_0 = 17.3$.

The Dingle temperature determined at $\sigma = 16$ kg amounts to $T_D = (2.2 \pm 0.3)$ K, thus pointi to a high degree of homogeneity of the strain in the investigated part of the sample.

The investigation of the Shubnikov oscillations in the trigonal-bisector plane in the directic $\phi = 1.5 \pm 0.5°$ and $\phi = 8 \pm 0.5°$ have revealed for the first time in Bi and in $Bi_{1-x}Sb_x$ alloys a sp damping (doubling of the frequency) in this plane.

In conclusion, we are sincerely grateful to Ya.G. Ponomarev for supplying the data on t structure of the spectrum of the investigated alloy.

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