Lifshitz singularities in the thermo-emf in n-$Bi_{0.9}Sb_{0.1}$ single crystals due to a 2.5-order transition induced by anisotropic strain

V. S. Egorov,[1)], M. Yu. Lavrenyuk, N. Ya. Minina, and A. M. Savin
M. V. Lomonosov State University, Moscow

(Submitted 25 May 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 1, 25–28 (10 July 1984)

The thermo-emf induced by anisotropic strain at helium temperatures was measured using single-crystal specimens of n-$Bi_{0.9}Sb_{0.1}$. As a result of this strain, all electrons on the Fermi surface (FS) flow over into a single ellipsoid. The topological transition to a single-ellipsoidal FS was monitored by observing the quantum oscillations of the thermo-emf. A characteristic peak is observed in the thermo-emf for strains corresponding to a change in the topology.

One of the most convenient methods of investigating electronic 2.5-order transitions, at which the anomalies in the kinetic and thermodynamic coefficients of the metals, predicted by Lifshitz,[1] should be observed, is the anisotropic strain. On the one hand, a continuous transition in this case is possible through the critical point and, on the other, a much larger range of variation of the relative dimensions of the unit cell and hence of the FS in comparison, for example, with the hydrostatic compression, is attained. A method of straining discotic samples by stretching a yoke that is more rigid than the sample, within which this sample is deformed, has turned out to be highly successful in obtaining record-high anisotropic strains of bulk single crystals. Several different topological changes of the FS of bismuth and its alloys with antimony have been observed by using this method.[2),1] However, aside from observing the electronic transition, which is monitored by observing oscillations of the resistance in a magnetic field (Shubnikov-de Haas effect), the possible anomalies predicted by I. M. Lifshitz were not measured.

Using the same method for obtaining strain as in Ref. 2 and the same types of samples, we measured the thermo-emf while observing the topological transition. As theoretical calculations have shown,[3] the strongest anomalies are expected to be seen in the thermo-emf, which has already been confirmed in the study of 2.5-order transitions in lithium-magnesium alloys.[4]

The investigations were performed on single crystals of n-$Bi_{0.9}Sb_{0.1}$. The three ellipsoids of the FS were filled with electrons due to the donor impurity of the tellurium, whose concentration was $\sim 10^{-4}$ at.%. The single crystals were stretched in the basal plane of the crystal along the C_2 axis, so that the change in the positions of the L terms, shown schematically in Fig. 1, caused all electrons in the FS to flow over into a single ellipsoid. The samples used in the measurements consisted of disks with a diameter of 3 mm and a thickness of 0.8 mm, which were firmly glued in the yoke, so that the $Ox \| C_2$, $Oy \| C_1$, $Oz \| C_3$ axis was the stretching axis (see Fig. 2). Stretching of the yoke along Ox led to a strain of the sample with a load F. This strain, determined by x-ray diffraction, was for 10 N load, respectively, $\epsilon_{xx} = 4.3 \times 10^{-5}$, $\epsilon_{yy} = -9.7 \times 10^{-5}$,

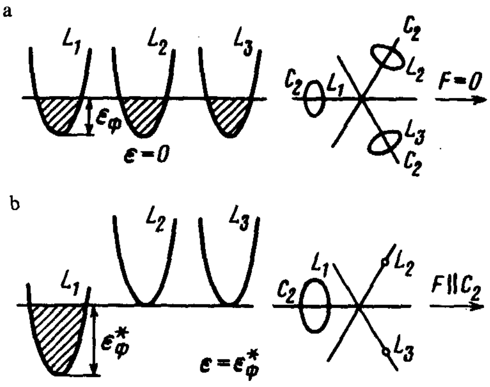

FIG. 1. Schematic diagram of the change in the position of the electronic extrema in n-$Bi_{0.9}Sb_{0.1}$ due to stretching along the C_2 axis. a) Symmetrical filling of extrema with zero load, b) position of extrema at the moment of the topological transition when the distance between the diverging terms is $\epsilon = \epsilon_\Phi^*$. Filling of the corresponding ellipsoids of the *FS* is shown on the right.

and $\epsilon_{zz} = 3.3 \times 10^{-5}$. The region of uniform strain at the center of the disk had dimensions of ~ 1.5 mm^2. Although the strain was reversible, the sample quality deteriorated appreciably after the maximum load was applied 20 times. The ratio of the resistances of the measured samples was $R_{300}/R_{4.2} = 2$. The sizes of the ellipsoids of the FS were monitored during the deformation process by measuring both the Shubnikov-de Haas effect (as in Ref. 2) and the quantum oscillations of the thermo-emf, which turned out to be more convenient. The topological transition occurred when the cross section of the remaining ellipsoid stopped increasing in magnitude, and its energy was determined to within ~ 1 meV. Because of the nonuniform distribution of tellurium, the transitions in different samples occurred at slightly different values of the strain.

The contacts for the measurements were prepared either as clamping contacts from beryllium bronze 0.15 mm in diameter or were welded on with copper wire 0.05 mm in diameter. Their position was determined, first of all, by the fact that the region of uniform strain was located at the center of the disk and, secondly, by the fact that

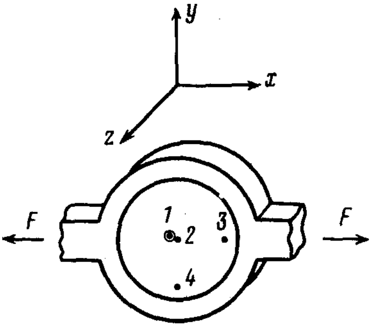

FIG. 2. Specimen with contacts in the stretching yoke. 1) Point heater, 2) "hot" potential contact, 3 and 4) "cold" voltage contacts.

during the flow of electrons into one ellipsoid the conductivity and thermal conductivity (the latter to a much smaller extent) became anisotropic in the plane of the disk. Figure 2 shows schematically the positioning of the clamping contacts with the measurement of the thermo-emf. The sample was heated locally at the point 1 with the help of a sharpened copper rod 0.2 mm in diameter, on which an 8-Ω heater made of manganese wire 0.05 mm in diameter was wound in a bifilar fashion. The "hot" potential contact 2 was placed at a distance of ~0.2 mm from point 1, and the contacts 3 and 4 were placed near the edge of the disk. The potential difference being measured $U_{23(4)}$ is determined by the difference in the thermo-emf in this temperature range is much higher and $\sim T \cdot 1\ \mu\mathrm{W/K}^2$. In this case, the change in U_{23} with the load F can be attributed entirely to the change in the thermo-emf of the sample. The main contribution to the signal which was measured came from the center of the sample, where the temperature gradient was maximum. The heat liberated by the heater was set low enough so that contacts 3 and 4 remained cold, i.e., their temperature was equal to the temperature of the surrounding liquid helium. The sharpest temperature gradient was created in the superfluid helium. The main error in the measurements could stem only from the possible change in the temperature of the "hot" contact 2 during the stretching of the yoke. However, the large number of results obtained in the experiments in which the temperature, power in the heater, and position of the contacts were varied, make it possible to assume that this circumstance could not have had a significant effect on the anomalies observed.

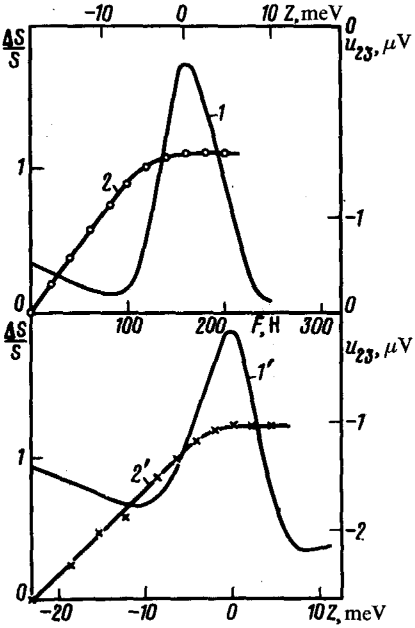

FIG. 3. Dependences of the thermo-emf U_{23} (curves 1 and 1', scale on the right) and of the relative change in the cross section of the growing ellipsoid $\Delta S/S$ (curves 2 and 2', scale on the left) on the magnitude of the load F for two samples. The values of the parameter $Z = \epsilon - \epsilon_\Phi^*$ are plotted on the scale at the top and at the bottom.

Figure 3 shows two typical traces, obtained on the automatic plotter, of the thermo-emf U_{23} as a function of the applied load F, obtained at a temperature $T \approx 2$ K for two samples with slightly different tellurium concentrations. The dependences of the relative change in the extremal cross sections of the growing ellipsoid of the FS for the corresponding samples are also shown here. The values of the load parameter $Z = \epsilon - \epsilon_{\Phi}^{*}$, (which varies linearly with the load), where ϵ is the difference in the energies of the nonequivalent terms L_1 and L_2 (L_3) (which increase with the load), and ϵ_{Φ}^{*} is the Fermi energy of the electrons flowing into one ellipsoid, which turned out to be 18 and 23 meV for curves 2 and 2′, respectively, are plotted at the top and bottom along the abscissa axis. At the transition point (Fig. 1b) $Z = 0$.

It follows from the results obtained that against the background of the monotonic change in the thermo-emf with the load in the region $Z = 0$ there is a positive peak, whose width is ~ 5 meV, i.e., slightly greater than the thermal smearing of the terms. The broadening could be caused by the nonuniform distribution of tellurium noted above, as well as by a possible error of $\lesssim 2°$ in the orientation of the sample.

It should also be noted that the phonon contribution to the thermo-emf, which is especially large in single crystals of pure bismuth, is very sensitive to deformations of the lattice and to the anisotropy of the conductivity. The thermo-emf of the strained sample can therefore become anisotropic. Furthermore, this anisotropy can vary during the deformation, which is highly undesirable. The quantity that we measured would then be the result of a very complicated averaging of the thermo-emf in different directions. However, from the temperature measurements of the thermo-emf in n-$Bi_{0.9}Sb_{0.1}$ alloys, whose compositions are similar,[5,6] we concluded that the contribution from the entrainment of phonons to the thermo-emf is insignificant. Because of this circumstance, the diffusion thermo-emf which we measured remains, as we know from Ref. 7, isotropic, in spite of the anisotropy of the conductivity, so that the observed singularity of the thermo-emf is attributable entirely to the singularity in the state density at the point $Z = 0$.

1) I. V. Kurchatov Institute of Atomic Energy.

2) Higher strain can be obtained only by stretching filamentary crystals (whiskers), which, however, unfortunately, do not grow in suitable, reasonable directions.

---

[1] I. M. Lifshitz, Zh. Eksp. Teor. Fiz. **38**, 1569, (1960) [Sov. Phys. JETP **11**, 1130 (1960)].

[2] N. B. Brandt, V. A. Kul'bachinskiĭ, N. Ya. Minina, and V. D. Shirokikh, Zh. Eksp. Teor. Fiz. **78**, 1114 (1980) [Sov. Phys. JETP **51**, 562 (1980)].

[3] V. G. Vaks, A. V. Trefilov, and S. V. Fomichev, Zh. Eksp. Teor. Fiz. **80**, 1613 (1981) [Sov. Phys. JETP **53**, 830 (1981)].

[4] V. S. Egorov and A. N. Fedorov, Zh. Eksp. Teor. Fiz. **85**, 1647 (1983) [Sov. Phys. JETP **57**, 960 (1983)].

[5] N. A. Red'ko, V. I. Pol'shin, V. V. Kosarev, and G. A. Ivanov, Fiz. Tverd. Tela (Leningrad) **25**, 3138 (1983) [Sov. Phys. Solid State **25**, 1807 (1983)].

[6] V. N. Galev, V. A. Kozlov, N. V. Kolomiets, and S. Ya. Skipidarov, Fiz. Tekh. Poluprovodn. **16**, 917 (1982) [Sov. Phys. Semicond. **16**, 589 (1982)].

[7] A. G. Samoĭlovich, M. V. Nitzovich, and V. M. Nitzovich, Phys. Status Solidi **16**, 459 (1966).

Translated by M. E. Alferieff
Edited by S. J. Amoretty