Reflection of electrons and holes of antimony from the sample boundaries

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Transverse focusing (Tsoĭ, 1974) of electrons and holes was observed in antimony. The sign of the carriers influences strongly the character of their reflection from the boundary: in the case of normal incidence the electrons are reflected almost specularly, and the holes diffusely. The difference in the electron and hole reflection is attributed to bending of the bands near the surface (Kravchenko and Rashba, 1969).

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Focusing of electrons (EF) in a metal by a transverse homogeneous magnetic field was observed by one of us experimentally in bismuth.[1] The purpose of the present study was twofold. First, taking into account the extensive possibilities of EF as a research method,[1–4] to observe EF in a metal whose Fermi surface (FS) is not so strongly cylindrical as in bismuth. Second, since investigations of the angular dependence of the electron reflection coefficient $q(\Theta)$ from the sample boundary in bismuth[3,5] have shown that $q(\Theta)$ has a strong dependence on Θ at $\Theta \approx 50=60°$ (steep descent), and the possible cause of so anomalous a behavior is[5] the near-surface bending of the bands,[6] it is of considerable interest to investigate the reflection of oppositely charged quasiparticles from the same section of the surface (the slight difference between the effective masses and velocities of the electrons and holes and the geometry of the FS of antimony favor such an investigation).

We used the same experimental setup as for the observation of EF in bismuth.[1] A plane-parallel antimony single-crystal sample 2 mm thick was cut from a single-crystal ingot by the electric-spark method in such a way that the C_3 axis was perpendicular to the plane of the sample. The initial material had a resistivity ratio $\rho_{room}/\rho_{4.2}=2700$ (ρ_{room} and $\rho_{4.2}$ are the resistivities at room temperature and 4.2 °K, respectively). The surface layer of the metal was etched prior to cutting, after which the sample was electrically polished. Two microelectrodes were attached on the sample, an emitter and a collector, at a distance $L \approx 0.15$ mm apart. Current was made to flow through the emitter, and we measured the collector voltage U relative to a peripheral point of the sample as a function of the magnetic field H. The electrode line was perpendicular to one of the mirror surfaces of the crystal, and **H** was perpendicular to the electrode line and parallel to the surface of the sample. Provision was made in the experimental setup for rotating **H** in the plane of the sample and inclining it ± 20° to the surface. The apparatus for the observation of the EF is described in[7].

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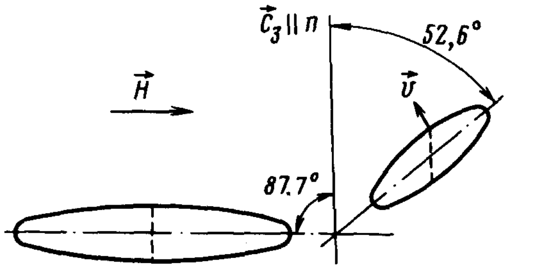

FIG. 1. Electron (angle 87.7° between the major axis and C_3) and hole ellipsoids of the FS of antimony; **n** is the normal to the sample plane.

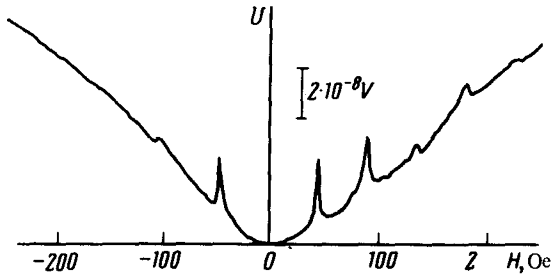

FIG. 2. Plot of $U(H)$ at $T = 1.7$°K; the ordinate scale is indicated.

Figure 1 shows the orientation of the electron and hole ellipsoids relative to C_3 as projected on the mirror plane. The major semiaxes of the ellipsoids lie in the mirror plane; the minor semiaxes, which lie in the same plane, are $p_e = 0.54\times 10^{-20}$ and $p_h = 0.48\times 10^{-20}$ g cm/sec for electrons and holes, respectively.[8] Figure 1 shows also the direction of **H** and the central sections of the FS (dashed), in the vicinity of which the focused electrons and holes are located at the employed experimental geometry.

The experimental plot of $U(H)$ is shown in Fig. 2. At $H > 0$ the trajectories of the electrons leaving the emitter turn towards the collector, and these electrons can strike the collector. For holes a similar situation can take place at $H < 0$, i.e., only electrons can be focused onto the collector at $H > 0$ and only holes at $H < 0$. The appearance of the $U(H)$ spikes, their positions relative to H, and their behavior when the direction of H is varied indicates that the quasiparticles focused on the collector are precisely those from the FS sections (or their vicinities) marked by the dashed lines in Fig. 1. The first spikes are due to focusing without reflections, and the succeeding ones to one, two, etc. repeated reflection from the surface. From the ratio of the amplitudes of the first and second lines[1] we obtain for the coefficient q of specular reflection in the case of normal incidence[1)] on the boundary the following values: for electrons $q_e = 0.8$ and for holes $q_h = 0.1$. We note that in this case both the electrons and the holes are reflected from the same sample-surface section located halfway between the junctions. The nonmonotonic variation of the amplitudes of the EF lines with increasing number, and the precipitous decrease of the amplitudes of the third and succeeding lines (at $H > 0$) is apparently due to local surface defects. When EF was observed in bismuth, this situation could be realized artificially by producing a surface section with defects between the junctions.[5]

Two results of this study are in our opinion of particular interest. First, the high degree of specularity of the reflection of electrons normally incident on the surface ($q_e = 0.8$). The de Broglie wavelength of the electrons of antimony is $\sim 10^{-6}$ cm, and consequently the surface-roughness dimensions sensed by the electrons is much less than this quantity. Second, the radical difference in the character of the reflection of the electrons and holes from the same section of the sample surface. This difference is possibly determined by the bending of the bands near the surface,[6] due to the onset of negative surface charge. In this case, the electrons are reflected not from the true boundary of the sample, but from the potential barrier produced by the field of the surface charge. The electrons are therefore not sensitive to the relief of the surface itself, and the degree of diffuseness is determined by the "relief" of the surface charge. A negative surface charge does not prevent holes from reaching the surface, and the degree of diffuseness of the hole reflection is determined by the roughness of the sample boundary itself, and this is the cause of the difference between the character of the reflection of the electrons and holes. The magnitude of the bending of the bands should be of the order of the Fermi energy, ≈ 0.1 eV in the case of antimony.

1) In the case of specular reflection, the motion of the focused electrons (holes) is periodic and takes place in a plane inclined several degrees to the C_3 axis ($\approx 30°$ for holes).

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