Galvanomagnetic effects near the common boundary of zinc bicrystals

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The distribution of the intensity of the electric field at the common boundary of zinc bicrystals in the presence of external magnetic field **H** and at $H = 0$ is investigated. In a strong magnetic field the length of the transition region was found to be much greater than the dimensions of the Larmor orbits of the carriers.

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In the absence of an external magnetic field the resistance of the boundary of two crystals perpendicular to the direction of an electric current **j** should cause a jump in the electrostatic potential. If there is a magnetic field $\mathbf{H}(\mathbf{H}\perp\mathbf{j})$ in addition to the electric field, the opposite situation occurs in the bicrystal—the region near the boundary now can be the section of enhanced conductivity because the frequency of collisions of the electrons increases in it compared to the inner volume. The observation of such effects was the goal of this work.

We investigated variation of the conductivity of zinc bicrystals near intercrystalline boundaries of the general type, which correspond to the rotation and tilt of the second crystal relative to the first and which probably scatter the electrons diffusely. The pronounced anisotropy of the galvanometric properties of zinc should also be taken into account. In a magnetic field the resistance of a right-handed crystal may be different from that of a left-handed crystal. As a result, a region with a certain thickness is formed at the boundary of the bicrystal, in which the conductivity depends both on the scattering of electrons by the grain boundary and on the components of the resistance tensor in the first and second crystals.

The distribution of the potential in such a transition layer was investigated at 4.2 K in cylindrical samples. The measurements were performed on five bicrystals. The samples were 15 to 17 mm long and 2.5 mm in diameter. The resistance ratio $\Gamma_{290\,\mathrm{K}}/\Gamma_{4.2\,\mathrm{K}}$ of different samples ranged from 1×10^4 to 2.5×10^4. Except for the fifth sample, all the bicrystals were obtained as a result of annealing for 6 hours at 400 °C the finely granular castings that were fabricated by filling the graphite capillary with a zinc melt. The ZnV sample was produced by crystallizing the melt in the capillary. The boundary was placed in the central part of the bicrystal approximately perpendicularly to its axis. The potential difference at the contact points (the potential contacts consisted of a 50-μ-diam beryllium bronze wire) was measured by a F-118 photoelectric amplifier. The location of the contacts is shown in the inset of Fig. 1.

If the x axis is directed along the sample (the magnetic field is parallel to z), then the results of the measurements can be represented either as the potential difference as a function of x (we started the measurements at the outer contact), i.e., we can establish directly a U_x distribution in the contact layer, or as a derivative of the potential as

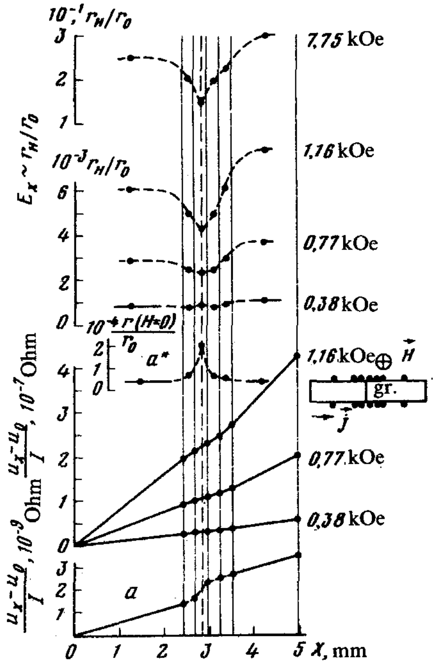

FIG. 1. Distribution of the potential U_x and of the transverse component of the electric field E_x near the boundary of the 2.5-mm-diam ZnI bicrystal. The vertical dashed line shows the location of the boundary and the vertical lines shown the location of the potential contacts. The schematic of the location of the contacts is given in the inset. I is the total current transmitted through the sample. The orientation of the crystals: the C_6 axes of the right-handed and the left-handed crystals are approximately parallel to the plane of contact of the grains and the angle between their basal planes is equal to 66°. a is the potential jump at the interface of the grains at 4.2 K and $H = 0$.

a function of x, i.e., as the dependence on x of the longitudinal component of the electric field in the sample. The latter value is proportional to the experimentally measured resistance ratio r_H/r_0 of the sections located between the neighboring contacts, since r_H, the resistance in the field H and r_0, the electrical resistance at 290 K and $H = 0$, respectively, are proportional to the potential difference and to the distance between the two measurement points of U_x.

In the region near the boundary the contacts were established at a distance of 250–300 μ and r_H/r_0 was measured in six intervals in the entire investigated section of the sample about 5 mm in length. These data are enough to illustrate, although not in great detail, the dependence of r_H/r_0 on x.

Figure 1 illustrates the behavior of r_H/r_0 in the boundary region of the ZnI bicrystal at different values of the field H. If $H = 0$ U_x decreases sharply in the interval that includes the grain boundary. The main variation of U_x, which is due to the presence of the boundary, is observed in the section Δx, which is comparable to the length of the mean free path of the electrons. The total variation of ΔU_x due to scattering by the boundary (potential jump in the ZnI bicrystal) makes it possible to calculate the corresponding resistance $\rho_{\text{bound.}}/S = (\Delta U_x/I)s = 3 \times 10^{-11}$ $\Omega\cdot\text{cm}^2$, where $\rho_{\text{bound.}}$ is the resistivity due to scattering by the grain boundary, S is the area of the boundaries per unit volume, s is the area of the transverse cross section of the sample, and I is the current transmitted through the sample.

Switching on of the magnetic field changes the picture of the potential distribution. As assumed, at sufficiently large H the region near the boundary corresponds to a region of slowed potential decrease. The upper row of curves in Fig. 1 shows the

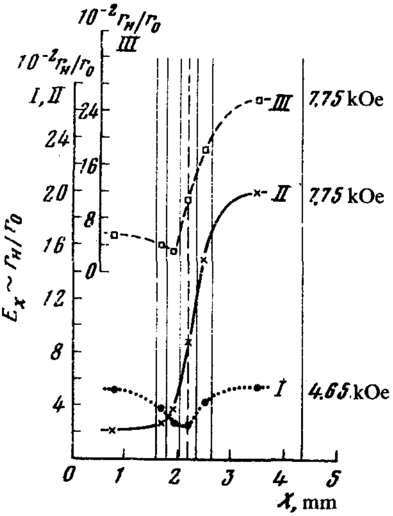

FIG. 2. Variation of the distribution of E_x at the boundary of the ZnI bicrystal for different orientations of **H**. The diameter of the sample is reduced to 1.5 mm. The numbers I, II, and III represent different orientations of the bicrystal in the magnetic field. In position II the magnetic field is weakly inclined toward the basal plane of the left-handed crystal.

variation of the r_H/r_0 dependence with increasing H for orientation of the magnetic field for which the values of r_H/r_0 are similar in the volume of both crystals. However, the total length, starting at the boundary, of the region of transition to the conditions that exist in the volume is about 1 mm. The transverse component of the voltage E_y also varies in this distance. This length, which is much greater than the characteristic dimensions of the Larmor orbits of the electrons and holes, does not decrease with increasing H, whereas it seems likely that the length of the transition region is of the same order of magnitude as the radius of the Larmor orbit. It should also be noted that the selected orientation of the samples used in the measurements excluded the transfer of carriers along open trajectories.

We could have attempted to link the presence of a broad transition region with special scattering conditions in the layer adjacent to the boundary. The elastic strain due to cooling of the bicrystals or an increased concentration of the scattering centers could be responsible for the volume differences of the conductivity at the contact. But, as determined in Refs. 1 and 2, even a strong elastic strain does not noticeably change the magnetic resistance of zinc. As for a possible plastic deformation at the boundary, repeated cooling of the samples did not change r_H/r_0.

By rotating the magnetic field in the plane of the boundary, we were able to produce a situation when r_H/r_0 of one crystal differed greatly from that of the other. When the difference in the values of the magnetic resistance is not as sharp the curve has a minimum point, but this point, which is shifted toward the crystal with lower magnetic resistance, is not in the interval that contains the grain boundary (Fig. 2, curve III). When the difference in the magnetic resistance is large the transition between the corresponding values of r_H/r_0 in the volume is smooth (Fig. 2, curve II). It is interesting to note that in the last case r_H/r_0 increases in the direction of the boundary of one of the crystals, whereas a more intensive scattering of electrons in the region near the boundary should always decrease r_H/r_0.

Further experiments with zinc bicrystals in which the C_6 axes are inclined symmetrically toward the interface or with metallic bicrystals with a cubic system will make it possible to determine the role of elastic strain in the observed effect.

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