Current in p-InSb which is even in the electric field

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An electric current which is even in the field has been discovered in a p-type InSb crystal. During the flow of a current $j_{\parallel}$ along the (110) direction, a current which is quadratic in the field E arises in the (001) direction. At $E = 50$ V/cm, the density of this current reaches 2% of $j_{\parallel}$.

As far back as 1964, Kazlauskas and Levinson[1] called attention to the possibility of observing a current which is even in the electric field **E** in crystals lacking an inversion center. This current is determined by a third-rank tensor:

$$j_{\alpha} = \chi_{\alpha\beta\gamma} E_{\beta} E_{\gamma} . \tag{1}$$

In crystals of the T_d class, the tensor χ has only a single linearly independent component, $\chi_{\alpha\beta\gamma} = \chi\,|\delta_{\alpha\beta\gamma}|$, where $\delta_{\alpha\beta\gamma}$ is the third-rank antisymmetric unit tensor. Correspondingly, when the field is directed along the (110) axis, a transverse current should arise:

$$j_{\perp} \equiv j_{(001)} = \chi E^{2}_{(110)} . \tag{2}$$

Baskin *et al.*[2] have calculated the contribution to current (1) which arises in a simple band with non-Born anharmonic corrections to the cross section for scattering by acoustic phonons and non-Born corrections to the cross section for scattering by impurities.

In addition to the ballistic contribution, which was studied in Ref. 2 and which results from the appearance of a directed momentum which is quadratic in the field as a result of the scattering by free carriers, there is a shift contribution, associated with the displacement of carriers in coordinate space during the scattering.[3] As Ivechenko and Pikus have pointed out,[4] a ballistic current will arise in a crystal with a degenerate band even in the absence of anharmonic corrections to the Hamiltonian of the electron-phonon interaction. In a weak field, i.e., at $eEl/k_B T \ll 1$, where l is the mean free path, the ratio of transverse current (2) to the current along the field direction, $j_{\parallel}$, is[4]

$$j_{\perp}/j_{\parallel} = a_0 \frac{eE}{k_B T} . \tag{3}$$

The characteristic length a_0 is determined by the ratio of constants in the terms of different parities with respect to the wave vector q in the operator representing the interaction of electrons with phonons or impurities. According to the estimates in Ref. 4, this characteristic length does not exceed q^{-1}, where $\hbar q$ is the average momentum transferred in the course of the scattering.

In an attempt to observe a current quadratic in the field we used p-type InSb samples with a hole density $p = 10^{16}$ cm^{-3}. In accordance with (2), the sample was cut

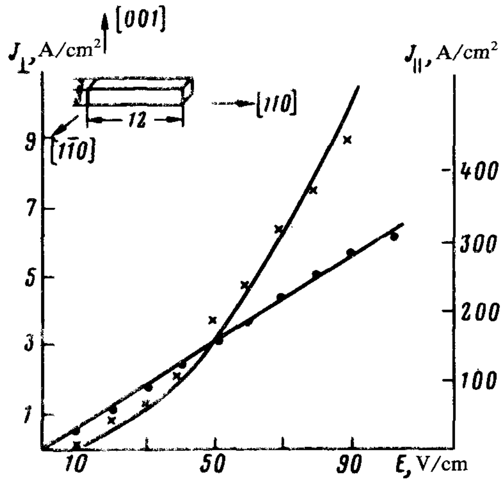

FIG. 1. The longitudinal and transverse current densities vs the applied electric field.

along the (110) axis, as shown in the inset in Fig 1. The sample was oriented by the method of Ref. 5. Indium electrodes were soldered onto the 3×3 mm faces. To measure the transverse current, we soldered two point contacts with an area of about 0.01 cm^2 onto one of the 3×12 mm faces, which are perpendicular to the (001) axis. These two point contacts were connected by a potentiometric resistance. On the opposite face we soldered a similar contact, which we placed between the two upper point contacts. The potentiometric resistance was significantly higher than the resistance between the contacts, and the equipotential point was selected by moving the slide contact of the potentiometer. The linearity of the electrodes was checked on the basis of the I–V characteristics. The measurements were taken at $T = 77$ K. Single voltage pulses up to 100 V high, 5 μs long, were applied to the sample. We found that when a voltage pulse was applied to the current electrodes a voltage pulse appeared across the lateral electrodes, with a sign which was independent of the sign of the applied field: The difference between the values of the transverse voltage for the opposite directions of the vector E at $V = 50$–90 V did not exceed 5%.

Figure 1 shows the experimental results as a plot of the longitudinal current density $j_\parallel$ (the scale at the right) and the transverse current density $j_\perp$ (the scale at the left) against the applied field. The solid line is the theoretical prediction $j_\perp = \chi E^2$ with $\chi = 1.3\times 10^{-3}$ A/V^2. We see that the $j_\perp(E)$ dependence is in fact approximately quadratic.

After carrying out these measurements, we soldered electrodes onto the faces perpendicular to the (110) axis on the same sample. According to the theory, a transverse current should not arise in this direction. Experimentally in this case we observed a voltage pulse which was at least ten times weaker than in the previous case, and its polarity changed with the direction of $j_\parallel$. This parasitic signal is apparently a consequence of a deviation from perfectly equipotential measuring electrodes.

In summary, these experiments indicate that a current quadratic in the field has been observed. The value found for the constant a_0 from (3) is 3×10^{-6} cm, which is at least an order of magnitude greater than the value expected on the basis of the estimates of Ref. 4. We suggest detailed measurements of the dependence of $j_\perp$ on the free-carrier density and on the temperature to determine the mechanisms for the current which is even in the field.

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