Anomalous anisotropy of the magnetoresistance and of the *g*-factor in InSb

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(Submitted July 22, 1975)
Pis'ma Zh. Eksp. Teor. Fiz. **22**, No. 6, 324–328 (20 September 1975)

Single-crystal InSb samples with $n = 4.5$, 5.0, 6.9, and 8.0×10^{15} cm^{-3} have revealed an anomalously large anisotropy ~800% of the magnetoresistance $\rho_\perp(H)$ and of the g-factor ($\Delta g/g_0 \approx 20\%$) at $n = 4.5 \times 10^{15}$ cm^{-3}; this anomaly decreases with increasing electron density n. The anisotropy of $\rho_\perp(H)$, decreases under hydrostatic compression and vanishes almost completely at $p \approx 16$ kbar. The anisotropy $\Delta g/g_0$ decreases accordingly by a factor of ~2.5.

PACS numbers: 72.10.G

The electronic equal-energy surface of InSb is a slightly-distorted sphere with convexities in the directions of the space diagonals [111]; these convexities are the results of the influence of the higher-lying terms. The anisotropy of the extremal sections $\Delta S/S$, in accord with Kane's model,[1] increases in first-order approximation in proportion to the square of the Fermi momentum, $\sim k_F^2$, i. e., like $n^{2/3}$, where n is the electron density in the conduction band. From the experimental data at $n \approx 10^{18}$ cm^{-3} we have $\Delta S/S \approx 1\%$,[2] in agreement with theoretical calculations by Kane's model. It has therefore been customarily assumed that InSb does not have so noticeable an anisotropy of the transverse magnetoresistance $\rho_\perp$(H), nor anisotropy of the g-factor.

We have investigated the monotonic and oscillatory parts of $\rho_\perp(H)$ and of its first derivative $\partial\rho_\perp/\partial H(H)$ in single-crystal n-InSb doped with Te, at $n = 4.5$, 5.0, 6.9, and 8.0×10^{15} cm^{-3} and at helium temperatures.

We have observed, unexpectedly, an anomalously large anisotropy of $\rho_\perp$(H), in contradiction to the standard ideas on the magnetoresistances of substances having closed isotropic Fermi surfaces. To exclude the possible influence of the sample geometry on the measurement results, many experiments were performed on crystal with different ratios of the length to the transverse dimensions, and also with different placements of the potential contacts on the sample faces. No noticeable influence of the shape of the sample and of the location of the electrodes on the magnitude of the observed anisotropy of $\rho_\perp$(H) was observed. The anisotropy of $\rho_\perp$(H) is maximal for samples with minimal electron density (Fig. 1a) and decreases with increasing degree of doping. In a sample with $n = 8 \times 10^{15}$ cm^{-3}, the anisotropy of $\rho_\perp$(H) is one-quarter as large as in the sample with $n = 4.5 \times 10^{15}$ cm^{-3}, while in samples with $n = 2 \times 10^{17}$ cm^{-3} there is no anisotropy of $\rho_\perp$(H) at all.

Also observed is a noticeable dependence on the orientation of **H** (relative to the crystallographic axes) of the positions of the last oscillatory peaks on the $\rho_\perp$(H) and $(\partial\rho_\perp/\partial H)$ (**H**) curves, from which the value of the

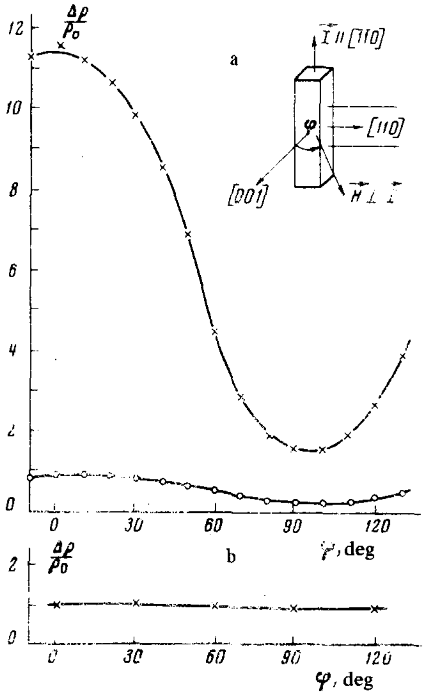

Fig. 1. Anisotropy of the transverse magnetoresistance of InSb with $n = 4.5 \times 10^{15}$ cm^{-3}: a) $p = 1$ atm, curves: ×—$H = 21$ kOe and $T = 4.2$°K, ○—$H = 12$ kOe and $T = 300$°K; b) $p = 16.2$ kbar; ×—$H = 21$ kOe, $T = 4.2$°K.

g-factor is determined. Figure 2 shows the positions of the zeroes of the derivative $(\partial\rho_\perp/\partial H)$ (H) and of the last maximum H_{0-} on the $\rho_\perp$(H) curves for the sample with $n = 4.5 \times 10^{15}$ cm^{-3} at various orientations of H in the (110) plane. For comparison, the same figure shows the angular dependence of the last minimum of $(\partial\rho_\perp/\partial H)$ (H) and of the last minimum of $\rho_\perp$(H) for the sample with $n = 5 \times 10^{15}$ cm^{-3}. On the basis of these data, the formula[3]

$$g(\phi) = \left(\frac{\hbar c}{e}\right)^3 \frac{4\pi^4 n^2}{[H_{0-}(\phi)]^3} \frac{m_0}{m^*} \qquad (1)$$

was used to calculate the g-factor.

We see that the anisotropy $g(\phi)$ in samples with $n = 4.5 \times 10^{15}$ cm^{-3}, which reaches $\Delta g/g_0 \approx 20\%$, differs appreciably from the character of the anisotropy of $g(\phi)$ in samples with $n = 5 \times 10^{15}$ cm^{-3}, where $\Delta g/g_0 \approx 16\%$, i.e., a qualitative change of the character of the anisotropy of g takes place in the concentration interval $4.5 < n < 5 \times 10^{15}$ cm^{-3}. With further increase of n, the character of the anisotropy of g does not change, but the magnitude of the anisotropy decreases. In samples with $n = 6.9 \times 10^{15}$ cm^{-3}, $\Delta g/g_0$ amounts to ~11%. We note that the character of the anisotropy of $\rho_\perp$(H) is also different for samples with $n = 4.5 \times 10^{15}$ cm^{-3} and $n \geq 5 \times 10^{15}$ cm^{-3}.

It was of interest to investigate the influence of pressure on the values of the observed anomalies. These measurements were performed on the sample with $n = 4.5 \times 10^{15}$ cm^{-3} at pressures up to 16 kbar. The reproducibility of the results was monitored by measurements made after the removal of the pressure. A strong reversible decrease of the anisotropy of $\rho_\perp$(H) and of the g-factor under the influence of the pressure was observed (Figs. 1b and 3). At $p \approx 16$ kbar, the anisotropy of $\rho_\perp$(H) practically vanishes, and the anisotropy of g decreases by a factor ~2.5 in comparison with its value at $p = 1$ atm. Figure 3 shows the change of the g-factor and its anisotropy (vertical bars) under the influence of pressure, for the sample with $n = 4.5 \times 10^{15}$ cm^{-3}. The monotonic decrease of the value of the spin splitting is well described by formula (1), if it is recognized that m^* is increased by compression, owing to the increase of the forbidden band ϵ_g.

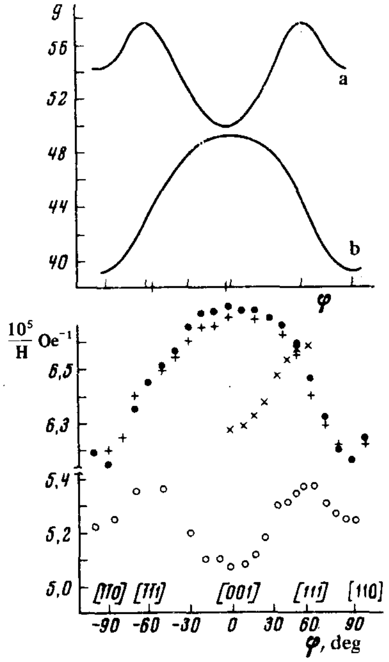

Fig. 2. Dependence of the positions H_{0-} of the last maximum on the $\rho_\perp$(H) curves of InSb samples with $n = 4.5 \times 10^{15}$ cm^{-3} (●, +) and $n = 5 \times 10^{15}$ cm^{-3} (×), and also of the last minimum of $(\partial\rho_\perp/\partial H)$ (H) for a sample with $n = 5 \times 10^{15}$ cm^{-3} (○). Upper curves—results of calculation of the g-factor by formula (1) for samples with $n = 5 \times 10^{15}$ cm^{-3} (a) and $n = 4.5 \times 10^{15}$ cm^{-3} (b).

The strong dependence of the observed anomalies on the electron density (on the position of the Fermi level) and on the pressure (the positions of the extrema in the spectrum) seems to point to a resonant character of these effects. It can be suggested that they result from the interaction of the carriers in the conduction

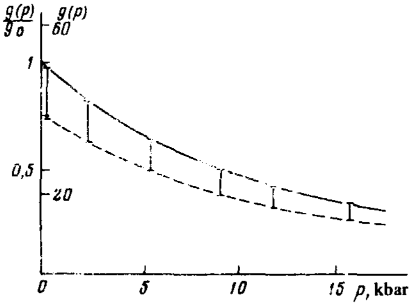

Fig. 3. Change of the g-factor and of its anisotropy in the InSb sample with $n = 4.5 \times 10^{15}$ cm^{-3} under pressure.

band (the vicinity of the Γ point of the Brillouin zone) with the strongly anisotropic[1)] localized magnetic states that result from localization of the electrons on the positively charged impurities of the donor centers.[4] Such states can exist, for example, at points X and L of the Brillouin zone, in which the spectrum is strongly anisotropic.[5] We note that the possibility of a change in the value of the g-factor of conduction electrons when they interact with localized magnetic moments is indicated by results of investigations of the de Haas–van Alphen effect in copper containing paramagnetic impurities from the Fe group.[6]

We take the opportunity to thank Ch. S. Rumenin for help with the experiments.

[1)] By anisotropy of a magnetic state is meant anisotropy of the effective magnetic moment of the electron in this state.

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