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INTERPRETATION OF THE TRANSVERSE MAGNETORESISTANCE IN p-TYPE INDIUM ANTIMONIDE AT LIQUID NITROGEN TEMPERATURE

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The variation of the transverse magnetoresistance ratio $\Delta\rho/\rho_0$ with magnetic field in p-type indium antimonide cannot be accounted for using a single carrier model.[1,2] The results can be explained, however, assuming the presence of heavy holes and less numerous light holes, as in p-type germanium. In order to calculate the mobilities and concentrations of the holes in a simple way from the experimental data, the following assumptions are made: (1) negligible intrinsic electron concentration at 77°K; (2) spherical energy surfaces in $\vec{k}$ space for both holes; (3) energy-independent relaxation times to avoid scattering coefficients.

Assumption (1) is well satisfied. Assumption (2) and (3) however are probably not true; they are only made for convenience. Suppose we have two sets of holes with mobilities μ_1 and μ_2 and concentrations p_1 and p_2, respectively. With the above assumptions the following expressions hold for the Hall coefficient (R_H), the conductivity (σ_0), the transverse magnetoresistance ($\Delta\rho/\rho_0$), and the fractional change of the Hall coefficient ($\Delta R_H/R_{H_0}$) in a magnetic field (H):

$$R_{H_0} = \frac{p_1\mu_1^2 - p_2\mu_2^2}{e(p_1\mu_1 + p_2\mu_2)^2} \tag{1}$$

where e is the electron charge;

$$\sigma_0 = e(p_1\mu_1 + p_2\mu_2); \tag{2}$$

$$\frac{\Delta\rho}{\rho_0} = \frac{bH^2}{1 + cH^2}, \tag{3A}$$

where

$$b = \frac{p_1p_2\mu_1\mu_2(\mu_1-\mu_2)^2}{(p_1\mu_1 + p_2\mu_2)^2}, \tag{3B}$$

$$c = \frac{\mu_1^2\mu_2^2(p_1 + p_2)^2}{(p_1\mu_1 + p_2\mu_2)^2}; \tag{3C}$$

$$-\frac{\Delta R_H}{R_H} = \frac{\Delta\rho}{\rho_0}\,\frac{c^{1/2}}{(R_H\sigma)_0} \tag{4}$$

If μ_2 corresponds to the light hole, let us suppose that $\mu_2 \gg \mu_1$ and $p_2 \ll p_1$. Then Eqs. (1), (2), (3A), (3B), and (3C) may be easily solved to give μ_1, μ_2, p_1, and p_2 in terms of the quantities $(R_H\sigma)_0$, σ_0, b, and c:

$$\mu_2 = \frac{c+b}{c^{1/2}} \tag{5}$$

$$p_2 = \frac{bc^{1/2}\sigma_0}{e(c+b)^2}, \tag{6}$$

$$\mu_1 = \frac{c+b}{c}\left[(R_H\sigma)_0 - b/c^{1/2}\right], \tag{7}$$

$$p_1 = \left(\frac{c}{c+b}\right)^2 \frac{\sigma_0}{e\left[(R_H\sigma)_0 - b/c^{1/2}\right]}. \tag{8}$$

From the observed results at 77°K on a p-type sample of indium antimonide (sample A of reference 2), it was found that the magnetoresistance variation could be fitted approximately by a formula of the form of Eq. (3A) with $b = 4 \times 10^7$ cm^4/volt^2 sec^2 and $c = 7 \times 10^8$ cm^4/volt^2 sec^2. Using the value $(R_H\sigma)_0 = 5000$ cm^2/volt sec and σ_0 =4 ohm^{-1} cm^{-1} at 77°K, Eqs. (5), (6), (7), and (8) give

$\mu_2 = 2.8 \times 10^4$ cm^2/volt sec,
$p_2 = 4.8 \times 10^{13}$/cm^3,

for a light hole, and

$$\mu_1 = 3.68 \times 10^3 \text{ cm}^2/\text{volt sec},$$
$$p_1 = 6.4 \times 10^{15}/\text{cm}^3,$$

for a heavy hole.

Thus the calculation would indicate that the light holes are 7.6 times as mobile as the heavy holes and have a density of only 0.75% of the total hole concentration.

A similar calculation for samples R and U of reference 1 gives the following results:

Sample R: $\mu_2 = 3.76 \times 10^4$ cm^2/volt sec,
$p_2 = 2.15 \times 10^{13}$/cm^3,
$\mu_1 = 7.03 \times 10^3$ cm^2/volt sec,
$p_1 = 1.93 \times 10^{15}$/cm^3,

so that

$$\mu_2/\mu_1 = 5.3 \quad \text{and} \quad p_2/p_1 = 1.1\%.$$

Sample U: $\mu_2 = 6.2 \times 10^4$ cm^2/volt sec,
$p_2 = 4.6 \times 10^{12}$/cm^3,
$\mu_1 = 8.4 \times 10^3$ cm^2/volt sec,
$p_1 = 3.6 \times 10^{14}$/cm^3,

so that

$$\mu_2/\mu_1 = 7.4 \text{ and } p_2/p_1 = 1.3\%.$$

The variation of the Hall coefficient with magnetic field can be calculated from Eq. (4). For $H = 5000$ gauss it is found that $-\Delta R_H/R_{H_0} = 18\%$ for sample R and 36% for sample U. The observed values (from Fig. 5 of reference 1) were, respectively, 33% and 38%, giving good agreement for sample U but indicating that possibly a larger value of c should apply to sample R than was found from the magnetoresistance calculations alone.

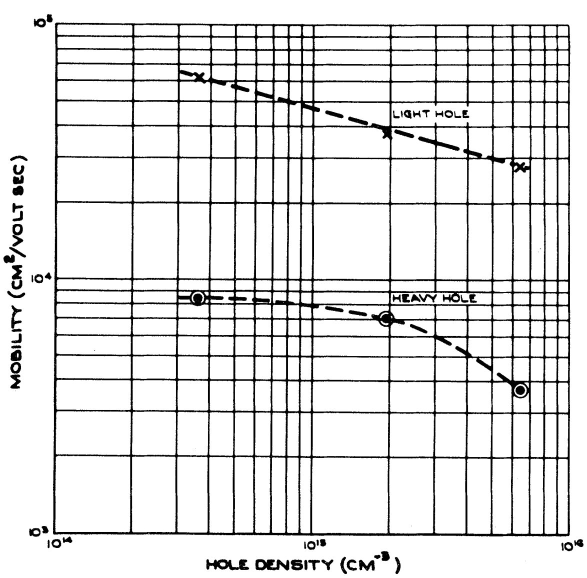

FIG. 1. Variation of the calculated light- and heavy-hole mobilities with hole density in p-type InSb at 77°K.

The variation of μ_1 and μ_2 with hole density ($p = p_1 + p_2$) shown in Fig. 1 shows that the mobilities decrease with increasing concentration of ionized acceptors as expected for impurity scattering. Because of the many approximations made in the calculation and the fact that there are only three points, a quantitative analysis to find lattice mobilities is probably not worth while. However, Fig. 1 suggests that at $p = 3.6 \times 10^{14}$ the lighter hole is still affected by impurity scattering whereas the other hole is not because of its greater mass.

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[1] H. P. R. Frederikse and W. R. Hosler, Phys. Rev. 108, 1146 (1957).

[2] C. H. Champness, J. Electron. and Control 4, 201 (1958).

NEW OSCILLATORY ABSORPTION OF ULTRASONIC WAVES IN BISMUTH IN A MAGNETIC FIELD*

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In the course of an attempt to study the Fermi surface in bismuth by magnetoacoustic resonance, a new oscillatory absorption phenomenon has been observed. In bismuth, because of the low momentum of the carriers, the magnetoacoustic resonance of the type observed by Bömmel[1] in tin and Morse et al.[2] in copper occurs in fields of the order of 100 oersteds. However, at fields of the order of 1000 oersteds a different kind of oscillatory absorption, periodic in reciprocal magnetic field, has been seen (see Fig. 1). The period of this component is independent of the sound wavelength. Measurements of the period in $1/H$ as a function of direction of the magnetic field for some 20 directions in a plane normal to the 3-fold axis agree to within 10% or better with the period of the de Haas-van Alphen oscillations in the susceptibility as observed by Shoenberg[3]