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Electrical Properties of P-Type Indium-Antimonide*

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Synopsis

Electrical properties of P-type InSb from ambient to liquid helium temperatures are measured and several parameters associated with the charge carriers are obtained.

I. Introduction

In this paper, the results of measurements of the electrical properties of polycrystalline P-type InSb from the range of room temperature down to that of liquid helium will be reported.

II. Specimens and experimental procedures

Metallic indium of 99.95 per cent and antimony of 99.99 per cent purity were zone refined more than a dozen times each; then they were mixed in the proportion of atomic equivalent and made to combine by heating in vacuo at 700°C for 20 hrs. The compound was again zone-melted 6 times, and from the purified ingot of InSb thus obtained, rectangular parallepipeds of $10\times 4\times 1$ mm^3 in size were cut out for the specimens. By spectroscopic analysis, the specimens were found to contain about 0.001 per cent of silicon and iron each as impurities.

For electrical measurement, the ordinary D-C method was adopted. The current sent through the specimen was 6~7 mA, after being ascertained that the Ohm's law is valid in this range.

III. Results

In the range of temperature higher than that of liquid nitrogen, our specimens show quite the similar behaviour as already been reported concerning the P-type InSb, having the characteristics justifying to take them as a common semiconductor, as illustrated in Figs. 1~3. From these results, the width of the forbidden zone E_0 at 0°K, under the assumption that the electrons or the holes are scattered only by lattice vibrations, is found to be 0.24 eV—a value in good agreement with that reported by Breckenridge et al(1). The mobility of electrons at room temperature is estimated at 2×10^4cm^2 volt^{-1} sec^{-1}, that of positive holes at 83°K at 1.1×10^3cm^2 volt^{-1} sec^{-1}, and the impurity level is removed about 10^{-2}eV above the top of valence band and the density of acceptors is 5.3×10^{16}cm^{-3}.

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* The 882nd report of the Research Institute for Iron, Steel and Other Metals.

(1) R. G. Breckenridge, R. F. Blunt, W. R. Hosler H. P. R. Frederikse, J. H. Becker and W. Oshinsky, Phys. Rev., **96** (1954), 571.

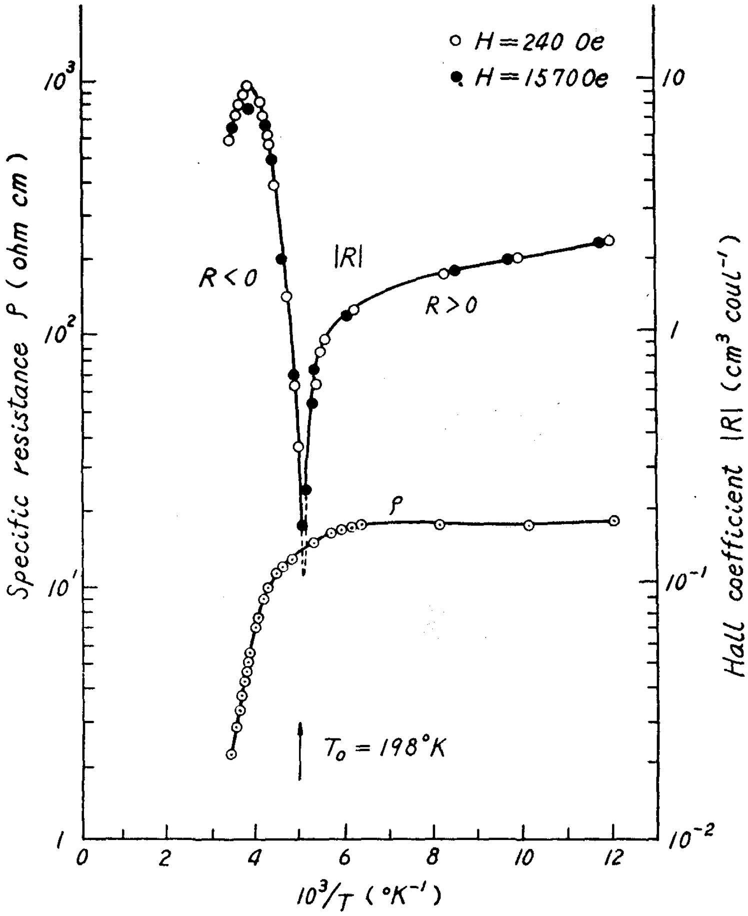

Fig. 1. Resistivity and Hall coefficient as functions of temperature from ambient to liquid air range.

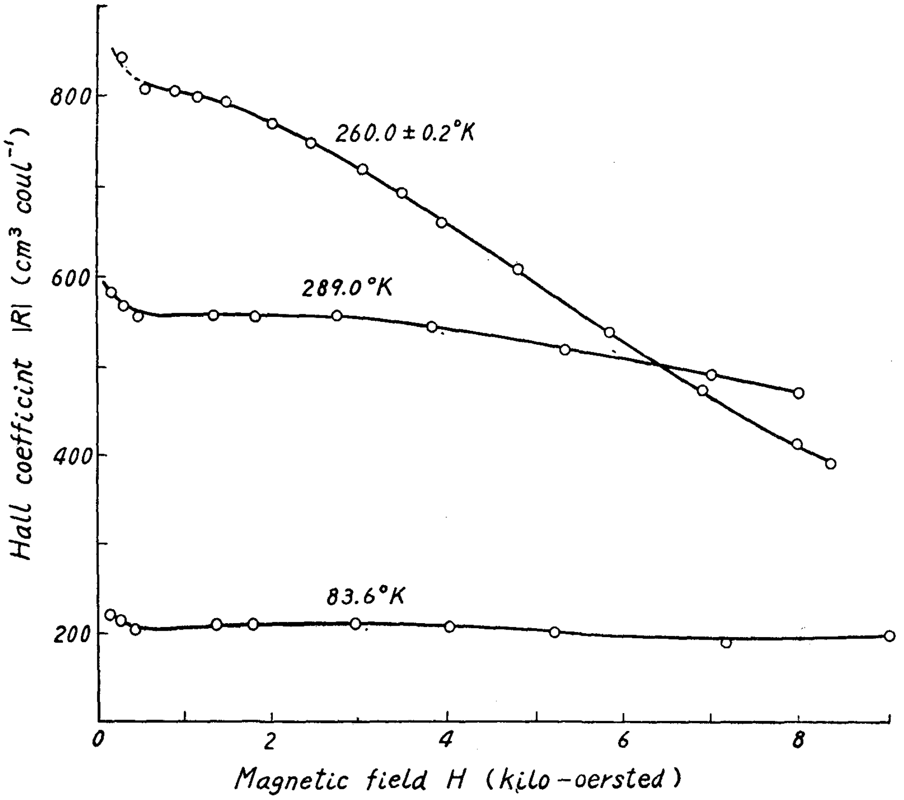

Fig. 2. Hall coefficients as functions of magnetic field intensity.

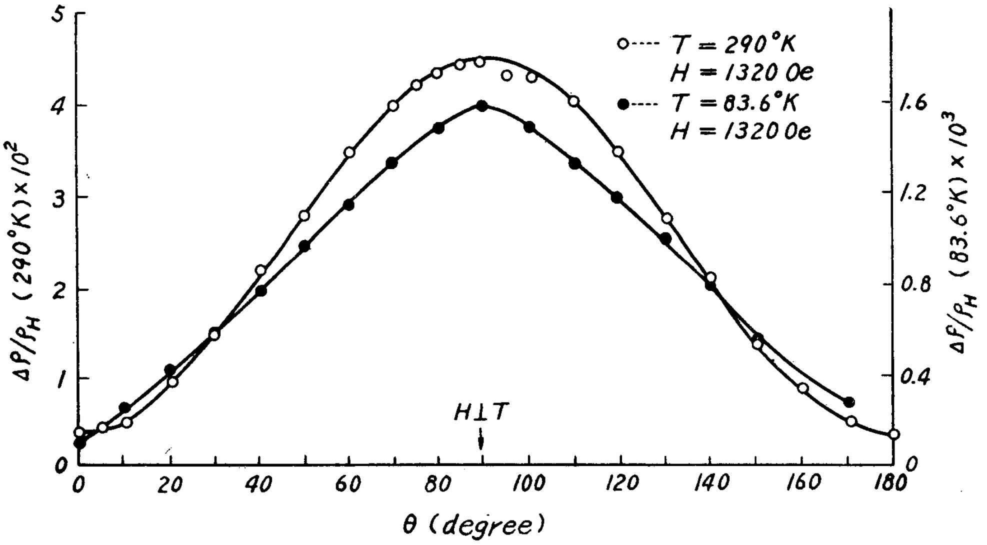

Fig. 3. Magneto-resistance effects as functions of θ, which is the angle between the specimen and the magnetic field.

The results of measurements of the changes in the specific resistance and the Hall coefficient with temperature in the range from the temperature of liquid nitrogen down to 1.4°K (Fig. 4) showed the same tendency as observed by Fritzsche(2) and Rollin(3)—a tendency associated with the conduction through the impurity band. Assuming that the electric conduction at the lowest temperature is effected exclusively by positive holes, the mobility of the positive holes in the impurity band is estimated at $\mu \fallingdotseq 10\sim40$ cm^2 volt^{-1} sec^{-1}. The results of measurements of the longitudinal and the transverse effects of magneto-resistance as

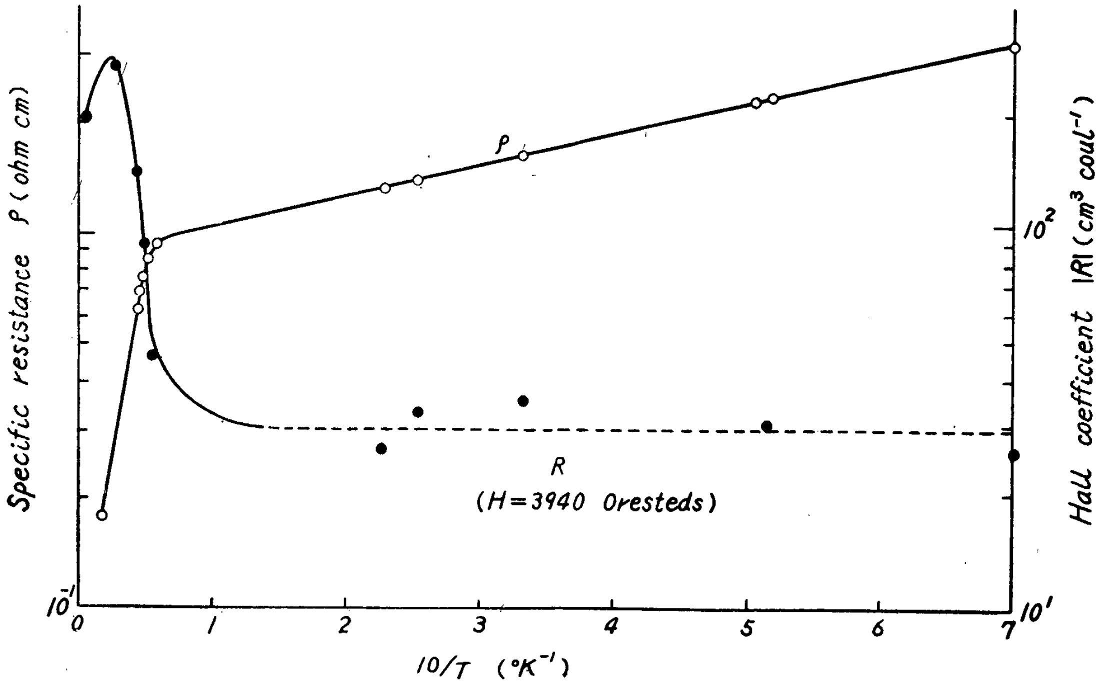

Fig. 4. Resistivity and Hall coefficient as functions of temperatures ranging from liquid nitrogen temperature to 1.4°K.

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(2) H. Fritzsche and K. Lark-Horovitz, Phys. Rev., **99** (1955), 400.

(3) B. V. Rollin and A. D. Petford, Journ. Electronics, **1** (1955), 171.

functions of the magnetic field (Fig. 5) showed that they both increase in proportion to the square of the intensity of magnetic field and even at the lowest temperature they remain positive and little different from the values at 4.2°K, in these respects our results differing from those reported by Fritzsche et al.(2) In the results of measurements at the temperature of liquid air and at room temperature, the transverse effect is about 10 times as large as the longitudinal effect, but at the temperatures of liquid helium, both the effects showed nearly the same values. For better clarification of this finding, we measured the magneto-resistance effect by changing the angle between the specimen and the magnetic field from 0° to 180° as shown in Fig. 6. Upon comparing the data with

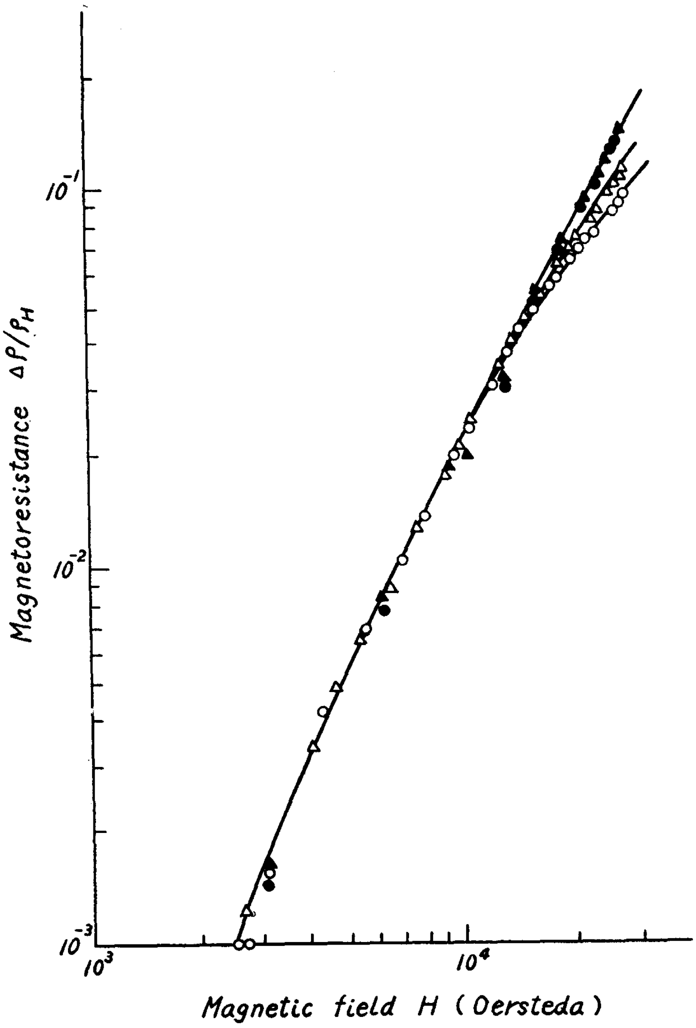

Fig. 5. Magneto-resistance versus magnetic field.
○ Longitudinal effect at 4.2°K
● Ditto at 1.4°K
△ Transverse effect at 4.2°K
▲ Ditto at 1.4°K

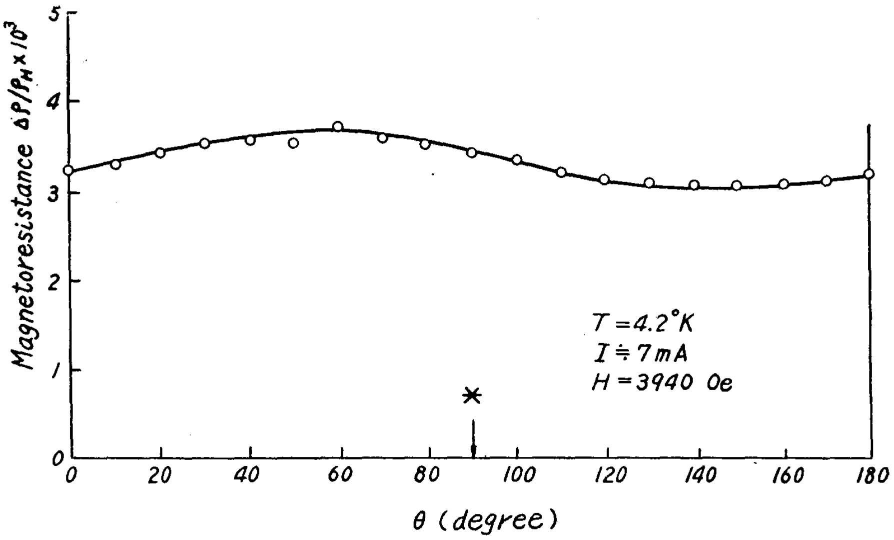

Fig. 6. Magneto-resistance as a function of θ, θ being the angle between the specimen and the magnetic field.
* mark indicates $\theta=90°$.

those obtained at the temperature of liquid air and at room temperature (Fig. 3), the maximum point was found displaced about 30°. Measurements of the change of Hall coefficient due to the change in the intensity of magnetic field at 289°K, 260°K and 83.6°K gave the results plotted in Fig. 2 and the same at 4.2°K and 1.4°K gave the ones shown in Fig. 7. While little or no dependence of the Hall coefficient on the intensity of magnetic field was found at the temperature of liquid air, showing perfect reproducibility, the values at the temperature of liquid helium showed strong dependence on the strength of the magnetic field. Moreover, the results of measurements at the lowest temperature (1.5°~1.4°K) were lacking in reproducibility. From the results shown in Fig. 6, we are led to suppose that the conducting carriers do not flow uniformly through the whole section of the specimen but by some limited paths, such as grain boundaries. The results shown in Fig. 7, however, were hardly analysable, since the specimens used were not single crystals, and it could not be assumed that the impurities were uniformly distributed throughout the specimens.

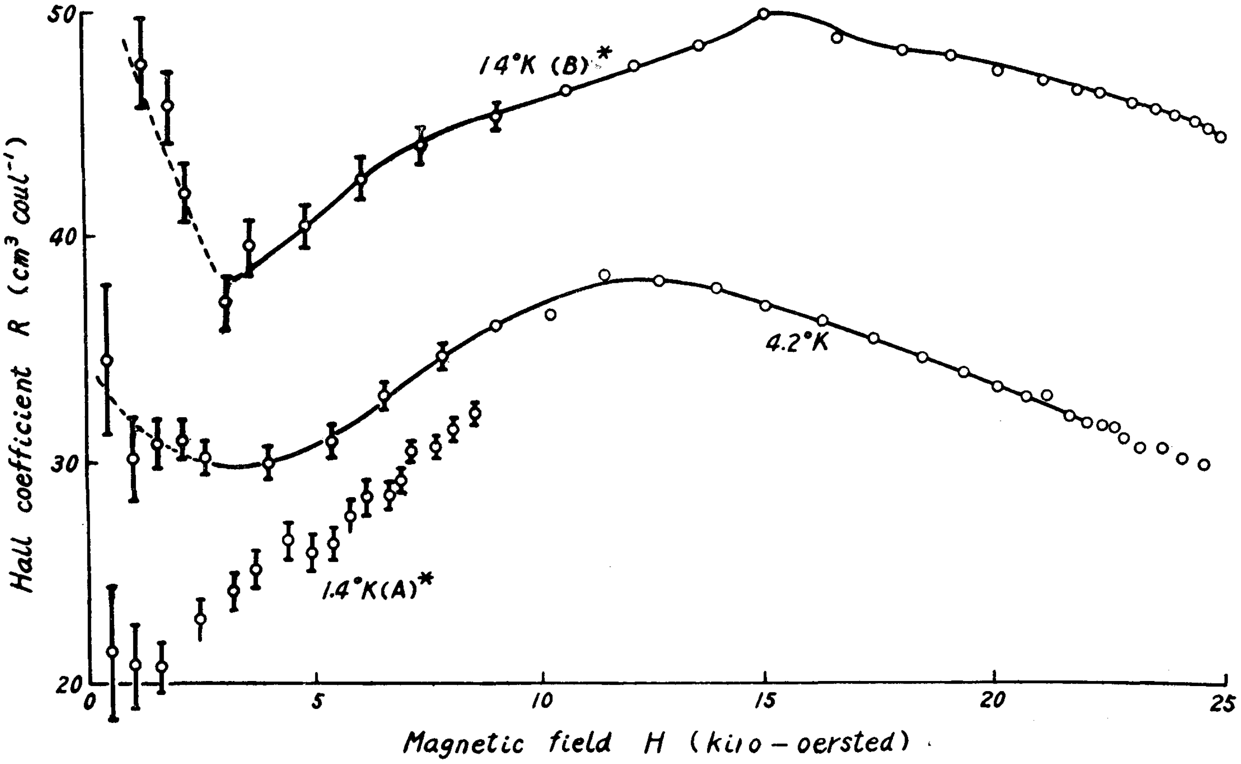

Fig. 7. Hall coefficients as functions of magnetic field at liquid helium temperatures. (B) * shows values obtained at the same temperature as (A)* but 3 months later; every run apt to give such widely different values and lack of reproducibility.

Here it is to be remarked that such an effect of non-uniform distribution of impurities only becomes noticeable as the temperature is decreased as low as 1.4°K.