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*See [5] concerning nonstationary defocusing.

CERTAIN FEATURES OF THE BEHAVIOR OF p-InSb SAMPLES WITH UNCOMPENSATED ACCEPTOR DENSITY $6 \times 10^{11} - 1 \times 10^{14}$ cm^{-3}

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Great interest has been shown in recent investigations of the properties of p-type indium antimonide in the question of the nature and location of the energy levels of the impurities, particularly of the so-called deep level. Several investigations have already been devoted to the observation of the deep level of p-type indium antimonide [1-5]. However, there is no unified point of view regarding the nature and character of this level as yet. One can hope that an increase in the scope of the research (with respect to the temperature, the carrier density, the number of doping acceptor elements) will uncover new approaches to the solution of this problem.

We have measured the temperature dependences of the Hall constant and the electric-conductivity and mobility coefficients of compensated (90% degree of compensation) samples of p-type indium antimonide with resistivities from 10 to 2740 ohm-cm and with low density of uncompensated holes ($6 \times 10^{11} - 1 \times 10^{-4}$ cm^{-3}) in the interval from 4.2 to 300°K. The single crystals were doped with acceptor impurities (manganese, silicon, germanium, gold) during the course of drawing by the Czochralski method.

The temperature dependence of the hole density, defined as $p = 1/Rec$, was investigated in more than 40 samples in the 55 - 130°K range. It has turned out that, regardless of the method used to obtain the sample and the nature of the doping impurity, the deep level is observed (we have in mind the corresponding inclinations of curves 1-5 of Fig. 1 in the temperature interval 78 - 110°K) only in samples with carrier density $p \approx 6 \times 10^{11} - 7 \times 10^{13}$ cm^{-3}. This level is not observed at higher densities of the uncompensated holes (curves 6 and 7 of Fig. 1). The activation energy of the deep level fluctuates in the range from 0.01 to 0.1 eV, depending on the carrier density. The fact that the activation energy of the deep level is independent of the doping impurity (Fig. 2) suggests that this level is caused by lattice defects.

Unlike [1-5], we measured samples with very low uncompensated-hole densities (6×10^{11} - 6×10^{12} cm^{-3}), and this has made it possible to observe a unique variation of the Hall constant and of the mobility coefficient with temperature, wherein, regardless of the kind of doping impurity: 1) samples with hole density on the order of $6 \times 10^{11} - 6 \times 10^{12}$ cm^{-3} have a clearly pronounced minimum in the plot of p vs. $(10^3/T)$, which is not observed in samples with uncompensated hole densities of the order of 10^{14} - 10^{13} cm^{-3}; 2) the plots of μ vs. T for these samples have maxima, whereas at hole densities $\sim 10^{13}$ - 10^{14} cm^{-3} a smooth decrease of mobility is observed in the same region of temperatures (Fig. 3).

Such a unique behavior of the samples with $p = 6 \times 10^{11} - 6 \times 10^{12}$ cm^{-3} is not connected with properties of their surfaces, since repeated etching, washing, and measurements on samples having different thicknesses did not change the form of the curves.

The form of the p = f(T) plot suggests the existence of an impurity band located within the forbidden band. However, the hole densities calculated using the two-band model [7] (valence and impurity) did not give satisfactory agreement with the experimental

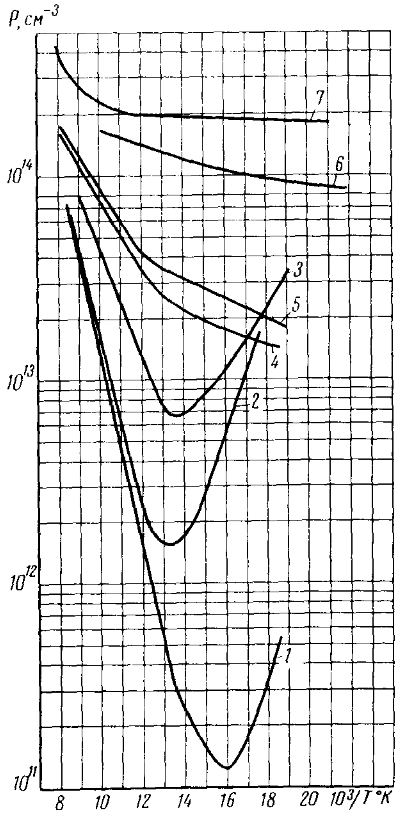

Fig. 1. Temperature dependence of hole density for samples doped with different impurities. Sample designations and parameters (at 78°K) are listed in the table.

Sample No	p, cm^{-3}	ρ, ohm-cm	μ, cm^2/V-sec	Impur.
1	$6.0 \cdot 10^{11}$	$2.74 \cdot 10^3$	$3.84 \cdot 10^3$	Ge
2	$1.6 \cdot 10^{12}$	$9.5 \cdot 10^2$	$4.15 \cdot 10^3$	Ge
3	$7.65 \cdot 10^{12}$	$4.52 \cdot 10^2$	$1.82 \cdot 10^3$	Au
4	$2.6 \cdot 10^{13}$	$4.8 \cdot 10^1$	$5.05 \cdot 10^3$	Mn
5	$3.7 \cdot 10^{13}$	$4.85 \cdot 10^1$	$3.5 \cdot 10^3$	Au
6	$1.3 \cdot 10^{14}$	$1.35 \cdot 10^1$	$3.6 \cdot 10^3$	Ge + Te
7	$2.0 \cdot 10^{14}$	4.5	$6.95 \cdot 10^3$	Ge

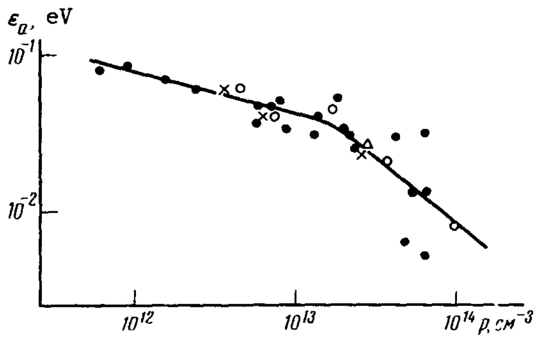

Fig. 2. Deep-level activation energy vs. hole density: × - InSb + Mn; o - InSb + Au; ● - InSb + Ge; ■ - zone; △ - heat-treated; ⊙ - nonstoichiometric melt.

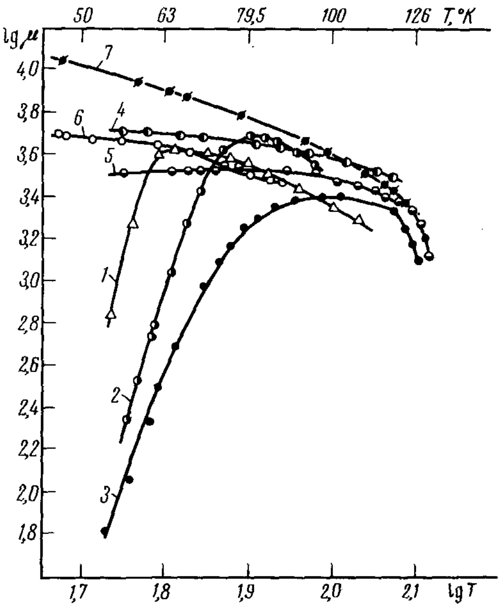

Fig. 3. Temperature dependence of samples doped with various impurities. Notation same as in Fig. 1.

curves. Measurements of the Hall coefficient of the same p-type InSb samples, with hole densities $p \sim 10^{14} - 10^{13}$ cm^{-3} at temperatures 4.2 - 50°K, revealed an impurity band due to shallow acceptors. Their ionization energy fluctuates in the range $(5 - 8) \times 10^{-3}$ eV. The separately determined acceptor and donor densities, for example in a sample with hole density $p \sim 3 \times 10^{13}$ cm^{-3}, were respectively $N_a = 2.653 \times 10^{16}$ cm^{-3} and $N_d = 2.650 \times 10^{16}$ cm^{-3} ($N_d/N_a = 99.95\%$). It must be noted that the maxima on the $R = f(10^2/T)$ curves shift towards higher temperatures with decrease of carrier density. Thus, in p-InSb samples with hole densities (at T = 77°K) 2.6×10^{13}, 9.85×10^{13}, and 1.47×10^{14} cm^{-3}, the maxima of $R = f(10^2/T)$ are observed at 18, 11.8, and 6.2°K respectively. In samples with uncompensated hole densities $\sim 6 \times 10^{11} - 6 \times 10^{12}$ cm^{-3}, no impurity zone was observed at temperatures lower than 50°K.

The new experimental facts reported in this paper cannot be convincingly explained as yet. We can propose the following preliminary suggestions: 1. It is possible that the maxima on the $R = f(T)$ curves, for samples with densities $6 \times 10^{11} - 6 \times 10^{12}$ cm^{-3}, are the results of the simultaneous action of the shallow-acceptor band and the deep defect level. 2. It can also be assumed that the appearance of the maxima is connected with the presence in the InSb of two kinds of holes, the density ratio of which changes under the influence of a number of factors[6].

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Article by S. P. Kapitza et al., Vol 6, No 2, p. 27.
In the figure caption, replace the symbol "o" by the symbol "●".

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Figures 2 and 3 should be interchanged, the captions remaining in place.