INVESTIGATIONS OF THE n-TYPE GaAs MONOCRYSTALS BY R, σ and T-EP MEASUREMENTS

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In the letter the results of measurements of the Hall constant, conductivity and thermoelectric power are presented. Several monocrystallic GaAs samples produced in Poland and Czechoslovakia were investigated and n-type conductivity was found beginning at the lowest measured temperatures. The concentration and mobility of the electrons in the conductivity band were measured as well as the positions of the Fermi level. A degeneracy of the electron gas was established. The Fermi energies calculated from the thermoelectric power measurements differed significantly from those calculated using the Kane theory with known electron concentrations.

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Experimental investigations were carried out on several monocrystallic samples. Samples marked t obtained from the Semiconductor Factory Tewa in Warsaw were non-doped, but differed in the carrier concentration due to different purities of the components. Samples marked d obtained from Czeschoslovakia were purer than samples t, and were doped with Selenium.

The values of R (Fig. 1) and σ (Fig. 2) were measured in the temperature range from 100°K up to 300°K. The measurements of the temperature dopendence of the thermoelectric power were performed for three samples (Fig. 4). The shapes of the R and σ curves as well as the sign of the thermoelectric power indicate, according to the author, the dominating conductivity contribution of electrons coming from the admixture levels or the impurity levels of the donor type in the investigated temperature range. Plateaus of the majority of curves in Fig. 1 and Fig. 2 may indicate donor activity even in the lowest temperatures investigated. This conclusion is also in agreement with the measurements of Nasledova and Emelyanenko [1] who estimate the activation energy of the donor levels in GaAs to be 0.003 eV at the most. Ehrenreich [2] mentioned two types of donors in GaAs whose activation energies are 0 and 0.04 eV respectively. In room temperatures the contribution of the intrinsic electrons is, according to the author, still negligible, as compared to the conductivity

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in the impurity band which is due to an appreciable energy gap in GaAs amounting to 1.4 eV [3]. Only the 2*d* sample exhibits a slight conductivity increase with temperature, nevertheless this does not mean that the sample passes into the intrinsic conductivity state in room temperatures. The shapes of the thermoelectric power *versus* temperature curves do also imply that the investigated samples were far from state of intrinsic conductivity. Taking into account only the electron type conductivity, the concentration and Hall mobility of electrons in the conductivity band were calculated using the formulas:

$$n_e = \frac{A}{eR}\,; \quad \mu_e = \frac{\sigma}{n_e e}$$

(the dependence of mobility on temperature is presented in Fig. 3). The results obtained are shown in Table I.

TABLE I

Mark of samples		1*d*	2*d*	3*d*	2*t*	3*t*
Concentration $n \times 10^{-17}$ (cm^{-3})	−140°C	7.6	1.05	13	2.95	39
	20°C	7	1.4	13.5	3	42
Mobility u (cm^2/V × *s*)	−140°C	2370	980	2000	2210	560
	20°C	2700	1330	1770	2050	500

An electron degeneracy was assumed in the investigated samples due to the following facts:

1 Low values of the thermoelectric power obtained in the measurements

2 Low effective mass of electrons in conductivity band. For $k = 0$, $m_e^* = 0.075\, m_e$ [4]

3 High electron concentration ranging from 10^{17} cm^{-3} to 5.6×10^{18} cm^{-3}. In order to make sure that there really exists an electron degeneracy in the investigated samples some attempts were made to calculate the position of the Fermi level using the Kane model for the band structure of the compounds III–V [5] and [6]. The following formulas were applied:

$$n = \frac{4}{3}\left(\frac{2\pi m^* kT}{h^2}\right)^{3/2} \frac{2}{\sqrt{\pi}}\, L_0^{3/2}(\eta, \beta) \tag{1}$$

where $L_0^{3/2}$ is an integral of the type:

$$L_0^{3/2} = \int_0^\infty \left(-\frac{df_0}{dx}\right)(x+\beta x^2)^{3/2}\, dx$$

dependent on the parameters η and $\beta \cdot \beta = \frac{kT}{\Delta E}$ and η is the reduced Fermi level: $\eta = \frac{E_F}{kT}$.
The results obtained are shown in Table II.

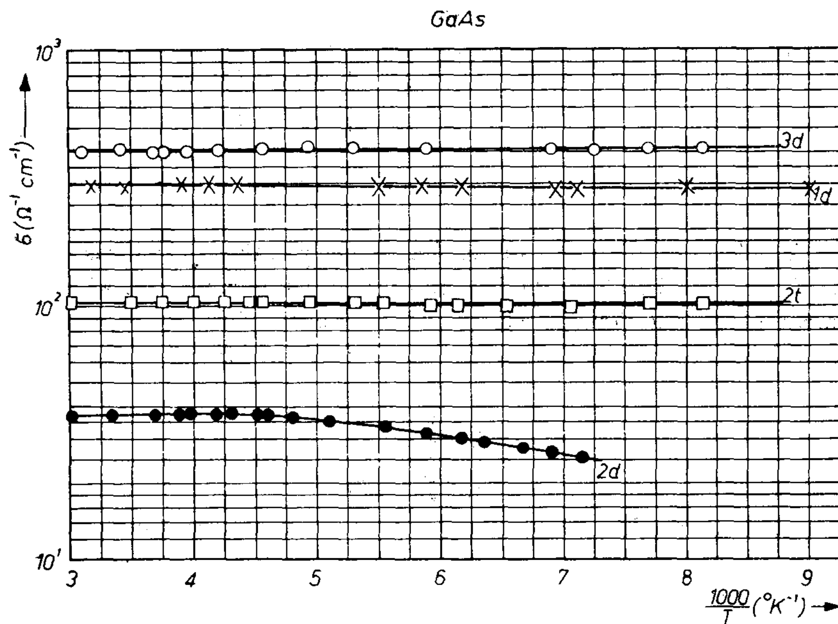

Fig. 1. Dependence of Hall constant R on temperature in n-type GaAs samples

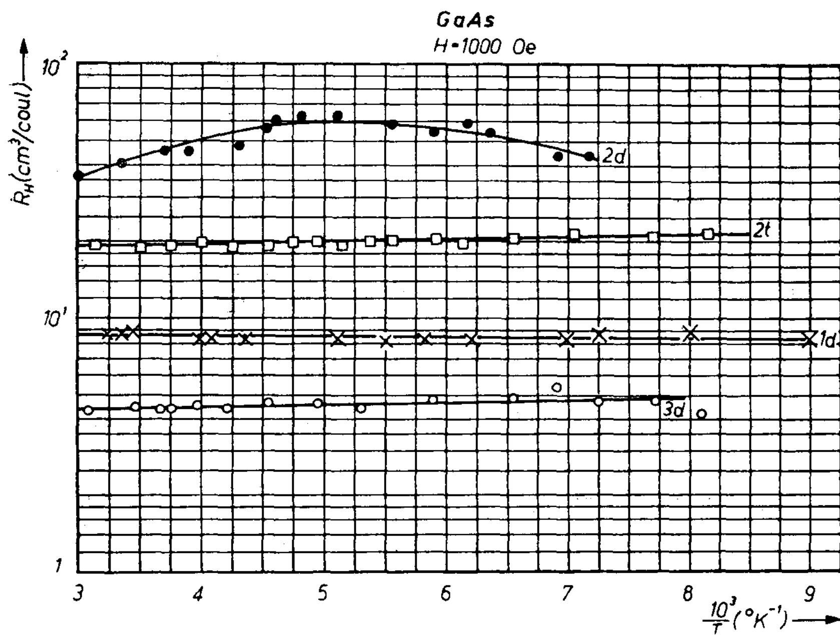

Fig. 2. Dependence of conductivity σ on temperature in n-type GaAs samples

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TABLE II

Mark of samples	1d	2d	3d	2t	3t	4t	5t	6t
Fermi level E_F (eV)	0.033	0.012	0.053	0.018	0.096	0.030	0.066	0.082

As seen from Table II there exists a small degeneracy of the electron gas in the samples because the Fermi level lies above the bottom of the conductivity band, which is assumed the zero energy point. The Fermi levels were also calculated from the experimental values of the thermoelectric power for comparison using the formula:

$$\alpha = -\frac{k}{e}\left\{\frac{{}^{1}L_{-2}^{\frac{r+5}{2}}(\eta, \beta)}{{}^{0}L_{-2}^{\frac{r+5}{2}}(\eta, \beta)} - \eta\right\} \quad (2)$$

where r determines the mechanism of electron scattering. If scattering on acoustic phonons is dominating, $r = -3$. In the case of scattering on ionized impurities, $r = +1$. Some calculations were performed for the sample 4t and 5t, using the values of the L — type integrals given in the work [6]. For $r = -3$ a significant disagreement was found while for $r = +1$ the difference between the left hand and the right hand side of Eq. (2) amounts to about 40%. The estimated values of E_F differ significantly from the values calculated from formula (1), as seen in Table III.

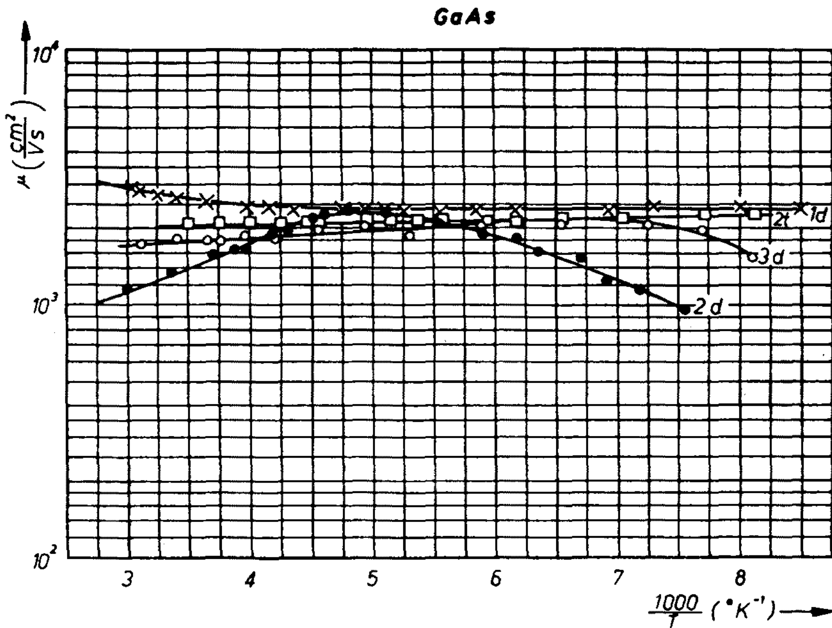

Fig. 3. Dependence of mobility μ on temperature in n-type GaAs samples

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TABLE III

Mark of samples	$4t$	$5t$	$6t$
Concentration n (cm^{-3})	6×10^{17}	2×10^{18}	3×10^{18}
E_F (eV)	0.030	0.066	0.082
E_F (with T-EP measurements) (eV)	0.12	0.215	0.26

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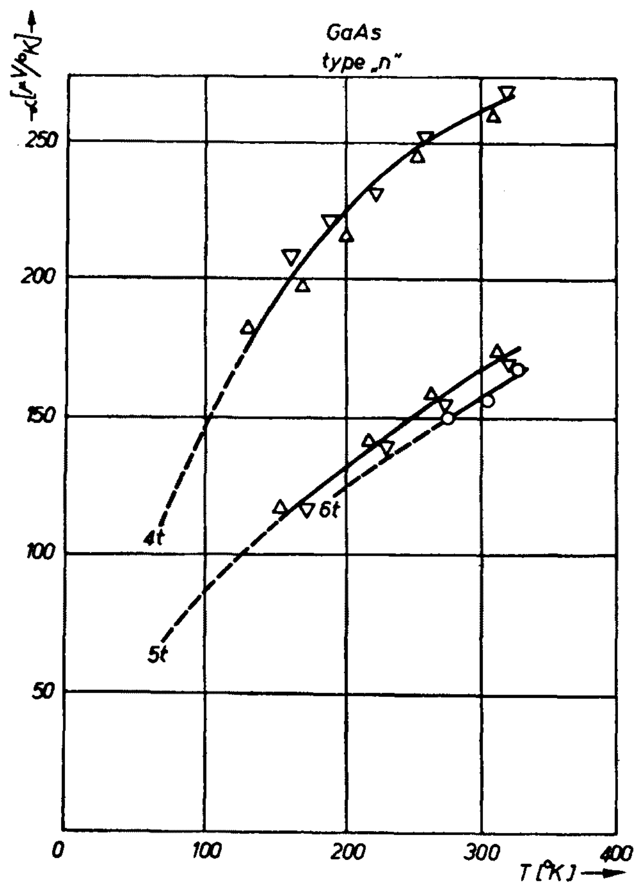

Fig. 4. Thermoelectric power *vs* temperature in three non-doped GaAs samples

Errors in determining the values of E_F from Eq. (1) together with the errors in the measurement of the thermoelectric power ($\sim 7\%$) cannot be responsible for such large differences in E_F (Table III). There must exist, in the author's opinion, a more complicated mechanism of collisions and the assumption of scattering on ionized impurities can lead to large erros in the estimated value of E_F.

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