TRANSPORT PHENOMENA IN HEAVILY DOPED n-TYPE InAs

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We investigated the thermoelectric power α, the magnetothermoelectric power in a strong field $\Delta\alpha_\infty$, the transverse Nernst–Ettingshausen coefficient $Q'_\perp$, the Hall coefficient R, and the electrical conductivity σ, as functions of the temperature (90-300°K) and the electron density ($1.7 \cdot 10^{18}$-$6.2 \cdot 10^{19}$ cm^{-3}). The results were interpreted on the basis of the theory valid for semiconductors in which carriers of one type are degenerate and have a Kane-type dispersion relation; the effect of nonparabolicity on the scattering probability was also taken into account.

In this case, the values of α, $\Delta\alpha_\infty$, and $Q_\perp^{is}$ ("is" stands for isothermal) in a weak field are

$$\alpha = \frac{k_0}{e}\frac{\pi^2}{2}\frac{k_0 T}{\hbar^2}\frac{2m^*}{(3\pi^2 n)^{2/3}}(\gamma'_r + 1), \tag{1}$$

$$\Delta\alpha_\infty = \frac{k_0}{e}\frac{\pi^2}{2}\frac{k_0 T}{\hbar^2}\frac{2m^*}{(3\pi^2 n)^{2/3}}\gamma'_r, \tag{2}$$

$$Q_\perp^{is} = \frac{k_0}{e}\frac{\pi^2}{2}\frac{k_0 T}{\hbar^2}\frac{2m^*}{(3\pi^2 n)^{2/3}}u\gamma'_r, \tag{3}$$

where

$$\gamma'_r = \frac{2}{3}\left(r - \frac{1}{2}\right) - \left[2 - (1+p)\frac{d\ln f_r\left(\frac{p}{p_0}\right)}{dp}\right]\gamma, \tag{4}$$

and u is the carrier mobility.

In Eq. (4), the nonparabolicity parameter γ is

$$\gamma = \frac{d\ln m^*}{d\ln n} = \frac{1}{3}\frac{p}{p+1}\left[1 - \left(\frac{p}{p_0}\right)^2\right],$$

where r is the scattering-mechanism parameter, equal to 0 and 1 for carrier scattering by acoustic and optical phonons, respectively, and 2 for carrier scattering by ionized impurities; $p = (1/m^*) - 1$, $p_0 = (1/m_0^*) - 1$; m^* and m_0^* are the effective masses at the Fermi level and at the bottom of the conduction band. The second term in the square brackets in Eq. (4) is due to the effect of nonparabolicity on the scattering probability. The factor $f_r(p/p_0)$ has various forms given by Eqs. (3)-(7) in [1], depending on the scattering mechanism.

It is seen from Eqs. (1)-(4) that the value of m_0^* and the variation of m^* with the electron density must be known in order to compute the quantities concerned. The dependence of m^* on the electron density was found from information on the behavior of $\alpha_\infty(n)$ and $R_\infty(n)$ at 300°K. The results for $m^*(n)$ are in accordance with the Kane-type dispersion relation. The values of m^* at low temperatures were calculated from the expression

$$\left(\frac{p_0}{p}\right)^2 = 1 + \frac{2p_0\hbar^2(3\pi^2 n)^{2/3}}{m_0^*\varepsilon_g}, \tag{5}$$

i.e., the Kane dispersion relation was assumed to be valid also at low temperatures, but the temperature dependence of ε_g and m_0^* was taken into account. The parameter values used in the calculations were $m_0^* = 0.023m_0$, $\varepsilon_g = 0.43$ eV at 90°K, and $\partial\varepsilon_g/\partial T = -4.5 \cdot 10^{-4}$ eV/deg [2, 3].

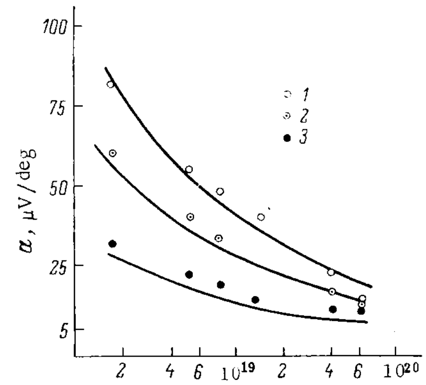

Fig. 1. Electron-density dependence of the thermoelectric power α. Continuous curves: calculated from Eq. (1). T (°K): 1) 300; 2) 200; 3) 90.

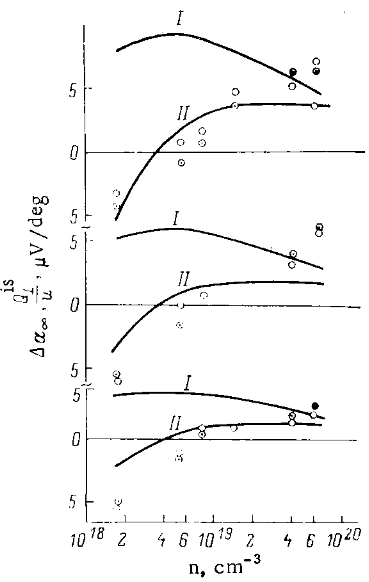

Fig. 2. Electron-density dependence of $\Delta\alpha_\infty$ and $Q_\perp^{is}/u$. Continuous curves: calculated from Eqs.(2) and (3) with and without inclusion of the factor f_r (curves II and I, respectively).

Figures 1 and 2 show the resulting theoretical curves of α, $\Delta\alpha_\infty$, and $Q_\perp^{is}/u$ as functions of r for r = 1 at 90, 200 and 300°K, together with the experimental results.

Figure 2 also shows the electron-density dependence of $\Delta\alpha_\infty = Q_\perp^{is}/u$ for r = 1, calculated without allowance for the effect of nonparabolicty on the scattering probability. It is clear from this diagram that, except at very high electron densities, an allowance for nonparabolicity in the scattering probability has a large influence on the thermomagnetic effects, the change of sign occurring at $n = 4 \cdot 10^{18}$ instead of $4 \cdot 10^{17}$ cm^{-3}.

From Figs. 1 and 2, the experimental values o α, $\Delta\alpha_\infty$, and $Q_\perp^{is}$ at temperatures from 90 to 300°K and electron densities from $1.7 \cdot 10^{18}$ to $6.2 \cdot 10^{19}$ cm^{-3} are satisfactorily represented by the theoretical curves with r = 1, corresponding to scatterin by optical phonons.

The temperature and electron-density dependences of the mobility do not agree with the hypothesis that electrons are scattered by optical phonons. The weak dependence of u on T is qualitatively in favor of scattering by ionized impurities, but this scattering mechanism cannot be reconcile with the values found for α and the thermomagneti effects. The temperature dependence of the mobil ty is not explained even by assuming that the electrons are scattered by both ionized impurities and acoustic phonons and choosing the deformation potential constant so as to obtain agreement with the experimentally found dependence of the mobility on the electron density at one particular temperature.

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