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ON THE ELECTRON MOBILITY IN GaAs SAMPLES WITH DOMINANT ELECTRICAL LEVEL 0.15 eV BELOW THE CONDUCTION BAND

О ПОДВИЖНОСТИ ЭЛЕКТРОНОВ В ОБРАЗЦАХ GaAs С ДОМИНАНТНЫМ ЭЛЕКТРОННЫМ УРОВНЕМ 0,15 эВ, РАСПОЛОЖЕННЫМ НИЖЕ ЗОНЫ ПРОВОДИМОСТИ

Ľ. HRIVNÁK[1]), M. KEDRO[1]), Bratislava

Look et al. [1] have shown that in several as-grown Bridgman and Czochralski GaAs crystals there exist dominant electrical defects with energy level approximately 0.15 eV below the conduction band, which were not connected with any impurity but may be considered as point defects. These authors published also the temperature dependence of electron mobility in the range 140 K—400 K of a sample with the concentration of the 0.15 eV centres being $N \simeq 8\times10^{15}$ cm^{-3}. Within this temperature range mobility decreased from 0.55 m^2/Vs to 0.39 m^2/Vs. Look et al. obtained a theoretical relationship for μ_n vs T from a variational solution of the Boltzmann equation. The following scattering mechanisms were considered: the optical deformation potential, the acoustic deformation potential, the piezoelectric potential, the neutral impurities and the ionized-impurity scattering. For the last mechanism the partial-wave-shift method was used as in the paper by Meyer and Bartoli [2] with a screened Coulomb interaction

$$U(r) = -\frac{e^2}{4\pi\varepsilon_0\varepsilon_s r}\exp(-r/\lambda). \tag{1}$$

This method gives in general more exact results than the Brooks–Herring theory. However, as it was shown in [2], for temperatures above 80 K and a carrier density below 10^{16} cm^{-3} the ratio of the phase-shift mobility to the Brooks–Herring mobility is very close to unity. According to our opinion the most important problem in the case of samples with a dominant electrical level of 0.15 eV below the conduction band is to express adequately the potential of such centres, since (1) is appropriate for shallow impurities only.

In a paper by Olejníková et al. [3] the model potential for deeper than hydrogenlike centres was used:

$$V(r) = \frac{e}{4\pi\varepsilon_0\varepsilon_s r}[1+(\varepsilon_s-1)\exp(-\beta r)]. \tag{2}$$

From the numerical solution of the Schrödinger equation for an electron with a potential energy $-eV(r)$ and an effective mass $m^* = 0.067\ m_0$, which is given in [3] for various values of the parameter

[1]) Institute of Electrical Engineering EPRC Slov. Acad. Sci., 842 39 BRATISLAVA, Czechoslovakia.

βa_1 ($a_1 = 4\pi\varepsilon_0\varepsilon_s\hbar/m^*e^2$, $\varepsilon_s = 13$), it follows that in order to get for the ground state the energy level of 0.15 eV below the conduction band we have to choose $\beta a_1 = 10$.

Following the approach to derivation of Conwell–Weisskopf and the Brooks–Herring formulas we have obtained [4] for the electron mobility limited by scattering on centres with potential (2) the expression:

$$\mu_\delta = AT^{3/2}\int_0^\infty \frac{x^3 e^{-x}\,dx}{\ln\left(1+\frac{T^2}{\Theta_1^2}x^2\right)+(\varepsilon_s^2-1)\ln\left(1+\frac{T}{\Theta_2}x\right)-(\varepsilon_s-1)^2\frac{Tx/\Theta_2}{1+Tx/\Theta_2}} \tag{3}$$

where

$$A = \frac{64\sqrt{2\pi}\varepsilon_0^2\varepsilon_s^2k_B^{3/2}}{3m^{*1/2}e^3N},\quad x = E/k_BT,$$

$$\Theta_1 = e^2N^{1/3}/4\pi\varepsilon_0\varepsilon_s k_B,\quad \Theta_2 = (\beta a_1)^2E_0/4k_B = \hbar^2\beta^2/8m^*k_B.$$

The temperature dependence of μ_δ calculated with $\beta a_1 = 10$, $m^* = 0.067\ m_0$, $\varepsilon_s = 13$ and $N = 3.68\times10^{16}$ cm^{-3} is shown in Fig. 1. The value of N was chosen to fit the experimental result at 400 K using the Matthiessen rule

$$\mu_n^{-1} = \mu_\delta^{-1}+\mu_L^{-1} \tag{4}$$

where μ_L is the lattice-limited electron mobility. In accordance with Pödör et al. [5] we have used the formulas

$$\mu_L^{-1} = \mu_{PO}^{-1}+\mu_{AC}^{-1}+\mu_{PIEZO}^{-1}, \tag{5}$$

where the contributions to the polar optical phonon, the acoustic phonon, and the piezoelectric scattering are given as (in units of cm^2/Vs)

$$\mu_{PO} = 243\ T^{1/2}\left[\exp\left(\frac{420}{T}\right)-1\right]\chi\left(\frac{420}{T}\right),$$
$$\mu_{AC} = 7.54\times10^8\ T^{-3/2}, \tag{6}$$
$$\mu_{PIEZO} = 6.94\times10^6\ T^{-1/2},$$

and the values of the χ function are those given by Fortini et al. [6]. The calculated temperature dependence of μ_L is plotted in Fig. 1 as a dashed curve. The total electron mobility obtained by using the formula (4) is compared with the experimental results of Look et al. [1]. Although the employed value of N is higher than the value of N for the 0.15 eV level estimated by Look et al., our results show that the applied model potential (2) can explain with the same values of parameters both the energy level and the electron mobility. However, the proposed explanation of the electron mobility temperature dependence cannot be considered unambiguous since in the given temperature range μ_δ plotted in Fig. 1 can be well described by the relation

$$\mu_\delta = 5.774\times10^{-2}\ T^{1/2}\left[\frac{m^2}{VsK^{1/2}}\right] \tag{7}$$

and according to Stratton [7] such a dependence can be attributed to the scattering on dipoles. The dipoles can arise due to the correlation between ionized shallow donors and acceptors.

The approximative Stratton formula is

$$\mu_d = \frac{16\varepsilon^2\hbar^2(2k_BT)^{1/2}}{e^3m^{*3/2}N_dL_d^2} \tag{8}$$

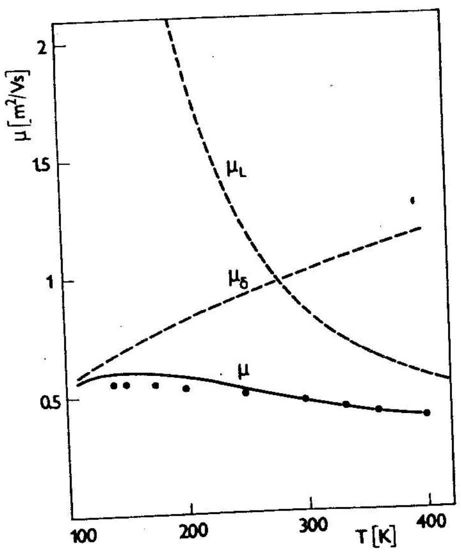

Fig. 1. The temperature dependence of electron mobility in a GaAs sample with a 0.15 eV dominant electrical defect. μ_L — lattice limited electron mobility calculated according to (5) and (6), μ_δ — calculated using formula (3) with parameters given in the text, μ — the total mobility calculated by the use of (4), ● — experimental values taken from Fig. 1 of reference [1].

where L_d is the dipole length and N_d is the dipole concentration. Taking $L_d \simeq 10^{-6}$ cm, $\varepsilon = 13\ \varepsilon_0$, $m^* = 0.067\ m_0$ we obtain $N_d \simeq 10^{15}$ cm^{-3}, providing the equivalence of (8) and (7). The obtained value of N_d is not unreasonable.

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