Evidence against the Negative-Charge-State Model for the *DX* Center in *n*-Type GaAs

Chadi and Chang[1] have recently proposed that the *DX* center in GaAs and $Al_xGa_{1-x}As$ alloys is a negatively charged defect resulting from the capture of two conduction electrons by the ionized donor: $d^+ + 2e^- \rightarrow DX^-$. This is in contrast to the neutral-charge-state model for *DX*: $d^+ + e^- \rightarrow DX^0$. We show here that the negative-charge-state model is qualitatively inconsistent with recent pressure-dependent electrical measurements on heavily doped *n*-type GaAs.[2]

The effect of hydrostatic pressure (P) is to increase the direct band gap and lower the energy of the *DX* level relative to the Fermi energy, ϵ_F, of the conduction electrons. The Fermi energy becomes pinned at the *DX* level above a critical pressure P_c at which electron capture at the *DX* level starts to occur. The carrier concentration $n(P)$ is measured using the Shubnikov-de Haas effect. The mobility μ is then given by $\sigma = ne\mu$. The decrease in n for $P > P_c$ is accompanied by a significant increase in μ as shown in Fig. 1 for two of the layers used in our previous study. For layer 1, $n = 1.8\times10^{19}$ cm^{-3} and $\mu = 800$ cm^2/V s, and for layer 2, $n = 1.1\times10^{19}$ cm^{-3} and $\mu = 1100$ cm^2/V s at atmospheric pressure.

For scattering by a screened ionized impurity potential, $V(r) = -e^2\exp(-\lambda r)/\epsilon r$, the Born approximation for a nonparabolic band gives[3]

$$\mu = \frac{Cn}{N_i m_1 (k_F)^2 F(\lambda, k_F)}, \quad (1)$$

where C is a constant, N_i is the ionized impurity concentration, $m_1 = \hbar k_F (\partial\epsilon/\partial k)^{-1}_{k=k_F}$, and

$$F(\lambda, k_F) = 2\pi\{\ln[1+(2k_F/\lambda)^2] - (2k_F/\lambda)^2/[1+(2k_F/\lambda)^2]\}. \quad (2)$$

At an arbitrary pressure

$$m_1(k_F) = \frac{m_0(1+\beta P)}{1-\alpha\hbar^2 k_F^2/2m_0},$$

where $\beta = 7.4\times10^{-3}$ kbar^{-1} (Ref. 4) and $\alpha = 1.07$ eV^{-1}.[5]

The variation of mobility calculated using the measured variation of n and Eqs. (1) and (2) for the two charge-state models is compared with the data in Fig. 1. For the negative-charge-state model (DX^-) we assume a constant $N_i = [d^+] + [DX^-]$. For the neutral-charge-state model (DX^0), $N_i = n$ at all pressures since the background acceptor concentration is low.[6]

It can be seen that the DX^0 model fits the mobility variation qualitatively. The increase in mobility with decreasing n is due partly to the decrease in $F(\lambda, k_F)$ and partly to the decrease of m_1 resulting from the nonparabolicity and lowering of the Fermi energy. The DX^- model, however, predicts a large decrease in μ above P_c since the decrease in n in Eq. (1) is not offset by any decrease in N_i. Analysis of the data for the other layers in our previous study[2] leads us to the same conclusion, namely, that the pressure dependence of the low-temperature mobility in heavily doped *n*-type GaAs is not consistent with the negative-charge-state model for the *DX* center.

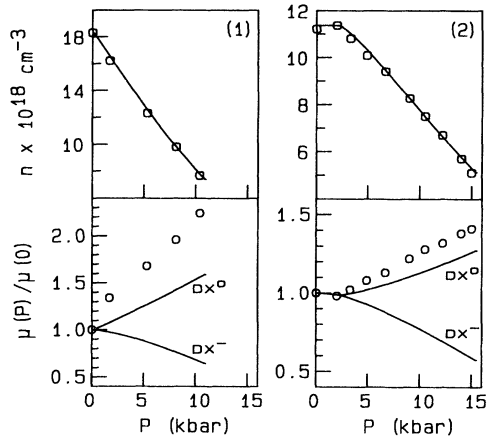

FIG. 1. Variation of carrier concentration n and normalized mobility $\mu(P)/\mu(0)$ with pressure P for heavily (1) Sn-doped and (2) Si-doped *n*-type GaAs layers. The solid lines in the mobility plot are calculated using the neutral- (DX^0) and negative-charge-state (DX^-) models.

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