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Deep electron trap level in semi-insulating GaAs

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Abstract. The experimental data on the Hall measurements have been used to characterize deep electron trapping levels in Cr doped semi-insulating GaAs crystals. The energy of the level below the conduction band edge has been found to be ~ 0·8 eV and is thought to be related to Ga vacancies in the host crystal and Cr impurities.

Keywords. Semiconductor devices and materials; semiconductors (III–V); Hall measurements; electron traps.

Transport properties of GaAs and $Ga_{1-x}Al_xAs$ alloys are important because of their potential applications in a variety of semiconductor devices both optical and microwave. The author has previously reported the interpretation and analysis of the Hall electron concentration n_H (Saxena 1982) and the capacitance measurements on the Schottky Barrier diodes (Bhattacharya *et al* 1979) to characterize various energy levels in the band gap of $Ga_{1-x}Al_xAs$ crystals, supported by semi-insulating (SI) GaAs substrates. From the point of view of device applications such as FET and integrated circuits, identification and characterization of energy levels in SI GaAs is extremely important. Although VPE, LPE and bulk GaAs crystals have been studied (Hasegawa and Majerfeld 1975), not much is known about the traps in SI GaAs. In the present letter, we present results on the temperature dependence of n_H for $Ga_{1-x}Al_xAs$/GaAs crystals to identify traps in SI GaAs.

The high purity $Ga_{1-x}Al_xAs$ layers were grown on Cr doped SI GaAs substrates by LPE. The Hall measurements were made on standard Clover leaf samples and in a magnetic field of 5 kgauss. Sn was used to make the ohmic contacts by firing them in an H_2 atmosphere for ~ 3 minutes at 500°C. The temperature of the sample could be stabilized to within ± 1 K and a high impedance electrometer was used to measure the signals through the samples. To account for the finite size of the contacts, correction factors as given by Van-Der Pauw (1958/59) were applied to calculate n_H from the measured values.

The variation of n_H with temperature for a typical $Ga_{1-x}Al_xAs$ ($X = 0{\cdot}23$) layer, supported by SI GaAs substrate is shown in figure 1 by full squares. The decrease in n_H below 300 K is due to electron 'freeze out' to a non-shallow level in the alloy while in the temperature interval $300 \lesssim T \lesssim 500$K, it is due to intervalley electron transfer from the central to the satellite minima. For $T \gtrsim 500$K, n_H increased sharply with temperature. This could be either due to (i) ionization of deep energy levels in the band gap of the alloy, or (ii) due to the electron conduction in the SI GaAs substrate. Next the epitaxial layers were removed by chemical etching and measurements repeated on SI GaAs only.

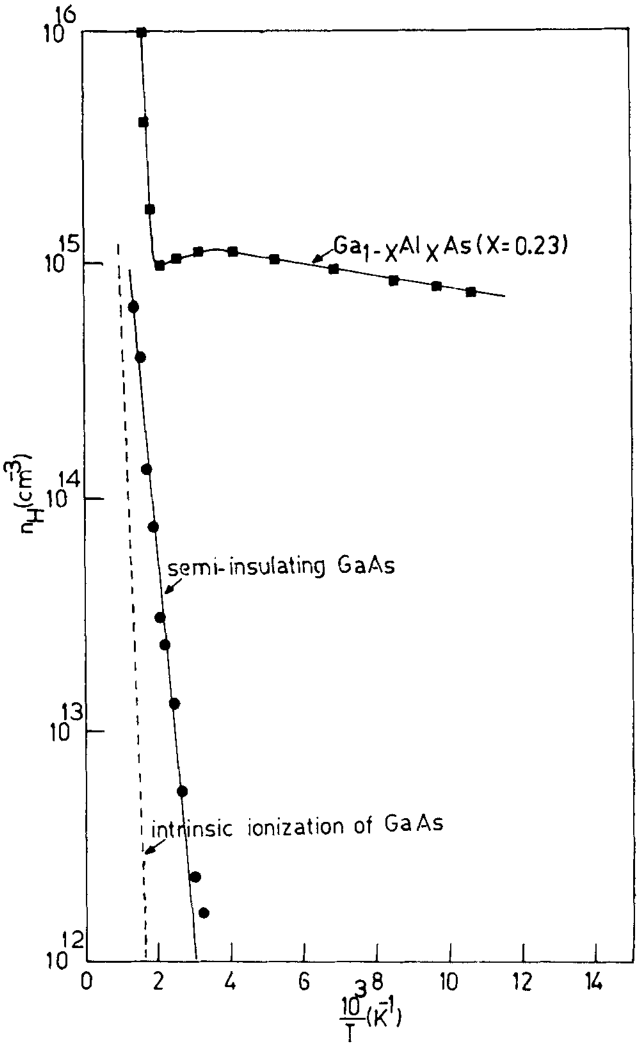

Figure 1. Temperature dependence of the Hall electron concentration n_H for LPE $Ga_{1-x}Al_xAs$ alloy ($x = 0{\cdot}23$) (■) and semi-insulating GaAs substrate (●). Also shown (broken line) is the calculated n_H due to the intrinsic ionization of GaAs.

The results so obtained are also shown in figure 1 by full circles.

The Hall concentration is calculated from the equation (Van-Der Pauw 1958/59)

$$n_H = B/(qt\Delta R), \tag{1}$$

where B = magnetic field strength, t = thickness of the layer on which measurements are made, q = electronic charge and ΔR = change in transfer resistance of the layer on the application of the magnetic field. From (1), it follows that

$$\frac{(n_H)_e}{(n_H)_s} = \frac{t_s \Delta R_s}{t_e \Delta R_e} \tag{2}$$

where the subscripts *e* and *s* represent the epitaxial layer and substrate, respectively. Since the parameters *t* and ΔR are known experimentally, we find that in the temperature interval $500 \lesssim T \lesssim 750$K, the ratio given by 2 is 35. On the other hand, the measured value of this ratio as obtained from figure 1 is also ~ 35 for the same temperature interval. Thus, the abrupt rise in n_H for $T \gtrsim 500$K is due to the electron conduction in the si GaAs.

In order to analyse the data for $Ga_{1-x}Al_xAs$ layers and to account for the abrupt rise in n_H at high temperatures, an electron level with activation energy of $\sim 0{\cdot}8$ eV was needed (Saxena 1982). However, using capacitance measurements on Schottky Barrier diodes, we could not detect any level in $Ga_{1-x}Al_xAs$ layers with such a large activation energy (Bhattacharya *et al* 1979). This further supports our conclusion that the rise in n_H at high temperatures is indeed due to the electron conduction in SI GaAs and not due to such deep energy levels in $Ga_{1-x}Al_xAs$ layers.

The next question arises about the possible conduction mechanism in SI GaAs at high temperatures. There could be two possibilities again namely (1) ionization of a deep energy level and (2) intrinsic ionization of GaAs.

We have calculated n_H due to intrinsic-ionization from the following equations (Saxena 1982)

$$n_H = \left[n_1 \left(1 + \frac{n_2}{n_1}\frac{\mu_2}{\mu_1} \right)^2 \right] \Big/ \left[\left(1 + \frac{n_2}{n_1}\frac{\mu_2^2}{\mu_1^2} \right) \right] \tag{3}$$

where
$$\frac{n_2}{n_1} = \left(\frac{N_{C2}}{N_{C1}} \right)^{3/2} \exp\left[-\Delta E_{12}/KT \right] \tag{4}$$

$$n = n_1 + n_2 = N_{C1} \exp\left[-E_G/2KT \right] \tag{5}$$

and
$$N_C = (4\sqrt{2}/h^3)\,(\pi m_{1,2} KT)^{3/2} \tag{6}$$

Here the subscripts 1 and 2 refer to the central and satellite minima, respectively. ΔE is the sub-band gap between these minima and E_G, the band gap. Considering $m_1 = 0{\cdot}067\, m_0$, $m_2 = 0{\cdot}55\, m_0$, $E_G = 1{\cdot}425$ eV, $\Delta E_{12} = 0{\cdot}285$ eV and $\mu_1/\mu_2 \simeq 8$ (Saxena 1982), n_H is calculated and the results are shown in figure 1 by the broken line. It is evident that the slope of the n_H curve for intrinsic ionization is different than for the measured n_H for GaAs. Also the intrinsic ionization occurs at much higher temperatures than the observed n_H for GaAs. Hence, the abrupt rise in n_H at high temperatures could not be due to intrinsic ionization. A computer analysis of the Hall data for $Ga_{1-x}Al_xAs$ layers indeed requires a deep level with an energy of $\sim 0{\cdot}8$ eV, which now turns out to be the activation energy of a level in si GaAs.

It is interesting to note that an electron trap level with an activation energy of 0·83 eV is present in *n*-type vpe and bulk GaAs (Hasegawa and Majerfeld 1975) and also in Cr-doped *n*-type lpe GaAs (Martin *et al* 1977). Compared to shallow donor density, the trap density has been found to be much larger in bulk GaAs, as expected, since the 0·83 eV trap level has been shown to be related to Ga vacancies in the host crystal (Hasegawa and Majerfeld 1976). Thus, it is tempting to think that the level observed in si GaAs in the present work is also related to a complex of Ga vacancies and Cr impurities. We would have liked to further verify our results by measuring n_H on pure epitaxial layers of $Ga_{1-x}Al_xAs$ without substrates but this could not be done due to the very small thickness ($\sim 5\ \mu$m) of these layers.

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