Electrical characterisation of 5.4 MeV alpha-particle irradiated; low doped, n-type gallium arsenide

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Abstract. We have investigated the effects of alpha particle irradiation on the electrical characteristics of Au/n-GaAs Schottky diodes The diodes were irradiated with an Am-241 alpha-particle source up to a fluence of 2.56×10^{10} cm^{-2} at room temperature. The induced defects were studied using deep level transient spectroscopy (DLTS) in the 15-300 K range and revealed the defects $E_{\mathbf{0.04}}$, $E_{\mathbf{0.14}}$, $E_{\mathbf{0.17}}$ and $E_{\mathbf{0.38}}$. The current-voltage *(I-V)* characteristics remain largely unchanged after irradiation, whilst capacitance-voltage (*C-V)* characteristics showed a decrease in net doping density**.**

1. Introduction

Defect engineering has enabled the development of optimized semiconductor material structures [1]. Understanding the physical properties and occurrence of defects will potentially lead to optimal device design. Particle irradiation induced defects modify the electronic properties of semiconductors [2, 3]. These modifications lead to applications such as carrier lifetime control and device isolation [1, 4].
GaAs based devices have been used in space applications, where they are exposed to irradiation from highly energetic particles. In the past, studies have been carried out in order to gain insight on the effects of particle irradiation on GaAs devices [4-8]. In this study we have investigated the defects introduced in Au-n/GaAs Schottky barrier diodes by alpha particle irradiation using DLTS. This study was limited to only low doped GaAs. DLTS is a convenient and powerful technique for studying defects in semiconductor materials [8].

2. Experimental details

(MOVPE) grown, silicon doped *n*-GaAs with an average free carrier density of 1.0×10^{15} cm^{-3} and <100> orientation, as specified by Epi Materials limited the supplier was used. The wafers were degreased and etched chemically using trichloroethylene and isopropanol. Au-Ge (88%:12%) ohmic contacts were resistively deposited on the n^+- backsides of the samples [1]. Thereafter 1000 Å thick Au contacts, 0.6 mm in diameter, were resistively deposited on the epitaxial layer. Contact quality was evaluated using *I-V* and *C-V* measurements.
The samples were irradiated with 5.4 MeV He ions (α-particles) from an Am-241 radionuclide for 20 min to a fluence of 2.56×10^{10} cm^{-2}. DLTS spectra were recorded at a scan rate of 3 K/min in the 15–300 K temperature range. The quiescent reverse bias was –2 V, filling pulse amplitude 0 V and filling pulse width 1 ms.

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The DLTS defect signature (energy level in the band gap, E_t and apparent capture cross section, σ) were determined from the slope and y-intercept, respectively, of log (e_n/T^2) versus (1000/T) Arrhenius plots according to the equation

$$e_n = \sigma_n \langle v_{th} \rangle \frac{g_o}{g_1} N_c \exp\left(-\frac{E_c - E_t}{k_B T} \right)$$

where e_n is the emission rate, k_B is the Boltzmann constant, T the temperature, $\langle v_{th} \rangle$ is the thermal velocity of electrons, N_c is the density of conduction band states, g_0 and g_1 are the degeneracy terms for the states before and after electron emission.

3. Results and discussion

The parameters deduced from the *I-V* and the *C-V* measurements of the Schottky diodes before and after irradiation are shown in Table 1. The *I-V* characteristics do not show any changes in ideality factor and barrier height after particle irradiation. However, the *C-V* characteristics show a decrease in the net doping density. The as-deposited value of carrier concentration is different to the one specified by the suppliers something which can be attributed to several factors chief amongst them a smaller active diode area. The decrease after irradiation has been explained as due to the electron traps introduced by the irradiation, trapping carriers [4].

Table 1. Schottky diode *I-V* and *C-V* parameters obtained from the Schottky diode before and after α-particle irradiation.

	Ideality factor	Barrier height (eV)	Nd ($\times 10^{14}$ cm^{-3})
As deposited	1.02	0.89	7.64
5.4 MeV irradiated	1.02	0.89	6.68

Figure 1 depicts the DLTS scans obtained at a frequency of 200 Hz. Curve (a) is the control spectrum obtained from the as-deposited samples before irradiation. It shows no defects present in measurable quantities in the 15-300 K temperature range. Curve (b) reveals emission peaks from defects induced by α-particle irradiation superimposed on a “skewed baseline’. The peaks are labelled $E_{\mathbf{0.04}}$, $E_{\mathbf{0.14}}$, $E_{\mathbf{0.17}}$ and $E_{\mathbf{0.38}}$ based on their energy levels.

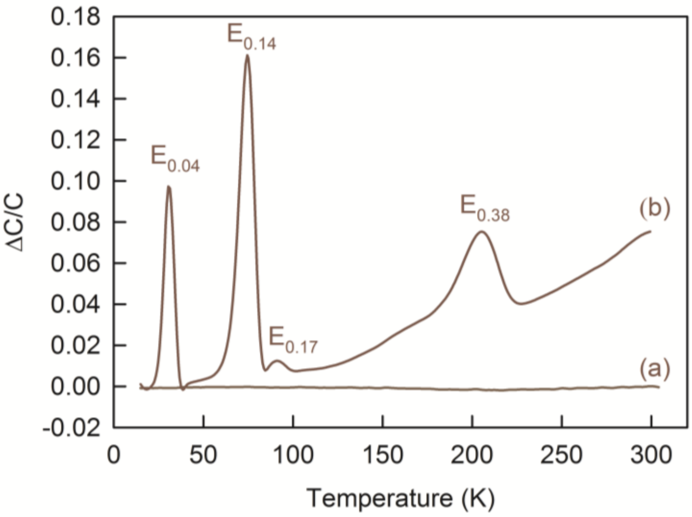

Figure 1. (a) DLTS spectra of un-irradiated (b) 5.4MeV alpha particle irradiated samples recorded at a quiescent reverse bias of 2 V at a rate window of 200 Hz and filling pulse 0 V and pulse width 1 ms.

A metastable defect that has been observed by other researchers was not observed in our scans [9]. This is because its presence and magnitude is highly dependent on the bias conditions, temperature and incident particle type [1, 5]. The "skewed baseline' in curve (b) has been observed only in α-particle irradiated gallium arsenide but not in other semiconductor materials exposed to the same type of radiation. It can therefore not be explained in terms of ion-solid interactions. A similar baseline was observed by Janse van Rensburg *et al* [10] in europium and xenon implanted GaN thin films without conclusion on its cause. The forward bias filling pulse in all the measurements done for the purpose of this study was -0.5 V in order to avoid the capacitance signal from surface states. This also shows that the baseline is not a consequence of surface states [11]. Surface states are sometimes confused with, or prevent, the detection of the presence of deep levels in the bulk of the material [12].

Irradiation induced defects are a result of collision of energetic particles. The Frenkel pair, is created when a particle imparts energy to a lattice atom to displace it forming a vacancy-interstitial pair [13]. However considering the energy transferred to atoms of the crystal by alpha-particles not only point defects, but defects consisting of clusters of atoms displaced from their normal lattice sites can be formed [7]. The Arrhenius plots for the defect characteristics are shown in Figure 2, from them defect 'signatures' shown in Table 2 were deduced.

The defects $\mathbf{E_{0.04}}$, $\mathbf{E_{0.14}}$ have been confirmed to be caused by primary defects such as the single and double charge states of the vacancy in the As sub-lattice. It has been proposed that both are different charge states (o/+) and (+/o) of the isolated vacancy V_{As} in GaAs. The $\mathbf{E_{0.38}}$ is speculated to be related to close As vacancy interstitials whilst the $E_{0.17}$ is a metastable defect with transformational kinetics that displays charge state dependent first order behavior [12, 14] .

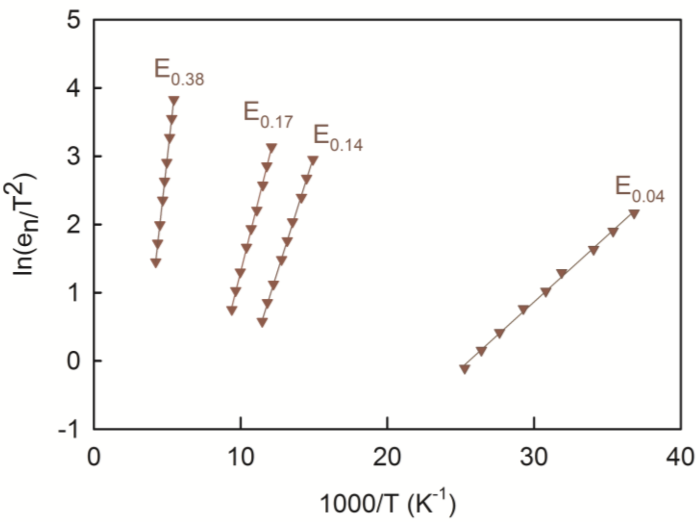

Figure 2. Arrhenius plots of defects observed after alpha particle irradiation.

$\mathbf{E_{0.04}}$, $\mathbf{E_{0.14}}$ and $\mathbf{E_{0.38}}$ have the same electronic structure and are point defect in nature as they are observable with the same signatures after being induced by different radiation types [11]. The charge state of the $\mathbf{E_{0.38}}$ is highly field dependent [4]. Further, the defects are dependent on the growth technique and carrier density implying that they emanate from the defects and impurities on the as grown GaAs [11].Table 2 summarizes the defect signatures. The defect characteristics shown in the table corresponds to those that have been observed by other researchers [7].

Table 2 . Characteristics of alpha-particle irradiation induced defects detected by DLTS in OMVPE-grown *n*-GaAs.

Defect label	Activation Enthalpy (meV)	Capture cross section (cm^{-2})
$E_{0.04}$	38.7	1.6×10^{-17}
$E_{0.14}$	135	3.0×10^{-15}
$E_{0.17}$	171	3.4×10^{-13}
$E_{0.38}$	382	7.4×10^{-16}

4. Conclusions

We have used DLTS to study the defects in the 15 -300 K range in α-particle irradiated GaAs. Four defect peaks were observed namely the $\mathbf{E_{0.04}}$, $\mathbf{E_{0.14}}$, $\mathbf{E_{0.17}}$ and $\mathbf{E_{0.38}}$ defects which are all point defect in nature. They have been associated with solid-ion interactions. The defects have been previously shown to be related to isolated vacancies and vacancy-interstitial pairs in the As sub-lattice. The $\mathbf{E_{0.38}}$ defect has been observed to be field dependent. The *(I-V)* characteristics remained significantly constant confirming the radiation hardness of GaAs. A decrease in carrier density was observed from the (*C-V*) characteristics after irradiation. We therefore can conclude that alpha particle irradiation affects the electrical characteristics of *n*-GaAs based devices.

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