Characterization of the fine structures associated with E3 defect in GaAs by application of Laplace DLTS

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Abstract. High resolution Laplace deep level transient spectroscopy was used to study the fine structure associated with the radiation induced bi-stable E3 centre in epitaxially grown GaAs. The samples were prepared using n-type GaAs that was doped with silicon to doping densities of 10^{14} cm^{-3} and 10^{15} cm^{-3}, respectively. To introduce the defect, the samples were subjected to MeV electrons emanating from a ^{90}Sr source at room temperature to a total flounce of 2.3 x 10^{15} cm^{-2}. Laplace DLTS measurements were carried out at 200 K. In addition to the two previously known states, a third stable state of the defect was also observed. It was also observed that at lower doping densities, the concentration of the third state is lower compared to the other two but increased as the doping density increased. From these observations, it was postulated that the existence of the third state could be the result of localized effects due to the close proximity of the E3 and a dopant atom.

1. Introduction

One of the most important contributions to the field of experimental semiconductor physics was the introduction of deep level transient spectroscopy (DLTS) by Lang in 1974 [1]. As a characterization technique, DLTS is capable of providing crucial information regarding the electrical behaviour of deep levels. However, even though the technique surpassed its predecessors in terms of sensitivity at the time of its conception, it still lacked the necessary resolution to reveal hidden fine structures associated with some of the observed deep levels and therefore further study of these structures was not possible at the time. It was only after the introduction of Laplace DLTS by L. Dobaczewski and A.R. Peaker [2], that it became possible to study defects with such level of detail. However, many of the previously identified defects in semiconductors are yet to undergo such studies.

Regardless of their origin, deep and shallow level defects are crucially influential on electrical and mechanical properties of semiconductors and more importantly, semiconductor based devices which can be considered one of the pillars of modern technology. Therefore, any and all efforts at improving current technology must include further and more detailed characterization of semiconductor defects, their effects, structure and their creation and annihilation dynamics. To accomplish this goal, several factors need to be considered. These factors include, but are not limited to, crystal growth methods, doping density, deep level introduction methods, defect annealing dynamics and environmental influences such as magnetic fields and temperature.

The aim of this study was to investigate one of the previously observed deep centers in epitaxially-grown thin film gallium arsenide. Gallium arsenide (GaAs) belongs to a group of semiconductors known as III-V compounds and is important due to its wide band gap, relatively high carrier mobility, etc. These attributes, many of which can be affected by the presence of defects and dopants, have made GaAs a very suitable candidate for application in development of high efficiency solar cells, electro optical devices, ultra-high frequency devices and lasers, just to name a few.

The defect in question for the present study is the E3 center, which is an intrinsic defect present in bulk-grown GaAs, while the E1 and E2 centers have been proposed to be two different charge states of an isolated As vacancy, V_{As}, the E3 was believed to resemble a close V_{As} –As pair [3,4]. However, based on the recent results reported by Schultz [5], the identification of E3 as an arsenic As mono vacancy, agrees more closely with the experimental data.

One method of introducing intrinsic point defects in crystals is through irradiation by alpha and beta particles. For this study, the preferred method of introducing arsenic mono vacancies was to subject GaAs based Schottky diodes to beta radiation emanating from a ^{90}Sr source. The incident electrons which possess energies ranging from 0.1-1 MeV have enough kinetic energy to displace one single atom [3] and therefore the possibility of creating only the desired arsenic vacancy increases while the chance of introducing other more complex types of defects decreases.

2. Experimental procedure

Samples were prepared according to the following procedure: Small rectangular shaped pieces of n-type GaAs were cleaved off as substrates for our samples from various wafers with different doping densities. The pieces were then chemically cleaned and degreased by boiling in trichloroethylene for 3 minutes and then boiling in isopropanol for 3 minutes. Afterwards, the samples were rinsed using deionized water and then chemically etched by being dipped in a solution of H_2O: H_2O_2: NH_4OH with 100:1:3 ratios for 30 seconds. After the etching process, the samples were rinsed in deionized water for the second time and then dipped in a 6 mol.dm^{-3} solution for 60 seconds and then rinsed in deionized water and blow dried by nitrogen gas.

After proper cleaning and etching, the substrates were placed in a resistive evaporation chamber in order to deposit a multi layered ohmic contact (Ni/Au-Ge/Ni) 50/1500/300 nm on one of the surfaces of each substrate. Afterwards, the freshly deposited ohmic contacts were annealed at 450°C for 2 minutes in an Ar filled environment.

The substrates were then put through a second cleaning procedure in order to prepare them for Schottky contact deposition. The second cleaning procedure was carried out following the same instruction as for the first one, with only skipping the step involving the dip in a solution of H_2O: H_2O_2: NH_4OH. The substrates were then placed in the same deposition chamber and Au Schottky contacts were deposited on to the other surface of the substrate through a metal contact mask.

After the samples were prepared, *I-V* and *C-V* measurements were carried out for each sample to obtain information regarding the newly deposited metal contacts. The information thus obtained includes: leakage current, ideality factor and free carrier density which made up the first set of experimental data for this study. The samples were then individually subjected to electron irradiation with each sample being irradiated for a specific duration. After the irradiation, once again *I-V* and *C-V* measurements were carried out and the results were compared against the first set of data.

The third part of the experiment, intended to confirm the existence of the defect of interest (E3) in each sample, was performed using conventional DLTS. After the confirmation step, E3 was characterized in each sample and in depth using Laplace DLTS. The goal was to observe the finer structure of E3 and characterize its formation and behaviour in each sample. The obtained results were then compared against each other in an attempt to determine the influence of duration of radiation as well as initial carrier density of each sample on the E3 center.

3. Results and discussion

Figure 1(a) shows the results of *I*-*V* measurements for n-GaAs based devices before and after irradiation. Under forward bias, the linearity of the log-I-V plot for unirradiated samples points to the high quality of these devices with an ideality factor of $n = 1.03$. However, after irradiation, the region of the plot between 0 to 0.2 V included a bump which perturbs the linearity of the plot and therefore the ideality factor was reduced to $n = 1.13$. The creation of the bump in the plot is associated with generation-recombination dynamics that take place during the measurement due to irradiation induced defects. By comparing the reverse current, I_R, the irradiated reverse current is higher than the unirradiated current.

Figure 1(b) includes *C*-*V* plots for the samples and aims to demonstrate the change in free carrier density as a result of electron irradiation. It can be seen that the slope of the line representing samples after the irradiation process is steeper which suggests a decrease in free carrier density, $N_D = 7.4\times10^{14}$ cm^{-3} compared to $N_D = 9.7\times10^{14}$ cm^{-3} for unirradiated samples.

Figure (2) shows both the conventional DLTS and Laplace DLTS spectra. The conventional DLTS spectrum shows three prominent peaks: E1, E2 and E3, which are spaced far from each other in terms of energy levels. These peaks are respectively observable at temperatures close to 30 K, 70 K and 200 K at a rate window of 80 per second. While E3 is identified as a single peak in the conventional DLTS spectrum, once characterization was carried out isothermally and by use of high resolution Laplace DLTS, which revealed that E3 was not a single peak but a combination of three individual peaks (E3a, E3b and E3c).

Figure 3 (a) shows the Arrhenius plots for 3 samples with different carrier density namely 9×10^{14}, 1.9×10^{15} and 9.5×10^{15} cm^{-3} for E3a, E3b and E3c, respectively. The Arrhenius plot shows three distinct levels. We obtained Arrhenius plots with a high degree of linearity. Activation energy increased with increasing free carrier density for E3a ($E_{0.38}$, $E_{0.37}$ and E_{036}).

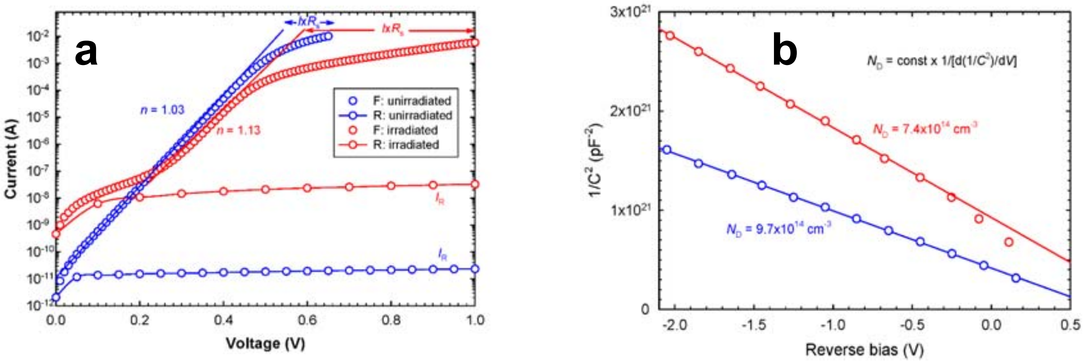

Figure 1. Demonstrates the change in (a) *I*-*V* and (b) *C*-*V* plots as a result of electron irradiation.

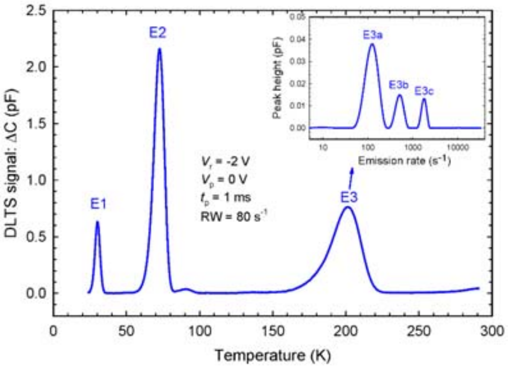

Figure 2. Conventional and Laplace DLTS spectra for E3 peak

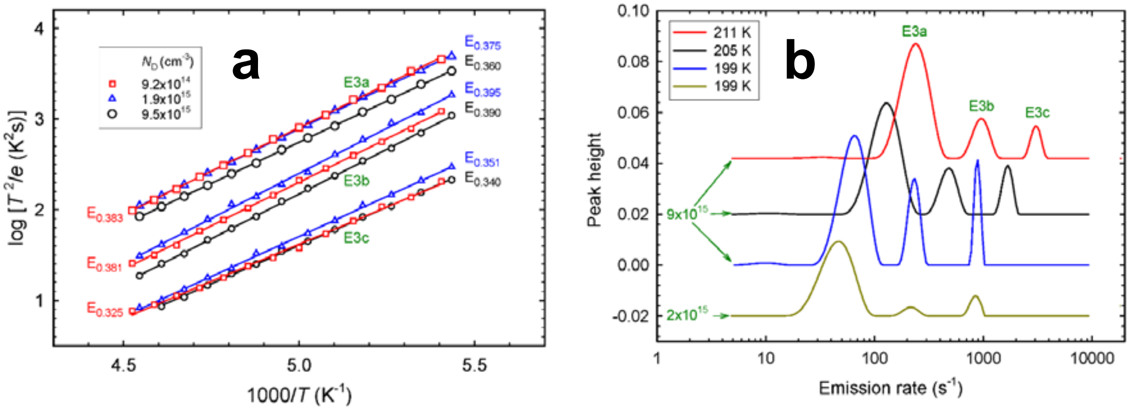

Figure 3. (a) Arrhenius plots associated with constituent peaks of the E3 and (b) the shift in the activation energy of all three constituent peaks as a result of changes in temperature.

Figure 3 (b) demonstrates the change in Laplace DLTS spectra as a result of change in temperature for 2 samples with different carrier densities (9×10^{15} cm^{-3} and 2×10^{15} cm^{-3}) at 211, 205 and 199 K. In both samples, all three peaks shifted together to the right in an orderly manner when temperature was raised. This is an indication that the splitting of the defect into three components is reliable.

4. Conclusion

We have shown that irradiating GaAs Schottky diodes, resulted in a higher leakage current and smaller free carrier density. Laplace DLTS demonstrated that the E3 peak has three components, E3a, E3b and E3c, with closely spaced energy levels. All E3 components shifted together when changing the temperature. Arrhenius plots confirmed the three distinct levels of E3 defect and for the main peak (E3a), that the activation energy increased with decreasing free carrier density.

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