Characterisation of Cs ion implanted GaN by DLTS

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Abstract

Deep level transient spectroscopy (DLTS) was used to characterise Cs implanted GaN grown by hydride vapour phase epitaxy (HVPE). This implantation was done at room temperature using energy of 360 keV to a fluence of 10^{-11} cm^{-2}. A defect with activation energy of 0.19 eV below the conduction band and an apparent capture cross section of 1.1×10^{-15} cm^2 was induced. This defect has previously been observed after rare earth element (Eu, Er and Pr) implantation. It has also been reported after electron, proton and He ion implantation.

Keywords: GaN; Cs implantation; Defect; DLTS

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1. Introduction

Gallium nitride (GaN) is a binary semiconductor with a direct bandgap of 3.4 eV. GaN based devices have promising prospects in military, satellite and commercial applications. This is due to the optical, electronic and mechanical properties of GaN. Devices which can be fabricated from GaN include both light detecting and emitting devices, such as solar-blind detectors and light emitting diodes (LED's) respectively [1].

An important mechanical characteristic of GaN is its radiation hardness. It has a strong resistance to radiation damage due to its high bond strength. The density of GaN is 6.10 g/cm^3 and the displacement energies of gallium and nitrogen are 19 and 22 eV respectively [2]. This makes GaN more radiation resistant than GaAs for instance. Moreover, the radiation hardness of GaN makes it more suitable for higher irradiation doses as the amorphisation threshold is much higher. Ion implantation has been employed in various studies for different purposes in GaN. It has been utilised for doping using rare earth elements and transition metals [3,4] and for processing GaN-based devices such as LED's and field effect transistors [1]. Material damage caused by ion implantation and the effect of this damage on material properties have also been investigated by Ronning *et al*. [5].

Of particular interest is the growing research related to ion irradiation of GaN and the effect of the induced defects on its electrical properties. These defects can have a detrimental or beneficial effect on the fabricated device depending on its application. Defects induced in GaN by different particles such as protons, electrons, and numerous ions have been studied by various authors. A variety of ions have been implanted in GaN at various energies, including the several hundred keV range, in order to study the effect on its electrical and optical properties [3,4]. To the best of our knowledge no studies have been done on Cs ion implanted GaN.

Cs is an alkali metal that has been utilised in photo sensitive applications. It has been used in the synthesis of highly spectrally sensitive photocathodes to produce GaN based photodetectors. Kampen *et al*. are among the few authors who have investigated the adsorption of Cs on *n*-GaN [6]. Also, Ji *et al.* used density functional theory (DFT) calculations to investigate the effects of Ga and N shallow vacancy defects on the adsorption of Cs on GaN [7]. In this study GaN was implanted with Cs ions with the view of studying the defects induced by this implantation process. The electrically active defects were measured *ex situ* using deep level transient spectroscopy (DLTS).

2. Experimental

In this study Si doped GaN grown by hydride vapour phase epitaxy (HVPE) was utilised. The samples had a free carrier density of 1×10^{17} cm^{-3}. The cleaning of the samples involved degreasing and etching. Firstly, the samples were submerged for 3 minutes in boiling TCE and for another 3 minutes in boiling isopropanol. They were then rinsed 3 times in de-ionised water. The samples were etched in boiling aqua regia for 10 minutes. This was followed by another etching process whereby the samples were dipped in HCl:H_2O solution for 60 seconds. Between each of the etching steps de-ionised water was used to rinse the samples. The samples were then blown dry with nitrogen prior to metal deposition. An ohmic contact consisting of Ti (150 Å)/ Al (2200 Å)/ Ni (450 Å)/ Au (550 Å) was then deposited onto the GaN using an electron beam system. The samples were later annealed at 500 ºC in a furnace for 5 minutes in an argon ambient with the argon gas flowing at 2 litres per minute. Annealing was done in order to minimise contact resistance. Schottky diodes with a diameter of 0.6 mm were then evaporated through a mask onto the GaN samples using a resistive evaporation system. The Schottky contact consisted of Ni (200 Å) as the first layer and Au (600 Å) as a cap layer. The characterisation of the samples involved measuring the currentvoltage (*I*-*V*) response to assess whether the diodes were good enough to characterise electrically active defects using DLTS. The defect characterisation was performed in the 80 to 200 K temperature range. The measurements were taken before and after processing the samples. The samples were implanted with Cs ions at 360 keV to a fluence of 10^{11} cm^{-2} at room temperature. To determine the DLTS signature, the spectra were measured at different emission rates ranging from 5 to 2000 s^{-1}. The DLTS measurements were performed by a computer controlled system with a closed cycle helium cryostat and a 1 MHz Boonton 7200 capacitance meter.

3. Results and discussion

The DLTS spectra of Cs implanted GaN are shown in Fig. 1. The measurements were performed at a reverse bias voltage of -1 V, a filling pulse amplitude of 0.5 V and a filling pulse width of 1 ms. The DLTS signature, namely the defect energy level and apparent capture cross section, was determined from the Arrhenius plots shown in Fig. 2. The defect with activation energy of 0.26 eV is a common as grown defect in GaN. The calculated apparent capture cross section was 9.4×10^{-16} cm^2. This defect was observed by Hacke *et al*. in HVPE grown GaN [8].

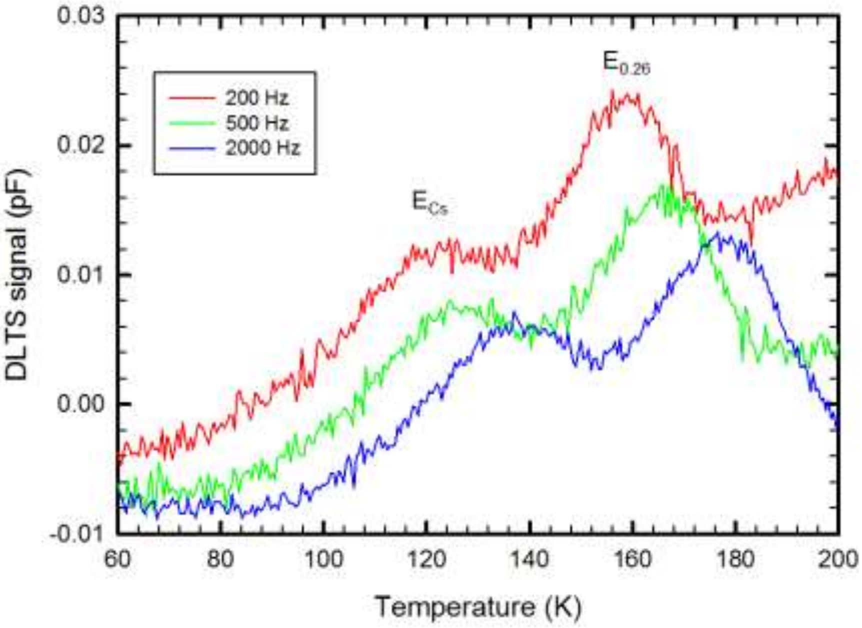

Fig. 1 DLTS signals of Cs implanted GaN measured at different rate windows.

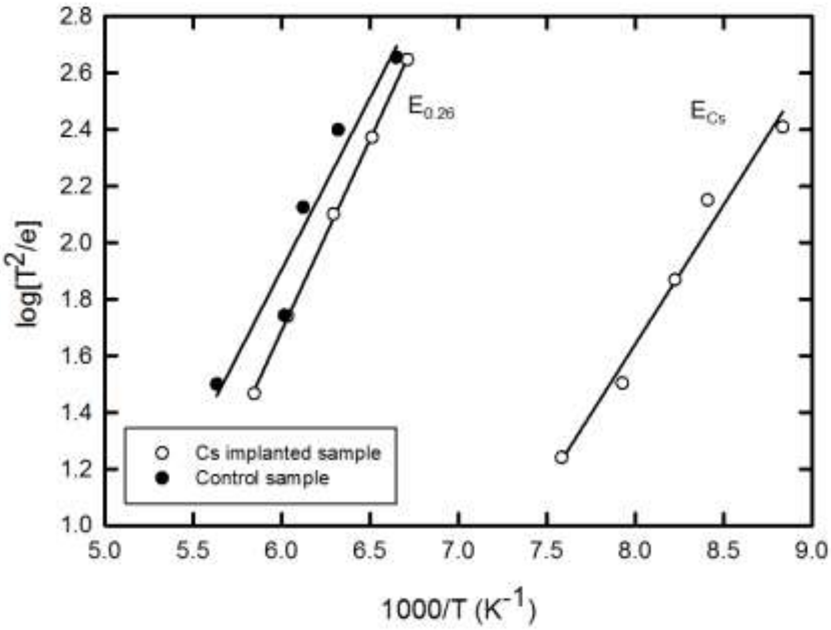

Fig. 2 Arrhenius plots of Ni/Au diodes which were resistively evaporated on GaN. One sample was subjected to Cs implantation while the other was used as a control sample.

A new defect, which we have labelled E_{Cs}, was observed after Cs ion implantation at peak temperature of 119 K using a rate window of 80 s^{-1}. This defect has an energy level of 0.19 eV and an apparent capture cross section of 1.1×10^{-15} cm^2.

Table 1 Comparison of defects with similar activation energies.

Process	Defect label	Defect level (eV)	Apparent capture cross section (cm^2)	Peak temperature (K)	Reference
Cs implantation	E_{Cs}	0.19	1.1×10^{-15}	119	This study
Electron beam deposition	Ee1	0.19	1.2×10^{-15}	120	[9]
Xe implantation	E_{Xe1}	0.19	1.2×10^{-15}	-	[3]
Eu implantation	E_{Eu1}	0.19	2.6×10^{-16}	-	[3]
Er implantation	Er15/900	0.19	5.6×10^{-16}	-	[13]
Pr implantation	Pr15/1050	0.19	5.6×10^{-16}	-	[13]
Proton and He ion irradiation	ER3	0.20	4.0×10^{-15}	121	[11]
Electron irradiation	-	0.18	2.5×10^{-15}	118	[10]

Table 1 contains defects which are similar to this defect. Auret *et al*. reported a defect with activation energy of 0.19 eV below the conduction band [9]. This defect was induced after the electron beam deposition of a Schottky contact consisting of Ru. They compared their findings to those of Fang *et al*. [10] and Auret *et al*. [11]. The former obtained a defect with activation energy of 0.18 eV after electron irradiation while the latter observed a defect with activation energy of 0.20 eV after both proton and He ion irradiation. In their study, Fang *et al*. noted that should the capture cross section that they obtained be temperature dependent, the 0.18 eV defect could be compared to the E_C – 0.07 eV defect observed by Look *et al*.

[12]. They used Hall measurements to study electron irradiated GaN. In their investigation they attributed the defect they had characterised to a nitrogen vacancy.

Janse van Rensburg *et al*. also observed a defect with activation energy of 0.19 eV [3]. They implanted GaN with Xe and Eu ions. Song *et al*. implanted GaN with 2 rare earth elements, namely Er and Pr [13]. They also obtained defects for both the Er and Pr implanted GaN with activation energy of 0.19 eV. They then compared their results to those obtain by Filhol *et al*. who used density functional theory (DFT) calculations to investigate doping of GaN with rare earth elements (Eu, Er, and Tm) [14]. Janse van Rensburg *et al*. also compared their results to those obtained by Filhol *et al*. By introducing rare earth dopants to GaN, Filhol *et al*. concluded from their studies that rare earth substitutional Ga sites, RE_{Ga}, bound more strongly with a nitrogen vacancy. Since in their investigation Janse van Rensburg *et al*. compared the implantation of Xe to the implantation of Eu, the latter being a rare earth element, and found the same activation energies for both defects, they concluded that the 0.19 eV defect is not just a rare earth element related defect. This defect, they added, was more of a general structure in which the Ga could have been substituted by another implanted species to form a defect complex with the nitrogen vacancy.

From transport of ions in matter (TRIM) calculations [15], the penetration depth of 360 keV Cs ions in GaN is 73 nm with a straggle of 30 nm and a fluence of 1×10^{11} cm^{-2} leading to a peak concentration of about 1×10^{16} cm^{-3} Cs atoms. From depletion width calculations, the depletion depth was 80 nm during the pulse bias and 160 nm during the quiescent reverse bias conditions. It is therefore expected that the DLTS measurements would probe a region with significant Cs concentration and that any electrically active defects directly related to Cs would be detected by DLTS. Since no unique DLTS peaks were observed, it is concluded that no Cs related peaks were observed, and that Cs probably does not lead to electrically active defects in GaN.

4. Conclusion

Cs ion implantation in GaN at room temperature induces a defect with energy level of 0.19 eV below the conduction band. Defects with this energy level have been observed using different processing methods including the deposition of Ru using electron beam deposition and Xe and Eu ion implantation. Other rare earth elements which have induced this defect after implantation include Er and Pr. This defect has also been observed after proton, He and electron irradiation. In comparison to defects obtained in other studies, it has become apparent that the E_{Cs} defect is not just a defect related to the implantation of Cs ions. It is therefore not an intrinsic defect but a defect related to irradiation effects.

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