Study of a common deep level in GaN

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ABSTRACT

A deep level with the activation energy around 0.45~0.6eV has persistently appeared in GaN samples grown by hydride vapor-phase epitaxy, organometallic vapor-phase epitaxy and molecular beam epitaxy. However, the origin of this deep level still remains unclear. In this study, we investigated this deep level trap E2 of GaN films by using deep level transient spectroscopy. The GaN films were grown by a conventional low pressure organometallic vapor-phase epitaxy technique with different V/III ratios. Frequency-dependent capacitance measurement was performed to determine the most proper frequency for capacitance measurements Capacitance-voltage measurements were then applied to obtain the carrier concentrations. The carrier concentration became higher as the flow rate of NH3 got lower. The deep level E2 is found in GaN samples grown with higher V/III ratios. The trap concentration of level E2 increased with increasing NH_3 flow rate. Compared with the theoretical prediction of the nitrogen antisite level in GaN, the level E2 was believed to be related to nitrogen antisites.

Keyword GaN, deep level, organometallic vapor-phase epitaxy, V/III ratios, frequency capacitance, antisite defect, DLTS

INTRODUCTION

Group III-V nitrides have wide bandgaps varied from 1.9eV, of InN, to 6.3eV, of AlN, and been promising materials for blue and ultraviolet optoelectronic devices[1], high temperature, and high power transisors[2,3], and solar-blind ultraviolet detectors.[4] However, the progress of GaN technology has often been limited by material quality, such as high defect densities. Therefore, it is important to investigate the deep level traps in GaN. Deep-level transient spectroscopy (DLTS) and transient capacitance methods have been used to characterize the deep level traps in GaN grown by hydride vapor-phase epitaxy (HVPE), organometallic vapor-phase epitaxy (OMVPE) and molecular beam epitaxy (MBE). Several deep level centers in n-GaN with activation energies ranging from 0.14-1.63eV have been reported[5-11]. Among them, a deep level with the activation energy around 0.45~0.598eV has been observed in samples grown by different techniques[5,6,7,9,10]. The origin of this deep level still remains unclear. In the present study, we characterized deep level traps of two sets of GaN films by using deep-level transient spectroscopy (DLTS) and transient capacitance method.

EXPERIMENT

Two sets of n-type GaN film were discussed in this study. The set I, fabricated by AXTRON planetary reactor, contained about 4 µm thick Si-doped GaN layer (labeled R1). The set II were prepared by a conventional low pressure OMVPE, and the thickness of undoped GaN film was about 2µm. The detail growth procedure had been described elsewhere.[12] The Set II, in brief, was grown by a conventonal low pressure OMVPE reactor with trimethylgallium (TMG) as the column III precursor, and NH_3 as the column V precursor, respectively. A thin (500Å) GaN buffer layer was deposited on c-plane sapphire substrate at 525 using TMG and NH_3, and GaN film was then grown at 1050 . The GaN films, set II, was grown with different V/III ratios. The flow rate of NH_3 were 2500 sccm 2000 sccm 1500 sccm, labeled GaN2500 GaN2000 GaN1500.

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Pt/Au and Au were used as Schottky contact metal on set I and set II, respectively. Aluminum was deposited a large area on the front surface as an ohmic contact. The current-voltage characteristic of Schottky diode at room temperature was well behaved. To determinate the most proper frequency of capacitance-voltage (C-V) and transient capacitance measurements, conventional capacitance-frequency (C-F) measurement were employed. Capacitance-voltage (C-V) measurements, to obtain the carrier concentration, were taken at different temperature to identify whether the carrier concentration was changing with temperature. A DLTS spectrometer by SULA Technology and a liquid-nitrogen cryostat operated in the temperature range between 90 and 530 K was used DLTS measurements. For the DLTS measurement, a 100 ms wide pulse at 0.3V was applied to fill the electron traps in GaN. A reverse bias of -3V was applied to remove electrons from the deep level in the depletion region, and the capacitance transient was detected by a 1MHz capacitance meter. The transient capacitance was measured by using a HP4194 impedance analyzer. The most proper measurement frequency used to do the transient capacitance measurements were indicated form C-F measurement.

RESULTS AND DISCUSSION

The response of parallel capacitance (C_p) to the frequency of GaN2500, at different temperature, is demonstrated in Fig.1. A Schottky diode can be simulated by a simple series RC alternating circuit. The charging and discharging of trap in low frequency can follow the input signal, while at higher frequency series resistance would affect on the result of capacitance. The abrupt increasing of capacitance at lower frequency, as shown from frequency-capacitance measurement, indicated that there are deep level traps in GaN films. According to Fig. 1 the range that the parallel capacitance do not vary with modulation frequency is around $10^3 \sim 10^4$Hz. The most proper capacitance-voltage measurement frequency of GaN2000 GaN1500 are 5KHz 10KHz as suggested by C-F measurement. Figure 2 shows the carrier concentration of set II varies with measuring temperature. As the flow rate of NH_3 getting lower, the free carrier concentration became higher as indicated in Fig. 2. The large background carrier concentration is usually regarded to be caused by the large amount of nitrogen vacancy[13]. The carrier concentration of R1 is 1.184×10^{17} (cm^{-3}) from the similar measurement.
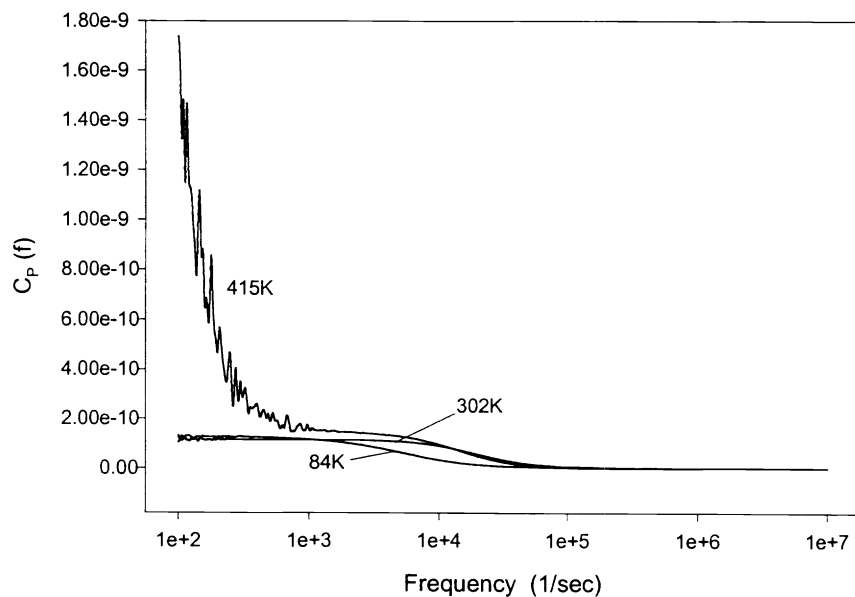
Fig. 1 The response of parallel capacitance to frequency of GaN2500 at different temperature. The abrupt increasing of C_p at lower frequency was caused by deep level traps in GaN films, and the proper measurement frequency of GaN2500 was around $10^3 \sim 10^4$Hz.
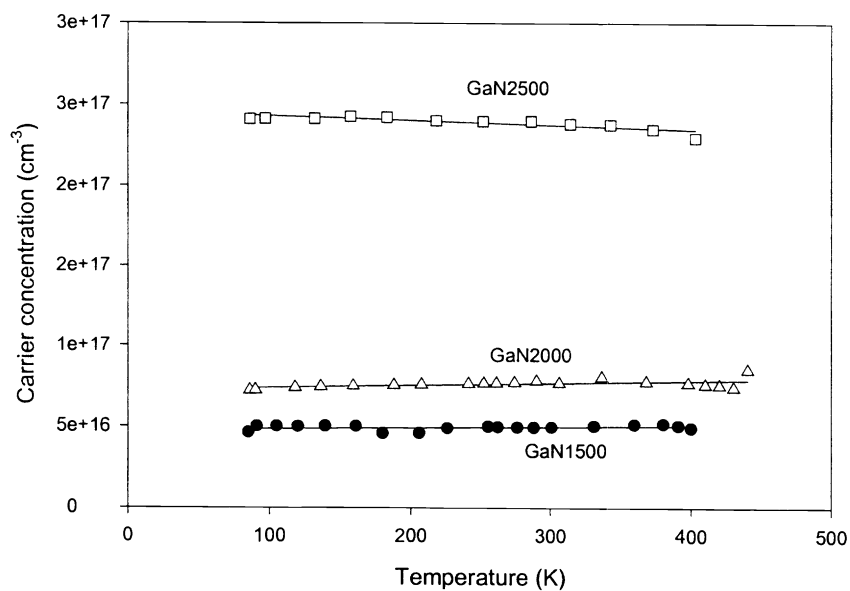

Fig. 2 Carrier concentration of set II varied with measurement temperature. Lower the NH_3 flow rate higher carrier concentration as indicated in Fig. 2. The large background carrier concentration is usually regard to cause by the big amount of nitrogen vacancy.

The results of DLTS spectra of R1 are presented in Fig.3 with the emission rate window which were set as 23.26 s^{-1} and 46.52 s^{-1}. Two distinct levels, labeled E_2 and E_4, were clearly observed on R1. The activation energy, ΔE, and the electron capture cross section, σ, of each deep level traps were extracted from Arrenius plots of $\log(T^2\tau)$ versus $1000/T$, where τ is the capacitance transient time constant deduced from the windows setting of the DLTS system and T is the corresponding temperature. A slop of linear least square fit to each set of data obtains the activation energy of each deep level. The characteristics of level E_2 and E_4 are listed in Table 1. Arrhenius plots reveal that level E_2 was closed to the level with activation energy of 0.49eV found by Götz et al.[5], 0.58eV report by Hacke et al.[6], 0.49eV reported by Lee et al.[7], 0.598eV reported by Haase et al.[9], and 0.578eV reported by Wang et al.[10]. Similarly, level E_4 was closed to 1.10eV reported by Chen et al.[8], and the 0.961eV reported by Wang et al.[10].
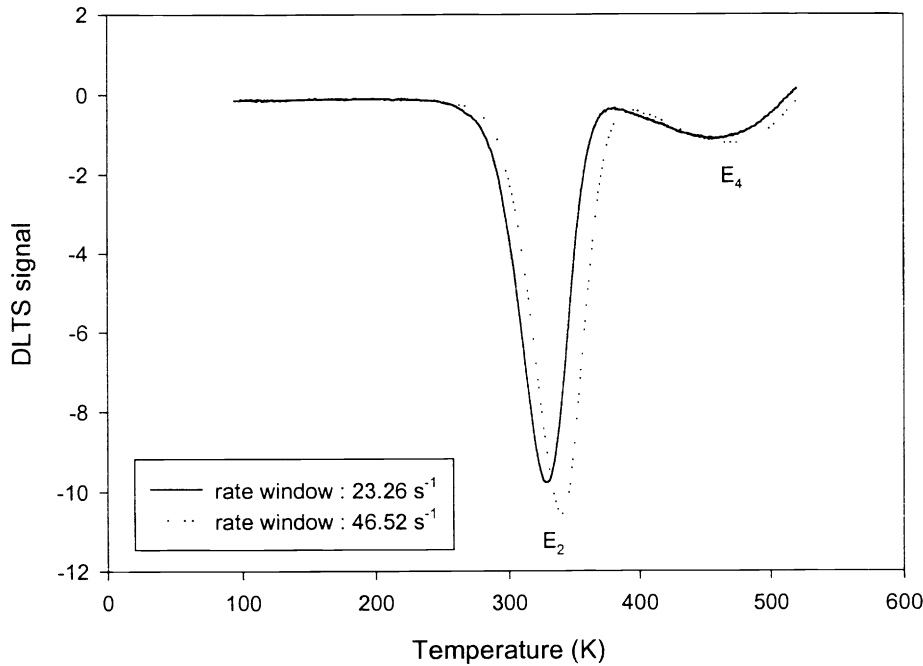

Fig. 3 DLTS spectrum measured on the sample R1 with emission rate windows of 23.26^{-1} and 46.52^{-1}.

Table 1. Characteristic of deep-level E_2 and E_4 measured by DLTS in the GaN sample Set I (R1)

Sample (Trap)	N_d (cm^{-3})	N_t (cm^{-3})	ΔE (eV)	σ (cm^{-2})
Set I ,R1 (E_2)	1.184×10^{17}	$N_{E2} = 4.258\times10^{16}$	0.556	1.244×10^{-18}
(E_4)		$N_{E3} = 6.011\times10^{15}$	1.018	3.310×10^{-19}

To measure the transient capacitance, the reverse bias voltage of -2V was first employed to remove electrons from deep level traps in the depletion region. The capacitance was decreased immediately as the schottky diode was reverse biased, then the capacitance was increased exponentially to a constant value. To extract the time constants τ for a given temperature the least square fit of an exponential function was employed.[8] Sample GaN1500 reveals only two levels, labeled as E_3 and E_5 Three majority traps, labeled as E_2, E_3 and E_5, are observed in GaN2000. GaN2500 illustrate three deep level traps, i.e. E_1, E_2 and E_3, too. The activation energy and capture cross-section

for E_2 in sample GaN2000 is 0.554eV and $5.905\times10^{-16}cm^2$ which correspond to the defect level E_2 found in Set I as illustrate in Arrhenius plots. The activation energy and capture cross-section for E_3 of sample GaN2000 is 0.649eV and $7.169\times10^{-20}cm^2$. It close corresponded to 0.665eV reported by Hacke et al.[6], 0.6eV measurement by Chen et al.[8], 0.670eV found by Haase et al.[9], 0.657eV found by Wang et al.[10] and 0.62eV reported by Fang et al.[11]. The activation energy ΔE and capture cross-section σ for E_5 in sample GaN1500 is 1.342eV and $1.759\times10^{-13}cm^2$. Level E_5 is similarly to the 1.44eV reported by Lee et al.[7] and 1.27eV reported by Chen et al.[8]. The concentration of deep level traps, n_t, are obtains from the capacitance transient height, assuming uniform trap distribution. The traps concentration of set II is demonstrated in Table 2.

Table 2. The trap concentration of set II

	GaN 2500 (cm^{-3})	GaN 2000 (cm^{-3})	GaN 1500 (cm^{-3})
E_1	2.092×10^{15}	-	-
E_2	1.754×10^{15}	1.608×10^{14}	-
E_3	7.479×10^{15}	1.491×10^{15}	4.660×10^{15}
E_5	-	1.382×10^{15}	1.398×10^{16}

The fact that level E_2 appears in both samples grown by different MOCVD reactors, and different growth techniques, i.e. MOCVD, HVPE, and MBE, indicates that level E_2 is originated either from a native defect or a common impurity during the growth of GaN film. The trap concentration of level E_2 increases as raising the NH_3 flow rate. This increment implies that level E_2 is associated with either the increasing of nitrogen atoms or decreasing the gallium atoms. If level E_2 is associated with Ga vacancy, then the trap concentration of E_2 should be increased as the carrier concentration is decreased. It is contradictory with the results of C-V measurement. Dow and Jenkins[14] calculated the deep level trap associated with Ga vacancy was acceptor like. However, the activation energy of E_2 is closed to conduction band, and it is donor like. The deep level traps for nitrogen substitution on Ga site below the conduction band 0.54eV, as indicated by Dow and Jenkins[14], was close corresponding to the activation energy of E_2. In addition, Haase et al.[9] demonstrated that deep level E_2 could be generated by nitrogen implantation and subsequently removed by thermal annealing. Therefor, level E_2 is interpreted as a result of the N-antisite defect.

The defect level E_5, which also found in samples grown by different techniques, indicated it might due to a native defect or a common impurity within the grown process. The broad photoluminescense emission band near 560nm[15] and broad cathodluminescence band near 520nm[16] is thought as a result of oxygen in GaN. Chen et al.[8] have suggest that level E_4 may be due to the oxygen impurities substitution on Ga site. The theoretical calculation the deep level of oxygen on Ga sites is 1.27eV, while it closed to the activation energy of E_5. Thus level E_5 is believed to be related oxygen impurities on Ga site.

CONCLUSION

In summary, two different sets of GaN films, grown by different organometallic vapor phase epitaxy (OMVPE), are investigated in this study. DLTS and transient capacitance are utilized to characterize the deep center in GaN layer. Two distinct levels with activation energy E_2=0.556eV and E_4=1.018eV are clearly observed on sample Set I. Four majority-carried traps were found in sample set II, as mention above. Trap E_2 is believed to relate with nitrogen antisite defect, since the trap concentration increases as NH_3 flow rate increases.

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