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Deep levels in n-GaN Doped with Carbon Studied by Deep Level and Minority Carrier Transient Spectroscopies

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1. Introduction

Carbon (C) is one of the most common impurities in the group of III-V nitrides. It has an amphoteric property that is expected to be a shallow acceptor substituting on N site (C_N) and a shallow donor on Ga site (C_{Ga}). Recently, this C_N has been reported to have an ionization energy of 0.9 eV determined from theoretical calculations [1]. On the other hand, high intensities of yellow luminescence (YL) band are attributed to carbon-related defects which introduce deep levels in the band-gap, as well as Ga vacancy (V_{Ga}) [2]. In addition, these defects influence on a current collapse in AlGaN/GaN high electron mobility transistors (HEMTs), while C incorporation is used to form high resistivity buffer layers [3].

In this study, we have investigated deep levels in the n-GaN doped with carbon by means of deep level transient spectroscopy (DLTS) and minority carrier transient spectroscopy (MCTS) measurements. MCTS is applied for the detection of hole traps in n-GaN Schottky diodes [4]. The hole trap with a thermal emission activation energy of 0.86 eV is obtained from the sample.

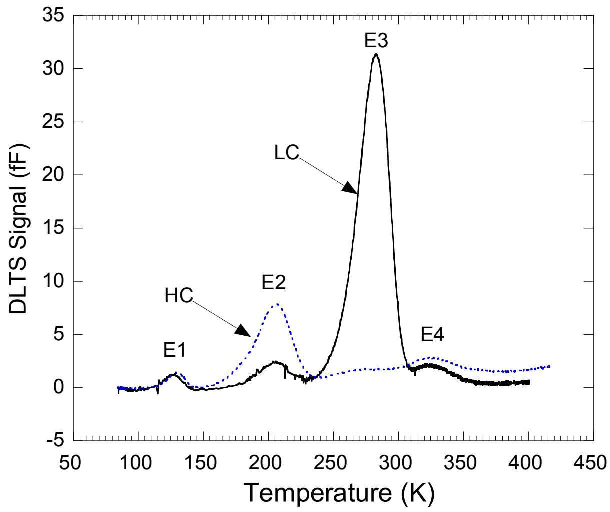

Fig. 1 DLTS spectra for the LC and HC samples. Solid and dashed lines show DLTS signals obtained from LC and HC samples, respectively.

2. Experimental Results

The n-GaN films doped with Si were grown on (0001) SI-SiC substrates using MOCVD method. The thickness was 2 μm and the Si concentration was 1.0×10^{17} cm^{-3}. Carbon concentrations were varied by changing the growth pressure. The growth pressure of 200 and 100 torr produced the n-GaN films with the carbon concentrations of $2\text{-}5 \times 10^{16}$ (LC sample) and 1×10^{17} cm^{-3} (HC sample), respectively. These doping concentrations were determined by secondary ion mass spectroscopy (SIMS). Ti/Al and Ni were then fabricated by the electron beam evaporation as Ohmic and Schottky contacts. MCTS measurement was performed to evaluate minority carrier traps using a 355nm UV LED as the optical source. (Nitride Semiconductors Inc., NS355L-5RLO)

Figure 1 shows typical DLTS spectra for the LC and HC samples. The presence of four electron traps labeled by us as E1-E4 is confirmed in both samples as shown in Figure 1. Their energy levels and electron capture-cross sections are summarized in Table 1 together with trap concentrations. The trap concentration of E1 and E4 shows the same values observed in both samples. However, that of E2 in the HC sample is approximately 3 times larger than the LC sample. This indicates that E2 might be associated with carbon incorporation. In contrast to the E2, the trap concentration of E3 strongly decreases with increasing the content of carbon incorporation. The mechanism of this negative correlation is unknown at present, however further study is underway to better explain this issue.

Figure 2(a) and (b) presents typical MCTS spectra for the LC and HC samples. Two hole traps labeled as H1 and H2 are found in the HC sample as shown in Fig. 2(a). The trap parameter of H1 is summarized in Table 1. On the other hand, that of H2 is not estimated due to the comparatively broader spectrum. Thus, there are no peaks in the LC sample. These results provide clear evidence that carbon-related defects are responsible for the hole traps of H1 and H2. It is found that E3 is the dominant trap in the LC sample among observed traps. By carbon incorporation, the dominant trap of E3 changes into H1 among traps with concentrations determined. These results are consistent with the recent observations by Armstrong et al. [5] for the GaN:C:Si samples grown by MBE in which E_c-0.61 eV

Table I Summary of observed energy levels, capture cross sections and trap concentrations.

Trap	Energy level (eV)	Capture cross section (cm^2)	Trap concentration (cm^{-3}) LC	HC
E1	E_c-0.24	1.4×10^{-15}	5.5×10^{13}	6.6×10^{13}
E2	E_c-0.40	1.4×10^{-15}	1.2×10^{14}	3.4×10^{14}
E3	E_c-0.61	5.5×10^{-15}	2.1×10^{15}	9.5×10^{13}
E4	E_c-0.73	1.4×10^{-15}	1.7×10^{14}	1.9×10^{14}
H1	E_v+0.86	7.1×10^{-15}	---	2.2×10^{15}

deep state is quenched and a hole trap emerges near E_v+0.9 eV, suggesting the hole trap manifests as a result of C incorporation. Also, the MCTS spectrum at the hole trap of H1 shown in Fig. 2(b) which appears only distinct peak for the HC sample indicates that this trap is attributed to the carbon-related defects.

The energy level of H1 at E_v+0.86 eV is very close to that of the ionization energy of 0.9eV for C_N which has been theoretically calculated by Lyons et al. [1]. This result implies that the hole trap of H1 corresponds to C_N. Since the hole trap with the thermal emission activation energy of about 0.9 eV might cause YL band [2] and current collapse of HEMTs [3]. MCTS is confirmed to be a useful technique to evaluate deep level defects in as-grown and processed n-GaN by fabricating Schottky diodes.

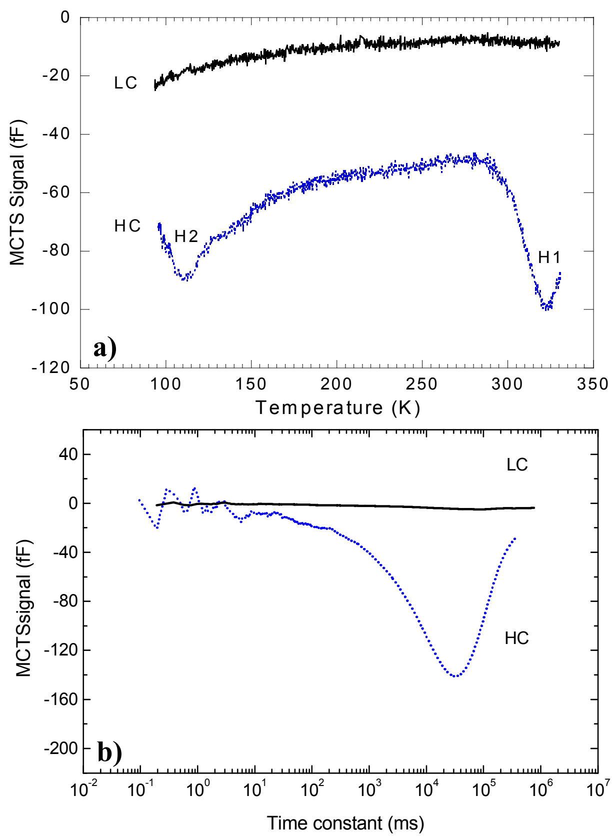

Fig.2 MCTS spectra for the LC and HC samples

3. Conclusions

Deep level spectra of n-GaN films grown by MOCVD were studied by DLTS and MCTS measurements in order to identify C-related deep levels. As a result, several traps of E2 (E_c-0.40 eV), H1 (E_v+0.86 eV) and H2 correspond to the carbon-related defects. Moreover, H1 is associated with the shallow acceptor level of C_N which might cause YL band and current collapse of HEMTs.

Acknowledgements

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