Deep levels in AlGaN/GaN HEMTs on silicon substrate are characterized by current deep level transient spectroscopy

H. MOSBAHI*, M. GASSOUMI, C. GAQUIERE[a], M. A. ZAIDI, H. MAAREF
Laboratoire de Micro-Optoélectronique et Nanostructures, Faculté´ des Sciences de Monastir, Avenue de l'environnement 5000 Monastir, Tunisia
[a]*Institut d'Electronique de Microélectronique et de Nanotechnologie IEMN, Département hyperfréquences et Semiconducteurs, Université des Sciences et Technologies de Lille, Avenue Poincaré, 59652 Villeneuve d'Ascq Cedex, France*

We report investigation of electron traps in AlGaN/GaN HEMTs, grown on silicon by molecular beam epitaxy. Deep levels analysis was performed by conductance deep level transient spectroscopy (CDLTS) under a drain pulse. CDLTS measurements reveal three traps with the energy levels of 0.11, 0.17 and 0.22 eV. The nature and the localization of there deep levels are discussed.

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1. Introduction

AlGaN/GaN based high electron mobility transistors (HEMTs) have become important because of their potential applications in electronic, optoelectronic, high-temperature and high-power devices [1,2]. AlGaN/GaN HEMTs have the desirable characteristics to replace GaAs based power amplifiers due to the very high breakdown field of GaN, which is estimated to be 3 MV/cm [3]. In addition, these devices require minimum cooling. The AlGaN/GaN HEMT devices can also be used for X and KU band radar and sensing applications. However, one of the major problems in fabricating these devices is the lack of commercial availability of native GaN substrates. Hence, several efforts were made in growing GaN epitaxially on foreign substrates, by various growth methods. However, heteroepitaxially grown GaN tends to have structural defects arising due to mismatch in lattice parameters and different thermal expansion coefficients between the GaN epilayers and the substrates such as silicon carbide or sapphire [4]. These structural defects in turn will impact the transport properties such as electron mobility [5] and the luminescence efficiency for light-emitting diodes [5,6]. Furthermore, the defects in the GaN layer may also propagate to the top AlGaN layer. Consequently, it is very important to investigate the origin of these defects. CDLTS (Conductance Deep Level Transient Spectroscopy) is a powerful technique to study the behavior of traps.

The paper is organized as follows. After a brief introduction, we present, in section II, the experimental; while section III outlines the static measurements and current transient spectroscopy measurements; conclusions derived from the study are summarized in the section IV.

2. Experimental

Devices adopted for this paper are AlGaN/GaN HEMTs grown on resistive silicon (111) substrate (4000-10000Ω) by MBE (Molecular Beam Epitaxy) using ammonia (Riber compact 21). Details of the growth are presented elsewhere [8] and layer quality can be summarized as follows: a 50 nm AlN nucleation is first grown on the Si (111) substrate followed by a 0.5 μm thick GaN/AlN sequence and a 30 nm thick undoped AlGaN layer grown on the 2 μm GaN buffer and is capped with 1 nm GaN.

The CDLTS measurements a constant drain to source voltage and a voltage pulse on the gate and a constant gate voltage with a pulse on the drain. The drain source current transient was recorded using a numerical multimeter (HP 34401A) and then, was treated numerically using the Lang method as in classical capacitance DLTS. The measurements were carried out between 77 and 520 K in a nitrogen cooled cryostat.

3. Resultats and discussion

3.1 Static measurements

Drain-source current voltage (I_{ds}-V_{gs}-T) measurements as function of temperature have been performed. Output characteristics registered at different temperatures show parasitic effect. Indeed, we can observed on Fig. 1 the threshold voltage shift (defined by a linear extrapolation of the drain current versus gate voltage to zero current) is -2.95 V at T=100 K, -2.77 V at T=300 K and -2.87V at T=500 K. This shift is thought to be caused by deep levels associated with electrically active defects in the heterostructures.

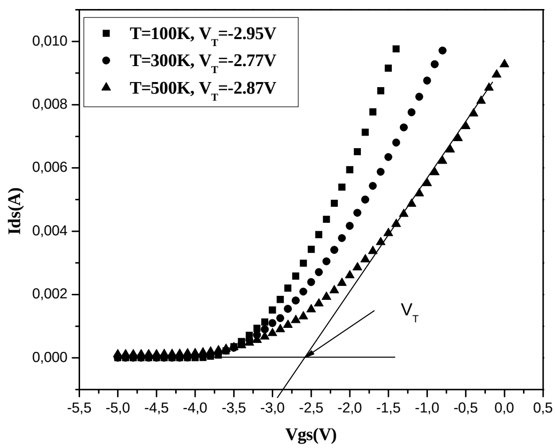

Fig. 1. Ids-Vgs characteristics at T=100 K, T=300 K and T=500 K showing the threshold voltage shift.

3.2. Capacitance-Voltage dependence

Fig. 2 shows the C-V measurements performed at T=300 K for the AlGaN/GaN HEMTs grown on Si substrate, the characteristics were measured under a frequency of f = 1 MHz with a 15 mV measuring signal. From the $1/C^2(V)$ linear curve we deduced the pinch-off voltage of Vb = 0.4V at room temperature.

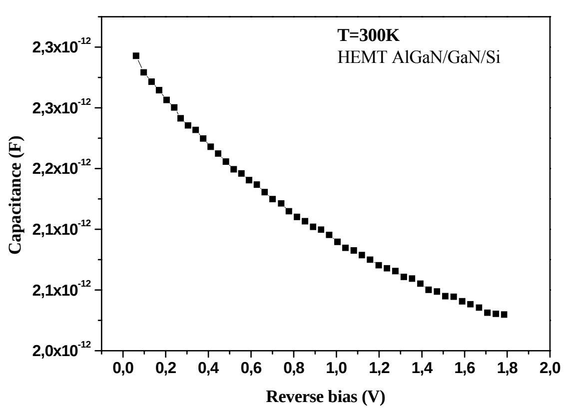

Fig. 2. C(V) measurements at performed at T =300 K.

3.3. Current transient spectroscopy measurements

Underisable phenomena such as threshold shift [9] are thought to be caused by deep levels associated with electrically active defects in the heterostructure. To characterize deep levels in HEMT AlGaN/GaN on Si substrate, Conductance Deep Level Transient Spectroscopy (CDLTS) is used.

The CDLTS spectrum is shown in Fig. 3. CDLTS measurements are performed under a drain pulse V_{ds} switching from 1 to 2V, at a gate-source voltage V_{gs} = -1V. This spectrum shows the presence of three traps called a_1, a_2 and a_3. The apparent activation energies and capture cross-sections of all observed electrons traps are deduced from the Arrhenius plot of Ln (T^2/e_n) versus 1000/T according to the following relation:

$$e_n = \sigma T^2 \exp\left(-\frac{E_a}{KT}\right)$$

Where e_n is the emission rate, E_a the activation energy, σ the capture cross section and T the temperature. The results are presented in Fig. 4.

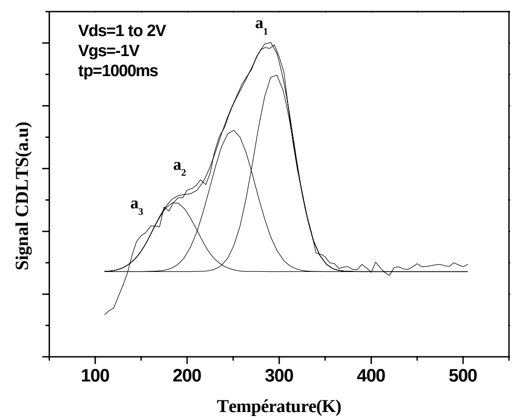

Fig. 3. A typical CDLTS spectrum showing the presence of three levels where Vgs=-1V and Vds= 1to2V at tp=1000 ms.

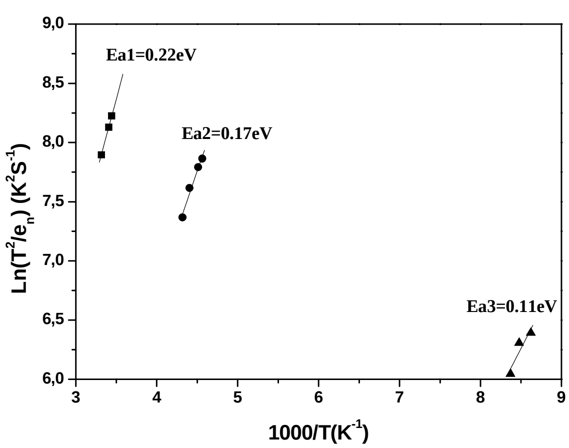

Fig. 4. Arrhenius plot for the deep levels observed in the AlGaN/GaN/Si HEMTs

The trap a_1, with an activation energy E_{a1}=0.22 eV and a capture cross section σ_n=2.42.10^{-21} cm^2 can be attributed to the defect level with activation energy of 0.26 eV reported by Hacke et al.[10] and 0.20 eV reported by Gassoumi et al. [11] using CDLTS measurements on AlGaN/GaN/Si HEMTs grown by MBE. The very close correspondence between the Arrhenius plots for these levels and the similar activation energies derived from these plots suggest that they correspond to the same defect level. Marso et al. have also observed a defect with similar signature in AlGaN/GaN/Si HEMTs and have shown that this trap is most probably located in the region bellow the 2DEG channel [12]. They are most probably located in the buffer layer or at the strained Si/AlN interface.

The electron trap a_2 with activation energy E_{a2}=0.17 eV and a capture cross section σ_n=3.83.10^{-20} cm^2. According to the literature, this defect was detected by Götz et al. [13], by taking measurements of spectroscopy of the transients of isothermal capacity at low temperatures on diodes n-GaN grown by MOCVD, they refer this trap to an origin called E_1.

The trap a_3 with activation energy E_{a3}=0.11 eV and a capture cross section σ_n=2.24.10^{-19} cm^2. This defect was detected by Soh et al. [14], using DLTS measurements on GaN grown by MOCVD, they assigned this defect to nitrogen vacancies.

4. Conclusion

Conductance Deep Level Transient Spectroscopy (CDLTS) was applied to the AlGaN/GaN/Si HEMTs to study the transient behavior on the device. Three electron traps, observed in the CDLTS spectrum under a drain pulse, are most probably located between the substrate and the 2DEG.

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*Corresponding author: gassoumimalek@yahoo.fr