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ELECTRICAL CHARACTERIZATION OF AlGaN/GaN HEMTs ON Si SUBSTRATE

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ABSTRACT

Deep traps in AlGaN/GaN high electron mobility transistors on silicon substrate were characterized by the means of current-voltage and Deep Level Transient Spectroscopy (DLTS). DLTS measurements have revealed only hole-trap with an activation energy of 0.82eV. The nature and the localization of this trap are discussed here.

Key words: AlGaN/GaN, HEMT, kink effect, DLTS, traps, surface state.

I. INTRODUCTION

High electron mobility transistors (HEMTs) based on AlGaN/GaN heterostructures have promising research interests due to their benefits for achieving electronic devices with high-temperature and high-power operations [1-4]. The main reason is that nitride based materials have wide band gaps, high drain current density, high saturation velocity and high breakdown field [5]. Important progress has been made in enhancing the performance of these devices to be used in power amplifiers. However, applications of these AlGaN/GaN HEMTs are largely limited by surface trapping effects through drain current collapse and Kink effect. RF power obtained is much lower than that expected from the device DC characteristics] owing to the electron trapping states at the active surface area, and this device degradation results in a significant decrease in the output power, as well as the power-added efficiency (PAE). Nevertheless, problems related to trapping of charge in AlGaN/GaN heterostructure amend the density of carriers in the channel and would affect the performance of electronic devices [6]. A number of works have been performed to study anomalous behaviours related to trapping effects on current-voltage [7]. The nature and location of traps determined by deep level transient spectroscopy (DLTS) measurements [8] or conductance deep level transient spectroscopy (CDLTS) measurements [9] have been discussed.

In this paper, we present some elements for trapping phenomena in current-voltage (I-V) characteristics and we investigate by DLTS the nature and location of the traps that can take account of the anomalies in the I-V characteristics.

II. RESULTS AND DISCUSSION

II.1. Experimental

The AlGaN/GaN HEMT grown by molecular beam epitaxy (MBE) on silicon substrate is shown in Fig.1. The epitaxial structure is composed of a 500 nm undoped buffer, an undoped 1.8 µm GaN channel, an undoped 23 nm $Al_{0.26}Ga_{0.74}N$ barrier and a 1 nm GaN cap layer. The ohmic contacts pads are patterned using e-beam littography. Hereafter, the metallization by means of evaporated 12/200/40/100 nm Ti/Al/Ni/Au is deposited at 900° C for 30s. The Schottky gate is realized using 100/150 nm Mo/Au layers. The gate length and the gate width were 0.25 and 150 µm respectively, and the source–drain spacing was a nominal 2.34µm.

Deep level transient spectroscopy has been used as a technique to characterize the electron traps in the AlGaN/GaN/Si heterostructures. Measurements were performed using double lock-in detection and a PAR410 capacitance meter and recorded in the temperature range 10-320K.

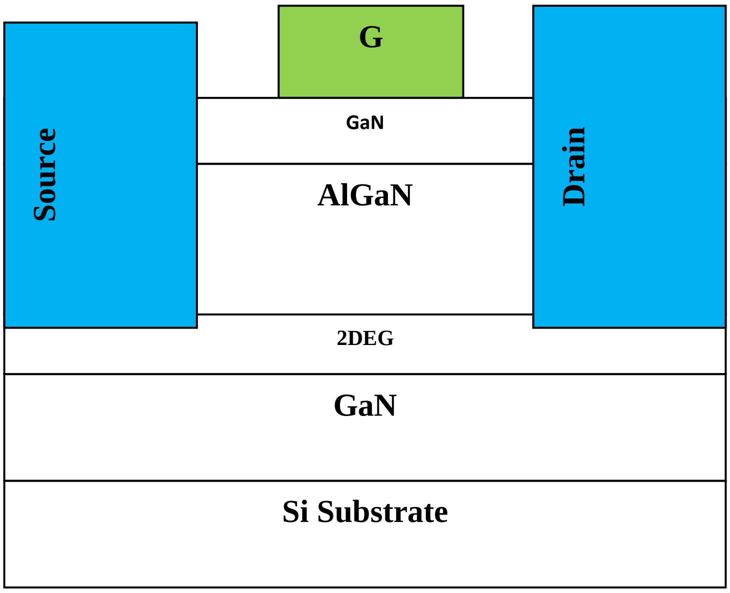

Figure 1: A schematic cross section of AlGaN/GaN HEMT on Si Substrate.

II.2. Current-voltage measurements

The current-voltage (I_{ds}-V_{ds}) characteristics as a function of gate voltage at room temperature are shown in Fig.2. A spectacular variation of the output conductance, known as Kink effect, is observed for high values of the voltages Vgs in absolute value. This parasitic effect appears on output characteristics and they limit the good performance expected on AlGaN/GaN/Si transistors. Some studies have established a link between the kink other studies have correlated this effect with the presence of traps in the structure [10]. At biases higher than a certain critical field, a significant number of carriers injected into the barrier region proved to have enough energy to de-trap the electrons, causing an increase in the 2DEG carrier density due to the increase of positive charge in the AlGaN layer [11]. Indeed, the degradation in current can be attributed to the presence of deep centers located in the vicinity of the channel surface. Trapping/detrapping phenomena on these centers can change the charge density near the surface. As Meneghesso et al. [12], since kink effect is correlated to pinch-off voltage shifts, traps should be located under the gate, either in the AlGaN barrier or in the GaN buffer. Suemitsu et al. [13] have reported many ways to eliminate or suppress the kink effect like

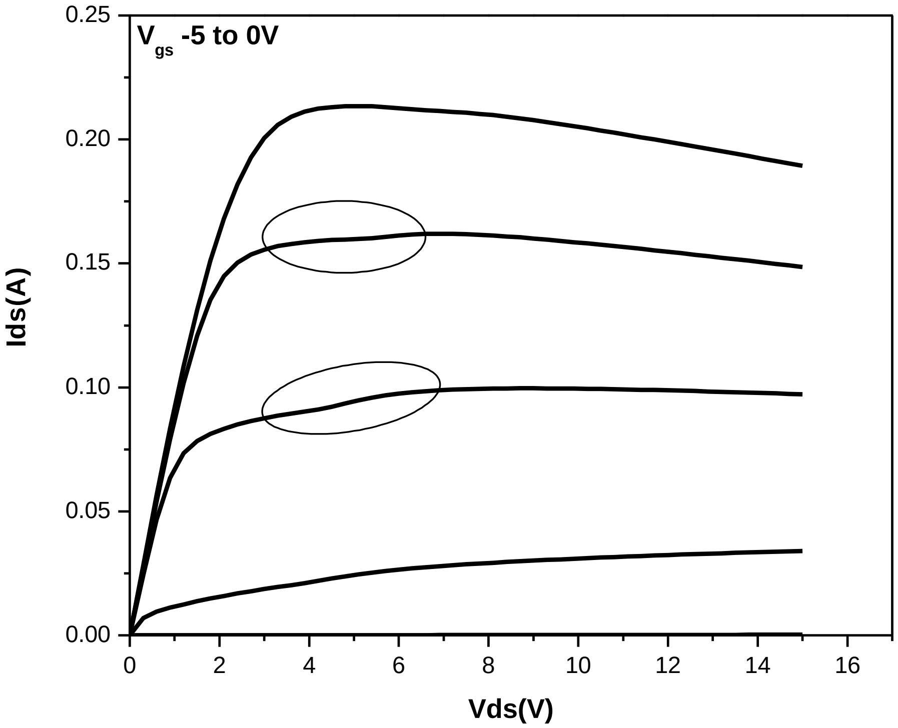

Figure 2: Typical static Ids(Vds) characteristics of AlGaN/GaN/Si HEMTs at T=300K.

keeping the electron density in the side-etched region high as a means to the suppress the change in parasitic source resistance caused by hole accumulation.

In the same figure we observed that the apparent saturation current exhibits a negative conductance at large Vds. The decrease in current at higher drain-source voltage is due to the self-heating and especially results in a decrease in electron mobility. In addition to self-heating, deep traps are also present in the AlGaN/GaN heterostructure and can reduce the microwave performance of designed HEMTs. Such trapping effects occur both at the surface and in bulk of the GaN epilayer [14, **15**].

The origin of the different parasitic effects in output characteristics may be explained by the presence of deep levels in the AlGaN/GaN HEMTs.

To characterize traps in AlGaN/GaN/Si HEMT, capacitance deep level transient spectroscopy is used.

II.3. DLTS measurements

DLTS measurements were performed at temperature between 10K and 325K using boxcar technique. The modulation of the space charge region under the gate induced by DLTS allows investigating the traps in the barrier layer.

Fig.3 shown the DLTS spectrum obtained for an emission rate e_n = 426s^{-1}, a reversed bias V_0=-3V, a pulse amplitude ΔV= 3V and a filling time t_p = 0.5ms. As seen, the spectrum indicates only hole-trap labeled HL_1. The ionization energy of the defect is evaluated from the signature, variation of the logarithm of $\frac{T^2}{e_n}$ versus temperature.

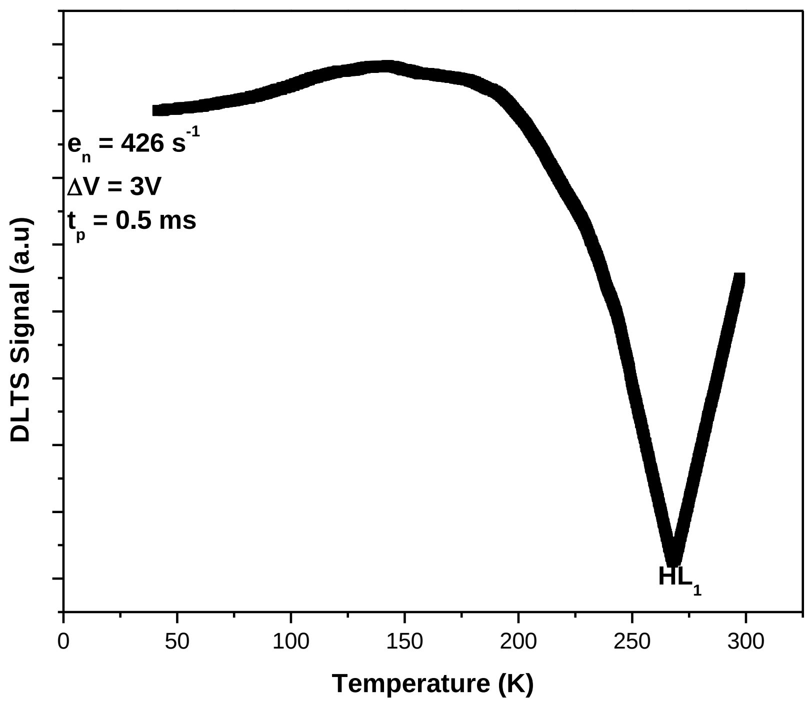

Figure 3: A typical DLTS spectrum showing the presence of one hole-like-trap (HL1).

The Arrhenius plot of the hole trap is shown in Fig.4. In order to compare the obtained activation energies with the ones reported in the literature, we notice that the origin of the hole-trap-like HL1, which appears as a shoulder at T = 275 K with Ea = 0.82 eV and capture cross-section 2.9x10^{-14} cm^2, can be attributed to the hole trap reported by Polyakov et al [16] using Photo-Induced Current Transient Spectroscopy (PICTS) measurements on AlN/GaN grown by MBE. It is also observed by Gassoumi et al [17] as well on AlGaN/GaN/SiC

HEMTs grown by metal organic chemical vapor deposition (MOCVD) with CDLTS measurements.

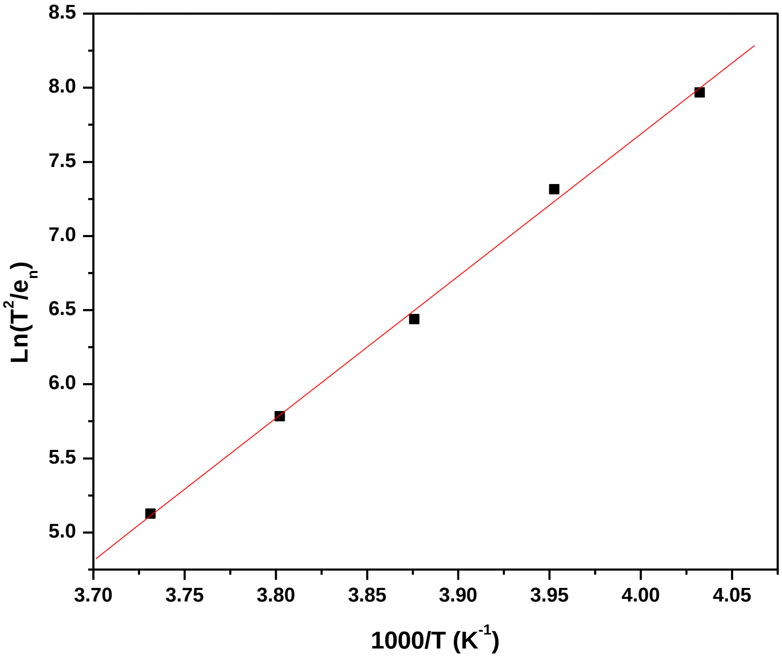

Figure 4: Arrhenius plots of HL1 observed in AlGaN/GaN/Si HEMTs.

We believe that the hole-trap-like signal (HL1) do not originate from changes in hole trap population in the channel, with no obvious mechanism for the injection of holes, but probably reflect the changes in the population of surface states in the HEMT access regions, resulting in modulation of the 2DEG density in the channel [14]. The change in the population of surface states is thought to be caused by capture and emission of the electrons injected from the gate electrode.

III. CONCLUSION

In summary, we have investigated static measurements and defect analysis on AlGaN/GaN/Si and grown by MBE. Current–voltage characteristics shows anomalies (kink effect) attributed to traps centers and deep levels. The self-heating is also observed in AlGaN/GaN HEMTs.

Traps analysis performed on these transistors by DLTS prove the presence of one hole-like-trap deep levels. The hole trap had an activation energy of 0.82eV, has been located in the AlGaN layer. It has been pointed out that the hole-trap-like signals did not originate from changes in hole-likes traps population in the channel, with no obvious mechanism for the injection of holes, but probably reflect the changes in the population of surface states in the HEMT access regions.

Finally, a direct correlation between parasitic effects in the output characteristics and the presence of deep traps has been evidenced for AlGaN/GaN HEMTs realized on Si substrate. The analysis makes possible the detection and the location of traps in HEMTs.

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