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Investigation of the origin of deep levels in Carbon-doped AlN/GaN/AlGaIn HEMTs

L. Ben Hammou^{1*}, F. Grandpierron¹, E. Carneiro¹, K. Ziouche¹, E. Okada¹, and F. Medjdoub¹

¹CNRS-IEMN, 59652 Villeneuve-d'Ascq, France, lyes.benhammou@univ-lille.fr

Abstract

In this work, we focused on understanding the origin and impact of deep levels in various AlN/GaN HEMTs with carbon doped GaN buffer including or not an AlGaIn back barrier. It is shown that the inclusion of a back barrier reduces drastically the current collapse. Furthermore, we examined the effect of carbon doping within the back barrier by comparing deep level signatures obtained from three variants. We show that a high concentration of carbon in the AlGaIn back barrier screens the impact of carbon doping in the GaN buffer to a certain extent.

Introduction:

Studies conducted in our research group on AlN/GaN HEMTs showed state of the art power performances at 40 GHz [1]. These devices use carbon doped GaN buffer and an AlGaIn back barrier (BB), that are essential to reach low leakage currents and good electron confinement under high electric field. The presence of carbon in GaN or AlGaIn layers introduces defects, which can cause current collapse and dynamic Ron. A first study [2] showed low trapping effects in these devices. A more detailed trapping investigation is carried out in this work.

Experimental Details:

Three HEMT structures were grown by metal organic chemical vapor deposition (MOCVD). They share identical stack, differing only in the inclusion of a carbon doped or undoped AlGaIn back-barrier layer as shown in Figure 1.a. Table 1 provides an overview about their composition and configuration.

The study of trapping effects was conducted using drain current transient spectroscopy (DCT). The measurement process comprised two distinct phases: an initial trap-filling phase under drain-lag conditions for 100 seconds to ensure the filling of all traps, followed by a measurement phase where device biasing was changed to allow for de-trapping. The recovery process was monitored over several decades, from the first microsecond up to 100 seconds, which in our case was sufficient for complete drain current recovery.

	Wafer A	Wafer B	Wafer C
GaN buffer	High C	Medium C	Medium C
AlGaIn back barrier	/	High C	Undoped

Table 1: Configuration of the measured devices.

Results and discussion

Impact of back barrier inclusion on current collapse.

Figure 1, shows current collapse for different filling durations in drain lag conditions for wafer A and B. We clearly observe that adding a carbon-doped AlGaIn BB layer in the HEMT structure reduces significantly the occurrence of current collapse as compared to the C-doped buffer devices without BB.

DCT measurements on wafer A and B:

Figure 2.a shows drain current recovery curves obtained at different temperatures for all wafers. These data are then fitted with a sum of stretched exponentials in order to extract the time constants of traps, which represent the peaks of the derivatives of the current as illustrated in Figure 2.b. These time constants

are used to extract trap signatures from the Arrhenius plot as illustrated in Figure 2.c.

Wafer A showed two positive transients labeled T_{1A} and T_{2A} . Wafer B showed two positive transients labeled T_{1B} et T_{3B} and a negative transient T_{3B} at high temperature, as shown in Figure 2.b.

Figure 2.c shows the extracted activation energies:

- T_{1A} and T_{1B} , present in both samples, indicate activation energies of 0.007eV and 0.02eV, respectively. Figure 1.c and 1.d show that the signature of these traps appears around 1ms, which is identical to the de-trapping time constant and thus indicates an emission capture process.
- T_{3B} shows a non-Arrhenius like behavior. It exhibits two activation energies: 0.21 eV at low temperatures and 0.79 eV at high temperatures. These activation energies are attributed to carbon substituting to Nitrogen C_N acceptors. The non-Arrhenius behavior suggests that at low temperatures, the trapping mechanism is governed by the transport of carriers to and from the deep levels, rather than trap capture or emission [3].
- T_{2A} showed an Arrhenius like behavior with an activation energy of 0.38eV, which is lower than the expected activation energy for C_N acceptors in the buffer region (e.g. 0.7-0.9eV). This suggests that the dominant trapping mechanism in this structure is the transport of carriers to and from the deep levels [4].

Impact of carbon doping in the AlGaIn back barrier:

DCT measurement on wafer C.

We observed four positive transients, labeled as T_{1C} , T_{2C} , T_{3C} , and T_{4C} . This wafer exhibited two slow processes T_{3C} , and T_{4C} , as shown in Figure 2.b

Figure 2.c shows the extracted activation energies:

- T_{1C} is the same trap as T_{1A} et T_{1B} in wafers A and B.
- T_{4C} slightly contributes to the current collapse. It showed the same non-Arrhenius like behavior with similar time constants and activation energies, as T_{3B} in wafer B. This result demonstrates that T_{3B} found in wafer B originates from Carbon doping in the AlGaIn BB, while in wafer C to a possible unintentional Carbon doping (C_N acceptors) in the AlGaIn BB.
- T_{3C} is only present in the wafer C. It shows a non-Arrhenius like behavior, with an energy activation of 0.56eV, related to C_N acceptors in the C-doped Buffer. The time constants are in the same range as T_{2A} in wafer A, suggesting that these are the same traps.

The presence of the C-doped buffer related trap T_{3C} in the wafer C with undoped (uid) BB, demonstrates that high Carbon doping in the AlGaIn BB in wafer B screens the carbon in the buffer.

Conclusions:

Our results demonstrate that incorporating carbon-doped AlGaIn back barrier could effectively reduce current collapse and screen the effect of carbon doping in the GaN buffer in AlN/GaN HEMTs. Therefore, engineering of this layer may play a significant role in optimizing the overall transistor performance. Through our deep level investigations, we observed unusual trapping behaviors induced by carbon doping. Trapping mechanisms could only be partially explained by DCT measurements, thus complementary techniques should be explored for even better understanding.

Acknowledgments

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References :

- [1] Harrouche, K. et al., Appl. Phys. Express, 15 (11), 2022
- [2] Harrouche, K. et al., Micromachines, 14 (2), 2023
- [3] C. Koller, et al. IEEE Trans. on Electron Dev., 65, (12), 2018
- [4] A. Nardo et al., Microelectronics Reliability (2021)

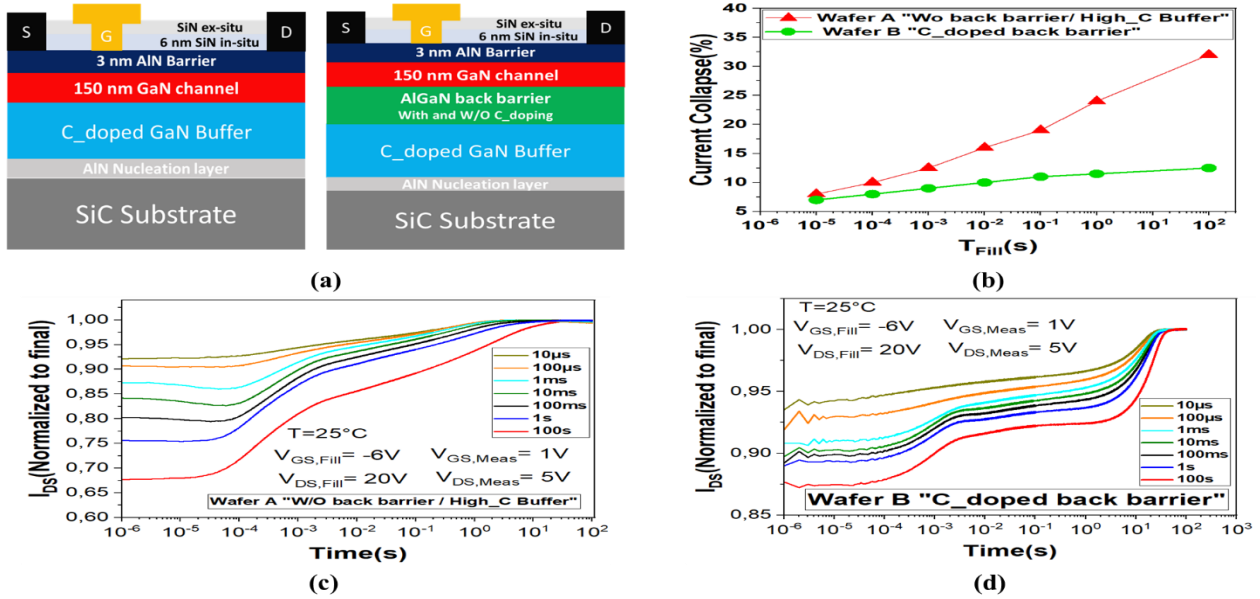


Figure 1. a) Schematic cross section of the AlN/GaN epitaxial structure with and without AlGaN back barrier., b) Current collapse vs filling time for wafer A and B, Drain current recovery with different filling durations in drain lag conditions c) for wafer A d) for wafer B

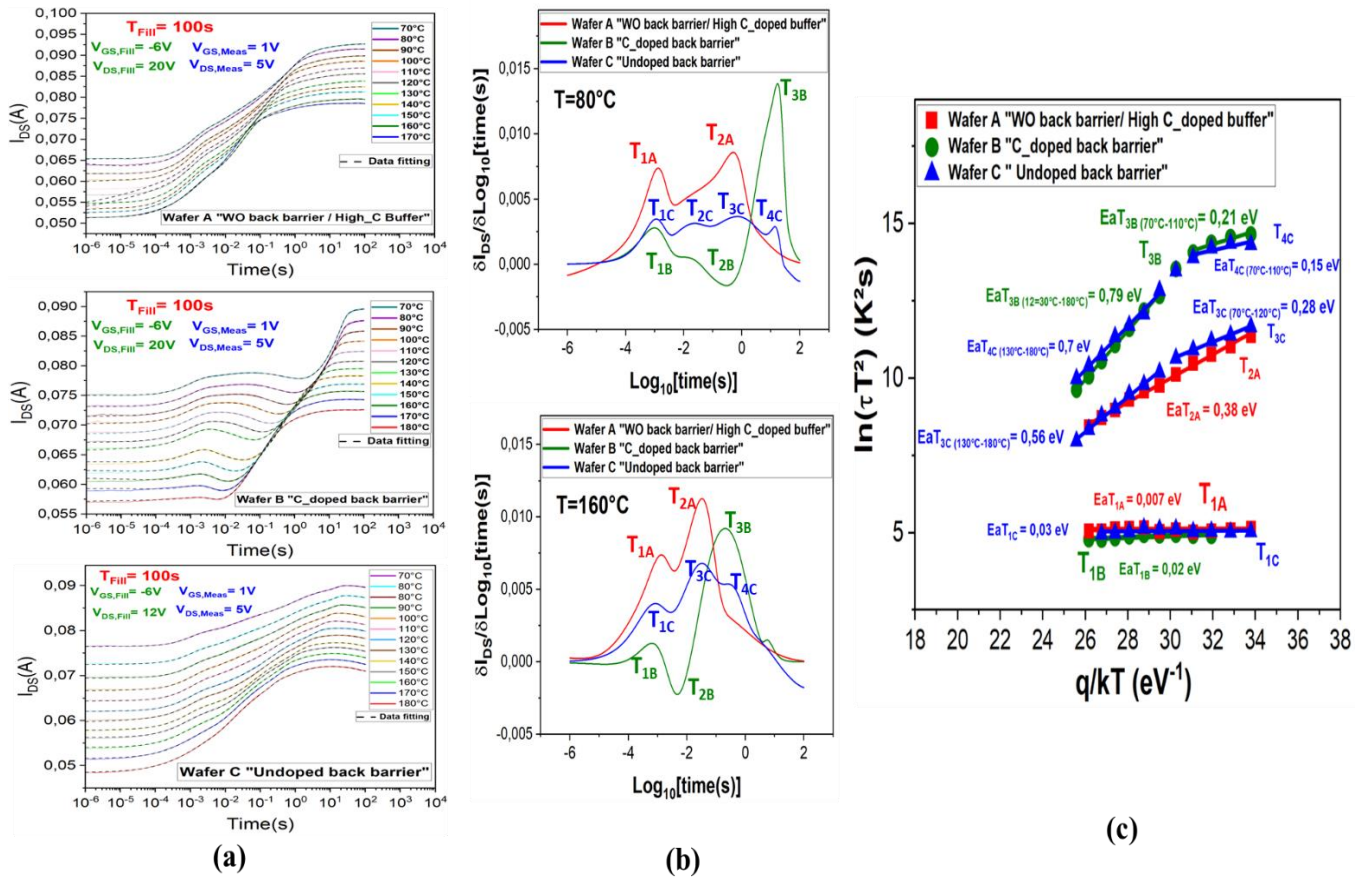


Figure 2. Drain current transient measurement on the three wafers A, B, C. a) Drain current recovery curve after drain lag stress conditions, measured on all, fitted with stretched exponentials. b) Extracted time constant spectrum for all wafers at T= 80°C and T= 160°C. e) Arrhenius plot showing the extracted activation energies of different deep level from all wafers.