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# Impact of Carbon-doped AlGaN back barrier in AlN/GaN/AlGaN HEMTs

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## Abstract

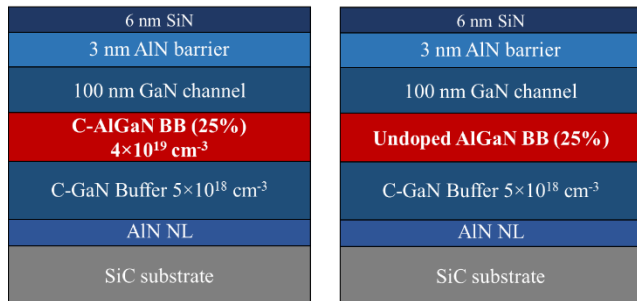
The impact of carbon doping into the AlGaN back barrier in AlN/GaN HEMTs is investigated. In this work, we demonstrate that a back polarization itself is not enough to ensure a proper electron confinement under high field, especially when using sub-150 nm. Experimental results are supported by TCAD showing that a doping compensation needs to be combined with the back barrier to allow for superior drain bias operation in the millimeter-wave range.

## Introduction

In our previous studies, we showed the interest of introducing a thin AlGaN back barrier in order to achieve both an excellent electron confinement (e.g. low DIBL) under high electric field and low current collapse in short AlN/GaN HEMTs resulting in state-of-the-art power performance at 40 GHz. [1-3]. In this work, we further scaled the undoped GaN channel thickness down to 100 nm and investigated the impact carbon doping into the AlGaN back barrier.

## Experimental / Computational Details

Two similar HEMTs have been grown by metal organic chemical vapor deposition (MOCVD) on 4-in. high resistive SiC substrates, except for the Al<sub>0.25</sub>Ga<sub>0.75</sub>N back barrier, which is undoped in one case and has a high carbon concentration of 4×10<sup>19</sup> cm<sup>-3</sup> in the other case. The GaN buffer below has a carbon concentration of 5×10<sup>18</sup> cm<sup>-3</sup> in both cases (see Fig. 1). The thickness of the undoped GaN channel is 100 nm. DC, pulsed and TCAD SILVACO simulations have been carried out on 2×50 μm transistors with gate lengths of 150 nm and 500 nm and a gate to drain distance of 0.5 μm.



**Figure 1.** Schematic cross section of the AlN/GaN epitaxial structure with and without C-doping in the back barrier

## Results and discussion

Fig. 2 shows the transfer characteristics with a compliance fixed at 150 mA/mm and swept from V<sub>DS</sub> = 2V up to 20V of

2×50 μm AlN/GaN HEMTs with L<sub>G</sub> = 500 nm and 150 nm in order to extract the Drain Bias Induced Lowering (DIBL) parameter. The open channel DC pulsed measurements are shown at V<sub>GS</sub> = +2V with various quiescent bias points: cold point at (V<sub>GQ</sub> = 0V, V<sub>DQ</sub> = 0V), gate lag at (V<sub>GQ</sub> = -4V, V<sub>DQ</sub> = 0V) and drain lag at (V<sub>GQ</sub> = -4V, V<sub>DQ</sub> = 15V) using a pulse width of 1μs and a duty cycle of 1%. A comparable saturated drain current is observed, which is consistent with the identical 2DEG properties and similar ohmic contact resistances. However, without doping of the thin back barrier, although the electron trapping is low, the DIBL is severely degraded when reducing the gate length despite the presence of carbon doping in the buffer layer underneath. When using a high carbon concentration in the back barrier, an excellent DIBL is obtained regardless of the gate length. Fig. 3 shows the experimental and calibrated TCAD results of the transfer characteristics at different drain voltages (V<sub>DS</sub>) with compliance set at 150 mA/mm. The simulations reveal that unlike the highly doped AlGaN back barrier, a significant amount of current flows through the undoped back barrier under pinch-off conditions. The vector electric field distribution of both devices in off-state clearly confirms that the GaN buffer is affected, which is reflected by the bent vector lines translating the electric field penetration. Therefore, the back barrier without doping compensation is not sufficient to ensure a proper electron confinement under such a high electric field (sub-150 nm gate lengths), which yields high DIBL.

## Conclusions

We have studied the impact of carbon-doped AlGaN back barrier in AlN/GaN/AlGaN HEMTs showing that the doping is mandatory to achieve low DIBL under high electric field. The electron trapping effect can be certainly improved by further tuning the carbon concentration in the back barrier.

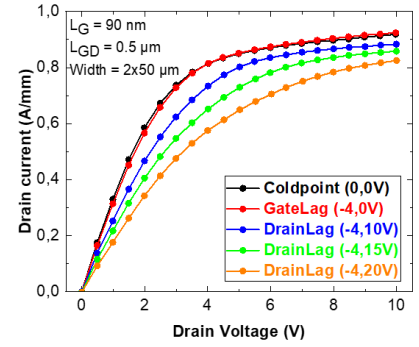
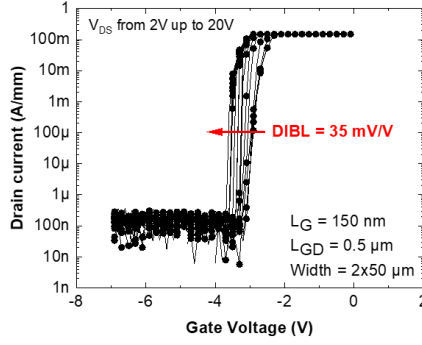
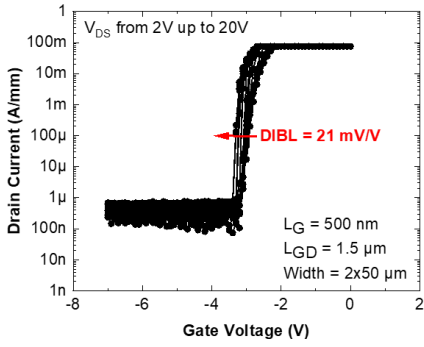
## Acknowledgments

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## References

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- [2] Harrouche, K. *et al.*, Micromachines, 14 (2), 2023.
- [3] Shanbhag, A. *et al.*, Appl. Phys. Letters, 123 (4), 2023.

### High-C AlGa<sub>N</sub> BB 25%



### Undoped AlGa<sub>N</sub> BB 25%

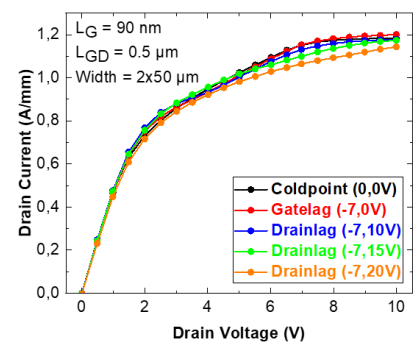
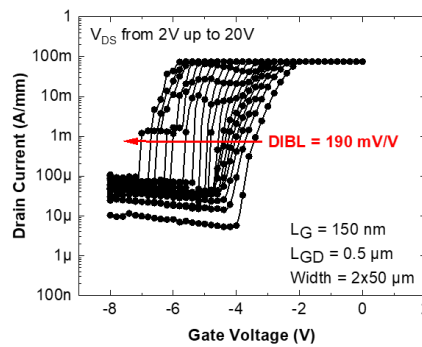
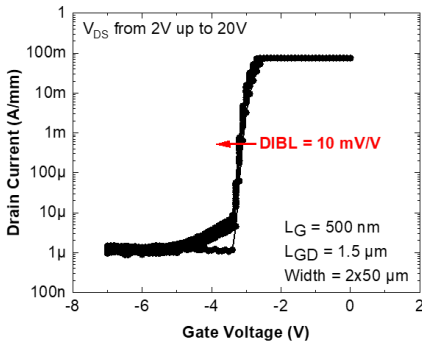
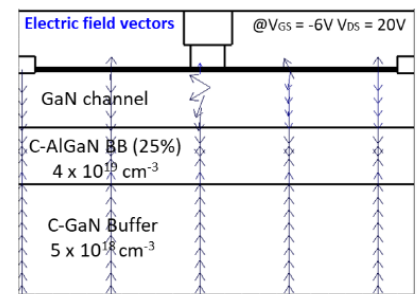
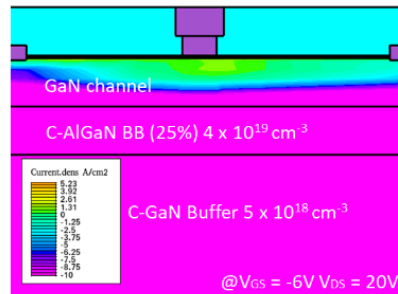
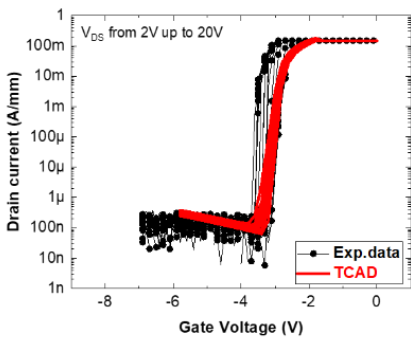


Figure 2. Transfer characteristics up to  $V_{DS} = 20$  V (with a compliance fixed at 150 mA/mm) of  $2 \times 50$   $\mu$ m AlN/GaN HEMTs with  $L_G = 500$  nm and 150 nm and open channel pulsed  $I_D$ - $V_{DS}$  output characteristics

### C-AlGa<sub>N</sub> BB (25%) $4 \times 10^{19}$ cm<sup>-3</sup>



### Undoped AlGa<sub>N</sub> BB (25%)

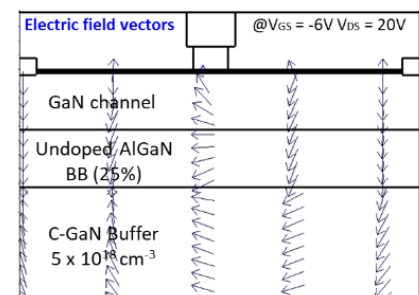
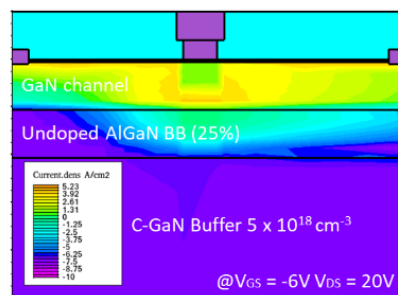
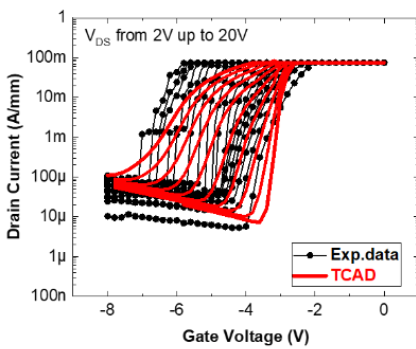


Figure 3. TCAD calibration, current density distribution and electric field vector distribution