

# Combining low trapping effects and high electron confinement in sub-100 nm AlN/GaN HEMTs under high electric field

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Gallium Nitride high electron mobility transistors (GaN-HEMTs) have a paramount importance in high power and high frequency microwave electronics for numerous applications owing to their superior material properties. However, achieving excellent electron confinement by eliminating punch-through effects under high electric field while ensuring low electron trapping remains a challenging task when using sub-100 nm gate lengths. This is in turn one of the main limitations of mm-wave GaN transistors in terms of drain bias operation. Recently, we reported AlN/GaN (3 nm/100 nm) HEMTs delivering state-of-the-art large signal performance at 40 GHz with an output power density  $P_{out} > 8$  W/mm and power-added efficiency (PAE)  $> 65\%$  in pulsed mode up to  $V_{DS} = 30$  V [1]. However, it was also shown that residual trapping effects still harm these devices in CW operation despite the high robustness up to high drain bias [2]. This is attributed to the high carbon (C) concentration close to the 2DEG, which is known to be at the origin of electron trapping. To overcome the issue of drain leakage current under high electrical field while minimizing the trapping effects, a thick AlGaN back barrier (BB) can be incorporated, thus forming a double heterostructure AlN/GaN/AlGaN [3], however at the expense of the thermal dissipation, which is a key factor for power applications.

In this work, a thin AlGaN BB with various Al-content is combined with a moderate C concentration away from the 2DEG. DC and RF performances have been studied, especially the balance between the electron confinement (e.g. DIBL) up to high drain bias and the trapping effects. The heterostructures were grown by metal organic chemical vapor deposition (MOCVD) on SiC substrate. Structure A consists of a nucleation layer, a highly C-doped GaN buffer, a 150 nm thick undoped GaN channel and a SiN capped 3 nm thin AlN barrier layer. Structure B is similar but with lower C concentration and the insertion of a thin AlGaN BB with 4% Al. Structure C is identical to structure B except for the AlGaN BB, which contains 18% Al in order to generate a higher polarization. Transistors with 80 nm gate length (T-shaped) deliver low off-state drain leakage current in all cases for  $V_{DS} < 10$  V. As expected, the high C doping in structure A enables high voltage operation but rather strong trapping effects as assessed with DC pulsed measurements. Structure B shows a significant leakage current due to the reduced C-doping and the low Al (4%) content. Structure C with a higher Al content (18%) into the AlGaN BB results in a DIBL well below 100 mV/V, an improved robustness above 20 V drain bias and remarkably low trapping effects despite the use of a sub-100 nm gate length. The extracted  $F_t/F_{max}$  is 64/228 GHz at  $V_{DS} = 20$  V with unilateral current gain of 18 dB at 40 GHz. Such devices are promising for achieving high power/high linearity performances for mm-wave applications.

## References

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- [2] Z. Gao *et al*, Micro.elec.rel., **123**, 114199 (2021)
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## Supplementary information

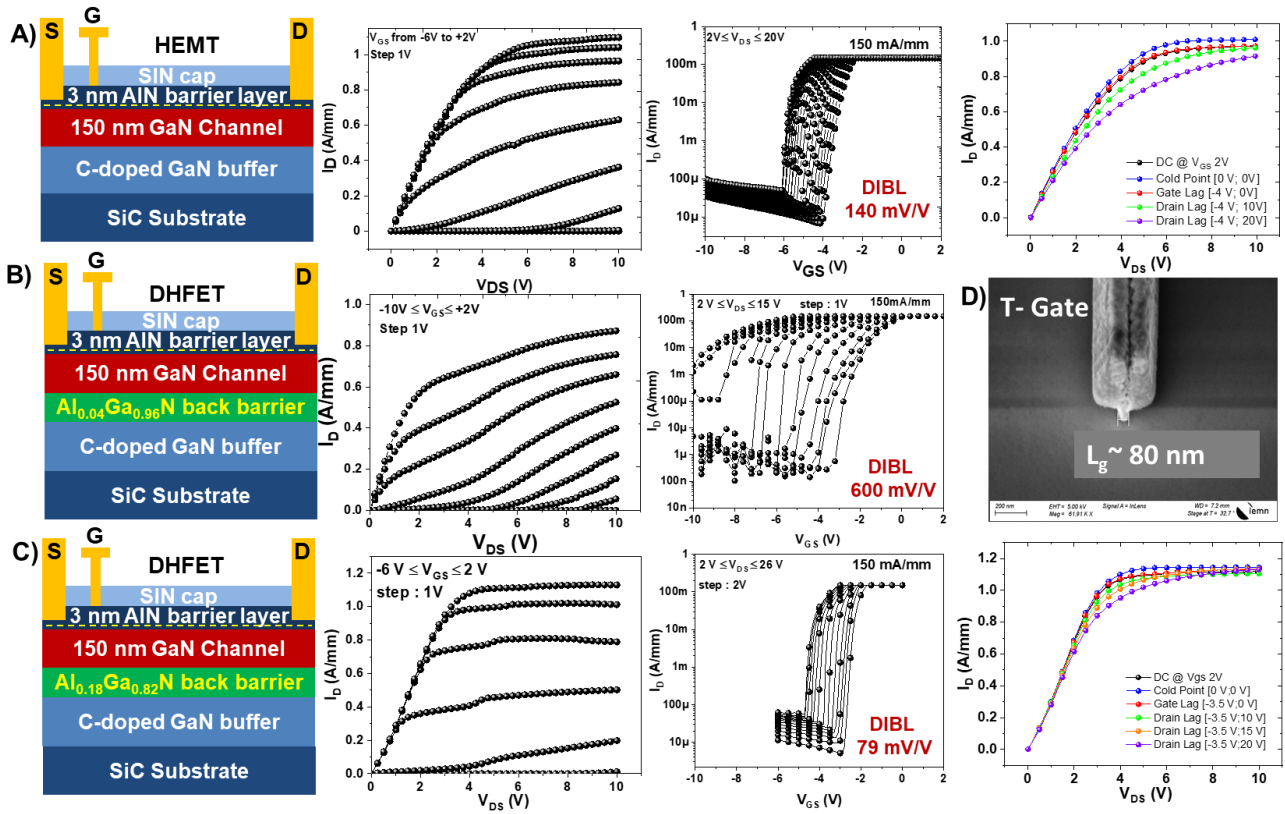


Figure 1: a) transfer characteristics ( $I_D$ - $V_{DS}$ ), semi-on robustness ( $I_D$ - $V_{GS}$ ) and pulsed d.c. characteristics of HEMT with a gate length  $L_g \sim 80$  nm, b-c) characteristics of double heterostructure field-effect transistor (DHFET) with two different back barrier compositions  $Al_{0.04}Ga_{0.96}N$ , and  $Al_{0.18}Ga_{0.82}N$ , respectively, d) scanning electron microscopy image of the fabricated T-gate on the structure 'c'