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The next Millimeter-Wave breakthrough coming up with advanced AlN/GaN transistors

L. Ben-Hammou, F. Grandpierron, K. Harrouche and F. Medjdoub

Abstract—GaN-based material enables higher power density, superior breakdown voltage, and higher thermal conductivity as compared to its counterparts. On the other hand, the power-added-efficiency (PAE) becomes a key parameter in order to support complex waveforms with high peak-to-average ratio and large instantaneous bandwidth required for 5G applications for instance. Overall, a high PAE is mandatory in order to reduce the power dissipation, which is a major issue for future compact solid-state power amplifiers. GaN-based HEMTs on SiC substrate have already demonstrated attractive efficiencies in the mm-wave range. However, state-of-the-art GaN HEMT PAE performances are typically limited to 50% or below in the Ka-band and above, especially for high power densities > 3 W/mm. This is mainly due to the lack of power gain, the enhanced trapping effects and reduced electron confinement when downscaling the device size. In this talk, promising solutions based on highly scaled epitaxial heterostructures will be addressed, enabling mm-wave GaN-based transistors high performances and robustness.

I. INTRODUCTION

Al-rich thin barriers such as $\text{In}_{0.17}\text{Al}_{0.83}\text{N}$ or AlN have been proposed as an alternative to AlGaIn barrier layers [1]. In this case, a high interfacial sheet charge density up to $3 \times 10^{13} \text{ cm}^{-2}$ can be achieved and has indeed been verified by CV and Hall measurements [2]. This allowed HEMT devices with high output current density and outstanding thermal stability up to 1000°C using barrier thicknesses down to couple of nm. Even though impressive performances have been established on both silicon and SiC substrates [3], highly scaled GaN devices generally suffer from relatively low breakdown voltage as compared to the inherent material properties. Moreover, other issues such as trapping effects or proper electron confinement in the 2DEG become more pronounced with reduced device dimensions. This is why, it is of utmost importance to explore solutions enabling GaN HEMTs downscaling delivering superior performances while maintaining high voltage capabilities and reduced electron trapping.

II. RESULTS AND DISCUSSIONS

Extensive buffer engineering is required in order to overcome the electron confinement issue under high electric field of short GaN HEMTs while ensuring low trapping effects. A commonly used way to force the electron confinement under high electric field is the use of doping compensation into the buffer layers.

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However, in the case of short gate length GaN transistors, high doping concentration close to the channel results in severe electron trapping as illustrated in the experiment shown in Fig. 1. In this study, we evaluated the impact of various carbon-doping concentrations into the buffer and undoped GaN channel thickness on the device performances. A matrix based on an extensive experimental variation of these two parameters as a function of the gate length showed a clear trade-off between electron trapping and short channel effects [4]. With the aim of overcoming this trade-off, we inserted a 100 nm thin AlGaIn back barrier between a moderately carbon-doped buffer and the undoped GaN channel. A variation of the Al-content from 4% to 25% in the AlGaIn back barrier has been implemented (Fig. 2). A higher Al-content in the AlGaIn back barrier shows an excellent electron confinement together with low trapping effects despite the significant electric field generated by the short gate length under high drain bias (> 20 V) owing to the moderate carbon concentration of $5 \times 10^{18} \text{ cm}^{-2}$ located 250 nm away from the 2DEG.

The benefit of low trapping effects combined with an excellent electron confinement under high electric field is directly reflected in the device performances. State-of-the-art PAE above 65% with $P_{\text{OUT}} > 3.5$ W/mm at 40 GHz (Fig. 3) and no degradation when subjected to RF stress at various temperatures during 24 hours with $V_{\text{DS}} = 20$ V [5].

III. CONCLUSION

Buffer engineering in highly scaled GaN transistors is clearly a key for pushing the boundaries of this technology and thus pave the way for highly efficient mm-wave robust GaN HEMTs delivering superior output power density as needed for next generation RF power devices.

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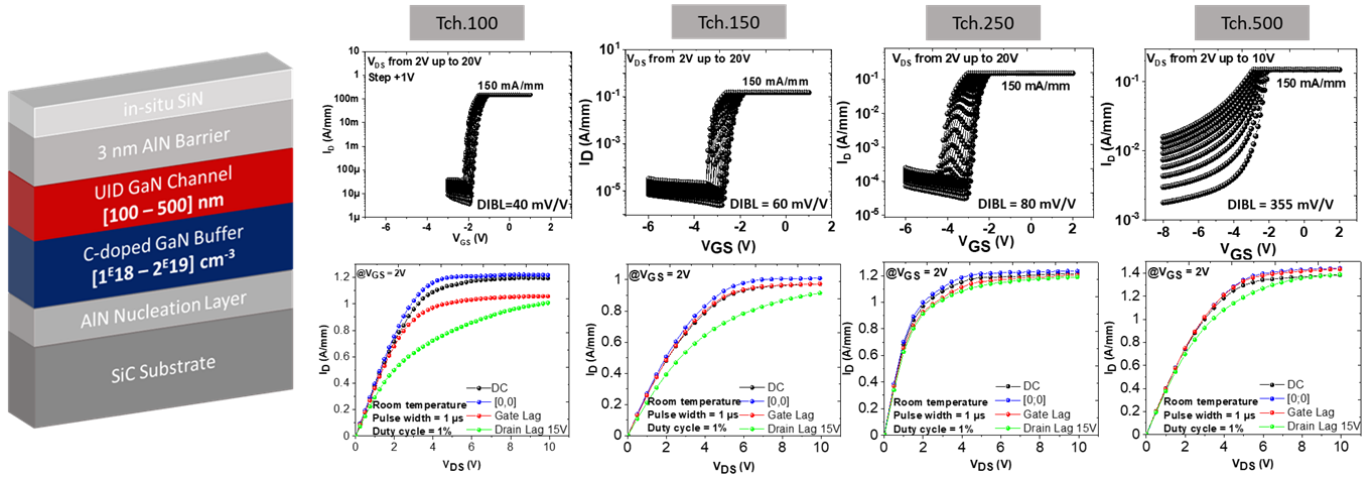


Fig.1. Transfer characteristics up to $V_{DS} = 20$ V and open channel pulsed I_D - V_{DS} output characteristics of $2 \times 50 \mu\text{m}$ transistors with $L_G = 100$ nm for various channel thicknesses.

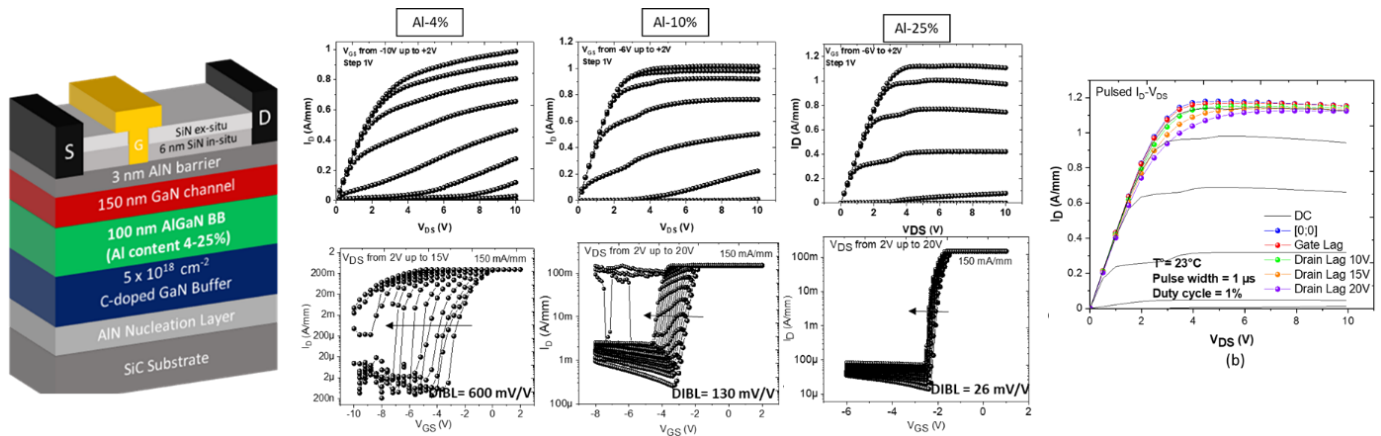


Fig.2. Output and transfer characteristics from $V_{DS} = 2$ V up to 20 V and typical open channel pulsed I_D - V_{DS} output characteristics of $2 \times 50 \mu\text{m}$ AlN/GaN HEMTs for $L_G = 100$ nm with various Al-content in the AlGaN back barrier.

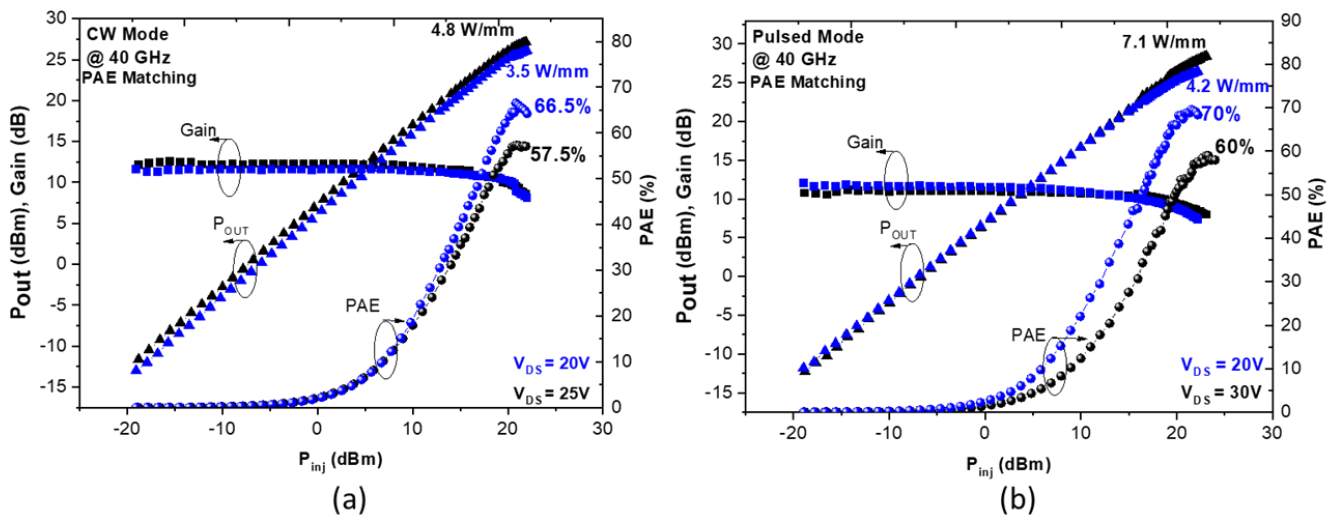


Fig.3. Typical large signal performances at 40 GHz for a $2 \times 50 \mu\text{m}$ AlN/GaN HEMT (Al-25%) with $L_G = 100$ nm in CW up to 25 V (a) and pulsed mode up to 30 V (b).