

# Above 70% PAE in Q-band with AlN/GaN HEMTs structures

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## Abstract

*In this paper, we report on a vertically scaled AlN/GaN HEMT technology. The comparison between a 3 nm and 4 nm barrier thickness shows both superior performances and robustness for the thinner barrier layer, which is attributed to the reduced mechanical strain into the heterostructure. The impact of the gate-to-drain distance ( $L_{GD}$ ) on the RF performances has been studied at 40 GHz. Pulsed mode large signal characteristics reveal an outstanding combination of power added efficiency (PAE) of 72% with a saturated output power density ( $P_{OUT}$ ) > 3.5 W/mm at  $V_{DS} = 20V$  with  $L_{GD}=0.5 \mu m$ . Furthermore, short term RF reliability assessment demonstrates a promising robustness.*

## Introduction

Recent improvements in GaN HEMT devices enabled the demonstration of a variety of next generation millimetre-wave applications owing to its material properties. Nevertheless, future applications operating at high frequency such as 5G need compact systems, for which the PAE is a critical parameter. Indeed, a high PAE is mandatory in order to reduce the power dissipation, which is a current major challenge for next generation of compact solid-state power amplifiers. We have already demonstrated attractive efficiencies in the mm-wave range using AlN/GaN HEMTs on SiC substrate [1]. In this work, a comparison of device performances of two HEMT structures using 3 nm and 4 nm AlN barrier thickness is reported with the aim of pushing the PAE limit of mm-wave GaN-based HEMTs.

## Experimental

The heterostructures have been grown by metal organic chemical vapour deposition (MOCVD) on 4-inch SiC substrates. They consist in an AlN nucleation layer, a carbon-doped GaN buffer layer followed by a 100 nm undoped GaN channel. Two different AlN barrier thickness of 3 nm and 4 nm have been used in order to study the impact on the device performances. Finally, a 10 nm thick in-situ Si<sub>3</sub>N<sub>4</sub> was deposited for both structures. More process details can be found in [1].

## Results and discussion

The transfer characteristics have been swept from  $V_{DS} = 2V$  to 20V with a compliance fixed at 150 mA/mm in order to evaluate the electron confinement. For the 3 nm AlN/GaN devices, an excellent electron confinement has been demonstrated, reflected by a DIBL as low as 14 mV/mm. However, the 4 nm AlN/GaN devices show rather poor electron confinement with a much higher DIBL of 55 mV/mm.

Large signal performances have been performed at 40 GHz for  $2 \times 50 \mu m$  transistors with  $L_G = 110$  nm and  $L_{GD} = 1.5 \mu m$ . Fig. 1 shows the pulsed power performances at  $V_{DS} = 20V$  of a 4 nm AlN/GaN HEMT. A peak PAE of 60% associated to a  $P_{OUT}$  of 3.2 W/mm has been obtained with PAE matching. However, a strong degradation of the drain leakage current is observed after the load-pull measurements at  $V_{DS} = 20V$  as shown in Fig. 2.

For the 3 nm AlN/GaN HEMTs, various  $L_{GD}$  designs have been used. For  $L_{GD} = 0.5 \mu m$ , a record PAE of 72% with a  $P_{OUT}$  of 3.5 W/mm has been achieved in pulsed mode (Fig. 3). As expected, the PAE decreases with larger  $L_{GD}$  due to the increase of the gate-to-drain access resistance. For  $L_{GD} = 1.5 \mu m$  and  $2.5 \mu m$ , while delivering comparable  $P_{OUT}$ , a PAE of 66% and 65% have been obtained, respectively as shown in Fig. 5 and 7. In contrast to the 4 nm, the 3 nm AlN/GaN HEMTs show no degradation of drain current leakage current after load-pull measurements (see Fig. 6).

Short-term large signal reliability assessment has been carried-out with various drain voltage as a function of temperature.  $2 \times 50 \mu m$  transistors with a  $L_{GD}$  of  $1.5 \mu m$  and  $L_G$  of 110 nm have been monitored during 24 hours under large signal conditions at 40 GHz and at peak PAE. The 4 nm AlN/GaN HEMTs show a strong degradation at  $V_{DS} = 12V$  and above. On the other hand, the 3 nm AlN/GaN HEMTs show no degradation of RF performances and leakage current up to  $V_{DS} = 30V$ . This is attributed to the lower defect density into the thinner barrier layer (closer to the critical thickness) subsequent to the reduced mechanical strain.

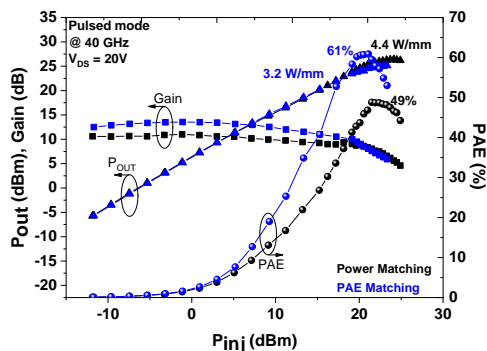
## Conclusions

In this work, we performed a comparison between two AlN/GaN HEMT structures on 4-inch SiC substrate using a 3 nm and 4 nm barrier thickness. The 4 nm AlN/GaN structure shows a poor device robustness with a strong degradation short term reliability assessment. On the other hand, the 3 nm AlN/GaN structure shows an outstanding RF performances at 40 GHz while demonstrating a promising device robustness. This result has been obtained on several tenths of devices, which confirm the excellent yield and uniformity.

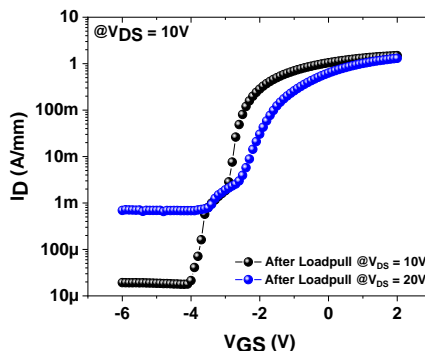
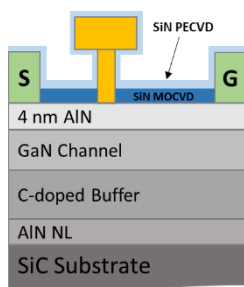
## References:

- [1] K. Harrouche and al, IEEE J. Electron Devices Soc., vol. 7, pp. 1145-1150, 2019.
- [2] R. Kabouche et al., Int. J. High Speed Electron. Syst., vol. 28, no. 1-2, 2019.

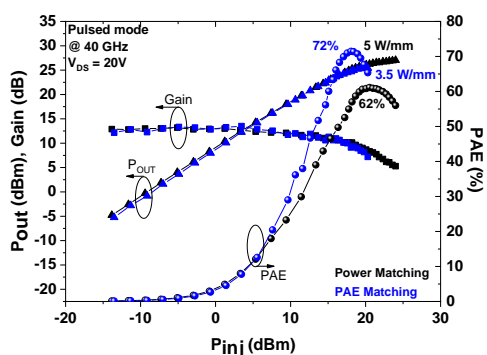
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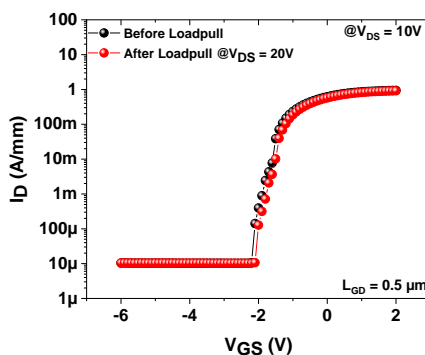
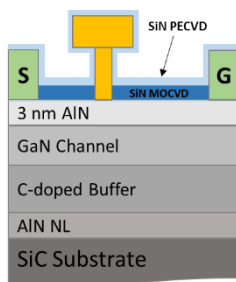
**Figure 1.** Pulsed power performances of a 4 nm AlN/GaN HEMT  $2 \times 50 \mu\text{m}$  with  $L_G = 110 \text{ nm}$  and  $L_{GD} = 1.5 \mu\text{m}$  at  $V_{DS} = 20\text{V}$



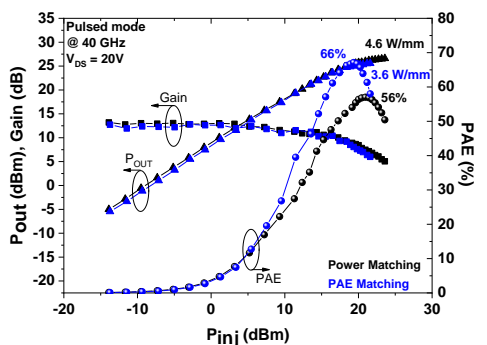
**Figure 2.** Transfer characteristic before and after load-pull measurements at  $V_{DS} = 20\text{V}$



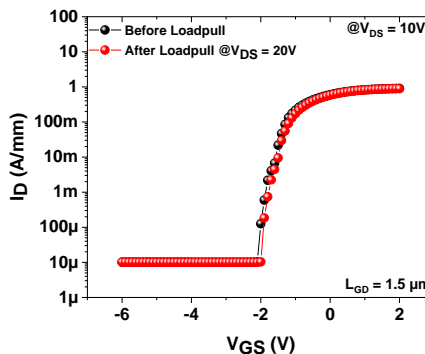
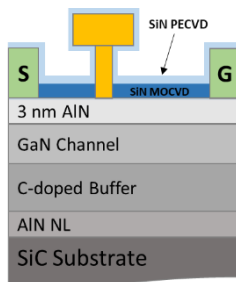
**Figure 3.** Pulsed power performances of a 3 nm AlN/GaN HEMT  $2 \times 50 \mu\text{m}$  with  $L_G = 110 \text{ nm}$  and  $L_{GD} = 0.5 \mu\text{m}$  at  $V_{DS} = 20\text{V}$



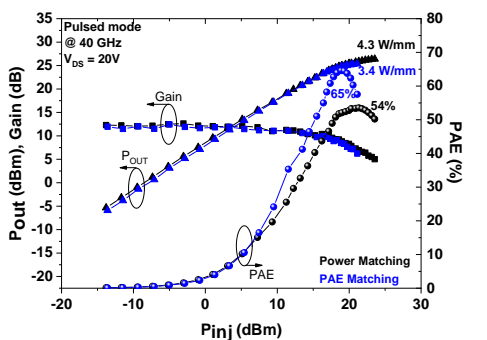
**Figure 4.** Transfer characteristics before and after load-pull measurements at  $V_{DS} = 20\text{V}$



**Figure 5.** Pulsed power performances of a 3 nm AlN/GaN HEMT  $2 \times 50 \mu\text{m}$  with  $L_G = 110 \text{ nm}$  and  $L_{GD} = 1.5 \mu\text{m}$  at  $V_{DS} = 20\text{V}$



**Figure 6.** Transfer characteristics before and after load-pull measurements at  $V_{DS} = 20\text{V}$



**Figure 7.** Pulsed power performances of a 3 nm AlN/GaN HEMT  $2 \times 50 \mu\text{m}$  with  $L_G = 110 \text{ nm}$  and  $L_{GD} = 2.5 \mu\text{m}$  at  $V_{DS} = 20\text{V}$

