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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 Si₃N₄ 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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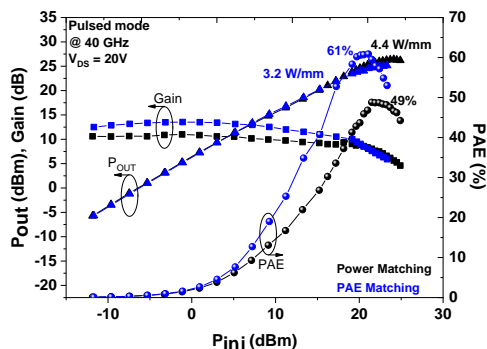


Figure 1. Pulsed power performances of a 4 nm AlN/GaN HEMT $2 \times 50 \mu\text{m}$ with $L_G = 110 \text{ nm}$ and $L_{GD} = 1.5 \mu\text{m}$ at $V_{DS} = 20\text{V}$

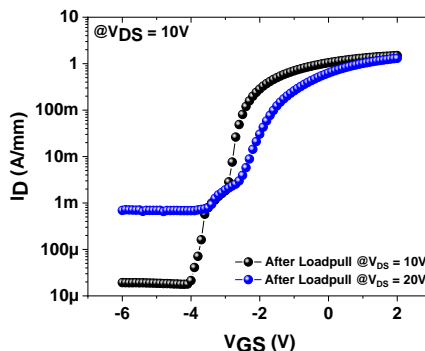
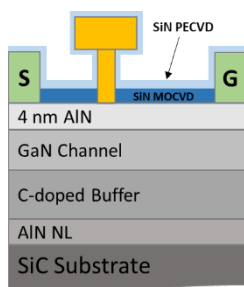


Figure 2. Transfer characteristic before and after load-pull measurements at $V_{DS} = 20\text{V}$

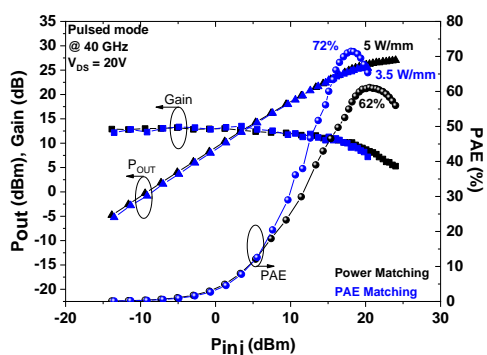


Figure 3. Pulsed power performances of a 3 nm AlN/GaN HEMT $2 \times 50 \mu\text{m}$ with $L_G = 110 \text{ nm}$ and $L_{GD} = 0.5 \mu\text{m}$ at $V_{DS} = 20\text{V}$

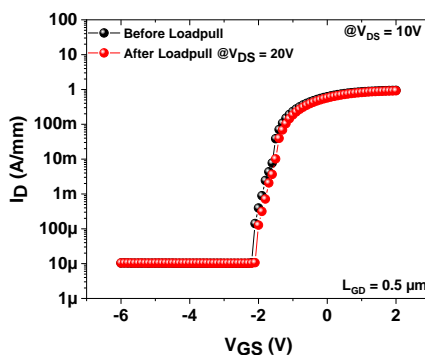
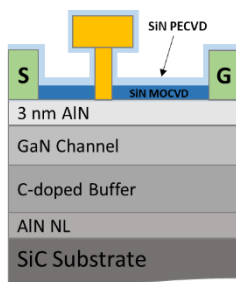


Figure 4. Transfer characteristics before and after load-pull measurements at $V_{DS} = 20\text{V}$

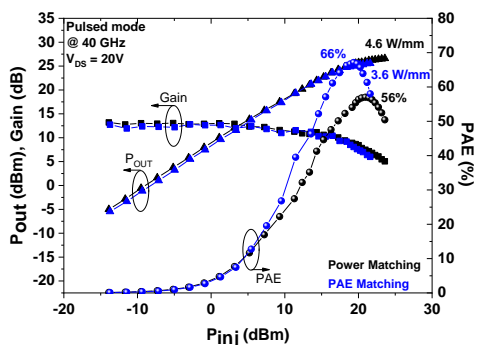


Figure 5. Pulsed power performances of a 3 nm AlN/GaN HEMT $2 \times 50 \mu\text{m}$ with $L_G = 110 \text{ nm}$ and $L_{GD} = 1.5 \mu\text{m}$ at $V_{DS} = 20\text{V}$

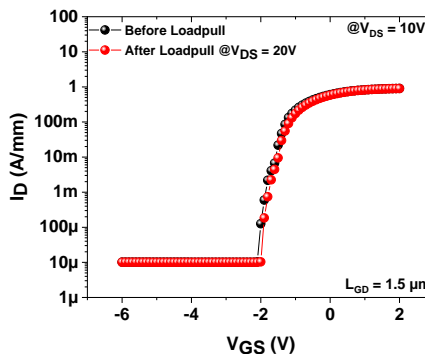
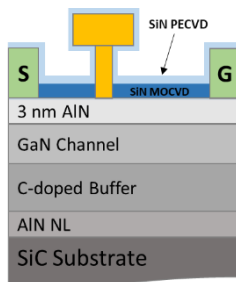


Figure 6. Transfer characteristics before and after load-pull measurements at $V_{DS} = 20\text{V}$

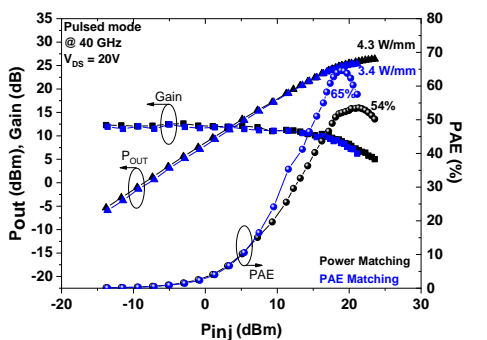


Figure 7. Pulsed power performances of a 3 nm AlN/GaN HEMT $2 \times 50 \mu\text{m}$ with $L_G = 110 \text{ nm}$ and $L_{GD} = 2.5 \mu\text{m}$ at $V_{DS} = 20\text{V}$

