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State of the Art 58W, 38% PAE X-Band AlGaN/GaN HEMTs microstrip MMIC Amplifiers

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Abstract—**This paper presents the results obtained on X-Band GaN MMICs developed in the frame of the Korrigan project launched by the European Defense Agency. A new step was achieved, 58W of output power with 38% PAE in X-Band were obtained using an 18mm^2 2-stages amplifier. To our knowledge, these results present a new state-of-the-art of X-Band MMIC power amplifiers.**

Keywords-HEMT, GaN, power amplifier, X-band.

I. INTRODUCTION

GaN Based HEMT show superior power-frequency performances than lower band-gap materials due to a high breakdown field and a high electron saturation velocity, as well as a high carrier density and mobility through the AlGaN/GaN heterostructures [1], [2], [3]. AlGaN/GaN HEMT based functions such as power amplifiers, switches or low noise amplifiers have been evaluated for many civil and military applications [4], [5], [6], [7], [8]. In this work, we report on the performances obtained with MMIC power amplifiers at X-band on AlGaN/GaN HEMT technology on SiC substrate. The most recent published results on either coplanar or microstrip GaN MMICs at X-band showed output powers in the range of [15-25]W [9], [10], [11], [12]. These results were already higher than performances reported with GaAs material [13], [14]. In this paper, we present output powers as high as 58W with 38% PAE at 9 GHz with a single MMIC chip of 18mm^2. (Figure 1). It is an important step in the development of GaN based circuits that leads to the improvement of architectures for the future generation of T/R modules of active antennas.

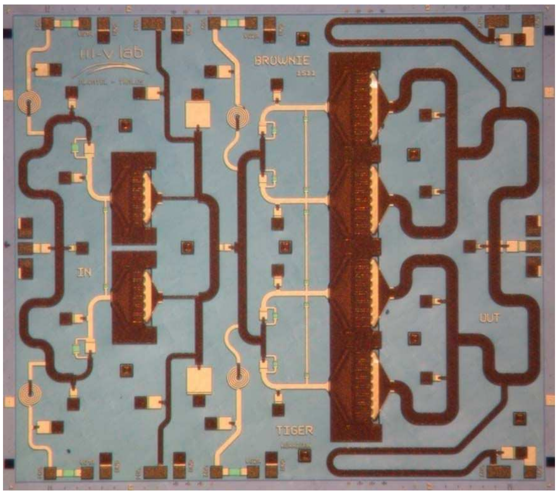

Figure 1. Photograph of amplifier. Chip size is 18mm^2.

II. MATERIALS

The AlGaN/GaN HEMT epitaxial layer was grown on a silicon carbide substrate by low-pressure metal organic chemical vapor deposition (MOCVD). Mercury probe C-V measurements showed a sheet carrier density of 1.1 1013cm-2 and TLM measurements a mean sheet resistance of 453 ohms per square.

III. DEVICE TECHNOLOGY

The electrical isolation of devices was performed by helium implantation. Ti/Al/Ni/Au ohmic contacts were formed using rapid thermal annealing at temperature of 900°C. Mean contact resistance extracted from TLM measurement is 0.21 Ω.mm. Mo-based T-gates with 0.25 µm length were defined by electron beam lithography. The devices were then passivated using plasma enhanced chemical vapor deposition (PECVD) of SiO2/Si3N4 at a temperature of 340°C. Interconnects were made with evaporated Ti/Pt/Au and electroplated gold for the 3D interconnects (bridges). Passive elements consist in PECVD nitride MIM capacitors, NiCr resistors and evaporated Ti/Pt/Au inductances. After front side processing, the SiC wafer was mounted on a sapphire substrate and thinned down to 100 µm. Plasma etching via-holes technology was used to ground the devices. Vias and back side metallization consisted in sputtered TiW/Au and Au plating.

IV. DEVICE TOPOLOGIES

Figure 2 shows a photograph of a microstrip 12x100µm power device used in the first stage the amplifier. This power transistor exhibited approximately 15dB of gain at 10 GHz at a drain voltage of 25V and a drain current of 210mA (figure 3).

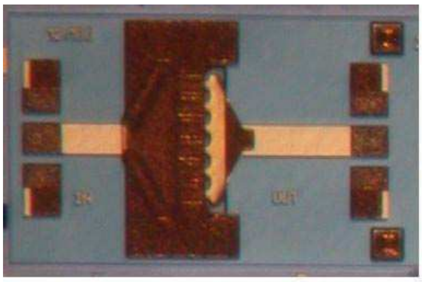

Figure 2. Photograph of the 12x100µm power device used in first stage.

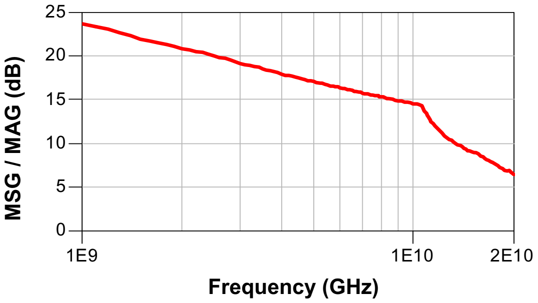

Figure 3. Measurement of the small signal power gain of the 12x100 µm device (Vds=25V, Ids=210mA).

V. AMPLIFIER DESIGN

The amplifier includes two stages. The first stage is composed of two 12x100µm and the second stage of four 16x140µm devices. The chip size is 4500 x4000 µm² (Figure 1).

In order to reduce losses in the transmission lines of matching networks, an additional electroplated gold layer was deposited on the output combiner as well as on the first and on the inter-stage combiners.

A parallel RC network in series at the input of each transistor enhances the stability of HPAs and prevents the occurrence of parametric oscillation phenomena [15]. The simulation of the stability of these amplifiers was first performed in linear operation mode at the quiescent biasing point. Then, the non linear stability was analyzed at high input power level [16].

VI. AMPLIFIER RESULTS

Amplifiers were characterized on wafer under pulsed drain conditions of 20µs / 10%. First, the amplifier was biased at a drain voltage of 25V and at a quiescent drain current of 2.3A.

Figure 4 shows the associated gain, output power and PAE of the amplifier versus the input power at 9 GHz.

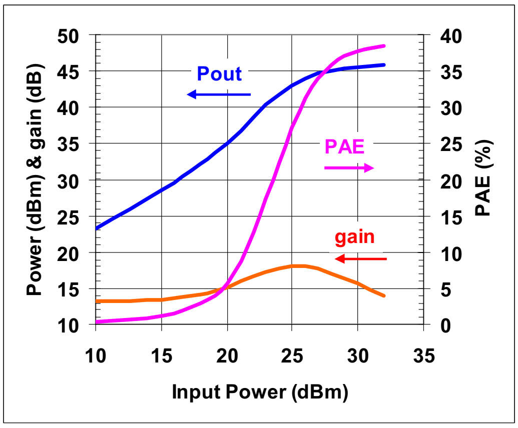

Figure 4. Gain (dB), Ouput power (dBm) and PAE (%) of amplifier at 9 GHz versus the input power (Vds0=25V, Ids0=2.3A).

The amplifier delivered a maximum output power of 46dBm (40W) with 38% of PAE and 14dB of associated gain at 9 GHz. The compression level of 4dB allowed the amplifier to deliver the best PAE.

The amplifier was also characterized versus frequency. The linear gain was between [14-16.5] dB in the [8-10] GHz frequency bandwidth. Figure 5 shows the power performances obtained at an input power of 32dBm.

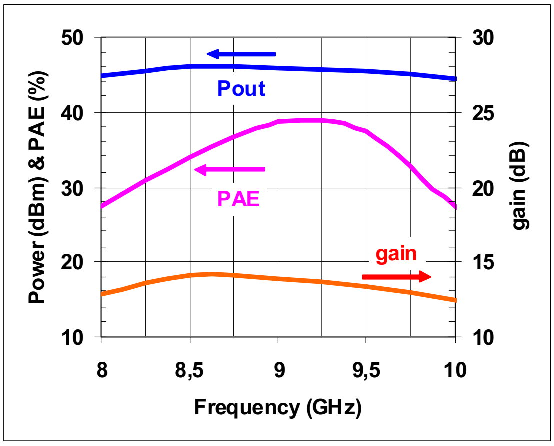

Figure 5. Gain (dB), output power (dBm) and PAE (%) of amplifier at input power of 32dBm (Vds0=25V, Ids0=2.3A).

The output power was higher than 44.8dBm (30W) and PAE higher than 33% in the [8.5-9.5] GHz bandwidth. The associated gain was in the range of 13.5 dB +/- 0.5dB.

Then, the amplifier was measured at a higher drain bias voltage of 32V. Figure 6 shows the performances obtained at 9 GHz.

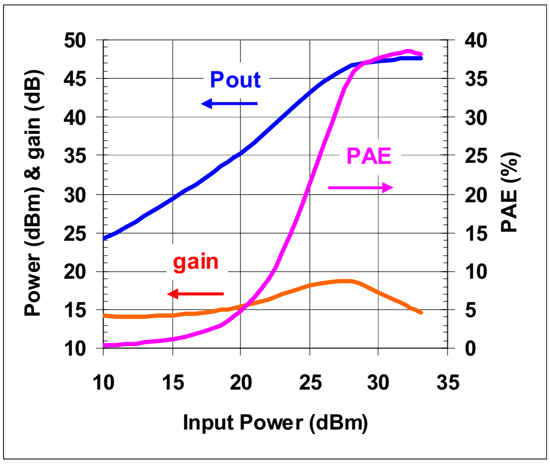

Figure 6. Gain (dB), Ouput power (dBm) and PAE (%) of amplifier at 9 GHz versus the input power (Vds0=32V, Ids0=2.3A).

The amplifier delivered a maximum output power of 47.7dBm (58W) corresponding to a power density of 6.5 W/mm with 38% of PAE and 14.6dB of associated gain at 9 GHz. To our knowledge, this result represents the new state of the art of the output power obtained on MMIC with AlGaN/GaN HEMT technology.

VII. CONCLUSION

State of the art X-band microstrip MMIC amplifiers performances based on AlGaN/GaN HEMT technology were presented.

At a drain voltage of 25V, amplifiers delivered an output power of 46dBm (40W) with 38% of PAE at 9 GHz. In the [8.5-9.5] GHz bandwidth, the output power was higher than 44.8dBm (30W) with a PAE higher than 33%.

At a higher drain bias voltage of 32V, the amplifier delivered a maximum output power of 47.7dBm (58W) with 38% of PAE and 14.6dB of associated gain at 9 GHz. This paper demonstrates once again the great interest of GaN technology for microwave power applications.

VIII. ACKNOWLEDGMENT

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