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

S. Piotrowicz^I, E. Morvan^I, R. Aubry^I, S. Bansropun^{III}, T. Bouvet^{III}, E. Chartier^I, T. Dean^{III}, O. Drisse^I, C. Dua^I, D. Floriot^{II}, M.A. diForte-Poisson^I, Y. Gourdel^{III}, A.J. Hydes^{IV}, J.C. Jacquet^I, O. Jardel^I, D. Lancereau^I, J.O. Mc Lean^{IV}, G. Lecoustre, A. Martin^V, Z. Ouarch^{II}, T. Reveyrand^V, M. Richard^I, N. Sarazin^I, D. Thenot^{III} and S.L. Delage^I.

^I: ALCATEL-THALES III-V Lab, Route de Nozay, 91461 Marcoussis, France.

^{II}: United Monolithic Semiconductors, Rd. 128, 91401 Orsay, France.

^{III}: THALES Research and Technology, RD 128, 91767 Palaiseau Cedex, France.

^{IV}: QinetiQ, Malvern Technology Centre, St. Andrews Road, Malvern, WR14 3PS, United Kingdom.

^V: XLIM, Faculté des sciences de Limoges, 87060 Limoges, France

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 18mm² 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 AlGa_N/Ga_N heterostructures [1], [2], [3]. AlGa_N/Ga_N 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 AlGa_N/Ga_N 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 18mm². (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.

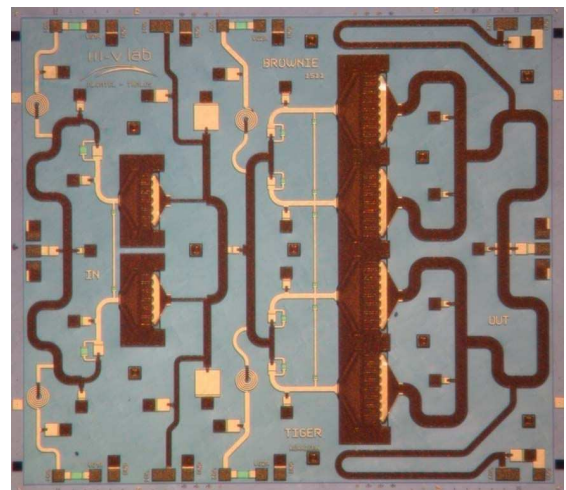


Figure 1. Photograph of amplifier. Chip size is 18mm².

II. MATERIALS

The AlGa_N/Ga_N 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).

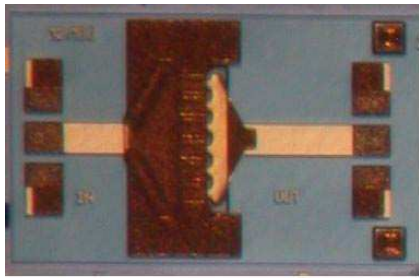


Figure 2. Photograph of the 12x100μm power device used in first stage.

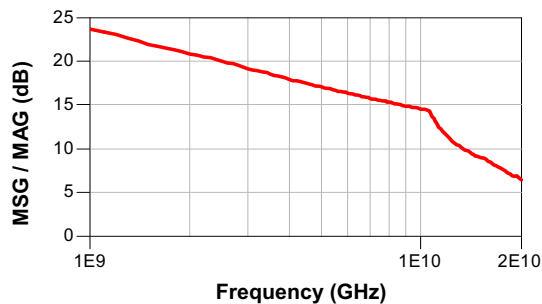


Figure 3. Measurement of the small signal power gain of the 12x100 μm device (V_{ds}=25V, I_{ds}=210mA).

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.

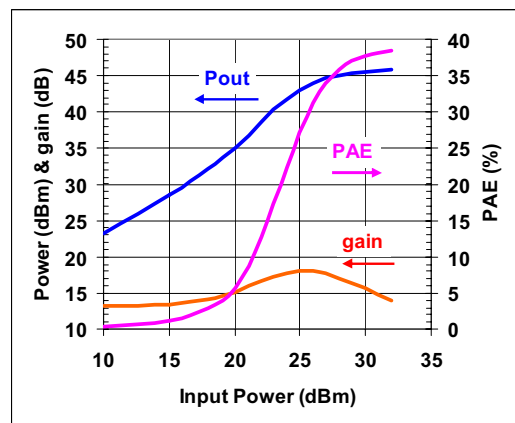


Figure 4. Gain (dB), Output power (dBm) and PAE (%) of amplifier at 9 GHz versus the input power (V_{ds}=25V, I_{ds}=2.3A).

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.

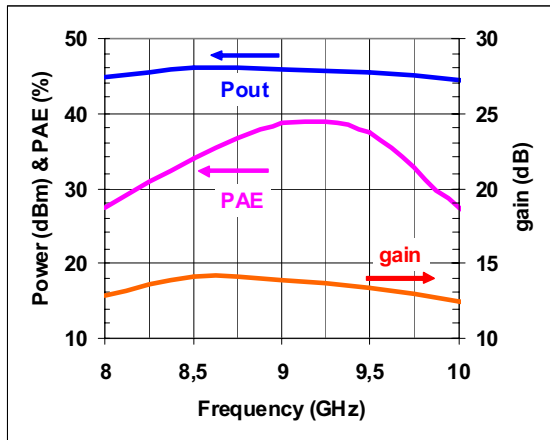


Figure 5. Gain (dB), output power (dBm) and PAE (%) of amplifier at input power of 32dBm ($V_{ds0}=25V$, $I_{ds0}=2.3A$).

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.

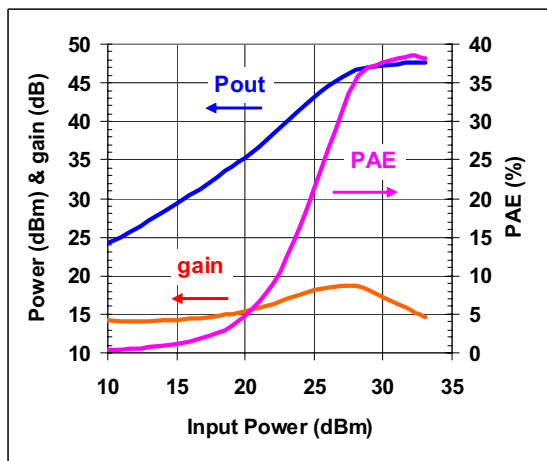


Figure 6. Gain (dB), Output power (dBm) and PAE (%) of amplifier at 9 GHz versus the input power ($V_{ds0}=32V$, $I_{ds0}=2.3A$).

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 AlGaIn/GaN HEMT technology.

VII. CONCLUSION

State of the art X-band microstrip MMIC amplifiers performances based on AlGaIn/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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IX. REFERENCES

- [1] Yi-Feng Wu, D. Kapolnek, J.P. Ibbertson, P. Parikh, B.P. Keller and U.K. Mishra. "Very-High power density AlGaIn/GaN HEMTs". IEEE Transactions on electronic devices, Vol. 48, n°3, pp.586-590, March 2001.
- [2] S.T. Sheppard et al. "High power microwave GaN/AlGaIn HEMT's on SiC substrate". IEEE Electron Device Letters, Vol. 20, pp.161-163, June 1999.
- [3] U.K. Mishra, P. Parikh and YF. Wu, "AlGaIn/GaN HEMTs- An overview of device operation and applications", Proc. IEEE, vol.90, no.6, pp.1022-1031, Jun. 2002.
- [4] K.W.Kobayashi, YaoChung Chen, Ioulia Smorchkova, Roger Tsai, Mike Wojtowicz and Aaron Oki. "A 2 watt, Sub-dB noise figure GaN MMIC LNA-PA amplifier with multi octave bandwidth from 0.2-8 GHz". IEEE IMS 2007 Conference, pp.619-622.
- [5] Y. Lee and Y. Jeong. "Applications of GaN HEMT's and SiC MESFETs in high efficiency class-E power amplifier design for WCDMA applications". IEEE IMS 2007 Conference, pp.1099-1102.
- [6] J. Lee and K.J. Webb. "Broadband GaN HEMT push-pull microwave power amplifier". IEEE Microwave and Wireless Components Letters, Vol. 11, n°9, pp.367-369, September 2001.
- [7] Y. Mancuso, P. Gremillet, P.Lacomme. "T/R- Modules Technological and Technical Trends for Phased Array Antennas". IEEE IMS 2006 Conference, pp.614-617.
- [8] S.Piotrowicz, R.Aubry, E.Chartier, O.Jardel, J.C.Jacquet, E.Morvan, B.Grimbert, G.Lecoustre, S.L. Delage, J. Obregon and D. Floriot. "Broadband Hybrid Flip-Chip 6-18 GHz AlGaIn/GaN HEMT Amplifiers". IEEE IMS 2008 Conference, pp.1131-1134.
- [9] H. Klockenhoff, R. Behtash, J. Wuerfl, W. Heinrich, and G. Trankle. "A Compact 16 Watt X-Band GaN-MMIC Power Amplifier". IEEE MTT-S Digest, pp.1846-1849, June 2006.
- [10] F. van Raay, R. Quay, R. Kiefer, W. Bronner, M. Seelmann-Eggebert, M.Schlechtweg, M. Mikulla, and G. Weimann. "X-Band High-Power Microstrip AlGaIn/GaN HEMT Amplifier MMICs". IEEE MTT-S Digest, pp.1368-1371, June 2006.

- [11] D. M. Fanning, L. C. Witkowski, C. Lee, D. C. Dumka, H. Q. Tserng, P. Saunier, W. Gaiewski, E. L. Piner*, K. J. Linthicum* and J. W. Johnson . "25 W X-band GaN on Si MMIC". GaAs Mantech Conference proceedings, 2005.
- [12] J.-S. Moon, D. Wong, M. Antcliff, P. Hashimoto, M. Hu, P. Willadsen, M. Micovic, H. P. Moyer, A. Kurdoghlian, P. MacDonald, M. Wetzel, and R. Bowen. "High PAE 1mm AlGaIn/GaN HEMTs for 20 W and 43% PAE X-band MMIC Amplifiers". IEDM Meeting 2006. 11-13 Dec. 2006. pp :1-2.
- [13] S.Piotrowicz, E.Chartier, J.C.Jacquet, D.Floriot, J.Obregon, P.Dueme, J.Delaire, Y.Mancuso. "Ultra Compact X-Band GaInP/GaAs HBT MMIC amplifiers : 11W, 42% of PAE on 13mm² and 8.7W, 38% of PAE on 9mm²". IEEE MTT-S Digest, June 2006.
- [14] A.M. Couturier, S. Heckmann, V. Serru, T. Huet, P. Chaumas, J J. Fontecave, M. Camiade, J.P.Viaud and S. Piotrowicz. "A Robust 11W High efficiency X-band GaInP HBT amplifier". IEEE MTT-S Digest, June 2007.
- [15] D.Teeter, A.Platzker and R.Bourque. "A compact network for eliminating parametric oscillations in high power MMIC amplifiers". IEEE MTT-S Digest, pp.967-970, June 1999.
- [16] A. Anakabe, S.Mons, T.Gasseling, P. Casas, R. Quéré, J.M. Collantes and A. Malet. "Efficient nonlinear stability analysis of microwave circuits using commercially available tools". European Microwave Week Conference, pages 1017-1020, 2002.