Low Noise - High Power GaN HEMT Technology for Mixed Mode Applications

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Abstract

This paper describes the first successful demonstration of a low DC power dissipation low noise amplifier (LNA) and a corresponding high power amplifier (HPA) at X-Band using a 0.32 µm X 300 µm GaN HEMT device. The low noise amplifier's measured performance shows a low DC power dissipation of 7.5 mW with 1.7 dB noise figure, 8 dB gain, and 17.7 dBm third order intercept point at 8.5 GHz. The power amplifier using the same device type achieved 30.9 dBm output power, 8 dB gain, and 39 % PAE at 10 GHz.

Introduction

For the past few years, there have been fervent GaN HEMT activities to develop high power performance resulting in excellent power density performance of 9.2 W/mm at X-Band [1] and 70 W CW operation at L-Band [2]. More recently, there is considerable interest in developing robust low noise devices [3-6] to enhance receiver front-end electronic survivability. The culmination of the low noise and high power GaN technology would have significant impact on the next generation military phase array systems; particularly for space-based radar systems. Space applications have a unique set of requirements in that space arrays typically have limited prime power, large array size, and reduced weight per T/R module, which ultimately lowers cost. These new drivers require the development of low DC power dissipation / robust low noise amplifiers for the receive function without compromising power performance to the transmit function. The robust LNA would eliminate the need for protection circuitry to the receiver front-end that would impact performance.

The aim of this paper is to demonstrate the feasibility of GaN HEMT technology in order to obtain low power / robust LNA and high power / highly efficient PA performance. To that end, an AlGaN/GaN HEMT material and fabrication process has been developed in order to produce devices capable of operating at 1V supply, while sustaining high breakdown voltage. This GaN HEMT technology is readily transferable to mixed-mode applications where both high power amplifiers and low DC power dissipation LNAs, comparable to GaAs PHEMTs, can be realized in a monolithic integrated circuit.

Device and Process Description

The GaN HEMT epitaxial layers were grown on an insulating 4H-SiC substrate by MOCVD, which generally exhibits lower dislocation densities than other available nitride epi material. The device structure consists of a 1.0 µm GaN buffer layer and a 250 Ǻ of $Al_{.24}Ga_{.76}N$ barrier layer. The fabrication process consists of (1) Mesa isolation using low power Cl_2/Ar ICP-RIE to nominally 1000 Ǻ, (2) Ohmic contact formation used Ti/Al/Ni/Au metal scheme and annealed at 850 °C in a nitrogen chamber, (3) T-gates formed by using electron beam lithography on a bi-layer PMMA/MMA-MAA resist scheme. The gate metal consisted of Ni/Au, and (4) devices passivated with PECVD silicon nitride at 300 °C giving 1500 Ǻ of thickness. The HEMT device used for this experiment is a two-finger device with 150 µm unit gate width. Figure 1 shows a micrograph of the e-beam defined T-gate illustrating a gate length of 0.32 µm. Source – drain spacing is nominally 2.5 µm. Contact resistance (Rc) based on TLM measurements indicate 0.33 Ω mm and sheet resistance of ~ 409 Ω/□. The combination of material and fabrication optimization provided a technology capable of achieving low DC power low noise performance and excellent power performance.

The 300-µm HEMT devices were fully characterized for both DC and RF. DC and small signal measurements of the device were carried out on Agilent 4142 / 8510C test set. Figure 2 shows the nominal current-voltage characteristics of the device for Vds biased up to 10V and Vgs biased from –5V to 1V. The knee voltage at Idss is ~ 2V with the maximum drain current density of 1.03 A/mm. The pinchoff voltage of the device is ~ -4 V. The peak transconductance of the device is 269 mS/mm at gate voltage of –3V. The gate-drain breakdown voltage is ~ 60 V while sustaining 46 GHz F_t and 64 GHz F_{max}. On-wafer noise measurements were performed from 2-18 GHz (at Vds= 1-5 V and Id=25-150 mA/mm at 25 mA/mm step) using an ATN NP5 noise parameter test set in conjunction with an Agilent 8510B network analyzer. Nominal minimum noise figure and the associated gain at 10GHz are 1.07 dB and 10.75 dB, respectively for 5V drain bias. At 1V drain bias, NFmin increases to ~ 1.5 dB and the associated gain is nominally 8 dB.

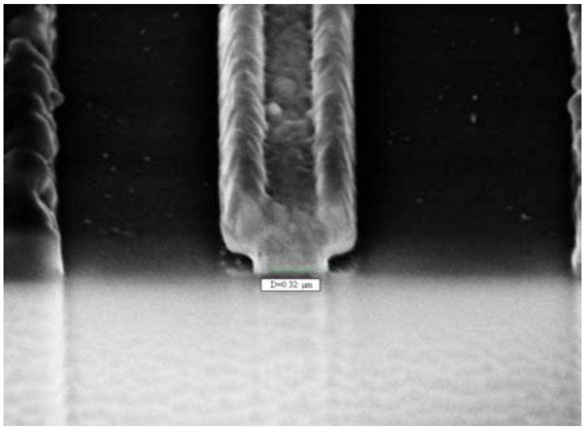

Figure 1: Micrograph of the E-beam T-gate.

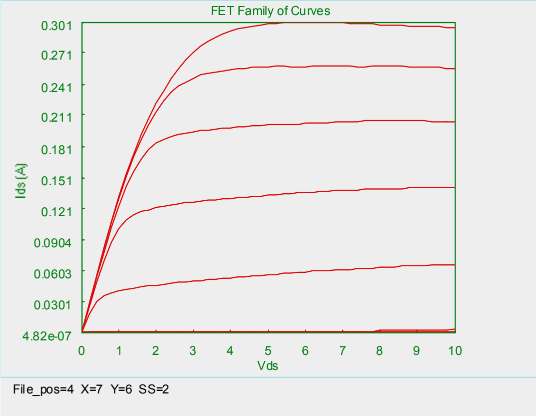

Figure 2: Measured DC-IV family of curves.

Circuit Design and Measurement Results

A single stage low noise amplifier (LNA), shown in Fig. 3, was used to demonstrate the GaN HEMT technology. The LNA employs source inductance (bond wires) degenerative feedback to improve noise matching at the device input and stability at the design frequency. The parallel LC network at the output-matching circuit serves the dual function of gain / power matching at the fundamental frequency and as a resonant network to reduce low frequency gain and hence improve out-of-band stability. The hybrid LNA was implemented using Rogers TMM-10 material (Er=10) with a substrate thickness of 20 mils. Capacitors in the circuit are ATC's high Q components suitable for X-Band operation. The LNA was measured across various bias conditions (Vds=1-5V and Ids=7.5-45 mA). Figures 4 and 5 show measured LNA noise figure and gain at 1V drain bias with drain current varying from 7.5-45 mA. The LNA exhibited the lowest power consumption at Vds=1V and Ids=7.5 mA, which yielded 1.7dB NF, 8.3 dB gain, and 17.7 dBm OIP3 at 8.5 GHz. Power measurements were also performed on the LNA circuit. At 1V supply, the LNA yielded an output power of 4.7 dBm at P_{1dB}, 6.7 dB gain, and 34.7% PAE. As the supply voltage increased to 5V, measurements show typical P_{1dB} power performance of 19.4 dBm Pout, 8.3 dB gain, and 40.8% PAE. Both sets of power measurements illustrate that the GaN HEMT device is capable of low voltage operation and the output power scales with drain bias.

Figure 3: Photograph of the hybrid LNA.

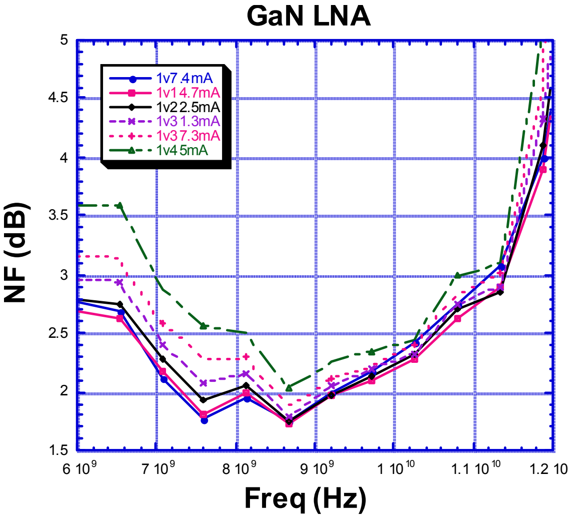

Figure 4: Measured noise figure of the LNA from 6-12 GHz at 0.5GHz step. Vds=1V and Id=7.5-45 mA.

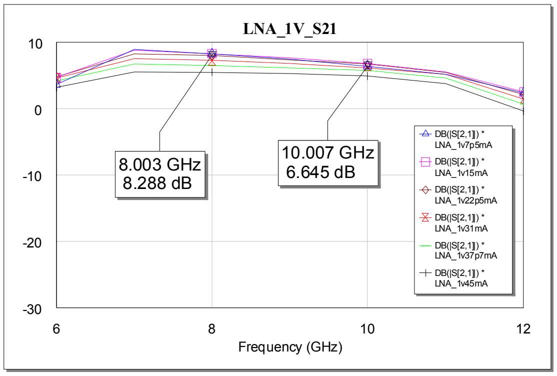

Figure 5: Measured gain plot of the LNA for Vds=1V and Id=7.5-45mA.

The power amplifier requires a minor redesign of the LNA at the input network to provide improved power match at Vds=25V. Figure 6 is a photograph of the single stage power amplifier. The small signal data is plotted in Fig. 7 showing input and output return loss of 10 dB from 9-10 GHz. The highest small signal gain is 11 dB at 9 GHz. Measured power performance at 10 GHz is shown in Fig. 8. For Vds=25V and Iq= 150 mA, the power amplifier achieved 30.9 dBm output power, 8 dB gain, and 39% PAE near P_{3dB} compression. This power amplifier yielded maximum power density of 4.6 W/mm at 10GHz. Both small signal and large signal gains are relatively low due to bond wires at the source to ground connection. The gain and perhaps efficiency would improve with via connection.

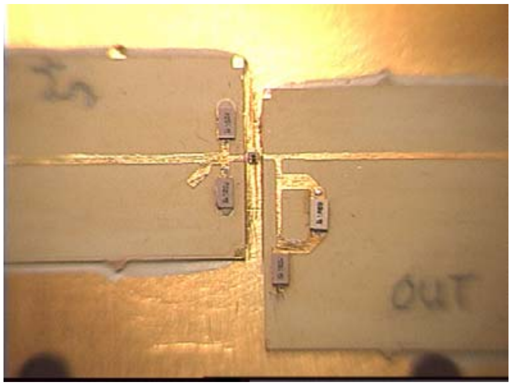

Figure 6: Photograph of the single stage power amplifier.

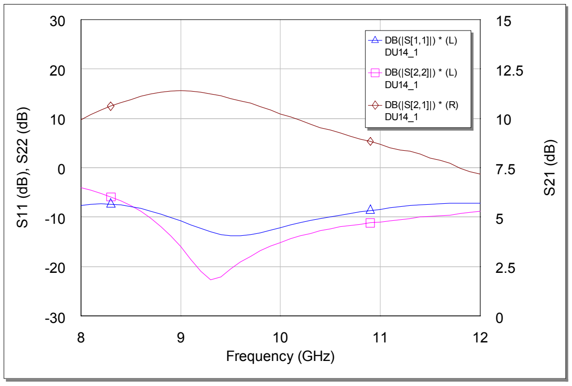

Figure 7: Measured S11, S22, and S21 of the hybrid power amplifier @ Vd=25V and Iq=150mA.

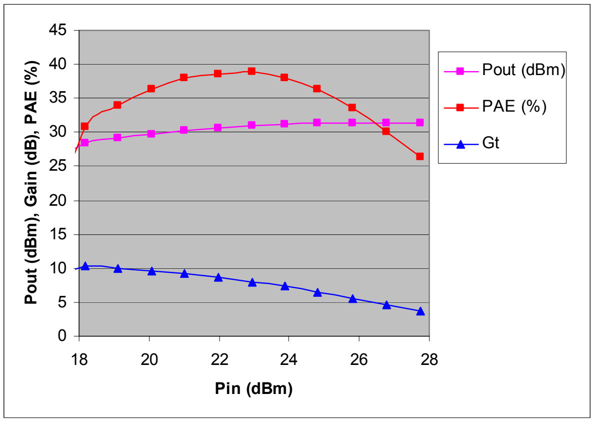

Figure 8: Measured power performance at 10GHz illustrating peak efficiency of 39% at 23-dBm input RF drive.

Conclusions

This work has demonstrated the feasibility of GaN HEMTs for producing low DC power LNAs and relatively high power density PAs utilizing the same device design. To the best of our knowledge, the LNA yielded the lowest DC power dissipation of 7.5mW with the corresponding 1.7 dB NF, 8.3 dB gain, and 17.7 dBm OIP3 at X-Band. The same device also yielded a power amplifier achieving 30.9 dBm Pout, 8 dB gain, and 39% PAE at 10 GHz. This work will have major implications for future radar and communication systems where transmit and receive functions require increased integration within a single technology platform.

Acknowledgements

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Acronyms

GaN:	Gallium Nitride
PHEMT:	Pseudomorphic High Electron Mobility Transistor
LNA:	Low Noise Amplifier
HPA:	High Power Amplifier
OIP3:	Output Third Order Intercept Point
ICP-RIE:	Inductively Coupled Plasma Reactive Ion Etching
PAE:	Power Added Efficiency