150 W GaN-on-Si RF Power Transistor

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Abstract **– A large periphery high power AlGaN/GaN HFET grown on a silicon substrate has demonstrated over 150 W of CW RF output power along with excellent drain efficiency of 65%. When operated under WCDMA modulation and 28 V_{dc} drain supply voltage, these devices produced 20 W of RF output power with a corresponding drain efficiency of 27% while achieving an adjacent channel power ratio (ACPR) of -39 dBc. A 36 mm device was tested in a DPD linearizer under multi-carrier WCDMA modulation and achieved 20 dB of linearity improvement with 35% drain efficiency. Lastly, device reliability data is presented and shows extrapolated 20 year drift estimates of less than 1 dB for Psat.**

Index Terms **– AlGaN/GaN HFETs, GaN high electron mobility transistor (HEMTs), linearity, reliability, RF power transistors.**

I. Introduction

GaN-based transistors have recently been targeted for a number of high power RF applications ranging from linear amplifiers to military radar systems. These applications require high total CW power and efficiency as well as excellent linearity and performance at backed-off power levels. Many impressive power densities have been reported from small-periphery AlGaN/GaN HFETs [1]; however only recently have these devices been scaled to provide useful power levels for high power amplifier applications [2]-[4]. In this work we present a dual-chip packaged power transistor demonstrating over 150 W of CW power along with excellent efficiency and linear performance. When operated under WCDMA modulation and 28 V_{dc} supply voltage, the device produced 20 W of output power with a corresponding drain efficiency of 27% while maintaining an adjacent channel power ratio (ACPR) of -39 dBc. With the application of a digital pre-distortion linearizer the ACPR improved by approximately 20 dB.

II. Overview of Packaged Device

All device results reported in this work are based upon a 36 mm AlGaN/GaN HFET die grown by MOCVD on 100 mm silicon (111) substrates in Nitronex's baseline manufacturing process, which has been shown to produce repeatable devices and promising reliability results [5]-[6]. Fig. 1 shows the layout of a single 36 mm gate periphery die composed of eighteen 2 mm cells.

Transistor die were attached into a high thermally conductive CuW single-ended ceramic packages using a AuSi eutectic process. The sources were grounded to the package base through backside vias in the 150 µm-thick silicon wafer.

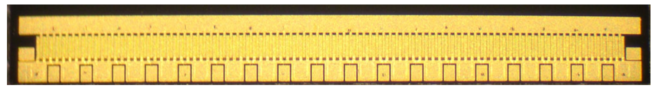

Fig. 1 Photograph of AlGaN/GaN die with total gate periphery of 36 mm. The unit gate width is 200 µm and the gate pitch is 30 µm.

The 72 mm packaged device consists of paralleled 36 mm die with internal matching networks to transform both the input and output packaged die impedances to approximately 3-j4 Ω, and were specifically designed to produce optimal performance at 2.14 GHz, see Fig. 2.

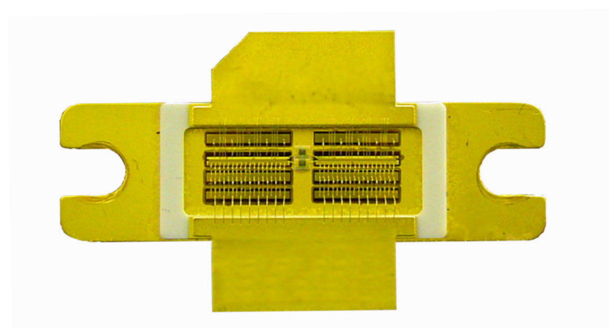

Fig. 2 Photograph of packaged device using two 36 mm die and independent internal matching networks.

III. Device Characterization

The packaged devices were measured in a 50 Ω test fixture maintained at 20º C by active water cooling under both single tone CW and WCDMA signals. All data was collected at a quiescent drain current of 2.0 A and an operating voltage of 28 $V_{dc}V_{dc}$ and 2.14 GHz.

A. CW Performance

A maximum power of 156 W with an associated drain efficiency of 65% and small-signal gain of 16 dB are shown in Fig. 3. To our knowledge, this represents the highest total power ever reported from a GaN-on-Si device and ranks among the highest total CW output power for a GaN device on any substrate (One would expect to achieve even higher power levels with a pulsed RF signal of low duty cycle and short pulse lengths).

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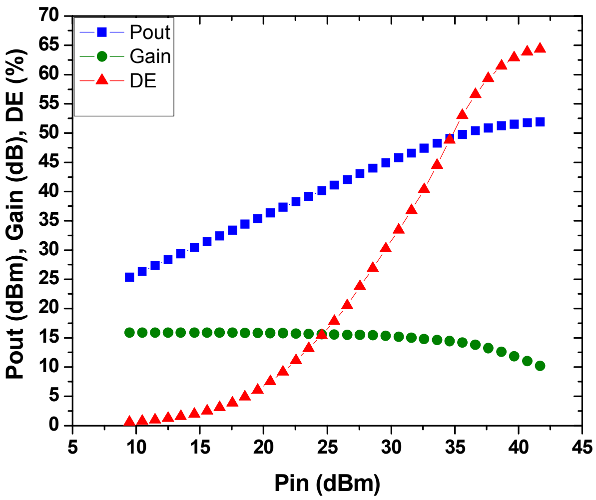

Fig. 3 CW power sweep on 72 mm device at 2.14 GHz demonstrates 156 W of output power and 65% efficiency with 16 dB small-signal gain. Bias conditions are 2.0 A and V_{ds}=28 V.

B. WCDMA Linearity

Linearity was characterized through ACPR measurements under a single WCDMA 3GPP modulated carrier (test model 1 with 64 users and 100% clipping, yielding a PAR of 9.8 dB @ 0.01% CCDF). Performance was optimized around an ACPR level of -39 dBc at 2.14 GHz and V_{ds}=28 V_{dc}. Measurements reported here were obtained in an application board transformed to 50 Ω. A photograph of the device and test board can be seen in Fig. 4. At an ACPR level of -39 dBc, these devices produced 20 W of linear power, 27% drain efficiency, and 14 dB of gain as seen in Fig. 5. Relaxing the ACPR requirement to -35 dBc raised the power and efficiency to 28 W and 32%, respectively. Specific device-level linearity requirements will be largely dictated by the method used for external linearization (e.g., feed-forward, digital pre-distortion, etc.). GaN-based devices may offer advantages over competing technologies, such as Si-LDMOS, in this area due to the potential for higher operating voltage and reduced thermal memory effects [2].

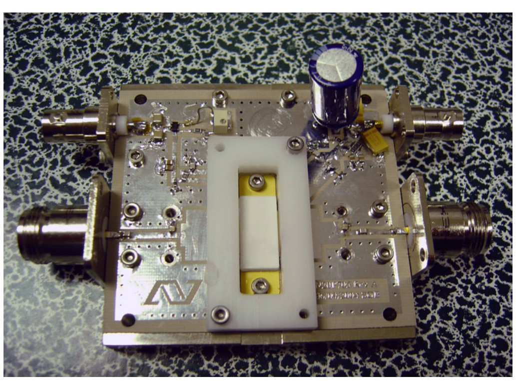

Fig. 4 Packaged GaN device mounted onto a 50 Ω application board used in WCDMA measurements.

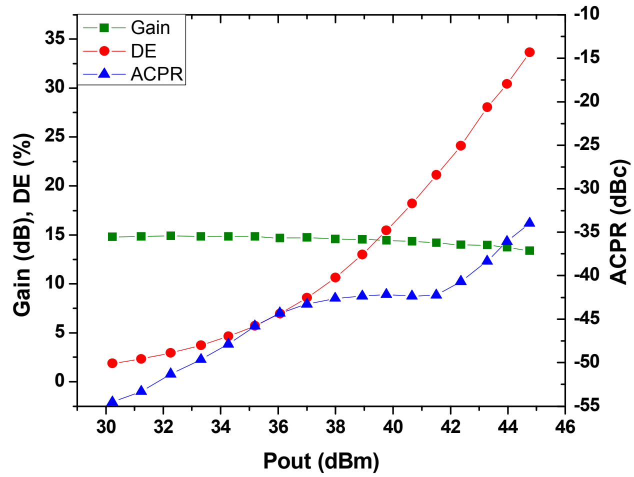

Fig. 5 WCDMA power sweep on 72 mm device at 2.14 GHz reveals at an ACPR level of -39 dBc the output power is 20 W with an associated drain efficiency of 27% and 14 dB gain. Bias conditions are 2.0 A and V_{ds}=28 V.

IV. Reproducibility

The 72 mm devices were manufactured on Nitronex's baseline process and the reproducibility of these results are demonstrated by the RF performance distribution plots in Fig. 6 and Fig. 7. Data collected under WCDMA modulation shows average drain efficiency over 25% and average RF output power of 19 W from 31 devices and 3 different baseline wafers.

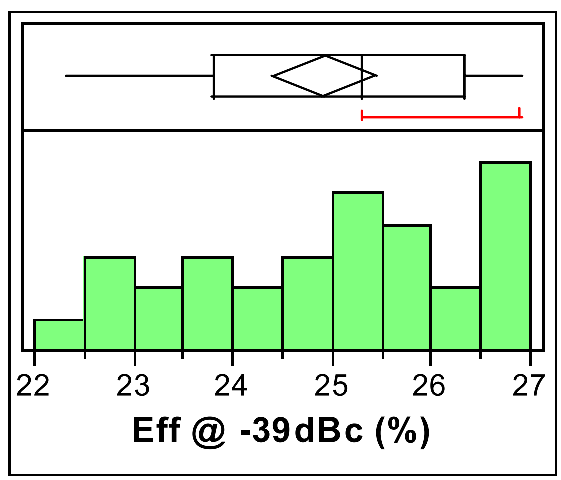

Fig. 6 Drain efficiency distribution for WCDMA signal shows average drain efficiency over 25% @ -39 dBc. Plots are from 31 devices and 3 different wafers, all from Nitronex's baseline process.

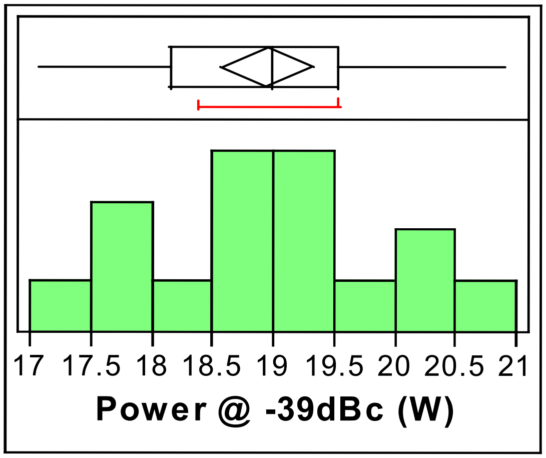

Fig. 7 RF output power distribution for a WCDMA signal shows over 19 W of average power @ -39 dBc. Plots are from 31 devices and 3 different wafers, all from Nitronex's baseline process.

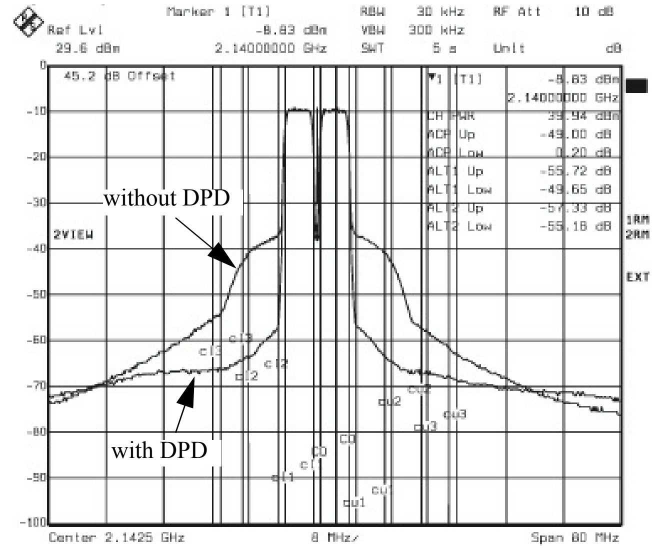

Fig. 8 PSD of a 36 mm GaN power transistor with and without DPD and crest factor reduction shows a nearly 20 dB improvement in ACPR for a two-carrier WCDMA signal. Drain efficiency increased from 24.0% to 35.7%

V. Digital Predistortion Performance

In order to achieve 3GPP UMTS basestation linearity specifications while also providing good amplifier efficiency, PA manufacturers have recently been implementing a combination of Digital Pre-Distortion (DPD) architectures and Crest Factor Reduction (CFR) algorithms [2], [7]. Therefore, a simple single or multi-carrier ACPR measurement at a given bias point, as previously reported in section III., ignores the impact these linearization techniques will have upon the underlying power transistor technology. A more realistic assessment of an RF power transistor's linearity performance requires the application of DPD linearization techniques and CFR algorithms.

Currently, DPD techniques have been utilized very successfully with Si-LDMOS and GaAs power transistors with a limited number of results being reported with newer GaN based devices [2], [7]. In this work a DPD technique was applied to a single 36 mm GaN die in a CuW ceramic package with internal matching networks and mounted to a 50 Ω application board. The device was biased at 28 V_{dc} and 1.0 A, and was excited with two and three carrier WCDMA 3GPP compliant test signals. Fig. 8 and Fig. 9 show the power spectral density (PSD) of the two and three carrier WCDMA signals, respectively, with and without DPD applied. As can be seen, the ACPR improved by nearly 20 dB for both the two and three carrier signals while the drain efficiency increased by ten percentage points to better than 35% while yielding nearly 20 W of RF output power.

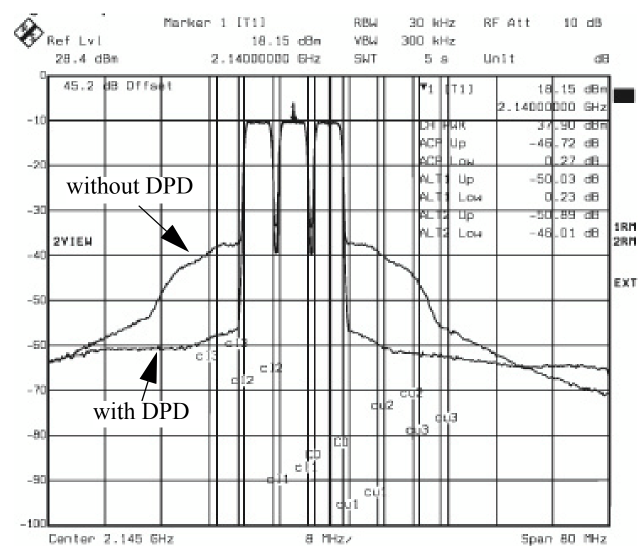

Fig. 9 PSD of a 36 mm GaN power transistor with and without DPD and crest factor reduction shows a nearly 20 dB improvement in ACPR for a three-carrier WCDMA signal. Drain efficiency increased from 24.0% to 35.3%

VI. Reliability

Extensive reliability testing is currently underway on the 36 mm GaN devices. To date, 1000-hour DC high temperature operating life tests have been performed on over 100 different devices. Log-normal fits have been used to extrapolate the data out to 20 years and shows an Idss drift of less than 10% and a P_{sat} drift of less than 1 dB. Further details on this work have been reported elsewhere [6].

RF stress testing has been performed on eight different devices ranging in power from 30 W to 80 W (16 mm to 72 mm gate periphery). All RF stress results are under 3 dB compression with the base plate temperature raised to ~40-80º C to produce a junction temperature of 200º C. The total device time for all the samples is over 900 hours (calculated by adding the stress time for all eight devices). The data shown in Fig. 10 is from a 36 mm device stressed for 115 hours. The total RF output power degradation is less than 0.2 dB and the majority of the shift occurs within the first hour. A log-normal fit was performed for all eight devices and 20 year drift estimates were calculated. The average 20 year power drift under 3 dB compression and 200º C is 0.62 dB, spanning a range of 0.25 dB to 1.0 dB.

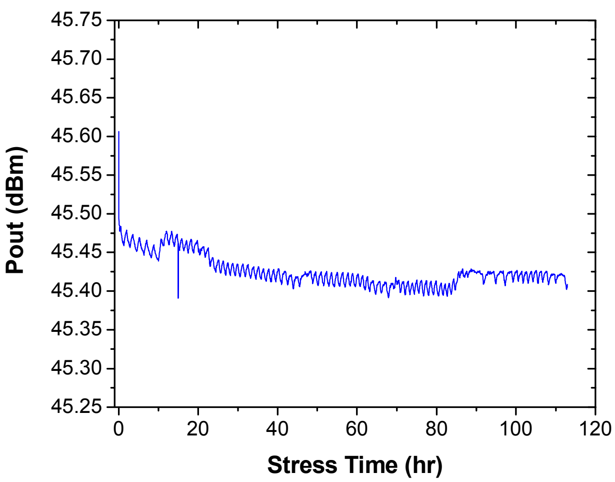

Fig. 10 Change in RF output power versus time for a 36 mm device. Device was initially set at 3 dB compression and a 200º C junction temperature.

VII. CONCLUSION

We have demonstrated GaN-based HFETs on large area silicon substrates with over 150 W of total CW power and 65% drain efficiency. Linearity performance was characterized under WCDMA modulation and revealed 20 W of power and 27% efficiency at an ACPR of -39 dBc. Similar data was shown on over 30 devices from multiple wafers all from a baseline production process. The application of a DPD technique had a significant positive impact upon the GaN device, yielding almost 20 dB linearity improvement and a ten percentage point increase in drain efficiency under multi-carrier WCDMA modulation and is worthy of further investigation. These results show the potential of GaN-on-Si as a manufacturable high power RF platform for both linear and non-linear applications. Moreover, excellent reliability has been demonstrated, including RF stress data showing less than 1 dB power drift over 20 years.

ACKNOWLEDGEMENT

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