

Large-Signal Characteristics of AlGaIn/GaN Power MODFETs

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Abstract—This work addresses the scalability of power performance of AlGaIn/GaN MODFETs with large gate periphery, as necessary for microwave power devices. High-frequency large-signal characteristics of AlGaIn/GaN MODFETs have been studied for devices with gate widths from 0.2 to 1 mm. 1-dB gain compression occurred at input power levels varying from -1 to +10dBm as the gate width increased, while gain remained almost constant at ~17dB. Output power density was maximum (1.3W/mm) for devices with 0.6mm gates and maximum output power (29.9dBm) occurred in devices with 1mm gates, while power-added-efficiency remained almost constant at ~30%.

I. INTRODUCTION

AlGaIn/GaN heterojunction FETs grown by RF-assisted MBE have a high potential for high-power electronics as previously reported by the authors [1]. A record output power density of 3W/mm at 18GHz and 5.3W/mm at 10GHz [2] was recently obtained using AlGaIn/GaN MODFETs. The DC and small-signal high-frequency performance of $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}/\text{GaN}$ MODFETs with gate widths ranging from 200 μm to 800 μm was also recently reported [3] and excellent uniformity of drain current across the wafer and scalability of drain current and transconductance with the gate width was demonstrated. However, there is lack of detailed information on the scalability of power

saturation characteristics for large-gate-periphery power devices. In this work, an automatic load-pull system is employed to obtain and compare the power performance and large-signal impedance of AlGaIn/GaN power MODFETs with gate widths up to 1 mm.

The AlGaIn/GaN layers were grown on sapphire substrates using RF-assisted MBE. The layer growth and fabrication details of 0.25 μm -long gate MODFETs on such layers have been reported elsewhere [4]. Power devices with 2, 4, 6, 8, and 10 100 μm -wide gate fingers (maximum width of 1.0 mm) have been investigated. The thermal effects were reduced by employing 30 μm -thick Au-plated heat sinks. AlGaIn/GaN MODFETs demonstrated typical $I_{\text{DSS}} \approx 500\text{mA}/\text{mm}$ and $g_m \approx 100\text{mS}/\text{mm}$.

II. SMALL-SIGNAL PERFORMANCE

Small-signal S-parameters of AlGaIn/GaN MODFETs with varying gate widths were measured between 0.5 and 25.5GHz. Current-gain cutoff frequency (f_T) and maximum oscillation frequency (f_{MAX}) extrapolated from the S-parameters for different bias conditions are shown in Figure 1. The figure shows that f_T and f_{MAX} were maximum for V_{GS} between -4 and -6V ($V_{\text{DS}}=15\text{V}$). f_T and f_{MAX} slowly increased with drain-source voltage for $V_{\text{DS}} > 5\text{V}$ when V_{GS} was fixed at -5V. f_T was 27GHz for most devices while f_{MAX} varied between 45 and 70GHz.

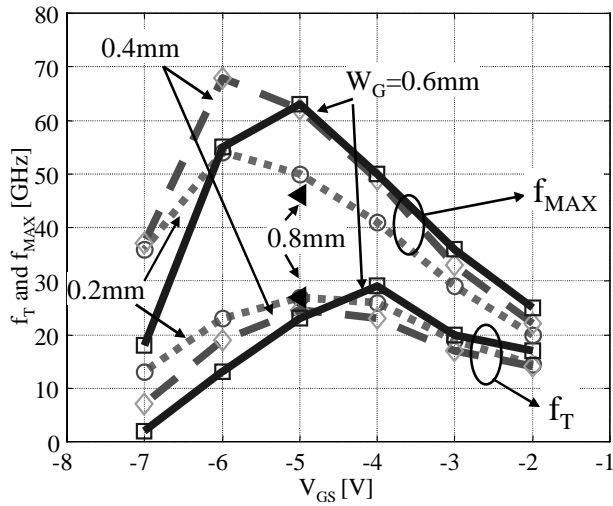


Figure 1. Bias dependence of f_{MAX} and f_T for AlGaN/GaN MODFETs with varying gate widths

Small-signal S-parameters were also used to extract equivalent circuit elements under optimal biasing conditions ($V_{DS}=15V$ and $V_{GS}=-5V$). The small-signal RF transconductance demonstrated notable scaling with the gate width ($G_M \approx 100mS/mm$) and agreed well with the transconductance extracted from DC measurements. It was observed that the output drain-source capacitance C_{DS} , the input gate-source capacitance C_{GS} , and the feedback drain-source capacitance C_{GD} , also scale linearly with the gate width. The values of C_{GD} , C_{GS} , and C_{DS} capacitance are 120fF/mm, 540fF/mm, and 440fF/mm respectively. This good scalability of the devices is very important for circuit design applications.

III. BIAS DEPENDENCE OF LARGE-SIGNAL CHARACTERISTICS

An automatic on-wafer load-pull system with electromechanical tuners has been employed to obtain P_{OUT} - P_{IN} characteristics of GaN-based MODFETs at 8GHz. Both source and load tuners were positioned to obtain best matching and therefore maximum gain at an input power level corresponding to $\sim 1dB$ gain compression. The bias-dependence of output power, power-

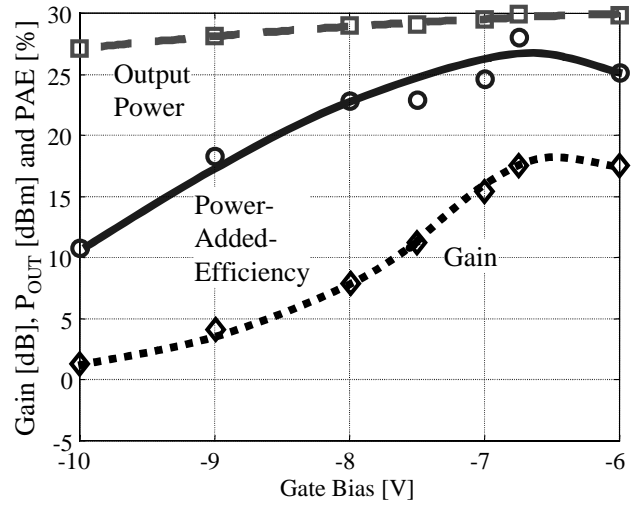


Figure 2. Dependence of output power and power-added-efficiency on gate bias

added-efficiency, and gain was investigated. Devices with 1-mm gate width demonstrated maximum output power (30dBm), PAE (28%), and gain (17.6dB) when the gate bias was set to $-6.75V$ as shown in Figure 2.

Limitations imposed by current handling of the microwave probes and bias tees used in characterization did not allow reducing the gate bias below $-6V$ as this led to drain current in excess of 500mA. Maximum output power and large-signal performance is therefore expected to be higher than described by the results of Figure 2.

The dependence of output power, PAE, and gain of 1-mm gate devices on the drain-bias was also investigated. Maximum PAE (32%) was obtained for drain bias of 15V, while maximum output (30dBm) occurred at 18V. Thermal effects are suggested as a cause for reduced efficiency and output power at drain bias exceeding 18V.

IV. GATE WIDTH DEPENDENCE OF LARGE-SIGNAL CHARACTERISTICS

The dependence of power performance on the gate width was investigated using AlGaN/GaN MODFETs with 2, 4, 6, 8, and 10

100 μ m-wide gate fingers. All devices were first biased for maximum gain at an input power level corresponding to \sim 1dB gain compression and load terminations corresponding to small-signal matching conditions. Then the source and load tuners were adjusted improve matching and maximize the gain.

P_{OUT} - P_{IN} characteristics of devices with different gate widths are shown in Figure 3. Biasing conditions, gain, output power, and power-added-efficiency are listed in Table 1. The largest gain (18.2dB) and power density (1.3W/mm) were obtained for devices with 0.6-mm gate width. The largest output power (29.9dBm) with associated gain of 4dB was obtained for devices with 1-mm gate width.

Table 1. Power Saturation Characteristics of AlGaIn/GaN Power MODFETs

Gate Width [mm]	V_{DS} [V]	V_{GS} [V]	Gain [dB]	P_{IN} -1dB [dBm]	Max P_{OUT} [dBm]	P_{OUT} [W/mm]	PAE -1dB [%]
0.2	15	-4.5	15.9	-0.8	22.5	0.89	30.3
0.4	12	-4.5	17.4	3.2	26.0	1.00	28.9
0.6	15	-5.5	18.3	7.8	28.9	1.31	29.5
0.8	12	-5.0	15.9	10.3	28.5	0.87	31.5
1.0	18	-6.75	17.6	7.3	29.9	0.99	28.1

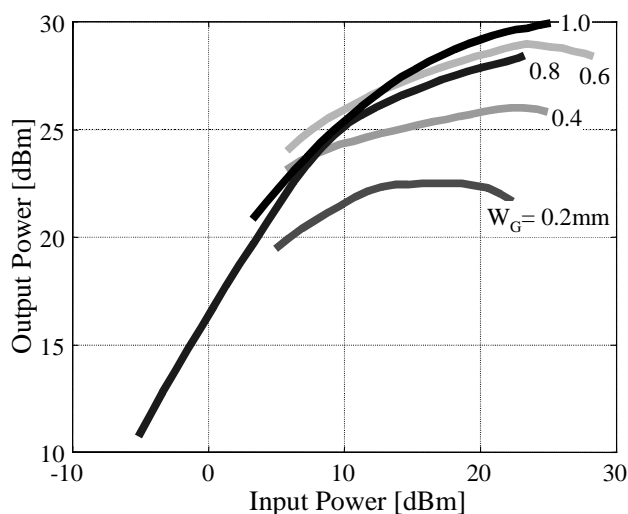


Figure 3. Power saturation characteristics of AlGaIn/GaN MODFETs with varying gate width

Devices with wider gates showed delayed onset of gain compression, as demonstrated by higher input power at 1-dB gain compression P_{IN1dB} for gate widths up to 0.8mm.

When the width is increased from 0.2mm to 0.8mm P_{IN-1dB} is increased from -1 to 10dBm, P_{OUT1dB} is increased from 20 to 25dBm, and P_{OUTMAX} is increased from 23 to 30dBm. The output power density (\sim 1W/mm), power-added-efficiency (\sim 30%) and gain (\sim 17dB) remained in general constant.

P_{IN1dB} and P_{OUT1dB} showed a small decrease in 1-mm devices compared with 0.8-mm MODFETs. This is probably caused by the limitations in current handling described earlier, which did not allow operation of the 1-mm devices at their maximum power capacity.

Constant output power (P_{OUT}) and constant power-added efficiency (PAE) contours of AlGaIn/GaN MODFETs were evaluated using the load-pull system and allowed to obtain loading conditions for maximum output power and efficiency as necessary for circuit design.

The contours of AlGaIn/GaN MODFET with 0.8mm gate under high input power conditions (P_{IN} =22dBm) are shown in Figure 4. The contours were found to remain circular up to power levels corresponding to severe gain compression (\sim 10dB). Moreover, the positions of the optimal loads for maximum P_{OUT} =28dBm and maximum PAE=32% are located close to each other on the Smith Chart. The latter suggests the possibility of power amplifier realization without a considerable tradeoff between output power and power-added-efficiency.

The dependence of the optimal load on the gate width is shown in Figure 5. When the gate width is increased from 0.2 to 1mm, the position of optimal load on the Smith Chart (complex conjugate of the device output impedance) moved along a line corresponding to increased

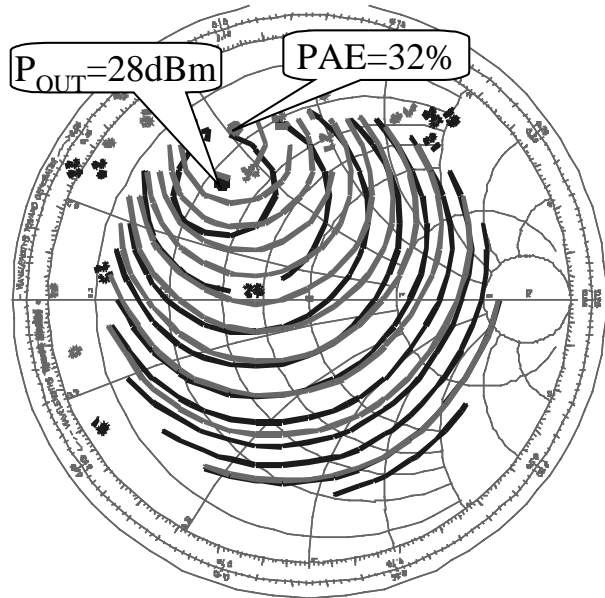


Figure 4. Constant output power (P_{OUT}) and constant power-added efficiency (PAE) contours for GaN MODFET with 0.8mm gate width under $P_{IN}=22\text{dBm}$

output capacitance and decreased output resistance. The large-signal output capacitance was in good agreement with extracted small-signal values, while the large-signal output resistance was significantly reduced under large-signal conditions.

The results illustrate a notable scalability of AlGaIn/GaN MODFET power characteristics and demonstrate their excellent potential for power applications.

V. CONCLUSIONS

Overall, AlGaIn/GaN power-MODFETs with gate widths up to 1mm have been characterized using an automatic load-pull system. High output power (29.9dBm) with high power-added-efficiency (32%) was obtained from discrete devices with 1.0mm gate width. The optimal loads for output power and efficiency were located close to each other as necessary for power amplifier applications. Excellent scalability of small- and large-signal characteristics was observed for devices with

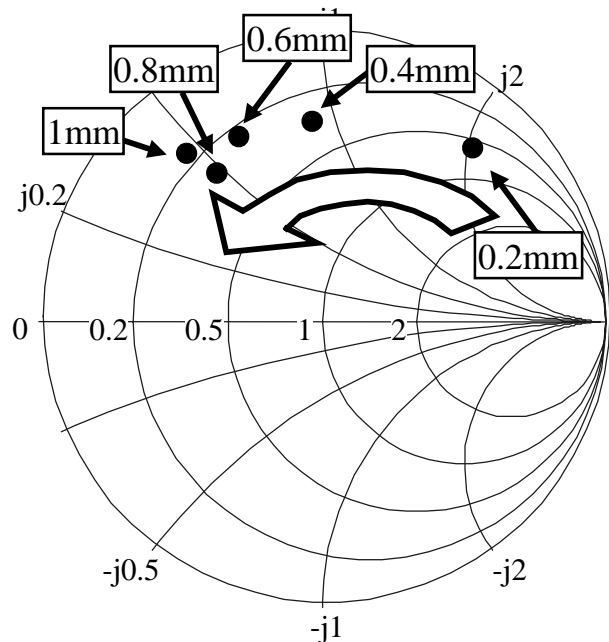


Figure 5. Dependence of position of the matched load tuner on the gate width of GaN MODFETs

gate widths varying from 0.2 to 0.8mm. Very high output power and power-added efficiency were obtained from discrete AlGaIn/GaN MODFETs grown on sapphire indicating the high potential of GaN-based technology for power applications.

ACKNOWLEDGMENTS

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