Experimental Investigation of DC-RF Dispersion in AlGaN/GaN HFET's Using Pulsed I-V and Time-Domain Waveform Measurements

Peter McGovern, Paul J. Tasker,

J. Powell*, K. P. Hilton*, J. L. Glasper*, R. S. Balmer*, T. Martin* M. J. Uren*

Cardiff School of Engineering, Cardiff University, Cardiff, UK. E-Mail: McGovernP@cf.ac.uk *QinetiQ Ltd, Malvern, Worcestershire, UK, WR14 3PS

Keywords*:* GaN, HEMT, HFET, DC-RF dispersion, current slump.

Abstract

AlGaN/GaN HFET's have been analyzed under DC and RF Stimulus in an attempt to analyze the phenomenon of DC-RF dispersion. DC pulsed I-V measurements were performed where the pulse "off" state was set to different bias points, to simulate a class A bias condition at various drain voltages. RF time-domain waveform measurements were also performed. The I-V measurements exhibited the common problem of current slump, as did the RF power performance of the device. Interestingly, it was found that there was strong correlation between the pulsed I-V and RF measurements when they are considered as a function of bias point. Although current slump is evident during pulsed I-V measurements, it is not permanent, and there is negligible degradation of the device after prolonged RF stimulus.

INTRODUCTION

In recent years GaN HFET technology has established itself as a long-term contender to other materials for use in power amplifier design. This is due to GaN's properties of high breakdown electric fields, high electron mobility and velocity, and the large bandgap of the epitaxially grown hetrojunction technology [1]. This means that GaN devices have large breakdown voltages, high cut-off frequency and large power handling capability of up to 30W/mm [2].

One of the main problems that remains with AlGaN/GaN devices is current slump. This is the reduction in drain current that is caused by trapping at the exposed gate-drain region of the device [3-5]. Silicon nitride passivation greatly reduces current slump, by removing the net surface charges. Other methods used to reduce trapping effects and hence current slump are the addition of a p-GaN cap layer [6], and the addition of field plates on the gate-drain region [2].

This phenomenon is also referred to as DC-RF dispersion or knee-walkout, and results in a discrepancy between the measured RF output power of the devices and the power that would be predicted from DC I-V characterization, according to the equation $P_{out} = (\Delta I \times \Delta V)/8$, where ΔI and ΔV are the RF current swing and voltage swing .

In this paper pulsed DC I-V and RF time domain waveform measurements are presented to analyze the problem of DC-RF dispersion.

The device under test is a 2x100µm AlGaN/GaN HFET on a SiC substrate. It has a gate length of 0.8µm, with a field plate overlapping the gate by 0.5µm [2], and source-drain gap of 4µm. The HFET layer structure is grown by MOVPE and consists of 30nm AlGaN (25%), and 1.2µm insulating GaN on vanadium doped SiC, with no intentional doping included in the structure. Silicon nitride passivation has been used to reduce current slump.

MEASUREMENTS

Pulsed I-V measurements were performed on the device, where the "off" state was set to different bias points, to simulate the bias conditions of a class A amplifier. Fig. 1 shows the pulsed I-V's when pulsed from V_D=0V/V_G=0V, and also when pulsed from V_D =40V/V_G =-3V. These results clearly show the effects of current slump in the device, as is well documented.

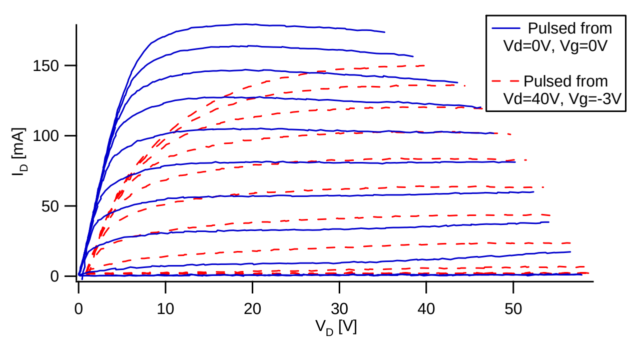

Fig. 1. Pulsed DC I-V measurements. V_G ranges from -8V → +2V in 1V steps

In order to analyze DC-RF dispersion, CW measurements were performed on the device using a vector-corrected on-wafer time domain measurement system, similar to that demonstrated in [7-8]. This system measures the input and output voltage and current time-domain waveforms.

In this case we are interested in plotting the RF dynamic load-line of the device (RF output current vs. RF output voltage). Fig.2 shows how the RF signal interacts with the knee region of the device when biased at different drain voltages.

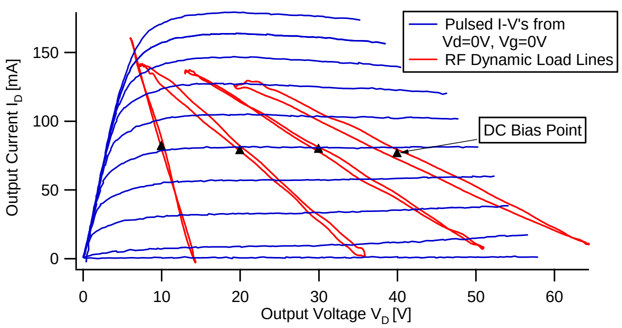

Fig. 2. RF dynamic load-lines at different drain voltage bias points.

The measurements are performed at 840MHz and the device is biased in class A (V_G=-3V), at different drain voltages. In order to penetrate the knee region at all times, the device is load-pulled into real impedances using an active harmonic load-pull system [8]. This system allows complete control of the impedances presented to the first three harmonics, which is important since all three harmonics must be presented with the same impedance in order to keep the RF dynamic load-lines straight. The compressed output current waveforms in Fig. 3 confirm that the device is in saturation.

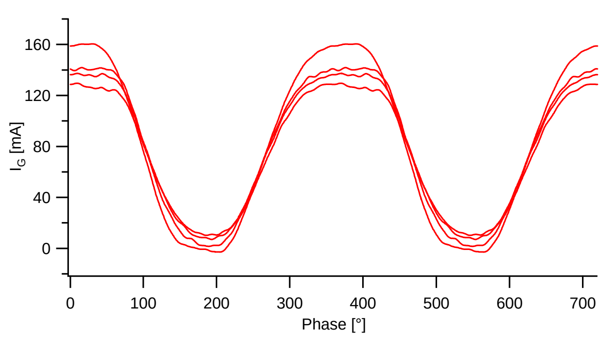

Fig. 3. Time-domain RF output current waveforms corresponding to the measurements shown in fig. 2

The RF dynamic load-lines clearly display DC-RF dispersion, and show that the RF knee-walkout increases with drain voltage bias. This is consistent with other work, and explains why GaN devices do not produce as much output power as might be expected.

During these measurements, the observed maximum RF input gate voltage is approximately 2V. Therefore, the RF dynamic load-lines should be consistent with that produced by the pulsed I-V measurement corresponding to V_G=+2V, which in this case is the top I-V trace. This is clearly not the case for the I-V in Fig.2, where the traces are pulsed from the "off" state V_G=0V/V_D=0V.

However, when the RF dynamic load-lines are superimposed on pulsed I-V plots which are pulsed from the same quiescent bias point as the RF measurement, the plots do correspond. i.e. the bias conditions for the four RF measurements are; V_G=-3V/V_D=10V, V_G=-3V/V_D=20V, V_G=-3V/V_D=30V, V_G=-3V/V_D=40V. These are also the points that the pulsed I-V's return to in the "off" state. This is shown in Fig. 4

It was also found that the device produced a maximum output power of 5.5W/mm, and experienced negligible degradation after prolonged DC and RF testing.

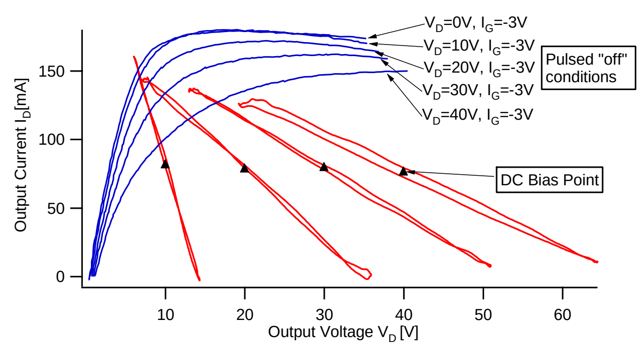

Fig. 4. RF dynamic load-lines superimposed on pulsed DC I-V's pulsed from the same bias points.

CONCLUSION

These results show that in class A operation, there is a strong correlation between the current slump observed in pulsed I-V measurements and that observed in the RF waveform measurements. This implies that the DC-RF dispersion in AlGaN/GaN devices may be dependant on the quiescent DC bias point and that there is a direct relationship between the two. This holds for operation in class A.

This result may be expected in class A operation, since the average RF voltage and current should be the same as the quiescent DC bias.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and support of QinetiQ Ltd, whose work is supported by the EMRS Defense Technology Centre, and the EUT Domain of the UK Ministry of Defense

REFERENCES

[1] Bruce M. Green et al., “High-Power Broad-Band AlGaN/GaN HEMT MMICs on SiC Substrates”, *IEEE Trans. Microwave Theory & Tech.*, vol. 49, Dec. 2001, pp. 2486-2493

[2] Y.F. Wu et al., “30W/mm GaN HEMTs by Field Plate Optimization”, *IEEE Electron Device Letters, Vol.25, no.3, March 2004.*

[3] B. M. Green, K. K. Chu, E. M. Chumbes, J. A. Smart, J. R. Shealy, and L. F. Eastman, “The Effects ofSurface Passivation on the Microwave Characteristics of Undoped AlGaN/GaN HFETs,” *IEEE Trans. Electron Devices*, vol. 48, pp. 560-566, Mar. 2001

[4] Ramakrishna Vetury, Naiqain Q. Zhang, Stacia Keller, Umesh K. Mishra, “The Impact of Surface States on the DC and RF Characteristics of AlGaN/GaN HFETs,” *IEEE Trans. Electron Devices*, vol. 48, no. 3, Mar. 2001

[5] A. M. Wells, M. J. Uren, R. S. Balmer, K. P. Hilton, T. Martin, M. Missous, “Direct Demonstration of the ‘Virtual Gate’ Mechanism for Current Collapse in AlGaN.GaN HFETs,” Sol. St. Elec., vol. 49, pp. 279-282, 2005

[6] L. Sheen, R. Coffie, D. Buttari, S. Heikman, A. Chakraborty, A. Chini, S. Keller, S. P. Denbaars, U. K. Mishra, “High Power Polarization-Engineered GaN/AlGaN/GaN HEMTs Without Surface Passivation”, *IEEE Electron Device Letters, Vol.25, no.1, January 2004.*

[7] P. J. Tasker et al, “A Vector Corrected High Power On-Wafer Measurement System with a Frequency Range for the Higher Harmonics up to 40GHz” *Proc. 24th European Microwave Conference*, 1994, pp.1367-1372.

[8] J. Benedikt, R. Gaddi, P.J. Tasker, “High-Power Time Domain Measurement System with Active Harmonic Load-Pull for High-Efficiency Base-Station Amplifier Design” *IEEE Trans. Microwave Theory & Tech.*, vol. 48, Dec. 2000, pp. 2617-2624.