Over 80% Drain Efficiency CW AlGaN/GaN HEMT Power Amplifier

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Abstract

Due to its superior material properties, AlGaN/GaN HEMT power amplifiers offer excellent capabilities, such as high efficiency, ease of matching and broad bandwidth. In this paper we report our initial development of AlGaN/GaN HEMT on GaN/SiC epi-materials. The 10mm gate-periphery device showed 40W CW output at 1.75 GHz, 12.6db liner gain and over 80% drain efficiency with a drain bias of 28V.

Introduction

The superior material properties of AlGaN/GaN HEMT structures, such as wide band gap, high breakdown electric field, high 2DEG carrier density and mobility, make it most attractive materials for high power electronics. The high breakdown electric field allows AlGaN/GaN HEMT to operate at high drain voltage, whereas the high 2DEG carrier density and mobility offering large current density. The high operating voltage and large current density offers a superior capability of high power density and high efficiency, which reduces the actual chip size. Therefore, the chip-level impedance is higher, bettering off the impedance matching. Due to those excellent capabilities, AlGaN/GaN HEMTs are of high commercial and defense interest for microwave amplifier applications, especially in the wide bandwidth arena [1-3].

The performance of AlGaN/GaN HEMTs, however, is heavily limited by electron trapping and the resulted current dispersion between DC and RF characteristics. Although SiN passivation has been successfully employed to alleviate this trapping problem, charge trapping can still be an issue due to the high electric fields existing in the HEMT structures, especially near the Gate-to-Drain edge area. Gate-connected field plates were successfully utilized to improve their operating characteristics [4].

In this work we report our initial development of high performance AlGaN/GaN HEMTs on SiC substrates as a function of device design, and fabrication process in Power Hybrids Operation section of Tyco Electronics. A field-plate connected to source and extending to the center of the gate-drain region was adopted to reduce the peak electric field in the gate-drain region so that the DC-RF dispersions could be suppressed efficiently.

Experiments

The AlGaN/GaN HEMT wafers were grown on 3” c-plane semi-insulating 6H-SiC substrates by MOCVD. The epi structure consisted of an AlN nucleation layer, GaN buffer, AlGaN Schottky layer and GaN cap. The device fabrication was a standard process, including Ti/Al/Ni/Au multilayer Ohmic metal deposition plus 850°C RTA annealing, device isolation by using N implantation, Ni/Au gate metal by using E-beam evaporation and lift-off process, SiN PECVD deposition, overlay metal deposition and SiN passivation.

All devices in this study have a gate length of 1μm and unit gate width of 200 μm. The wafer was thinned down to 6 mils before back metal deposition. The dies were packaged using Au-Ge eutectic die attach in industry standard CuW RF packages without internal matching.

Our initial development work produced a 40W CW AlGaN/GaN HEMT power amplifier. The 10mm gate-periphery AlGaN/GaN HEMT showed excellent performance, where a CW output power over 40W at 1.75 GHz, a liner gain of 12.6db and over 80% drain efficiency were achieved with a drain bias of 28V.

Results and Discussions

Fig. 1 show I-V characteristics of a 3mm gate-periphery device, exhibiting an Idsat ~ 1.8A and a pinch-off voltage Vp ~ -3.5V. The 80µs short pulse sweep is also shown in Fig. 1. There were no obvious DC-RF dispersions observed, likely due to good epi-materials, SiN passivation and the adoption of source field-plate. The I-V curves of a 10mm gate-periphery devices exhibited an Idsat ~ 4.6A and a pinch-off voltage ~ -3.5V. The G-D Schottky turn-on curve show a sharp turn-on characteristic and a turn-on voltage of 1V observed.

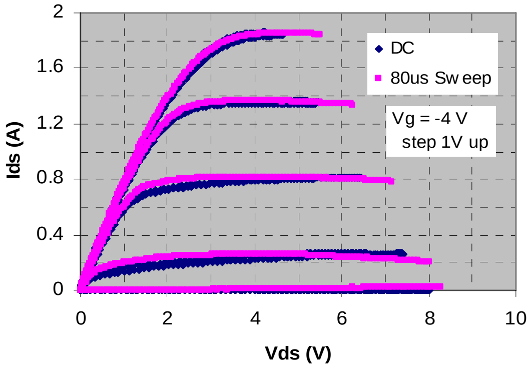

Fig. 1 I-V characteristics of a 3mm gate-periphery device

The breakdown voltages of both two-terminal D-G and three-terminal (Vgs= -8V to completely pinch-off the channel) are shown in Fig. 2 for the 10mm gate-periphery device with a D-G space of 3 µm. The leakage currents for both of them were less than 0.25mA/mm at 100V drain bias. The knee point of the breakdown voltage was near 100V.

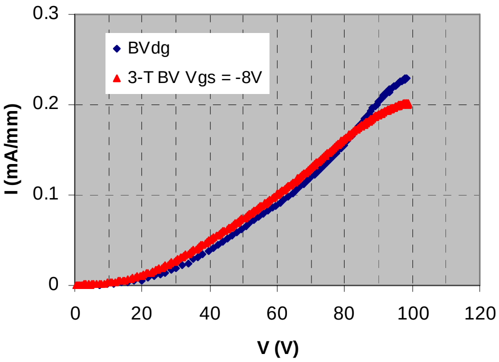

Fig. 2 Breakdown voltages of both two-terminal and three-terminal for the 10mm device with 3µm D-G spacing

To explore the effects of D-G spacing on the breakdown voltage, a series of 10mm devices were fabricated with D-G spacing of 3, 5, 7 and 9 µm, respectively. With increasing D-G spacing, the breakdown voltage was increased as expected. As shown in Fig. 3, the leakage current for the device with 9µm D-G spacing was 0.32mA/mm at a drain bias of 320V, a merit of GaN materials.

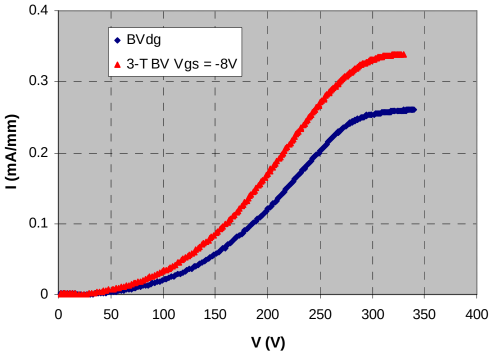

Fig. 3 Breakdown voltages of both two-terminal and three-terminal for the 10mm device with 9µm D-G spacing

Fig. 4 show the I-V curves of those 10mm gate-periphery devices. The Idss was decreased with increasing D-G spacing as a result of the increased Rdson, as shown in

Fig.5. Since the available RF output of the AlGaN/GaN HEMT is proportional to its breakdown voltage and inversely to Rdson, there is a trade-off to choose the optimum D-G spacing.

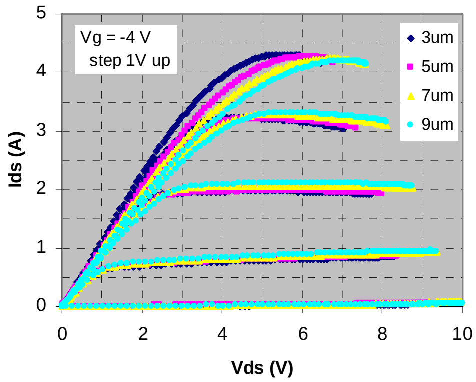

Fig. 4 I-V curves of 10mm gate-periphery devices.

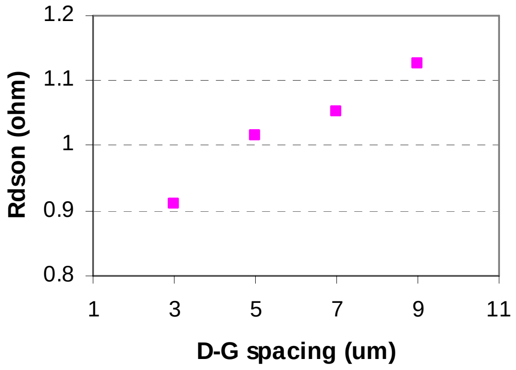

Fig. 5 Rdson as a function of D-G spacing

Fig. 6 shows the output power as a function of drain bias at 1.75GHz for those devices. The RF powers were very similar for the devices with 3 and 5µm D-G spacing, but much lower for 7 and 9µm spacing devices, likely due to the detrimental effect of high Rdson. These results indicate that 3 to 5µm D-G spacing is a good window for the layout design.

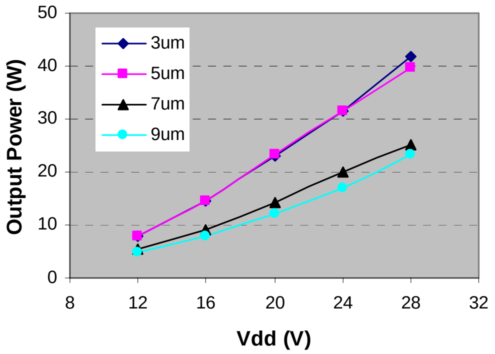

Fig. 6 CW RF output power as a function of drain bias at 1.75 GHz for various D-G Spacing

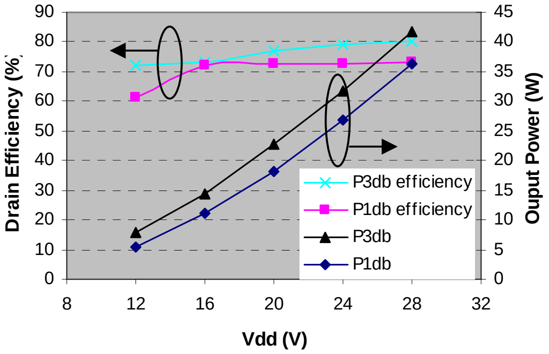

Fig. 7 CW RF results of a 10mm gate-periphery device with 3µm D-G spacing at 1.75GHz.

Fig. 7 show CW RF results of a 10mm device with 3µm D-G spacing at 1.75GHz. With increasing the drain bias from 12 to 28V, the P1db power was up from 5 to 36W. The P3db power was 42W at 28V drain bias with a drain efficiency of 80%.

Conclusions

Those encouraging results during our initial development work indicate the AlGaN/GaN HEMT is a very good candidate for the high-efficiency power amplifier applications. The results of on-going work on the optimization of the fabrication process and layout design, and initial reliability testing will be reported later.

Acknowledgement

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Acronyms

GaN: Gallium Nitride
AlGaN: Aluminum Gallium Nitride
SiC: Silicon Carbide
HEMT: High Electron mobility Transistor
MOCVD: Metal Organic Chemical Vapor Deposition
PECVD: Plasma Enhanced Chemical Vapor Deposition
I-V: Current-Voltage
CW: Continuous Wave