Performance of AlGaN/GaN HEMTs for 2.8 GHz and 10 GHz Power Amplifier Applications

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***Abstract* — AlGaN/GaN high electron mobility transistors (HEMTs) have demonstrated great potential for microwave power transmitter applications as required by phased array radar and wireless base stations. In this paper, we report on state-of-the-art power density generated from large gate periphery AlGaN/GaN HEMTs. At 2.8 GHz, 7 W/mm gate periphery (14.7 W total) was obtained under pulsed conditions from 2.1 mm gate periphery devices and 5W/mm (42 W total) pulsed power was demonstrated from 2×4.2 mm gate periphery devices. At 10 GHz, 9.2 W/mm (13.8 W total) power was obtained under pulsed conditions from 1.5 mm gate periphery devices with drain bias up to 55 V. The 4×4.2 mm (16.8 mm) multiple-die hydride power amplifiers at 2.8 GHz and 4×1.5 mm (6 mm) multiple-die package at 10 GHz were also evaluated.**

I. Introduction

AlGaN/GaN HEMTs has been viewed as highly promising for microwave power generation from S band up to Ka band [1-4]. The power density demonstrated by AlGaN/GaN HEMTs is ten times greater than that of its GaAs counterpart. Up to 12 W/mm pulsed power has been demonstrated from a 250 μm device at 3.5 GHz [5]. 11 W/mm has also been demonstrated at 10 GHz from a 150 μm device [6, 7]. However, these impressive power densities were achieved only from small gate periphery devices. For practical applications, large gate periphery devices must be used to generate sufficient total output power levels. With the increase of device gate periphery, the self-heating effect and the defect trapping effect will both be more profound [8]. In this paper, we report on the state-of-the-art power density achieved from large gate periphery AlGaN/GaN HEMTs. Multiple-die packages with internal matching circuits were also evaluated.

II. DEVICE RESULTS: DC

AlGaN/GaN HEMT structure was grown by metalorganic chemical vapor deposition. The layer structure is shown in Figure 1. 4H-SiC (0001) semi-insulating substrates were employed, followed by AlGaN nucleation layer to accommodate the lattice mismatch between GaN and SiC. An undoped GaN buffer layer was deposited, followed by an AlGaN (30% Al) barrier layer. 2-dimensional electron gas (2DEG) is created by AlGaN/GaN heterostructure in GaN side due to the strong piezoelectric polarization and spontaneous polarization. The 2DEG density achieved can be up to $1.5\times10^{13}cm^{-2}$, which is an order of magnitude higher than that of 2DEG from AlGaAs/GaAs heterostructures.

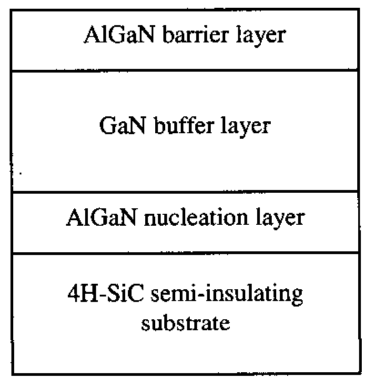

Fig. 1. Schematic of AlGaN/GaN HEMT layer structure.

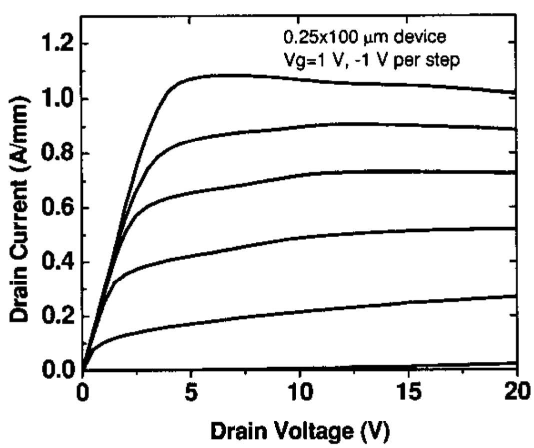

Fig. 2. Typical current-voltage characteristics of 100 μm gate periphery AlGaN/GaN HEMTs.

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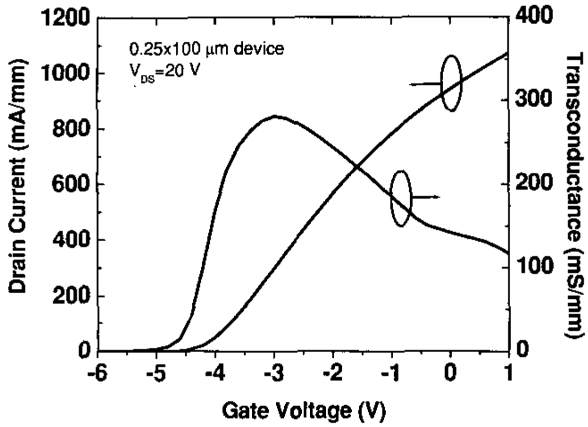

Fig. 3. Transfer characteristics of 100 μm AlGaN/GaN HEMTs.

The typical current-voltage characteristic of a 100 μm AlGaN/GaN HEMT is shown in Figure 2. The gate length was 0.25 μm. The device exhibited full channel current of more than 1000 mA/mm and knee voltage of 4 V. The maximum transconductance was 285 mS/mm obtained at – 3 V gate bias, as shown in Figure 3.

III. DEVICE RESULTS: 2.8 GHZ

AlGaN/GaN HEMTs are excellent candidates for S band applications. Compared to SiC MESFETs, AlGaN/GaN HEMTs exhibit much higher full channel current and comparable breakdown voltage.

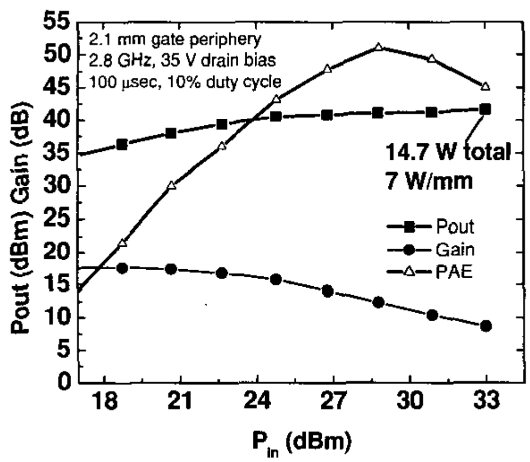

Fig. 4. Large signal characteristics of 2.1 mm AlGaN/GaN HEMTs at 2.8 GHz and 35 V drain bias.

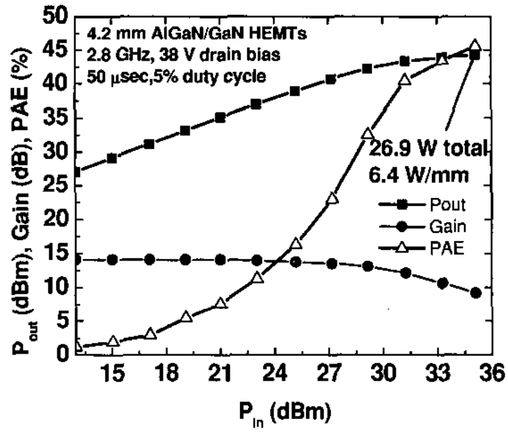

Fig. 5. Large signal characteristics of 4.2 mm AlGaN/GaN HEMTs at 2.8 GHz and 38 V drain bias.

Figure 4 shows a 2.1 mm gate periphery device tested at 2.8 GHz under pulsed conditions. The pulse width was 100 μsec with 10% duty cycle. The device was operated at Class AB toward Class A and exhibited 7 W/mm power density (14.7 W total power) at 35 V drain bias. The associated PAE exceeded 45 %.

A 4.2 mm gate periphery device tested at 2.8 GHz under the pulsed conditions is shown in Figure 5. The 50 μsec pulse width and 5% duty cycle were used. The device generated 26.9 W (6.4 W/mm) total output power with associated PAE of 45 % at 38 V drain bias. There were no matching circuits used for this device.

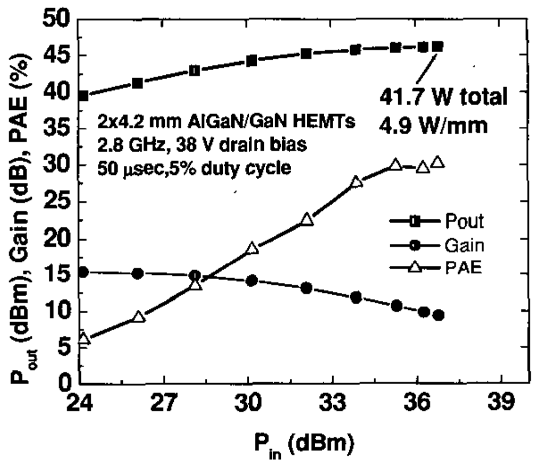

Fig. 6. Large signal characteristics of combined 2×4.2 mm (8.4 mm) AlGaN/GaN HEMTs at 2.8 GHz and 38 V drain bias.

To further boost the total power, combined 2×4.2 mm (8.4 mm) packaged devices were tested at 2.8 GHz under the pulsed conditions, as shown in Figure 6. The package demonstrated 41.7 W (4.9 W/mm) total output power with associated PAE of 30 % for 38 V drain bias. There were no internal matching circuits used. The device performance would improve if the matching circuits were used for better impedance matching.

IIII. DEVICE RESULTS: 10 GHZ

The 2DEG in GaN close to AlGaN/GaN interface offers very high carrier density of more than 1.5×10^{13} cm^{-2}. This property has made GaN/GaN HEMTs exhibit excellent frequency response. Compared to SiC MESFETs, AlGaN/GaN HEMTs have showed much greater potential for 10 GHz high power applications.

Fig. 7 shows the large signal performance of 400 µm AlGaN/GaN HEMTs at 10 GHz. The device demonstrated 6.7 W/mm power density (2.68 W total power) under CW conditions. The associated PAE was 57% and gain was 10 dB. This power density is almost one order of magnitude higher than that of GaAs MESFETs. The test was performed on-wafer without active chuck cooling. Three-dimensional thermal simulations indicated a maximum junction temperature of 84 °C for the above operation conditions.

The large gate periphery devices were diced from 2" wafer and mounted into a conventional package with AuMo (1 µm), MoCu (20 µm) and Cu heat conducting layers. Figure 8 shows the large signal characteristics of a 1.5 mm gate periphery device at 10 GHz under pulsed conditions. The pulse width was 50 µsec with 5% duty cycle. The test was performed at room temperature without active cooling on the package. The device exhibited 9.2 W/mm power density (13.8 W total power). To our best knowledge, this is the highest power density achieved, for similar size devices, from any semiconductor technology. The associated PAE was 31 %. The device was biased at up to 55 V drain bias. Based on 3-dimensional thermal simulations, the maximum junction temperature was approximately 170 °C.

Figure 9 shows the 1.5 mm device power density and associated maxmimum junction temperature as a function of applied drain bias during the large signal power sweep. The power density increased from 5.7 W/mm at 25 V drain bias to 9.2 W/mm at 55V drain bias. The associated junction temperature increased from 90 °C at 25 V drain bias to 170 °C at 55 V drain bias. The power density was eventually limited by the device self-heating effect, which is evidenced by the fall-off of power density beyond 50 V drain bias.

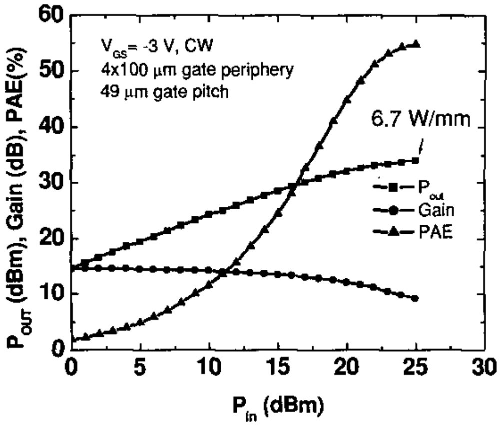

Fig. 7. Large signal characteristics of 400 µm AlGaN/GaN device tested at 10 GHz and 30 V drain bias under CW conditions.

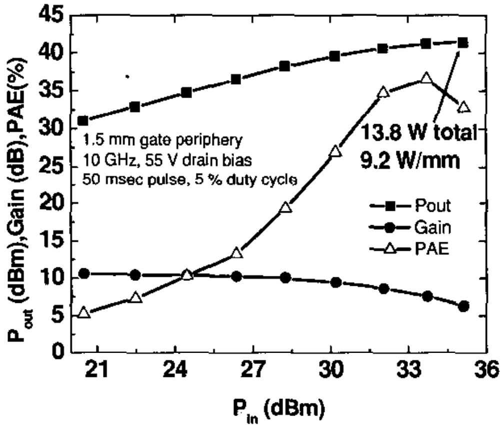

Fig. 8. Large signal characteristics of 1.5 mm AlGaN/GaN HEMTs at 10 GHz and 55 V drain bias under pulsed conditions.

IV. HYBRIDE POWER AMPLIFIERS

The multiple-die packages with internal matching networks have also been evaluated at both 2.8 GHz and 10 GHz. At 2.8 GHz, 4×4.2 mm (16.8 mm) AlGaN/GaN HEMTs were integrated into one package with L-C-L matching circuits. At 10 GHz, 4×1.5 mm (6.0 mm) AlGaN/GaN HEMTs were also packaged with appropriate L-C-L matching circuits. These multiple-die packages are under test now and the results will be included in the final submission.

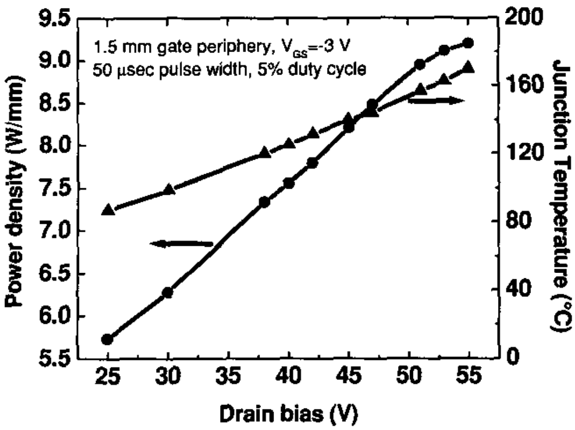

Fig. 9. Power density and maximum junction temperature as a function of drain bias.

V. Conclusion

AlGaN/GaN HEMTs have demonstrated superior power density and total output power generation. The large gate periphery devices have exhibited the highest power density among all semiconductor device technologies for similar device dimensions. Although the long-term reliability must be proven before this technology can be used in the real applications, AlGaN/GaN HEMTs have established themselves as a very attractive candidate for next generation high power amplifier designs.

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