An Over 100 W CW Output Power Amplifier Using AlGaN/GaN HEMTs

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Abstract

We describe high power 150 W CW output power 36-mm gate-periphery AlGaN/GaN HEMTs on a SiC substrate with a power added efficiency (PAE) of 54% operated at 63 V drain bias voltage (Vds). Vds dependence of third order-intermodulation (IM3) was also characterized at Vds up to 50 V. Preliminary reliability was characterized using a RF power stress test. A CW P_{3dB} RF-power measurement at Vds of 60 V exhibited good reliability for 1000 h.

INTRODUCTION

AlGaN/GaN-based high electron mobility transistors (HEMTs) are promising for microwave power applications, including wireless base stations. There are many reports related to high output power characteristics [1-2]. However, not many papers exhibited high efficiency characteristics using a large gate-periphery device operated at over 40 V drain bias voltage. Base station system demands high efficiency from amplifier, requiring low quiescent bias current. In this paper, we demonstrate high power performance near class-B operation. To obtain higher RF-power and efficiency, we have to suppress frequency dependent instabilities, such as large transconductance (gm) dispersion, gate-lag and current collapse. We controlled the polarization-induced surface charge by n-type doping in a thin GaN cap on AlGaN and stabilized n-GaN-surface between electrodes using SiN [3]. A 150 W CW saturation power was achieved at a 63 V operation with a PAE of 54% and a linear gain of 12.9 dB [4].

In addition, a low distortion characteristic near class-B operation is required for the base stations using digitally modulation scheme such as IMT-2000. The crest factor of a peak to average power ratio is as high as 8 dB. Therefore, it is important to consider the distortion at an average power level 8 dB back-off from saturation level. Thus, in addition to the high saturation power (Psat), high efficiency and low distortion at 8-10 dB backed-off power level from Psat is required. Moreover, pre-distortion systems can better predict the pre-distorted input signal if the device presents a simple monotonic IMD profile without sweet spots. We obtained a superior linearity profile for a 1mm-gate periphery AlGaN/GaN HEMT [5] biased at 30 V. We also studied distortion characteristics for larger gate-peripheries.

Reliability has become an important issue to be discussed in the manufacturing of AlGaN/GaN-HEMTs. For this purpose, we submitted the device to RF stress to investigate stability of HEMT performance under continuous power operation. A CW P_{3dB} RF-power measured at 60V drain bias exhibited good reliability for 1000 h.

DEVICE TECHNOLOGY

To suppress instabilities related to frequency dispersion, such as large-signal current collapse and gm dispersion, we introduced an n-type doped GaN cap layer into the AlGaN/GaN HEMTs structure to control the polarization-induced surface charges [3]. Figure 1 shows the device structure on SiC substrates investigated in this study. Detailed fabrication method was described in the previous papers [3-6].

Recessed ohmic technology was introduced to obtain lower ohmic contact resistance [7]. Only n-type doped GaN cap layer was removed. Figure 2 shows etching depth

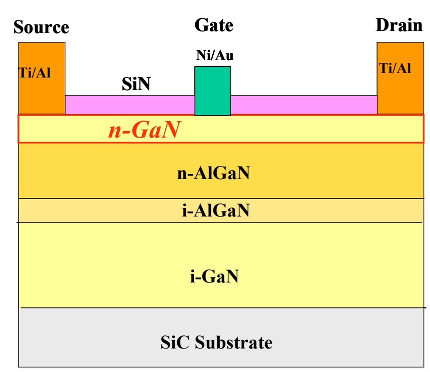

Fig.1. Schematic drawing of investigated the surface-charge-controlled n-GaN-cap structures. Thin n-type GaN cap layer was grown on AlGaN/GaN structure. SiN passivation was formed on GaN cap layer between electrodes.

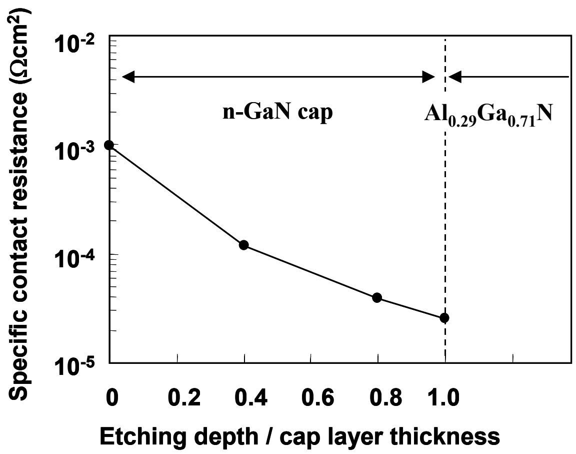

Fig. 2 Etching depth dependence of specific contact resistance.

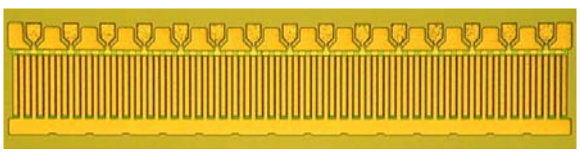

Fig. 3. Photograph of AlGaN/GaN HEMT chip.
The total gate width is 36 mm with a unit gate width of 400 µm.

dependence on specific contact resistance. The Al content in the AlGaN layer was 29 %. Specific contact resistance decreased from 9.80 x 10^{-4} Ωcm^2 for conventional structure to 2.56 x 10^{-5} Ωcm^2. These results mean that removing n-GaN cap layer enhanced tunneling transport of electrons.

The current-collapse-free AlGaN/GaN HEMT die was mounted on a conventional metal/ceramic package. The gate periphery is 36 mm with a unit gate width of 400 mm, as shown in Fig. 3. A single-chip amplifier was designed for W–CDMA base station applications with a frequency of 2.1 GHz. Quiescent drain current (Idsq) is 1.4% Ifmax near class B, which is mainly used in base station system [6]. We measured all performance using a packaged chip on a test-fixture, which was tuned at 30 V drain bias voltage. When we changed the drain voltage, the matching conditions remained the same.

RESULTS AND DISCUSSION

1) DC & RF Characteristics: Figure 4 shows I-V characteristics. Good pinched-off characteristics were obtained. On-state and off-state breakdown voltages were over 100 V and 160 V respectively. Figure 5 shows pulsed I-V characteristics. Power operation was obtained with device biased at 50V in class B. Pulsed mode on-resistance (Ron) did not increase compared with DC-mode, indicating that

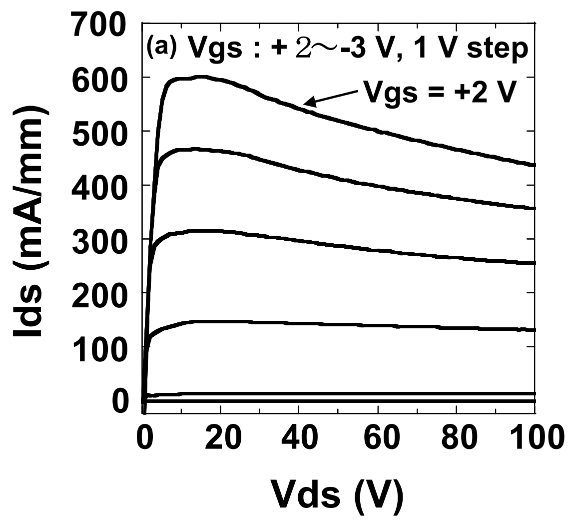

Fig. 4. I-V characteristics of 40-µm gate periphery. 100 V operations were studied using (a) a semiconductor parameter analyzer and (b) a 100-Hz curve tracer.

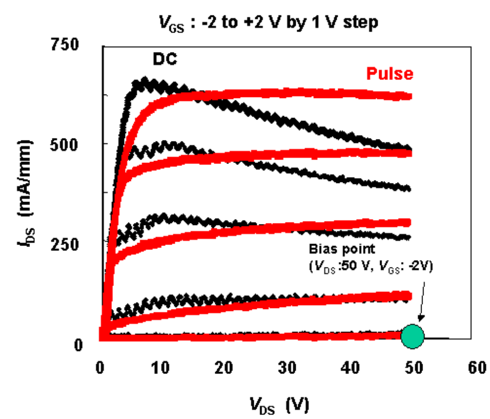

Fig. 5. Pulsed I-V characteristics. Bias point was Vds of 50 V and Vgs of –2 V. Pulse period and pulse duration are 1 ms and 1us, respectively.

current collapse can be suppressed with our proposed device structure.

2) Power performance: Figure 6 shows power performance measured at Vds equal to 63 V. A state-of-the-art 150 W CW saturation power was achieved with a PAE of 54% and a linear gain of 12.9 dB. Figure 7 shows the drain supply voltage dependence of the power amplifier performance. The PAE decline is drastically improved due to the current-collapse-free operation. We also obtained the record saturated peak power of 174 W in practical 4-carrier W-CDMA modulation scheme [6].

3) Distortion characteristics: We reported previously [4] that superior linearity can be obtained at Vds equal to 30 V for a 1mm-gate periphery AlGaN/GaN HEMT. In this paper, a larger gate periphery is investigated and the intermodulation results are in Figure 8. Tone spacing is 1 MHz. A simple IM_3 profile could also be obtained for a large gate-periphery device at Vds equal to 24V. However, at 50V, IM_3 profile had sweet spot feature [5]. We performed the measurement with the same matching circuit as 24V, so the tuning condition was not optimized for 50V operation. We believe optimized tuning for 50V gives a simple IM_3 profile as good as 24V. Figure 9 shows the difference of upper sideband IM3 and lower sideband IM3. This memory effect is important for digital pre-distortion system in IMT-2000 [4]. As shown in Fig. 9, the difference of upper IM3 and lower IM3 is quite small for a wide range of output power for 50V operation.

4) Reliability: We investigated reliability performance, a very important issue at high drain bias operation. The RF-stress test was examined under P_{3dB} conditions at Vds between 30-60 V as shown in Fig. 10. To accelerate the aging test, Idsq was set at 15 mA/mm. In the previous reports, Pout and Gain decreased almost 0.2 dBm within one hour, when operated at 30-40 V [8]. Now, with our newly improved collapse-free AlGaN/GaN HEMTs operated at 60 V, showed no degradation of power and gain for 1000 h. This is the first report of stable operation at 60 V.

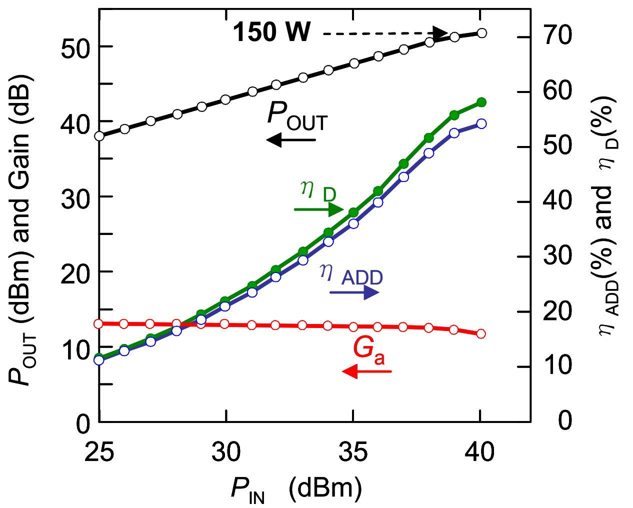

Fig. 6. CW power measurement results of single-chip AlGaN/GaN HEMT amplifier at 2.1 GHz. Quiescent drain current is 500 mA at V_{DS}=63 V.

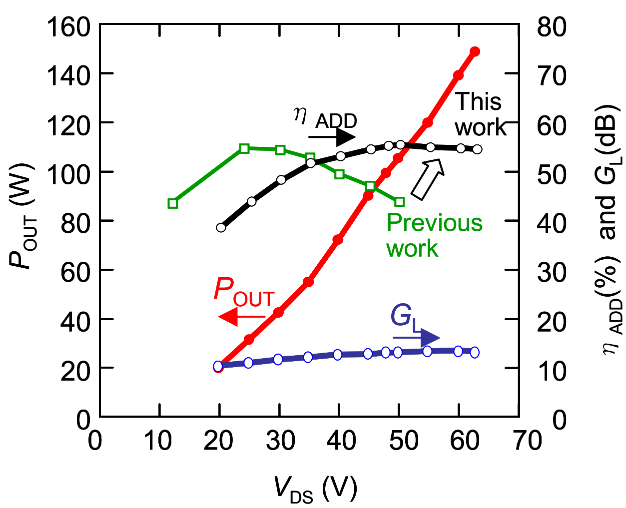

Fig. 7. Drain supply voltage dependence of output power POUT , Gain GL and power-added efficiency PAE of AlGaN/GaN HEMT amplifier at 2.1 GHz.

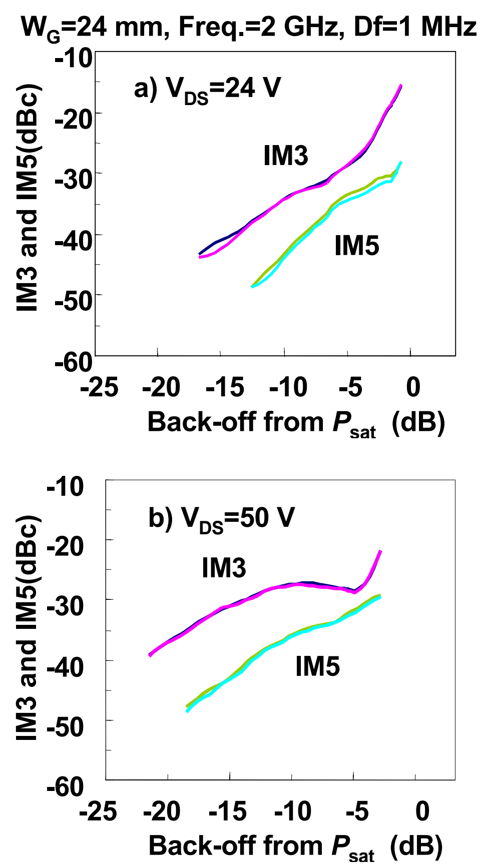

Fig. 8. 2-tone intermodulation characteristics measured at a) 24 V and b) 50 V. Measured frequency is 2.2 GHz. Idsq is 1.4% Ifmax near class-B. Gate width is 24 mm. Tone spacing is 1 MHz. Both upper and lower distortions are shown in this figure.

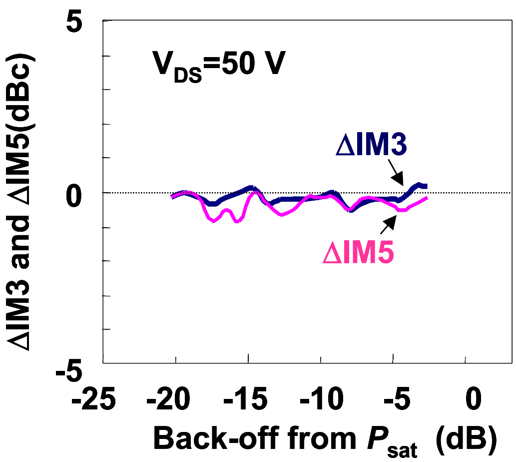

Fig. 9. Memory effect of GaN-HEMT at Vds of 50 V. Difference between upper distortions and lower distortions are shown in this figure. Gate width is 24 mm. Tone spacing is 1 MHz.

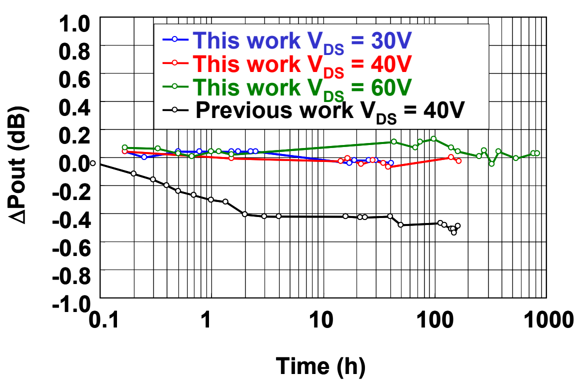

Fig. 10. Power characteristics under P3dB RF-stress test at 30 V, 40 V and 60 V.

CONCLUSIONS

In summary, we have demonstrated successful AlGaN/GaN HEMT operation with no current collapse at high drain bias voltages of up to 63 V. To our knowledge, the AlGaN/GaN HEMT single chip amplifier exhibited the highest saturated peak power of 150 W in CW mode and the highest saturated peak power of 174 W in W-CDMA modulation reported so far. RF-stress test under P_{3dB} showed stable performance up to 60 V for 1000 h, for the first time. These results are very promising for application of AlGaN/GaN HEMTs to the wireless infrastructure market, especially 3rd-generation base station power amplifiers.

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