High-Power and High-Efficiency AlGaN/GaN HEMT Operated at 50 V Drain Bias Voltage

T.Kikkawa[1], M.Nagahara[2], N.Adachi[2], S.Yokokawa[2], S. Kato[2], M.Yokoyama[2], M.Kanamura[1], Y.Yamaguchi[2], N.Hara[1], and K.Joshin[1]

[1]Fujitsu Laboratories Ltd., 10-1 Morinosato-Wakamiya, Atsugi, Kanagawa, 243-0197, Japan

[2]Fujitsu Quantum Devices, 1000 Kamisukiawara, Nakakoma-Gun, Yamanashi, 409-3883, Japan

Abstract — **We describe high power 70 W CW operation at 52 V drain bias voltage (Vds) using 24-mm gate-periphery AlGaN/GaN HEMTs on SiC substrate. A 48 W output power with the drain efficiency of 60% was also obtained at Vds of 50 V under the efficiency-matched condition near class-B. At 40 V, the drain efficiency reached 68%. Vds dependence of third order-intermodulation (IM3) was also characterized at Vds up to 50 V. This is the first report about IM3 profile characterization for a large gate-periphery device at Vds of 50 V. We also investigated RF-stress life test at Vds up to 40 V. The AlGaN/GaN HEMT in this study exhibited good reliability over 100 h.**

I. 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 [1-4]. However, a few papers exhibited high efficiency characteristics using large gate-periphery device over 40 V drain bias voltage (Vds) [5]. Base station system demands high efficiency from amplifier. So we need to make the quiescent bias current low. In this paper, we demonstrate high power performance near class-B operation. A 70 W output power for a 24-mm gate periphery HEMT was obtained at Vds of 52 V. We also report 48 W output power with power added efficiency (PAE) of 48% and drain efficiency (nd) of 60% at Vds of 50 V under efficiency-matched conditions.

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 8dB. The distortion at the averaged power level, that is 8dB back off output level from saturation, is important. Therefore, 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, predistortion system prefers the simple IMD profile without a sweet spot because it easily predicts the predistorting input signal.

We previously reported that superior linearity profile can be obtained at Vds of 30 V for a 1mm-gate periphery AlGaN/GaN HEMT [6]. In this paper, we demonstrate the superior IMD profile can also be obtained at high Vds for a large-gate periphery device. And furthermore, we investigated the Vds dependence of linearity characteristics up to 50V drain bias operation. This is the first report related to IM3 profile up to 50 V drain bias operation for a large periphery HEMT.

Reliability has become an important issue to be discussed for manufacturing of AlGaN/GaN-HEMTs. We performed the RF-stress examination to investigate stability of HEMT performance under continuous power

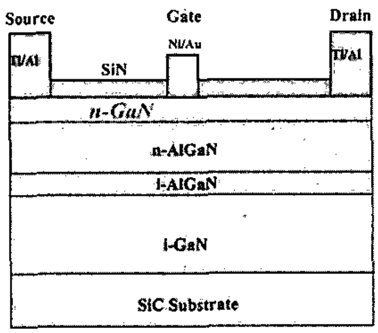

Fig.1. Schematic drawing of investigated surface-charge-controlled n-GaN-cap structures. Thin n-type GaN cap layer was grown on AlGaN/GaN structure. SiN passivation was formed on GaN cap layer between electrodes.

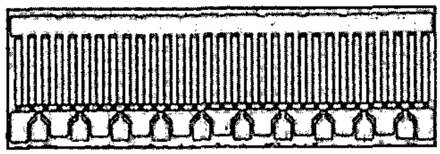

Fig. 2. A 24-mm gate periphery AlGaN/GaN HEMT.

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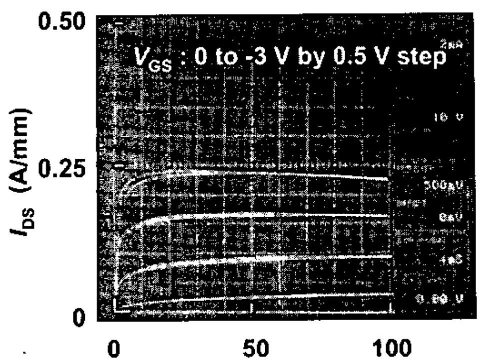
operation. A CW P3dB RF-power measurement at Vds of 40 V exhibited good reliability over 100 h.

II. EXPERIMENTAL

To obtain higher RF-power and efficiency, we have to suppress frequency dependent characteristics, such as large transconductance (gm) dispersion, gate-lag and current [7-9]. 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 [10].

Figure 1 shows the device structures on SiC substrates investigated in this study. Detailed fabrication method was described in the previous papers [4,6,10]. Gate width (Wg) was varied from 40μm to 24mm (Fig.2). Power performance was measured using load-pull system. Quiescent drain current (Idsq) is 1.4% Ifmax near class B, which is mainly used in base station system [6].



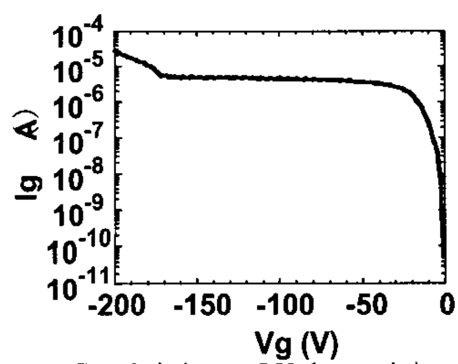


Fig. 4. Gate-drain inverse I-V characteristics of 80 μm gate periphery.

III. RESULTS AND DISCUSSION

A. High Power Performance

Figure 3 shows typical I-V characteristics in this study. We realized high on-state breakdown voltage over 100 V and good pinched-off till 100 V. [4,10]. Fig. 4 shows gate-drain inverse I-V characteristics under source is open. Breakdown voltage defined as a gate-drain voltage at a drain current of -0.5 μA/mm is over 200 V.

Fig. 5 shows power performance measured at Vds of 52 V under power-matched conditions when Idsq was 1.4% Ifmax. 70 W CW saturation power was achieved for a 24-mm periphery device. Figure 6 shows efficiency-matched condition case at Vds of 50V. 48 W CW-output power could be obtained with high drain efficiency of 60% and high PAE of 48%, respectively. Figure 7 shows the Vds dependence of Psat, Gain, drain efficiency, and PAE under efficiency matched conditions in Fig.6. At Vds of 40 V, we achieved high drain efficiency of 68% and high PAE of 50%. This is the state of the art high efficiency over 40V for a large periphery device with over 36 W output power.

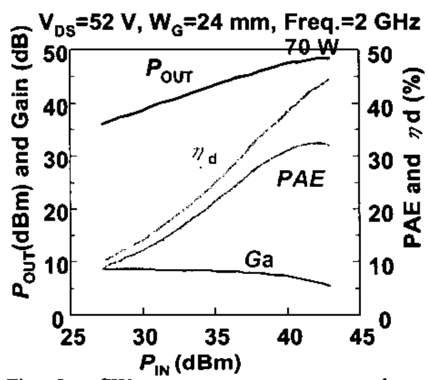


Fig. 5. CW power measurement results at Vds of 52 V.. Measured frequency is 2.2 GHz. Gate width is 24mm. Packaged chip was measured. Power-matched-condition.

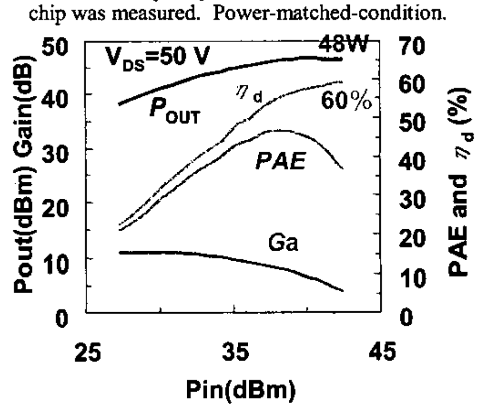


Fig. 6. CW power measurement results at Vds of 50 V.. Measured frequency is 2.2 GHz. Efficiency-matched-condition.

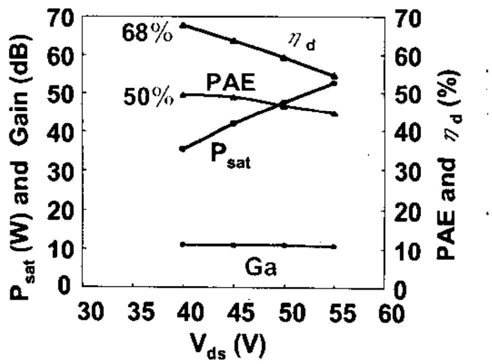


Fig. 7. CW power measurement results, as a function of Vds. Measured frequency is 2.2 GHz. Gate width is 24 mm. Efficiency-matched-condition.

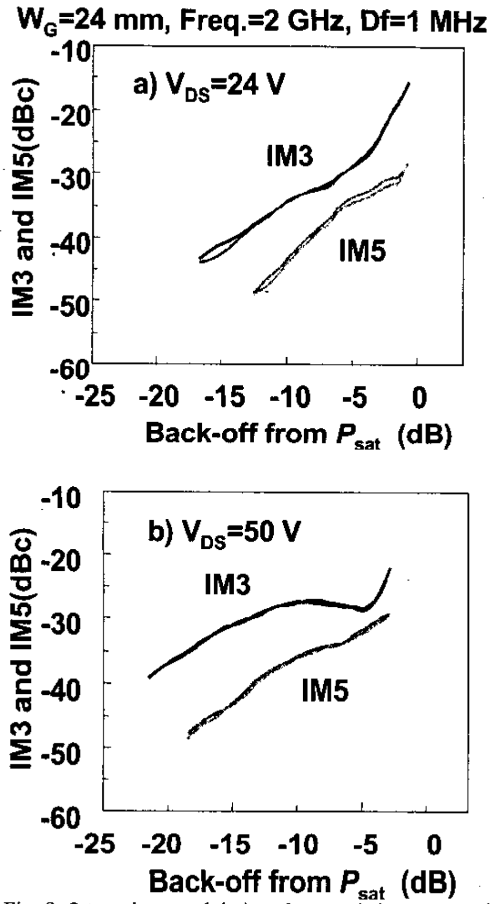


Fig. 8 2-tone intermodulation characteristics measured at a) 24 V and b) 50 V. Measured frequency is 2.2 GHz. Idsq is 1.4% Ifmax near class-B. Gate width is 24 mm.

B. Intermodulation Characteristics

Figure 8 shows intermodulation characteristics measured at 24 V or 50 V for a 24-mm gate periphery HEMT. As we previously reported using a small gate periphery device [6], simple IM3 profile could also be obtained for large gate-periphery device at Vds of 24 V. However, at 50 V, IM3 profile had sweet spot feature. In this case, same matching circuit was used for various Vds operation between 12 and 50 V. Figure 9 shows Vds dependence of IM3, 2-tone drain efficiency and PAE at 8 dB backed-off power with 1-tone power parameters. 1-tone PAE-max over 50% was obtained around 20-30 V. Thus, we suppose that intermodulation-matched condition was also realized around Vds of 24 V. The 2-tone drain efficiency and PAE at 8 dB backed-off power lever from Psat showed small deference within 5 % among various Vds operations. This indicates that only adjusting matching circuit might result in more superior IM3 profile at 50 V.

C. Reliability

We investigated preliminary reliability performance, which becomes a most important issue at the high drain bias operation. The RF-stress test was examined under P3dB conditions at Vds of 30 V and 40 V. To accelerate the aging test, Idsq was settled at 7.5% Ifmax which is larger than power measurement in Figs.5-10. Gm profiles are the same between before and after RF-stress test operated at 30 V as shown in Fig.10. Power characteristics measured at 40 V is also shown in Fig.11. After 162-hour

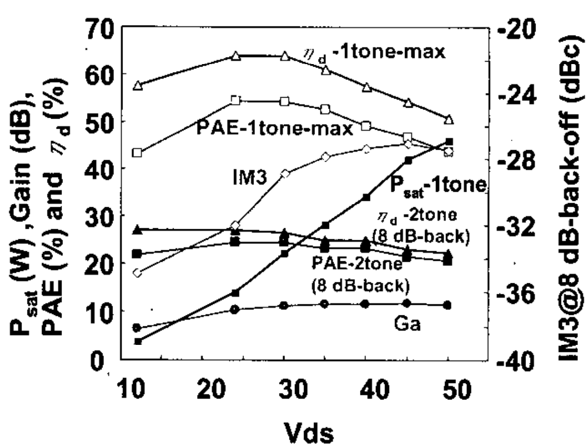


Fig.9. 2-tone intermodulation characteristics as a function of Vds. Matching circuit was not changed in this measurement. 2-tone IM3, drain efficiency and PAE at 8 dB backed-off power lever from Psat are shown. 1-tone Pout and Gain are also shown with 1-tone maximum drain efficiency and maximum PAE. Idsq is 1.4% Ifmax near class-B. Gate width is 24 mm.

RF-stress test, Pout and Gain decreased only 0.2 dBm, Although some reports showed degradation phenomena at 30 V operations, we never detected significant degradation over 100 h at 40 V operations, indicating that the AlGaN/GaN HEMTs in our study has long reliability at 40 V. This is the first report of stable operation at 40 V

IV. CONCLUSION

In summary, we fabricated 24mm-gate-periphery AlGaN/GaN HEMTs using a surface-charge-controlled structure on SiC. 70 W CW saturation power was obtained at Vds of 52 V. 48 W CW output power with high drain efficiency of 60 % was also obtained at Vds of 50 V. IM3 of 24-mm device at Vds of 24 V indicated simple good profile. IM3 at 50 V has small sweet spot but it will be improved by adjusting matching circuit. RF-stress test under P3dB showed stable performance up to 40 V. These results verify that the high-efficiency AlGaN/GaN in this study has suitable performance for base station amplifier.

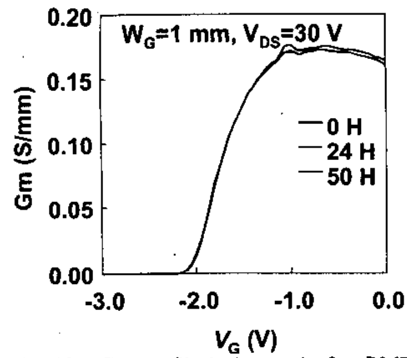


Fig. 10. Gm profile before and after P3dB RF-stress test at 30 V. During RF stress test, Idsq is 7.5% Ifmax.

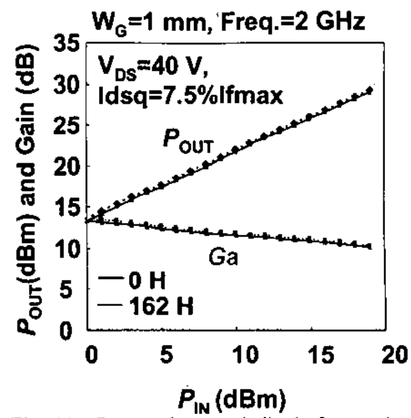


Fig. 11. Power characteristics before and after P3dB RF-stress test at 40 V. Idsq is 7.5% Ifmax. Gain-matched conditions. Pout difference is 0.2 dBm after 162 h.

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