Field-Modulating Plate (FP) InGaP MESFET with High Breakdown Voltage and Low Distortion

Akio Wakejima, Kazuki Ota, Kohji Matsunaga, Walter Contrata, and Masaaki Kuzuhara

System Devices and Fundamental Research, NEC Corporation
2-9-1 Seiran, Otsu, Shiga 520-0833, Japan

Abstract — **This paper describes a successfully developed field-modulating plate (FP) InGaP MESFET with an extremely high breakdown voltage of 100V. The FP-FET, consisting of a 2.62 mm gate width, delivered an output power of 4.2 W, an output power density of 1.6 W/mm at 1.95 GHz operated at a drain bias (Vd) of 55 V. A low 3rd-order intermodulation distortion (IM3) of −31 dBc was also achieved at 8 dB back-off from saturation power. These results show the developed FET is suited for applications in the next generation cellar base station.**

I. INTRODUCTION

High output power amplifier with low distortion is strongly required for next generation wireless-communication system. A field-modulating plate (FP) GaAs HFET under high drain voltage operation has been developed to satisfy these demands. [1-3]

In order to operate the device at higher voltages, a novel FP InGaP MESFET was fabricated, taking an advantage of higher band gap and lower impact ionization coefficient of InGaP [4]. The FP InGaP MESFET exhibited extremely high gate-to-drain breakdown voltage (BV_{gd}) characteristics with a reasonable maximum drain current (I_{max}), which significantly improves the trade-off relationship between I_{max} and BV_{gd}. Due to the superior breakdown characteristics, RF power operation under a highest drain voltage supply, ever reported in any GaAs-based FETs, was successfully achieved. Low distortion characteristics under RF power operation at high drain voltage were also demonstrated.

II. DEVICE FABRICATION AND DC PERFORMANCE

Figure 1 shows a cross-sectional view of the developed FP InGaP MESFET. Epitaxial layers consist of a buffer layer, a 150 nm thick InGaP channel layer with Si doping of 3×10^{17} cm^{-3}, an undoped InGaP Schottky layer, and a Si-doped GaAs ohmic contact layer. To obtain both BV_{gd} and low ohmic contact resistance, a wide-recess structure was employed. After standard GaAs-based FET processing, an FP electrode was formed on the 100 nm thick SiO_2 surface passivation layer in the gate-drain recessed region. The gate length (Lg) and the FP length (Lf) were 1.5 µm and 0.7 µm, respectively.

Figures 2 and 3 show the drain I-V characteristics and the gate-to-drain reverse breakdown characteristics, respectively. The fabricated FP InGaP MESFET exhibited a maximum drain current (I_{max}) of 200 mA/mm, and a threshold voltage of –3.9 V. The transconductance was 45 mS/mm. BV_{gd} was over 100 V. To our knowledge, this is the highest breakdown voltage ever reported for all GaAs-based FETs. This correlation between I_{max} and BV_{gd} surpasses that of the conventional GaAs HFET, as shown in Fig. 4.

Figure 5 shows drain current dispersion under pulse operation. The gate was driven from –5 V to +1 V with a pulse width between 10 µsec and 100 msec, and the drain current was measured while the FET was turned on (V_{gs} = +1 V). The fabricated FP-FET exhibited no appreciable frequency dispersion in the pulse I-V characteristics, ensuring high output power performance capability with good linearity.

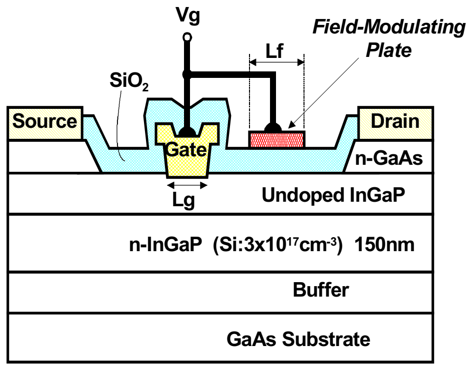

Fig. 1. Cross sectional view of developed FP InGaP MESFET. Lg and Lf are 1.2 µm, and 1.0 µm, respectively.

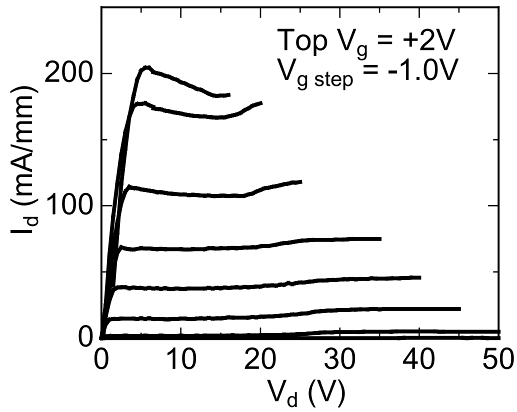

Fig. 2. Drain I-V characteristics for FP InGaP MESFET. Gate voltage (V_g) was changed from +2 V to –5 V in 1 V step.

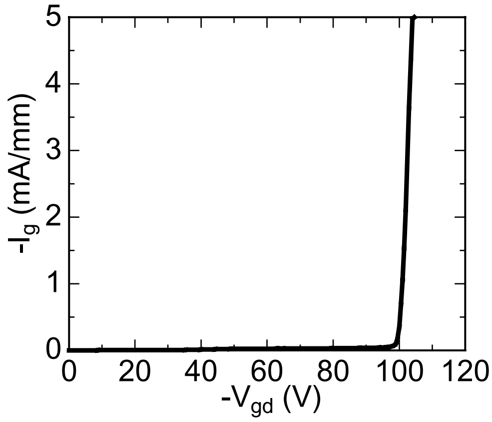

Fig. 3. Gate breakdown characteristics for FP InGaP MESFET.

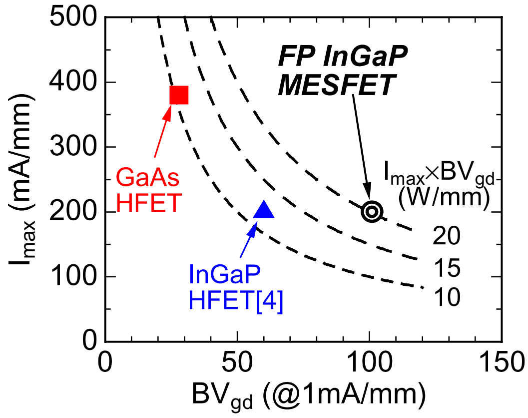

Fig. 4. I_{max} versus BV_{gd} for FP InGaP MESFET, InGaP HFET[4], and GaAs-channel HFET. Dashed lines represent $I_{max} \times BV_{gd}$ = 10, 15, and 20 W/mm.

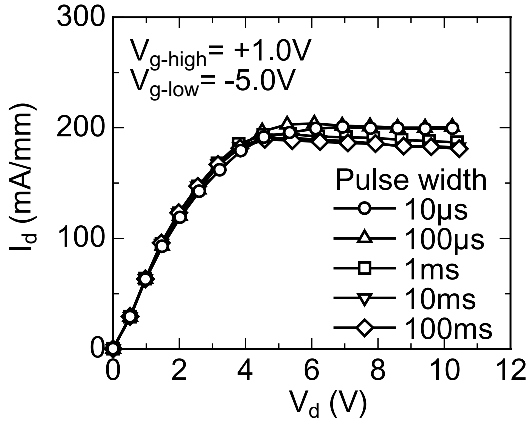

Fig. 5. Pulse I-V characteristics for FP InGaP MESFET. The gate was driven from –5 V to +1 V with a pulse with between 10 µsec and 100 msec, and the drain current was measured while the FET was turned on (V_{gs} = +1 V).

III. RF Performance

Small signal gain performances were evaluated for the FETs with (with-FP) and without FP (w/o-FP). Gate width of the devices was 200 µm. Figure 6 shows the drain bias-voltage (V_d) dependence of maximum stable gain (MSG) at 2 GH. At a low drain bias-voltage (V_d) (less than 15 V), MSG of the FP FET was smaller than that of the FET without FP. This is attributed to the larger gate capacitance for the FP-FET at low V_d. However, it was found that the gain was improved with an increase in V_d. Thus the difference in gain characteristics between FETs with and without FP became negligible. The improved gain observed at higher drain bias voltages for the FP-FET is reasonably explained by the relatively reduced contribution of gate capacitance associated with FP.

RF power performance was evaluated at 1.95 GHz for the FP-FET with 2.62 mm gate width. Figure 7 shows V_d dependence of output power density and power-added efficiency (PAE). For comparison, data for FETs without FP are also plotted in the figure. The devices were matched for a maximum output power at each bias. The FP-FET exhibited a linear increase in the output power up to 55 V, where a power density achieved 1.6 W/mm. This high power density is comparable to the record value established for an FP GaAs HFET at 35 V [1]. Moreover the FP InGaP MESFET maintained the high PAE of more than 45 % between 30 and 55 V. The FET without FP, however, exhibited negligible increase in the output power density and decrease in the PAE with increasing V_d.

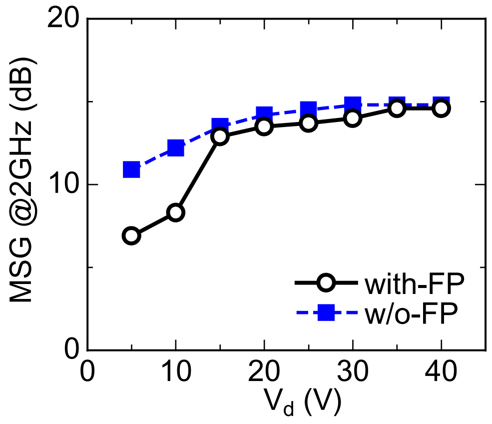

Fig. 6. Maximum stable gain (MSG) versus drain voltage for InGaP MESFETs with (○) and without FP (■). Gate width of the FETs measured was 200 µm.

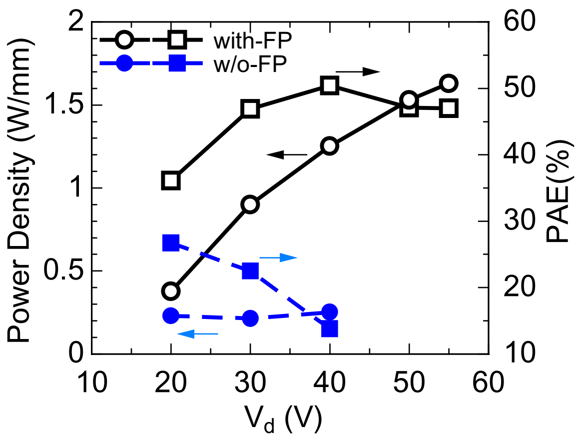

Fig. 7. Drain voltage dependence of output power density and power added efficiency of the FETs with (○,□) and without FP (●,■).

Figure 8 shows the output power (P_{out}) and the PAE of the FP InGaP MESFET as a function of input power at V_d of 55 V. A saturation power of 4.3W (36.3 dBm) was achieved for the FP-FET with a linear gain of 11.9 dB and a PAE of 47 %. To our knowledge, this is the first 50 V RF power operation for a GaAs-based FET. This high voltage operation with high PAE results from high BV_{gd} with reasonable I_{max} mentioned above.

The 3rd order intermodulation distortion (IM3) characteristics (f_0=1.95 GHz, Δf=1 MHz) for the FP InGaP MESFET was evaluated at V_d = 20 V and 45 V, as shown in Fig. 9. For comparison, IM3 for the GaAs-channel HFET evaluated at V_d =10 V was also plotted. The FP FET revealed lower IM3 plateau level than that of the GaAs HFET. Moreover, appreciable improvement in IM3 was achieved with increasing V_d from 20 V to 45 V. At 8 dB power back-off from saturation power, the IM3 for the FP InGaP MESFET at V_d = 45 V was –31 dBc. It is considered that these low distortion characteristics are caused by the low and linear drain conductance and the large load impedance of the FP InGaP MESFET operated at high V_d condition [3]. These results suggest that the FP InGaP MESFET is suitable for high power amplifier applications, where both high voltage operation and low distortion characteristics are required.

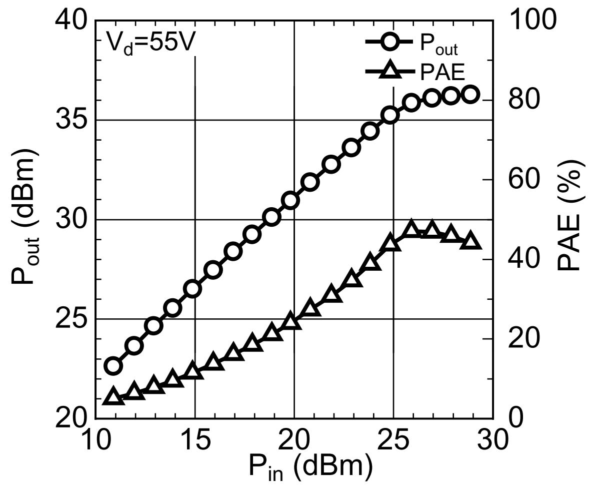

Fig. 8. Output power (P_{out}) and power-added efficiency versus input power at 1.95 GHz and V_d=55 V

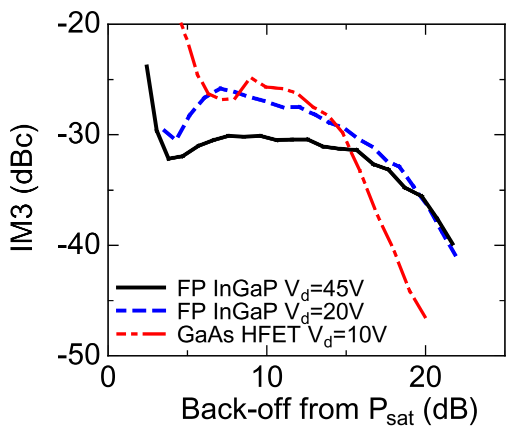

Fig. 9. 3rd order intermodulation distortion (IM3) as a function of back-off power from saturation power. Solid line and dashed line represent results for FP InGaP MESFET operated at 45 V and 20 V, respectively. Solid and dashed line represents for GaAs HFET operated at 10 V.

IV. Summary

We have successfully fabricated a low distortion FP InGaP MESFET with a high breakdown voltage. The highest BV_{gd} of 100V and RF operation voltage of 55 V were achieved. A saturation power density of 1.6W/mm and PAE of 47 % were obtained at 1.95GHz under 55 V operation. Low IM3 of -31 dBc was obtained at 8 dB power back-off under 45 V operation.

These results indicate that the developed FP InGaP MESFET is promising as high-voltage power device with low-distortion characteristics for the next generation wireless communication systems.

Acknowledgement

The authors wish to thank M. Ogawa and T. Uji for encouragement throughout this work. We also would like to thank M. Kawanaka, H. Takahashi, M. Tokushima, N. Sakura, I. Takenaka, and K. Ishikura for their help in device fabrication and evaluation.

References

[1] K. Asano, Y. Miyoshi, K. Ishikura, Y. Nashimoto, M. Kuzuhara, and M. Mizuta, "Novel High Power AlGaAs/GaAs HFET with a Field-Modulating Plate Operated at 35V Drain Voltage," *1998 IEEE IEDM Dig.,* pp. 59-62, 1998.

[2] N. Sakura, K. Matsunaga, K. Ishikura, I. Takenaka, K. Asano, N. Iwata, M. Kanamori, and M. Kuzuhara, "100W L-Band GaAs Power FP-HFET Operated at 30V," *2000 IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 1715-1718, 2000.

[3] K. Matsunaga, K. Ishikura, I. Takenaka, W. Contrata, A. Wakejima, K. Ota, M. Kanamori, and M. Kuzuhara., "A Low-Distortion 230W GaAs Power FP-HFET Operated at 22V for Cellular Base Station," *2000 IEEE IEDM Dig.,* pp. 393-396

[4] N. Hara, Y. Nakasha, T. Kikkawa, H. Takahashi, K. Joshin, Y. Watanabe, H. Tanaka, and M. Takikawa, "Low-Distoriton GaAs-Based Field Effect Transistors with InGaP Channel Layer for High-Voltage Operation", *1998 IEEE IEDM Dig.,* pp. 63-66, 1998.