High-Gain SiC MESFETs Using Source-Connected Field Plates

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***Abstract*—We demonstrate for the first time improvement of radio-frequency (RF) gain of SiC MESFETs by using source-connected field plates (FPs). MESFETs fabricated with this approach show a new record maximum stable gain exceeding 15.7 dB at 3.1 GHz. This is 2.7 dB higher than the baseline devices without FP. RF power output greater than 4W/mm was also achieved showing the potential of these devices for high-power operation.**

***Index Terms*—MESFETs, SiC, source-connected field plates (FPs).**

I. INTRODUCTION

SILICON carbide MESFETs are very attractive for high-power microwave devices due to the combination of high electron velocity, high breakdown strength, and high thermal conductivity of SiC. Significant progress has been made in this technology and devices with proven reliability are commercially available at 10 and 60 W power levels. However, a limitation of current SiC MESFETs is that the maximum stable gain (MSG), which is the maximum gain that can be obtained when designed for unconditional stability, is limited to about 13 dB at 3 GHz. In these fully passivated MESFETs, the gate-to-drain feedback capacitance C_{gd} limits the MSG. Reducing C_{gd} will increase the gain (MSG) and will also improve the ease of use of the device. An effective way to reduce this capacitance is to introduce a shield electrode, commonly known as field plate (FP), between the gate and the drain, and by electrically connecting it to the source. These FPs are commonly used in Si LDMOS [1], [2], GaN HEMTs [3]–[5], and GaAs PHEMTs [6], [7]. In this letter, we demonstrate for the first time improvement of gain (MSG) of SiC MESFETs by using source-connected FPs. These devices show a record high gain exceeding 15.7 dB at 3.1 GHz.

II. DEVICE FABRICATION

The MESFETs in this letter were fabricated on 3- or 4-in diameter high-purity semi-insulating 4H-SiC substrates. The device structure was grown by vapor-phase epitaxy [8]. The MESFETs were fabricated with dry-etched isolation mesas, ion-implanted n+ source and drain regions, sintered Ni ohmic contacts, thermally grown passivation oxide layer, and source vias. The gate length was 0.4 μm. After gate fabrication, a layer of silicon nitride was deposited and the FP was formed on top of this layer. The FP consisted of a 0.7-μm-long metal electrode and was formed in the gate-to-drain space. It partially overlapped the gate and was isolated from it by the silicon nitride layer. The FP was connected to the source at two discrete points along its width by extending it across the gate to the source ohmic contact. A final layer of silicon nitride passivation was deposited for environmental protection and reliability. Devices fabricated with this process typically show maximum channel current $I_{\max}$ greater than 360 mA/mm, pinchoff voltage of -8.5 V, and gate–drain breakdown in excess of 120 V. For comparison, devices with no FPs were also fabricated on the same wafer. These devices showed drain current and pinchoff characteristics similar to those with the FP. However, the breakdown voltage was typically lower for devices without FP.

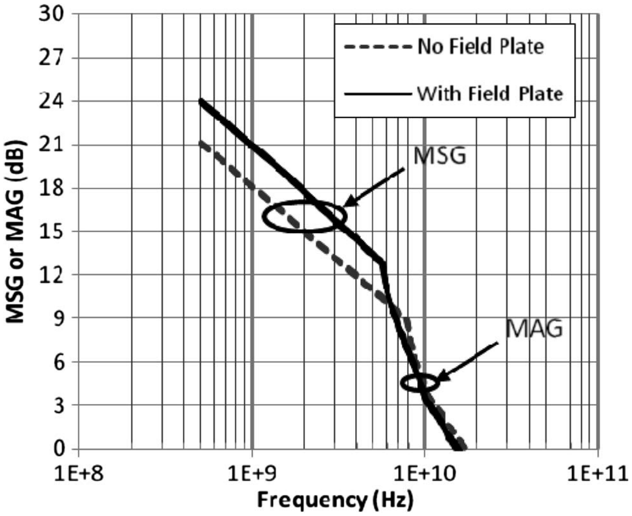

Fig. 1. Small-signal gain, MSG, or MAG of SiC MESFETs with and without source-connected FPs.

III. RESULTS AND DISCUSSION

Small-signal radio-frequency (RF) characteristics of the MESFETs were measured on-wafer from 0.5 to 19.9 GHz using a vector network analyzer. The measured devices had two gate fingers, each with unit gate width of 500 μm, for a total width of 1 mm. The bias was $V_{\mathrm{ds}} = 48$ V, and $I_{\mathrm{ds}} = 50$ mA, a class AB condition that is normally used for high-efficiency power operation. The maximum small-signal gain was calculated from the

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TABLE I
COMPARISON OF THE SMALL-SIGNAL EQUIVALENT CIRCUIT PARAMETERS FOR DEVICES WITH AND WITHOUT FP
$V_{\mathrm{ds}} = 48$ V, $I_{\mathrm{ds}} = 50$ mA; GATE WIDTH = 1 mm

Parameter	Field Plate	No field plate
C_{gs}(fF)	650	470
C_{gd}(fF)	46.6	85.9
C_{ds}(fF)	219	136.4
g_m (mS)	31.3	32.3
R_{ds}(ohms)	448	379
R_s+R_i+R_g (ohms)	7.96	8.49

s-parameters and is shown in Fig. 1. It is shown in Fig. 1 that the FP device shows MSG of 15.7 dB at 3.1 GHz. This is the highest gain yet reported for SiC MESFETs. Similar results have been consistently obtained on more than 50 wafers over several process lots. It may be noted that the FP device has 2.7 dB higher MSG than the baseline device without FP. The increase in gain is a direct result of the reduction in C_{gd} for the FP device. This can be seen in Table I which shows the equivalent circuit parameters extracted from the measured s-parameters. The FP device has lower C_{gd} of 46.6 fF/mm in comparison with the value of 85.9 fF/mm for the non-FP device. The devices were also measured at various drain bias values from 20 to 50 V, and C_{gd} for the FP devices was lower throughout this bias range. In addition, device simulations show that further reduction in C_{gd} with a corresponding increase in MSG to about 17.5 dB at 3 GHz can be obtained by further optimization of the FP structure.

The lower value of C_{gd} is important for several reasons. First, it improves ease of use of the device due to the lower input-output coupling. This offers an advantage for wideband amplifiers by minimizing the interaction of input and output matching networks. Second, it allows higher gain to be obtained with unconditional stability. Finally, the linearity of source-connected FP structure has also been shown to be superior in GaAs pHEMTs [9]. While the FP device showed higher C_{gs} (see Table I), the total input capacitance during operation is similar for the two devices due to the lower Miller effect capacitance of the FP device. This is an important consideration for wide bandwidth designs.

RF power performance at 3.5 GHz in CW conditions was measured on-wafer using a Focus Microwaves load pull system. The devices were tested in Class AB bias condition of $V_{\mathrm{ds}} = 48$ V, and $I_{\mathrm{ds}} = 50$ mA. The FP devices showed power output power greater than 4 W/mm with drain efficiency of 57%. These values are very similar to those obtained for devices with no FP. FP devices were found to be more easily matched without encountering oscillation in the load pull test system, experimentally verifying their improved stability. This load pull measurement was not able to distinguish any differences in gain, due to the inability of the test system to produce the optimum input match condition at the transistor gate. This limitation is due to finite limits on the range of available impedances imposed by coax line and probe losses between the input tuner and the transistor.

IV. CONCLUSION

In summary, we have demonstrated significant improvement in gain of SiC MESFETs using source-connected FPs. These fully passivated devices with 0.4-μm gate lengths show MSG of 15.7 dB at 3.1 GHz in a Class AB bias condition. This represents a 2.7-dB improvement over conventional devices without FPs and is also the highest gain reported to date for SiC MESFETs at this frequency. The improved gain results from the nearly factor of two reduction in the feedback capacitance C_{gd}. The higher gain and lower feedback capacitance of the new structure will enable development of wide bandwidth, high-power amplifiers, and MMICs using SiC MESFETs.

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