High-Power GaN MESFET on Sapphire Substrate

C. Gaquiere, S. Trassaert, B. Boudart, and Y. Crosnier

Abstract—**The first power results of GaN MESFET achieved at 2 GHz are presented. A power density of 2.2 W/mm has been obtained with an associated power-added efficiency of 27% at $V_{\rm ds} = 30$ V and $V_{\rm gs} = -2$ V. These results represent a significant improvement over similar MESFET's or HFET's grown on GaAs or InP substrates.**

Index Terms—**MESFET, microwave power.**

I. Introduction

IN RECENT years the wide-bandgap semiconductors, silicon carbide (SiC) and gallium nitride (GaN), have received increased attention because of their potential for use in a wide variety of high-power high-frequency devices [1], [2]. Their unique material properties, high electric field breakdown due to the wide band gap, and high saturated electron drift velocity are what give these materials their tremendous potential in the high-frequency power device area. In these conditions these devices will become the microwave amplifier of choice for the rising wireless communication market of the future. In this regard, few studies have been achieved on GaN MESFET's as compared to HFET's, whereas the MESFET's epilayers are easier to realize and the physical effects are easier to interpret (no heterojunctions and piezoelectric strain effects). Hence, GaN MESFET's devices have been investigated. After a brief device technology description, small and large signal results are presented.

II. Device Description

The device structure was grown by metal organic chemical vapor deposition on a (0001) sapphire substrate. A 25-nm GaN nucleation layer was followed by a 3.6-μm undoped GaN layer and a 200-nm n-GaN active layer. A doping level of 2.7 10^{17} $\rm cm^{-3}$ and a mobility of 330 $\rm cm^2/V \cdot s$ were deduced from Hall measurements performed at room temperature. Then, Ti/Al/Ni/Au (15/220/40/50 nm) metallization layers were evaporated to realize ohmic contacts. These contacts were annealed under nitrogen atmosphere at 900°C during 30 s. The device isolation was made by reactive ion etching using 8 sccm of $SiCl_4$ gas, a radio frequency (RF) power of 200 W, and a pressure of 40 mTorr. This results in an etch rate of 20 nm/min. The submicrometer gate was defined by electron beam lithography. Pt/Au (10/100 nm) metallization layers were used for the Schottky contact.

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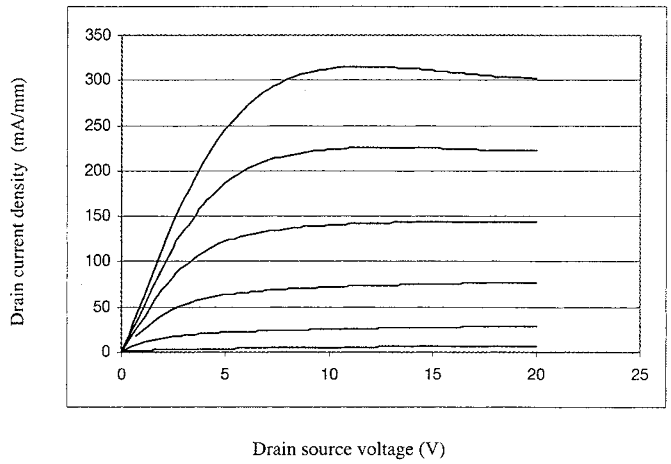

Fig. 1. I–V characteristics of a $2*50*0.3$ $\mu \rm m^2$ MESFET for $V_{\rm gs}$ from -9 to 1 V (step 2 V).

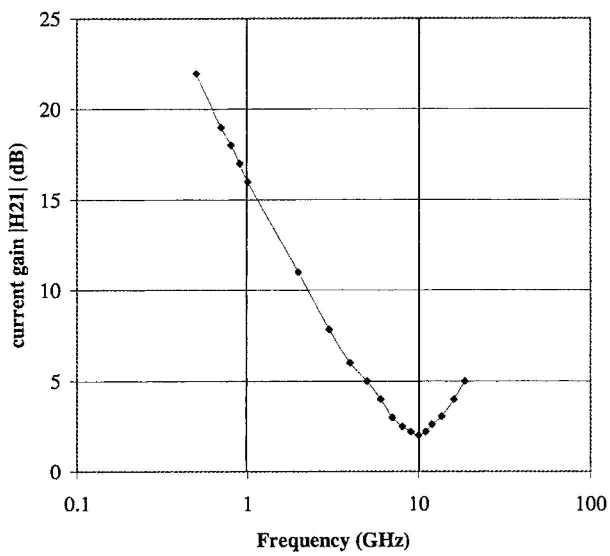

Fig. 2. Short-circuit current gain (|H21|) versus frequency for a $2*50*0.3$ $\mu \rm m^2$ MESFET at $V_{\rm ds}$ = 30 V and $V_{\rm gs} = -2$ V.

Devices with a source-drain spacing of 2.3 μm, a gate length of 0.3 μm, and a gate width of 2 × 50 μm were fabricated. The gate to source spacing is 1 μm. These devices are not passivated.

III. Microwave Measurements

Fig. 1 shows the output I–V characteristics of a typical device. The drain saturation current is higher than 300 mA/mm at $V_{\rm gs} = 1$ V. The I–V characteristics exhibit negative differential resistance characteristic at high drain current due to self heating as the drain–source voltage $V_{\rm ds}$ was swept up to 20 V.

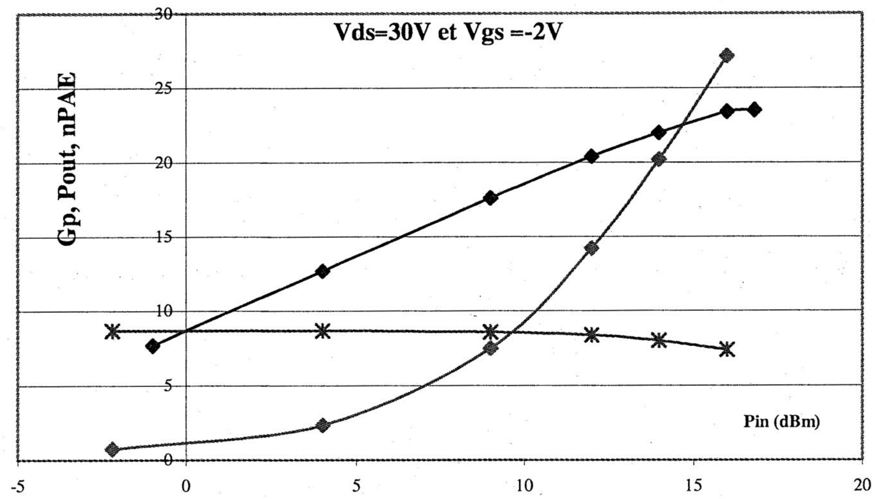

Fig. 3. Output power, power gain, and power-added efficiency versus input power at 2 GHz for a $2 * 50 * 0.3$ μm^2 MESFET at $V_{ds} = 30$ V and $V_{gs} = -2$ V.

These devices are fabricated on a sapphire substrate, hence, the high-power thermal effects are encountered. This excessive heating of power GaN FET's can be overcome by using a SiC substrate in place of a sapphire substrate [3] or a flip chip packaging [4].

The small-signal RF performance were measured on-wafer. These devices were not provided with any special measures to alleviate the thermal problem imposed by the poor thermal conductivity of the substrate. The substrate was placed on a room temperature chuck. Fig. 2 illustrates the short-circuit current gain |H21| as a function of frequency calculated from scattering parameters. The device shows a current cutoff frequency F_T of 11 GHz. A slope of 20 dB/decade has been checked.

Then large-signal measurements have been carried out on a specific cell associated with microwave tuners of very low loss in order to obtain optimum match for output power load and input return loss. The power measurements have been achieved at 2 GHz on a $2 * 50 * 0.3$ μm^2. When the device is biased at $V_{ds} = 30$ V and $V_{gs} = -2$ V, the linear power gain is 9 dB. The maximum output power density reached is 2.2 W/mm with an associated power-added efficiency of 27% (Fig. 3). This is one of the highest power density reported for MESFET's on sapphire substrate. This power result has been obtained for a gate to source voltage higher than the voltage which is required to bias this device in class A. Indeed, if the device is biased in class A or AB, a premature clipping of gate forward conduction occurs accompanied with a drop in drain current and forward gate current. These behaviors have been studied by dc and RF pulsed measurements with several quiescent bias points and different conditions (with and without light). These measurements are described in [5] and prove the existence of electrical traps associated with the surface states. Hence, when the gate source voltage increases the trap effects are less important and in these conditions the power results obtained are very encouraging.

IV. Conclusion

To our knowledge this is the first GaN MESFET's power measurements conducted at 2 GHz. A power density of 2.2 W/mm has been obtained with an associated power-added efficiency of 27% at $V_{ds} = 30$ V and $V_{gs} = -2$ V. These power results are very promising. With an improvement in the quality of epilayers, better device performances could be expected.

References

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