High Power Performances of AlGaN/GaN HEMTs On Sapphire Substrate At F=4GHz

N. Vellas, C. Gaquiere, Y. Guhel, M. Werquin, D. Ducatteau, B. Boudart[1], J. C. de Jaeger

Institut d'Electronique et de Microélectronique du Nord – U.M.R. – C.N.R.S. 8520
Département Hyperfréquences et Semiconducteurs
Cité Scientifique – Avenue Poincaré – B.P. 69 – 59652 Villeneuve d'Ascq Cedex – France

[1]Now in : EIC-LUSAC, Site universitaire BP 78 50130 Octeville

Z. Bougrioua[2], M.Germain, M. Leys**, I. Moerman, S. Borghs****

INTEC, IMEC- Ghent University, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium

**IMEC, Kapeldreef, 75, B-3001 Leuven, Belgium

[2]Now in : CRHEA, Rue Bernard Gregory, Sophia Antipolis F-06560 Valbonne – France

Abstract:

The high potential at microwave frequencies of AlGaN/GaN HEMTs on sapphire substrate for power application has been demonstrated in this paper. An output power density close to 5W/mm has been measured on a 2x25x0.5µm² HEMT on sapphire substrate. This result is very interesting because the devices have not been passivated. At present time, it is the best power result in Europe on this substrate.

INTRODUCTION

AlGaN/GaN high electron mobility transistors (HEMTs) have recently received considerable attention for power applications at microwave frequencies. In fact, the GaN material presents a wide band gap, a high saturation velocity and a high thermal stability, so it constitutes an ideal candidate for such applications. At present time, silicon carbide (SiC) and sapphire materials are the main substrates used for the GaN HEMT device production. Recently, a power density of about 10.7 W/mm has been obtained with AlGaN/GaN HEMTs on silicon carbide at 10 GHz and 6.6 W/mm at 20 GHz [1], [2]. Nowadays, these results constitute the state of the art on silicon carbide substrate. On the other hand, the results obtained on sapphire substrate are lower. The state of the art is about 6.5 W/mm at 8 GHz and 3.3 W/mm at 18 GHz [3], [4].

In this paper, we report small and large-signal results of AlGaN/GaN HEMTs on sapphire substrate.

First, a brief description of GaN HEMT fabrication is presented. The main DC and small signal microwave results are summarised. Secondly, the static results are compared to those obtained by pulsed measurements and thermal effects are shown. Then, the large signal characterisation is described, including measurement conditions and power results obtained.

II. DEVICE DESCRIPTION AND SMALL SIGNAL RESULTS

The AlGaN/GaN structures (figure 1) have been grown by LP-MOCVD [5] on sapphire substrate using ammonia, TMGa and TMAl as precursors. After deposition of a thin nucleation layer at low temperature, the wafer is brought to high temperature for recrystallisation. A 3.12 µm thick GaN layer is then grown at 1200 °C at a pressure of 100 Torr. The $Al_xGa_{1-x}N$ layer is deposited at lower pressure. The aluminum content in the AlGaN layer is 36 % and its thickness is 180 Å.

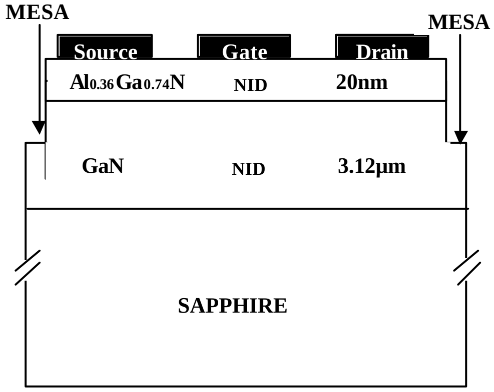

Figure 1: Device structure

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The devices have gate-drain and gate-source spacings of 1 µm, a gate width of 50 µm and a gate length of 0.5 µm. The mesa isolation is made by reactive ion etching (RIE) with $SiCl_4$. An etch rate of 180 Å/min has been obtained with the following conditions: a RF power of 200 W, a pressure of 20 mTorr and a flow rate of 4 sccm. The ohmic contact metallization is Ti/Al/Ni/Au with respective thickness of 150/2200/400/500 Å. A small etching (RIE) is realized before deposing metals and after it, this contact is annealed under nitrogen atmosphere at 900°C during 40 s. The Schottky contact metallization is Pt/Au (100/2000 Å) then bonding pads deposition are achieved with Ti/Au (1000/4000 Å) [6]. The devices are not passivated.

Table 1 summarizes the electron mobility, the sheet carrier concentration at T=300 K, the main DC and small signal microwave performances of a device with a geometry of 2x25x0.5 μm^2.

µ (cm^2/Vs) at T=300 K	1170
n_s (cm^{-2}) at T=300 K	1.5 10^{13}
I_D (A/mm) at V_{GS}=1V and V_{DS}= 27V	1.15
g_{mext} (mS/mm) at V_{GS}=0.5V and V_{DS}= 15V	160
V_P (V)	-6
f_T (GHz) at V_{GS}=-2V and V_{DS}= 10V	18
f_{MAG} (GHz) at V_{GS}=-2V and V_{DS}= 10V	50
f_{MAX} (GHz) at V_{GS}=-2V and V_{DS}= 10V	75
P_{DC} (W/mm) expected at V_{DS}=27V and for I_{Dsat}=1.2A/mm	6.25

Table 1: Device parameters

The cut-off frequencies f_T, f_{max} and f_{MAG} determined from the scattering parameters on a Vector Network Analyzer (VNA) HP8510 are respectively 18 GHz, 75 GHz, 50 GHz. The breakdown voltage in transistor configuration (at open and close channel) appears at a drain-source bias voltage higher than 30 V. The drain current density is 1.15 A/mm at V_{GS}=1 V and the DC extrinsic transconductance is 160 mS/mm. The static and pulsed drain current characteristic versus drain-source bias voltage for several gate-source voltages are shown figure 2.

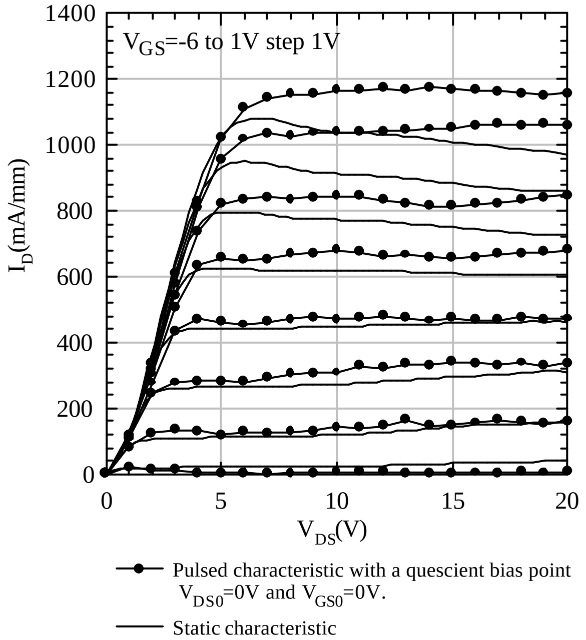

Figure 2: Pulsed and static characteristics

The pulsed I(V) measurement has been carried out at a quiescent bias point of V_{GS0}=0 V and V_{DS0}=0 V. This quiescent bias point (cold polarization) permits to eliminate the thermal effects. The pulsed set up is described elsewhere [7].

On the $I_D(V_{DS})$ static characteristic, the channel conductance is negative. This phenomenon is attributed to thermal effects because the channel conductance is nearly zero in pulsed configuration. Moreover, the maximum drain current (at V_{GS}=1 V) on the pulsed characteristic is higher than the one coming from the static characteristic. The output power density expected from the static $I_D(V_{DS})$ characteristic is 6.25 W/mm ($\Delta I*\Delta V/8$). This one has been calculated at V_{DS}=27 V with I_{DSAT}=1.2 A/mm and V_{knee}=7 V at V_{GS}=2 V.

III. LARGE SIGNAL CHARACTERIZATION

III.1 Set up description and measurement conditions

This set up permits the device measurement at microwave frequencies on wafer or in fixture and gives the possibility to observe the power performances, the signal forms of the drain-source voltage versus biases and load impedances conditions simultaneously. It is an automatic passive load-pull system. The calibration procedures are described elsewhere [8].

A VNA allows to determine the load impedance presented at the output plane of the DUT (Devices Under Test). The load impedances are carried out with a double slugs tuner.

III.2 Power results at 4GHz

The power measurements have been performed near the breakdown voltage in order to obtain a high drain-source voltage swing in power condition.

The DUT has been biased at V_{GS}=-2.9 V, V_{DS}=27 V and the optimal power load impedance presented at the output plane of this device is Z_{load} (Ω) =1200 + j200 in large signal condition.

Figure 3 presents the power gain, the power added efficiency (PAE), and the output power for a HEMT with a geometry of 2x25x0.5µm² versus the absorbed input power.

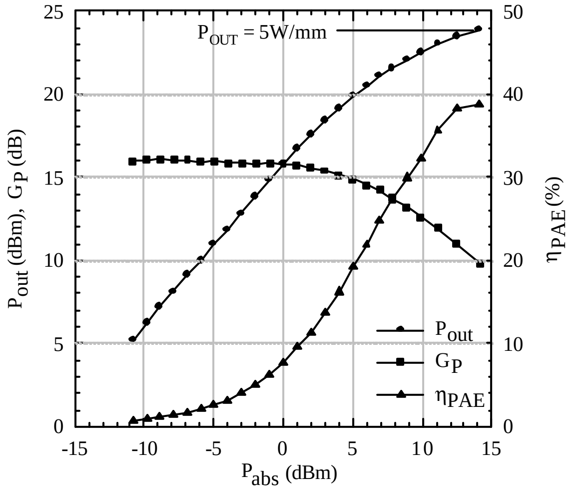

Figure 3: Power results of a 2x25x0.5µm² device at V_{DS}=27 V and V_{GS}=-2.9 V (Z_{load}(Ω)=1200+j200) at F=4 GHz

The maximum output power reaches 5 W/mm, the respective power gain is about 10dB (on the other hand the linear power gain is 16dB) and the associated PAE is 39%. Now, this power result represents the state of the art to our knowledge in Europe on sapphire substrate. Moreover, the output power density expected of 6.25W/mm (see table 1) is not reached. The difference between the DC output power density expected and the RF output power measured can be explained by thermal effects or/and by the presence of traps [8], [9]. A passivation step with Si_xN_y can be used on this sample in order to limit trap effects and so to increase the microwave output power [10].It is well know that sapphire has not a good thermal conductivity (0.46W/cm.K). For this reason, to increase the thermal dissipation, the sapphire substrate can be thinned and power performances can be improved.

IV. CONCLUSION

An output power density of 5 W/mm and a linear power gain close to 16 dB have been measured with AlGaN/GaN HEMTs on sapphire substrate at 4 GHz. These results constitute the state of the art in Europe. The high potential of AlGaN/GaN/Al_2O_3 HEMT devices for power applications at microwave frequencies has been demonstrated. There is still a weak difference between the output power density expected and the measured one. This difference can be explained by thermal effects and trap effects.

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