Silicon Carbide MESFETs Performances and Application in Broadcast Power Amplifiers

F. Temcamani[1], P. Pouvil[1], O. Noblanc[2], C. Brylinski[2], P. Bannelier[3], B. Darges[3] and J.P. Prigent[3]

[1]ENSEA-EMO, 95014 Cergy-Pontoise Cedex, France
[2]THOMSON-CSF LCR, 91404 Orsay Cedex, France
[3]THOMCAST, 78702 Conflans Ste Honorine Cedex, France

Abstract **In this paper we present DC, small signal and power characterization of recent Thomson Silicon Carbide MESFETs. We present also performances of SiC power amplifiers designed for use in broadcast digital television. A comparison with a LDMOS amplifier showed that SiC is a very promising material for microwave and RF power amplification.**

I. Introduction

Silicon Carbide have many potentialities for RF and microwave power amplification. Its physical properties are a wide band gap, a high breakdown field high thermal conductivity and a high electron velocity. Recent progresses in SiC material and component technology and performances [1-3, 6] made it a serious challenger to Silicon LDMOS for high-power amplification (TV broadcast, base stations, etc…). In these paper we present recent performances of SiC MESFETs processed by the central laboratory (LCR) of THOMSON-CSF and their applications in broadcast systems.

II. Transistors Performances

All SiC MESFET studied here were made on 4H epitaxial structures supplied by Cree Research. They only differ by the type of substrate (conductive or semi-insulating) and the buffer layer. Main technological characteristics of MESFETs mentioned in this paper are presented on table 1. All components were characterized on DC, small signal S-parameters and load-pull conditions. The fabrication processing of these MESFETs [5] and their detailed characterization results [6] have already been published elsewhere. Here, we recall the main and recent measurements results and focus on the amplifiers design for specific applications.

The DC measurements show that the drain saturation current (Idss) is in the 150 to 300 mA/mm range and the breakdown voltage is over 200 V. The pinch-off voltage (and therefore the knee voltage) are generally around 10-15 V. This high value is due to the low electron mobility of SiC. It will limit the ultimate drain efficiency to values similar to theoretical GaAs devices with same geometry.

The small signal characterization shows a maximum oscillation frequency (f_{max}) of 20 GHz obtained on the recent small size (0.1 mm periphery) devices processed on semi-insulating substrates.

Load-pull characterization has been performed. The main results are (at 1 dB compression):

- At 1 GHz, the best output power in class-A amplification and for Vds=40 V is around 20 W (1.25 W/mm). At 2 GHz, up to 9 W output power has been obtained with Vds=40 V, 7dB power gain and 30 % drain efficiency.

Table 1 Technological characteristics of mentioned transistors.

transistor	substrate	buffer		Active layer		Gate	
		doping level	thickness	doping level	thickness	length	width
LCR-52	***conductive***	<10^{16} cm^{-3}	10 µm	1.5 10^{17} cm^{-3}	0.4 µm	0.7 µm	9.6 and 24 mm
LCR-129	***SI***	5.2 10^{16} cm^{-3}	1 µm	1.5 10^{17} cm^{-3}	0.4 µm	1.2 µm	9.6 ; 7.2 ; 8 and 6 mm
LCR-161	***SI***	No buffer		1.5 10^{17} cm^{-3}	0.4 µm	1.2 µm	14.4 mm
LCR-265	***SI***	5. 10^{16} cm^{-3}	0.5 µm	1.5 10^{17} cm^{-3}	0.4 µm	1.2 µm	10.8; 21.6; and 36 mm

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

- The best output power density for a large gate periphery (10.8 mm) is 2.1 W/mm in class-AB, at 1.5 GHz and 55 V of drain voltage.
- The higher output power obtained with a single chip (LCR 265) is 45 W in class-AB (at 0.4 dB compression), at 1.5 GHz and 55 V of drain voltage.

For the best devices, the output power is roughly proportional to V_{ds} bias voltage (Fig. 1). For example, the output power density of the transistor sample LCR-161, increases from 10.5 W at Vds=40 V to 18 W at Vds=80 V. This shows that the SiC MESFET can take advantage of its high breakdown voltage. The best measured breakdown voltage was 250 V. Increasing the bias point to 100 V should become possible in the future when traps effects problems will be solved, giving further increase of power density.

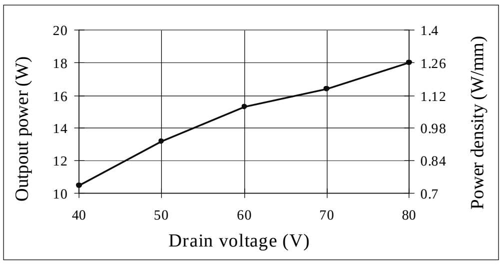

Fig. 1. Output power versus bias drain voltage.

In order to increase the output power, large gate widths were used up to 36 mm. Power density obtained with two recent processes (LCR-161 and LCR-265) decrease from 2.5 to 1 or 1.5 W/mm (Fig. 2). This decrease is probably due to stimulation of trapping by overheating.

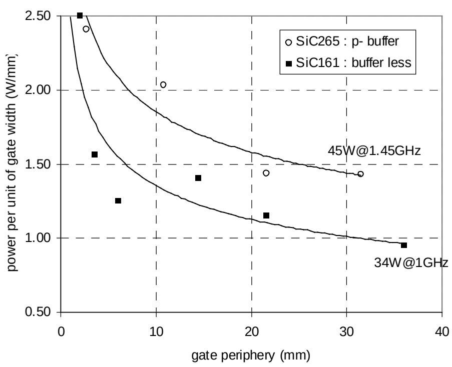

Fig. 2. Output power versus the gate periphery.

III. Power Amplifiers

The aimed application was future digital television. It needs UHF wideband amplifiers (480 – 860 MHz). Many prototypes were designed and we present the most representative of them.

A. Amplifier 1

It's a wideband UHF amplifier. The main characteristics are 10 W output power, 12 dB power gain and 1 dB ripple. Three transistors were chosen, two SiC MESFETs respectively on conductive (LCR 52) and semi-insulating substrate without buffer layer (LCR 129) and a commercially available Si LDMOS (Motorola MRF 182). The samples have been chosen because of their similar output power in class-A regime (about 10 W). All devices were characterized between 470 and 860 MHz on a load-pull system to determine the outside passive networks in order to create a flat power gain over the whole UHF band. The amplifiers were designed using an analytical method [4] and built on microstrip circuits.

B. Amplifier 2

It's a UHF push-pull amplifier operating in class-AB. The main expected characteristics are 40 W output power, 10 dB power gain and 1 dB ripple. We chose the SiC MESFET LCR 265, with a semi-insulating substrate and a thin buffer layer, because of its high power density. Two MESFETs with 21.6 mm gate width each were used. They were mounted in a push-pull circuit using input and output transformers and four matching networks (two for each transistor, Fig. 3). Each matching cell is a LC ladder circuit. To design them with an analytical method [4], both transistors were characterized on a load-pull system. The amplifier was built on micro-strip circuit.

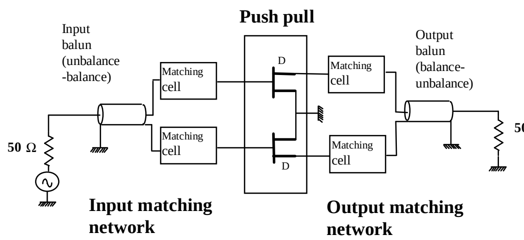

Fig. 3. Amplifier 2 topology.

IV. Measurements And Discussion

A. Amplifier 1

Measurements show that all prototypes are equivalent (table 3) in terms of power gain efficiency and gain ripple. The main differences are a greater output power density for SiC (0.94 W/mm versus 0.15 W/mm) and higher input and output impedances for SiC that makes matching design easier. On the other hand the compression was greater for the SiC MESFETs. The SiC MESFET high access impedances (from five to ten times the LDMOS ones, table 2) are due to its smaller size for a same output power and its higher drain bias voltage. These comparison results must be moderated because of the LDMOS better performances (0.5 W/mm) at its optimal operating class (AB), the recent progress of its power density [7] and its technology maturity. The SiC progression margin is nevertheless great because of its high breakdown voltage and its published high power density values [2].

Table 2 Load and source impedances of the three transistors.

Frequency		**570 MHz**	**870 MHz**
MRF182 (Si)	Z Load (Ω)	2.9 + j6.2	2.1 + j4.7
	Z Source (Ω)	4.5 - j4.3	1.4 - j1.7
LCR 52 (SiC)	Z Load (Ω)	14.7 + j23.4	9.5 + 14.9
	Z Source (Ω)	10.2 + j26.3	10.3 + j18.4
LCR 129 (SiC)	Z Load (Ω)	28.2 + j35.2	13 + j29.7
	Z Source (Ω)	16.3 + j21	6.7 + j16.6

Table 3 Comparison of the three amplifier 1 prototypes.

Amplifier	**MRF 182**	**LCR52**	**LCR129**
Output power (W)	10	7	9
Power density (W/mm)	0.15	0.73	0.94
Power gain (dB)	12.5	12.5	14
Drain efficiency (%)	30%	35%	38%
Compression (dB)	0.4	1.5	1
Ripple (dB)	1	1	1.5

B. Amplifier 2

The output power (Fig. 4) response showed a low gain ripple (0.3 dB) witch means a good impedance matching. Output values are less than expected (33 W instead of 40 W). The power gain is also smaller (6 dB). The drain efficiency is 55 %. We will come back on these performances inadequacy in paragraph IV-C.

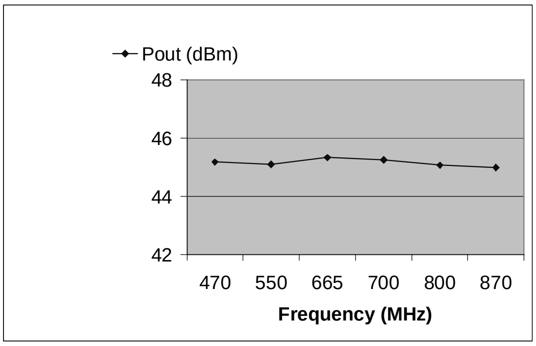

Fig. 4. Amplifier 2 power response.

C. Trapping effects

Performances of all these amplifiers are very promising. These performances were strongly limited by the drain current decreasing because of trapping effects. It was in particular valid for the amplifier 2. Two kinds of phenomena was observed:

The first one is a slow decrease of drain bias current. For example, for an amplifier not mentioned in this paper, the current was divided by two after 20 minutes operation. It was observed only for MESFETs without buffer or with a thin buffer layer. It could be explained by trapping of injected electrons in the substrate by deep acceptors.

The second one is a fast decrease of the static drain current when RF power is injected and increased, even for very low input power. It is a phenomenon located in the buffer layer and was observed only for a few samples with a thick buffer layer. Its explanation is more complex than the previous one.

These traps problems can't be resolved by an adequate choice of the buffer layer thickness. The solution lies in the improvement of doping and growth techniques[3].

VI- CONCLUSION

The silicon carbide is a good candidate for RF and microwave power applications and for taking over Silicon. The SiC MESFET characterization results showed a strong enhancement of its performances. Typical recent current density is 300 mA/mm and breakdown voltage over 200 V. The maximum oscillation frequency F_{max} which is about 20 GHz, was increased by using SI substrates. Our best power result is 45 W output power for a single chip at 1.5 GHz and 2.1 W/mm power density. The studied amplifiers prototypes are very promising. In particular access impedances are high and impedance matching are easier than LDMOS because of high bias voltage and high power density. A large increasing of the amplifiers output power is possible by increasing the gate width and the operating bias voltage. Power densities are nevertheless still far from what is currently expected (in the 3-4 W/mm range). Better results will be obtained when the technological process would be matured and trapping effects resolved. First measurements performed very recently on a new THOMSON LCR MESFET process allow to hope a solution of this problem. If it is confirmed, 100 W class and stable MESFET will be quite soon available.

ACKNOWLEDGEMENT

SiC technology and its applications were supported by EU (TELSIC ESPRIT Program), French Defence Administration (DGA) and French National Network for Telecommunication Research (RNRT).

REFERENCES

[1] A. W. Morse et al, "Recent application of Silicon Carbide to high power microwave", IEEE MTT'S Digest, 1997.

[2] S. T. Allen et al, "Progress in high power SiC microwave MESFETs", IEEE MTT'S Digest, 1999

[3] O. Noblanc et al "Power density comparison between microwave power MESFET's processed on conductive and semi-insulating wafer", ICSCRM'99, North Carolina, 1999.

[4] Tri T. Ha. "Solid state microwave amplifier design", John Wiley and sons, New York, 1981.

[5] O. Noblanc et al, "Microwave power MESFET on 4H-SiC", Diamond and related materials, 1997.

[6] J. F. Broch et al, "Power amplification with Silicon Carbide MESFET", Microwave and Optical Tech. Lett., volume 23, 1999

[7] E. Gebara et al, "Power characteristics of high voltage LDMOS transistors", EuMC, Paris, 2000.