Influence of passivation on High-Power AlGaN/GaN HEMT devices at 10GHz.

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ABSTRACT — AlGaN/GaN high electron mobility transistors (HEMTS on SiC) were characterized before and after SiO_2/Si_3N_4 passivation. DC, small signal, pulsed and large signal measurements were performed. We discuss the role and the influence of passivation on the device performance and characteristics. A good correlation is observed between pulsed and power measurements. At 10GHz, a 6.3W/mm power density with a 36% PAE at 2dB of compression was obtained after passivation, while only 2.9W/mm before passivation.

I. Introduction

AlGaN/GaN HEMTs are very promising candidates for future microwave power applications due to a combination of high breakdown voltage, high electron velocity, high current density and high thermal stability. Nevertheless, the power density performance of these transistors is limited by trapping effects during large signal operation at high frequency. This trapping effects lead to current collapse and an increase of the knee voltage [1]. In this paper, we have studied the influence of the SiO_2/Si_3N_4 passivation of AlGaN/GaN HEMT devices on Silicon Carbide substrate. This step is done to suppress or minimize the trapping effects [2]. A complete characterization has been performed under probes under dc, small signal, pulsed and large signal conditions before and after passivation. First, a brief description of GaN HEMTs fabrication is presented. Second, the main dc characteristics and small signal microwave measurements are summarized. Then, pulsed measurements and large signal characterization are described. Finally, the interest of the passivation step will be underlined.

II. Device structure.

The devices were processed on an AlGaN/GaN heterostructure grown by metalorganic chemical vapor deposition on SiC substrate. This epilayer has been provided by QinetiQ. The Figure.1 shows the epitaxial structure. The process steps were performed at TIGER. Firstly, the device was isolated by mesa etching using $SiCl_4$ RIE. Source and drain ohmic contacts were formed by Ti/Al/Ni/Au evaporation with thicknesses of 12/200/40/100nm and alloyed at 900°C for 30sec. TLM measurements gave a contact resistance between 0.2 and 0.3Ωmm. The Schottky mushroom gate was formed by Pt/Ti/Pt/Au evaporation and the subsequent lift-off process. The gate lengths were 0.15 and 0.25µm. Following first electrical characterizations, a SiO_2/Si_3N_4 passivation with respective thickness of 100 and 50 nm was deposited. Subsequent electrical characterizations were performed after SF_6 nitride opening.

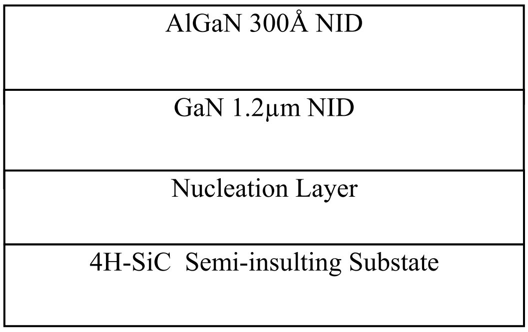

Fig. 1. Schematic drawing of the AlGaN/GaN HEMT layer structure.

III. DC and small signal microwave results.

Small signal characterization was performed with a vector network analyzer (VNA) HP8510 up to 40GHz and dc measurements were made with a HP4142A power supply. The same device was measured before and after passivation. Figure.2 shows a typical DC characteristics of a $2*50*0.15\mu m^2$ HEMT device and shows the influence of passivation. From these DC characteristics, small shifts are noted before and after passivation whatever the knee voltage and maximum drain current. First of all, after passivation, the drain current density is slightly increased from 1.25A/mm up to 1.3A/mm. A low knee voltage remained almost unchanged (Vknee # 3.2V).

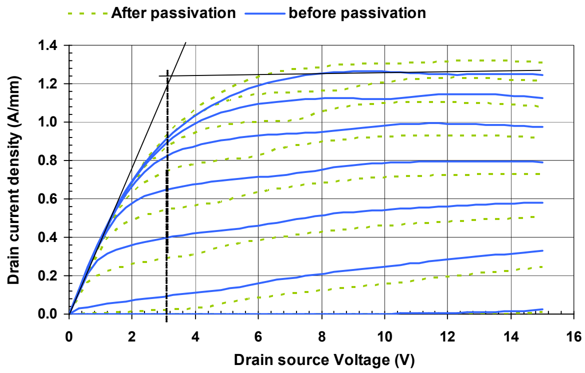

Fig. 2. Typical static Id (Vds) characteristics of a 2*50*0.15µm2 HEMT. The gate voltage was swept from -6V to 0V before passivation and -7V to 0V after passivation.

Nevertheless, larger shifts were observed on the threshold voltage and the value and the position of the maximum transconductance. The threshold voltage shifted from –6.3V to –7.5V after passivation. This shift is shown on Figure.3 by the transfer characteristics of the device. This passivation scheme was designed to be strain free and the shift in threshold voltage should not be attributed to strain. Therefore, we think that the shift was due to charge redistribution in the structure after the passivation process. Moreover, the transconductance shape of this device could be very interesting for high power and high linearity because G_m was remaining high over a large gate source voltage range.

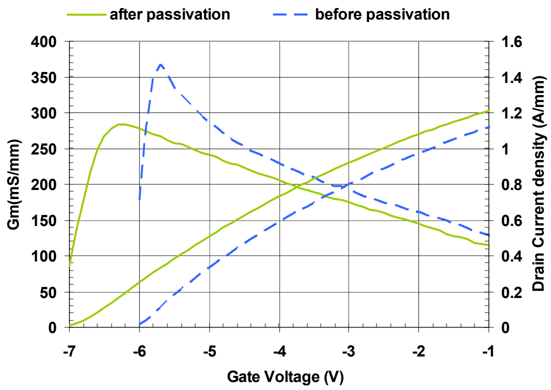

Fig.3. Transfer characteristics at Vds=15V before and after passivation of a 2*50*0.15µm^2 AlGaN/GaN HEMT.

The scattering parameters were measured on-wafer up to 40GHz using a vector network analyzer and a LRM calibration. Table.1 summarizes the main small signal characteristics and performances of the same device. This table shows that passivation has a slight effect on the current gain (F_t) and maximum power gain (F_{max}) cut-off frequencies. The electrical equivalent scheme will be extracted in order to explain these behaviors. In table.1, the gate voltage is chosen to obtain the maximum value of the current gain cut-off frequencies.

Passi-vation	Bias condition	H_{21}(dB) at 10GHz	F_T (GHz)	F_{MAX} (GHz)
Before	V_{ds}:15V V_{gs}:-5V	14.2	50	96
After	V_{ds}:15V V_{gs}:-5.5V	13	44	89

Table 1: Main Small signal results of a 2*50*0.15µm^2 HEMT on SiC substrate before and after passivation.

IV. Pulsed measurements and large signal characterisation.

Before load-pull characterization, pulsed measurements were carried out in order to predict the output power density we could expect under large signal conditions. The small signal pulsed characterization was performed with the pulsed vector network analyzer Wiltron 360B and test set 3636 up to 20GHz. The DC pulsed measurements were made with a specific equipment developed in our laboratory. For more details, the setup is described elsewhere [3].

We chose pulse duration of 500nsec shorter than the time constant of most traps and the duty cycle was fixed at 10µsec to have a good dynamic for the S parameters measurements. Two quiescent bias points have been chosen:

- V_{ds0} = 0V, V_{gs0} = threshold voltage.
- V_{ds0} = 15V, V_{gs0} = threshold voltage.

These two quiescent bias points permitted to simultaneously eliminate the thermal effects and reveal the trapping effects (cold polarization) [4].

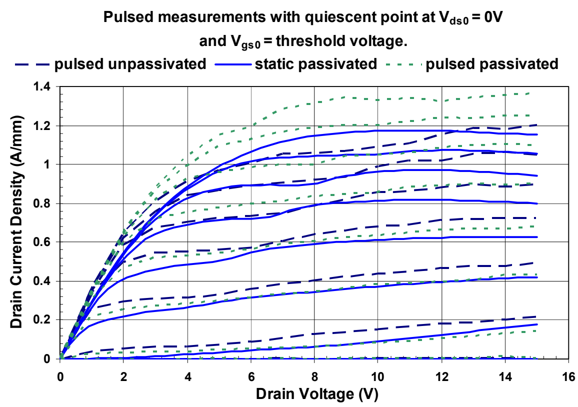

Fig.4 Static and pulsed I-V characteristics of GaN/AlGaN/GaN HEMT before and after passivation (static: passivated only). The gate voltage was swept from -6V to 0V before passivation and -7V to 0V after passivation.

The Figure.4 shows firstly the thermal effect on passivated devices by comparing the DC conditions and pulsed conditions. This effect involves a decrease of the access resistances and an increase of the maximum drain current density. Secondly, the beneficial effects of the passivation are clearly demonstrated on this Figure.4 because the gate lag is reduced after passivation. Then, a second quiescent bias point was chosen to mainly study the drain lag and hence to be close to the power bias conditions (Fig.5). Here, comparing passivated and unpassivated devices with pulsed measurement, the beneficial effect of the passivation is clearly demonstrated. An increase of the maximum drain current and output resistance in linear regime is obtained on the same sample for the same quiescent bias point between the unpassivated and passivated device.

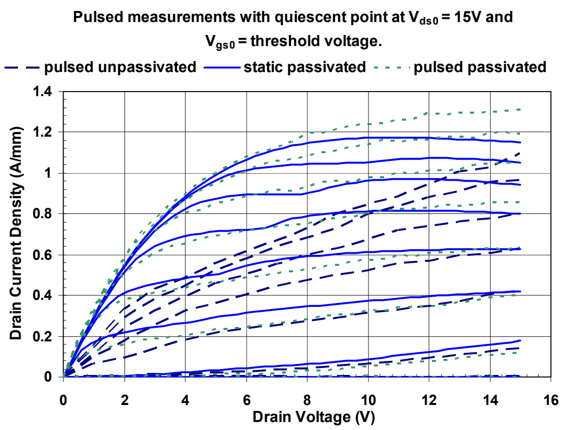

Fig.5 Static and pulsed I-V characteristics of GaN/AlGaN/GaN HEMT before and after passivation (static : passivated only). The gate voltage was swept from -6V to 0V before passivation and -7V to 0V after passivation.

Then, large signal measurements were made under probes at 10 GHz using an automatic tuner from Focus Microwaves. This load-pull characterization was made before and after passivation. In agreement with pulsed measurements, load-pull characterizations showed a strong improvement of the maximum output power density [5]. Moreover, Figure.6 shows a linear dependence of the output power at 2 dB of compression versus the drain source voltage. This shows the strong improvement provided by this optimized passivation process on the microwave power performances. At 30V, we have obtained at 10GHz the following results, an output power density at 2 dB of compression of 6.3W/mm, a linear power gain of 10dB and with a PAE of 36%.

This results shows that the passivation of the surface has a strong influence on the power performance of AlGaN/GaN HEMT. In particular, drain lag effects were dominating the device behavior before passivation (Fig.5) and were suppressed by passivation. This allowed to obtain excellent power performance. This demonstrates that surface plays an important role in the device performances of AlGaN/GaN HEMTs.

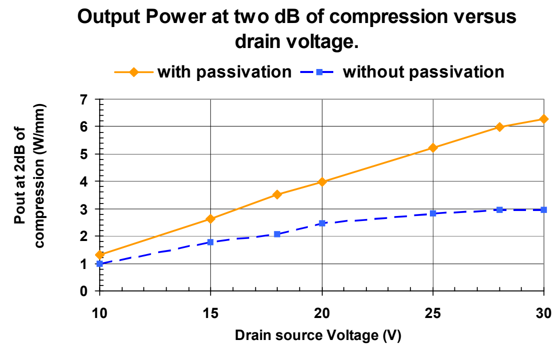

Fig.6 Evolution of output power density at 2dB of compression versus drain source voltage for passivated and unpassivated devices

V. Conclusion.

The effect of an optimized passivation step has been clearly demonstrated either under pulsed conditions or large signal measurements. A good correlation has been established between these two kinds of measurements.This passivation step allows to strongly decrease the drain lag effect which gives rise to an increase of the output power density. In these conditions, on this wafer, at 10GHz an output power density at two dB of compression of 6.3W/mm has been measured after passivation and 2.9W/mm before passivation. Moreover this demonstrates that SiO_2-based passivation can be as efficient as Si_3N_4 one.

Acknowledgement

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