Increased reliability of AlGaN/GaN HEMTs versus temperature using deuterium

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Abstract— **Low frequency noise (LFN) is a reliable diagnostic tool to evaluate and locate the defects of a technology. In this study, LFN is used to assess effects of deuterium (H^+ ions) in diffusion condition on the robustness of 0.25 *2*75 µm² gate area AlGaN/GaN high electron mobility transistors (HEMT) grown on Si substrate. H^+ Ions are diffused from the above AlGaN/GaN layer through the AlGaN/GaN interface and GaN layer, notably under the gated channel where the defects are located. Two batches of devices are stressed under high temperature condition at 400°C during 5 minutes (step 1) and 500°C during 15 minutes (step 2). The first batch is composed with 8 deuterated transistors while the second batch is composed with 8 non deuterated transistors. Static measurements and low frequency noise spectral density measurements of the drain current (S_{ID}) are examined after each step of temperature. The first step does not reveal any degradation, while the second step highlights significative differences between the deuterated and non deuterated devices: LFN of deuterated devices remains constant, whereas LFN of non deuterated devices increases (GR superimposed with 1/f flicker noise). The deuteration of the devices can open the way to robust temperature devices, as AlGaN/GaN HEMT are dedicated to applications at high power and high temperature.**

I. INTRODUCTION

The development of wideband gap technology is convenient for integrated circuits design such as VCO and LNA. AlGaN/GaN high electron mobility transistors stand as promising candidates to substitute GaAs and SiGe technologies for power applications at high frequency. They take advantages from a higher breakdown voltage, higher power density and higher thermal conductivity that are suitable for power applications while keeping good carrier mobility for high frequency applications. Recent studies revealed also very good low noise performances for this technology [1] [2]. Thus, GaN devices can pretend to be used in transceivers for power amplification, for low noise amplification and for frequency synthesis (voltage controlled oscillation) over a wideband of frequencies ranging from L up to Ka band.

LFN measurements provide valuable information about noise source location and failure prediction [3], and can also assess devices robustness. In a previous work, deuterium has been used as a probe in diffusion condition to locate the defects density at the AlGaN/GaN interface as well as in the GaN 2DEG using SIMS (Secondary Ions Mass Spectrometry) measurements [4]. This result corroborates interpretations from LFN measurements for devices grown on SiC substrate [5] [6]. In this work, we focus on the effects of deuterium on AlGaN/GaN HEMT devices under thermal stress in order to improve devices robustness. LFN and static measurements are performed at two time and temperature steps to evidence the different behaviours between the deuterated devices and the non-deuterated devices .

II. ALGAN/GAN HEMT ON SI

HEMT devices are grown by MOCVD techniques on silicon substrate using the AlGaN/GaN HEMT TIGER usual process. Transistors feature 0.25*2*75 µm² gate area and 24% alumina content.

For this study, deuterium is brought in a half of the wafer before gate deposition, while the second half is finalized without deuterium. After this process step, deuterium is located in AlGaN/GaN layer (from source to drain) and diffuses toward the GaN layer by means of a RF plasma (3W during 30 minutes at a temperature of 300 K) (figure 1).

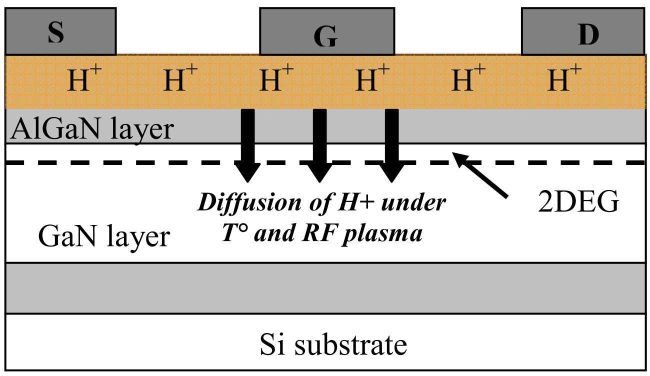

Fig. 1 Deuterium diffusion in AlGaN/GaN structure

III. INITIAL MEASUREMENTS

Initial static and LFN measurements are performed on each batch of samples (15 deuterated devices for “batch 1” and 58 non-deuterated devices for “batch 2”). No significant difference is found between the deuterated and non deuterated samples before the application of the temperature stress, neither on the DC characteristics (I_{dss}, V_T, R_{on} …), nor on the LFN spectra. A slightly higher drain current on batch 1 can be attributed to an increase of the charge density due to the deuterium diffusion. The two batches have equivalent R_{on} of 34,5 Ω (meaning value) and an I_{dss} of 100 mA and 105 mA respectively for the meaning value of batch 2 and batch 1(figure 2).

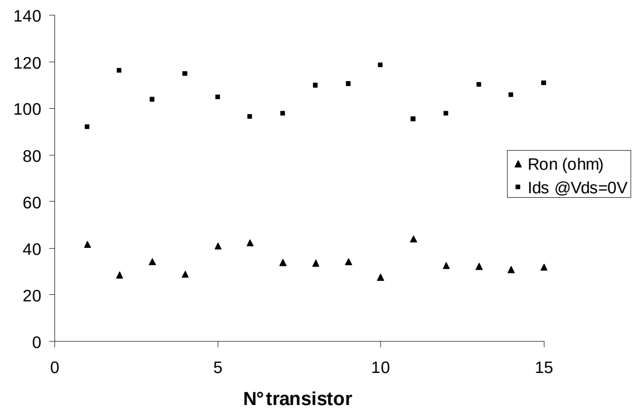

Fig. 2 DC characteristics repartition of devices from batch 1

S_{ID} spectra, measured at V_{GS}=-3 V and V_{DS}=10 V feature a $1/f^{\gamma}$ behaviour (with γ=1,27) (figure 3).

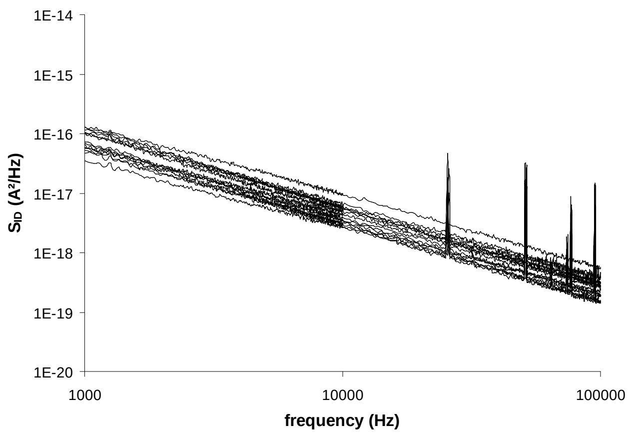

Fig. 3 S_{ID} spectra repartition of batch 1

We can conclude about the initial good homogeneity of the two batches. Next, two batches of 8 transistors, representative of each initial batch are chosen for the study.

IV. THERMAL STRESS

A. *Stress conditions*

First, the two batches are thermally stressed at 400°C during 5 minutes in an air oven (step 1), above the classic deuterium diffusion temperature (300°C). Then, temperature is elevated at 500°C during 15 minutes (step 2). All devices are measured at T_0 (initial), T_1 (step 1) and T_2 (step 2).

B. *Results and discussion*

Static measurements reveal a decrease of drain and gate leakage currents after each step. The decrease of leakage current can be attributed to the improvement of surface states induced by thermal annealing.

After step 1, constant or improved (slightly lower) spectra are measured for both batch 1 and batch 2: it thus cannot be attributed to deuterium effects. This is probably due to AlGaN/GaN interface improvement during the burn-in phase.

Step 2 represents harder stress conditions applied to the samples of each batch. However, no degradation is measured on DC characteristics and LFN spectra for the deuterated structures (figure 4).

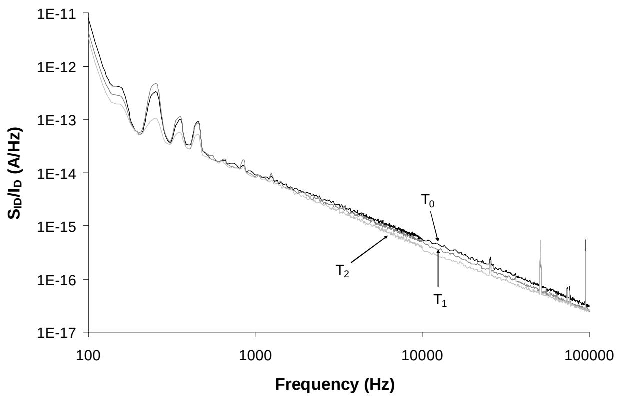

Fig. 4 S_{ID} spectra at T_1, T_2 and T_3 of deuterated device

Samples from batch 2 systematically have their LFN spectra degraded after this step 2, with different degradation signatures: the flicker noise $1/f^{\gamma}$ source increases for some devices, while LFN spectra of some other devices have changes on their frequency index γ. Whatever the variation of the flicker noise source, all the devices from batch 2 suffer from the apparition of a trapping-detrapping noise source (G-R center) (figure 5). These defects for devices of batch 2 are attributed to the lower crystal quality under the gate (where the defects are located). Temperature plays here a strong role in the activation of new noise sources.

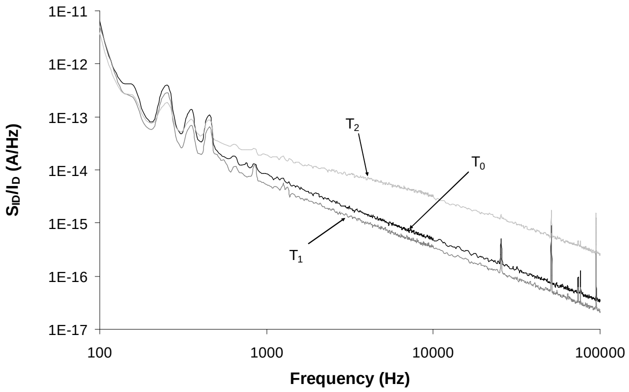

Fig. 5 S_{ID} spectra at T_1, T_2 and T_3 of non deuterated device

The devices from batch 2 seem to be sensitive to different degradation mechanisms and their LFN spectra systematically degrades whatever the cause. The investigation on the comprehension of the degradation mechanisms is not in the scope of this study as we propose here the evidence of deuteration effect on the devices robustness improvement.

Recent studies [3][5][6] have already underlined traps location at the AlGaN/GaN interface and in GaN bulk (2DEG) under the gated channel. Temperature activates defects for devices without deuterium in the noisy part of the device (batch 2), and the devices degrades. Transistors with deuterium in the channel under the gate (batch 1) do not suffer from any degradation: H^+ seems to passivate the defects, and the devices are thus more reliable.

V. CONCLUSION

Conspicuous effect of deuterium on devices robustness seems to offer a new solution to improve the reliability of GaN devices. We have evidenced the effect of deuterium diffusion in the noisy part of the devices on the low frequency noise spectra. Deuteration can open the way to more temperature-robust GaN technologies, but other investigations must be driven using different stress and bias conditions.

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