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Gate Defects in AlGaIn/GaN HEMTs Revealed by Low Frequency Noise Measurements

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Abstract—From the last decade, Nitride-based High Electron Mobility Transistors (HEMTs) have demonstrated excellent electrical and noise performances to address transceivers modules. Within this paper, a discussion on the low frequency noise on the gate access (i.e. gate current spectral density S_{IG}) in the frequency range of 1Hz-100kHz is presented. S_{IG} spectra reveal different signatures according to the configuration of biasing of the transistor, and to the dimensions of the transistor: the noise of the Schottky diode is studied alone (under open drain configuration), and compared with S_{IG} of the transistor biased in the saturated region (at $V_{DS}=8V$). Two designs of devices are tested: research-level devices featuring single gate finger are compared with commercial devices featuring four gate fingers, where each finger is four times larger (i.e. 16 times larger gate width than research level devices). The two sets of devices followed the same fabrication process. It is found that whatever the sizing and the gate pad configuration of the devices, the LFN spectra observed on each set of transistors feature identical signatures. The leakage carriers are following the same path between the gate and source accesses. LFN can be used as an accurate tool to discriminate between conduction mechanisms of devices, and to help to understand what are the underlying mechanisms leading to the conduction of the Schottky diode (and thus to its degradation). Moreover, it is shown that the S_{IG} measurements under transistor biasing conditions can be correlated to the gate current spectral density in diode mode: the leakage current zone can also be tracked under this biasing operating mode.

Keywords—AlGaIn/GaN HEMT; gate access; gate leakage current; Schottky diode; low frequency noise; gate conduction mechanisms; current power law.

I. INTRODUCTION

The study of AlGaIn/GaN HEMTs is of great interest due to its application fields for high power, high frequency and high power added efficiency for highly integrated circuits [1]. These HEMT devices have shown promising results [2-6], but the gate access remains a critical key point considering the reliability of the devices. The gate conduction mechanisms are usually pointed out to be the main limiting parameter leading to failures in AlGaIn/GaN HEMTs. This paper focuses on the gate access of two sets of devices; research-level mono-finger devices with small dimension and commercial large finger devices (total width W_G 16 times larger). Low frequency noise (LFN) measurements are performed on the two sets of devices under reverse bias conditions. The Schottky diode is studied

alone (under open drain configuration) and then the devices are measured in transistor mode at $V_{DS}=8V$. The LFN technique as reported in the literature [7-10] is a rigorous investigation technique on the noise behavior of the device that measures the current fluctuations, at the gate access (related respectively to the gate current) and also at the drain access (not presented here), as well as the possible correlation between the accesses to verify if the two accesses' spectral densities can be interpreted alone or not. It is a non-destructive technique and can reveal the presence of several different noise sources (1/f, thermal noise floor, and also several trapping-detrapping processes).

The paper is organized as follows. In section II, we precisely describe the differences of the devices structures, even if the technological process and masks are the same. In the same section, the experimental conditions are also mentioned. Section III reports on the LFN measurements on gate currents, whereas, section IV sets the conclusions drawn from the study.

II. DEVICES UNDER TEST AND EXPERIMENTAL CONDITIONS

The AlGaIn/GaN HEMTs under test are fabricated at United Monolithic Semiconductors (UMS) [11]. They are grown on SiC substrate and feature 18% of Al content in the high bandgap layer. The surface is SiN passivated and the Schottky contact is formed by deposition of Ni/Pt/Au. Two sets of devices are tested (the fabrication process is similar for both sets of devices under test):

- #A: Mono-finger research-level devices ($1 \times 100 \mu\text{m} \times 0.5 \mu\text{m}$) as shown in Fig. 1a. Two declinations are proposed for these devices: devices with and without field plate are measured to highlight on the impact of the field plate on the electrical and noise performances. As the results are similar for both electrical and LFN measurements on the gate current, only the structures with field plate will be presented next.
- #B: Commercial declination of the HEMTs under study as proposed for the final design for applications. These devices feature four gate fingers, with individual gate width four times larger than devices from #A ($4 \times 400 \mu\text{m} \times 0.5 \mu\text{m}$) as shown in Fig. 1b. These devices are proposed only under the field plate

version, but experiments on #A devices have cleared up the absence of impact of such a structure on noise characteristics. This set is composed of devices presenting high (#B_L) and low (#B_NL) gate leakage currents (with an average ratio of $\times 3.5$ between leaky and non-leaky devices).

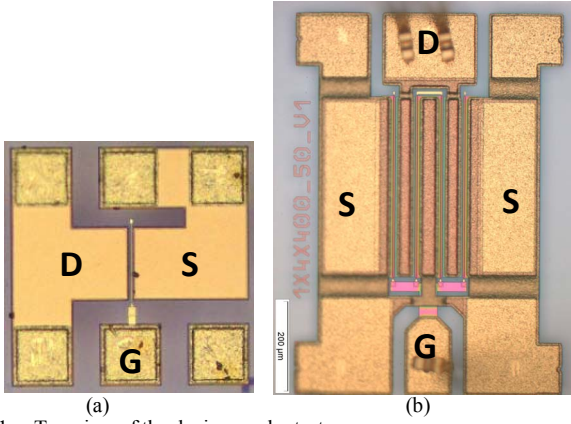


Fig. 1. Top view of the devices under test. (a) Picture of the devices with single gate finger. (b) Picture of the devices featuring four gate fingers.

DC current voltage measurements are performed using an Agilent 4156C. Fig. 2 shows $I_G(V_{GS})$ characteristics of the Schottky diode (open drain) and of the transistor when V_{DS} is biased from 0V to 8V. Diode with shorted drain has also been measured and features the same trend as with open drain (with a slight increase on I_G). This study focuses on the two extreme I_G plots extracted from our measurements (the diode alone and the transistor at $V_{DS}=8V$).

The LFN measurements are performed at room temperature in the frequency range of 1Hz to 100kHz using Model 5182 transimpedance amplifier in a shielded room to reduce interference with the external environment. The amplifier is connected to HP89410A analyzer and to a computer program to monitor and collect the results. The measurements are carried out under reverse biases on the

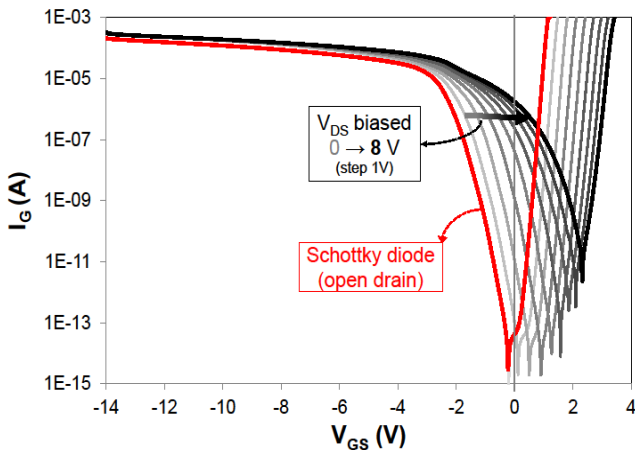


Fig. 2. DC I_G - V_{GS} gate characteristics of the Schottky diode (red solid line) and of the transistor biased from $V_{DS}=0$ to 8V with $\Delta V_{DS}=1V$ (grey to black characteristics).

Schottky diode (open drain configuration) and when the transistor is biased at $V_{DS}=8V$.

III. GATE CURRENT LFN CHARACTERIZATION

The measurements are performed on the mono-finger devices (#A) and on the leaky (#B_L) and non-leaky (#B_NL) devices at $V_{GS}=-2, -3, -5, -7$ and $-9V$. The evolution of the gate current low frequency noise S_{IG} spectra is presented in Fig. 3 for #A device alone. Fig 3a shows the measurements carried out under open drain configuration, whereas Fig. 3b illustrates the measurements when the transistor is biased at $V_{DS}=8V$.

The measurements performed on the three sets of devices under both configurations (on the Schottky diode and on the transistor) exhibit a $1/f$ trend superimposed with many generation-recombination centers (from 3 up to 15 GR centers). From the raw values taken at a frequency of 100 Hz,

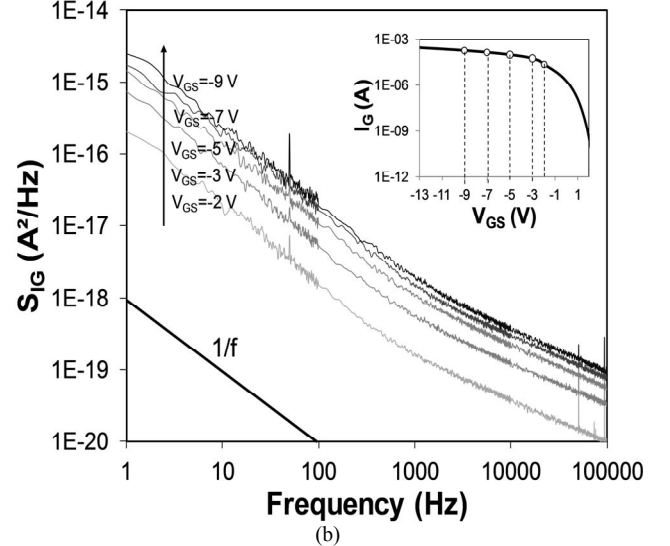
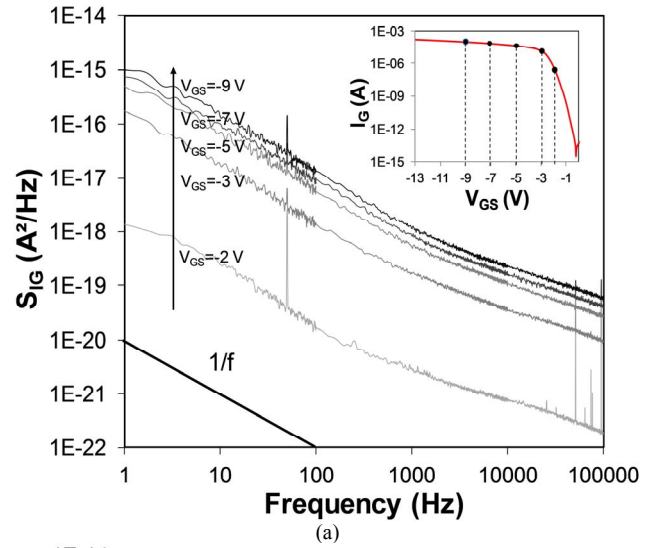


Fig. 3. Gate noise current spectral density of the #A AlGaIn/GaN HEMT (a) of the Schottky diode (open drain). (b) of the transistor biased in the saturation region at $V_{DS}=8V$. Insets: reverse gate I_G - V_{GS} characteristics featuring gate biases where S_{IG} LFN measurements are carried out.

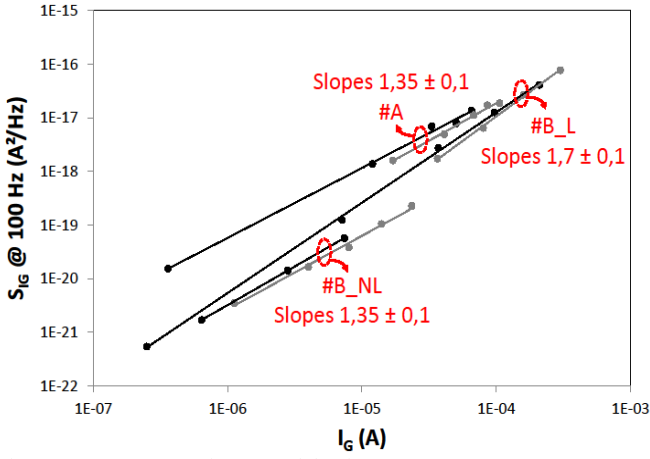


Fig. 4. Gate current noise spectral density (S_{IG}) at 100Hz versus gate current (I_G) for the Schottky diode ($-9V \leq V_{GS} \leq -2V$, black plots) and for the transistor ($V_{DS}=8V$, $-9V \leq V_{GS} \leq -2V$, grey plots).

the evolution of the magnitude of a generation-recombination (GR) center is extracted for every bias. Fig. 4 shows the dependence of the gate current noise spectral density (S_{IG}) when the gate current (I_G) varies. An I_G power law of 1.35 ± 0.1 is found for the diode and for the transistor both for the monofinger (#A) and for the non-leaky device (#B_NL) [12]. A different power law of 1.7 ± 0.1 is found for the leaky device (#B_L).

Fig. 5 shows the gate current spectral density S_{IG} normalized as $S_{IG}/I_G^{1.3}$ for #A and #B_NL devices and as $S_{IG}/I_G^{1.7}$ for #B_L corresponding to $I_G^{1.3}$ and $I_G^{1.7}$ respective power laws as presented in Fig. 4. This identical signature observed for the diode ($-9V \leq V_{GS} \leq -5V$) and for the transistor ($-9V \leq V_{GS} \leq -2V$) can be imputed to the same noise sources, and to the same path where the electrons flow from the gate to the source and from the gate to the drain accesses [12]. The leakage current responsible for I_G is of the same nature for the diode (under high reverse biases) and for the transistor (regardless the gate bias and at $V_{DS}=8V$). Low leakage #B_NL large devices and low leakage #A small devices share the same power law over the whole frequency range, whereas another type of leakage is involved in leaky #B_L large devices. Consequently, the devices driven under high reverse bias conditions will be sensitive to different leakage mechanisms and thus to different degradation modes under the application of stresses such as HTRB (high thermal reverse bias) stress for example. However, even if sharing the same power law, the spectra differs from #A structures to #B_NL devices. This indicates that different GR (visible in the lower frequency range of #B_NL) appears (Long term memory effects).

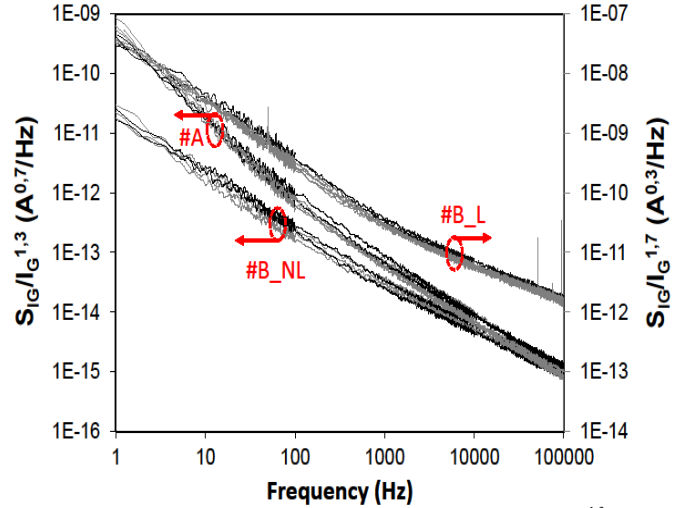


Fig. 5. Normalized gate current noise spectral density $S_{IG}/I_G^{1.3}$ for the Schottky diode under high reverse biases ($-9V \leq V_{GS} \leq -5V$, black plots), and for the transistor ($-9V \leq V_{GS} \leq -2V$, grey plots) for #A, #B_NL and #B_L devices.

IV. CONCLUSION

Gate current low frequency noise measurements of AlGaIn/GaN HEMTs grown on SiC substrate are investigated under two different configurations: The Schottky diode alone (open drain) and when the transistor is biased in its saturated region at $V_{DS}=8V$. The methodology applied is a good indicator to discriminate between the gate leakage paths for devices featuring differences on their dimensions (large and small gate dimensions), and leakage levels. It is found that gate leakage currents are sensitive to the same power law for both biasing configurations (diode or transistor mode), with an exact superimposition of the spectra versus frequency for different biasing conditions; this is attributed to common electron path between gate to source and gate to drain accesses.

On the other hand, the 3 sets of devices feature different behaviors:

- #A and #B_NL sets of devices show a power law of $I_G^{1.3}$, with a same leakage trend even if GR centers are not exactly the same
- #B_L set of devices presents an $I_G^{1.7}$ power law. This represents a radically different leakage mechanism, which also reveals likely different activation energy after the application of a stress.

The present study proves the needs to control and study the gate access performances through its technological structure. The evidence of different conduction mechanisms observed on the devices under test is useful to identify the electrical parameter to be monitored during the application of a stress to discriminate between early failures and long term stability devices.

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