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# Dynamic $R_{DS-on}$ degradation analysis on power GaN HEMT by means of TCAD simulations and experimental measurement.

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## Abstract

This paper deals with the dynamic  $R_{DS-on}$  degradation of GaN HEMT for 650V application. An overview of different parameters impacting the performances of the devices were investigated experimentally. From temperature dependent characterisations the main trap at the origin of the degradation could be extracted. The signature of carbon in the GaN buffer could be confirmed by TCAD simulation, where the same trends were reproduced.

## Introduction

Gallium Nitride (GaN) high electron mobility transistors (HEMTs) has been widely accepted in power application due to their high current and voltage capabilities. However, due to the nature of hetero epitaxy, the GaN present numerous defects that can impact the electrical performances of the devices [1], such as the well-known on-resistance ( $R_{DS-on}$ ) degradation [2]. This effect has been widely documented and many trap signatures were extracted [3, 4]. In order to sustain the high voltage and limit the leakage currents in the GaN buffer, iron (Fe) or carbon is introduced [5]. However, the introduction of these species generates traps that could affect the RDS-on performance.

In this paper, we deal with the evaluation of RDS-on degradation on GaN HEMT for 650V applications by monitoring the RDS-on recovery following a high voltage stress. The performance degradation, attributed to carbon, could be reproduced by TCAD simulations.

## Experimental setup

Experimental characterizations were performed on D-mode power AlGaIn/GaN HEMT for 650V applications on 8 inches wafer on Silicon substrate. The tests were performed with the high voltage / high current fast switch (N1267a) option of the Keysight B1505a associated to a semiautomatic probing station. Temperature control was possible thanks to the thermally regulated chuck.

We were able to monitor the  $R_{DS-on}$  variation of the HEMT after an off-state drain bias for different conditions: drain bias, stress duration and temperature.

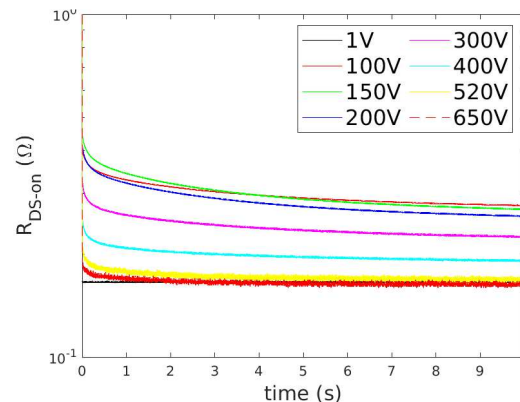


Fig. 1.  $R_{DS-on}$  variation after a stress of 1min at different off-state drain biases

## Experimental results

Figure 1, representing the  $R_{DS-on}$  variation at 100°C after a stress of one minute shows a degradation of  $R_{DS-on}$  several time higher than static value ("1V"). The degradation is more pronounced at lower  $V_{DS}$  stress (100 and 150V) with a recovery in the order of ten seconds and is less pronounced at higher stress voltage.

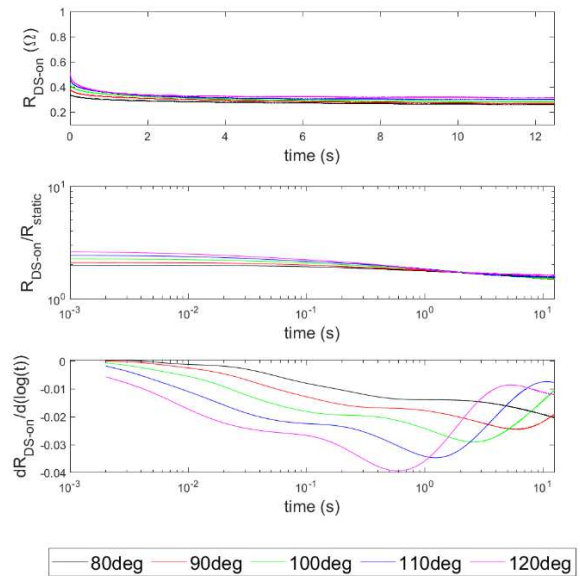


Fig. 2. RDS-on variation after a stress of  $V_{DS}=100V$  for 1min at different temperatures

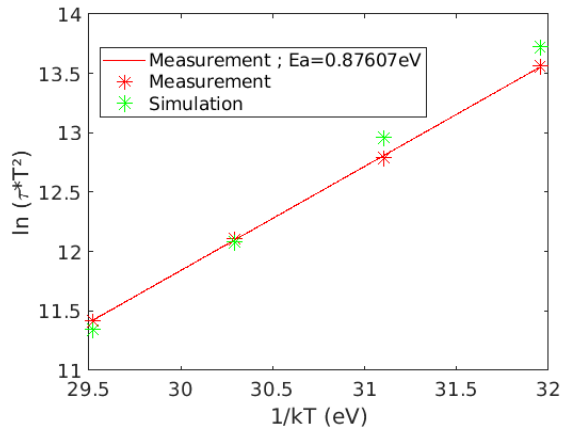
Figure 2 presents the  $R_{DS-on}$  recovery for a 100V stress at different temperature. A higher  $R_{DS-on}$  value just after the stress and an accelerated recovery at higher temperature is a sign of a thermally activated mechanism. On Figure 2 is also represented the derivative of the  $R_{DS-on}$  as a function of  $\log(t)$ . The curves show a minimum corresponding to the main time constant of the  $R_{DS-on}$  recovery.

From the time constant extracted at different temperatures, we could extract an activation energy of 0.88eV (figure 3). This energy should be assigned as a carbon related trap that is present inside the buffer layer [6, 7].

## Simulations

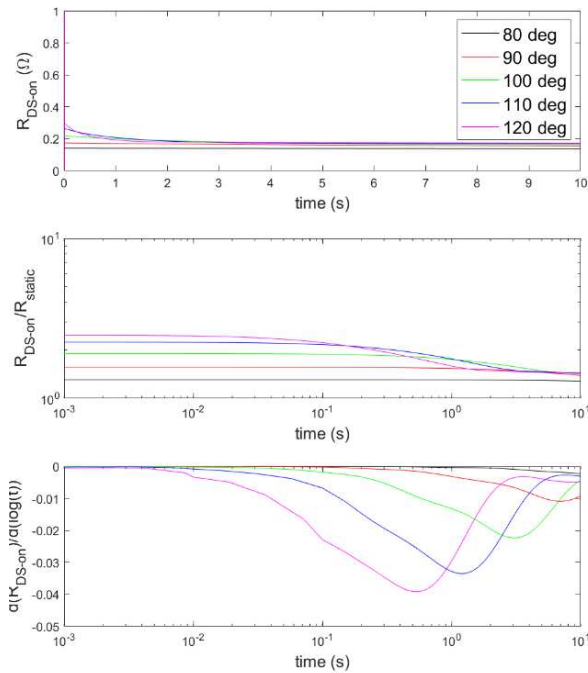
TCAD simulations were performed with same electrical conditions to reproduce the  $R_{DS-on}$  degradation observed experimentally. Acceptor with activation energy of 0.9eV from valence band were used in the GaN buffer; the trap capture cross section was used as a fitting parameter. This buffer is partially compensated by shallow donor, modeled by N-type doping.

We also used the standard piezo-electric polarization model based on Ambacher [8] theory, as well as SRH recombination for traps. We also considered the temperature dependence mobility degradation due to phonon scattering.



**Fig. 3.** Arrhenius plot from main trap mechanism: measurement with activation energy, and simulation

Figure 4 shows the transient of simulated  $R_{DS-on}$  after a stress of 100V for different temperatures. Same trends could be observed with measurements in terms of variation with time and amplitude. Maximum degradation magnitude was adjusted to experimental data by varying the acceptor traps concentration in the GaN buffer.



**Fig. 4.** Simulated  $R_{DS-on}$  recovery after a drain stress of 100V for 1min.

From derivative spectrum also represented figure 4, we were able to represent the results on the Arrhenius plot on figure 3. Good fit with measurement can be observed, confirming the origin of the trap that is the cause of the main  $R_{DS-on}$  degradation.

**Conclusions**

On this paper, we analysis the  $R_{DS-on}$  degradation on power HEMT by means of characterizations and simulations. The measurement on different biases and temperatures allowed us to identify the worst stress conditions for dynamic RDS-on degradation and thanks to simulations, we were able to identify the cause.

Thank to this analysis, we have now a better understanding of the mechanisms of the  $R_{DS-on}$  degradation. With the help of TCAD simulations, we could improve the transistor design to mitigate this effect.

**Acknowledgments**

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