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Monitoring Dynamic Resistance of AlGaN/GaN Schottky Diodes After Quasi-Static and Hard Switching Stresses

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Abstract—The development of gallium nitride (GaN) components is one of the most noticeable advances in power electronics and for high-frequency applications. Nevertheless, GaN components are not yet totally reliable, mainly because of the trapping phenomenon which affects the static characteristics of GaN components, including the on-state resistance. Dynamic resistance degradation studies have been carried out, for quasi-static and hard switching (Double Source Test: DST) stresses. The results show the influence of the reverse stress voltage and hard switching on the characteristics of the AlGaN/GaN Schottky diodes.

Keywords— Trapping; quasi-static stress; hard switching; Double Source Test; AlGaN/GaN Schottky diodes.

1. Introduction

Gallium nitride (GaN) owns very interesting electrical properties for applications in power electronics. Indeed, GaN has a wide-band gap, a high critical electric field ($E_c = 3.4 \text{ MV.cm}^{-1}$), which is defined as the maximum field in a junction at the onset of avalanche breakdown, and high electron mobility, which makes it possible to have GaN-based components that operate at a high switching frequency with a high breakdown voltage ($> 650 \text{ V}$) and low on-resistance. Nevertheless, GaN-based components are not yet reliable, because of the various phenomena which affect the behavior of these components, such as trapping/de-trapping and the hot electron phenomenon which affects the dynamic resistance [1][2]. Therefore, it is necessary to know the undesirable effects of power electronics devices to predict possible dysfunctions during their use in real conditions.

This article aims to study the evolution of dynamic resistance after a period of stress. Two types of stress are targeted on

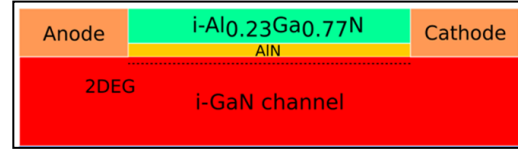


Fig. 1 Schematic device structure of the AlGaN/GaN lateral Schottky diodes such as the anode is a schottky contact and the cathode is ohmic

AlGaN/GaN lateral diodes (650V) received from STMicroelectronics (Fig. 1):

- Quasi-static stress: application of DC voltage in reverse while the component is in the off state during a time t_{off} ;
- Hard switching: impose a series of hard switching on the component, with a time in the off state corresponding to ΔT_{off} .

The on-resistance is measured after each type of stress, and the robustness of the component against trapping caused by these stresses can be determined. The DUTs used in the paper came from a research project where 650 V Schottky GaN diodes are only test vehicles, but results are similar to those observed in HEMT studies [3][4].

Quasi-static stresses are carried out using the Keysight B1505 curve tracer and hard switching will be carried out with a measurement circuit developed within the Ampère laboratory: The Double Source Test (DST).

2. Quasi-static stress

Quasi-static stress aims to observe the evolution of the dynamic resistance and the threshold voltage of AlGaN/GaN diodes when subjected to reverse electrical stress cycles. By applying electrical stress in reverse, negative charges can be placed near

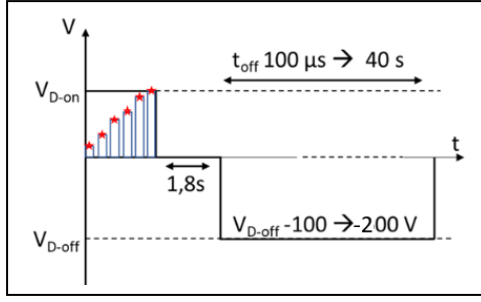


Fig. 2 Quasi-static stress measurement protocol. The red stars represent the time when the current is measured

the 2DEG channel which will be compensated to maintain the neutrality of the charges in this area. This compensation is achieved by a decrease in the concentration of charges in the 2DEG which induces a variation of the dynamic resistance in the ON state.

The experiment consists of applying a forward voltage to the diodes followed by a reverse DC voltage to study the behavior of the diode after stress (Fig. 2).

The measurement parameters are:

- $V_{D-on} = 1.5 \text{ V}$, with $t_{pulse} = 200 \text{ } \mu\text{s}$, $\tau_{repetition} = 50 \text{ ms}$ and pulses = 10 mV
- Current measurement at V_{D-on}
- Variation of V_{D-off} : $-100 \text{ V} \rightarrow -200 \text{ V}$
- Variation of t_{off} : $100 \text{ } \mu\text{s} \rightarrow 40 \text{ s}$
- Study of the influence of stress on the current at V_{D-on}

Cycles of 10 stress pulses were performed on a 6 A diode (650 V), for a voltage V_{D-off} of 100 V and 200 V in reverse and a t_{off} period of 1 s and 20 s.

For stress of $t_{off} = 1 \text{ s}$, the on-state resistance at 2 A, the threshold voltage at 10 mA, and the current at 1.5 V are calculated to determine the influence of stress on these parameters. The anode current shows a decrease of 4% after the 10 stress pulses at $V_{D-off} = 100 \text{ V}$ and the R_{dyn} increases from 122 mΩ to 125 mΩ (an increase of 2.2%) (Fig. 3). After that, additional 10 stress pulses have been applied at $V_{D-off} = 200 \text{ V}$, where it can be noticed that the anode current continues to decrease and the R_{dyn} increases by 6% compared to the dynamic resistance in the initial state (before stress). Fig. 4 shows the evolution of the dynamic resistance after the stress of 100 and 200 V and $t_{off} = 20 \text{ s}$,

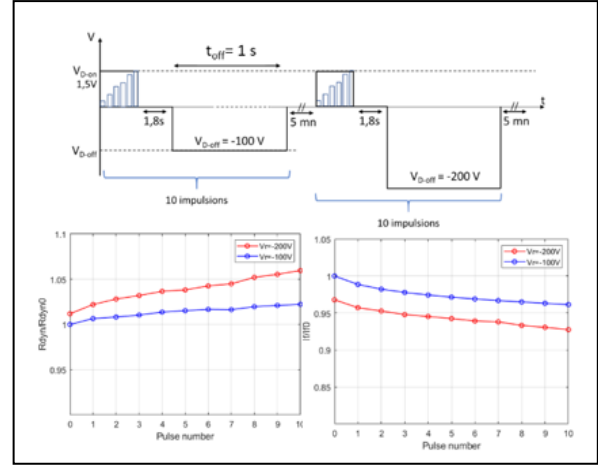


Fig. 3 Quasi-static stress for $V_{D-off} = -100 \text{ V}$ and -200 V and $t_{off} = 1 \text{ s}$.

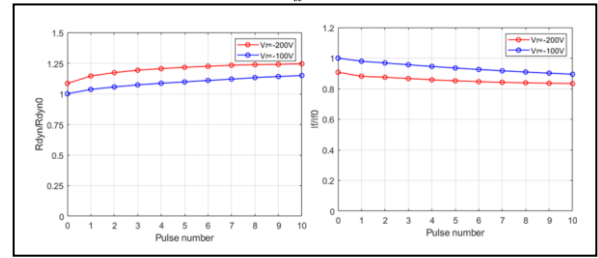


Fig. 4 Quasi-static stress for $V_{D-off} = -100 \text{ V}$ and -200 V and $t_{off} = 20 \text{ s}$

where one can notice that the current in the anode decrease and the R_{dyn} increases by 25 % compared to the dynamic resistance in the initial state.

The results show a degradation of the on-state resistance for electrical stresses of 100 V and 200 V and, moreover, the level of the degradation changes by varying the time of the stress. For $t = 1 \text{ s}$, the resistance increases by 6% compared to the initial state, while for a time $t_{off} = 20 \text{ s}$, the resistance increases by 25%. Thus, by increasing the stress time applied in reverse, additional negative charges are placed near the 2DEG channel which will be compensated by a reduction in the concentration of electrons in the 2DEG which induces a greater variation in the dynamic resistance to passing state.

3. Hard switching commutation

Hard switching applied to a lateral GaN component, named High Mobility Transistor (HEMT), induces hot carriers in the 2DEG conductive channel [3][4][5]. These hot carriers have a high probability of being trapped in the passivation layer of the

component [6]. As a consequence, the dynamic resistance of the component increases, and the breakdown voltage of the component may change [7].

A. Double Pulse Test “DPT”

Tests under hard switching of a transistor or a diode have several applications, in particular, to validate equivalent models of the components, and to experimentally verify nominal parameters such as the slew rate, among others.

One of the most popular hard switching tests is the double pulse test, DPT, which is the standard method for measuring the switching parameters of power devices.

B. Double Source Test “DST”

The double source test, DST, method was developed at the Ampère laboratory, to characterize the switching of silicon diodes [8]. Contrary to DPT, DST allows independent control of voltage and current during switching phases. The DST is an experiment that measures the voltage and current of a transistor during hard switching. The diagram of the DST is given in the Fig. 5. As its name suggests, the bench has two voltage sources: V_A and V_F . The source V_A imposes the voltage V_{KA} on the terminals of the component. With the source V_F and the circuit elements to the right of the switching cell, it is possible to control the current I_A .

A benefit of the DST is the ability to reduce the stress that is not applied to the component when the bench is out of the test.

C. Results for 15 Diode

Switching measurements were carried out on a 15 A diode. Fig. 6 shows the switching (turn on and turn off) for a reverse voltage $V_{KA} = 200$ V across the diode for $t_{off} = 1.2$ μ s to arrive at the steady-state in the blocked state (without oscillations) and $I_A = 15$ A (for $V_F = 26.48$ V) at the ON-state. In addition, it illustrates the current in the anode, I_A , and in the inductor, I_L which shows an almost, stable current, and the time to reach a steady state at 10% of the ON current (1.5 A) is equal to 0.55 μ s.

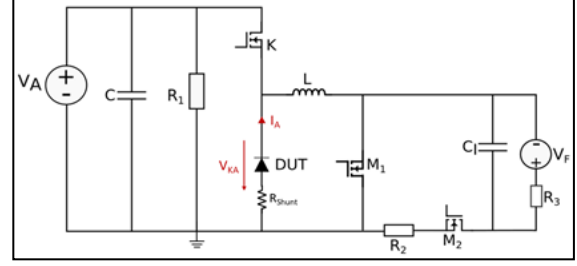


Fig. 5 Schematic diagram of the Double Source Test (DST) bench for diodes

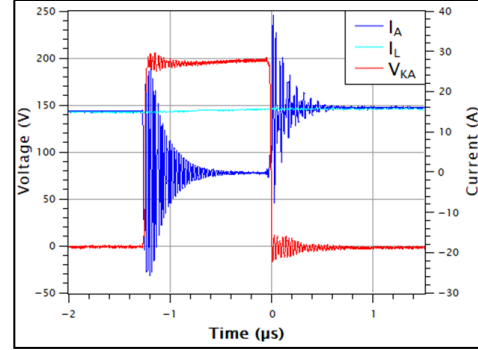


Fig. 6 DST switching of 15 A diode with $V_{KA} = 200$ V and $I_A = 15$ A

To calculate the switching speed between the on state and the off state (turn off switching), the maximum slope of the current and the voltage V_{KA} (slew rate) used are in the range of few A/ns and few V/ns respectively.

Due to the high switching speed, parasitic elements have a greater impact on switching transients and can cause unwanted overshoots as well as oscillations in these transient phases. This causes voltage and current stresses on the switched devices, leading to higher losses.

The 15 A diode shows switching with a current peak of $I_{RM} = -25.1$ A and voltage peak of $V_{RM} = 205$ V.

Switching stress (SS) of 390000 commutations were applied to diode 15 A with a repetition time between measurements $\tau_{rep} = 10$ ms. To know if there is the phenomenon of self-heating which can also affect the current in the ON state then the dynamic resistance R_{dyn} , a thermocouple has been added to the diode (DUT) to measure the top-case temperature during switching, which gives a temperature change of 2°C for SS which does not affect the current in the ON state. The stress induces the decrease of

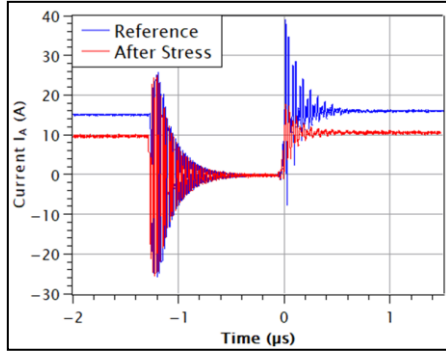


Fig. 7 Stress of 390k switching on 15 A diode

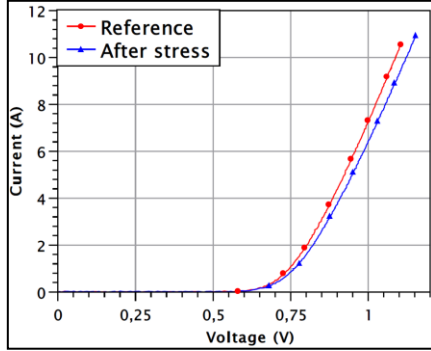


Fig. 8 Direct characterization of 15 A diode after 390k commutations

the current in the anode in the ON state. The current in the anode shows a decrease from 15.136 A to 9.747 A after a cycle of SS, which is equivalent to a decrease of 35.61% (Fig. 7). The DUT is not permanently under voltage, so the decrease in current in the anode after a cycle of switching is mainly due to hard switching. These findings were in agreement with the literature where it has been proved that hot-electron effects play a major role in the dynamic performance under hard switching [3].

Direct characterization has been applied to the diode to calculate the static resistance before and after stress. Fig. 8 shows the variation of the static resistance R_{on} after 390k cycles of switching. The variation is consistent with the observed current decay in Fig. 7.

4. Conclusion

In this paper, two types of stress have been carried out on AlGaIn/GaN Schottky diodes.

The first one is a quasi-static stress which aims to apply a forward voltage to the diodes followed by a reverse DC voltage to study the behavior of the diode after stress. This type of stress shows a degradation of the dynamic resistance after voltage stresses of

100 and 200 V in reverse biases.

Secondly, a double source test bench (DST) is developed to apply hard switching on diodes and HEMT, where switching can be applied by varying the reverse voltage V_{KA} and the current I_A independently. Switching measurements were performed on 15 A diodes, followed by SS. During switching cycles, traps are produced. The hot carriers have a high probability of being trapped in the passivation layer of the component, which induces degradation of the dynamic resistance and then a decrease in the current in the anode in the ON state. The current in the anode shows a decrease of 35.61% for the 15 A diode, whereas the DUT is not permanently under voltage, so the decrease in current in the anode after a cycle of switching is due to hard switching.

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