Impact of high-power stress on dynamic ON-resistance of high-voltage GaN HEMTs

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Impact of high-power stress on dynamic ON-resistance of high-voltage GaN HEMTs

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Abstract- We have investigated the impact of high-power (HP) stress on the dynamic ON-resistance ($R_{ON}$) in high-voltage GaN High-Electron-Mobility Transistors (HEMT). We use a newly proposed dynamic $R_{ON}$ measurement methodology which allows us to observe $R_{ON}$ transients after an OFF-to-ON switching event from 200 ns up to any arbitrary length of time over many decades. We find that HP-stress results in much worsened dynamic $R_{ON}$ especially in the sub-ms range with minor changes on a longer time scale. We attribute this to the stress-induced generation of traps with relatively short time constants. These findings suggest that accumulated device operation that reaches out to the HP state under RF power or hard-switching conditions can result in undesirable degradation of dynamic $R_{ON}$ on a short time scale.

I. INTRODUCTION

In the last decade, GaN Field-Effect Transistors have emerged as a promising disruptive technology for both power electronics and high power microwave applications. However, in spite of great progress in device fabrication and material growth technologies, limited device reliability still precludes the wide spread deployment of this technology [1].

A particular concern is the dynamic ON-resistance ($R_{ON}$) in which after an OFF-ON switching event, $R_{ON}$ of the transistor remains high for a certain period of time [2]. This is also known as current collapse and greatly affects the power electronics and RF power applications of these devices [3]. The detailed physics of dynamic $R_{ON}$ are not completely understood. Much less understanding exists regarding the impact of electrical stress on dynamic $R_{ON}$ [2, 4].

We have recently developed a new measurement technique that allows the observation of $R_{ON}$ transients over a time period that spans many decades [5]. Using this technique, we study here the impact of high-power (HP) stress on dynamic $R_{ON}$. We find that HP-stress results in much worsened dynamic $R_{ON}$ in the sub-ms range. This occurs as a result of the creation of traps with relatively short time constants. On a longer time scale, negligible degradation of dynamic $R_{ON}$ is observed. Our results point out the importance of characterizing electrically stress-induced dynamic $R_{ON}$ and current collapse over very short time scales.

II. EXPERIMENTS

In this study, we have characterized industrial research AlGaN/GaN HEMTs grown on SiC by MOCVD. The device features an integrated field plate and a source-connected field plate and exhibits a breakdown voltage higher than 200 V.

We have stressed these devices in the high-power state with $V_{GS} = 2$ V ($I_D \approx 0.6$ A/mm) and $V_{DS} = 20$ V at room temperature. The channel temperature during the stress is estimated to be around 380 C. This is a very harsh stress condition designed to accelerate the rate of degradation. We interrupt the stress every minute and characterize the evolution of important figures of merits such as $R_{ON}$ and maximum drain current ($I_{D,MAX}$) using a benign characterization suite. Dynamic $R_{ON}$ is investigated using a recently proposed methodology [5] in which $R_{ON}$ recovery transients originating from an OFF-to-ON switching event are recorded from 200 ns to any arbitrary length of time. This is accomplished by combining

![Fig. 1 Time evolution of $R_{ON}$ and $I_{D,MAX}$ (normalized to their initial values) during a constant HP-state stress in GaN HEMTs. The stress conditions are $V_{GS} = 2$ V, and $V_{DS} = 20$ V. Up to about 30 min of stress, the device characteristics show minor changes. Beyond 30 min, prominent degradation in both $R_{ON}$ and $I_{D,MAX}$ is observed.](image-url)
measurements using an Auriga AU4750 pulsed IV system and an Agilent B1500A semiconductor device analyzer. We applied this method to five identical test systems and an Agilent B1500A semiconductor device.

**Fig. 1** plots the time evolution of DC $R_{ON}$ and $I_{DMAX}$ normalized to their initial values as a function of stress time for the sample that was stressed for 40 min. The device shows quite robust characteristics up to 30 min, but beyond this point, significant degradation takes place. The samples stressed for 10, 20 and 30 mins exhibit very minor degradation in their DC $R_{ON}$ and $I_{DMAX}$ values, consistent with the results of Fig. 1.

**Fig. 2** shows $R_{ON}$ recovery transients from 200 ns up to 200 s for all devices after an OFF-state pulse ranging from 0 to 40 min. Up to 30 min of stress, minor changes in dynamic $R_{ON}$ are observed. After 40 min of stress, there is a more than ten-fold increase in dynamic $R_{ON}$. Very fast $R_{ON}$ recovery down to ms range is observed in all cases.

**Fig. 2** Dynamic $R_{ON}$ transients from 200 ns up to 200 s from OFF ($V_{GSOQ} = -10$ V, $V_{DSQ} = 50$ V) to ON ($V_{GS} = 1$ V and $V_{DS} = 0.05\sim0.5$ V) switching in different samples that have been subject to different HP-state stress periods ranging from 0 to 40 min. Up to 30 min of stress, minor changes in dynamic $R_{ON}$ are observed. After 40 min of stress, there is a more than ten-fold increase in dynamic $R_{ON}$. Very fast $R_{ON}$ recovery down to ms range is observed in all cases.

In order to understand the physical origin of these prominent transients, we have analyzed the time domain $R_{ON}$ data by fitting it with a sum of exponentials [6]. The amplitude of the various components as a function of their respective time constants is shown in **Fig. 4**. It is clear that after 40 minutes of stress time, fast transients emerge with time constants in the ms to ns range. In contrast, negligible changes occur in the long time constant domain.

**Fig. 3** Dynamic $R_{ON}$ ($R_{ON}/R_{ON\ DC}$) of **Fig. 2** at different times (200 ns, 10 μs, and 10 ms) and $R_{ON\ DC}/R_{ON\ DC\ virgin}$ ($R_{ON\ DC}$ value in the virgin device) as a function of HP-state stress time in a semilog scale. Dynamic $R_{ON}$ mostly increases in a time range from 200 ns up to a few ms. $R_{ON\ DC}/R_{ON\ DC\ virgin}$ shows small increase up to 16% in comparison to dynamic $R_{ON}$ suggesting minor permanent (non-transient) degradation.

In contrast, negligible changes occur in the long time constant domain.

Dynamic $R_{ON}$ measurements at different temperatures (T) have been performed with the goal of selecting an appropriate time scale for the study of degradation. These findings highlight the importance of dynamic $R_{ON}$ and current collapse in GaN HEMTs after electrical stress.
located below the conduction band edge of the AlGaN barrier. The observed traps are presumed to have been created as a result of high-power electrical stress (in microwave applications) or under hard-switching conditions (in power management) can result in an undesirable increase in dynamic R\textsubscript{ON} on a very short time scale.

### III. Conclusions

In summary, we have experimentally observed a large increase in dynamic R\textsubscript{ON} on a short-time scale after high-power electrical stress of GaN HEMTs. The cause is attributed to the formation of shallow traps inside the AlGaN barrier or at its surface. This work suggests that prolonged device operation of GaN HEMTs under RF power conditions (in microwave applications) or under hard-switching conditions (in power management) can result in an undesirable increase in dynamic R\textsubscript{ON} on a very short time scale.

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**Fig. 5** R\textsubscript{ON}/R\textsubscript{ON,DC} transients at different temperatures between 25 C and 150 C for V\textsubscript{GSQ} = -10 V and V\textsubscript{DSQ} = 50 V after 40 min HP stress. The inset shows the absolute value of the R\textsubscript{ON} transient. As the temperature goes up, the dominant traps are substantially accelerated. This suggests that the transients are due to generated traps.

**Fig. 6** Arrhenius plot of time constant spectra extracted from Fig. 5. The size of the symbols is proportional to the height of the time constant peaks. The dominant trap energy levels have also been reported in similar structures after electrical stress by other authors [7-8].