Aging and gate bias effects on TID sensitivity of wide bandgap power devices

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***Abstract*—The effect of oxide stress on the total ionizing dose (TID) radiation sensitivity of silicon carbide (SiC) power MOSFETS and TID sensitivity of gallium nitride (GaN) power transistor is reported. Difference in TID response for stressed and unstressed devices was observed.**

***Index Terms*—TID, silicon carbide, gallium nitride, power devices**

I. Introduction

Wide bandgap (WBG) materials are promising candidates for use in power devices. Material properties of Silicon Carbide (SiC) and Gallium Nitride (GaN) are superior compared to Silicon. GaN and SiC can operate at higher voltages, at higher temperatures and at higher frequencies [1]. GaN material is expected to be radiation hard due to high ($(19 \pm 2)\,\mathrm{eV}$) displacement energy of Gallium atom in the lattice [2]. Along with superior material properties compared to Silicon, it is an interesting material for space applications. The main aim of this study is to compare sensitivity to total ionizing dose (TID) under x-ray irradiation of stressed and unstressed devices and also two power transistor technologies based on GaN and SiC. Effect of irradiation on both Id-Vg- and Ig-Vg-characteristics was studied.

Studies of radiation response of GaN devices exist, but they focus mainly on gamma-ray [3], proton [3]–[8], electron [9], [10] irradiations and heavy ion irradiation [3], [6], [8], [11]. For AlGaN/GaN HFET device, the increase in I_{GS} and negative shift in V_{TH} after $0.5\,\mathrm{MeV}$ electron irradiation is reported by Moran *et al.* for a electron fluence of $5 \cdot 10^{14}\,\mathrm{e/cm^2}$. SiC power devices has been reported to have high sensitivity to single event effects (SEE) and parameter degradation under heavy ion irradiation [3], [12]. For SiC power MOSFET under gamma ray irradiation, $-2\,\mathrm{V}$ threshold voltage shift and $15\,\%$ reduction after $1\,\mathrm{Mrad}$ dose has been observed by Gerardin *et al.* [3].

This article focuses on the effect of x-ray irradiation on SiC- and GaN-based power transistors: 900 V SiC MOSFET and 200 V GaN High Electron Mobility Transistor (HEMT) and effect of oxide stress on TID sensitivity of SiC power transistor.

II. Experiments

The devices used in this study were commercial power transistors manufactured by CREE (SiC MOSFET) and EPC (GaN HEMT). SiC MOSFET is a vertical device whereas the GaN HEMT is a lateral device. Device characteristics are indicated in table I.

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TABLE I
Characteristics of the studied devices

Part number	Manufacturer	$V_{DS(max)}$	$V_{GS(min/max)}$	$I_{DS(max)}$
EPC2012	EPC	200 V	-5/6 V	3 A
C3M0120090D	CREE	900 V	-4/15 V	23 A

Characterizations before and between irradiation steps included I_{DS} and I_{GS} measurements, while V_{GS} was swept from $0\,\mathrm{V}$ to $6\,\mathrm{V}$ and the V_{DS} was held at $100\,\mathrm{mV}$. Sources of the transistors were connected to the ground.

The oxide breakdown charge $Q_{BD} = 166\,\mathrm{mC}$ was determined for one device by applying current through the gate oxide until sharp decrease of the V_{GS} was observed.

A constant current stress (CCS) has been performed on 5 SiC devices by applying a current through the gate oxide while keeping the drain and source grounded. The $100\,\mathrm{\mu A}$ constant current was applied for $100\,\mathrm{s}$ resulting in a final injected charge of $10\,\mathrm{mC}$. All the 5 devices have been subjected to the same stress with an identical $10\,\mathrm{mC}$ injected charge. This first process was intended in order to create some defects clusters inside the active gate oxide layer.

TID irradiation have been performed using the on-site X ray source (X-RAD 320 x-ray cabinet) with $320\,\mathrm{keV}$ electron gun energy and current of $12.5\,\mathrm{mA}$. Transistors were subjected to x-ray radiation at room temperature (RT). During irradiation, $80\,\%$ of maximum V_{DS} rating was applied to the drain while the source was grounded. Maximum negative bias was applied to the gate to make sure that the transistor was off, even in case of a strong V_{Th}. For SiC and GaN devices, total ionizing absorbed dose of $1\,\mathrm{Mrad}$ and $500\,\mathrm{krad}$ respectively was used with a dose rate of $14.75\,\mathrm{rad/s}$. Characterization of each device was performed before and after each irradiation step.

III. Results

A. Silicon Carbide Power devices

The current-voltage characteristics of the devices were investigated and threshold voltages (V_{Th}) were determined using the drain current ratio method [13]. This method consists in plotting $I_{DS}/\sqrt{gm}$ as a function of V_{GS} and to extract V_{Th} from the intercept of the linear part of the curve with the X-axis. Contributions of interface an oxide traps on threshold voltage shift were determined based on shift in midgap voltage V_{mg} [14]. Figure 1 represents the evolution of the measured threshold voltage shift as a function of TID for stressed and unstressed devices, as well as contributions of the oxide and interface traps.

Unstressed devices exhibit approximately $-0.4\,\mathrm{V}$ threshold voltage shift at $1\,\mathrm{Mrad}$.

Regarding preliminary stressed devices, the behavior of their threshold voltage is different. It can indeed be seen in the

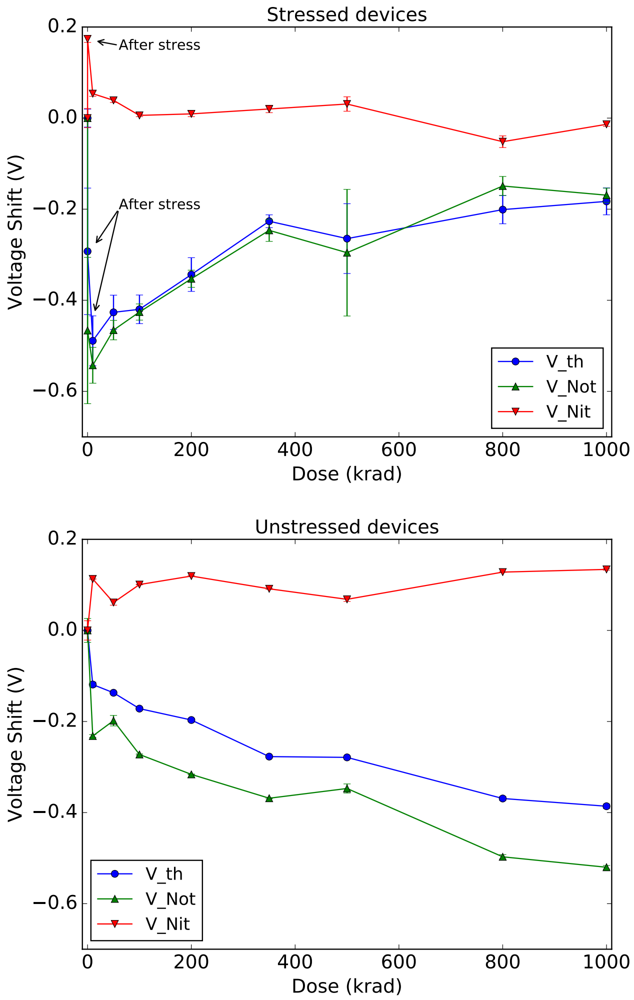

Fig. 1. Threshold voltage shift of stressed (top) and unstressed devices and contribution of interface and oxide traps

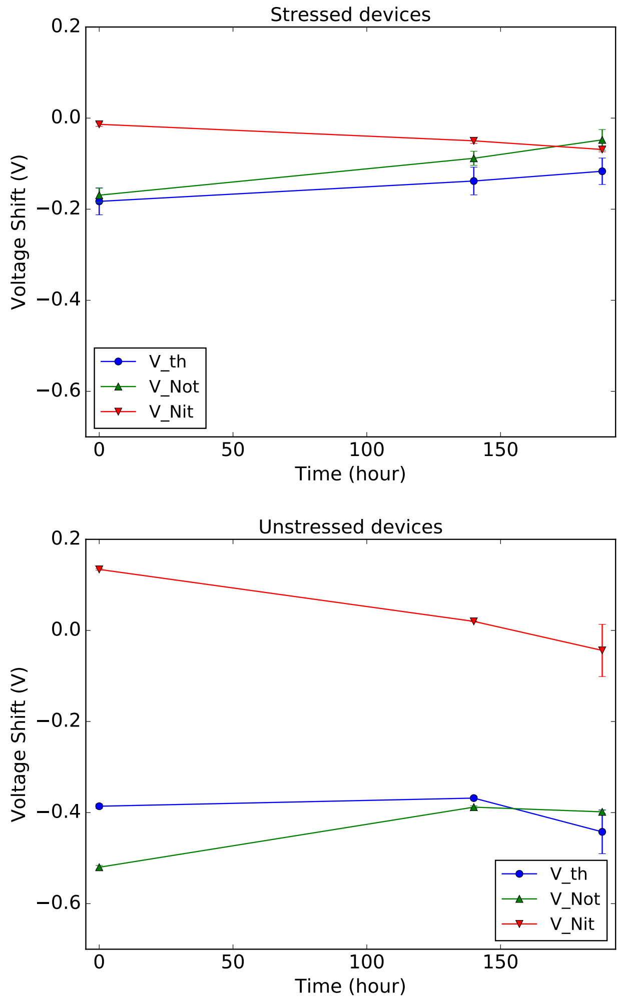

Fig. 2. The effect of annealing at RT on threshold voltage shift of stressed (top) and unstressed devices and contribution of interface and oxide traps after 1 Mrad dose.

figure 1 that after the first 10 krad irradiation step, the threshold voltage shifts approximately -0.2 V but after that, it starts to recover. The most significant shift occurs due to the stressing.

The annealing behaviour for the stressed and unstressed devices was also studied and results are presented in figure 2. No significant recovery of threshold voltage was observed after 188 h of RT annealing.

We can observe that the degradation seems to be mainly driven by the oxide trapping for both stressed and unstressed devices. It appears however that the threshold voltage shift has opposite trends when devices have been first stressed. This specific behavior seems to be related to the negative gate bias during irradiation. This point as well as the mechanisms at play will be discussed in the final paper, adding next irradiation results obtained with a positive gate bias during irradiation.

B. *Gallium Nitride Power devices*

Since those devices are lateral structure and do not have any active gate oxide, no preliminary stress has been performed before irradiation and only threshold voltages shifts have been extracted. Figure 3 represents the threshold voltage shift as a function of TID for five irradiation steps from 10 krad to 500 krad

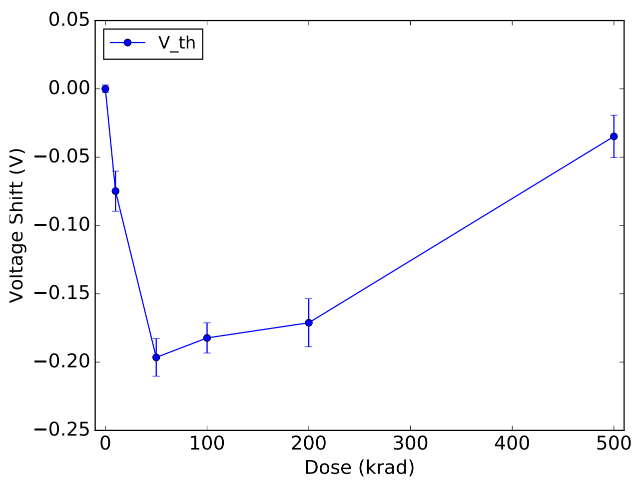

Fig. 3. Threshold voltage shift of GaN HEMTs

It appears that a rebound-like effect is observed in the V_{Th} at 50 krad. The impact of gate bias during irradiation (negative or positive gate bias) will be discussed in the final paper.

IV. Conclusion

Two recent commercial power devices technologies have been investigated. As a first result, they seem to exhibit a rather tolerant behavior regarding TID. Indeed, threshold voltage shifts do no not exceed $20\,\%$ in the worst case. However, the final paper will investigate the impact of electrical aging on TID sensitivity as well as the impact of gate bias. Both of them will be linked to the switching operation mode of the devices in the application and are the first step toward a system level study.

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