Experimental study of Single Event Effects induced by heavy ion irradiation in enhancement mode GaN power HEMT

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INTRODUCTION

GaN Power HEMT (High Electron Mobility Transistor) have been introduced in the late 80’s of the last century in their normally on version as very performing RF devices [1-3]. Some works have been dedicated to study Single Event Effects (SEE) induced by heavy ion irradiations in normally on GaN power HEMT for RF applications [4-8]. A first study about SEE induced by heavy ions in normally off GaN has been recently presented and the occurrence of SEB was for the first time observed in these devices [9]. In this paper an experimental study of Single Event Effects, SEE, induced by heavy ion irradiation on commercial GaN power HEMTs rated between 40V and 200V is presented.

EXPERIMENTAL PROCEDURE

The schematic of the experimental circuit used during the irradiation is depicted in Fig. 1. It is an extended version of the circuit previously described in [10].

The irradiation experiments were conducted at the INFN National Laboratory of Legnaro with $^{127}$I at 276 MeV. During the irradiation, the devices are exposed to a flux of about 500 ion cm$^{-2}$s$^{-1}$. A significant number of events (at least 1500) are registered either for performing statistical analyses or for identifying specific single event effects. After each irradiation gate and drain leakage characteristics of the DUT are measured for evaluating the damage induced by the irradiation.

Commercial power HEMTs rated at 40V, 100V and 200V (EPC2015, EPC1007, EPC2012), produced by Efficient Power Conversion, were used in irradiation experiments. These devices have no lead terminations and must be directly soldered on the Printed Circuit Board, PCB. For permitting the ions to impact on the active part of the device, which is on the metal side, the PCB was designed to have several holes, with a diameter of 350µm, underneath the device.

CHARGE AMPLIFICATION

The mean value of the charge collected at the drain terminal is shown in Fig. 2 as a function of $V_{DS}$ applied during irradiations. Each data point corresponds to the mean value of the collected charge computed as the integral of the current pulses over a population of 1500 events. Data refer to irradiations performed on EPC2015 and EPC1007 with $V_{GS}$=0V and $V_{DS}$ ranging from 20V to 60V.

It is worth to outline that the charge collected by the device with larger blocking voltage (EPC1007) is up to four times larger than the one collected by the lower voltage one (EPC2015).

The scatter plot of the collected charge as a function of the current peaks of EPC2015 at $V_{GS}$=0V and $V_{DS}$=40V clearly indicates a single population of events. While, the situation is much different for the scatter plot of EPC1007 at $V_{GS}$=0V and $V_{DS}$=100V (the area around the origin of the axes is displayed in Fig. 3) that reveals the formation of a second population of events with collected charges larger at the same current peaks.

We propose here that bipolar and back-channel effects, invoked to explain the enhancement of the collected charge in normally on RF GaN power HEMT operated in pinched conditions [4], can also be applied to normally off devices. In particular, we propose that back-channel effect is dominant in lower voltage devices like EPC2015.

For high voltage normally off power HEMTs like EPC1007, we propose that together with the back-channel effect the bipolar effect could be considered to explain the formation of the second population of events.
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fluence of about $5 \times 10^6$ ions/cm$^2$. The sample under test was biased with $V_{GS} = 0$V and $V_{DS} = 60$V.

**DAMAGES INDUCED BY HEAVY ION IRRADIATION**

The current pulses induced by the ion impacts can cause damages to the DUT. These damages are very similar to the ones observed in [9] and are proved by the increase of the drain current leakage. The time evolution of this leakage is shown in Fig. 4 (black curve) for the irradiation with $^{127}$I at 276 MeV of an EPC2012 device ($V_{DS} = 60$V, $V_{GS} = 0$V). The drain current pulses are reported as vertical segments topped by small circles and are superimposed on the drain leakage current evolution. It is shown that the steps of the current leakage are caused by the pulses with the largest amplitudes. This suggests that the damages are the consequence of significant energies released in a very small region along the ion track, causing a huge increase of the temperature, as it happens in other power devices like SiC Schottky diodes [11].

We performed several irradiations with increasing $V_{DS}$ ranging from 20V to 90V with steps of 10V on EPC1007. Almost no damage is observed in the gate structure whereas drain leakage current increases after each irradiation. This behaviour was previously observed [9] and may compromise the reliability of the device even without the occurrence of single event failure.

As already observed in [9], no SEE failure was registered on 40V rated devices, instead, destructive Single Event Burnouts were registered on devices rated at 100V and 200V. An example is depicted in Fig. 5 which displays the time evolutions of drain leakage currents during the irradiation of an EPC1007 with $^{127}$I at 276MeV. The sample under test was biased with $V_{GS} = 0$V and two values of drain voltage, namely $V_{DS} = 90$V and $V_{DS} = 100$V. Drain leakage current for the irradiation at $V_{DS} = 100$V exhibits a sudden and large increase after 340 s corresponding to a fluence of about $5 \times 10^6$ ions/cm$^2$. It corresponds to a SEB.

In fact, the gate leakage current (not reported here for brevity) shows a transient after which its value goes back to the value hold before the single event. This behavior confirms the occurrence of a SEB more clearly than what reported in [9] where both gate and leakage current had an increase at the device failure.

For completeness we outline that 200 V EPC2012 devices irradiated with $^{127}$I at 276 MeV show SEB at 90 V.

**CONCLUSIONS**

An experimental characterization of the behavior of GaN power HEMTs during heavy ion irradiation is presented. It is performed by means of an experimental set-up which allows to monitor the evolution of the gate and drain leakage current and to correlate it with the current pulses due to the impacts.

It is demonstrated that GaN power HEMTs exhibit a significant charge amplification when hit by heavy ions. These devices are subjected to damages implying relevant increases of drain leakage current. Higher voltage devices evidenced Single Event Burnouts, which can compromise their qualification for space applications.