SEE Sensitivity of a COTS GaN Transistor and Silicon MOSFETs

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***Abstract*—Researches on prototype AlGaN/GaN transistors provided evidence for their tolerance to cumulated dose effects. However, only few studies have been done to evaluate their sensitivity to Single Event Effects (SEE). This paper reports SEE test results on a commercial GaN High Electron Mobility Transistor with 14 MeV Neutron and Heavy Ion irradiations (N, Fe, Br, Xe). Results show that the component under test is not sensitive to Single Event Burnout (SEB), however phenomenon similar to Single Event Gate Rupture (SEGR) was observed. The SEE test bench used for our experiments has been validated with measurement of SEB and SEGR on MOSFETs.**

***Index Terms*—GaN, HFET, Single Event Effect, Single Event Burnout, Single Event Gate Rupture, MOSFET.**

I. INTRODUCTION

GaN power transistors are of major interest in microwave circuits [1][2] for space applications because of their reliability in radiative environments [3]. Previous studies on AlGaN/GaN components have shown that this technology presents a good response to proton and heavy ion irradiations [4-8], especially to the total dose effect. To our knowledge, there is no available data on the vulnerability of this new technology to Single Event Effect phenomenon.

This paper gives experimental results of 14 MeV neutron and heavy ions irradiation on commercial RFHIC's 10W GaN transistors. These measurements have been performed with a SEE test bench designed to observe Single Event burnout (SEB) and Single Event Gate Rupture (SEGR) in power MOSFETs. Preliminary measurements on two MOSFETs references (International Rectifier HEXFET IRF230 and IRF440) validate the test bench and provide SEB and SEGR cross-section curves which can be compared to GaN measurements.Experimental setup

A. Tested Component

The tested GaN component is a commercial High Electron Mobility Transistor (HEMT) supplied by RFHIC under the reference RT240PD.

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This transistor, designed to operate up to 10 W, is used in RF applications. Its maximum operating voltages are ±30 V on the gate and 70 V on the drain.

The packaging of RT240PD components, illustrated in Fig. 1, is composed of a metallic plate on which the chip is fixed through source access. Gate and drain are connected to two lateral pins. The component is protected with a plastic cover that has to be removed for the irradiation tests.

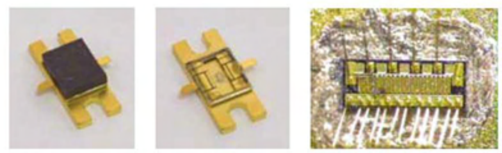


Fig. 1 : Packaging of the HEMT from RFHIC reference RT240PD

The component has a "multi-finger" structure but the exact composition of its active layers is not known. Fig. 2 shows a schematic representation of GaN HEMTs. These components consist of a layer of undoped GaN surrounded by one or several AlGaN layers. This structure induces a two Dimension Electron Gaz (2DEG) near the junction. This thin layer of electrons is the channel, the gate voltage allows to modify the electron mobility and by the way the transistor state.

This HEMT structure is normally ON, so the gate pin must be biased with negative voltage to obtain the OFF state. The tested component has a threshold voltage around -2 V. As a consequence during the irradiation tests, we tuned the gate bias to less than -5 V.

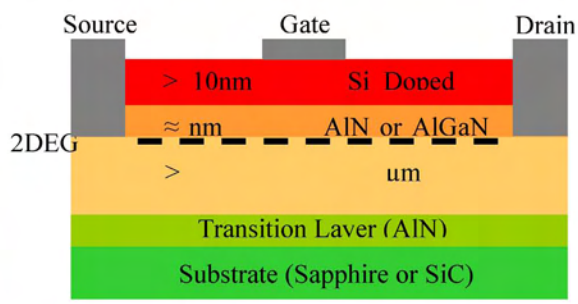


Fig. 2 : Example of GaN HEMT structure

Compared to the MOS structure, the GaN HEMT has no parasitic bipolar transistor which induces SEB when a charge is collected. Moreover, the width of the channel is about several millimeters, allowing the collected charges to be well dissipated. From these differences, we can assume that the GaN HEMTs are less sensitive to SEB than the HEXFET structure used in MOSFETs.

Furthermore, no oxide is used to insulate the gate electrode, so the SEGR can not appear from the same mechanism than in MOSFETs. However, there are several layers between the gate electrode and the substrate which can be modified by radiations and induce similar phenomenon.

B. Test Bench and irradiation facilities

The test bench was design according to the MIL-STD-750D standard requirements [9]. The transistors are biased in the OFF state with stabilization circuit on the gate. The drain is biased through a circuit composed of a serial resistor, a parallel capacitor and 1Ω resistor (Fig. 3). The capacitor C provides the transient current when SEB occurs while R limits it to avoid the destruction of the component. The 1Ω resistor allows to measure this transient current with an oscilloscope.

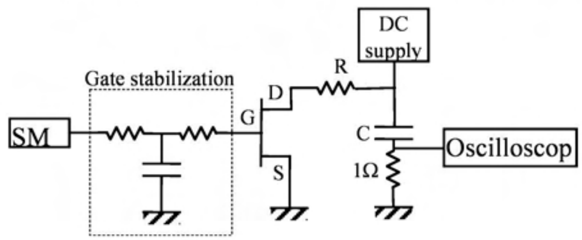


Fig. 3 : Test Bench

This method allows the observation of SEGR through the monitoring of the gate current with a Source-Meter Unit (SMU). Non-destructive SEBs are detected and counted through oscilloscope trigger measurements [10].

14 MeV neutron tests have been performed using the SAMES facility from CEA Valduc, France.
Heavy ions measurements have been done with the RADEFF facility at the University of Jyvaskyla, Finland, and with the TANDEM facility of the «Institut de Physique Nucléaire » of Orsay, France.
100 MeV and 500 MeV proton irradiations were done at TRIUMF , Vancouver, Canada.
The main characteristics of the ion beams used for these tests are given in Table 1. The corresponding LETs in Silicon and GaN were calculated with the software SRIM© [11].

TABLE 1 : ION BEAM CHARACTERISTICS AT JYVASKYLA UNIVERSITY AND IPN FACILITIES

Ion	Energy (MeV)	LET in Si ($MeV \cdot mg^{-1} \cdot cm^2$)	LET in GaN ($MeV \cdot mg^{-1} \cdot cm^2$)	Range (µm)
N	139	1.8	1.3	202
Fe	523	18	14	97
Br*	236	42	32	31
Xe	1217	60	47	89

* : IPN beam
All irradiations were performed under normal incidence.

II. RESULTS

A. MOSFET's tests

The SEB sensitivities of the two IRF230 and IRF440 MOSFETs were evaluated to 14 MeV neutrons, 100 MeV and 500 MeV protons and heavy ion exposures. These transistors are commercial HEXFETs produced by International Rectifier without radiation-hardening specifications. Their V_{dss} are respectively 200 V and 500 V. During irradiation, their TO-3 packages have been open to expose the chips in front of the ion beams.

Fig. 4 and Fig. 5 represent the SEB cross-sections of the two MOSFETs versus Vds and ion LETs. Dash lines represent the shape of SEB cross section usually found for this kind of component [12]. The maximum tested fluence is of 10^6 ions·cm^{-2}. When no event is detected the cross-section is arbitrarily set at the value of 10^{-6} cm². Each point over 10^{-6} has been computed with a minimum of 100 SEB.

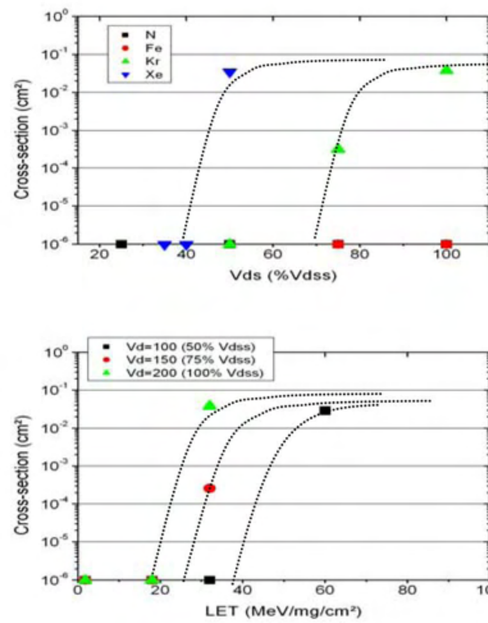
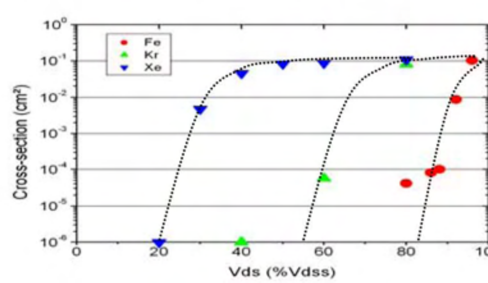


Fig. 4 : SEB cross-section of IRF230 versus Vds derating and ion LETs (Vg=0 V)

No events were measured during the neutron and proton exposures of the IRF 230 components.



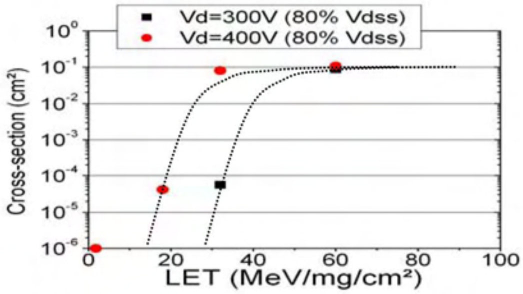


Fig. 5 : SEB cross-section of IRF440 versus Vds derating and ion LETs (Vg=0 V)

Because of its higher drain bias voltage, SEB phenomena were observed on IRF440 components under neutron and proton irradiations. Fig. 6 represents the SEB cross-section versus Vds derating.

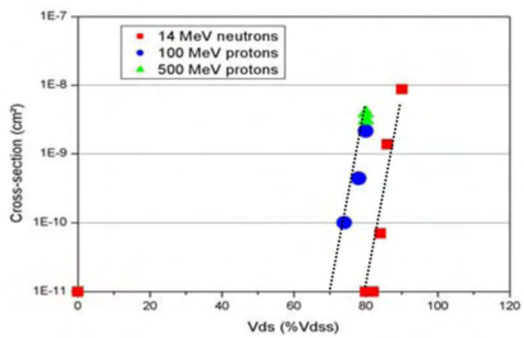


Fig. 6 : SEB cross-section of IRF440 versus Vds derating under neutron and proton irradiations (Vg=0V)

These results show that our test bench allows to measure SEB cross-sections that agree with previous measurements [12-14].

SEGR were also observed, they induced gate current steps corresponding to the interaction of an ion with the gate oxide. The amplitude of these steps depends of several parameters like bias conditions, cumulative fluence, ion characteristics, etc. Consequently, we observe several shapes for SEGR from soft-damage to component breakdown (Fig. 7).

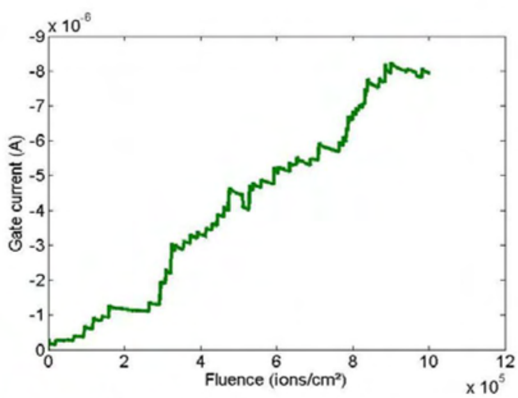


Fig. 7 : Observed SEGR on IRF 440 with Xe ion beam, V_{gs}=0V, V_{ds}=100V

For higher LETs, the impact of one ion can be sufficient to induce component burnout. Then, it is possible to have a large dispersion in SEGR threshold measurements.

The number of results obtained during these campaigns are not sufficient to provide a good estimation of the cross-sections but allows to validate our test bench for SEGR detection.

B. GaN component tests

GaN transistor has been tested to 14 MeV neutrons with -10 V gate bias and drain voltage up to 70 V. Up to a fluence of 10^{11} neutrons·cm^{-2}, we observe no functional change, the gate current remains unchanged at about 0.1 mA.

With Nitrogen ion beam (LET=1.8 MeV·mg^{-1}·cm^{2}), four runs were made on the same component with gate bias respectively tuned at -5, -10, -20 and -30 V. During all tests the drain voltage was set at 53 V (75% V_{dss}). For each run, the flux was fixed to 10^3 ion·cm^{-2}·s^{-1} and the fluence at 10^6 ions·cm^{-2}. We observed no change of the gate currents or component operating parameters.

The three runs made with iron ions (LET=18.5 MeV·mg^{-1}·cm^{2}) have been done with the same drain bias, flux and fluence characteristics. Gate voltages of -5, -10 and -30 V were successively tested. No changes were observed.

With Bromine ions (LET=39 MeV·mg^{-1}·cm^{2}), three different samples of the transistor was damaged when gate bias were fixed at -15 V or below. These failures consist in an increase of the leakage currents from less than 0.2 mA to several mA. Fig. 8 illustrates the various tested bias conditions and the resulting functional integrity of components during irradiation. Three different behaviors have been observed and associated with the following symbols:

■: The component functionality is not affected by a fluence up to 10^6 ions·cm^{-2}.

●: Additional leakage currents (ΔI <200µA) are measured but do not affect the functional behavior of the component up to a fluence of 10^6 ions·cm^{-2}.

▲: Component is permanently damaged (Fluence associated to the component failure is noted near the symbol)

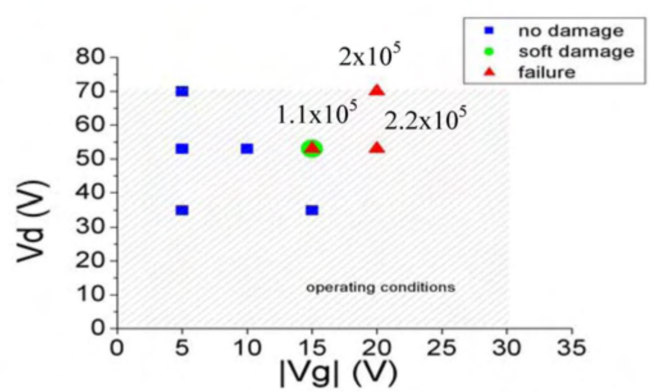


Fig. 8 : Component polarization and issue of Bromine irradiation runs

These results show that the damage occurrence depends on both drain and gate biases. For a low polarization of the gate,

the components are not sensitive to a LET of 39 $\text{MeV}\cdot\text{mg}^{-1}\cdot\text{cm}^2$ but when gate bias increases, failures appear at lower drain voltage.
The results of our Single Event Effect tests are shown in Fig. 9 that illustrates the three types of current change during irradiation corresponding to the three classes of damage shown in Fig. 8.
The first curve (Vg=-5 V; Vd=53 V) illustrates the case where the component is unaltered: the current does not change during the irradiation. The dashed line represents soft damage induced by a decrease of 0.3 mA of the gate current. The steps on this curve are due to the impacts of ions in active part of the component. The worst case of this phenomenon is shown with the third curve representing the failure of the component.

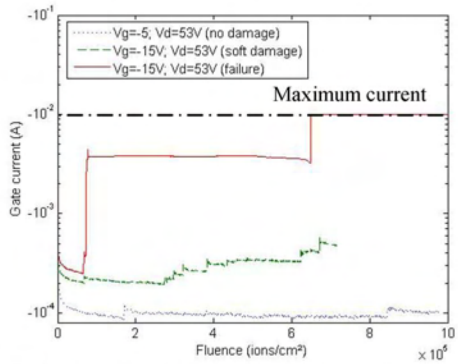


Fig. 9 : Comparison between the gate currents monitored during Br irradiation for each damage class

Such radiation-induced phenomena are well-known in silicon power transistors and have been attributed to the degradation of the gate oxide (SEGR) [10-13] (cf. part III section A). However, for GaN transistors, no oxide is used to insulate gate but several layers of AlGaN are used between the 2DEG channel and the gate electrode [15-18]. We supposed that the observed SEE could be due to defects made by tracks of ions in the AlGaN layers. This hypothesis may be validated by structure analysis on failed components.

Five runs were made using Xenon beam (LET=60 $\text{MeV}\cdot\text{mg}^{-1}\cdot\text{cm}^2$) on three samples. Fig. 10 represents the tested bias conditions and the resulting functional integrity of component during irradiation. The square symbols indicate unaffected components and triangles symbols destroyed components.

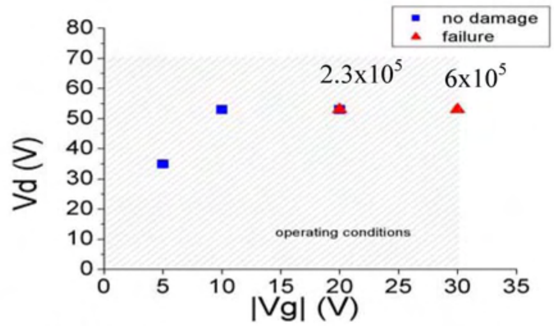


Fig. 10 : Component polarization and issue of Xenon irradiation runs

These results confirm that the gate voltage affects the component radiation sensitivity with a threshold around -15 V.
For the bias Vg=-20 V and Vd=53 V, we observed two different results. This difference of sensitivity between these two samples is not due to the cumulated fluence from previous runs because the failed component had received a lowest cumulative dose than the damaged component. So, this can be explained by the location of the ion impact. This phenomenon, that has been already studied in MOSFETs [19-20], can lead to a statistic effect on failure.
Furthermore, the Ig monitoring plots in Fig. 11 show that the gate current increasing up to the supply compliance at the first impact of an ion. This result shows the observed phenomenon is a Single Event Effect which can destroy the component. Our number of samples was not enough to obtain a statistic estimation of the SEE threshold.

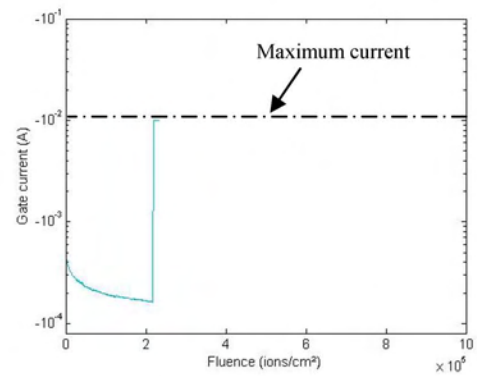


Fig. 11 : Gate current monitoring of failure component under Xe ion beam

During all these experiments, no SEB has been detected on the GaN components. So, it seems that the HEMT structure is naturally immune to Single Event Burnout.

III. Conclusion

These irradiation tests show that GaN Product HEMT reference is unaffected by 14 MeV neutron irradiation and heavy ions with LETs of 1.8 and 18.5 $\text{MeV}\cdot\text{mg}^{-1}\cdot\text{cm}^2$. For the LET of 39 $\text{MeV}\cdot\text{mg}^{-1}\cdot\text{cm}^2$ soft damages can appear and induce significant gate leakage current. For a LET of 60 $\text{MeV}\cdot\text{mg}^{-1}\cdot\text{cm}^2$ the component can be destroyed with only one interaction with an ion.

The gate current monitoring has shown that these damages are due to Single Event Effects assumed to be similar to SEGR. Whereas, because of the absence of oxide under the gate, we supposed that the incident particles interact with AlGaN layers and create defects of the gate insulation. Like in MOSFETs components, bias conditions on both gate and drain pins impact the radiation sensitivity of GaN HEMTs. A first analysis of the GaN transistor vulnerability shows that this component is less sensible to Single Event Burnout than MOSFETs. This hypothesis is comforted by our test conditions for which no SEB was detected. More experiments with other configurations and with other GaN transistors should be performed to confirm our assumption that the GaN HEMTs is naturally insensible to Single Event Burnout.

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