I. INTRODUCTION

The decision to use a commercial power MOSFET in a harsh radioactive environment,[1] such as outer space, is subordinated to the capacity of the device to tolerate single event effects (SEE)[2] caused by single ionising particles. An incident ion may trigger charge generating mechanisms in the active volumes of the device that may give rise to a simple momentary malfunction or to a destructive event.

We propose an original statistical characterization of two different charge generation mechanisms based on experimentally measured drain current pulses obtained in various operational conditions (different ion species and different bias voltages). In a power MOSFET, single event effect failure modes include both single event burnout (SEB) and single event gate rupture (SEGR)[3].

The occurrence of a destructive SEB is related to the activation of the parasitic transistor of the structure. The activation is due to the interaction of the ionisation space charge, produced by the energetic ion along its trajectory through the device, with the intense electric fields in the depletion regions of the reverse biased n/epi-p+/bulk junction[4].

The amount of ionisation, described by the Linear Energy Transfer (LET), depends on the ion species and energy, while the shape of the electric fields and the active volume of the parasitic transistor depend on the topology of the MOSFET device, hence on the technology.

Low voltage power MOSFETs are robust in terms of SEB. Nevertheless, the charge associated to the ionisation avalanche mechanisms may generate current pulses that could cause malfunctions of the external circuit.

One must therefore perform a classification of the pulse shapes that a low voltage power MOSFET may generate, in particular a detailed study of the relation between the total charge generated, the ion energy and species, and the voltage between drain and source.

An accurate analysis of the possible pulse shapes and the relationship of the generated charge, the ion energy and the applied bias voltage is thus required.

II. EXPERIMENTAL SET-UP

The experimental analysis of the mechanisms of charge generation in a power MOSFET to be used in outer space requires the choice of the radiation type and energy to best simulate the interaction with cosmic rays. The ions and energy were chosen so that the Linear Energy Transfer in the epitaxial region was high and the longitudinal range was sufficient to ensure penetration into and through the active layers of the device in order to make the current pulses precursor to SEB events detectable.

The Irradiation experiments have been conducted at the Laboratori Nazionali di Legnaro – INFN - ITALY. the device under test (DUT) was a commercial power N-channel MOSFET designed to handle a maximum of 30V between source and drain. During the first phase of the experiment the gate and source terminals were shorted together and a positive VDS voltage was applied so that the N/epi-P+/body junction was inversely biased. The DUT was exposed to energetic ions: 139 MeV 58Ni, 250 MeV 79Br and 301 MeV 127I. The VDS voltage was then varied from a minimum of 15V up to almost the nominal maximum. The charge generated during an ion impact produces a drain current transient that is detected by a fast sampling oscilloscope. The time scale of the current pulse is of the order of a few nanoseconds hence the circuitry was adapted to the impedance of the cables (50 Ω). During these measurements no SEB was observed, nevertheless, the charge associated to the ionisation avalanche mechanisms may generate current pulses that could cause malfunctions of the external circuit.

III. EXPERIMENTAL RESULTS

Experimentally it was found that the drain pulse waveforms recorded by the oscilloscope are essentially independent on the presence of the gate circuitry and can be classified into two types (classes) that strongly differ with respect to pulse shape and associated charge. The maximum current attained by the wave forms of one class (2nd class) is orders of magnitude higher than that achieved by those of the other class (1st class) and, correspondingly, the integrated charge is larger too.

The bimodal behaviour becomes evident when one considers the distributions of the charge, peak current, and decay time of each ion impact wave form, in particular when considering the scatter plots of one quantity versus another.

The characteristics of the charge mechanisms were studied by a parametric statistical analysis of the reduced information of the wave forms. The first step was to
describe the distribution of the integrated charge of the wave forms with a parametric shape: the gamma function well describes the experimental charge distributions[5],[6].

Fig.1 reports the first moment (mean value) of the charge distribution functions for the first typology of pulses as a function V_{DS} for different species of impacting ions, i.e. $^{127}$I, $^{97}$Br and $^{58}$Ni. The figure refers to the conditions when the gate is shorted to the source and it shows that the generated charge depends strongly on the ion energy.

![FIG. 1: Mean value of the first class drain charge v/s Vds.](image)

The charge generation mechanism is attributed to the simple turn-on of the parasitic transistor by the ionisation column produced by the impacting ion.

The charge generation mechanism responsible for the pulses of this class is attributed to the simple turn-on of the parasitic transistor by the ionisation column produced by the energetic ion.

The relation of the first moment of the charge of the drain pulses of the 2nd class with respect to the applied voltage V_{DS} is shown in Fig.2. The charge generation mechanism for this class of pulses is evidently a threshold mechanism: these pulses do not occur if V_{DS} is below a critical value. In addition the average charge developed by these pulses is quite insensitive to the LET of the ion.

The charge generation mechanism of the second population is attributed to regenerative mechanisms initiated by an avalanche effect that occurs in sufficiently high electric fields. The large current of holes, produced by the avalanche, when injected into the base from the collector, causes a violent turn-on of the parasitic transistor and a saturated current pulse.

The regenerative mechanisms that further increase and sustain the charge generation may lead to burnout. However, during this experimental phase, burnout was not observed, on the other hand, the external circuit was strongly perturbed by current spikes up to 0.3Amps.

![FIG. 2: Mean value of the second class drain charge v/s Vds.](image)

IV. ACKNOWLEDGEMENTS

This work is supported by Agenzia Spaziale Italiana (ASI) under contract n. I/R/162/01.

The authors wish to acknowledge Dr. Fallica and Dr. Frisina (ST Microelectronics) for the support given to the work. Special thanks to Dr. A. Sanseverino for her valuable contribution to the preparation of the samples.

A special thanks also to Dr. Alexander Kaminsky of the SIRAD group for his assistance during the experiment.

Last but certainly not least we thank the INFN Labs of Legnaro for the stimulating hospitality and efficiency.