Single Event Effect: methodolody for modelling and analysis of experimental data

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***Abstract*—This paper briefly describes a methodology of treatment and analysis of SEE experimental data, obtained in the Brazilian heavy ion accelerator (Pelletron). the circuit simulator models, which are implemented in MATLAB in a formal optimization strategy. The drain current transient curves, extracted in a commercial pMOS transistors, were used for this analysis. The methodology of experimental data treatment involves; SEE event discrimination and automatic identification been able to detect and segregate it from all measurements; uncommon artifact analysis detected on the current transient curves; and a inquiry of the current amplitude deviation.**

Keywords—SEE, pMOS sensor, methodology, drain current transient.

I. INTRODUCTION

Brazilian facility (LAFN-USP/São Paulo) has been successfully performing analysis on the atmospheric radiation impact on semiconductor devices [1]. One of the most serious problem that these devices experience, when used on the natural radiation environment of space, is the single-event effects (SEE). Specifically, SEE radiation is caused by a single heavy particle interacting with the device. While the majority of heavy ion passing through the component probably will not clash, nevertheless those that strike silicon atoms can flip bits. Among the dramatic disturbances induced by ionizing radiation reported do date, that it is possible to mention the loss of data in memory; microprocessor halts; erroneous transients at the circuit output, among other.

Heavy ion accelerator is the most classic method for SEE evaluation, and have to be in accordance with the radiation effects community that developed a number of hardness assurance test guidelines to assess and assure the radiation hardness of semiconductor device. Additionally, the Linear Energy Transfer (LET) has been ideally used as the engineering metric to assess heavy ion in microelectronics components.

In the last few years, it has been suggested that electronic devices could be used as radiation monitor since the effects of the interaction of radiation with electronic devices are relatively simple and reliable.

Basing on the exhibited, the main of this paper is to present an experimental study of Single Event Effects (SEE), induced by heavy ion irradiation on commercial MOSFET transistors.

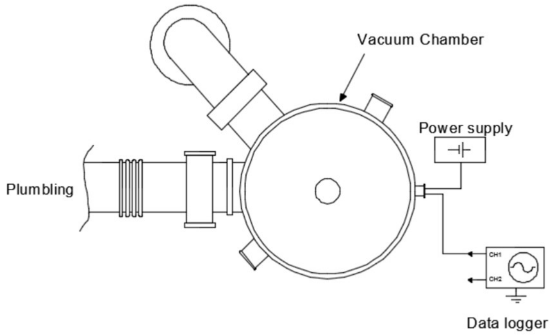
II. EXPERIMENTAL SETUP

A. Experimental Facility

The experimental radiation effect facility is an effective tool for the qualitative evaluation of SEE, and the Brazilian research community own a heavy ion accelerator installed at Laboratory of Nuclear Physics of the University of São Paulo (LAFN-USP), where the irradiation experiments were conduct. The radiation facility presents an 8 UD Pelletron accelerator were energies up to 70 MeV are available.

The devices were place in one of the spreading chamber, which has a diameter of 1 meter per 30 centimeters height, maintaining a pressure of about 102 torr. From the ion beam focus, the transistors were set at 15 degrees and to 40 centimeters from the chamber center. To disperse the ion beam, a gold leaf was place at the center of the chamber, being this able to modulate the beam flux scattered through its thickness. Figure 1 below presents a schematic drawing of the chamber. The tests were performed at room temperature. The CI ion beam were used with a LET around 175 MeV.cm2/mg; an energy of 71,5 MeV and the range in Si expected to be 19.5 µm.

Fig. 1. Schematic drawing of the scattered-ion irradiation

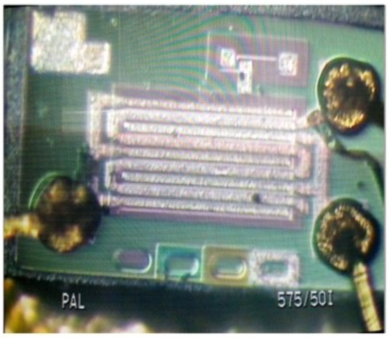


B. Electrical test system and device under test

Test boards containing the DUT were mounted inside the vacuum chamber and during the exposures, the power supply currents were continually monitored to detect the occurrence of SEE´s. The sampling rate was 10G samples/s, using a 1-GHz Rohde & Schwarz RTO1012 scope, equipped with a real time digital trigger system. The high-performance trigger system showed to be determinant for the success of the experiment, because it allowed an accurate detection of the pulses during long time lasting experiments without consuming excessive amounts of digital memory. Hundreds of pulses were registered for each ion beam, and their characteristics are clearly associated to ion strokes on the sensor.

The device chosen as heavy ion bean radiation detector was a commercial one p type MOSFET transistor (3N163) with large impedance, breakdown voltage, and very reduced leakage current (Figure 2). Assembled in a TO-72 package configuration it became easy to withdraw it and expose the die directly to the radiation. Moreover, it was decided to bias the device at triode region where the device behaves like a controlled resistor and the channel depth can be considered almost constant. On Figure 2 it is possible to see a photograph of the transistor with the die exposed.

Fig. 2. Photograph of the transistor used for the analysis.



III. SEE Evaluation Methodology

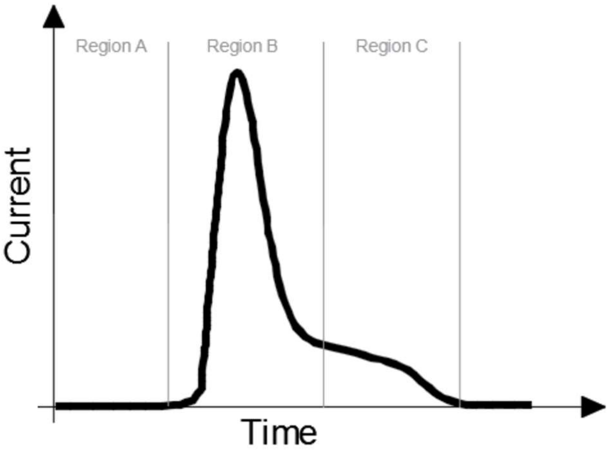
A. *Drain current transient curve*

Single-event effect indicates a change in sate or performance of a semiconductor devices, component or system (digital or analog) that is a result from a single energetic particle strike. Not all SEEs which propagate through a system result in a failure, it will depend of the location that the fault occurs in system.

When an ionizing radiation event begins, where the ion pass through it is formed a submicron radius cylindrical path of high carrier concentration of electron hole pairs (region A). As this path is becoming close to the depletion region, carriers are collected by the electric field inducing a large voltage current transient. At this moment, the cylindrical path changes its format to a funnel shape, this in turn, enhances the drift collection efficiency and the depletion region deeper as well (region B). The last region of the curve (region C), indicates the completed collection phase, followed by a phase where diffusion begins the collection process dominant.

Considering integrated circuits, any semiconductor device that presents a reverse-biased junction become very sensitive to an ionizing radiation event. At this moment, when a heavy ion strikes this junction, a drain current transient is observed at the drain terminal, as shown in Fig. 3.

Fig. 3. Time evolution of currents induced by a heavy-ion strike.



B. *Characterization using MATLAB Simulation*

In order to create a methodology to treat the experimental data, Matlab software was used. Figure 4 below presents the flowchart that represents the algorithm implemented in the numerical simulator. The instrument was triggered considering the fall edge of the curve, thus measuring 2031 points of data in format of 1×2031 array. In this array format the current value was being added until the total points and after that a new measurement was achieved. Basing in this background, the first algorithm performed consist in split the data in 2031 samples.

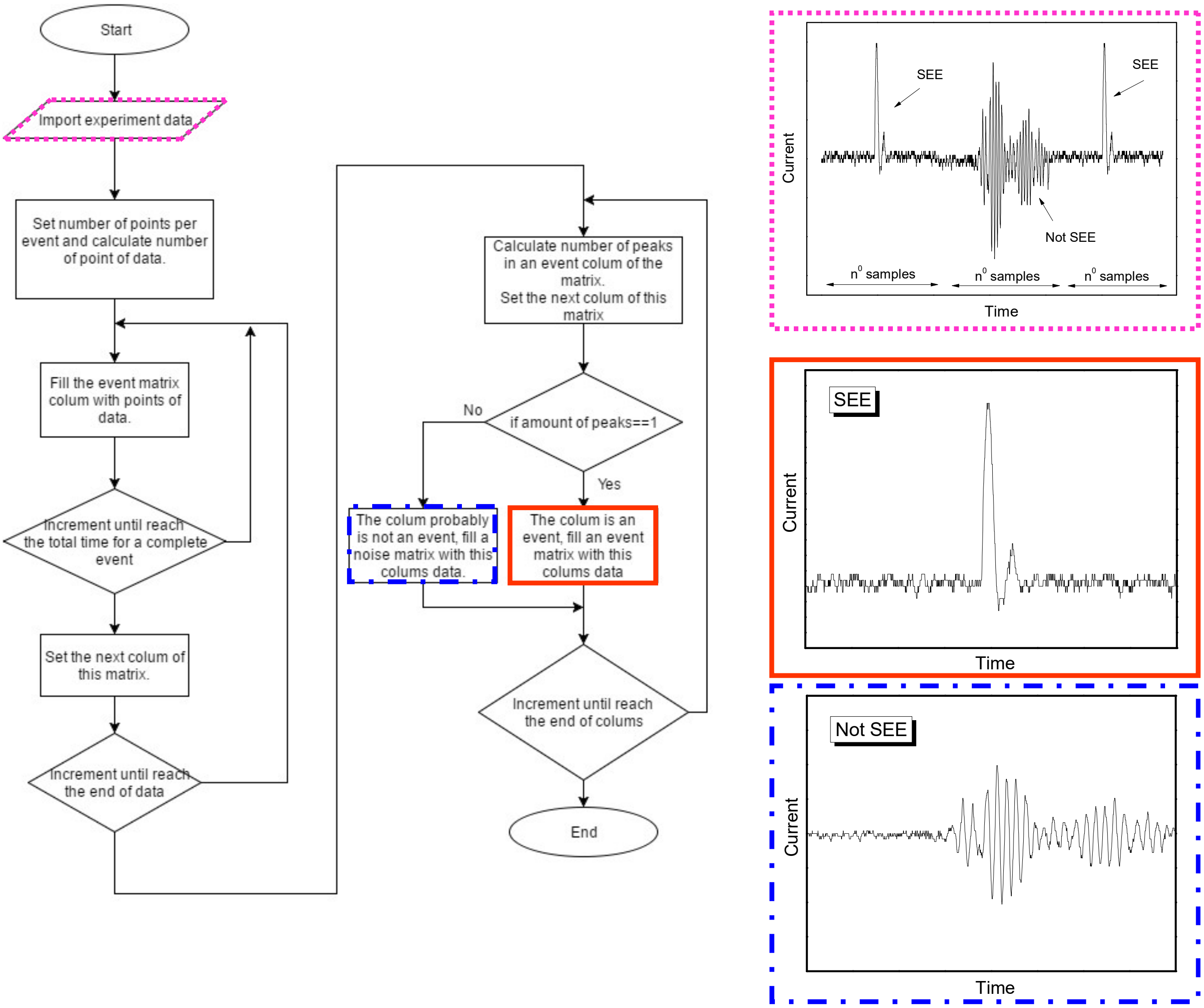
In a second time, it was required to distinguish what is SEE event and what is not. Not all data saved represent a SEE transient, there is more evidence of system noise indeed. An automatically system to realize a data analysis is proposed here, in order to perform a faster analysis and with more confidentially. The algorithm considers that for an SEE event only one peak could be observed, otherwise, it would not be a SEE event.

C. *Drain current transient artifact removal*

Ownership now only the SEE experimental curves, we recognized the presence of an artifact on the expected drain current transient behavior (Fig. 5). This could be allied with the long distance between the spreading chamber and the test facility system, which require lengthy cables and furthers connectors.

Fig. 6 presents the circuit model that represents the electrical test system used. It is possible to notice the mailing parameters that could affect the measurement: the transistor, the coaxial cable and the oscilloscope. Table I presents the description of witch components and its importance on the circuit model.

Fig.4. Flowchart for SEE experimental data treatment



Eq. (1) presents the output voltage extracted from the circuit model, and correspond to the transient voltage measured on the transistor during radiation. With Matlab tool support it is possible to correlate the artifact with the circuit model components.

$$Vout(s) = \frac{\frac{R}{1+sRCo}}{(R_{DS}+R_1)+sL+\frac{R}{1+sRCo}} - R_{DS}I_{DS} \qquad (1)$$

The drain resistance transistors are around 250 Ω extracted from datasheet. The oscilloscope input impedance was regulated to 50 Ω and the capacitance is too high in compared with the resistance, and can thus be disregarded. The parameters used for the coaxial cable, was calculated according to the manufacturer application note [2]. The shunt capacitance (C) can be calculated throw Eq. (2) resulting in a 930pF and the Eq. (3) results in the series inductance L=0.3μH.

$$C = \frac{24.161 * \varepsilon_r}{\log(\frac{D}{d})} l \qquad (2)$$

ε_r	relative dielectric constant
d	inside radius of outer conductor
D	outside radius of inner conductor
l	coaxial cable length

$$L = 0.459 * log \frac{D}{d} \qquad (3)$$

Fig. 5 SEE signal view observed with the oscilloscope using ^{35}Cl heavy ion beam.

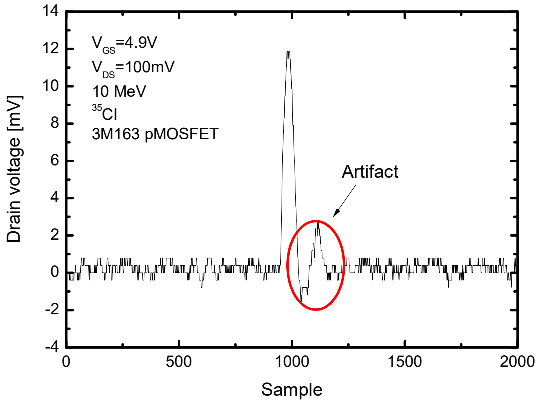


Fig. 6 Electrical test system circuit model.

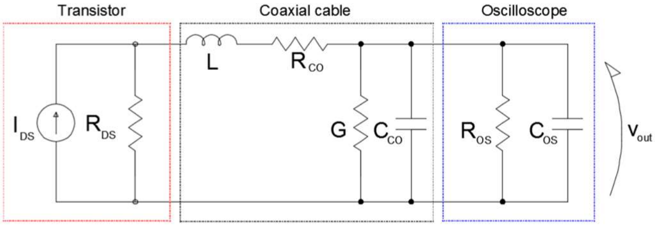


TABLE I. CIRCUIT MODEL PARAMETERS.

Component	Parameter	Description
Transistor	I_{DS}	Drain current
	R_{DS}	Drain-source resistance
Coaxial cable	L	Coaxial cable series inductance
	R_{co}	Series resistance of inner conductor, that are very small in low frequencies
	G	Shunt conductance, consider very small due to the good dielectric properties
	C_{co}	Coaxial cable shunt capacitance
Oscilloscope	R_{os}	Oscilloscope input impedance matching
	C_{os}	Oscilloscope input capacitance, around 13fF, with can be negligible.

The results of the numerical simulation realized on Matlab (Fig. 7) with the values previously imputed, indicated that the drain-source resistance, parameter dependent from the transistor, presents a larger impact on the artifact and the value suggested of 250Ω (inset of Fig. 7) didn´t demonstrated the artifact on drain current transient. This value was reduced to 10 Ω and in that way, the artifact could be seen. This reduction on the drain-source resistance could be related with the radiation effect on the transistor. Moreover, a transistor with larges R_{DS} could prevent this apparition, or a higher gate voltage can be used. The other parameters dependent from the coaxial cable and oscilloscope not indicated to be relevant in the artifact appearance.

D. Current transient peak variation

Fig. 8 presents the SEE signal view observed with the oscilloscope using ^{35}Cl heavy ion beam indicating the different peak amplitude. The cross sectional area is a figure of merit that establishes how sensitive the component is to the effects of atmospheric radiation. Estimating the single event effect cross sections is important in developing a fault-tolerant system; predict the system failure rate and its susceptibility to radiation. The literature has already reported, through simulations, a dependence of the LET crossing the transistor but at different positions from drain to source. It was seen that shorter transients and smaller current peaks are observed when ion strikes closer to the drain [3-4].

Fig. 7 – Drain current transient simulated at Matlab indicating the artifact presence.

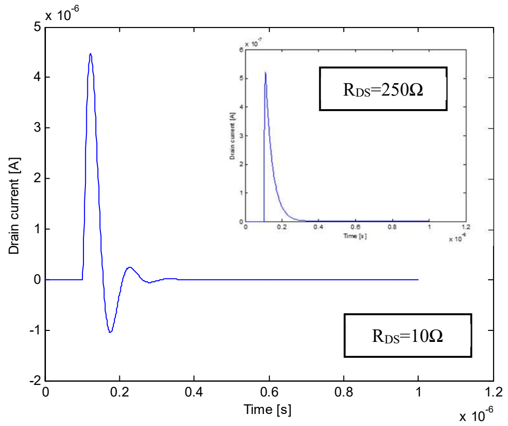
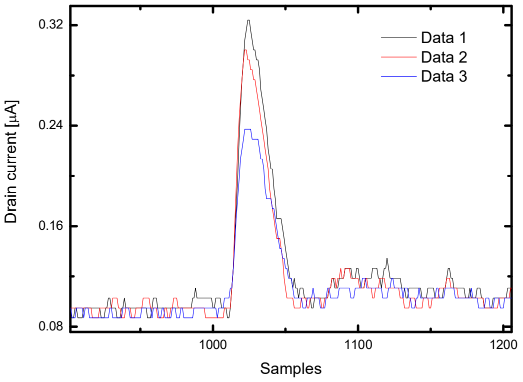


Fig. 8 - SEE signal view observed with the oscilloscope using ^{35}Cl heavy ion beam indicating the different peak amplitude.



IV. CONCLUSION

This paper presents experimental data analysis of SEE effect through drain current transient obtained in pMOSFET transistors. The devices were irradiated with heave ion radiation using Pelletron accelerator (LAFN-USP-Brazil). The results indicated a huge influence of the transistor drain resistance on the transient behavior when a heavy ion strikes the semiconductor. Moreover, the impact site seems to affect the drain current amplitude.

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