Comparison of the transient current shapes obtained with the diffusion model and the double exponential law - Impact on the SER

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Comparison of the Transient Current Shapes Obtained With the Diffusion Model and the Double Exponential Law - Impact on the SER

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Abstract— **We calculated neutron induced Single Event Upset (SEU) cross-section as well as the Soft Error Rate (SER) at ground level. For this purpose, we first used an accurate model based on simulation of atmospheric neutron-induced transient currents in a 90-nm drain electrode, through a detailed diffusion model. Then, we performed the same simulations by replacing each transient current by a simple double exponential law model, for which the parameters were set in order to keep the same total charge as for the diffusion model, as well as the same value of maximum current and its corresponding occurrence time. Our results show a little increase of the cross section while using the double exponential law and we established a correlation between the parameters characterizing the double exponential and the diffusion model curves.**

Index Terms— **Transient currents, single event upset, MC-Oracle, atmospheric neutron, double exponential law, diffusion model, Monte Carlo method**

I. Introduction

Single Event Upset induced by radiations and more generally single event transients (SETs) represent a major concern for microelectronic reliability [1-3]. For ground level applications, there are two main sources of soft errors. On one hand, neutrons are produced by cosmic rays in the atmosphere and are able to trigger nuclear reactions in the electronic devices [4], producing ionizing particles (recoiling nuclei and secondary light particles). On the other hand, radioactive pollutants, such as alpha emitters, are able to ionize the materials of the electronic devices [5]. In both cases, the electron-hole pairs, which are generated in these reactions, may lead to transient currents that affect directly the device reliability.

In order to accurately evaluate the reliability of a given device, it is mandatory to understand in detail the main properties of the transient currents (e.g. the shape) that are generated during particle incidence. In [6], it has been asserted that a double exponential law can model the shape of the transient current, but it is a priori difficult to determine realistic values of the parameters of this law. Moreover, these parameters strongly depend on the technology. Some Monte Carlo tools, as in [7-9], use the ambipolar diffusion law in order to calculate, event by event, the transient current at each node of the electronic circuit. Then, the tool calculates directly the effect of the transient current on the system without storing the information on the properties of the transient current pulse.

The double exponential law is often used to represent the shape of the transient current induced by particles but there was no attempt to show its validity compared to a physical model such as the diffusion model.

The aim of this paper is to compare the incidence of the choice of the model of parasitic current pulses, in particular their shape, on the SEU cross section. We compared the double exponential current shape and the diffusion model, through simulating their effects on the SRAM cell. Starting from a transient current provided by the diffusion law, we calculated the corresponding double exponential current for which we kept the total charge, the maximum current and the time of its occurrence.

The rest of the paper is structured as followed. Section II introduces the simulation tool and shows how the current shapes can be compared. It shows how the double exponential law parameters are extracted from the diffusion model, in order to have a consistent comparison. In Section III, we provide some results, for a 90 nm SRAM device, in terms of SEU cross section and SER. Results for more integrated devices will be given in the final paper. In Section IV, we show how we can link the parameters of the two models. Section V concludes the paper.

II. Current pulse Characterization

We used the Monte Carlo code MC-Oracle which has been presented in [9] and will be described in the final paper.

In our study, the simulated structure is a bulk made of a silicon layer with a surface of 30 µm x 30 µm and a thickness of 20 µm (see fig. 2). Above this bulk, we added a layer of 10 µm of silicon dioxide to account for the Back End Of Line (BEOL). At the Si/SiO_2 interface, we simulate 20 x 20 drain

Manuscript received April 5th, 2013.

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This work has been supported by the National Research Agency in the framework of project ANR-09-BLAN-0155-01.

electrodes.

The nuclear reactions are triggered in the structure by using a Monte Carlo approach. Incident neutrons have either a given energy with a given direction or an isotropic distribution and their energies are drawn in an atmospheric-like spectrum [12].

By using the MC-Oracle tool we investigated the SEU cross-section variation due to the use of a double exponential current pulses instead of those resulting from the more precise diffusion model. While the diffusion model is based on physical phenomena, the double exponential law is based on a simple analytical law, easier to use since it does not need any integration. Its common expression is given by the following equation:

$$I = \frac{Q}{\tau_f - \tau_r}\left[e^{-\frac{t}{\tau_f}} - e^{-\frac{t}{\tau_r}}\right] \qquad \text{eq. 1}$$

where Q is the total collected charge (in C), t is the time (in s), and τ_r and τ_f are two features of the current peak named rising time and falling time respectively (in s).

The double exponential law is often used as an input of simulation tools which aim to evaluate the sensitivity of a device. Nevertheless, the main drawback is that neither the collected charge nor the rising and falling times are actually known. Here, we propose to use data calculated for the diffusion current pulses in order to determine these parameters for each transient phenomenon. Thus, generating the double exponential current pulses as simplified model of the diffusion model, we are able to consistently compare the effects of the two current shapes.

From the diffusion model we extract, for each current pulse, the total collected charge Q (which also appear in the double exponential law), the current maximum I_{max} and the time at which the current reaches the peak T_{max}. Vanishing the derivate of the double exponential law gives a first relationship between the maximum current and the rising and falling times:

$$T_{max} = \frac{ln\left(\frac{\tau_f}{\tau_r}\right)}{\frac{1}{\tau_f} - \frac{1}{\tau_r}} \qquad \text{eq. 2}$$

Moreover, since $t=T_{max}$ the current is I_{max} we obtain a second relationship:

$$I_{max} = \frac{Q}{\tau_f - \tau_r}\left[e^{-\frac{T_{max}}{\tau_f}} - e^{-\frac{T_{max}}{\tau_r}}\right] \qquad \text{eq. 3}$$

Starting from a transient current provided by the diffusion law, it is thus possible to deduce an equivalent double exponential current for which the total charge, the maximum current and the time at which the current is maximum are conserved. While Q is immediately extracted, τ_r and τ_f are obtained by solving eq. (3) and (4) through a numerical method which will be detailed in the final paper.

Fig. 3 gives an example of an obtained diffusion current and its equivalent double exponential law. Even if it is clear that some differences exist between the two shapes the main issue is then to know whether there is an impact of the shape on the SEU cross section or not. Notice that the log-log scale lets think that the area of the two curves are different but they are actually identical.

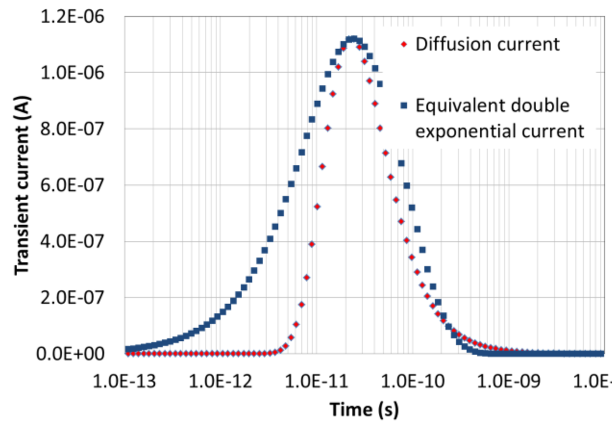

Fig. 3. An example of a transient pulse obtained by the diffusion model and the equivalent current obtained with a double exponential law. Notice that the log-log scale lets think that the area of the two curves are different but they are actually identical.

III. Cross Sections and SER Calculations

We performed extensive simulations for monoenergetic neutrons and for an energy spectrum representative of the atmospheric environment at ground level in New York City.

The graph in Fig. 4. plots the SEU cross section obtained for both current shapes (diffusion and double exponential) for a typical SRAM cell array in 90 nm technology. Despite the huge differences between the shapes of the diffusion model and double exponential (Fig. 3), the deviation in terms of SEU cross-section is not very important and it is typically around 10-20%. The double exponential law provides systematically a higher cross section than the diffusion model. This increment is due to the fact that the double exponential current is higher than the diffusion one during a time that is longer than T_{max}. This extended high intensity of the current increase the probability of cell upset. The simulations made with a ground level neutron spectrum lead to a soft error rate of 389 FIT/Mbit for the diffusion law and 456 FIT/Mbit (+17%). Both values are consistent with the data published in literature for 90 nm SRAMs. More results will be given in the final paper for more integrated technologies.

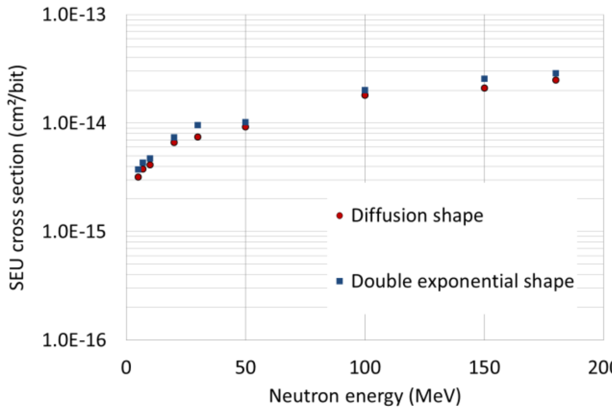

Fig. 4. SEU cross section obtained for both current shapes (diffusion and double exponential) for a typical 90 nm SRAM.

IV. Correlation between the diffusion model and the double exponential law

Since the difference between the two investigated shapes is not significant, it is useful to establish a formal correlation between the parameters of the diffusion law and those of the double exponential law. The graphs in Figs. 5 and 6 plot respectively the rising time and the falling time of the double exponential law as a function of T_{max} (time when the current reaches its highest value) in the diffusion law. Each spot on these graphs corresponds to a transient current pulse.

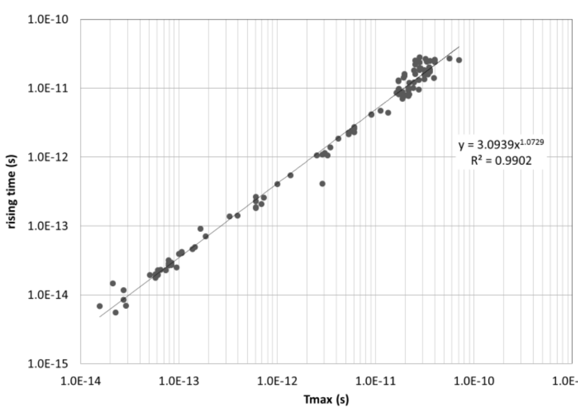

Fig. 5. Relationship between the rising time (from the double exponential law) and the Tmax (from the diffusion law).

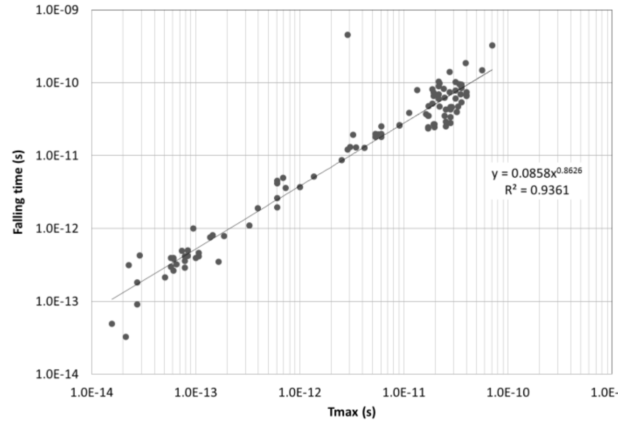

Fig. 6. Relationship between the falling time (from the double exponential law) and the Tmax (from the diffusion law).

Both the rising and the falling times follow approximately a power law. Therefore, while using a double exponential law, instead of using three parameters (Q, τ_r and τ_f) it is possible, in the framework of the diffusion model, to use only two parameters (Q and T_{max}) :

$$I = \frac{Q}{\tau_f - \tau_r}\left[e^{-\frac{t}{\tau_f}} - e^{-\frac{t}{\tau_r}}\right] \qquad \text{eq. 4}$$

where:

$$\tau_r = 3.0939 \times T_{max}^{1.0729} \qquad \text{eq. 5}$$

$$\tau_f = 0.0858 \times T_{max}^{0.8626} \qquad \text{eq. 6}$$

The use of these equations allows having pulses with more realistic features.

V. Summary and conclusions

In order to study SET, it is crucial to obtain realistic information on the characteristics of the transient currents generated by ionizing particles. Monte Carlo tools are very useful for this purpose as it allows studying each event independently. For each event the diffusion process is then used to calculate the transient current at a given drain electrode.

Practically, a double exponential law is often assumed to well represent the transient current induced by an ionizing particle because such analytical law is easy to handle. However, the three involved parameters such as the total collected charge, the rising and the falling times are actually not known, even approximately.

In this work, we mainly focus on the shape of the transient pulse in order to state whether the double exponential law is realistic enough to well represent the current induced by a particle regardless the choice of the parameters. In order to make a fair comparison, we imposed that the equivalent double exponential law would have the same total collected charge, maximum current and its time occurrence as the diffusion law.

Our simulations results revealed that the current shape has a small incidence on the SEU cross-section and SER since the double exponential law exhibits an increase of only 20% for the cross section. The use of a double exponential law is thus acceptable in order to have a rough evaluation of the SEU cross-section. Furthermore, we proved that it is possible to fully determine the double exponential current with the help of only two parameters, which are the collected charge Q and the time T_{max} , in which the current reaches its maximum.

In conclusion, the double exponential law shape is acceptable to simulate the transient currents induced by ionizing particles and it actually requires only two parameters (the collected charge and T_{max}) instead of the three that are used. Even if there are some differences between the shape of the double exponential law and the diffusion model, this is not significant to modify significantly le SEU cross section. However, there is still incertitude on the value of the remaining parameters which should be used and future work will give some guidelines about the distributions of these parameters.

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