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► **To cite this version:**

S. Guagliardo, Frédéric Wrobel, Y. Q. Aguiar, J.-L. Autran, P. Leroux, et al.. Single Event Latchup Cross Section Calculation from TCAD Simulations – Effects of the Doping Profiles and Anode to Cathode Spacing. IEEE RADECS 2019, Sep 2019, Montpellier, France. hal-02446849

HAL Id: hal-02446849

<https://hal.science/hal-02446849v1>

Submitted on 1 Apr 2021

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Single Event Latchup Cross Section Calculation from TCAD Simulations – Effects of the Doping Profiles and Anode to Cathode Spacing

S. Guagliardo, F. Wrobel, Y.Q. Aguiar, J-L. Autran, P. Leroux, F. Saigné, V. Pouget and A.D. Touboul

Abstract— In this paper SEL cross sections were calculated from TCAD simulations varying doping profiles and anode-to-cathode spacing values. We found that doping profiles variation has a stronger impact on SEL sensitivity than variation of spacing.

Index Terms— Single-Event Latchup, TCAD simulations, Cross section.

I. INTRODUCTION

SINGLE event latchup (SEL) is a potential catastrophic condition that affects CMOS technology. It arises from parasitic bipolar transistors that are structurally intrinsic to this technology (Fig. 1.) [1]-[4]. If a radiation particle hits the component, electron-hole pairs are generated in the structure and thus they can lead to the activation of the parasitic transistors if the deposited energy is large enough. However, the deposited energy by the radiation particle is not the only parameter to consider as far as SEL sensitivity is concerned. In fact, numerous parameters can influence it, such as the angle of incidence of the ion, doping profiles, P+ to N+ spacing, temperature and biasing conditions. Different works have investigated the effect of these parameters [5]-[7]. For instance, in the work of Rezzak *et al.* [8] it is shown that an increase of the doping in the N-well or in the P-substrate harden the component. Furthermore, in the work of Al Youssef *et al.* [9], dependence on anode to cathode spacing (A-C spacing) has been studied. In this case, if the A-C spacing is increased, the sensitivity to SEL is decreased.

However, in these works the evaluation has been done focusing on the minimum linear energy transfer (LET) necessary in order to trigger SEL. In our work, we performed TCAD (Technology Computer Aided Design) simulations and calculated the SEL cross section curves. As a result, more detailed information on the device SEL sensitivity is available. For example, the SEL rate in a specific environment can be

calculated using SEL cross section curves. Moreover, we have been able to evaluate the trend not only for the minimum LET, but even for higher LET.

In order to perform that, we thus used TCAD simulations. They have been used widely in the literature [10][11] and provide an insight view of the mechanism of Single event Latchup. In our work, we have performed 2D simulation using Sentaurus Synopsys tools. Even though SEL is a 3D effect, in order to save calculation time, it is possible to perform 2D simulations. As a matter of fact, it has been shown that SEL sensitivity in 3D simulations follow the same trend as in 2D simulation [10], [12]. Furthermore, with TCAD simulations it is possible to evaluate the importance of the parameters that influence SEL sensitivity. It is important to understand the relevance of each of these parameters, because knowing how much they influence SEL sensitivity, could be helpful during the design of the components but also for the development of a predictive tool. Nonetheless, TCAD simulations provide information only about electrical characteristic like current or

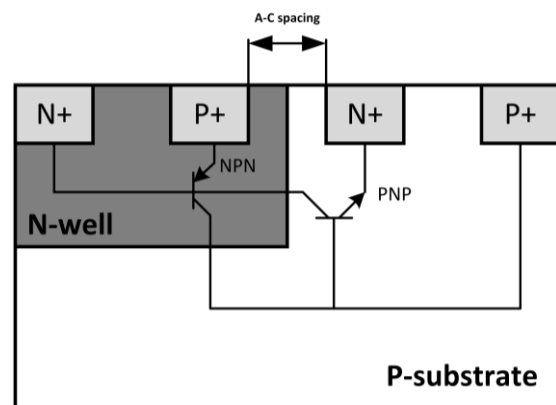


Fig. 1. Simplified PNP structure used in our work. A-C spacing is depicted.

Manuscript received April 15, 2019. This work was realized within RADSAGA project. The RADSAGA Innovative Training Network project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie-Sklodowska-Curie grant agreement number 721624.

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voltage, or about doping profiles and carrier characteristics.

Hence, parameters that are strictly related to radiation sensitivity, like cross section, must be retrieved by these data, as we have performed in our work.

Here, we focused our analysis on the effects of temperature, A-C spacing and doping profiles variation. The aim is to quantify the influence of these parameters on SEL sensitivity, not only in term of threshold LET. In order to perform that, the cross section obtained through 2D simulations results have been used. This method combines the opportunity to run fast 2D simulations while obtaining a key parameter to measure SEL sensitivity. The results can be helpful in order to understand which parameter must be carefully chosen for the design of a CMOS component or for the creation of a SEL predictive tool.

The structure of the paper is the following: in Section II we explain how we performed TCAD simulations and how we calculated SEL cross section curves. In Section III the results are presented and discussed and finally Section IV includes our conclusion.

II. TCAD SIMULATIONS

A. Device structure and simulation setup

A PNP structure (Fig. 2) formed by a PMOS source and an NMOS source has been used. This is the basic structure that SEL requires in order to be investigated [1]. The structure is based on a 65 nm CMOS inverter. All simulations have been performed using Sentaurus Synopsys tools. The component has a width of 3 μm . The contact width is 0.14 μm and the anode to cathode spacing (A-C spacing) is 0.32 μm . The doping profile is based on a commercial bulk 65nm process. Then, the A-C spacing has been changed for the simulations and the following values have been chosen: 0.25, 0.27, 0.32, 0.37 and 0.40 μm . The doping profiles have been changed multiplying the current profiles respectively times 0.75, 0.85, 1.15 and 1.25.

Simulation have been performed using Sentaurus Device tools. The hydrodynamic model has been chosen along with Fermi statistics as carrier transport model. Also, electron and hole carrier heat energy equation have been solved. The mobility was modelled with the built-in model by Arora [13], which is a doping and temperature dependent model. For recombination the doping dependent Shockley-Read-Hall, Auger recombination and avalanche generation have been chosen. Finally, bandgap narrowing for high doped region has

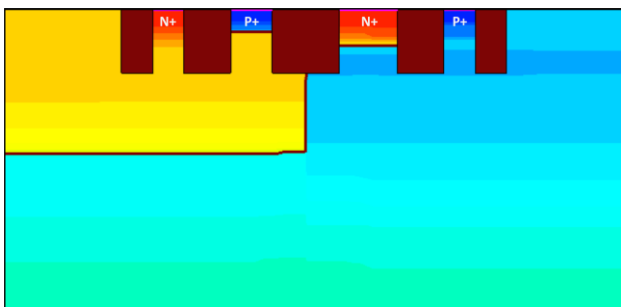


Fig. 2. 2D structure of the PNP built with Sentaurus Structure editor

been selected.

To generate the ion track, the built-in tool provided by Synopsys has been used. Before that, we have run different simulations with SRIM [14]. Using as a reference the ions available in the RADEF facility, we found that the LET was constant along the component. So, linear energy transfer has been chosen constant and the range is 2.3 μm in order to cover the entire structure. The radial distribution has been set with a Gaussian profile with a 0.05 μm radius, according to previous works [15][16].

B. Cross section calculation

Simulations with ions have been performed in order to obtain the SEL cross section. The strike position of the ions was simulated in different part of the structure along its width. The aim was to obtain the minimum LET necessary in a specific location to trigger SEL. The sensitivity is 2 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$. After that, a chart with minimum LET versus position has been created as in Fig. 3. To estimate the cross section the method as reported in [17] has been used. For various LET we calculated the width of the sensitive zone from charts like Fig. 3, interpolating the values when necessary. The obtained value of width (that is σ/d , as shown in Fig. 3) is then multiplied by the depth of the component “ d ”.

C. Preliminary results

According to our method we first investigated the effect of temperature on the SEL cross section (Fig. 4). It is widely known that temperature is a key parameter for Single event Latchup [18][19]. From the simulations we obtained results that agree with the literature that is to say that CMOS components become more sensitive to SEL when the temperature increases. So, for the same value of LET, cross section increases for higher temperatures.

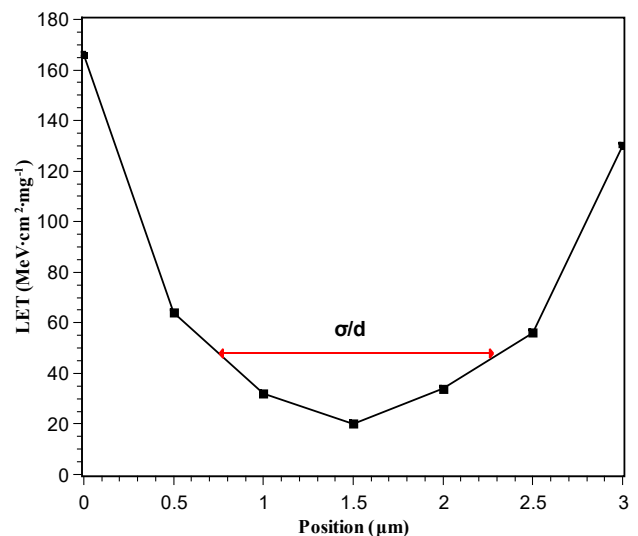


Fig. 3. Minimum LET value versus position along the component. “ d ” is the depth of the component.

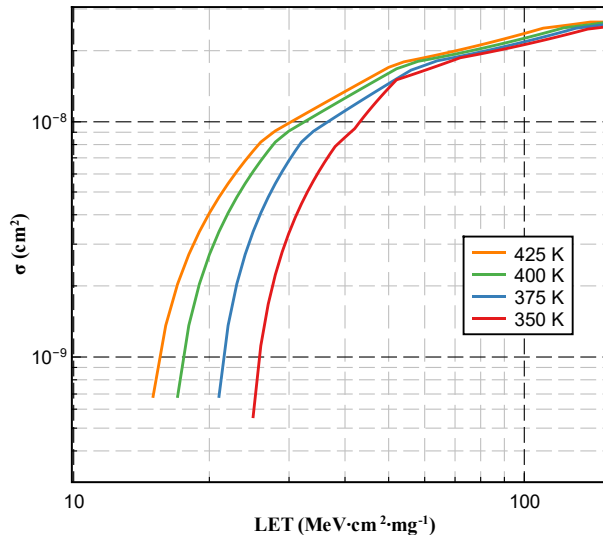


Fig. 4. SEL cross section curves obtained from TCAD simulations for four values of temperature (425 K, 400 K, 375 K, 350 K)

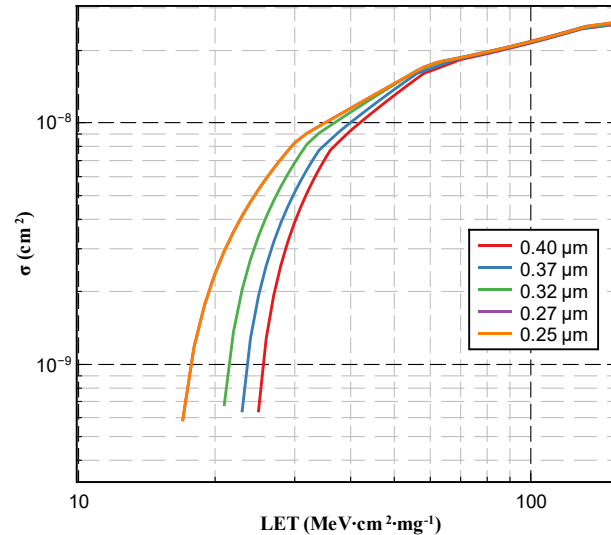


Fig. 5. SEL cross section curves obtained from TCAD simulations for different A-C spacing values.

III. RESULTS AND DISCUSSION

A. Anode to cathode spacing

First, the cross sections for different A-C spacing (see Fig. 1) are shown (Fig. 5). These results agree with literature [9]. Increasing the A-C spacing results in a decrease of the SEL sensitivity, except that for 0.27 and 0.25 μm values. In this case the cross section shows no difference between these two values. The LET threshold ranges from a value of 16 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ for the smallest value of A-C spacing to 24 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ for the higher value. Moreover, the same trend is obtained for the LET value at which the saturation cross section (which we consider as the value of cross section corresponding to the highest value of LET obtained with the simulations and that also corresponds to the whole area of the component) is achieved. Indeed, as for the minimum LET, the lowest value is 160 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ and it is obtained for the smallest A-C spacing, whereas a value of 172 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ is reached for the highest value of A-C spacing (0.40 μm).

B. Doping profiles

Secondly, the doping profile variations effects are plotted in Fig. 6. Even in this case, results agree with literature [8]. A component with a higher doping profiles results in a more hardened one. In this case, the LET threshold goes from 12 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ to 30 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$. As for the A-C spacing, the saturation follows the same trend of the LET threshold. It ranges from a value of 116 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ when the doping profiles is 75% of the reference and increases to a value of 216 $\text{MeV}\cdot\text{cm}^2\cdot\text{mg}^{-1}$ when the doping profile is 125% of the reference. It is interesting to mention that for a value of 150% the reference value, no SEL has been obtained.

C. Discussion

From the simulations it can be observed that variation of doping profiles has a stronger effect on SEL sensitivity

compared to the variation of the A-C spacing. Also, as a result of the approach we used, this trend is verified not exclusively for the LET threshold, but also for increasing values of LET. To explain this, SEL dynamic must be considered. As aforementioned, SEL is generated because of the parasitic transistors created within the device structure. A variation of the A-C spacing leads to a variation of the path of charges inside the component. So, if the distance between anode and cathode is increased, the NMOS and PMOS will be physically separated and thus activation of the parasitic transistor is less likely to happen. Instead, doping profiles influences the resistances inside the component. This mean that for the same amount of charge a higher potential drop can be obtained inside the structure and thus it is more likely to trigger the parasitic transistor on. Hence, according to our simulations, the variation of resistances plays a more important role respect to the decoupling of the NMOS and PMOS.

This aspect can be taken into consideration in the design phase of a component. Both methods can be used for hardening the component, but both come with drawbacks. In fact, increasing A-C spacing leads to an area penalty, whereas variation of the doping profiles may not be possible because of process related issues. So, a compromise must be made in order to harden CMOS components.

IV. CONCLUSION

In this work a comparison between the effects on SEL sensitivity from three different parameters has been made. Cross sections for each parameter have been calculated using 2D TCAD simulations. This approach allows to perform fast simulations and to calculate an important value to estimate SEL sensitivity.

First, we have investigated the effects of temperature on SEL sensitivity. As demonstrated in other works, we have shown that for higher temperatures, the SEL sensitivity

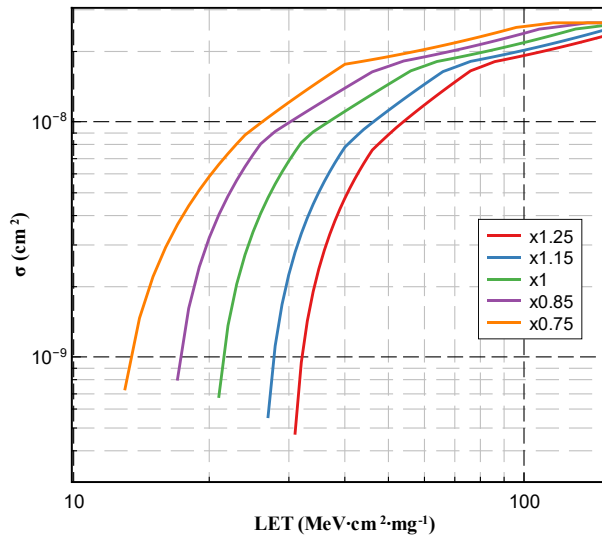


Fig. 6. SEL cross section curves obtained from TCAD simulations for different doping profiles values.

increases. Similarly, the increase of doping profiles increases the SEL sensitivity while increasing A-C spacing decreases it. Then, we observed that doping profiles variations have a stronger impact on SEL sensitivity compared to A-C spacing variation. This result is highly important in design phase to decide which strategies can be adopted to harden the component.

ACKNOWLEDGEMENT

This work was realized within RADSAGA project. The RADSAGA Innovative Training Network project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie-Sklodowska-Curie grant agreement number 721624.

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