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Prediction of proton cross sections for SEU in SRAMs and SDRAMs using the METIS engineer tool

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ABSTRACT

METIS, SIMPA and PROFIT are engineer tools based on heavy ion cross section for the assessment of Single Event Upsets induced by protons. Whereas SIMPA and PROFIT were based on analytical models; METIS has the particularity to rely on Monte-Carlo simulations of nuclear reactions and simple assumptions for upset triggering. Such tools are very useful for end-users because no information about the technology is needed to perform the sensitivity prediction, not even the feature size. The work presents the prediction results achieved on sub-100 nm technology SRAMs and SDRAMs with METIS and compares them with the ones obtained using SIMPA and PROFIT, widely applied for space radiation environment. METIS gives much more accurate results than the former analytical models.

1. Introduction

Single Event Upsets (SEUs) occur when a single ionizing radiation event produces a burst of hole–electron pairs that is large enough to change the state of a storage element, such as configuration memory cell, user memory, and register.

In space, SEUs are caused by charge collection at sensitive circuit nodes following a proton or a heavier ion strike. The heavy ions produce the effect directly while high energy protons induce upsets through ions emitted as a result of their nuclear interactions with the device matter. Furthermore, low energy protons may cause direct ionization SEU in very sensitive devices. Less than 1 proton in 10^5 will encounter a nuclear reaction in a silicon device. Although this seems like a very rare event, for low Earth orbits, the trapped proton fluxes are so high that they will contribute to more upsets than the heavy ion cosmic rays.

In order to reduce the cost and the number of radiation tests, it is interesting to develop bridges from one particle to another.

Among the large number of analytical predictions methods for SEU induced by protons based on heavy ion data, SIMPA [1] and PROFIT [2] are the most widely used by the European space community, as they are included in the OMERE package [3]. These models were developed in the middle of 90s, both require to specify the sensitive thickness and both rely on simplifications which have shown their limits for process technologies below 130 nm (see Table 1).

Monte Carlo codes based upon more physical triggering criteria compute the energy deposition by tracking all the secondary particles generated from nuclear interactions. Despite being more time consuming, they can be more accurate and detailed than analytical approximations [4].

Unfortunately, for an end-user, and so in space engineer working in radiations, technological data required for full physical simulations can be hardly obtained. An irradiation experiment often remains the only way to characterize the device sensitivity to radiation effects. The METIS (Monte-Carlo Engineering Tool for Ion-induced SEE) tool offers to extrapolate heavy ion data to proton or neutron cross section, which makes it therefore very close to the SIMPA and PROFIT approaches. Based on a nuclear database, and simple assumptions, it constitutes a relevant trade-off between accuracy and access to technological data. For SEU investigations in SRAMs, METIS is perfectly suitable for the end-user needs because no information about the technology is needed, not even the feature size, and the calculation is fast.

The tool has been extensively validated for SEU calculation on SRAM devices, bulk or SOI up to 45 nm [5]. We propose here to further validate the tool for very deep submicron SRAMs (45 and 28 nm) and to extend the validation to SEU in SDRAMs. Results are also compared with the ones achieved by SIMPA and PROFIT.

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Table 1
Features of the 3 prediction methods.

	METIS [5]	SIMPA [1]	PROFIT [2]
Inputs	Heavy ion cross section		
	Sensitive thickness only required for SEU in DRAM.	Sensitive thickness (default value 2 μm)	
			Average diffusion angle (default value 90°)
Collection	IRPP		Rectangular surface
Criteria	Critical energy		Critical LET
Nuclear data	Monte-Carlo selection	Experimental energy deposition in diodes	Analytical expressions for LET (E_{Si}) and $\sum_{nucl}$
Time-efficiency	~7 s/energy	<1 s	<1 s

Table 2
Weibull parameters for the SRAM and DRAM devices.

	Weibull parameters	Saturation cross section (cm^2/bit)	LETth (MeV·cm^2/mg)	W	S
45 nm SRAM	DNW	6.0E−8	1.0	105	1.0
	no DNW	1.8E−8	1.0	80	1.0
45 nm SRAM-based-FPGA	BRAM	1.8E−8	0.4	30	1.0
	CRAM	1.5E−8	0.8	20	1.8
28 nm SRAM-based-FPGA	BRAM	7.94E−9	0.8	5	0.7
	CRAM	1.43E−8	1.9	125.3	0.78
45 nm SOI	L2 cache	2.5E−9	0.4	32	0.8
DRAM Samsung		1.7E−9	1.5	22	2.0
DRAM Manufacturer C		1.0E−9	2	35	2.5

2. METIS overview

METIS relies on the same expression as the SIMPA methodology for a "gateway" tool between heavy ion and proton. The SEU proton cross section is given as a function of the heavy ion cross section by:

$$\sigma_P(E_p) = \int \sigma_{HI}(E_d)\ .\ P_{E_p}(E_d, V)\ .\ dE_d$$

with E_p the incident proton energy, σ_{HI} the heavy ion cross section, and $P_{Ep}(E_d)$, the probability to obtain a deposited energy E_d from the secondary ions in a given volume V.

Based on the concept of sensitive sub-volumes having rectangular parallelepiped (RPP) shape, an upset occurs when the energy deposited by the ions in the charge collection region exceeds the threshold energy. For the estimations performed in this paper, around 30 nested sensitive volumes were selected along a Weibull curve of the experimental heavy ion cross section. For each sensitive sub-volume, the threshold energy is the product of the heavy ion LET per the sensitive depth. In METIS, the probability for energy deposition is calculated using SRIM tables [6] and a Monte-Carlo selection of nuclear interactions from a pre-calculated database, which differs from the analytical expression used by the SIMPA method.

The nuclear database is constituted by listing the characteristic (type, energy and direction) of the secondary ions induced during elastic scattering and nuclear reactions. It was built using the MC-RED (Monte Carlo Recoil Energy Determination) code and was experimentally validated [7,8]. In this nuclear physics code, elastic reactions with silicon nuclei are studied with the ECIS [9] calculation code using the optical parameters from Koning and Delaroche [10]. Non-elastic reactions are simulated following, step by step, the nucleus decay. The pre-equilibrium stage is calculated using the 1D exciton model [11,12]. Equilibrium processes are simulated using the Hauser-Feshbach formulation [13]. The angular distributions are evaluated using the Kalbach systematics [14]. In the following studies, only nuclear reactions with silicon induced by protons are considered. Nuclear interactions with other elements than silicon used in the manufacturing process can be easily covered by including the proper database.

Table 1 presents a comparison between METIS and the former methodologies SIMPA and PROFIT.

3. SEU in SRAMs

For SEU studies in SRAMs with METIS, all input parameters are extracted from the measured heavy ion cross section. No technological data is required, and we assume that the heavy ion cross section fully characterizes the device sensitivity.

The sensitive areas are directly related to the measured heavy ion cross section curve. For submicron feature sizes, charge collection is mainly driven by diffusion mechanism and the sensitive thickness is therefore strongly linked to the sensitive surface (and is no more a constant value as it is in PROFIT and SIMPA). The sensitive thicknesses are then sized as half of the areal dimensions to approximate a hemisphere shape and are then increasing along the heavy ion cross section curve.

In order to achieve a good trade-off between computing time and accuracy, the nuclear interactions are generated in a silicon layer of 20 μm below the active surface and an upper layer of 5 μm, simulating the back end of line.

More details about the tool algorithms can be found in [5].

In [5], the METIS tool was validated for SEU simulation in SRAMs using a large number of commercial CMOS memories. For most of the devices, especially for deep submicron technologies, this tool gives more accurate predictions than SIMPA and PROFIT and the margin of 10 recommended in the ECSS Standard [15] when using SIMPA and PROFIT as a prediction tool could thus be reduced to about 3 when using METIS. Since then, new data are becoming available and this work investigates SEU in advanced SRAMs. Weibull fits, tabulated in Table 2, were made to all of the heavy ion data.

3.1. 45 nm SRAM

In [16], heavy ion (see Fig. 1) and proton (see Fig. 2) accelerator data are presented on 2 types of 45 nm SRAM from ST, with deep N-well layer (DNW) and without deep N-well structure. METIS simulations show fairly well accordance with experiments for both devices (see Figs. 2 and 3). SIMPA and PROFIT mainly underestimate the proton experiments when using 0.2 to 2 μm sensitive thicknesses and 90° of average diffusion angle for PROFIT.

3.2. 45 nm SRAM-based-FPGA

The susceptibility of a SRAM-based-FPGA based on a 45 nm technology was characterized under heavy ions and protons at UCL (see Fig. 4).

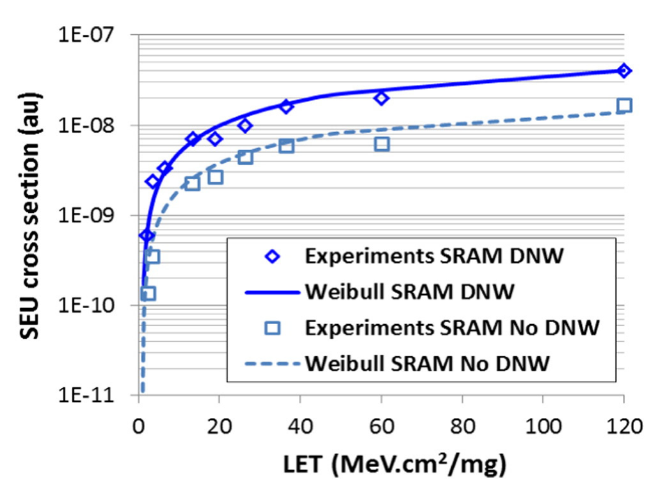

Fig. 1. Heavy ion cross sections for the 45 nm SRAMs.