Complementary modelling tools

Frédéric Wrobel / Giuseppe Lerner

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WP8: Work Package Overview

- **Task 8.1:** Coordination (UM, CERN, GSI, ELI)
- **Task 8.2:** Impact of low energy particles on SEU rate prediction (UM)
- **Task 8.3:** Circuit level modelling (UM)
- **Task 8.4:** Facility modelling (CERN, GSI, ELI)
- **Task 8.5:** Dose Effect with ECORCE (UM)
- **Task 8.6:** Integration of SEE event-by-event scoring in FLUKA (CERN)

Deliverables and milestones

T0+18	dec-22	D8.1	Frederic Wrobel	+ Ygor Aguiar	+ Cleiton Marques
		M8.1	Roberto Versaci	+ All	+ Postdocs
		D8.2	Roberto Versaci	+ Jérôme Boch	+ Postdocs
T0+24	june-23	D8.3	Frederic Wrobel	+ Ygor Aguiar	+ Cleiton Marques
T0+30	dec-23	D8.4	Frederic Wrobel	+ Ygor Aguiar	+ Cleiton Marques
		M8.2	Alain Michez	+ Jérôme Boch	
T0+36	june-24	M8.3	David Lucsanyi	+Giuseppe Lerner	+ Gabrielle Hugo
T0+42	dec-24	D8.5	Alain Michez	+ Jérôme Boch	

D8.1	Simulation results of the importance of 1-10MeV energy range on the SER for neutrons (T0+18months)
D8.2	Modelling of the X-Ray generator and Co60 source (T0+18months)
D8.3	Recommendation for simulating low energy protons (T0+24months)
D8.4	**Simulation results and report on circuit modelling (T0+30months)**
D8.5	**Determination of the fitting parameters for the target device and comparison with the experimental results (T0+42months)**

M8.1	Facility modelling for RADNEXT experimental conditions (modelling released and simulations are running at T0+18months)
M8.2	**ECORCE evaluation (Modelling released and simulations are running at T0+30months)**
M8.3	**Validation of Fluka SEE module (Report including benchmark results and instructions for users at T0+36months)**

D8.4: Simulation results and report on circuit modelling (T0+30months)

- Spice model often not known => use of a basic transistor model (source current and node capacitance)
- Parameters are taken to be representative of the technology
- Monte Carlo tool used: PredicSEE

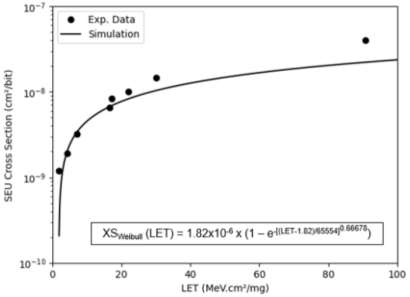


Fig. 16. Heavy ions SEU cross-section for 90 nm 6T SRAM [

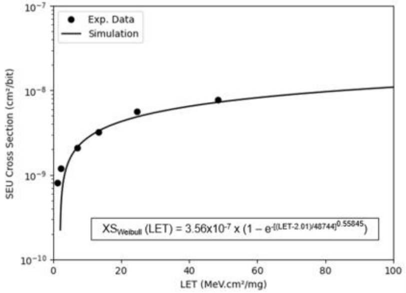


Fig. 17. Heavy ion SEU cross-section for 65 nm SRAM [21]

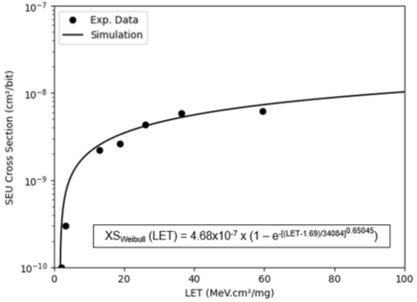


Fig. 18. Heavy ion SEU cross-section for 45 nm SRAM [28].

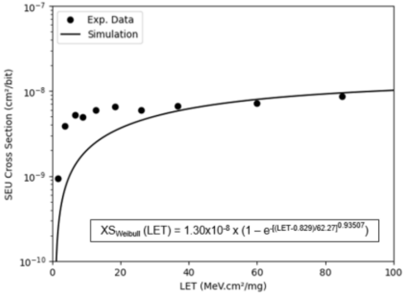


Fig. 19. Heavy ion SEU cross-section for 32 nm 6T SRAM [29].

- Good agreement with experimental data, though some discrepancies at low LET for 32nm node.

D8.4: Simulation results and report on circuit modelling (T0+30months)

- Effect of voltage

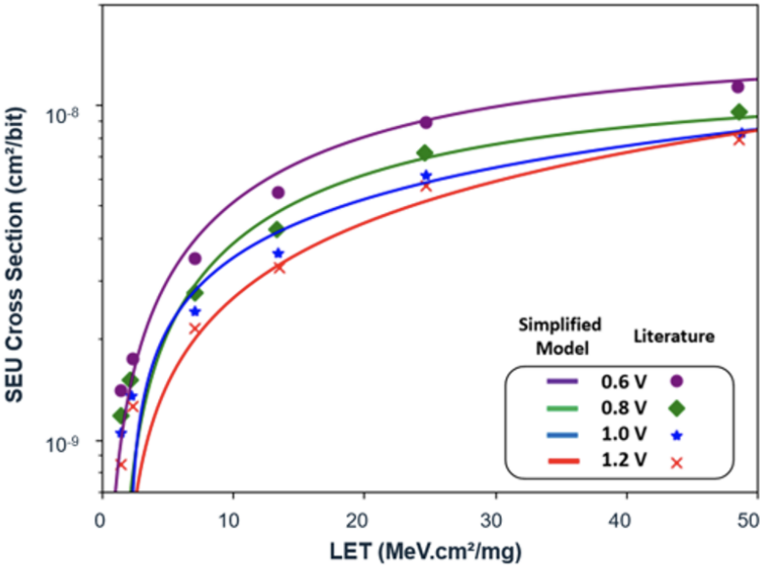
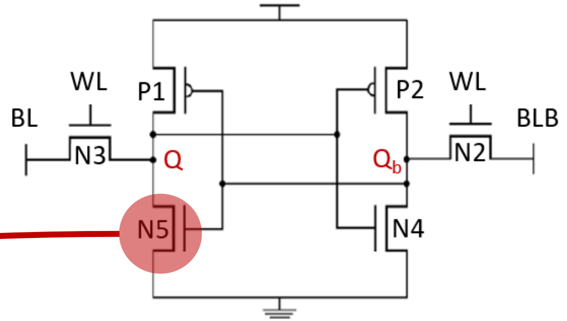


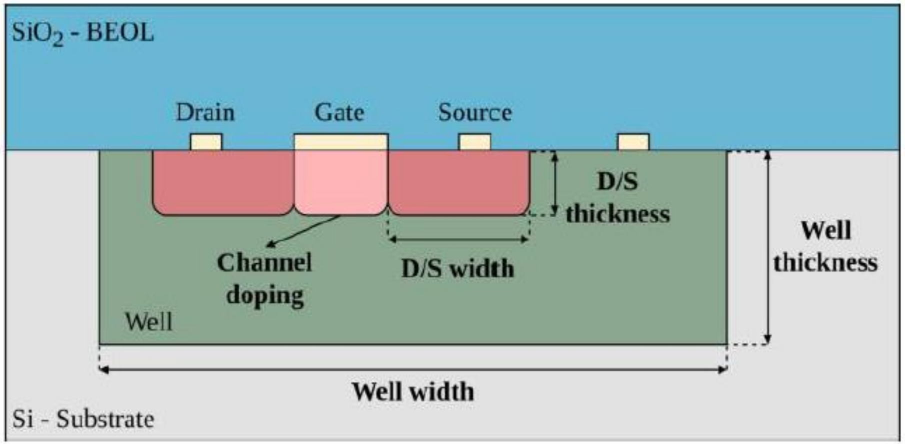
Fig. 20. Voltage scaling result for heavy ion SEU cross-section at 65nm [21].

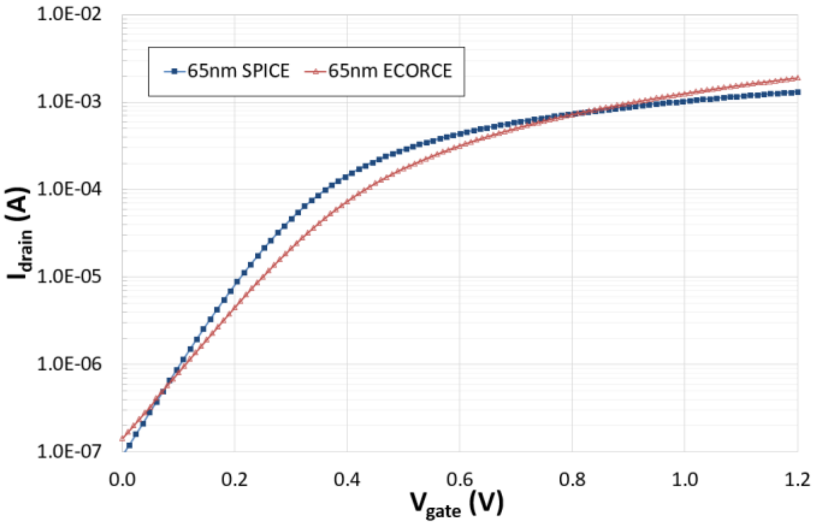
- Very good agreement with experimental data

2D TCAD modeling

Aim: estimate the SEU cross-section dealing with the disadvantages related to the lack of technological information and the complexity of the TCAD simulations.







See Cleiton's presentation

M8.2: ECORCE evaluation (T0+30months)

TCAD modeling: solve differential equations in semiconductors and insulators
→ Poisson
→ electron and hole transport equations
→ heat equation
→ electron and hole trapping equations

Microchip microcontroler using 150nm technology node

First step: create the model based on technology node
→ get technological informations
→ fit experimental Id=f(Vgs)
→ need to adjust the model parameters

This study → Microchip 150nm technology node.

TCAD tool: ECORCE (Etude du COmportement sous Radiation des Composants Electroniques)

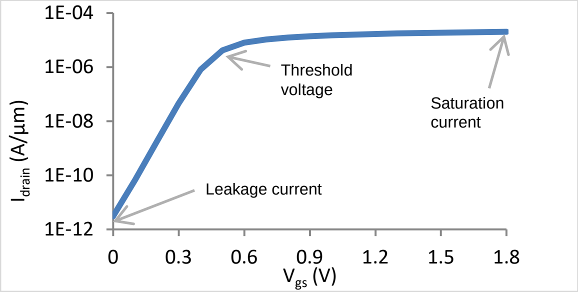
Question: what parameters should be adjusted ?

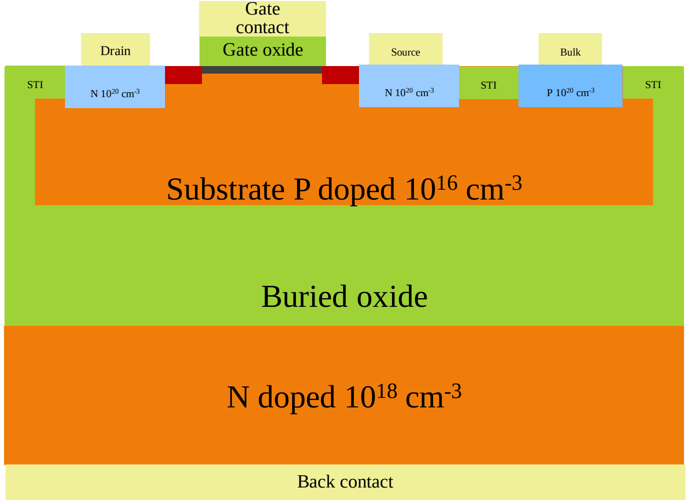
Effect of parameter variation on the Id=f(Vgs) characteristic

To answer → analyze of parameter variation on Id=f(Vgs)

3 values of the Id=f(Vgs) characteristic selected

Effect of 6 parameters analyzed





Lightly Doped Drain (N type), $5x10^{17}$ cm^{-3}

Vt adjust doping (P type), $5x10^{17}$ cm^{-3}

Structure of a 1.8V NMOS transistor of the 180nm Microchip technology, approximate values for privacy concern

	Leakage current (A/µm)	Threshold voltage (V)	Saturation current (A/µm)
Interface trap 0 to $6x10^{11}$ cm^{-3}	10^{-11} to 10^{-11} 0%	0.39 to 0.45 13%	$2.28x10^{-5}$ to $2.31x10^{-5}$ 1.7%
Substrate doping density 10^{15} to $2x10^{16}$ cm^{-3}	$2.9x10^{-12}$ to $4.2x10^{-8}$ 4 orders of magnitude	0.416 to 0.421 1.2%	$2.2x10^{-5}$ to $2.4x10^{-5}$ 10%
Channel doping density 10^{17} to 10^{18} cm^{-3}	$1.2x10^{-12}$ to $8x10^{-8}$ 5 orders of magnitude	0.19 to 0.53 300%	$6.4x10^{-6}$ to $6.9x10^{-5}$ 1 order of magnitude
LDD doping density 10^{16} to 10^{18} cm^{-3}	$2.1x10^{-14}$ to $1.2x10^{-10}$ 4 orders of magnitude	0.43 to 0.62 36%	$1.4x10^{-9}$ to $4.7x10^{-5}$ 4 orders of magnitude
LDD diffusion length 0 to 0.1 µm	$2.7x10^{-12}$ to $9.3x10^{-5}$ 7 orders of magnitude	-1.8 to 0.4 313%	$1.9x10^{-5}$ to $1.3x10^{-4}$ 1 order of magnitude
N+ doping density, drain and source area 10^{19} to $2.1x10^{20}$ cm^{-3}	$8.2x10^{-12}$ to $1.1x10^{-11}$ 5.8%	0.42 to 0.42 0%	$2.3x10^{-5}$ to $2.3x10^{-5}$ 1.5%

Id=f(Vgs) fitting with these information

First result: high interface trap density for pristine devices (3 10^{11} cm^{-2})

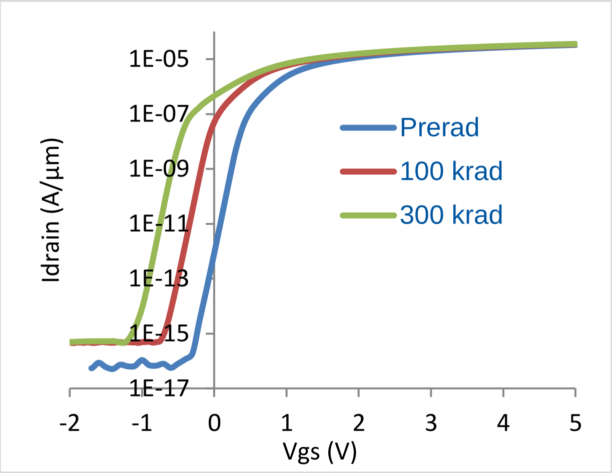
Total Ionizing Dose (TID) modeling

Effect of TID → positive electric charge in insulators

Most often used model: apply fixed charge in the oxide.

Weak model since it does not take into account:

- → thermal reemission
- → trapped carriers recombination by opposite free carriers
- → charge displacement induced by the electric field
- → change of the electric field induced by trapped charges



Change of the Id=f(Vgs) characteristic of a 5V NMOS of the 150nm Microchip technology induced by 100 krad and 300 krad dose.

ECORCE uses the Curtis model that takes all these phenomena into account.

O. L. Curtis Jr and J. R. Srour, "The multiple-trapping model and hole transport in SiO2," *J. Appl. Phys.*, vol. 48, no. 9, pp. 3819–3828, 1977.

Next steps:
To get TID experimental results from Microchip
Compare to TID simulation for 2 transistors

M8.3: Validation of Fluka SEE module (T0+36months)

- SEE simulation features have been implemented for FLUKA.CERN v5 package
(under development, not publicly released yet)
- These SEE simulation features have been released to the public as a standalone toolkit called G4SEE
- Experimental validation was successful for neutrons and protons with various SRAMs and silicon diode detector
- Tutorials and user guides are provided for users
- More details in David's presentation (link)

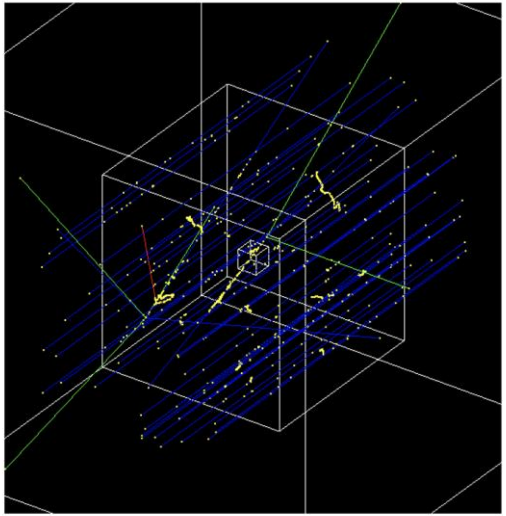


Figure 8: Visualization of particle tracks in micro-metric target geometry during a G4SEE simulation run with 10 MeV protons

Scientific publication and communications

- Frédéric Wrobel, Ygor Aguiar, Cleiton Marques, Giuseppe Lerner, Rubén García Alía, Frédéric Saigné, and Jérôme Boch.
  "**An Analytical Approach to Calculate Soft Error Rate Induced by Atmospheric Neutrons**".
  MDPI Electronics 2023, 12, 104. https://doi.org/10.3390/electronics12010104.

- Cleiton M. Marques, Leonardo H. Brendler, Frédéric Wrobel, Alexandra L. Zimpeck, Walter E. C. Bartra, Paulo F. Butzen, Cristina Meinhardt.
  "A Detailed Electrical Analysis of SEE on 28 nm FDSOI SRAM Architectures". 2023 36th SBC/SBMicro/IEEE/ACM Symposium on Integrated Circuits and Systems Design (SBCCI), Rio de Janeiro, Brazil, 2023, pp. 1-6,
  doi: 10.1109/SBCCI60457.2023.10261665.

- Cleiton M. Marques, Frédéric Wrobel, Ygor Q. Aguiar, Alain Michez, Frédéric Saigné, Jérôme Boch, Luigi Dilillo, and Rubén García Alía.
  "Evaluation of a Simplified Modeling Approach for SEE Cross-Section Prediction: A Case Study of SEU on 6T SRAM Cells". MDPI Electronics 2024, 13, 1954.
  https://doi.org/10.3390/electronics13101954.

Last deliverable of WP8

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