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ONERA
THE FRENCH AEROSPACE LAB

comet

MUSCA SEP3 / TERRIFIC

The SEE prediction software platform by ONERA

COMET

December 13th 2022

Talk overview

- **Context of the SEE prediction**

- **Global simulation framework of SEE modeling at ONERA**
  - **Tools methodology**
  - **Inputs overview**
  - **Physical modeling**

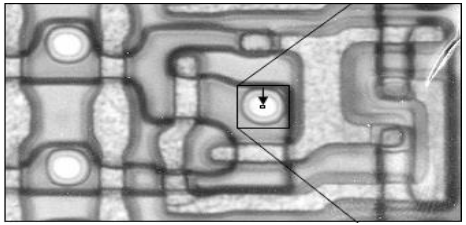
- **Example of SEE modeling at ONERA: from emerging effects to hardening by design support**
  - **From emerging effects**
  - **To hardening by design support**

Context for SEE prediction

- **The evolution of SEE prediction methodologies depends on:**
  → Scaling, architecture, materials

1980 : 1700 µm²

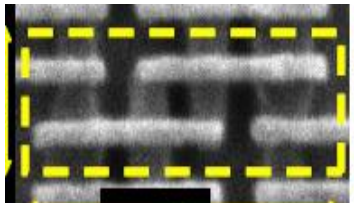
CMOS



~Scell /70000

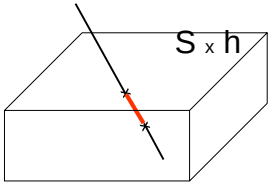
Today: 5nm ~ 0.025/0.021 µm²

FinFET … GAA



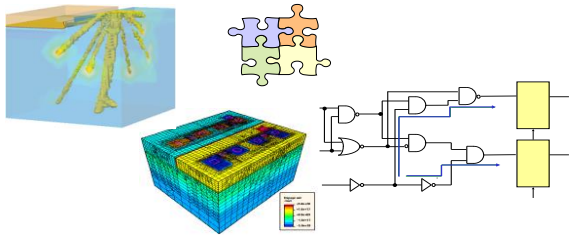
Basic Approach

Qcrit



RPP/IRPP

Advanced Approach



Global framework of SEE modeling at ONERA

BEOL FEOL

Environment specification

Models
AE8, AP8, Cosmic
Data
GOES, IPODE …

Facility environment | Space environment | Avionic environment

Models
ATMOS CORE
Data
Neutron network

STEP 1

Shielding / design / technology /temperature / bias …

Radiation Modeling

MUSCA SEP3
Multi SCAle Single Event Phenomena Predictive Platform

Multi RPP | RPP

STEP 2

SET database

Functional circuit/ parasitic circuit / PDK / bias / temperature

TERRIFIC
Transient ERRor Injection Framework for Integrated CMOS

Experimental measurements

STEP 3

SET characteristics (location, duration…)
SEU assessment (mapping/cross section / rate)
SEFI assessment (mapping/cross section / rate)
SEL assessment (mapping/cross section / rate)

SEE assessment cross section / rate

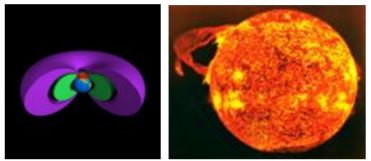
SEE cross section / laser mapping

STEP1: The radiation environment – MUSCA SEP3

- **Definition of radiation constraints**

Space environment
Inputs:
- Models: AE8, AP8, cosmic
- Measurements

Cosmic, radiation belt, sporadic event (solar flare)

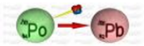


Accelerated (test) environments

Heavy ion, proton, neutron, electron …

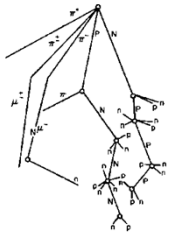
Intrinsic environment

alpha emitter contamination



Atmospheric/ground environment
Inputs:
- Models: ATMOS CORE
- Measurements

Neutron (fast and thermal), proton, muons, pions



Radiation field

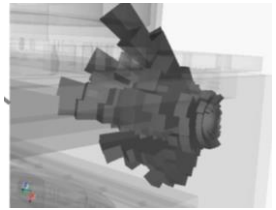
- Isotropic, unidirectional or anisotropic
- Ion species, proton, neutron
- Mono-energetic or spectrum
- Dynamic: sporadic events (solar flare)

→ **Radiation spectrum**

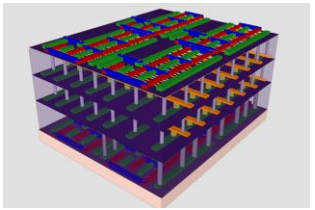
STEP2: Radiation modeling – MUSCA SEP3 (1/2)

- **Definition of the local radiation environment**
  - **Shielding definition (thickness and materials) in 3D**
  - **Description of the Back-End-Of-Line (BEOL)**

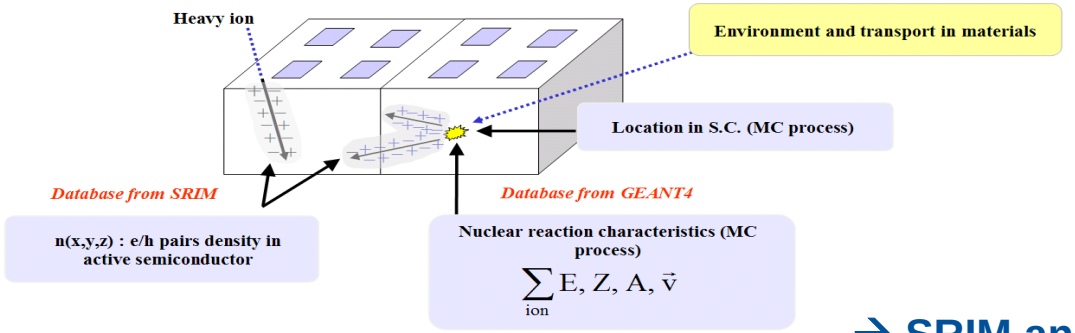
Inputs:
Sector Shielding analysis



Inputs:
IEDM roadmaps for BEOL
PDK BEOL



- **Carrier generation in semiconductor**



→ **SRIM and/or GEANT database**

STEP2: Radiation modeling – MUSCA SEP3 (2/2)

- **Generation of SET database regarding the layout of gate/circuit**
  - **3D Analytical modeling of I(t)**
  - **Modeling of each floating nodes**

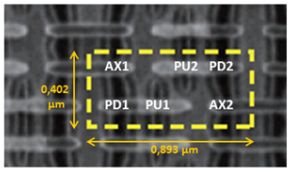
Design modeling:
reverse engineering
GDS extractor

Physical mechanisms

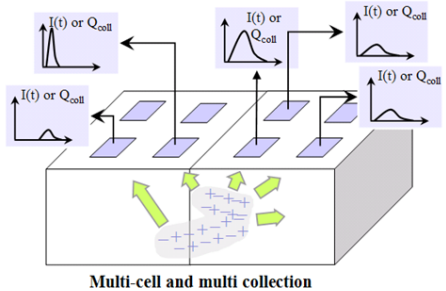
- Ambipolar and drift diffusions
- Potential/impedance variations
- Multi-collection and charge sharing
- Parasitic structure activation
- Bipolar amplification …

SET database

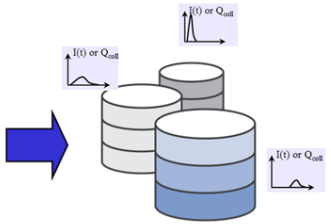
Inputs:
IEDM roadmap for FEOL
GDS files
PDK files




(b)



Multi-cell and multi collection

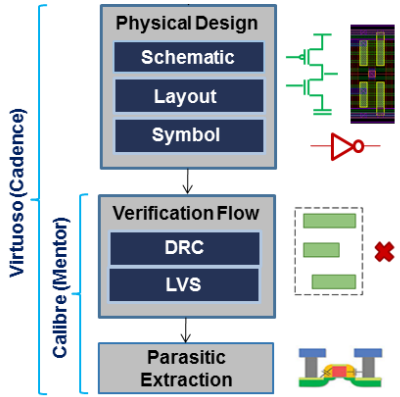


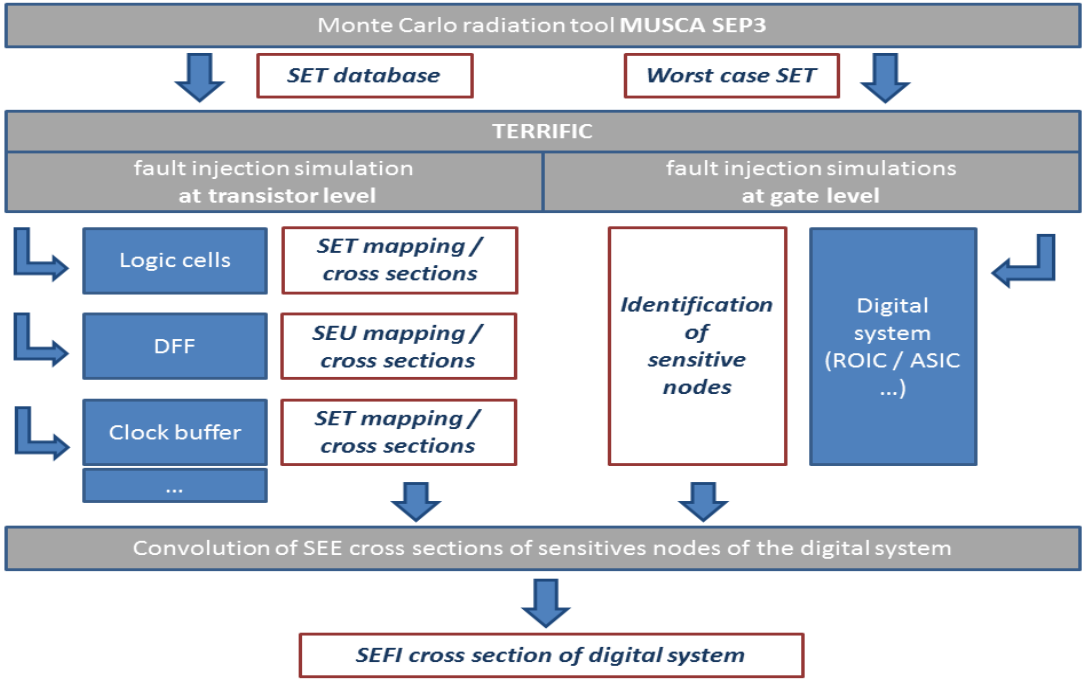
→ **Fault injection at transistor and/or gate level**

STEP3: Fault injection – TERRIFIC

- **Multiple fault injections and electrical simulations**
  - **SET/SEU/SEFI detection and post-process**

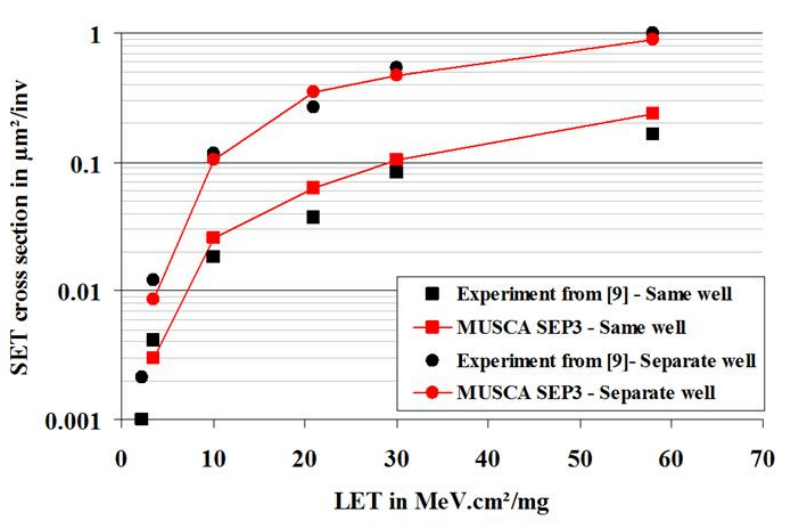
Inputs:
Gate/Circuit schematic
PDK
Inputs vectors / frequency …

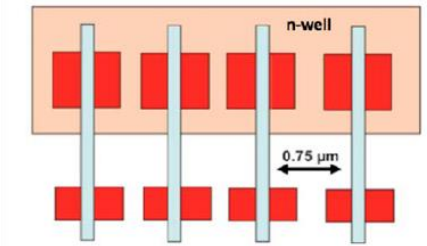




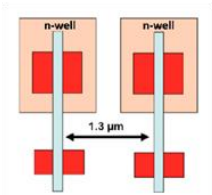
Example of SEE modeling at ONERA

- **Pulse quenching in Bulk technologies**
  - **Validation of SET cross section with SET measurements**





Same Well

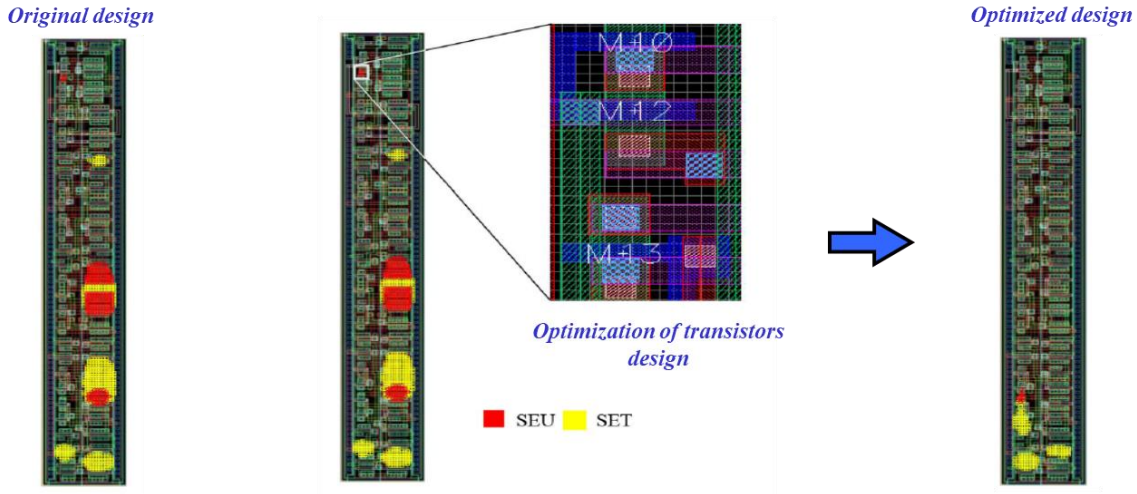


Separate Well

→ **SET modeling with multi-collection and charge sharing allows for complex circuit feedback such as pulse quenching**

Example of SEE modeling at ONERA

- **Hardening by design**
  - **Identify critical area and analyze failure occurrence at layout level → Support for design mitigation**



→ Integration of MUSCA SEP3 in the MICROCHIP design flow since 2015

Conclusions and perspectives

- **Since 2012 ONERA has developed a SEE prediction tool based on a multi-physics and multi-scale approach**

- **A global simulation framework for various activities**
  - **Study of emerging effects (multi-collection, techno/architecture dependence, particles)**
  - **Support for hardening by design digital gates and circuits**
  - **Support for *end user* analyses of COTS devices based on VLSI radiation database**

- **Technologies transfer to industries for addressing the space issues**
  - **For hardening radiation devices**
  - **Engineering tools derived from the ONERA methodology and models**

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They trust in ONERA SEE modeling tools

cnes
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MICROCHIP

UFRGS

LYNRED
BY SOFRADIR & ULIS

Inria
INVENTEURS DU MONDE NUMÉRIQUE

DGA

Thank you for your attention

Questions ?

Laurent.artola@onera.fr