SEE mechanisms in power MOSFET devices:
theoretical, simulation and experimental approaches

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Indico link: https://indico.cern.ch/event/760345/

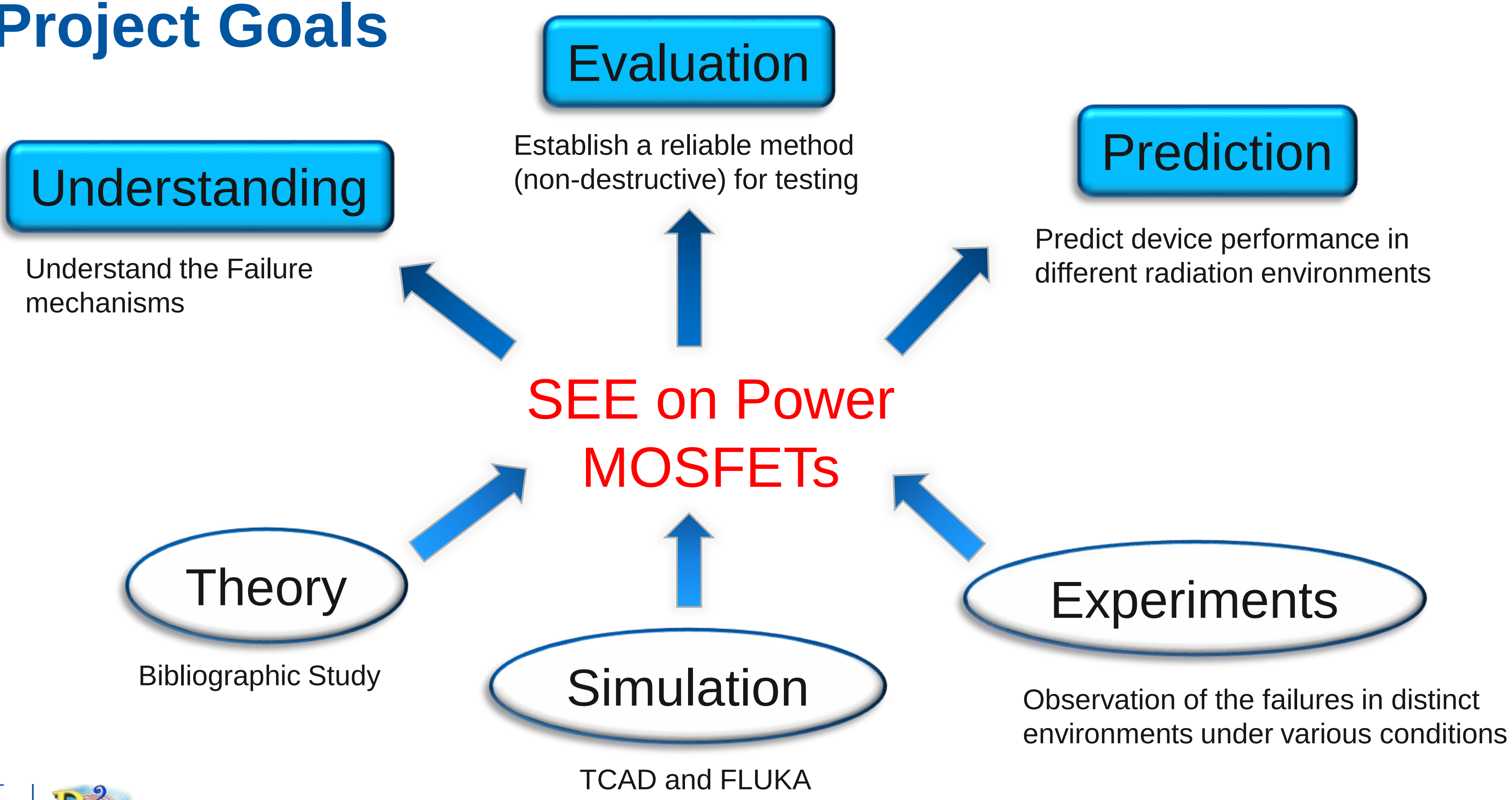
R2E Annual Meeting

DEC, 11-12TH | CERN, 774/R-013

Outline

- Project goals
- Theoretical approach
- Simulation approach
- Experimental approach
- Future steps and Outlook

Project Goals



Understanding

Understand the Failure mechanisms

Evaluation

Establish a reliable method (non-destructive) for testing

Prediction

Predict device performance in different radiation environments

SEE on Power MOSFETs

Theory

Bibliographic Study

Simulation

TCAD and FLUKA

Experiments

Observation of the failures in distinct environments under various conditions

Theoretical approach (i.e. Dig into the literature)

Two main action fields:

- Understand the physical mechanisms leading to SEE
- State of the art of the experimental techniques to study this effects

SEE on power MOSFETs have been studied since the late 80´s → Many of our questions can be solved with a convenient bibliographic study

Don´t reinvent the wheel!!!

Simulation approach

- Semiconductor Device Simulation (a.k.a. TCAD):

  Homemade definition:

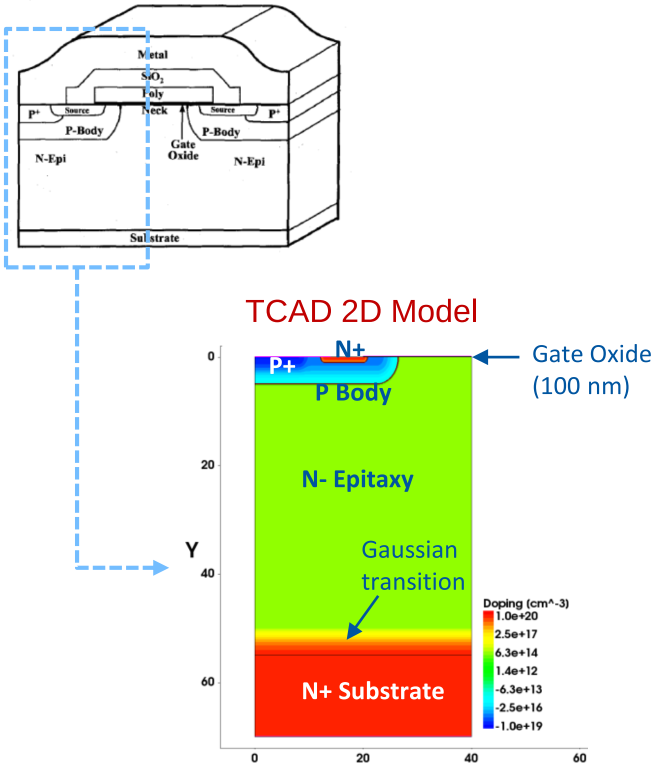
  > *Find the solution of the semiconductor equations for a model of a semiconductor device, under some specific boundary conditions, taking into account the solid state physics and by using numerical (Finite Difference / Finite Element) methods.*

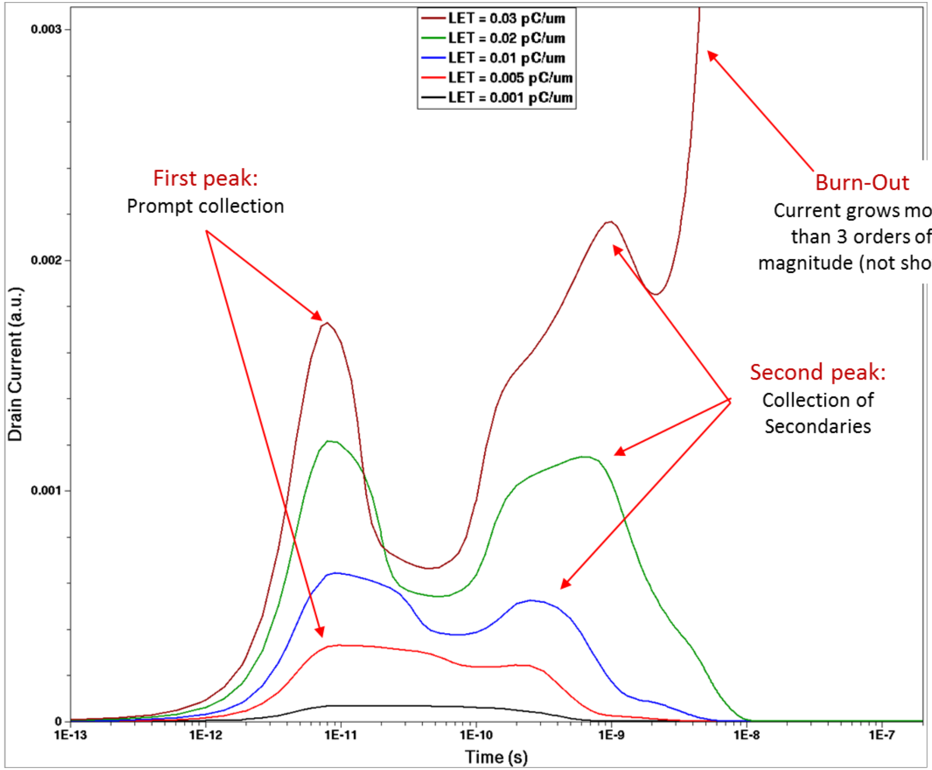
- How to simulate SEE effects with TCAD?

  We act on the physical model for the carrier Generation, including a Charge Distribution in a specific region of the semiconductor and then we simulate its evolution.

  - The Charge Distribution Profile (amount of charge, length, width…) is correlated with the incident radiation properties (LET, range, etc…)
  - but the relationship is not calculated in the TCAD Simulation (we need the input from FLUKA or similar….)

Simulation approach



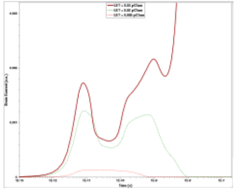


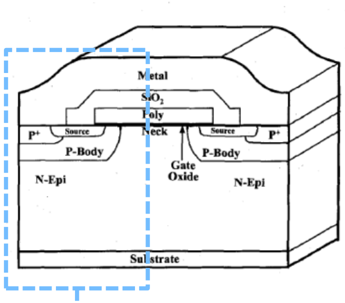
First peak:
Prompt collection

Burn-Out
Current grows more than 3 orders of magnitude (not shown)

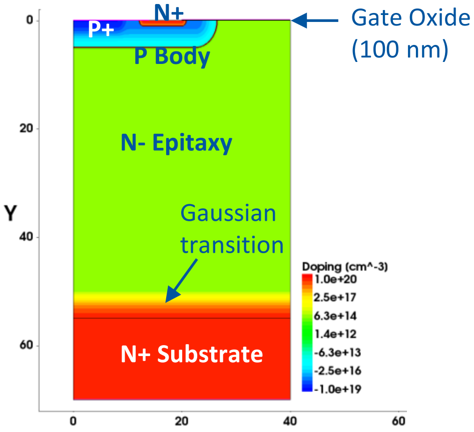
Second peak:
Collection of Secondaries

Simulation approach



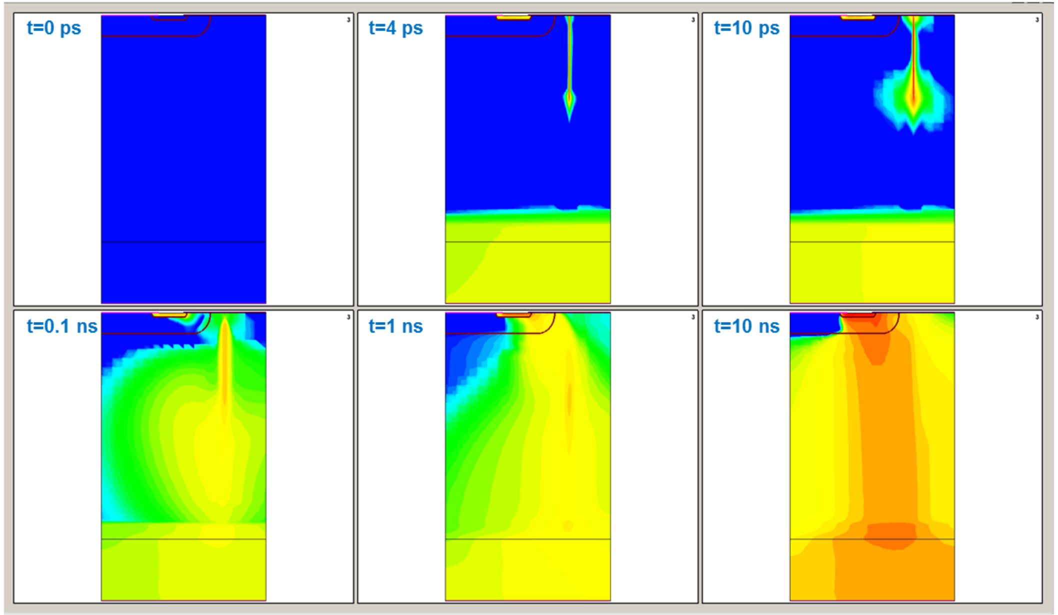


TCAD 2D Model



LET = 0.03 pC/µm (LET$_{th}$)

Electron Current Density



Simulation approach

SEE: Stochastic ↔ TCAD: Deterministic

- TCAD Simulation is an excellent tool to evaluate the consequences of the SEE at device level
  - Evaluate and define Sensitive Volumes
  - Define SOA: LET, range, voltage thresholds
- TCAD Simulation cannot give statistic predictions

FLUKA/TCAD Combination

From FLUKA to TCAD:

FLUKA: how the event-by-event energy is deposited in the device
TCAD: What are the consequences on the device performance

From TCAD to FLUKA:

TCAD: Identification of SV and triggering criteria
FLUKA: Interaction only on this SV with triggering criteria

Experimental approach

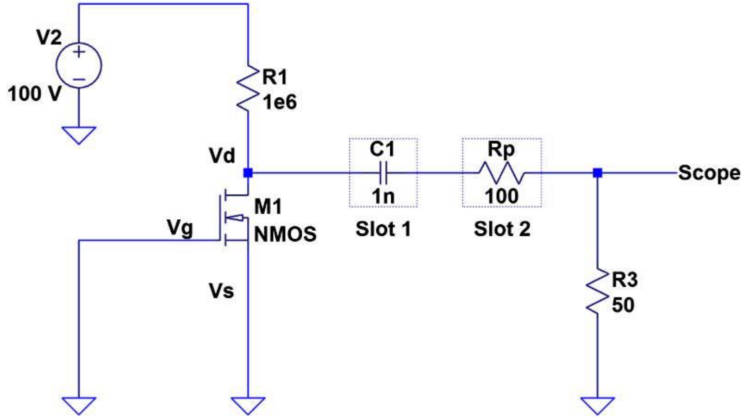
Credits to G. Tsiligiannis, G. Foucard and S. Danzeca

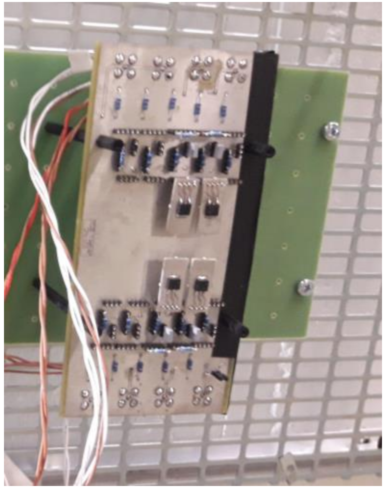
- How to test SEE on Power MOSFETs?

Destructive vs. Non-destructive

“Standard” setup for each kind of SEE?

Case of Study: SEB on COTS Power MOSFET



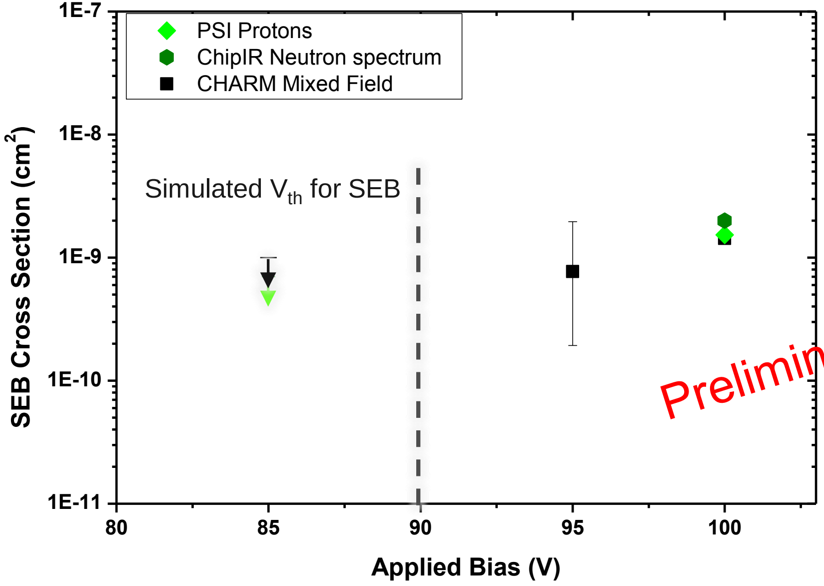


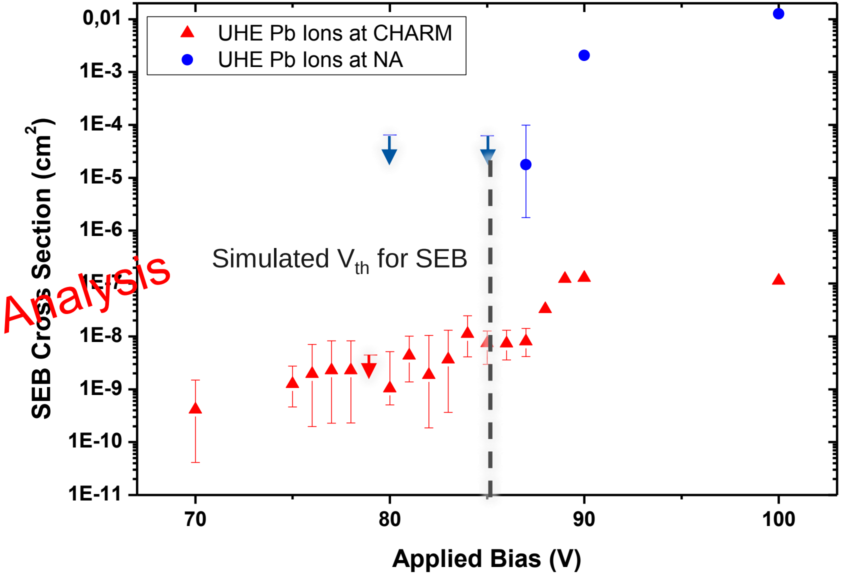
Based on P. Oser et al. IEEE TNS, 61 (2014)

Experimental approach

COTS MOSFET: Tested in mixed-field (CHARM), atmospheric-like neutron spectrum (ChipIR) and UHE HI beams (CHARM and SPS-NA)

STD10: 100 V, 13 A





Preliminary Analysis

Outlook and Future work

- The study of SEE on Silicon Power MOSFETs is faced from a theoretical, simulation and experimental point of view
- R2E related objectives:
  - To provide a list of MOSFETs of different characteristics that are compliant with the high-energy accelerator radiation environment and typically radiation tolerance requirements
  - To outline possible links between the MOSFETs technology and its sensitivity/tolerance to radiation
- Future: New references/components, new technologies, new tests, improved setups….

¡Muchas Gracias!

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