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

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

**Theory**
Bibliographic Study

**Simulation**
TCAD and FLUKA

**Experiments**
Observation of the failures in distinct environments under various conditions

SEE on Power MOSFETs

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11-12 December 2018  
R2E Annual Meeting – SEE on Power MOSFETs
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

TCAD 2D Model

- N+ Substrate
- N- Epitaxy
- P Body
- Gate Oxide (100 nm)
- Gaussian transition

Drain Current (a.u.)

Time (s)

First peak: Prompt collection

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

Second peak: Collection of Secondaries

LET = 0.03 pC/μm
LET = 0.02 pC/μm
LET = 0.01 pC/μm
LET = 0.008 pC/μm
LET = 0.001 pC/μm
Simulation approach

TCAD 2D Model

N+ Substrate

N- Epitaxy

Gaussian transition

Gate Oxide (100 nm)

Let = 0.03 pC/μm (LET_{th})

Electron Current Density

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Simulation approach

SEE: Stochastic  \quad \text{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

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

- 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

- PSI Protons
- ChipIR Neutron spectrum
- CHARM Mixed Field

Simulated \( V_{th} \) for SEB

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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