Predictive tools and "Radiation Hardening By Design" (RHBD) SEL and Temperature Effects

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RADSAGA Final Conference and Industrial event

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RADiation and Reliability Challenges for Electronics used in Space, Aviation, Ground and Accelerators (RADSAGA) is a project funded by the European Commission under the Horizon2020 Framework Program under the Grant Agreement 721624. RADSAGA began in Mars 2017 and will run for 5 years.
PRESENTATION OUTLINE

- Introduction
- Research Activities
- Ongoing work
- General conclusions
INTRODUCTION
Radiation effects pose a major threat to electronic components

It exists a list of these effects

- Total Ionizing Dose
- Displacement Damage
- Single Event Effects (SEE)

Simulation of those effects is crucial to understand their mechanism

In our work, we investigated Single Event Latchup (SEL)
SINGLE EVENT LATCHUP

CMOS

WELL TAP

P+N+ P+N+N+P+

N-substrate

N-well

PNP

RADIATION PARTICLE

NPN

P+ SUBSTRATE TAP

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RESEARCH ACTIVITIES
GOALS

- To propose a simulation chain, that includes various environments, built on existing methodologies and tools to predict the SEL sensitivity of digital circuits.
- To investigate how certain parameters (design parameters and temperature) influence SEL sensitivity.
- To predict Single Event Latchup using SPICE simulations.
**METHODOLOGY**

- **65nm CMOS Design Rules and SPICE model**
  - Circuit Design
  - Layout Design
    - Cadence Virtuoso
  - 2D Device Structure Design
    - Design parameter variation
    - Temperature variation
    - Synopsys Sentaurus
    - SEL simulation analysis
    - SEL Rate calculation
  - TRAD OMEREE

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2D Device Structure Design

- Circuit Design
- Layout Design

Cadence Virtuoso

- 2D Device Structure Design
- Design parameter variation
- Temperature variation

Synopsys Sentaurus

- SEL simulation analysis
- SEL cross section calculation

TRAD OMERE

65nm CMOS Design Rules and SPICE model

WELL TAP

SUBSTRATE AND WELL TAPS DISTANCE

SOURCE TERMINAL

A-C SPACING

SUBSTRATE TAP

N+  P+  N+  P+
N-well
PNP
NPN

P-substrate
WHAT

- Investigate and compare the effects of three parameters
  - Anode to cathode spacing
  - Doping profile
  - Well and substrate taps placement

HOW

- Cross section from 2D simulations
  - Usually, only LET threshold is investigated
  - Our goal is to study the trend
WHAT

- Investigate the temperature variation on the three parameters

HOW

- LET Threshold
- SEL Rate in GEO orbit
## PARAMETERS

<table>
<thead>
<tr>
<th>DOPING PROFILE FACTOR</th>
<th>x0.75</th>
<th>x0.85</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1 (Reference)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x1.15</td>
<td></td>
<td></td>
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<tr>
<td>x1.25</td>
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<table>
<thead>
<tr>
<th>ANODE TO CATHODE SPACING</th>
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</thead>
<tbody>
<tr>
<td>0.25 µm</td>
</tr>
<tr>
<td>0.27 µm</td>
</tr>
<tr>
<td>0.32 µm (Reference)</td>
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<tr>
<td>0.35 µm</td>
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<td>0.4 µm</td>
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<table>
<thead>
<tr>
<th>SUBSTRATE AND WELL TAPS DISTANCE</th>
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</thead>
<tbody>
<tr>
<td>1.05 µm</td>
</tr>
<tr>
<td>1.25 µm (Reference)</td>
</tr>
<tr>
<td>1.55 µm</td>
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<tr>
<td>1.85 µm</td>
</tr>
<tr>
<td>2.15 µm</td>
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<table>
<thead>
<tr>
<th>TEMPERATURE</th>
<th>350 K</th>
<th>375 K (REF)</th>
<th>400 K</th>
<th>425 K</th>
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<tr>
<td>SUBSTRATE AND WELL TAPS DISTANCE</td>
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<tr>
<td>WELL TAP</td>
<td>SOURCE TERMINAL</td>
<td>A-C SPACING</td>
<td>SUBSTRATE TAP</td>
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</tr>
<tr>
<td>N+</td>
<td>P+</td>
<td>N+</td>
<td>P+</td>
<td></td>
</tr>
<tr>
<td>PNP</td>
<td>NPN</td>
<td>P-substrate</td>
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</tbody>
</table>
RESULTS – DESIGN PARAMETER VARIATION

DOPING PROFILE

A-C SPACING: 0.32 µm
TEMPERATURE: 375 K
W-T DISTANCE: 1.25 µm

WELL AND SUBSTRATE TAPS DISTANCE

LET Threshold

ANODE TO CATHODE SPACING

TEMPERATURE: 375 K
W-T DISTANCE: 1.25 µm

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**Example**

**Worst-case scenario:** Favorable condition to SEL (lower threshold)

**Best-case scenario:** Device less sensible to SEL (higher threshold)
RESULTS – TEMPERATURE VARIATION

Doping profile: 5 CASES

x0.75 , x0.85 , x1 , x1.15 , x1.25

Reference value

*No SEL at 350 K for x1.15 and x1.25
**RESULTS – TEMPERATURE VARIATION**

**Doping profile: 5 CASES**

- x0.75, x0.85, x1, x1.15, x1.25

### Reference value

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<th>x1.15</th>
<th>x1.25</th>
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</thead>
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<tr>
<td>425 K</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>400 K</td>
<td>-30%</td>
<td>-34%</td>
<td>-39%</td>
<td>-58%</td>
<td>-67%</td>
</tr>
<tr>
<td>375 K</td>
<td>-41%</td>
<td>-38%</td>
<td>-47%</td>
<td>-73%</td>
<td>-97%</td>
</tr>
<tr>
<td>350 K</td>
<td>-39%</td>
<td>-59%</td>
<td>-80%</td>
<td>NO SEL</td>
<td>NO SEL</td>
</tr>
</tbody>
</table>

*No SEL at 350 K for x1.15 and x1.25*
We compared the effects of three parameters.

We calculated cross section from 2D simulations.
- Fast simulations.
- Key value to estimate sensitivity.

Doping profile variation and substrate and well tap placement have a stronger impact respect to anode to cathode spacing.

These results are highly important in design phase to decide which strategies can be adopted to harden the component.
CONCLUSIONS

- We have observed, for every case, that when the component is less sensitive to SEL, temperature has a stronger impact on LET threshold, with respect to the opposite case.
- The same trend has been observed for SEL rate.
ONGOING WORK
GOALS

- To define a precise dynamic of Single Event Latchup
- To predict Single Event Latchup using SPICE simulation
SEL DYNAMIC

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1. Ion hits the device (in this example, in point B)

↓

2. A current flows from BN+ to BP+

↓

3. The current activates one of the parasitic transistor (in this example the PNP).

↓

4. The current flows in the substrate and it activates the second parasitic transistor (NPN)

↓

5. SEL occurs
The PNPN structure can be also simulated in SPICE.

The ion can be modeled as an injected current.

We can predict SEL by linking the ion LET to the injected current.

We are developing a new structure to simulate SEL in SPICE.

CONCLUSIONS
CONCLUSIONS

- The effects of layout design on SEL sensitivity has been investigated
- The effects of temperature has been investigated
- A new predictive method is under development


SPARE
Simulation performed with TCAD

↓

Minimum LET evaluated

↓

Calculation of sensitive zone

↓

Calculation of Cross Section