Radiation Test Results and 3D TCAD Simulations in UTBB FD-SOI 28nm

Philippe Roche, Gilles Gasiot, Victor Malherbe, Dimitri Soussan

Contact: philippe.roche@st.com

STMicroelectronics

Central R&D, Crolles, France
Outline

- Background on SER and FDSOI28

- Experimental radiation test results
  - heavy ions
  - Multiple Cell Upsets
  - alpha particles and neutrons
  - SRAMs and microprocessors

- 3D TCAD simulations for key SEU parameters
  - sensitive volume for charge collection
  - charge amplification with parasitic bipolar

- Take-aways
Radiation Impact on Circuit Reliability

- Bit flips, latch-up, leakage currents

- Soft Error Rate now higher than all other reliability mechanisms
  - constant evolution of SER/ Mb
  - SER/chip increase when left unmitigated

![Alpha contaminants](image1)

![Atmospheric neutrons](image2)

![X-ray IC inspections](image3)

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ST, Central CAD and Design Solutions, SER FDSOI28, P.Roche et al.
Radiation tolerance of IPs ensured with extensive simulations and irradiations
- radiation qualification part of TP certification

Highest robustness with ST patented rad-hard IPs
- rad-hard SRAMs, logic, PLL, IOs, triplication, dual clocks, ECC, space platform, ...

ST Radiation-Hardening Flow at a glance

How is FDSOI changing the radiation paradigm?

0.12µ2
FD28 SRAM bitcell

Chip irradiation

ST, Central CAD and Design Solutions, SER FDSOI28, P. Roche et al.
Key Features of 28nm UTBB FD-SOI

- Shorter channel length
  - 24nm technology

- Better electrostatics
  - faster operation
  - low voltage
  - reduced variability

- Total dielectric isolation
  - latch up immunity

- Lower leakage current
  - less sensitive to temperature

- Moore’s law continuation

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ST, Central CAD and Design Solutions, SER FDSOI28, P.Roche et al.
Radiation Test Results in FDSOI 28nm
### Three qualification circuits tested
- SRAMs, Flip-flops, SPARC V8, ARM cores, …
- more to come in 2015

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### FDSOI28 Radiation Test Plan

- **Three qualification circuits tested**
  - SRAMs, Flip-flops, SPARC V8, ARM cores, …
  - more to come in 2015

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Lowest heavy ion SEU cross-sections in FDSOI 28nm

- 3 and 2 decades lower respectively than CMOS 65nm and 28nm (no SEGR/SEL)
Heavy-Ion Multiple Cell Upsets in SRAMs: Bulk vs FDSOI

- **Same SRAM design 0.12μ2 at the 28nm node**
  - Bulk with Deep N-Well against SEL

- **Heavy Ion testing with ESA: <1% MCU\(^3\) with FDSOI28 versus MCU\(^{59}\) in BULK28**
  - RADEF test facility, Finland, ESA SCC 25100, Xenon, high-LET, fluences: 1.5e6 ions/cm\(^2\) (SOI), 5e5 ions/cm\(^2\) (BULK)

**FDSoI 28nm**
- 312x
- 6x
- Occurrence with 1.5E6 ions/cm\(^2\)
- MCU# = 321

**BULK 28nm with Deep N-Well**
- 18x
- 32x
- Occurrence with 5E5 ions/cm\(^2\)
- MCU# for same fluence ~ 126,000

ST, Central CAD and Design Solutions, SER FDSOI28, P. Roche et al.
Alpha and Neutron Test Results on SRAMs in FDSOI28

- **Unmitigated n-SER < 10 FIT/MB**
  - dynamic test algorithms
  - 3 test patterns
  - RT and 125°C
  - 0.8V - 1.3V
  - TRIUMF, Canada

- **Unmitigated α-SER ≪ 1 FIT/MB**
  - Typically ~0.1 FIT/MB
  - Am$^{241}$ and Th$^{232}$
Radiation Test Results on SPARCv8 in FDSOI28

- Radiation test setup for 32b SPARC
  - 3 SPARCv8 processors
  - 1 FPGA controls DUTs: boot, reset, collect execution reports
  - CPU computes FFTs
  - Test SW handles errors, scrubbing, timing, bad computation, crashes

- CPUs tested with alphas @ Crolles and neutrons @ Vancouver
  - Ref CPU with alphas < 0.01 FIT/chip
  - Ref CPU with neutrons < 1FIT/chip
  - Hardened CPU (ECC, rad-hard FFs...): fully immune

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![Chip comparison](image-url)
- Very low neutron-SER SRAM <10 FIT/ Mb
  - 100× better than BULK counterpart
  - ECC/EDAC not systematically required

- Single Event Latchup immunity
  - tested with neutrons 125°C/1.3V

- Alpha quasi-immunity <1 FIT/ Mb
  - no need for ultra-pure alpha packaging

- Very small error clusters: 99% single bits
  - Single Error Correction efficient
  - no need for bit scrambling as for BULK
### FDSOI28 Radiation Test Synthesis

- **Three qualification circuits already tested**
  - SRAMs, Flip-flops, SPARCV8, ARM cores, …

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<tr>
<th>Radiation</th>
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<td><strong>Atmospheric neutrons</strong></td>
<td>Neutron-SER &lt; 10FIT/Mb</td>
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<td>Alpha-SER &lt; 1 FIT/Mb</td>
<td>1000x</td>
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<td>RHBD microprocessor immunity</td>
<td>100x</td>
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<td>(@0.001cph/cm²)</td>
<td>Ultra low alpha wafer counting</td>
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<tr>
<td><strong>Thermal neutron</strong></td>
<td>Thermal-SER &lt; 2 FIT/Mb</td>
<td>20x</td>
</tr>
<tr>
<td>(&lt;25meV)</td>
<td>Peak error rate 10x lower than Bulk</td>
<td>&gt;10x</td>
</tr>
<tr>
<td><strong>Muons</strong></td>
<td>Asymptotic error X-section=10^{-10} cm²/bit</td>
<td>100x</td>
</tr>
<tr>
<td><strong>Heavy ions</strong></td>
<td>Error cross-section &lt; 10^{-14} cm²/bit</td>
<td>1000x</td>
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<tr>
<td>(≤60MeV/(mg/cm²) )</td>
<td>VTH shift &lt;1mV/krad (till 100krad)</td>
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Key SEU Parameters
3D TCAD Simulations in FDSOI 28nm
Very small volume for charge collection

- 160×/70× smaller Si film than PDSOI 130nm/65nm

Very low parasitic bipolar gain

- minimize the charge amplification inherent to every SOI technology
- thanks to full depletion

 Ion strike on 0.120μm² cell – Current density at various instants
Sensitive Volume and Bipolar Amplification

- **Sensitive volume:** limited to Si film, high field region

- **Parasitic bipolar gain:** \( \beta = \frac{Q_{\text{coll}}}{Q_{\text{dep}}} \)

**Graphs:**
- Collected charge vs. LET [MeV·cm²/mg]
- Deposited charge vs. ion track charge density

**Equations:**
- \( Q_{\text{dep}} = \int_{\text{active Si}} \text{ion track} \)
- \( Q_{\text{coll}} = \int_{\text{time}} \text{drain current} \)
FDSOI28 Bipolar Gain for Back Biasing Schemes

- **Body Biasing**: voltage applied to the substrate/body
  - when voltage is positive, called Forward Body Biasing
  - much wider range of biasing in FDSOI compared to Bulk

**FBB: Forward Back Biasing**
- Reduces $V_t$
- Charge amplification slightly
- Speed

**RBB: Reverse Back Biasing**
- Increases $V_t$
- Charge amplification
- Power consumption

- FDSOI enables optimum trade-off b/w rad tolerance, performances and power
**Take-aways**

- **FDSOI has changed the radiation paradigm**

- **Upset rates improved by 100× to 1000×**
  - against neutrons, alphas, heavy ions, protons, muons, thermals, low energy protons …
  - due to both very small sensitive volume and very low bipolar gain

- **Enabling new classes of products: networking, automotive, IoT, medical…**
Thanks for your attention!

STMicroelectronics, CMOS Headquarters, 200mm/300mm wafer fabs, Crolles, France

Contact: philippe.roche@st.com