Simulation of SEU cross-sections using MRED under conditions of limited device information

J.M. Lauenstein, NASA/GSFC

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Objective

- Develop an upset response model of a Sandia CMOS6r 16Kb SRAM block using:
  - "Best guess" assumptions about the process and geometry (= naïve model)
  - Direct ionization, low-energy beam test results
- Simulate single-event upset (SEU) cross-sections:
  - Include angular and high-energy responses
  - Compare with beam test data for model validation
Sandia CMOS6r technology

- 0.5 um rad hardened twin-well CMOS technology/process
- Tungsten vias
- Shallow-trench isolation
- 3 metal layers (Al/Cu)

The SRAM block we are simulated has no feedback resistors
Accelerator beam test data

- Extensive set of test data available
- SEU cross-section for a fixed LET depends on ion energy and species

<table>
<thead>
<tr>
<th>Test Facility</th>
<th>Species (Atomic Mass)</th>
<th>Energy (MeV)</th>
<th>LET (MeV-cm²/mg)</th>
<th>Angles Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNL</td>
<td>C-12</td>
<td>12</td>
<td>1.464</td>
<td>0, 45</td>
</tr>
<tr>
<td>BNL</td>
<td>C-12</td>
<td>98.7</td>
<td>5.07</td>
<td>0, 45</td>
</tr>
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<td>BNL</td>
<td>F-19</td>
<td>141</td>
<td>3.428</td>
<td>0, 45</td>
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<td>BNL</td>
<td>Si-28</td>
<td>185</td>
<td>8.126</td>
<td>0, 30</td>
</tr>
<tr>
<td>BNL</td>
<td>Ti-48</td>
<td>193.8</td>
<td>11.81</td>
<td>0, 30</td>
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<tr>
<td>BNL</td>
<td>Cl-35</td>
<td>210</td>
<td>20.54</td>
<td>0, 30, 45</td>
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<tr>
<td>BNL</td>
<td>Ni-58</td>
<td>265</td>
<td>27.49</td>
<td>0, 30</td>
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<tr>
<td>BNL</td>
<td>Br-81</td>
<td>279</td>
<td>38.24</td>
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<tr>
<td>TAMU</td>
<td>Ar-40</td>
<td>509</td>
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<td>0, 45</td>
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<td>3.9</td>
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<tr>
<td>TAMU</td>
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<td>20.4</td>
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<tr>
<td>TAMU</td>
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<td>2981</td>
<td>14.7</td>
<td>0, 45</td>
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<tr>
<td>TAMU</td>
<td>Xe-136</td>
<td>2835</td>
<td>40.2</td>
<td>0, 30, 45</td>
</tr>
</tbody>
</table>
Accelerator beam test data

- Developed MRED model based solely upon normal-incident, low-energy BNL test data
- Defined threshold LET as $7.5 \text{ MeV} \cdot \text{cm}^2/\text{mg}$
  - for upsets induced by direct ionization
MRED model

- Sensitive volume (SV) defines region of charge collection
  - is for a single bit
- SV constructed from concentrically-nested set of 10 regions having different charge collection efficiencies
  - Regions sized according to cross-section area at each of 10 logarithmically uniform points along the BNL normal-incident upset curve
- Simple overlayer composition:
  - Tungsten vias modeled as 0.5\(\mu\)m layer 0.5\(\mu\)m above the base of a 5.5\(\mu\)m SiO\textsubscript{2} overlayer
Model calibration and results: Direct ionization events at $0^\circ$ incidence

- Value for critical charge ($Q_{\text{crit}}$) determined to be 0.133 pC for normally incident direct ionization events
  - Fit the BNL data off which the model was developed
  - AND high energy, directly ionizing events
Model calibration and results: 0° incidence

- Qcrit for indirect ionization events: 0.121 pC - 0.163 pC
  - Range due to simplified model geometry and Geant4 systematic errors

- Good prediction of normally-incident cross-section data
  - Directly ionizing events, threshold events showing possible Coulombic scattering contribution, and low-energy indirectly ionizing events are well-simulated
  - High-energy Argon cross-section is due to indirect ionization; limitations in Geant4 preclude accurate fit
Angle dependence

- MRED simulations reproduce 30° and 45° angle dependence for SEU response without any adjustable parameters
  - Measured data presented without angular correction to fluence
Summary

- Using MRED, we produced a reasonably accurate upset response model of a low-critical charge SRAM without detailed information about the circuit, device geometry, or fabrication process
  - The detailed physical processes included in the Geant4-based MRED tool enabled us to capture the complexities of the experimental cross-section curve
- The model was developed from low-energy, normally-incident test data
  - Angle dependence of upset response was successfully predicted from the normally-incident data
  - Simulation results suggest that for some devices and technologies, MRED may prove useful to guide limited high-energy testing for model validation and bounding in the areas of Geant4 physics limitations, possibly reducing the cost of SEU testing
Sponsors

- NASA Electronic Parts and Packaging Program
- Defense Threat Reduction Agency Radiation Hardened Microelectronics Program
- U.S. Department of Energy