A First Look at 22 nm FDSOI SRAM Single-Event Test Results

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Acronyms

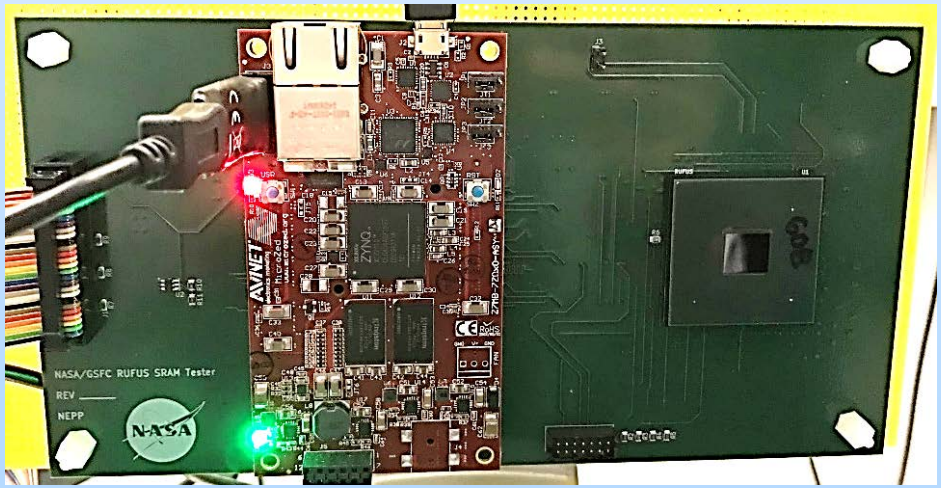
- 22FDX® – GlobalFoundries 22 nm Fully-Depleted SOI Process
- BGA – Ball Grid Array
- DMEA – Defense Microelectronics Activity
- FD – Fully Depleted
- LET – Linear Energy Transfer
- LGA – Land Grid Array
- MBU – Multi-Bit Upset
- PD – Partially Depleted
- SOI – Silicon-on-Insulator
- SEFI – Single-Event Functional Interrupt
- SEE – Single-Event Effect
- SBU – Single-Bit Upset
- SRAM – Static Random Access Memory

Introduction

- The per-bit cross-section for heavy ions was found to be identical in 65 nm and 45 nm partially depleted SOI SRAMs manufactured by IBM [Heidel TNS 2009]
  - However, the number of MBUs increased from 65 nm to 45 nm and only double bit errors were observed
- At 32 nm, direct-ionization proton effects were primarily studied, but there is some heavy ion data [Pellish TNS 2014]
  - No saturated cross-section was identified
  - Multi-bit upsets continue to increase and up to four bit upsets were observed
  - Little difference in roll angles was observed

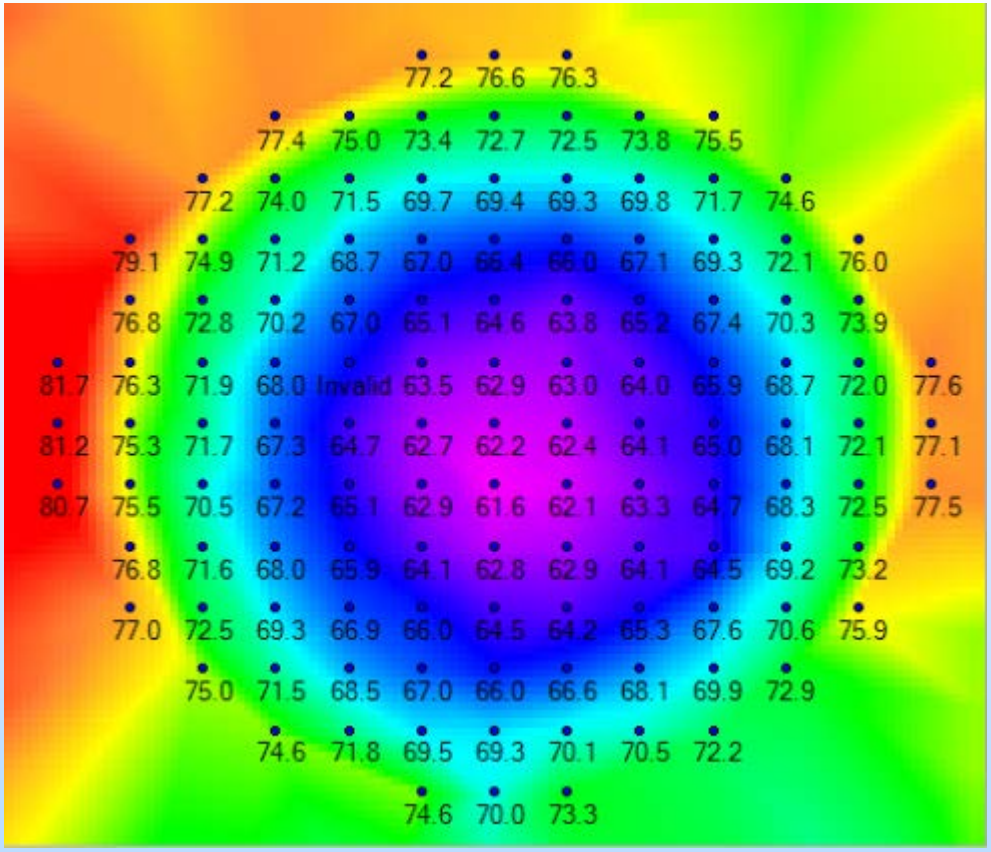
Background

- RUFUS is a 128 Mbit SRAM test vehicle designed in GlobalFoundries 22 nm FDX process
  - FDX is fully-depleted SOI
- The nominal voltage is 0.8 V, but a range from 0.64 V to 1.08 V is supported by the technology
- Custom test boards were fabricated for single-event testing and interfaced to MicroZed™ for data collection and control
  - MicroZed™ is a low cost evaluation board that employs a Zynq® 7010



Part Preparation

- Samples were packaged in BGAs
- They were thinned to a minimum thickness of 80 um
- After thinning, the were mounted on adapter boards that converted the BGA package to an LGA



Measured silicon thickness of test DUT
Image provided by DMEA

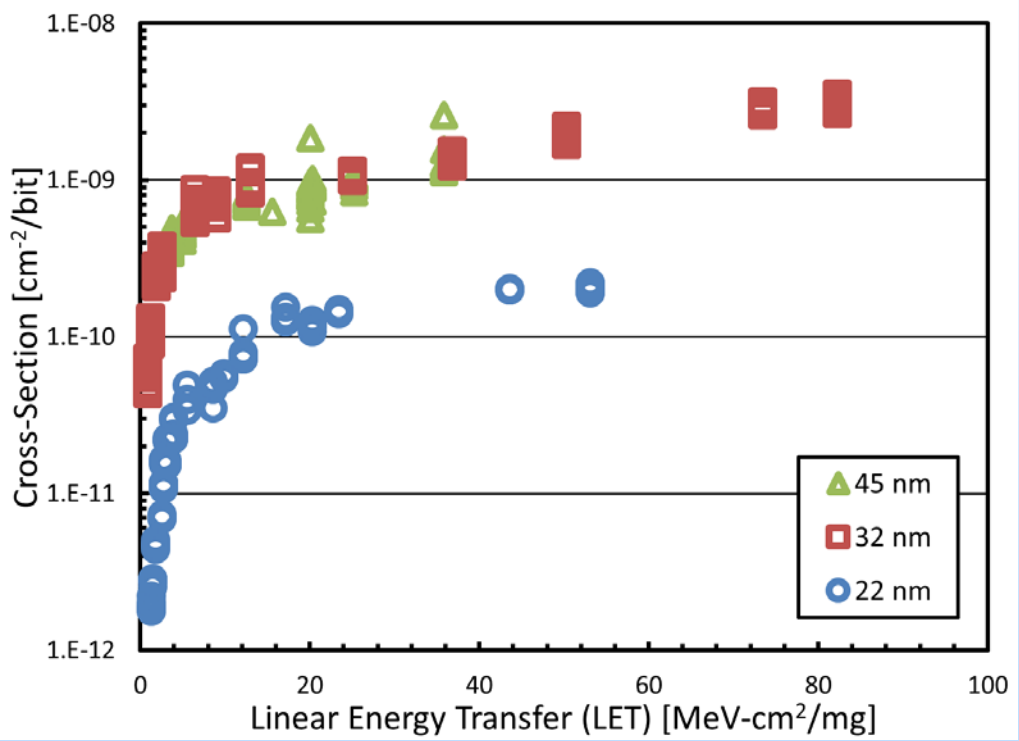
Test Conditions & Beams Used

- All voltages were nominal
- Static tests – write test pattern, irradiate, read back cells
- Dynamic tests – write memory block, read all cells in the block
  - This was repeated several times depending on the length of the irradiation

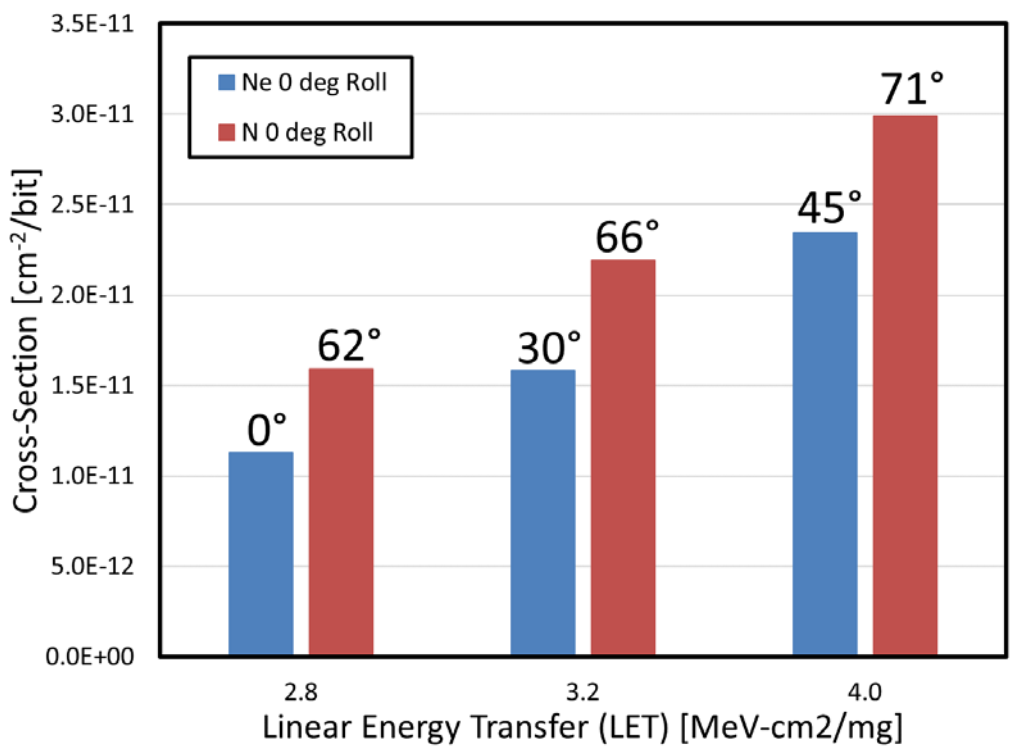
Ion Species	Energy (MeV)	Nominal LET (MeV-cm^2/mg)	Nominal Range (µm)	Tilt Angles (°)	Roll Angles (°)
^{14}N	195	1.3	379.6	0, 30, 45, 60, 62, 66, 71	0, 90
^{20}Ne	270	2.8	267.5	0, 30, 45, 60	0, 90
^{40}Ar	508	8.6	180.1	0, 30, 45, 60	0
^{63}Cu	729	20.3	123.5	0, 30, 45	0, 90
^{109}Ag	1170	43.6	107.2	0, 30	0
^{129}Xe	1366	53.1	107.7	0, 30	0, 90

Initial Results vs 32/45 nm

- Approximately an order of magnitude lower cross-section per bit in the 22 nm FDX® than was observed in either the 32 or 45 nm SRAMs
  - This is not surprising with the expected reduction in charge collection of fully-depleted SOI compared to partially depleted SOI
- The onset LETs, while not conclusively found, appear to be roughly the same for this node geometry

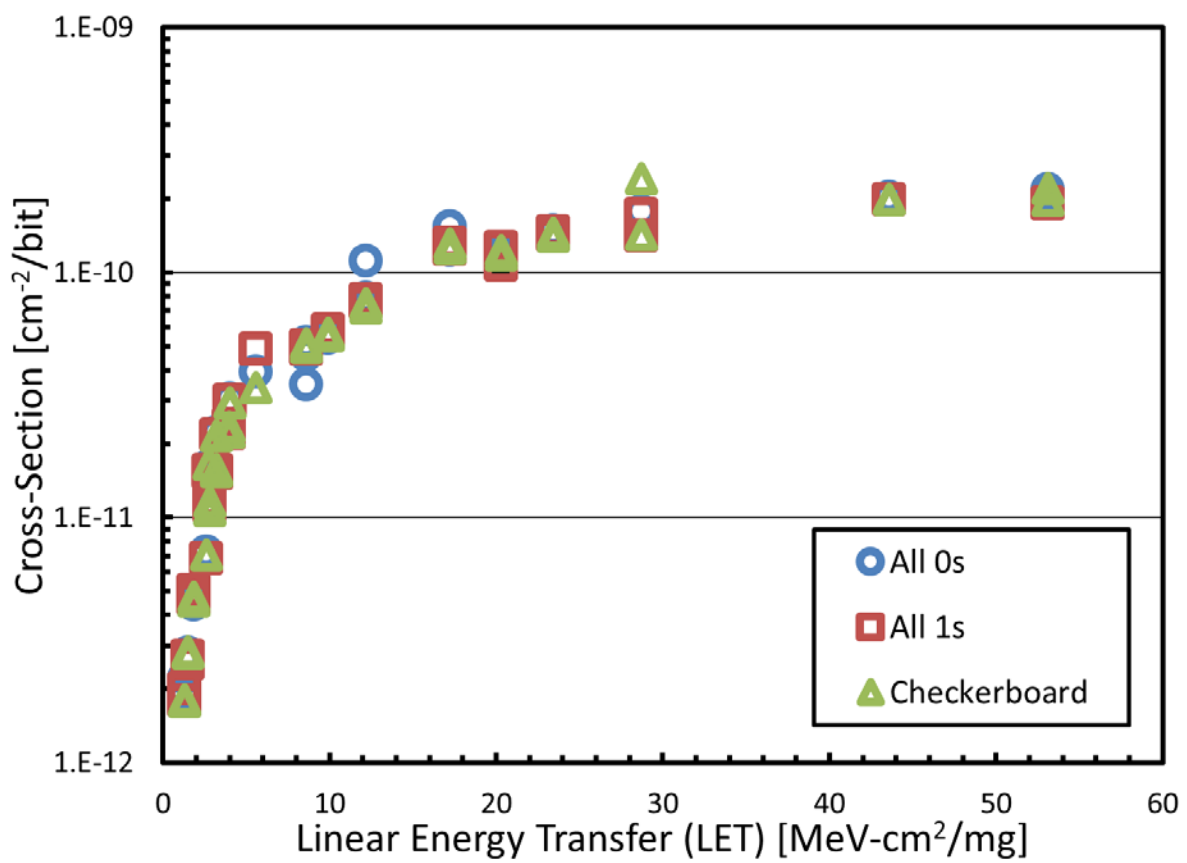


Cosine Law



- Appears to still follow cosine law
- Difference in cross-sections at same LET are about 30-50%
  - Increase with N may be due to high angles and increased MBU
  - Will continue to investigate with additional ions and with smaller angles

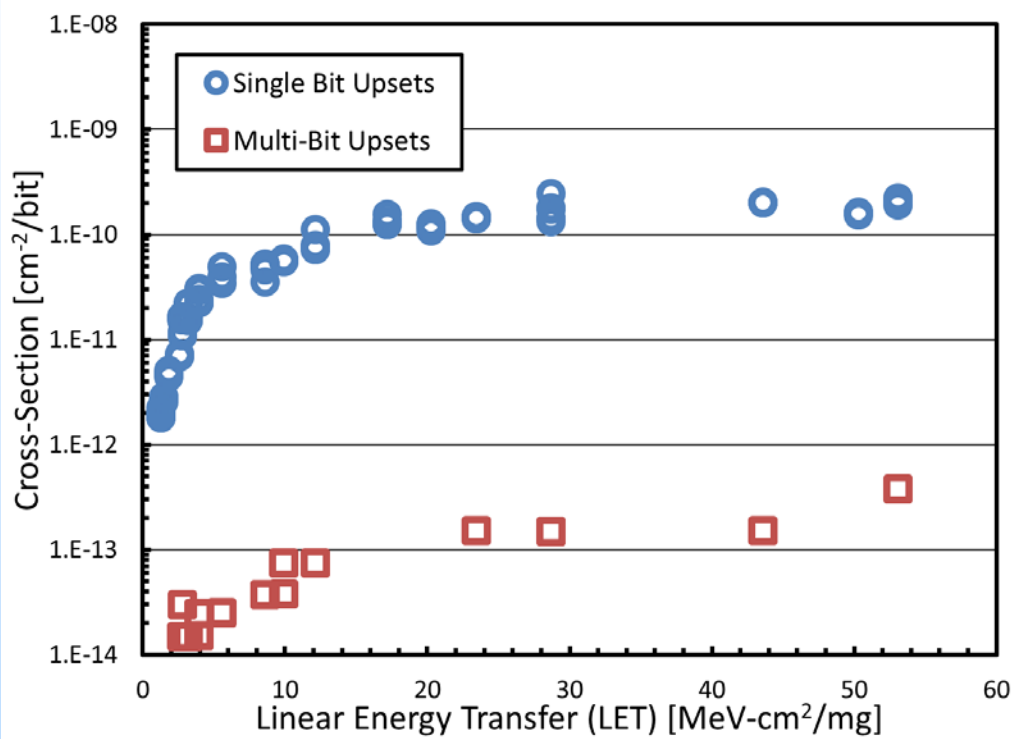
Input Pattern



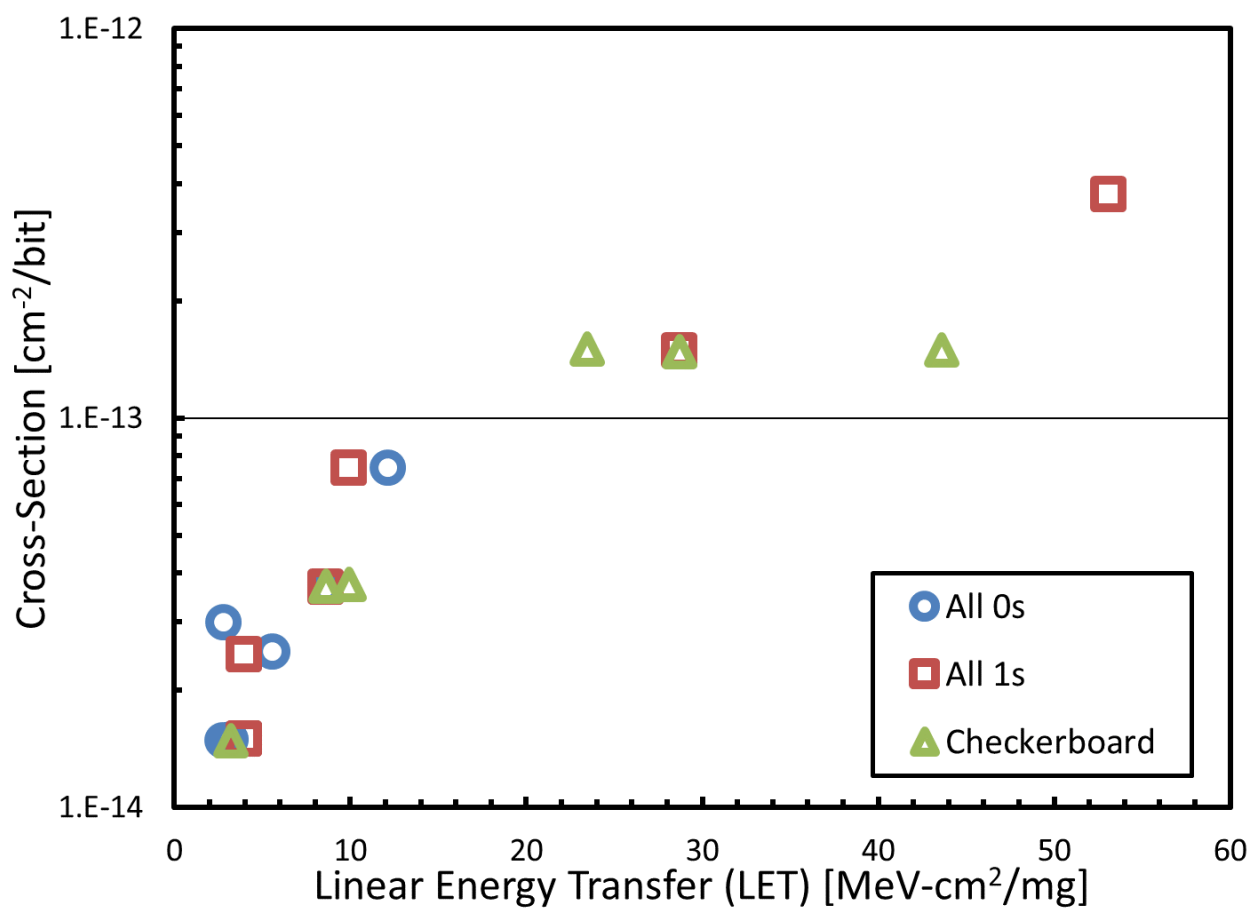
No observable difference in the cross-sections as function of the input pattern (all 0s, all 1s, and logical checkerboard)

Single-Bit vs Multi-Bit Upsets

- Only single and double bit errors were observed
  - No higher order multi-bit upsets were observed
  - Angle did not increase likelihood of MBU
- The MBUs accounted for approximately 0.01% of the total number of errors
- At 45 nm, there was a strong dependence on input pattern with MBU probability, however, at 22 nm, all patterns were equally likely to exhibit MBUs



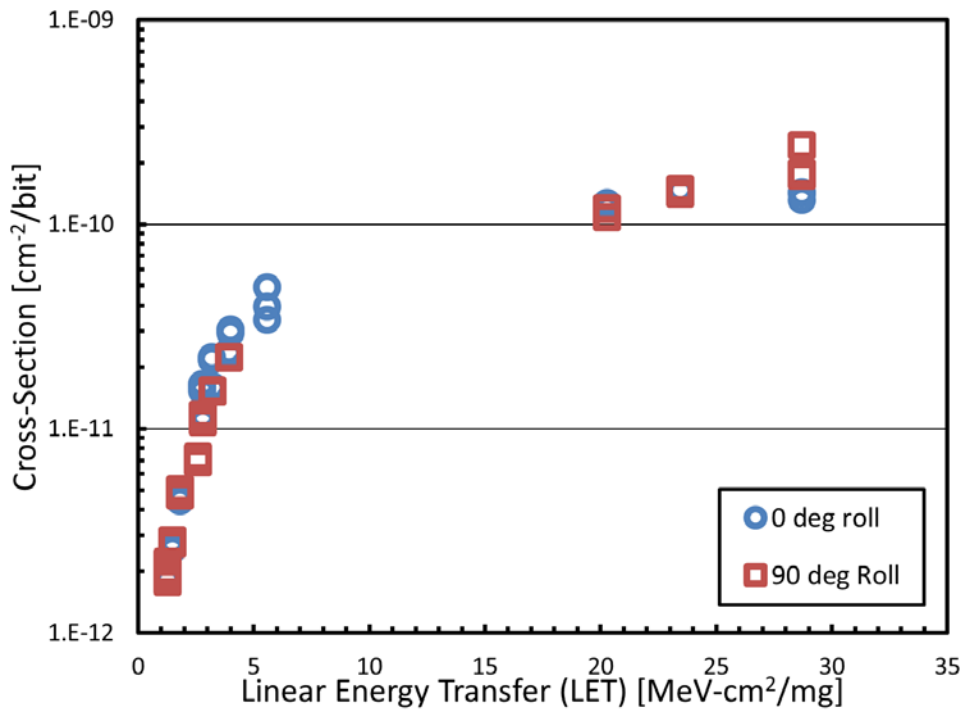
MBUs – Input Pattern



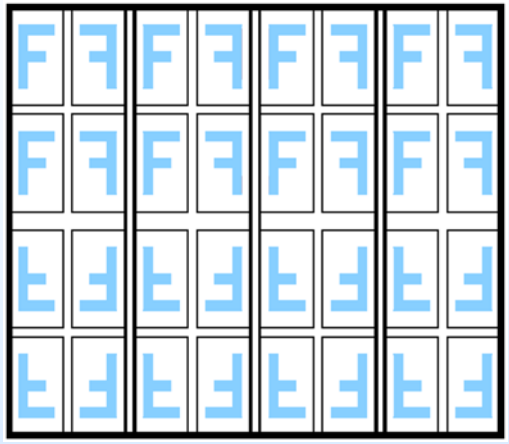
Pattern also does not appear to effect the likelihood of MBU

Roll Angle

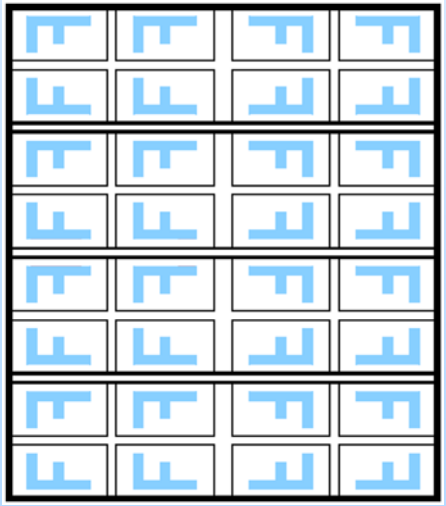
- There is a strong directionality in the layout of the cells of the SRAMs and the transistors within the cells
  - No apparent effect on the cross-section



0° Roll Angle

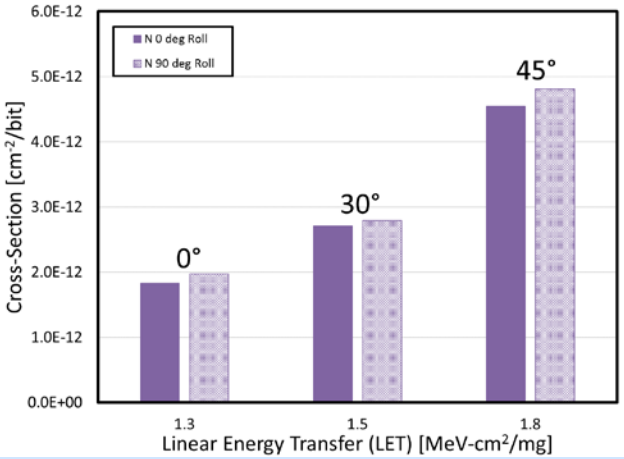


90° Roll Angle

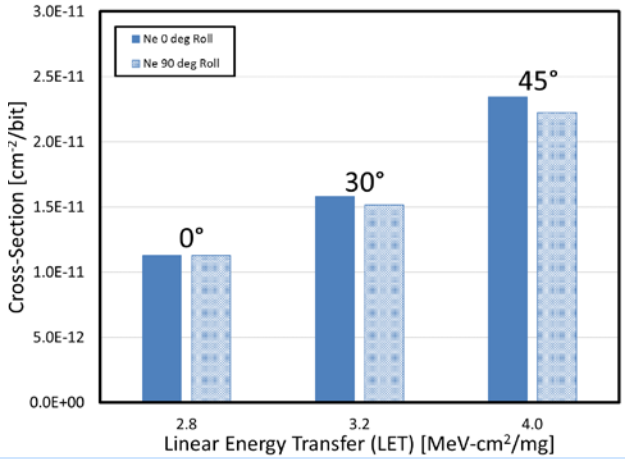


Roll Angle

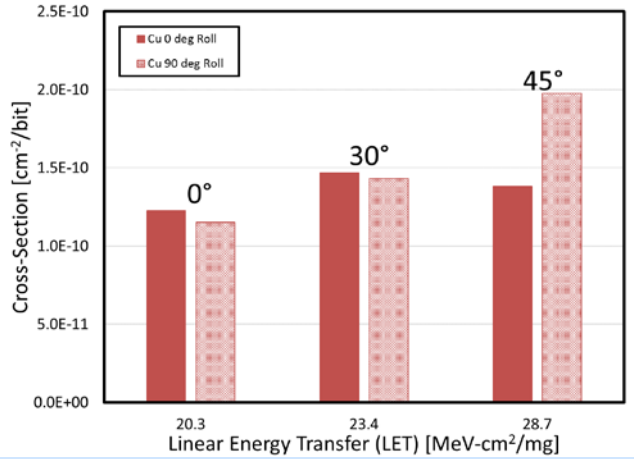
Nitrogen



Neon



Copper



No significant difference in 0° and 90° roll angle

Approximately 3-7% difference with the exception of copper at 45° tilt angle (~30%)

Copper at 45° may be due to ion range issues

Dynamic Testing – SEFIs

- Dynamic testing wrote pattern to one block and then read the same block
  - Then moved to the next block and repeated until all 36 blocks had been written and read
  - This was repeated for the entire memory several times (12-30 depending on duration of the irradiation)
- Only one SEFI was observed: During the last Xe dynamic test, every address in one block was in error
  - This persisted through each subsequent R/W cycle until the irradiation concluded and was only cleared by a power cycle
  - Test conditions: All 1s pattern, LET = 53.1 MeV-cm^2/mg, nominal supply voltages, average flux was ~500 cm^{-2}/s

Initial Conclusions

- 22 nm FDSOI SRAM upset cross-section per bit is about an order of magnitude lower than 32 and 45 nm
  - Onset LETs appear to be similar, although additional testing is required to verify
- There does not appear to be any dependence on the roll angle or the input pattern, and cosine law is consistent with the tilt angle results
- MBUs accounted for a maximum of approximately 0.01% of the errors on any given run
  - Physical mapping of upsets is being attempted – MBU results may change substantially after post-processing
- One SEFI was observed when dynamically testing the DUT
  - Additional testing at higher LETs and with a laser will be conducted to investigate further

Future Work

- Additional single-event tests
  - More heavy ions
  - Laser test
  - Low-energy electrons
  - High-energy protons
- Investigate the effect of voltage on the SRAM array voltage (near threshold computing), as well as the n- and p-well voltages (body biasing)
- Further investigate the cosine law effect with additional low LET ions
- Further investigate SEFIs – cause and approximate likelihood
- Comparison to bulk 28 nm SRAM – process uses several of the same manufacturing steps as the 22 nm SOI

Acknowledgments

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