Radiation Effects on Emerging Electronic Materials and Devices

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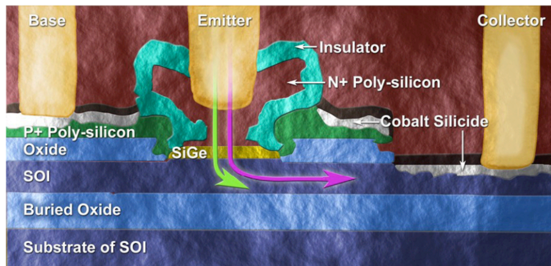
The Commons

Radiation Effects in Emerging Electronic Materials and Devices

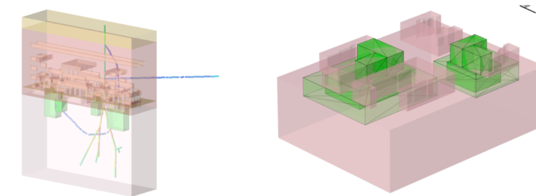
Motivation

- More changes in IC technology and materials in past five years than previous forty years—impact on radiation response is dramatic



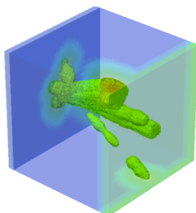
Approach

- Experimental analysis of state-of-the-art technologies through partnerships with semiconductor manufacturers
- Identification of critical mechanisms through first-principles modeling
- Implementation and application of a revolutionary multi-scale radiation-effects simulation tool to identify key challenges and develop hardening approaches



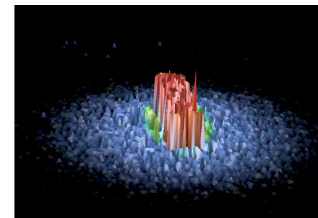
Selected Results

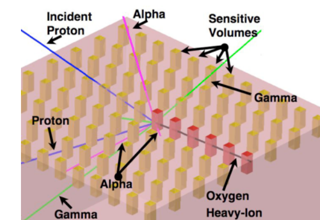
- Development of most accurate rate-prediction tool to date
- Identification of tungsten as key rad-effects issue
- Fabrication of rad-hard, reliable alternative gate dielectrics
- Demonstration of extremely rad-hard SiGe technology
- First examination of rad effects in strained-Si CMOS



Impact

- Design tools and methods demonstrated for future rad-hard technologies
- Greatly improved error-rate analysis tools allow implementation of more reliable space electronics
- First radiation-effects characterization of most advanced technologies (strained Si, HfSiON, etc.)—essential for deployment of state-of-the-art electronics in DoD systems





Team Members

- Vanderbilt University
  - Electrical Engineering: Mike Alles, Dan Fleetwood, Ken Galloway, Marcus Mendenhall, Lloyd Massengill, Robert Reed, Ron Schrimpf, Bob Weller
  - Physics: Len Feldman, Sok Pantelides
- Arizona State University
  - Electrical Engineering: Hugh Barnaby
- University of Florida
  - Electrical and Computer Engineering: Mark Law, Scott Thompson
- Georgia Tech
  - Electrical and Computer Engineering: John Cressler
- North Carolina State University
  - Physics: Gerry Lucovsky
- Rutgers University
  - Chemistry: Eric Garfunkel, Gennadi Bersuker
- Industrial and government collaborators
  - IBM, Intel, Texas Instruments, Freescale, Jazz, National Semiconductor, SRC/Sematech, Sandia, NASA/DTRA, Lockheed-Martin, Oak Ridge National Lab, CFDRC

Institute for Space and Defense Electronics

Resource to support national requirements in radiation effects analysis and rad-hard design

Bring academic resources/expertise and real-world engineering to bear on system-driven needs

ISDE provides:

- Government and industry radiation-effects resource
  - Modeling and simulation
  - Design support: rad models, hardening by design
  - Technology support: assessment, characterization
- Flexible staffing driven by project needs
  - 10 Faculty
  - 25 Graduate students
  - 14 Staff and Research Engineers

Schedule—May13 AM

8:40 MURI Overview
Ron Schrimpf, Vanderbilt University

9:00 Overview: Atomic-Scale Theory of Radiation-Induced Phenomena
Sokrates Pantelides, Vanderbilt University

9:20 Displacement Damage Effects in Single-Event Gate Rupture
Matt Beck, Vanderbilt University

9:40 Role of Hydrogen in Aging of Electronics
David Hughart and Sasha Batyrev, Vanderbilt University

10:00 Break

10:20 Effects of Aging and Moisture on 1/*f* Noise in MOS Devices
Xing Zhou, Vanderbilt University

10:40 Defects in Non-Crystalline and Nano-Crystalline Alternative Transition Metal Dielectrics
Gerry Lucovsky, North Carolina State University

11:00 Total Dose Response of Ge-substrate MOS Capacitors
Rajan Arora, Vanderbilt University

11:20 Total Dose Effects on Ge pMOSFETs with High-k Gate Stacks: On–Off Current Ratio
Shrinivasrao Kulkarni, Vanderbilt University

11:40 Lunch

Schedule—May13 PM

12:40 Overview: Radiation Effects in Emerging Materials
Len Feldman, Vanderbilt University

1:00 Interface Structure and Charge Trapping in HfO_2-based MOSFETs
Sriram Dixit, Vanderbilt University

1:20 Radiation Effects in Advanced Gate Stacks
Eric Garfunkel, Rutgers University; Gennadi Bersuker, Sematech

2:00 Break

2:20 Total Dose and Single Event Effects in Strained Si Technologies
Scott Thompson, University of Florida

2:40 Single-Event Transients in Strained-Si Devices
Mark Law, University of Florida

3:00 Single-Event Transient Pulse-Width Measurements in Advanced Technologies
Balaji Narasimham, Vanderbilt University

3:20 Assessing Alpha Particle-Induced Single Event Transient Vulnerability
Matt Gadlage, Vanderbilt University

3:40 Analysis of Single-Event Latchup Cross-Section in 65 nm SRAMs
John Hutson, Vanderbilt University

4:00 Overview: Monte Carlo Radiative Energy Deposition (MRED) Code
Bob Weller, Vanderbilt University

Schedule—May14

8:00 Registration and Continental Breakfast

8:30 Radiation Effects in SiGe Devices
John Cressler, Georgia Tech

9:10 Radiation-Induced Current Transients in SiGe HBTs
Jonathan Pellish, Vanderbilt University

9:30 Modeling Total Ionizing Dose Effects in Deep Submicron Bulk CMOS Technologies
Hugh Barnaby, Arizona State University

9:50 Mechanisms of Enhanced Radiation-Induced Degradation due to Excess Molecular Hydrogen
Jie Chen, Arizona State University

10:10 Break

10:30 Radiation Induced Leakage Current Enhancement in Irradiated Fully Depleted SOI Devices
Farah El-Mamouni, Vanderbilt University

10:50 Single-Event Rate Prediction for Advanced Technologies
Kevin Warren and Robert Reed, Vanderbilt University

11:10 Variation in Proton-Induced Energy Deposition in Large Silicon Diode Arrays
Christina Howe, Vanderbilt University

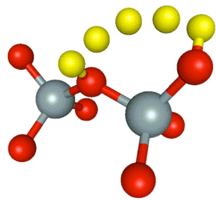
11:30 Device-Orientation Effects on Single Event Upsets in 65-nm SRAMs
Alan Tipton, Vanderbilt University

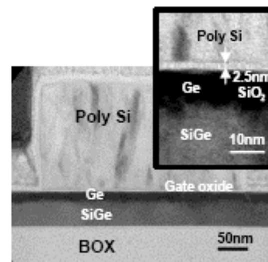
11:50 Meeting Ends

Radiation Effects in Emerging Electronic Materials and Devices: Results

Radiation Response of New Materials

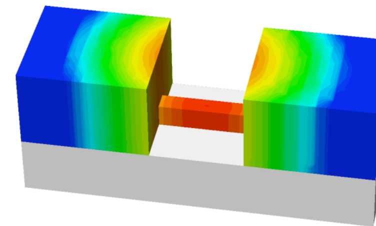
- Incorporation of new materials *dramatically* impacts radiation response
- HfO_2-based dielectrics and emerging high-k materials tested; HfSiON is very promising
- Substrate engineering (strained Si, Si orientations, Si/SiGe, SOI, Ge substrates)

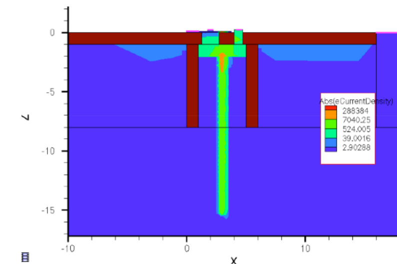




Impact of New Device Structures

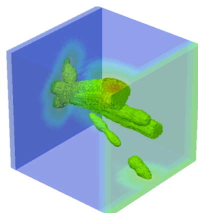
- New device technologies strongly impact single-event response and TID leakage current
- SiGe HBTs, strained Si CMOS, ultra-small bulk CMOS exhibit complicated charge collection mechanisms
- Floating-body SOI found to exhibit high radiation-induced off-state leakage due to tunneling

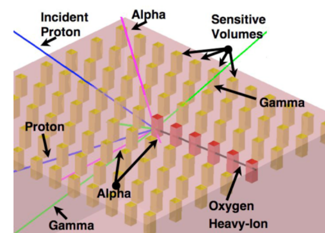




Single Events in New Technologies

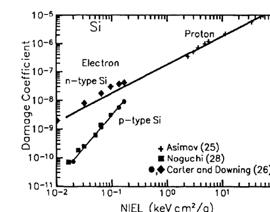
- RADSAFE—Most advanced Monte Carlo single-event/rate-prediction tool
- Passivation/metallization found to *dominate* SEE response in some hardened technologies
- Excellent agreement with on-orbit data; conventional rate-prediction methods underestimate rate by orders of magnitude

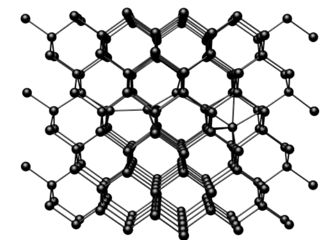




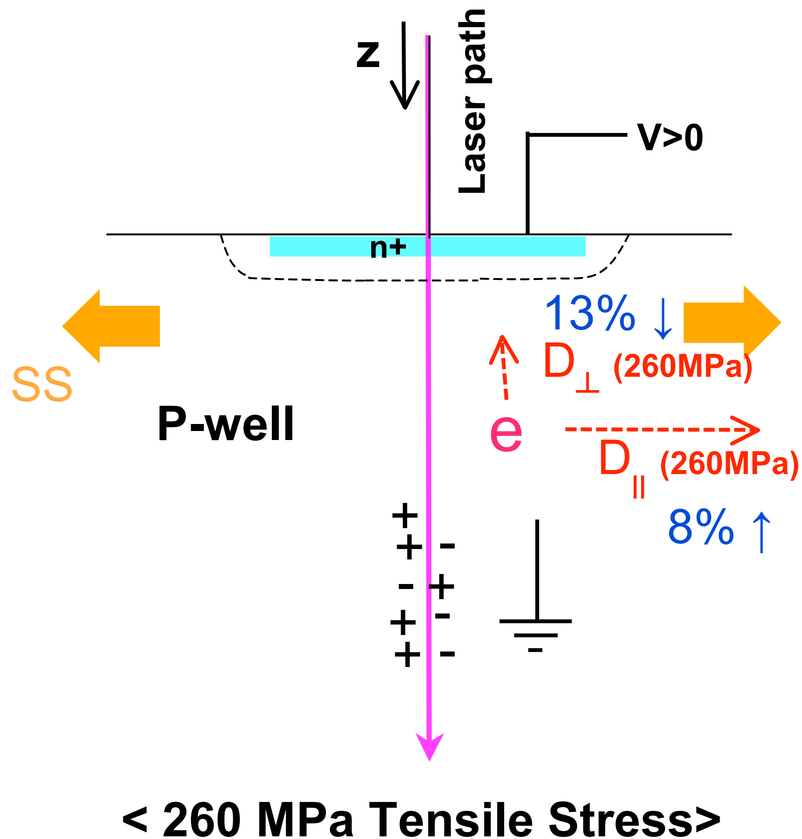
Localized Radiation Damage

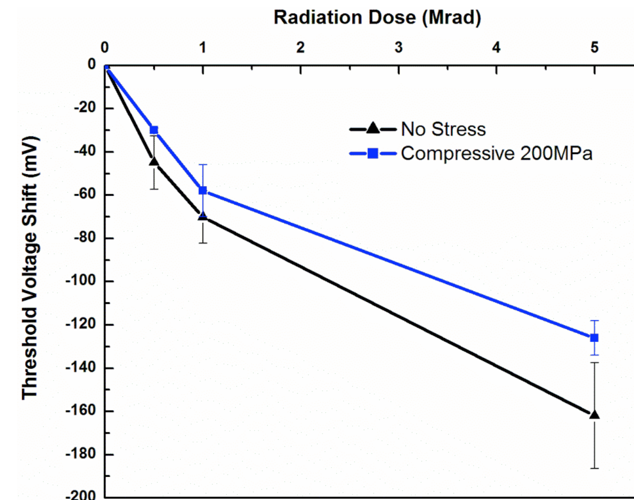
- First-principles evidence of micro-melting in small devices
- Displaced atoms affect single-event dielectric rupture
- Monte-Carlo simulation tool for non-ionizing energy loss developed

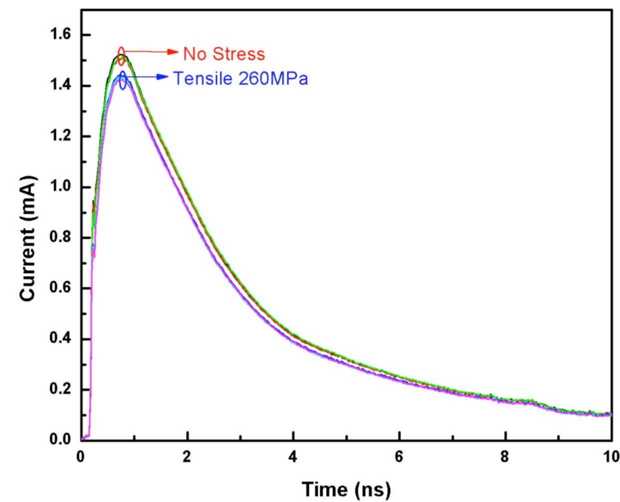




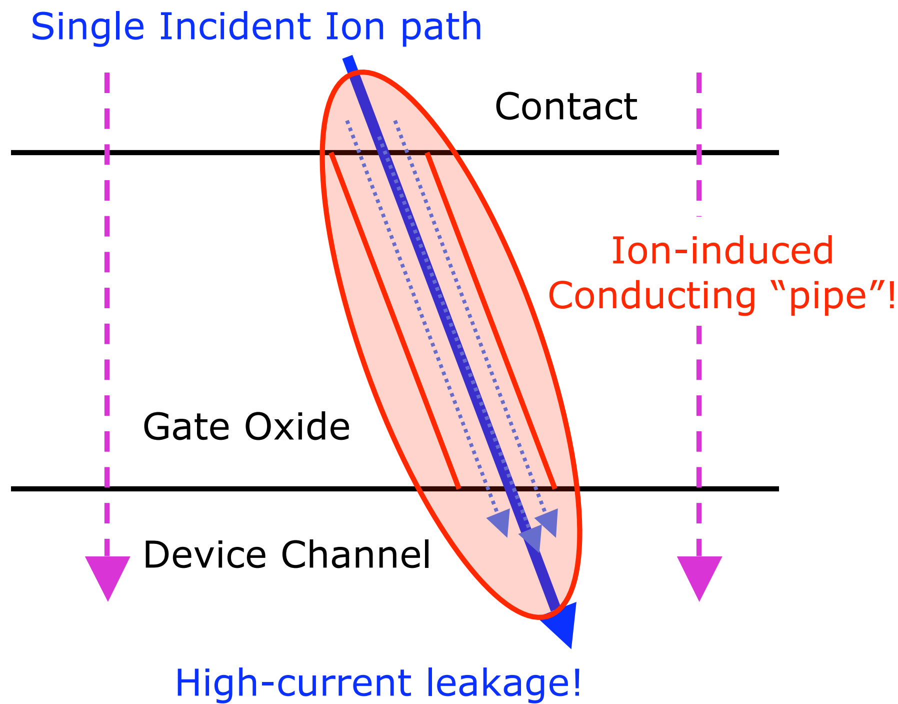
Stress Effects on Radiation Response

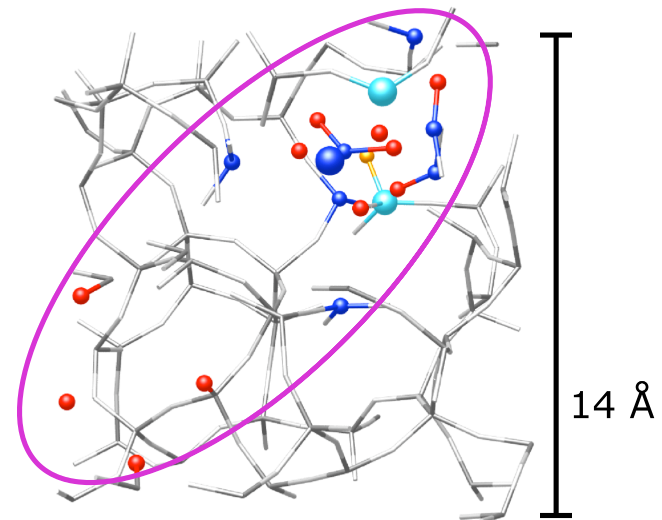






Single-Event Dielectric Rupture





SOI Device Modeling

Irradiation conditions:
Gate bias = 0.8 V
Back gate bias = 3.0 V

W/L = 0.15/0.5 μm

V_{ds} = 1.3 V

200 krad and 300 krad
150 krad
120 krad
100 krad
80 krad
60 krad
40 krad
20 krad
10 krad
Pre-rad

Hysteresis
Forward sweep
Reverse sweep

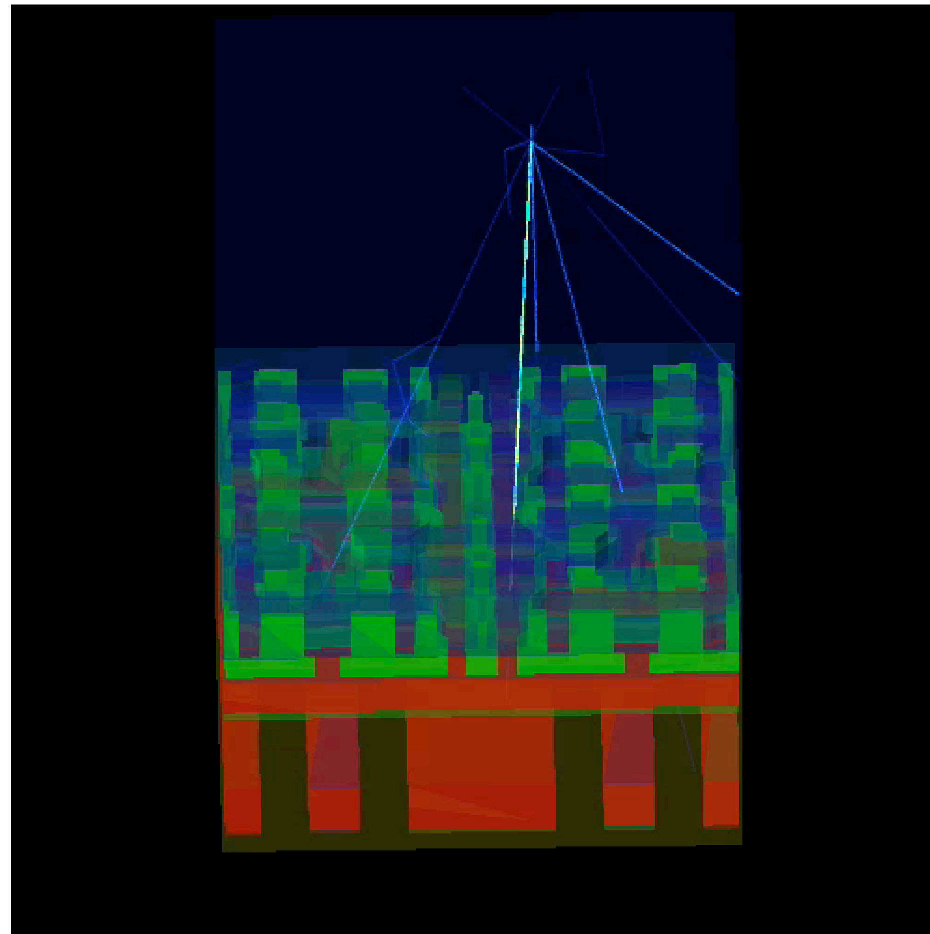
Drain Current (I_{ds})

1×10^{-4}
1×10^{-5}
1×10^{-6}
1×10^{-7}
1×10^{-8}
1×10^{-9}
1×10^{-10}
10^{-11}
10^{-12}

-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0

Gate Voltage (V_{gs})

Energy Deposition Processes



523 MeV Ne

from Marcus Mendenhall

Charge Collection Mechanisms

0.5 pC in a 1 μm strip

ElectrostaticPotential [V]

3.6E+00

2.7E+00

1.9E+00

1.1E+00

2.6E-01

-5.6E-01

2×10^{-10} s

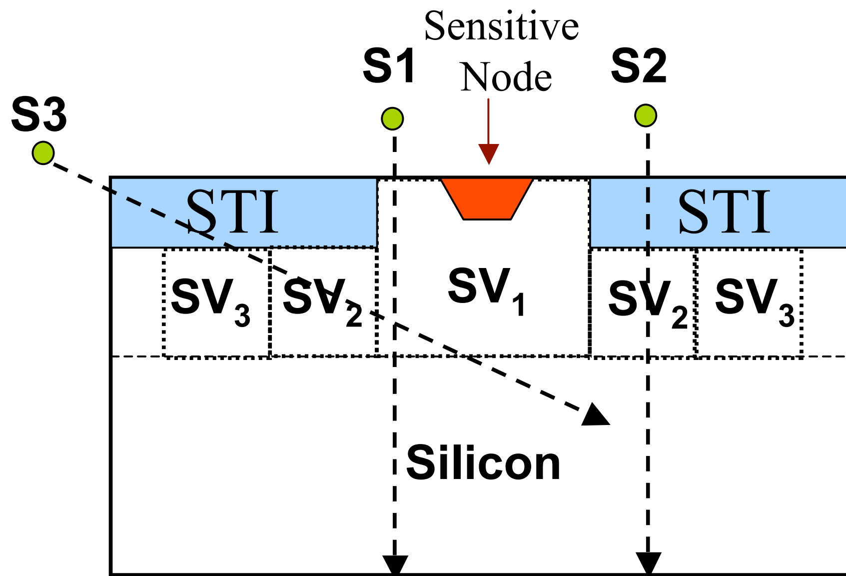
6×10^{-10} s

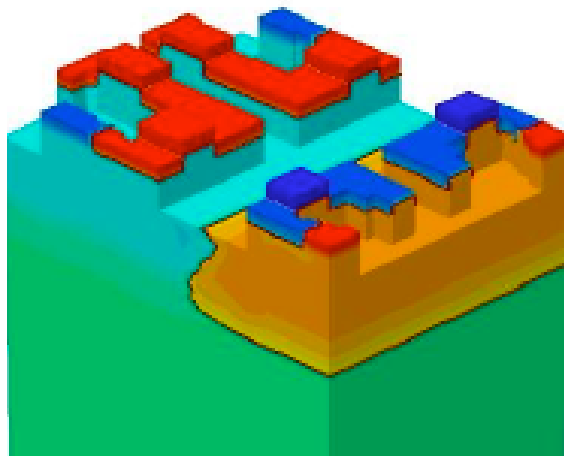
1×10^{-09} s

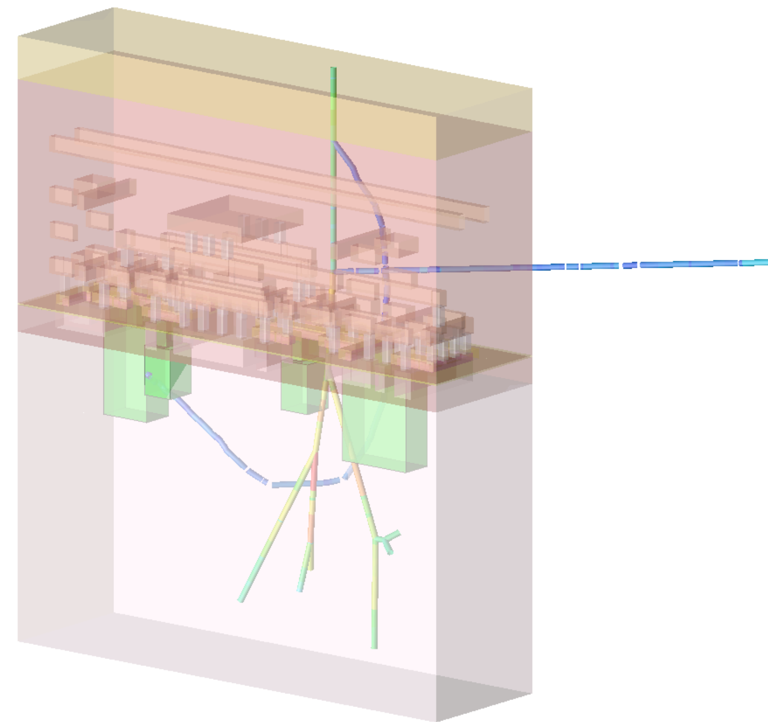
4×10^{-09} s

Electrostatic Potential Modulation

Advanced Rate Prediction







Extensive SET Measurements

Proton, Neutron, Alpha and Heavy-ion induced SETs in 90-nm

SET pulse-width (ps)
1600
1400
1200
1000
800
600
400
200
0

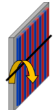
max
+1ó
avg
-1ó
min

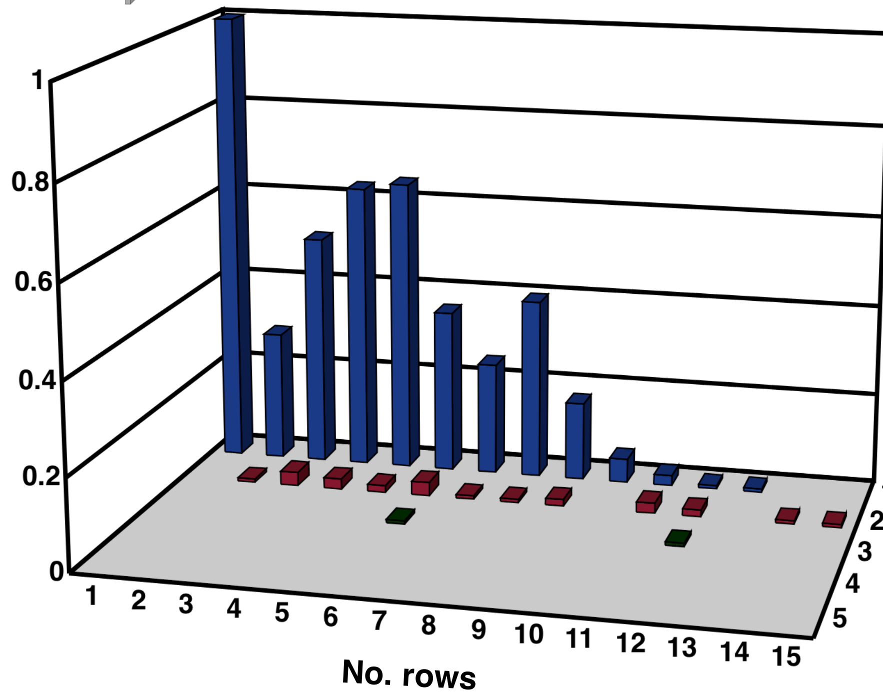
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
Event Cross Section (μm^2/inverter)

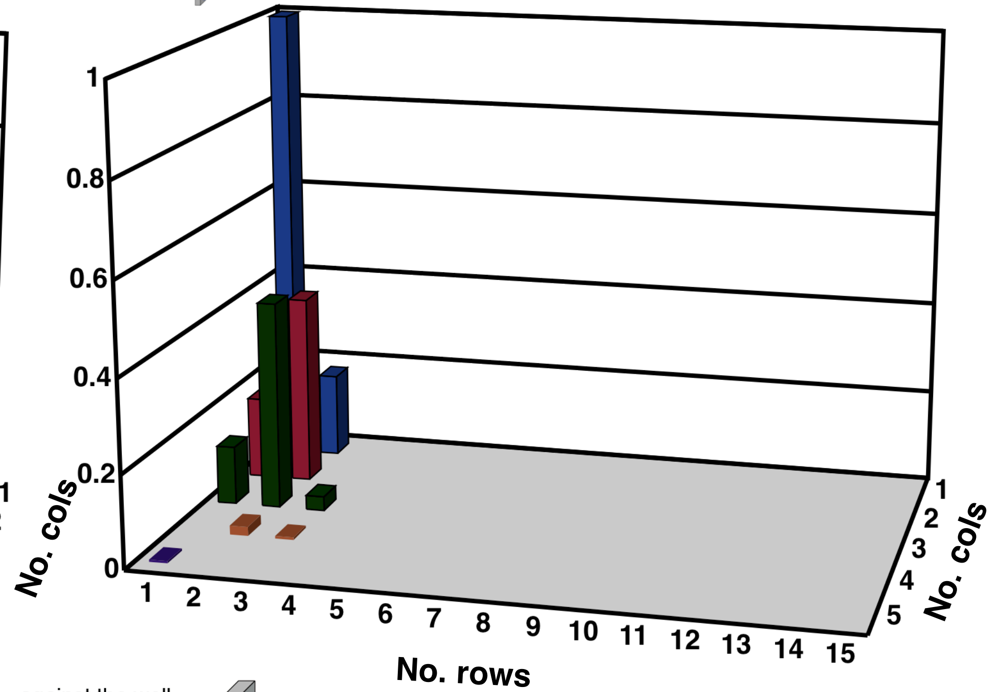
proton 200 MeV
neutron spectrum
alpha (5.5 MeV)
Ne - 3
Ar - 5.7
Kr - 20.6
(LET values)

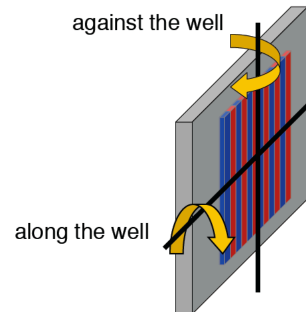
Energetic particle

Device Orientation Effects on Multiple-Bit Upset









A few metrics…

- Personnel (2006-07)
  - 16 graduate students
  - 2 post-docs
  - 11 professors
- Publications
  - 51 appeared in print in 2006-07
  - 10 additional accepted