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Radiation Effects on Emerging Electronic Materials and Devices

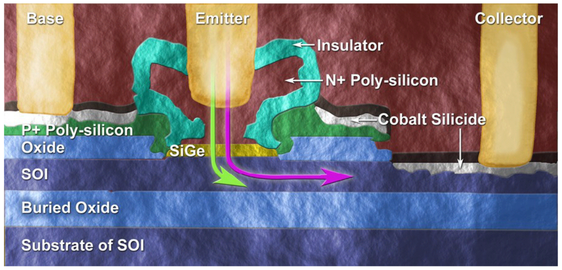
Ron Schrimpf
Vanderbilt University
Electrical Engineering & Computer Science Department
Institute for Space and Defense Electronics

ASU · UNIVERSITY OF FLORIDA · Georgia Tech · NC STATE UNIVERSITY · THE STATE UNIVERSITY OF NEW JERSEY RUTGERS · Vanderbilt University ISDE

Radiation Effects in Emerging Electronic Materials and Devices

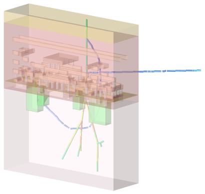
Motivation

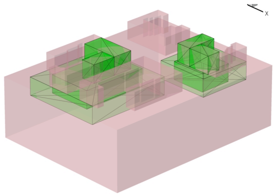
- More changes in IC technology and materials in past five years than previous forty years—impact on radiation response is dramatic



Approach

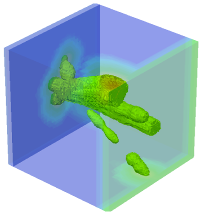
- Experimental analysis of state-of-the-art technologies through partnerships with semiconductor manufacturers
- Identification of critical mechanisms through first-principles modeling
- Implementation and application of a revolutionary multi-scale radiation-effects simulation tool to identify key challenges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

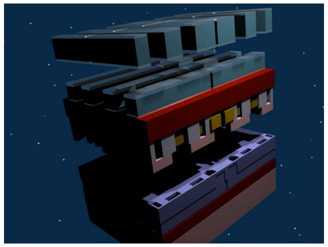




Selected Results

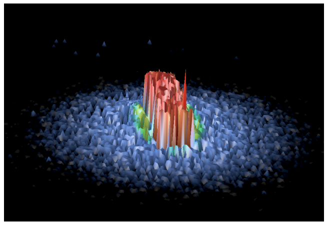
- Development of most accurate rate-prediction tool to date
- Identification of tungsten as key rad-effects issue
- Fabrication of rad-hard, reliable alternative gate dielectrics
- Demonstration of extremely rad-hard SiGe technology
- First examination of rad effects in strained-Si CMOS

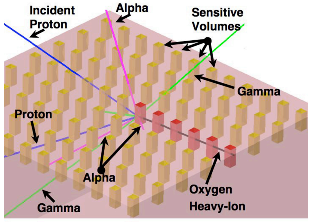




Impact

- 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, Len Feldman, Gennadi Bersuker

Collaborations

- Government: DTRA, NASA, Navy, Sandia, Oak Ridge National Lab
- Industry: IBM, Intel, Texas Instruments, Freescale, Jazz, National Semiconductor, Lockheed-Martin, CFDRC, SRC/Sematech
- University: IMEC, INPG (Grenoble), Griffith University

Schedule—June 10 AM

8:30 Welcoming Remarks
Kitt Reinhardt, AFOSR
8:35 MURI Overview
Ron Schrimpf, Vanderbilt University
8:55 Overview: Atomic-Scale Theory of Radiation-Induced Phenomena
Sokrates Pantelides, Vanderbilt University
9:10 Ion-induced leakage currents I: Defect generation.
Matt Beck, Vanderbilt University
9:25 Ion-induced leakage currents II: Quantum transport
Nikolai Sergueev
9:40 Ion-induced leakage currents III: A percolation model
Yevgeniy Puzyrev, Vanderbilt University
9:55 H_2 in Oxide: Implications for Radiation Response
Blair Tuttle, Vanderbilt University
10:15 Break

Schedule—June 10 AM

10:40	Effect of Ambient Hydrogen on Radiation-Induced Interface-Trap Formation David Hughart (presenter), Vanderbilt University and Jie Chen, Arizona State
11:00	Effects of Moisture on 1/*f* Noise and Radiation Response in MOS Devices Ashley Francis, Vanderbilt University
11:20	Reliability and total dose effects in Ge MOS devices Rajan Arora, Vanderbilt University
11:35	Charge trapping properties of 3C and 4H SiC MOS capacitors John Rozen and Rajan Arora (presenter), Vanderbilt University
11:50	Overview: Radiation Effects in Emerging Materials Len Feldman, Rutgers University
12:05	Defects in Non-Crystalline and Nano-Crystalline Alternative Transition Metal Dielectrics Gerry Lucovsky, North Carolina State University and Len Feldman (presenter), Rutgers University
12:20	Lunch

Schedule—June 10 PM

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

2:00 Total Dose and Single Event Effects in Strained Si Technologies
Scott Thompson, University of Florida

2:20 Break

2:40 Simulating Hydrogen Transport and Single-Event Transients
Mark Law, University of Florida

3:00 Overview: Monte Carlo Radiative Energy Deposition (MRED) Code
Bob Weller, Vanderbilt University

3:20 SEE Rate Prediction Based on an Integrated Monte Carlo/SPICE Simulation Methodology
Kevin Warren, Vanderbilt University

3:40 Low-Energy Proton Single Event Effects
Brian Sierawski, Vanderbilt University

4:00 Single-Event Transient Pulse-Width Measurements in Advanced Technologies
Matt Gadlage, Vanderbilt University

4:20 Discussion

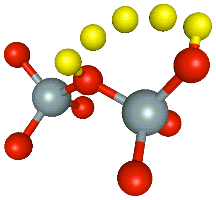
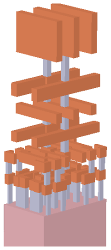
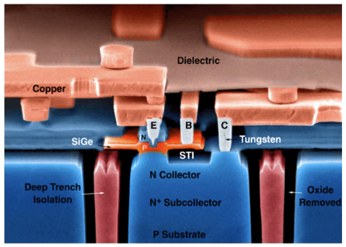
Schedule—June 11

8:30 Radiation Effects in SiGe Devices
John Cressler, Georgia Tech
9:10 High-Speed Single-Event Current Transient Measurements in SiGe HBTs
Jonny Pellish, NASA GSFC and Robert Reed, Vanderbilt University
9:30 Modeling Total Ionizing Dose Effects in Deep Submicron Bulk CMOS Technologies
Hugh Barnaby, Arizona State University
9:50 Effects of STI Topology on Radiation-Induced Leakage
Nadia Rezzak and Mike Alles, Vanderbilt University
10:10 Break
10:30 Modeling the dose rate response and the effect of hydrogen in bipolar technologies
Jie Chen, Arizona State University
10:50 Total-Dose Effects in 100-nm FinFETS
Farah El-Mamouni, Vanderbilt University
11:10 Radiation Effects on ZRAMs
Enxia Zhang, Vanderbilt University
11:30 Meeting Ends

Radiation Effects in Emerging Electronic Materials and Devices: Results

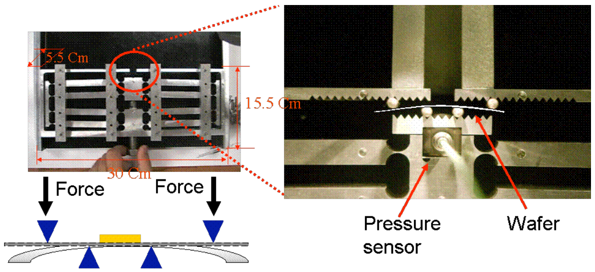
Radiation Response of New Materials

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

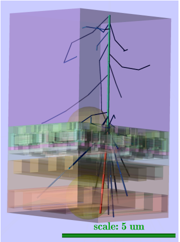
Impact of New Device Structures

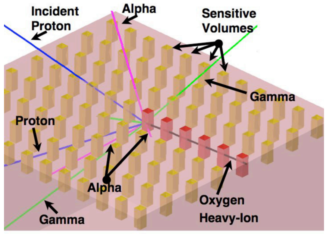
- New device technologies strongly impact single-event response and TID leakage current
- SiGe HBTs, strained Si CMOS, ultra-small bulk CMOS exhibit complicated charge collection mechanisms
- Strain can *improve* the TID response of scaled CMOS technologies



Single Events in New Technologies

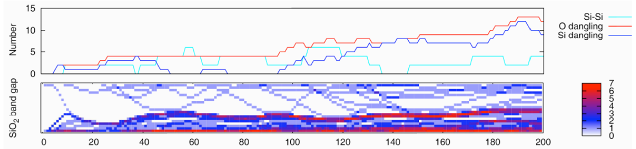
- New rate prediction approach based on combined experiments and Monte Carlo simulation
- Passivation/metallization found to *dominate* SEE response in some hardened technologies
- Excellent agreement with on-orbit data; conventional rate-prediction methods underestimate rate by orders of magnitude

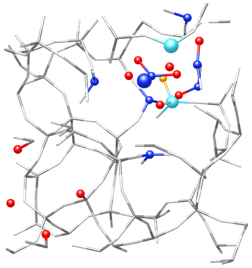




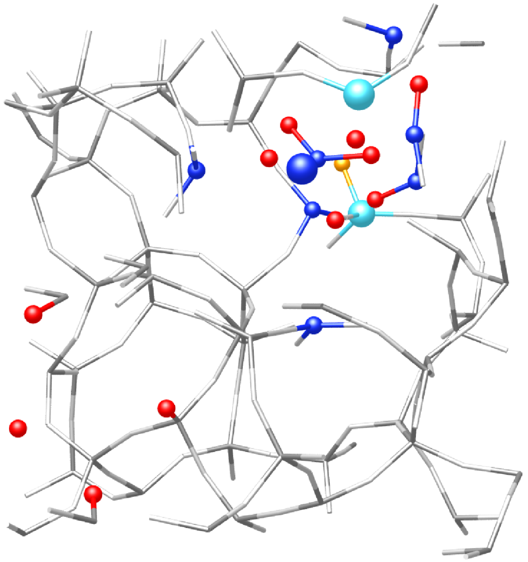
Localized Radiation Damage

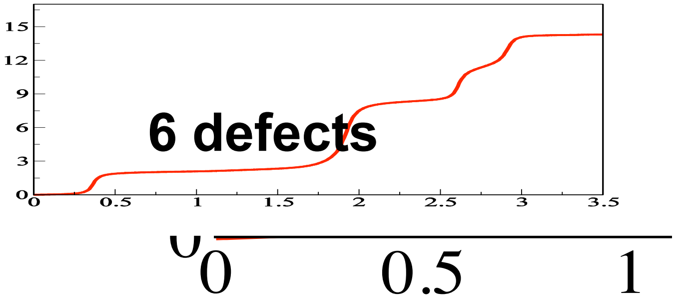
- Evidence of particle-induced micro-melting in small devices
- First physically-based explanation of single-event dielectric rupture
- Temporary conducting paths formed in dielectrics by energetic particles



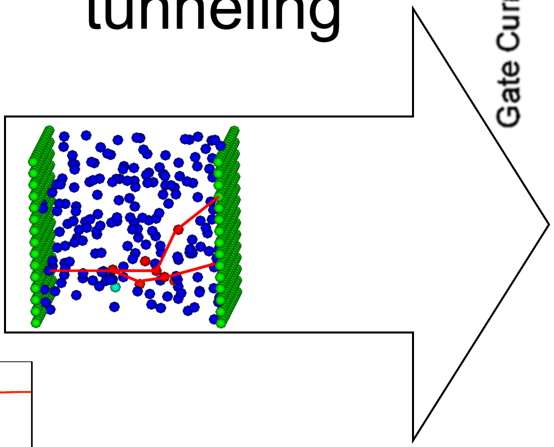


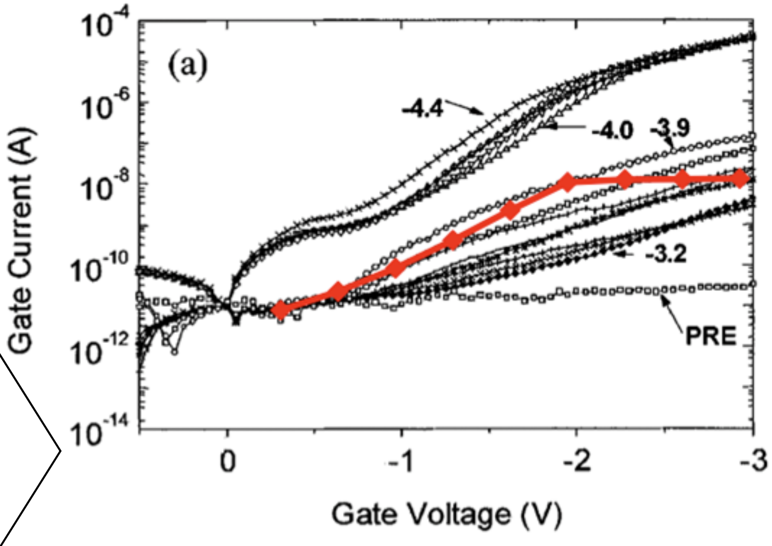
Multi-scale calculation
From QM transport to I-V device characteristics

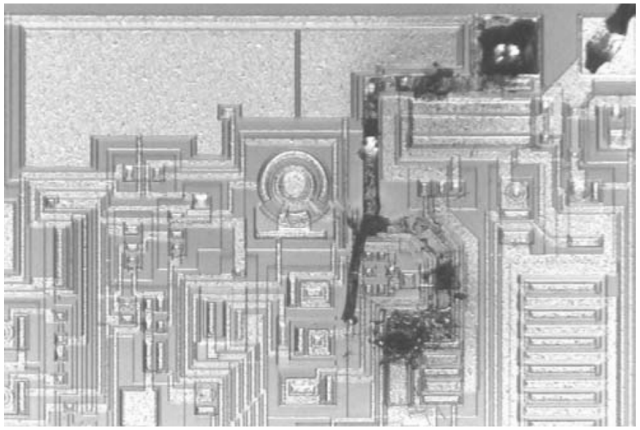




Mott's
defect-defect
tunneling

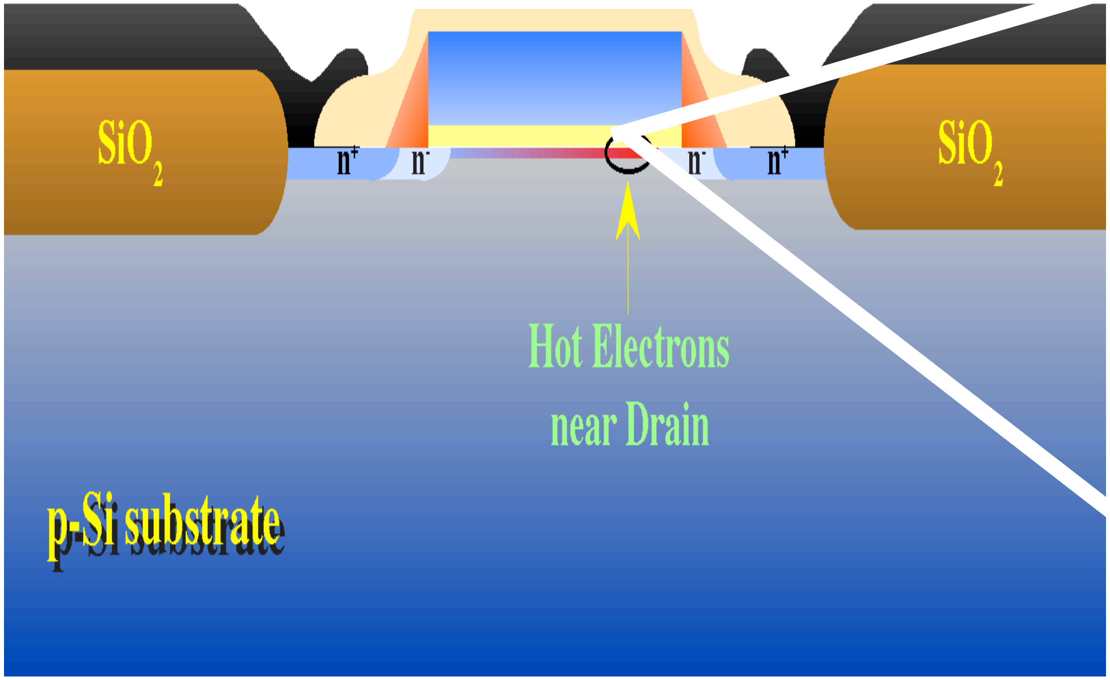


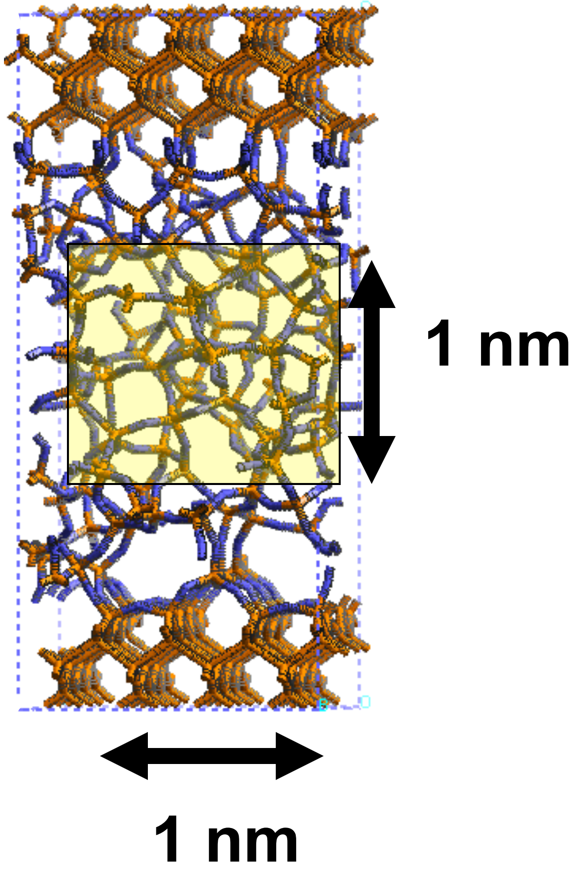




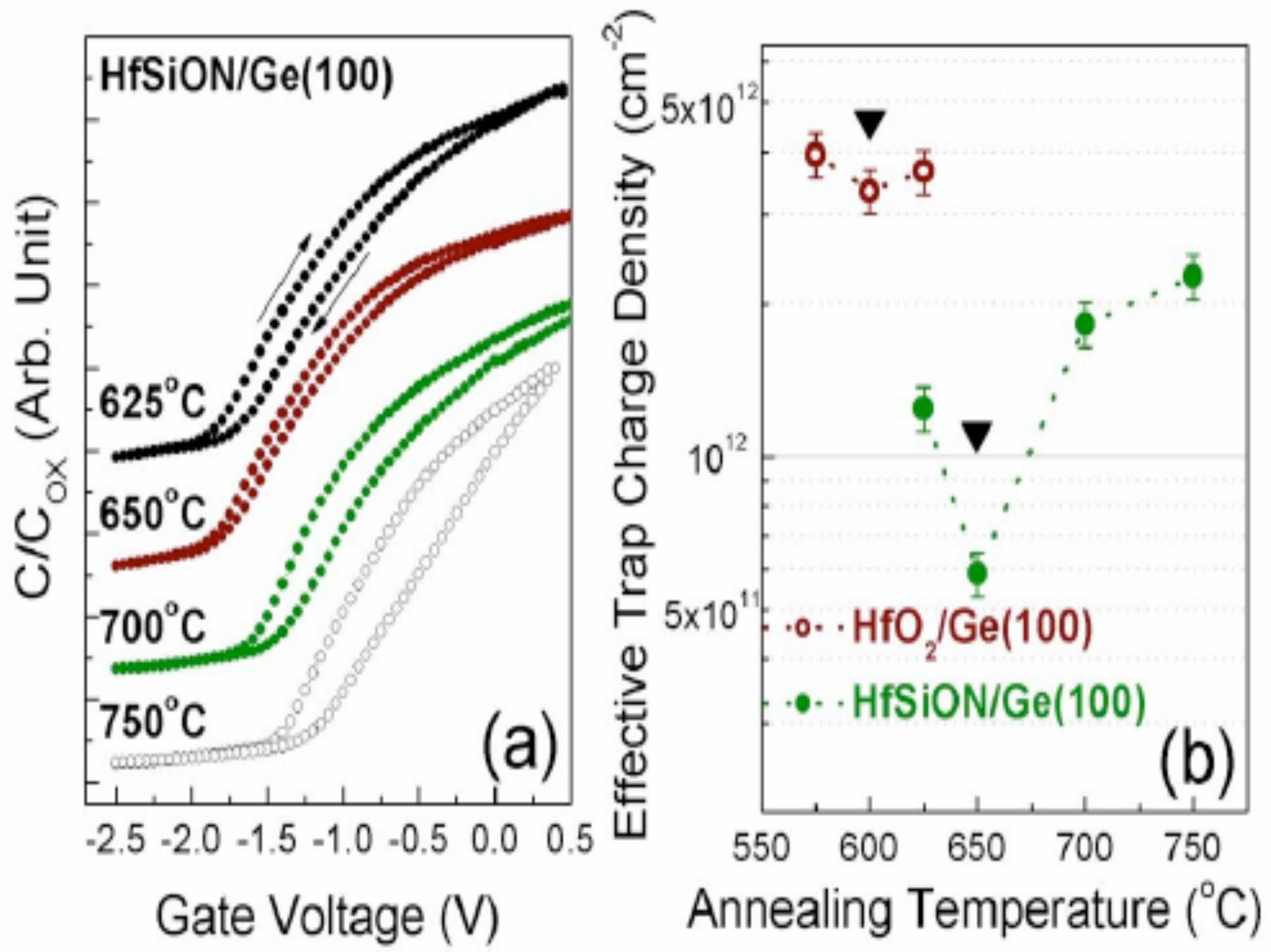
Atomic-scale modeling of oxides

MOSFET





Lowest interface trap density for alternative dielectrics on Ge

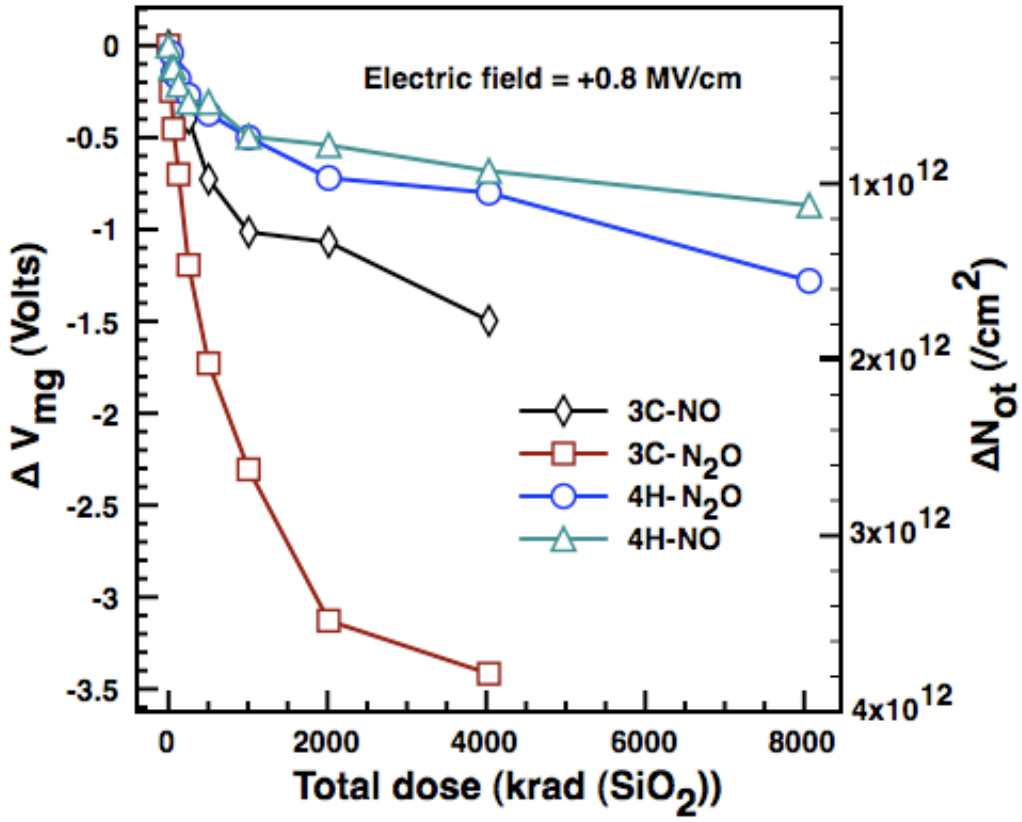


lowest trap density same as Saraswat's (Stanford Univ) best

HfSiON on Si - X-ray stress similar to SiO2 no negative fixed charge as in HfO2

defects lower than in HfO_2 agree with XAS

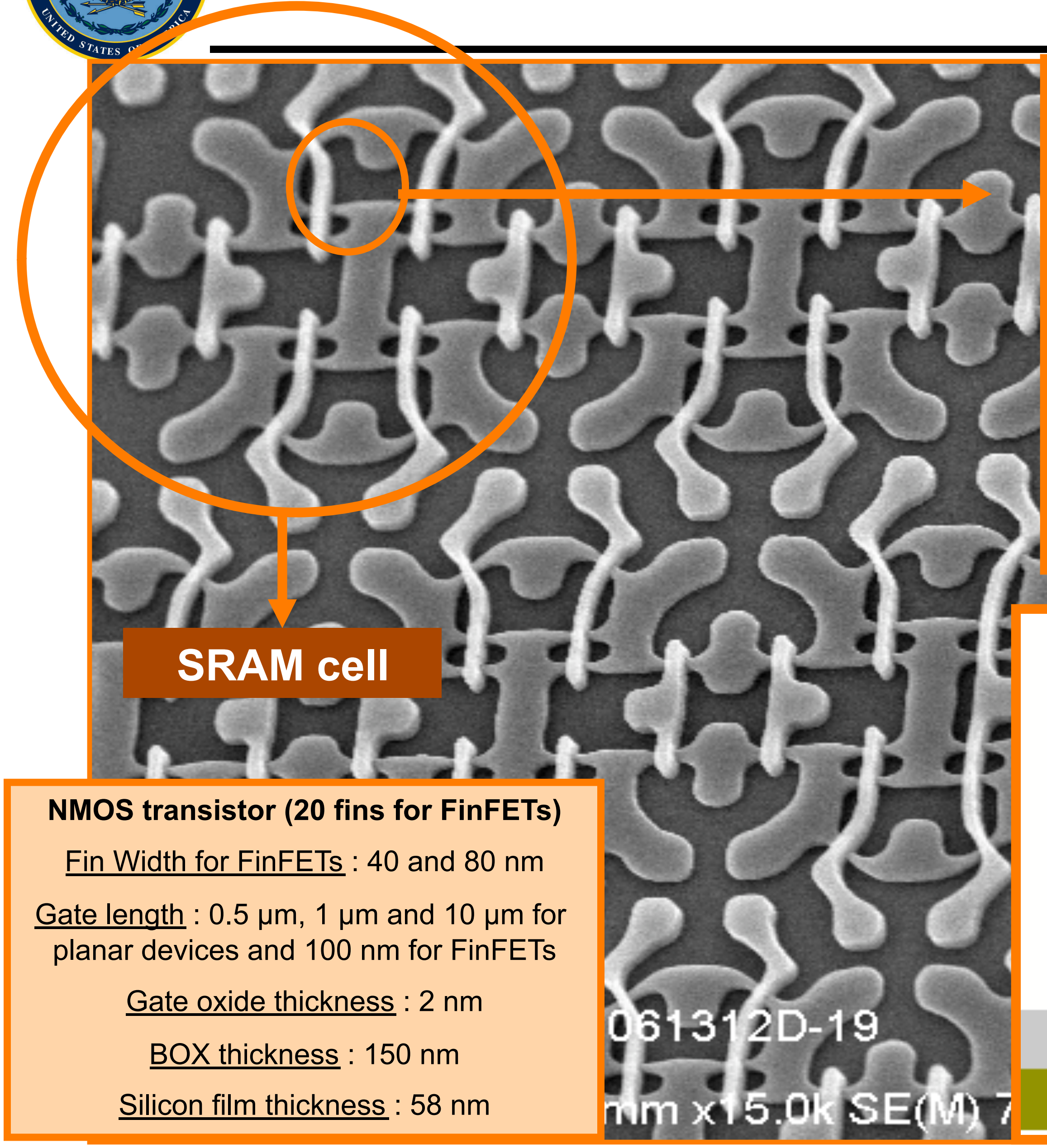
Total dose response of SiC capacitors



✧ Greater charge trapping for N_2O treated oxide than for NO treatment.

✧ Greater charge trapping for 3C- than 4H-SiC substrate

Total dose effects on FinFETs



NMOS transistor (20 fins for FinFETs)

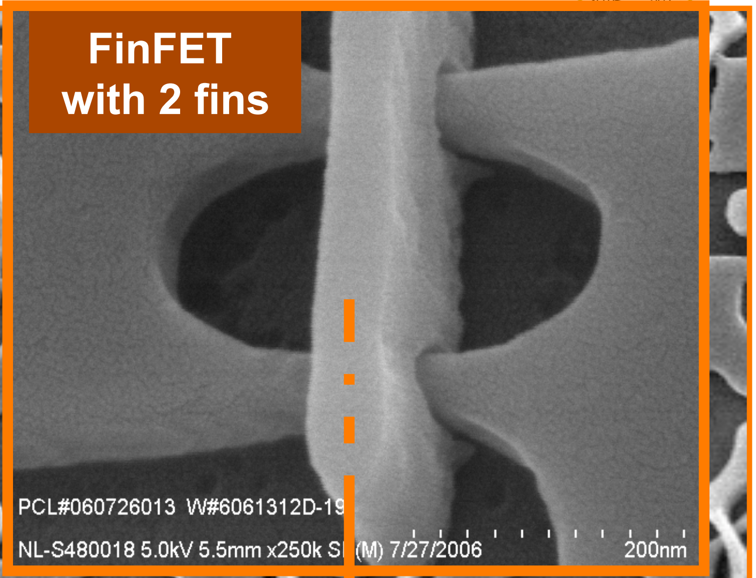
Fin Width for FinFETs : 40 and 80 nm

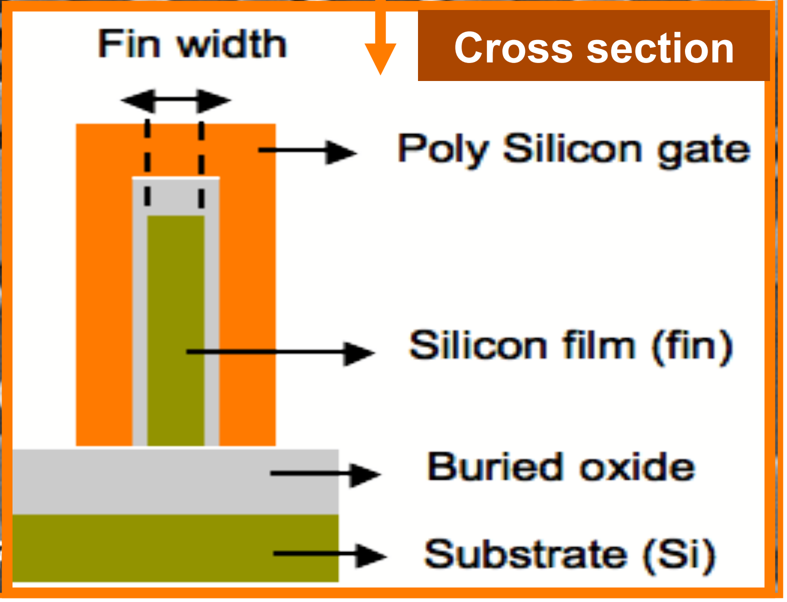
Gate length : 0.5 µm, 1 µm and 10 µm for planar devices and 100 nm for FinFETs

Gate oxide thickness : 2 nm

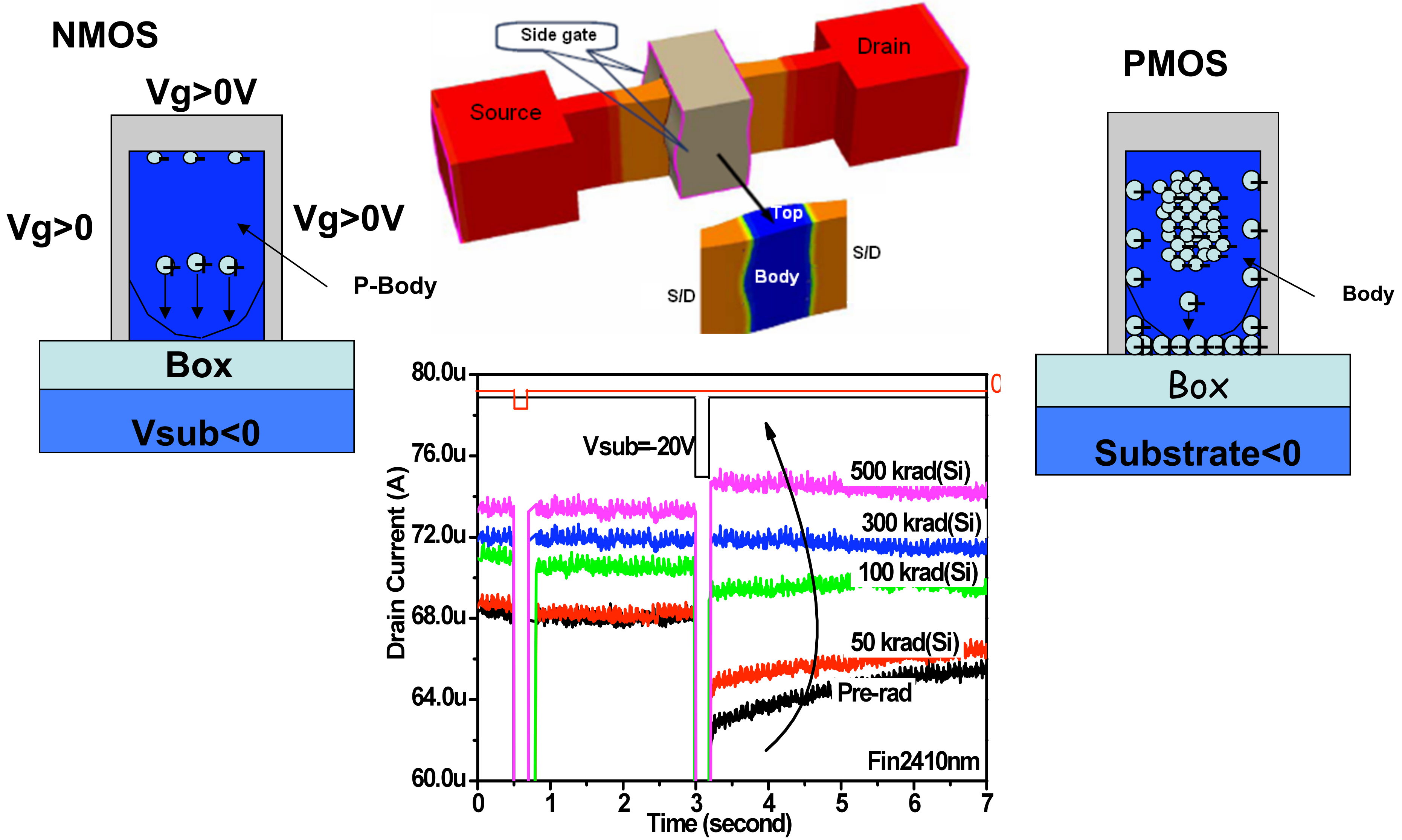
BOX thickness : 150 nm

Silicon film thickness : 58 nm

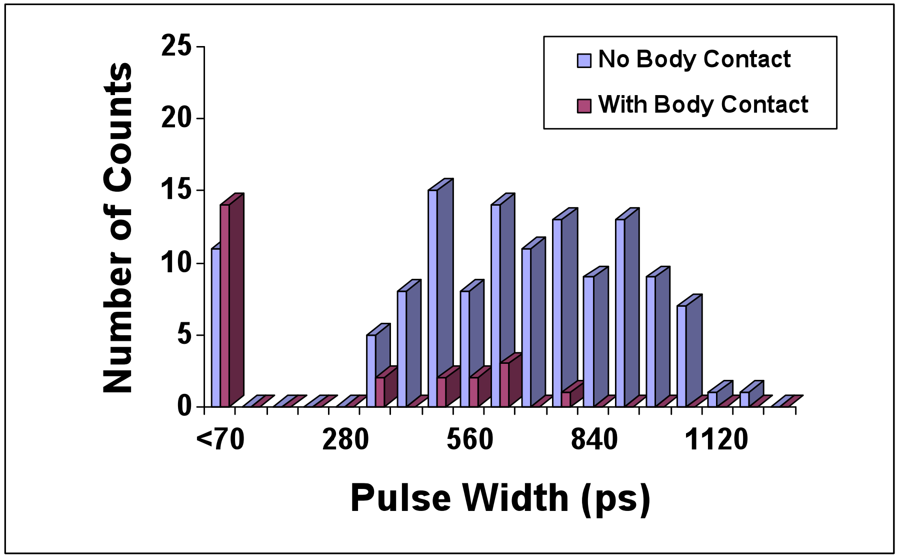




Total Dose Effects on ZRAMs



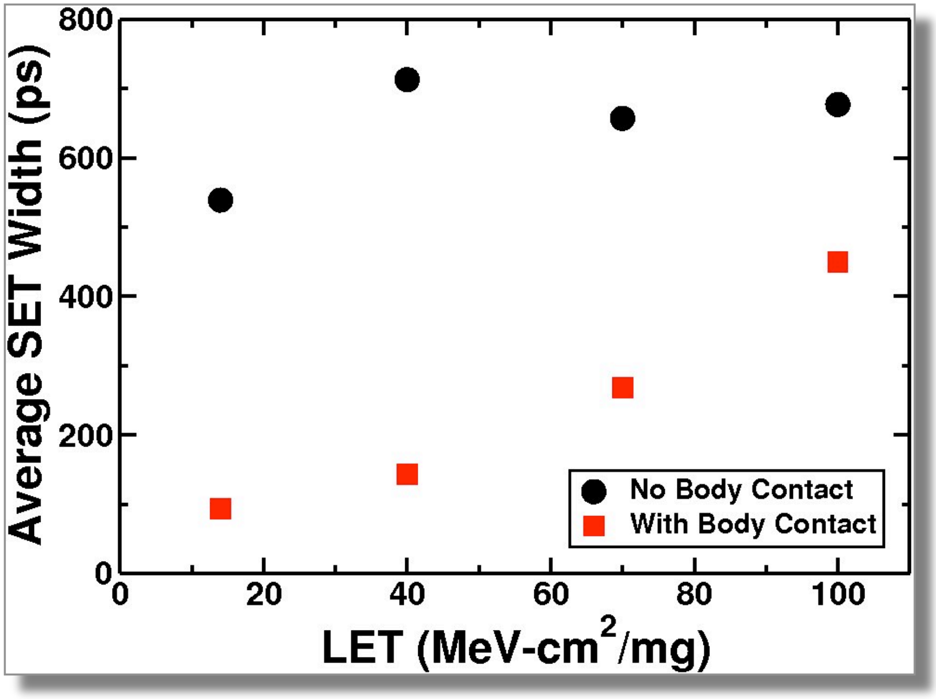
FDSOI SET Pulse Width Measurements



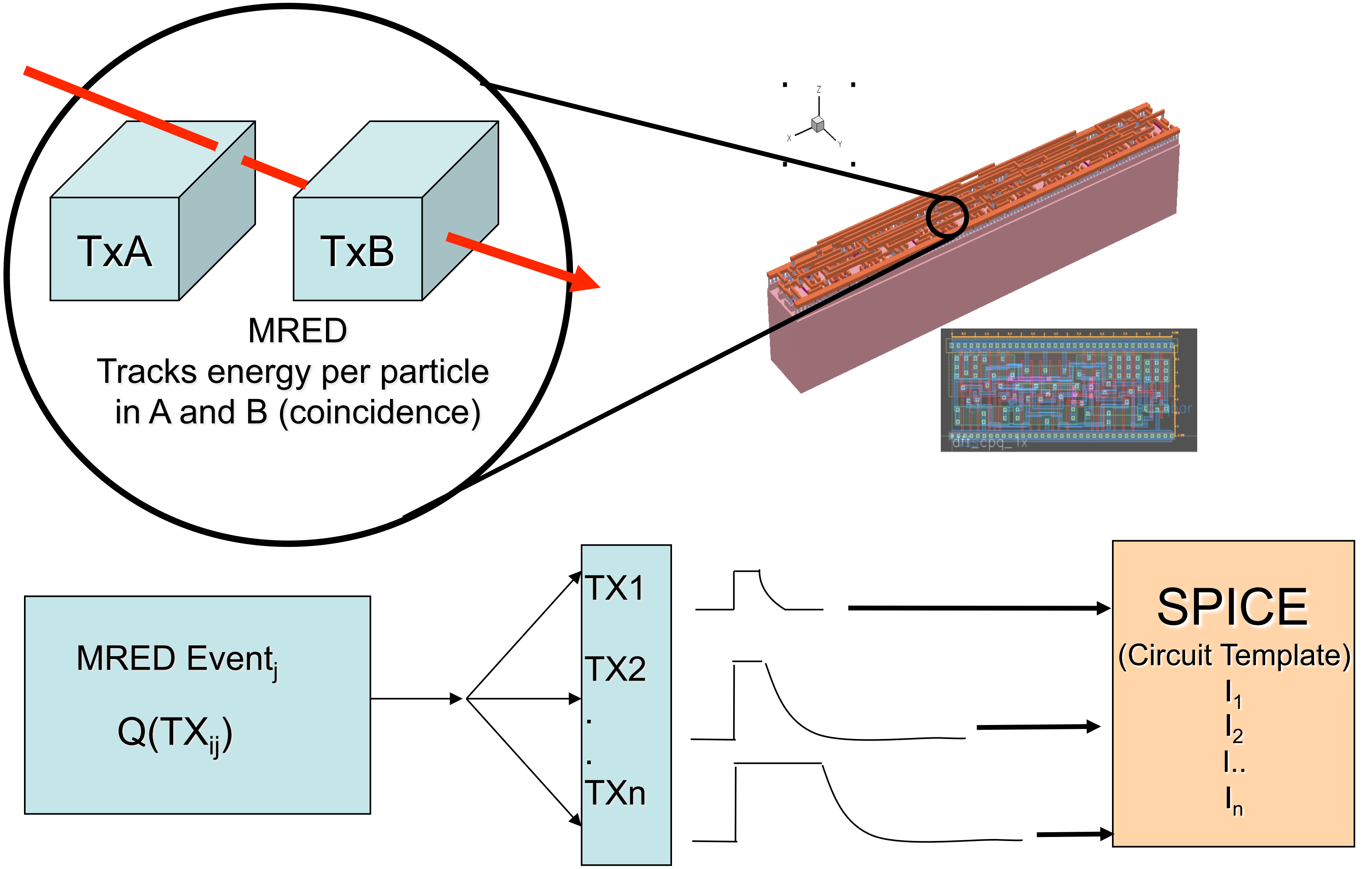
SET Pulse Width Distribution for an LET of 69 MeV-cm^2/mg

- Pulse broadening effects are greatly reduced with the body contact.
- For the circuit with body ties, the average SET pulse width increases with LET.

- Heavy ion data obtained at Berkeley National Labs
- Cross section and measured pulse widths are significantly shorter for the body contacted inverters.



Advanced Event Rate Prediction



TxA

TxB

MRED
Tracks energy per particle
in A and B (coincidence)

MRED Event$_j$

Q(TX$_{ij}$)

TX1

TX2

.

.

TXn

SPICE

(Circuit Template)

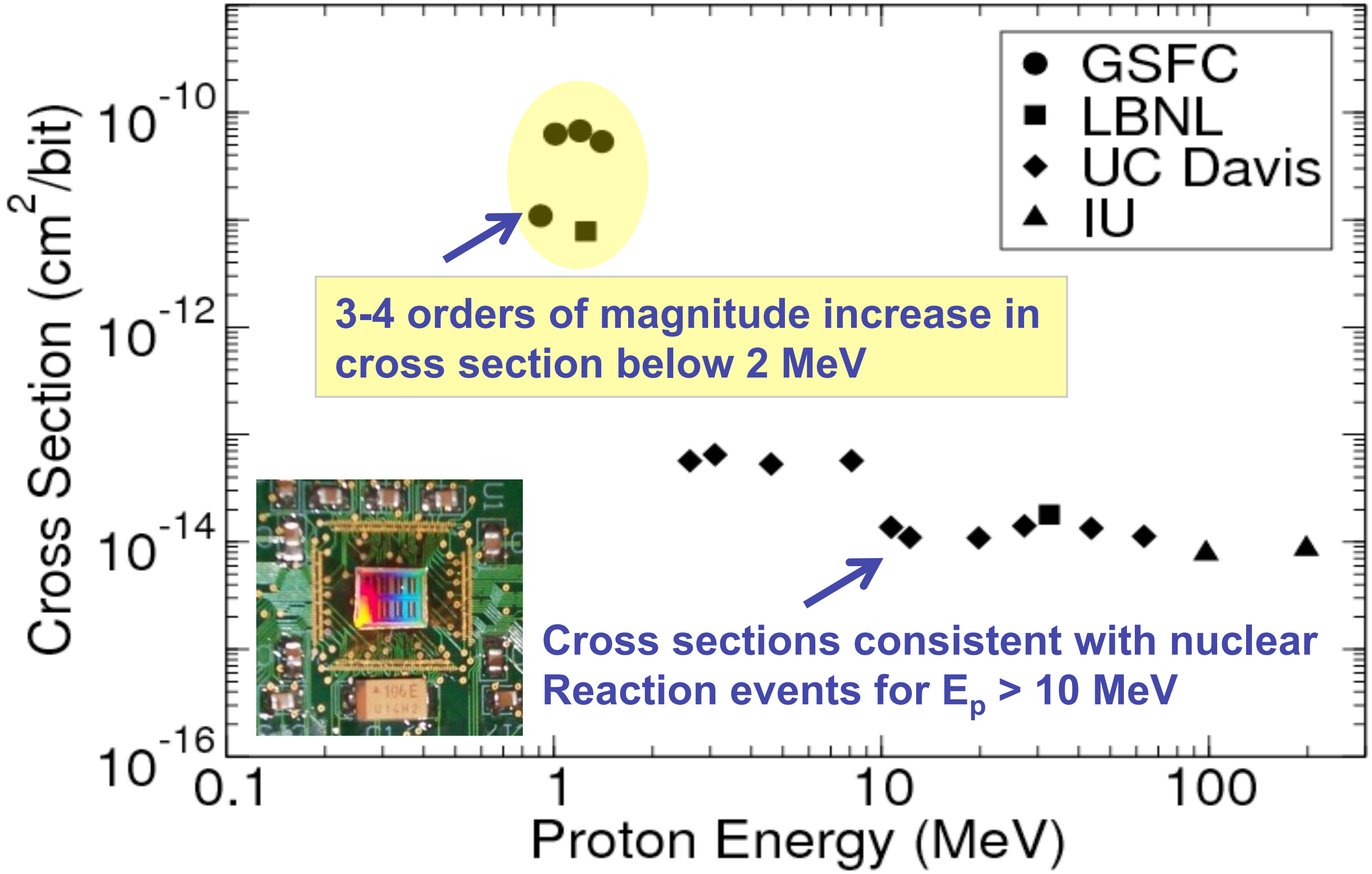
I_1

I_2

I..

I_n

Mechanisms of Low-Energy Proton Upset Cross Sections



3-4 orders of magnitude increase in cross section below 2 MeV

Cross sections consistent with nuclear Reaction events for E_p > 10 MeV

A few metrics…

- Personnel (2006-07)
  - 16 graduate students
  - 3 post-docs
  - 13 professors
- Publications
  - 78 appeared in print in 2007-08
- Patent disclosure
  - A. T. Thrivikraman, A. Appaswamy, and J.D. Cressler, “Cascoded Silicon-Germanium Heterojunction Bipolar Transistors Using Shared Subcollector Inverse Mode Device,” Georgia Tech Research Corporation Invention Disclosure, #4390, 2008.

Honors and Awards

- Jiahui Yuan (Georgia Tech) was awarded a 2008 IEEE Electron Devices Society Ph.D. Fellowship Award, 7/08.
- Jie Chen (ASU) received the 2008 NPSS Phelps Award.
- M. L. McLain (ASU) received the 2008-09 Achievement Award for College Scientists, ARCS Phoenix Chapter.
- Dan Fleetwood (VU) received the IEEE NPSS Merit Award.
- Ken Galloway (VU) was elected chair of the Engineering Deans Council Executive Board.
- Ron Schrimpf (VU) was selected as the VU Harvey Branscomb Distinguished Professor.
- Dan Fleetwood and Ron Schrimpf were selected for endowed chairs.