Sentaurus TCAD
Introduction

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TCAD Application Segments

CMOS
- Advanced CMOS (Si, SOI, etc.)
- Atomistic modeling
- Statistical modeling
- Reliability

Memory
- Flash
- DRAM
- ReRAM

Opto
- Image Sensors
- Solar Cells
- Photodetectors

Analog/RF
- High-speed devices
- Compound semiconductors

Power
- Discrete devices
- Power ICs
- Silicon and wide bandgap
- ESD
TCAD Product Portfolio

Process Simulation
- Sentaurus Process
- Sentaurus Lithography
- Sentaurus Topography

Structure Editing
- Sentaurus Structure Editor

Device and Interconnect Simulation
- Sentaurus Device
- Raphael
- Sentaurus Interconnect

Framework
- Sentaurus Workbench
- Sentaurus PCM Studio
- Raphael

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TCAD Development Focuses

• New Technology Support
  – More Moore
    – FinFET, FDSOI, III-V, etc.
  – More than Moore
    – Analog/RF, CIS, solar, power (Si, SiC, GaN), TSV, etc.

• 3D Support (FinFET, NVM, Power, SRAM, CIS)
  – Improved meshing and geometric operations
  – Stress modeling
  – BEOL reliability modeling
  – Topography simulation

• Performance and Usability
  – Improved multi-CPU scaling
  – Process simulation speed-up
  – More intuitive user interface
Platforms supported in I-2013.12 release:

- x86_64\(^1\) Red Hat Enterprise Linux 5.7, 5.9, 6.2, 6.4
- x86_64\(^1\) SUSE Linux Enterprise Server 10SP3, 10SP4\(^2\), 11SP1\(^2\), 11SP2\(^2\)
- IBM RS6000 64-bit AIX\(^3\) 6.1-TL6-SP5

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1. The 64-bit (x86_64) Linux software is binary compatible with the Intel or AMD x86_64 processors running Red Hat Enterprise Linux.
2. Binary-compatible hardware platform or operating system. Note, however, that binary compatibility is not guaranteed.
3. Sentaurus Device Electromagnetic Wave Solver, Sentaurus Interconnect, Sentaurus Topography, and Sentaurus Topography 3D are not available on AIX.
Sentaurus Workbench – TCAD Simulation Platform

- Sentaurus Workbench GUI
Sentaurus Workbench – Easy Material & Manual Access

Public Application Example Library

Manuals

HTML-training
Sentaurus Workbench – Node Explorer

- Node Explorer (F7) provides quick access to all node data.

![Node Explorer window]

- Mouse double-click on node.
Sentaurus Workbench – Flexible Execution Controls

selected nodes run with one mouse click
Sentaurus Process Simulator

- General purpose multidimensional (2D/3D) process simulator
- Integrated 3D geometric modeling engine (depo/etch/pattern)
- Adaptive meshing (to geometry/species changes)
- API for user-defined models
- Advanced physical models:
  - Analytic and Monte Carlo implantation
  - Diffusion: laser/flash annealing, kinetic Monte Carlo
  - Mechanical stress
  - Oxidation/Silicidation

FinFET SRAM

Mechanical Stress  Kinetic Monte Carlo  Adaptive Meshing  Oxidation
Implantation

- **MC Implantation**
  - Sentaurus MC
  - (Crystal-TRIM)

- **Analytic Implantation**
  - Primary Distributions
    - Gaussian
    - Pearson (4 parameters)
    - Dual Pearson (9 parameters)
  - Screening
  - Damage Model
  - Amorphization
  - Molecular Implant
  - Calibrated Implantation Tables

```plaintext
 implant Arsenic dose=1e14 energy=50 tilt=7 rotation=0 info=2
```
Dopant Diffusion

- Flash/Laser Anneal
- Dopant Activation and Clustering
- Solid Phase Epitaxial Regrowth
- Epitaxy
- Clustering of Defects
- Pressure-dependent Defect Diffusion
- Segregation & Dose Loss
- Kinetic MC Diffusion

Diffusion Model Hierarchy
- Constant (constant diffusion coefficient)
- Fermi (point defects equation not solved, defects in equilibrium)
- Charged Fermi (same as Fermi+total dopant flux is due to dopant-defect pairs)
- Pair (dopant-defects pairs are in local equilibrium with dopant and defect concentrations)
- Charged Pair (same as Pair+reaction rates are state charge dependent)
- React (incl.defects, rates are not charge state dependent)
- Charged React (same as React+mobile charged dopant-defects)
Oxidation/Silicidation

- Oxidation Model Hierarchy
  - Deal/Grove Model
  - Massoud Model
  - Mixed Flows (Hirabayashi approach)
- Stress-Dependent Oxidation (SDO)
- Orientation-Dependent Oxidation
- Doping-Dependent Oxidation
- Trap-Dependent Oxidation
- In Situ Steam-Generated Oxidation (ISSG)
- Silicidation
- Oxynitridation (N_2O)
- Moving Boundaries and Adaptive Mesh
- 3D Oxidation

\[
\frac{dx}{dt} = \frac{B}{A + 2x} + C \exp \left( -\frac{x}{L} \right)
\]

\[
\frac{dx}{dt} = \frac{dx_{H_2O}}{dt} + \frac{dx_{O_2}}{dt} = \frac{B_{H_2O}}{A_{H_2O} + 2x} + \frac{B_{O_2}}{A_{O_2} + 2x}
\]
Mechanical Stress Modeling

- Stress Model
  - Viscoplasticity
  - Plasticity
  - Viscoelasticity

- Stress Causing Mechanisms
  - Stress Induced by Growth of Material
  - Stress Induced by Densification
  - Stress Induced by Thermal Mismatch
  - Lattice Mismatch Stress
  - Intrinsic Stress
Etching/Deposition

- Etch Models
  - Isotropic
  - Anisotropic & Directional
  - Polygonal
  - CMP
  - Fourier
  - Crystallographic
  - Trapezoidal

- Depo Models
  - Isotropic
  - Fill & Polygon
  - Fourier
  - Selective Deposition

- Algorithms
  - Analytic
  - Level-set

- 3D Geometry Generation
  - MGOALS3D (level-set)
  - Integrated SDE
  - S-Topo 3D
  - Meshing with Sentaurus Mesh
Non-Si Materials Process Simulation

- MC Implantation
  - SiGe and Ge
  - 4H-, 6H-SiC
  - III-V, including III-N
- Diffusion & Activation
  - First prototype available in H-2013.03 release for 4H-SiC and III-V (InGaAs/InP)
Sentaurus Process Kinetic MC

- Command to switch
  
  \textbf{SetAtomistic}

- Considers only defects and impurities, and ignores the lattice for diffusion simulation
- Supported options: \textit{diffuse, deposit, etch, implant, init, line, photo, profile, region, select, strip}
- LKMC: Fully Atomistic Modeling of SPER (Solid Phase Epitaxial Regrowth)
  - SPER velocity depends on the substrate orientation with approximate ratios of 20:10:1 for orientations (100), (110), and (111)
Sentaurus Topography 3D

General overview

- Sentaurus Topography 3D is a three-dimensional simulator for evaluating and optimizing critical topography-processing steps such as etching and deposition
- Simulates deposition and etching processes by using the level-set method to evaluate the surface evolution during the process
- Models categories:
  - Built-in models
  - User-defined models within Rate Formula Module (RFM)
  - User-defined models within a Physical Model Interface (PMI)
- Support of different reaction species, different fluxes, re-deposition, …
Sentaurus Topography Simulator

- Multidimensional (2D/3D)
- Robust level-set numerical models
- Deposition models (LPCVD, PECVD, HDP-CVD, APCVD, SOG, reflow)
- Etching models (wet, HDP, RIE, ion milling, CMP)
- Interface to Sentaurus Process & Sentaurus Lithography

- Physical vapor deposition
- Ion milling
- RIE
- O3 / TEOS APCVD
- Tench filling with void formation
Etching and Deposition Example

DRAM Flow, using built-in models
Coupling Topography to Process

Geometry
Sentaurus Topography

Doping and meshing
Sentaurus Process
Sentaurus Interconnect

REALISTIC STRUCTURE GENERATION

MECHANICAL STRESS ANALYSIS

THERMAL ANALYSIS

ELECTRICAL ANALYSIS
Sentaurus Interconnect Tool Overview

- Focus on BEOL device structures
Sentaurus Interconnect Simulation Flow

- Process Info
  - Deposition material=Oxide
  - Etch mask=Metal_2

- Layout Info GDSII
  - ICWB-EV Plus

- Material Property Database

Sentaurus Interconnect

Realistic 3D Structures with:
- Mechanical Stress Fields
- Electrostatic Potential
- Current Density
- Thermal hot-spots
- Mobility Variations
- Crack Propagation

- TSV Stress
- Crack
- Stress
- Current
- Temperature
BEOL Structure Meshing
Self Heating and Temperature Gradients

- Performing electrical and thermal simulation alongside stress simulation, using the same input file and structure setup helps evaluate reliability and performance trade-offs efficiently.

- Self-heating simulation allows 3D-IC engineers to estimate impact on transistor performance and validate chip-level models for thermal-aware placement.
Sentaurus Structure Editor

- Geometrical operations
- Easy to use GUI
- Scripting language
- Advanced geometrical modeling with analytic doping definitions
- Direct interface to meshing engines

**S-RCAD DRAM**

**CIS pixels with microlenses**

**TSV Structure**
ACIS Geometry Kernel

- Based on boundary representation.
- An ACIS boundary representation is a hierarchical decomposition of the topology of the model into lower-level topological objects.
- A typical body contains faces, edges, vertices, and may also includes lumps, shells, loops, and wires.

Tessellation controls
Scheme Language

- Strings
- Lists
- Arithmetic Expressions
- Boolean Operations
- Loops
- Logical Operations
- Procedures
- System Calls

- (sde:clear)
  - It is helpful to reset SDE
- (define “var_name” “Value”)
- (define VAR 0)
  - a constant
- (define VAR (+ 1 4))
  - an operation
- (define VAR (list 1 2 3 ‘a ‘b “f g”))
  - a list
2D -> 3D Structure Construction
Layout Based Device Design

- Loaded Layout
- Resist for STI
- Silicon etching
- STI formation (oxide filling) and Polysilicon / gate oxide generation
- Metal generation for contacts
- Final boundary structure
Process Emulation Mode

- Translates processing steps into geometric operations
- Works only in 3D
- Commands not accessible from GUI
- Support for:
  - Iso- & Aniso- Depo/Etch
  - Placement of analytical profiles w.r.t mask
  - GDS2 file loading
  - Masks definition and Patterning
Process Emulation - 3D CIS Structure

- A Sentaurus Structure Editor (SDE) script was done to generate “boundary” and “doping” files for Sentaurus Mesh (S-Mesh)
- GDS2 file is loaded into SDE and layers are built out of GDS2 layers

```scheme
(define GDSFILE "TCAD PIXEL_v3.gds")
(define CELLNAME "TCAD PIXEL_v3")
(define LAYERNAMES (list 'PWELL 'POLY 'ACT 'NO_PW 'NPLUS 'CONT 'PW_LVT 'MET1 'VIA1 'MET2 'VIA2 'MET3 'VIA3 'MET4 'ULENS 'PD1 'PD2 'SN1 'SN2 'SN3 ))
(define LAYERNUMBERS (list '1:0 '8:0 '9:0 '17:82 '32:0 '34:0 '35:0 '40:0 '41:0 '42:0 '43:0 '44:0 '49:0 '50:0 '89:0 '92:82 '93:0 '94:0 '94:43 '94:95 ))

(sdeicwb:gds2mac "gds.file" GDSFILE "cell" CELLNAME "layer.names" LAYERNAMES "layer.numbers" LAYERNUMBERS "sim3d" (list 0 -6000 6000 0) "scale" 1.0e-3 "domain.name" "SIM3D" "mac.file" "TCAD PIXEL")
```
Process Emulation - 3D CIS Structure

- Geometry is built step by step using deposition/etch/patterning features of SDE
- Scripting language (scheme) allows full customization, using variables, lists, strings and built-in ACIS functions.

```
(define TSUB 7.0)
(sdepe:add-substrate "material" "Silicon" "thickness" TSUB "region" "substrat")
(sdepe:pattern "mask" "ACT" "polarity" "light" "material" "Resist" "thickness" 1 "type" "aniso" "algorithm" "sweep")
(sdepe:etch-material "material" "Silicon" "depth" 0.420 "taper-angle" 5)
(entity:delete (find-material-id "Resist"))
(sdepe:fill-device "material" "Oxide" "height" (+ TSUB 0.008))
(sdepe:pattern "mask" "POLY" "polarity" "light" "material" "PolySilicon" "thickness" 0.3 "type" "aniso" "algorithm" "sweep")
```
Process Emulation - 3D CIS Structure

- SDE is based on ACIS (product from Spatial, Dassault-System) and allows complex solid modeling
- Micro-lens is part of a sphere inserted on top of the CIS
Process Emulation - 3D CIS Structure + doping

- Doping from analytical or SIMS profiles
- Doping from 1D/2D or 3D process simulation
- Meshing with Sentaurus Mesh
Advanced Tool Operations

2D geometry sweep with SDE / 2D doping sweep with SnMesh

2D submesh:

Definitions {

SubMesh "trench2D" {

Geofile = "trench2D.tdr"

}

}

Placements {

SubMesh "trench2D" {

Reference = "trench2D"

EvaluateWindow {

Element = SweepElement {

Base = Polygon [(0 20 3.3288) (8.2 20 3.3288) (8.2 20 -20) (0 20 -20)]

Path = [(8.2 20 3.3288) (8.2 22 3.3288) (8.21 22.1 3.3288) ... ]

}

}

Resulting 3D mesh/profile:
SnMesh - Quadtree/Octree Spatial Decomposition

(A) Quadtree algorithm - mesh step proportional to device size
(B) Quadtree algorithm - mesh step not proportional to device size
(C) Quadtree algorithm - non axis-aligned boundary
(D) Octree algorithm - mesh step proportional to device size
Unified (octree/quadtree + normal offsetting) Meshing Algorithm

Definitions {
  Refinement "R5" {
    MaxElementSize = ( 0.026 0.026 0.026 )
  }
}

Placements {
  Refinement "GDJ_RP" {
    Reference = "R5"
    RefineWindow = Cuboid [(-0.2 -0.2 0) (0.20 0.2 0.5)]
  }
}

Offsetting {
  noffset material "Silicon" "Oxide" {
    hlocal=0.002
  }
  noffset material "Oxide" "Silicon" {
    hlocal=0.002
  }
}
Doping Deatomization

Particle "BoronParticles" {
  ParticleFile = "kmc_final.tdr"
  Species = "BoronActiveConcentration"
  ScreeningFactor = 3.5e6
  AutoScreeningFactor
  Normalization
}

BoronActiveConcentration [cm^-3]
- 1.9E+19
- 5.1E+18
- 1.4E+18
- 3.7E+17
- 9.8E+16
- 2.6E+16
Sentaurus Device Simulator

- General purpose multidimensional (2D/3D) device simulator
- Silicon, SiGe, Ge, SiC, III-V compounds (including III-N materials)
- Drift-diffusion, Hydrodynamic, Thermodynamic, and Monte Carlo transport
- Wide range of advanced physical models
  - Stress-dependent mobility enhancement
  - Quantization and random doping effects
  - Circuit mixed-mode, small-signal AC, Harmonic Balance
  - Variability Analysis
Sentaurus Device for CMOS

- Carrier quantization in the channel
- Hydrodynamic transport
- Noise analysis
- High-k dielectrics
- Mechanical stress and strain effects
- Stochastic geometry and doping variability
- Remote Coulomb scattering
- Advanced surface mobility modeling
- Non-local band-to-band and impact ionization
- Gate leakage
- Energy dependent energy relaxation time
- Degradation kinetics
- IFM based variability analysis

50nm NMOS

IdVg

Line Edge Roughness Variability

Calibration to SIMS, Roll-off and Ion
Sentaurus Device for Memory

- Carrier quantization in the channel
- Spherical Harmonic Expansion
- Non-local tunneling
- Hot Carrier Injection
- 3D capacitive effects
- Multi State Configuration including the state dependent physical models and parameters
- Cycling analysis
- Mixed-mode simulations
- Advanced surface mobility modeling
- Non-local band-to-band, TAT, and impact ionization
- Interface trap degradation
Sentaurus Device for Power

- Thermodynamic carrier transport
- 3D geometry effects
- Mixed-mode simulations including the circuit protective elements, represented by compact models
- Heat dependent kinetic model parameters
- Non-local gate tunneling
- Trapping dynamic
- Composition dependent model parameters
- Heterointerface carrier transport
- Carrier thermionic emission
- Carrier quantization in the channel
- Piezo and spontaneous polarization
- Doping Incomplete Ionization
- Material anisotropy
Sentaurus Device for RF

- Hydrodynamic transport
- Small-signal AC analysis
- Harmonic balance analysis
- Carrier quantization
- Bulk and interface traps
- Mechanical stress and strain effects
- Energy dependent energy relaxation time
- Anisotropy effects
- Composition dependent model parameters
- Non-local barrier tunneling
- Stress dependent models
- Polarization fields
Sentaurus Device for Optics

- Drift-diffusion carrier transport
- Advanced optical solvers:
  - Transfer Matrix Method
  - Beam Propagation Method
  - Raytracing
  - FDTD Maxwell solver
- 3D geometry effects
- Mixed-mode simulations including the circuit periphery elements
- Carrier trapping
- Composition dependent model parameters
- Heterointerface carrier transport
- Advanced models for photon and free carrier absorption
- Organic semiconductors
Sentaurus Visual - New TCAD Visualization Platform

- Visualization product for 1D, 2D and 3D plots and structures generated by all TCAD tools
Sentaurus Visual - Enhanced GUI

- Better utilization of GUI real estate
Sentaurus Visual - Tcl Scripting Interface

- Powerful TCL Interface
- Consistent with Scripting Capabilities in other Sentaurus TCAD tools

**Active TCL Command Window**

**TCL Script For Corresponding GUI Action**

**Saving TCL Script to File**
Sentaurus TCAD
Radiation Analysis
Radiation Environment

• Single Event
  – Due to single ionizing particle (alpha particle, heavy ion or neutron), generation of electron-hole pairs in semiconductors
  – Leading to Soft-Error as Single Event Upset (SEU)
  – Leading to Hard-Error as Single Event Gate Rupture (SEGR), Latch-Up (SELU) or Breakdown (SEB)

• Total Dose
  – Due to long radiation exposure (nuclear power, aerospace), resulting in trapped carriers in insulators
  – Leading to performance degradation (increased leakage current, threshold voltage shift)
Sentaurus Device Models: Particle Interaction

• Alpha Particles
  – Analytical description of the carriers generation depending on the incident particle energy
  – 3D cylindrical distribution

• Heavy Ion
  – Analytical description of the carriers generation depending on the incident ion
  – Spatially defined charge description through LET
  – 3D cylindrical distribution
2D vs 3D Description of Charge Track

2D Extrusion: Unphysical Track

Full 3D: Realistic Track
Sentaurus Device Heavy Ion Model

Electron-hole generation rate:

\[
G(l, w, t) = T(t) \times R(w, l) \times G_{LET}(l)
\]

\[
T(t) = \frac{2 \cdot \exp \left( -\left( \frac{t - \text{time}}{s_{hi}} \right)^2 \right)}{s_{hi} \sqrt{\pi} \left( 1 - \text{erf} \left( \frac{\text{time}}{s_{hi}} \right) \right)}
\]

\[
R(w, l) = \begin{cases} 
  e^{\frac{w}{w_j(l)}} & \text{if } \frac{w}{w_j(l)} \leq 0 \\
  e^{-\frac{w}{w_j(l)}} & \text{otherwise}
\end{cases}
\]

\[
G_{LET}(l) = a_1 + a_2 \times l + a_3 e^{a_4 \times l} + k' \left[ c_1 \times (c_2 + c_3 \times l)^{c_4} + \text{LET} - f(l) \right]
\]
Simulation of Charge Track

Physics { Recombination ( SRH(DopingDep) )
    HeavyIon {
        Direction = (0,0,1)
        Location = (0.5,0,0.7)
        Time = 1.0e-13
        Length = [1e-4 1.5e-4 1.6e-4 1.7e-4]
        LET f = [1e6 2e6 3e6 4e6]
        wt_hi = [0.3e-4 0.2e-4 0.25e-4 0.1e-4]
        Exponential }
}
Models for Total Dose Radiation

- Electric-Field Dependent Yield Function
- Self-Consistent Trapping Kinetics in Oxide:
  - Standard V-model based on carrier concentration
  - Proprietary J-model based on carrier current
- Spatial Distribution of Traps
  - Region or interface-wise
  - User defined profile
- Arbitrary Energy Spectra of Traps
- Electric-Field Dependent Cross Section
- Thermal Ionization of Traps
Mixed-Mode Simulation

- Sentaurus Device is a device and circuit simulator
- Allows numerical devices to be embedded in SPICE netlist
Mixed-Mode Compact Models

• Standard SPICE Models
  – BJT
  – Berkeley SPICE 3 Version 3F5 models
  – BSIM1, BSIM2, BSIM3, BSIM4
  – B3SOI
  – MESFET

• User-Defined
  – Compact model interface (CMI) available for user-defined models.
  – Implemented in C++ and linked to executable at run-time
Sentaurus Advantages for Rad-Hard

- 1D / 2D / True 3D
- DC, AC, Transient
- Most Advanced Transport Models in Semiconductors and Insulators
- Mixed-Mode: Numerical and SPICE Models
- Robust Numerical Algorithms
- Parallel Solvers
- Dynamic Memory Allocation
- Physical Model Interface
2D Application Examples
Total Dose Effect: SOI nMOSFET

SOI nMOS transistor structure

Drain current vs. irradiation time

The leakage current increases with the dose and drain bias showing electric field dependence
Total Dose Effect: SOI nMOSFET

Electron Current Density in SOI Device after Irradiation

Expected back-channel in irradiated SOI nMOS devices is observed
Total Dose Effect: SOI nMOSFET

Trapped Hole Distribution in Irradiated Device

Because of self-consistent and field-dependent trapping kinetics, trapped hole distribution strongly depends on electric field.
Total Dose Effect: SOI nMOSFET

Transient Evolution of Trapped Hole Density after Irradiation

Sentaurus Device enables the modeling of de-trapping, depending on the energetic distribution of traps
3D Application Examples
Structure Generation

Loaded Layout
Resist for STI
Silicon etching

STI formation (oxide filling) and Polysilicon / gate oxide generation
Metal generation for contacts
Final boundary structure
Doping Definition

- Constant doping profile in Polysilicon and Pwell
- Analytical doping profile (Gaussian) in the Source/Drain of NMOS and PMOS Transistors
- Analytical doping profile (Gaussian) in the channel of NMOS and PMOS Transistors
- Analytical doping profile (Gaussian) in the access drain (bit line) and access gate (word line).
Meshing

• Meshing strategy:
  • Refinement on doping (junctions refinement)
  • Refinement at Silicon / Gate Oxide interface
  • Refinement in the channel of NMOS and PMOS Transistors.
  • Relaxed mesh inside the substrate

• Mesh statistics:
  • Mesh nodes number: 31825
  • Meshing time: 114 s
Bit Flipping

- At $t=1e^{-13}s$, $V_{ds(nmos2)}=1.5V$ and $V_{ds(nmos1)}=0V$.
- The peak of the Gaussian Distribution of Heavy ion is at $1e^{-11}s$.
- At $t=1e^{-8}s$, $V_{ds(nmos1)}=1.5V$ and $V_{ds(nmos2)}=0V$.
- The SRAM cell switched states.
Generation Rate from Particle Strike
Dependence on Impact Points

• The heavy ion direction is set to (0, 0, -1).

• Four different heavy ions impact points are simulated:
  • Source NMOS2
  • Source PMOS2
  • Drain PMOS2
  • Oxide

• The SRAM cell does not switches states anymore for impact points in Source & Drain PMOS2 and in the oxide.

Node voltages versus time for NMOS drains as a result of a single event strike. Depending on the impact point, the SRAM cell switched states.
Total Dose Effect: 3D SOI nMOSFET

Trapped Hole and Electron Current Distributions in 3D SOI nMOS after 300kRad Irradiation

Expected trapped hole profile in the buried oxide and induced back-channel are observed in 3D
Total Dose Effect: 3D nMOS w/ LOCOS

Noffset meshing of 3D MOS with LOCOS

Trapped hole density after 10kRad irradiation

Noffset3D, normal offsetting mesh, creates fine grid along the interfaces where traps are located
Total Dose Effect: 3D Trench MOSFET

Threshold Voltage Shift

Geometry and Doping

Drain Current vs. Gate Voltage

- Red: Dose = 939 krad
- Blue: Dose = 0
CMOS SOI

SEU: SOI SRAM Cell Upset

3D charge deposition profile

Voltage response for different ion energies

SEU can be accurately modeled using a mixed-mode approach including part of the system as SPICE elements
As expected, the three dimensional SRAM flips depending on the incident particle energy, the ion strikes into the drain of the off-nMOS.
Because of parasitic bipolar effects in CMOS structure, the device latches up when incident particle energy is high enough.
Thank You