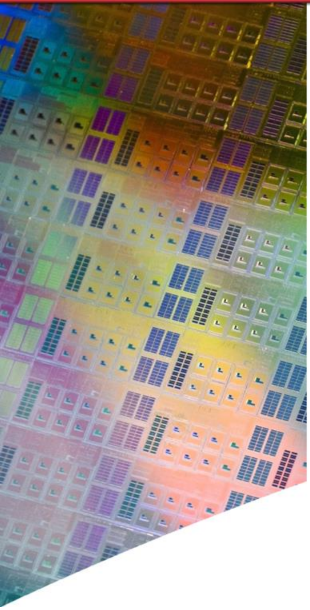
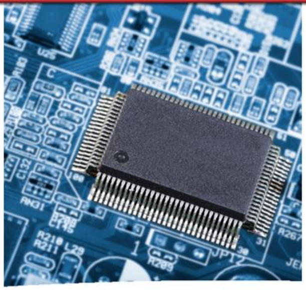
Silvaco TCAD for Radiation Simulation





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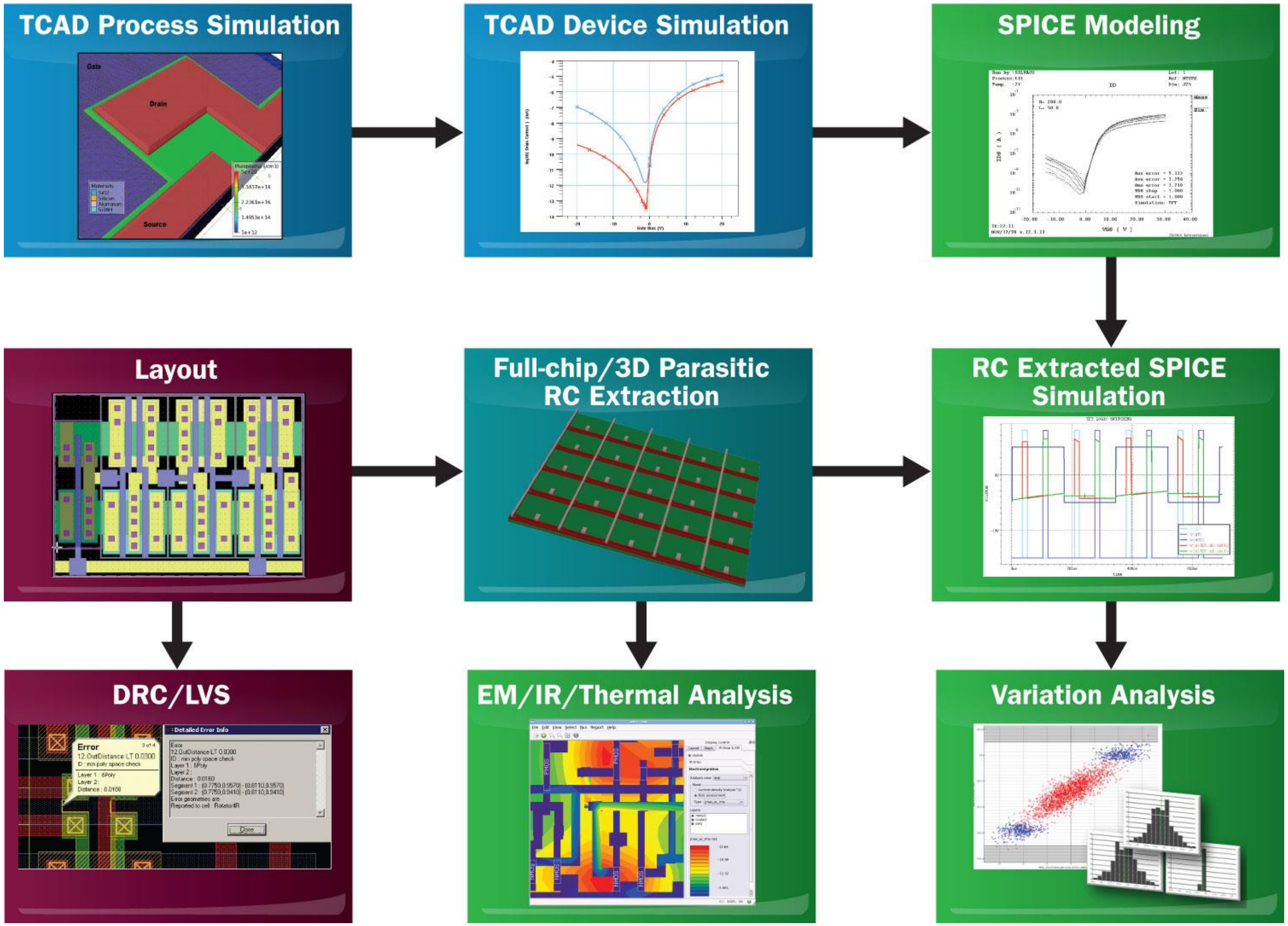
Silvaco - Introduction

- Founded in 1984.
- Market leader in TCAD, Spice simulation & IC CAD.
- Large customer base of Foundry, IDM, ASIC and Fabless semiconductor Companies.
- Debt free, privately held. No VC funding.
- Fifteen locations worldwide.
- Silvaco Europe is a major R&D centre for TCAD and EDA modelling.

Silvaco – Software flow



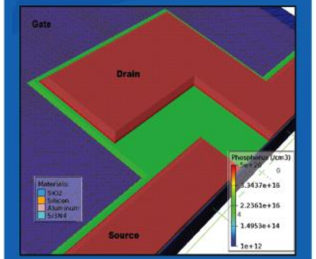
Topics

- Why use physical TCAD simulations
- Available resources for Silvaco software users
- Silvaco TCAD overview
- ATHENA
- ATLAS
- VICTORY
- Interactive tools
- C-Functions
- Conclusions

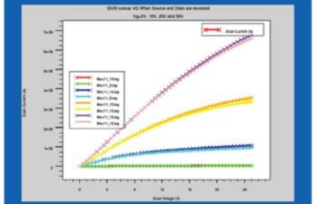
Design for various technology sectors

Display

TFT, LCD,
LED, OLED



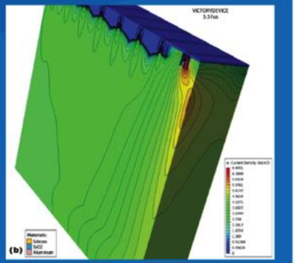
3D A-Si:H TFT



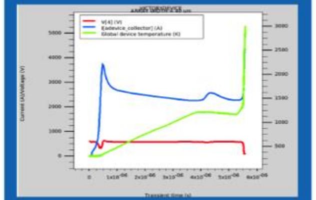
IdVd simulation with reverse source and drain

Power

BCD, SJ-IGBT, SiC,
GaN, ESD



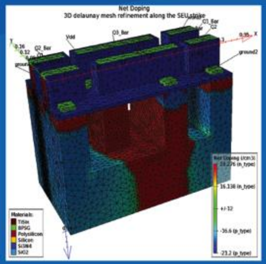
3D IGBT with rounded edge trench



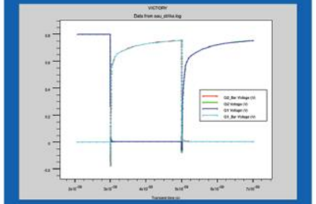
Electron current density distribution at device failure point t = 5.57 µs.

Reliability

SEB, SEGR, SEU,
HCI, NBTI



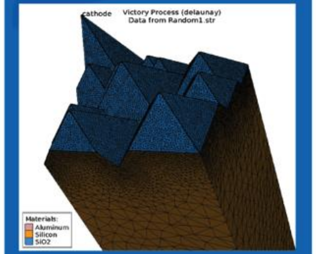
SRAM 22 nm



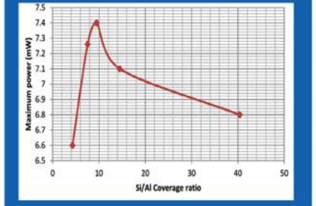
6T SRAM cell hit with an SEU causing switching of the memory

Optical

CCD, CIS, Laser,
Solar Cell, Photodiode



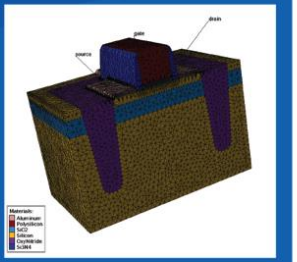
3D CMOS image sensor



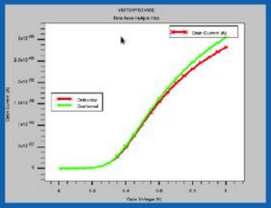
Showing the relationship between the maximum output power and the metal coverage ration R.

Advanced Process Development

FinFET, FDSOI, 3D Flash,
STTRAM, TFET



3D FinFet



Vth simulation comparing a conformal and a Delaunay mesh

Physical design plays a cruicial role in a variety of technology sectors.

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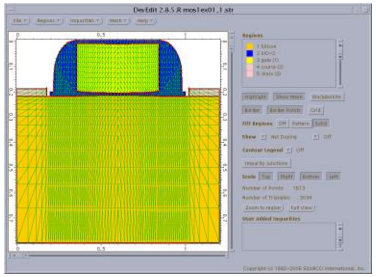
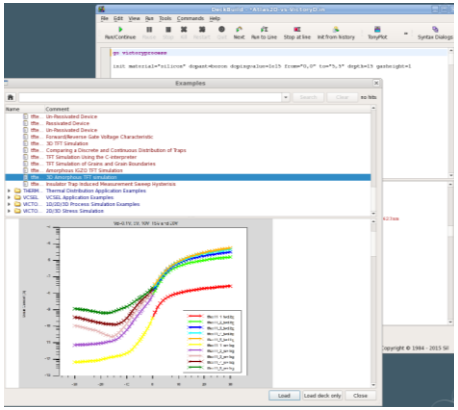
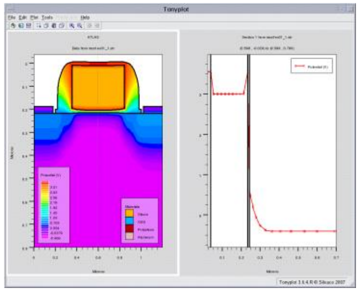
Why use physics based modelling?



Define structure



Define models



Obtain data

- Three main reasons to opt for physical simulations:
  - Predictive.
  - Provides insight.
  - Captures and visualizes theoretical knowledge.
- Unlike empirical models, physically-based simulation provide insight, and encapsulates fundamental phenomena.
- Complements experimental investigation.
- Provides information that is difficult or impossible to measure.
- **Challenge:** requires in-depth knowledge of device physics..

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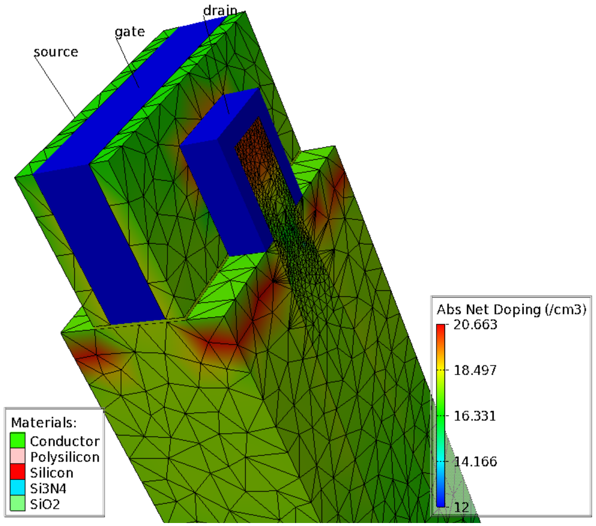
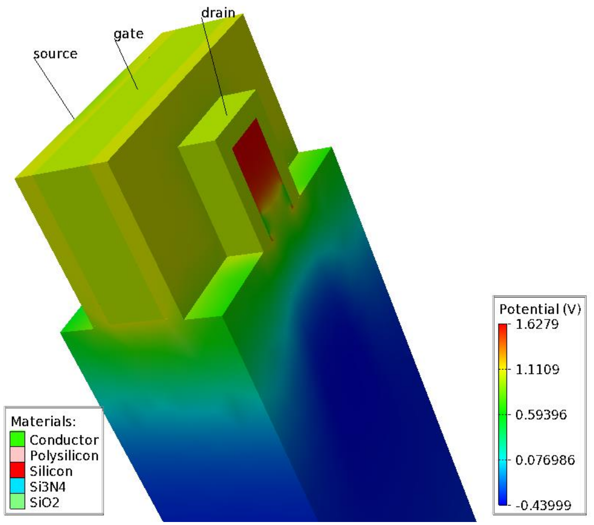
Available utilities

- Advanced interactive GUI tools.
- Design space exploration (DOE & Optimisers) tools.
- Worked standard examples with results. Available on the Silvaco web site and through deckbuild.
- Simulation Standard articles with archive extending back to 1992.
- Webinars. Recorded archives available.
- Presentation materials.
- Extensive manuals and release notes.
- Active support, training & seminars.
- Partner in many EU collaborative projects.





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Silvaco TCAD Overview

Athena 2D Process

Atlas 2D / 3D Device

DevEdit 2D / 3D Editor

Victory Process Mode
Full 3D (inc stress dependent oxidation)

Victory Cell Mode
Full 3D (optimised for large area)

Victory Device

Interactive Utility Tools

DeckBuild
Deck Editor
*new release

TonyPlot 2D/3D
View structure and analyse results

VWF
Design Of Experiments

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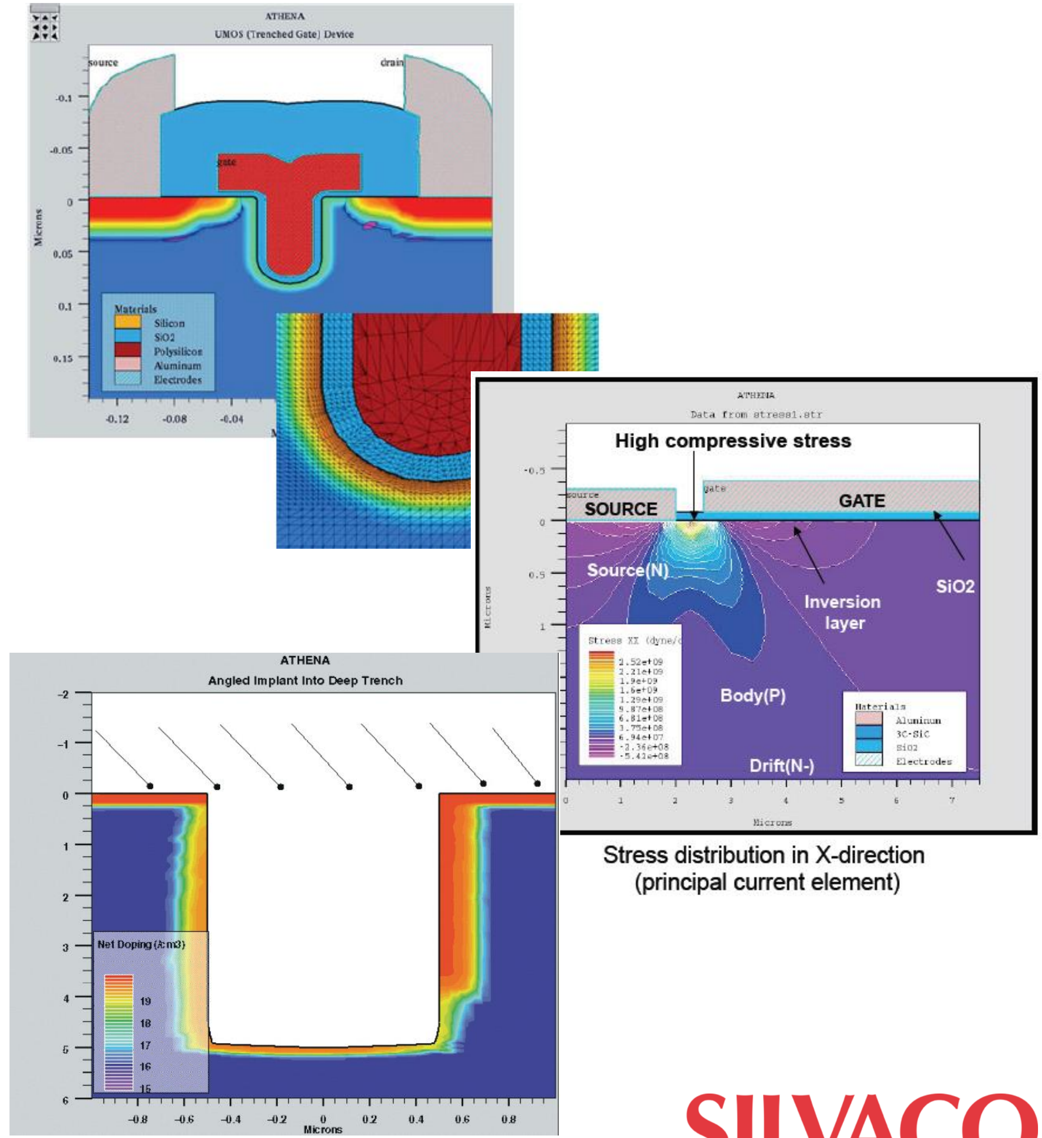
Athena: 2D Process Simulator

- Simulation of all critical fabrication steps
- Prediction of multi-layer topology, dopant distributions, and stresses
- Import mask files
- Automatic and user-defined mesh generation and control
- Run-time extraction of process and device parameters
- Optimization of process flow and calibration of model parameters



Stress distribution in X-direction (principal current element)

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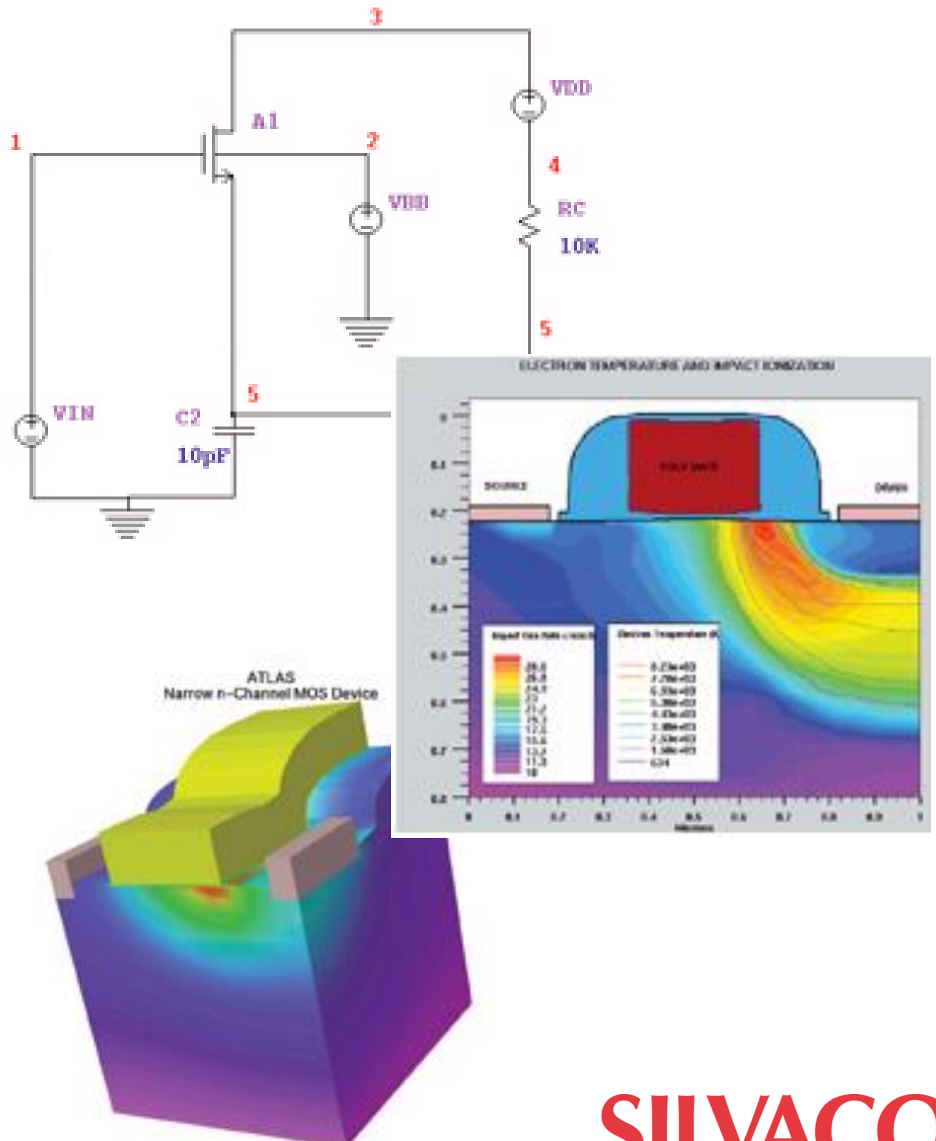
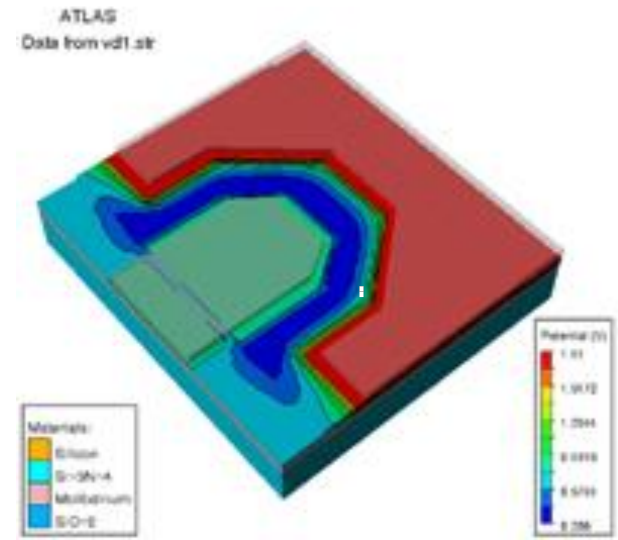
Atlas: 2D/3D Device Simulator

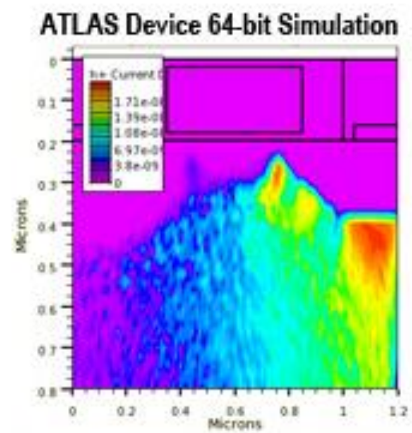
- Modular, and extendible platform
- Analyze DC, AC, and time domain responses for all semiconductor based technologies in 2D/3D
- Parallel processing supported on multi-core machines
- Fully integrated with Athena & DevEdit
- MixedMode: circuit and device simulation using SPICE netlists and SmartSpice models

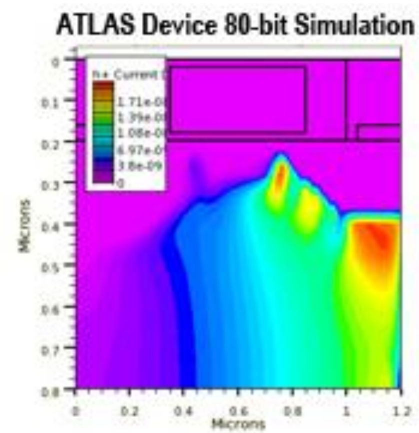


Atlas: Advanced Solutions

- Incorporate effects of self-heating in 2D/3D device simulation, DC, AC, transient analysis
- Extended precision
  (80, 128, 160 & 256 bit)
- Curvetrace algorithm
- Traps, interface traps, and defects
- Comprehensive library of binary, ternary, quaternary and organic semiconductors
- User defined models with
  C-Interpreter

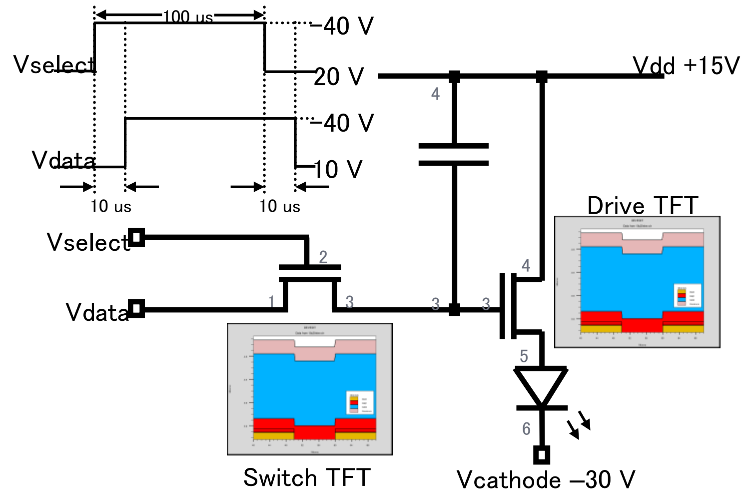


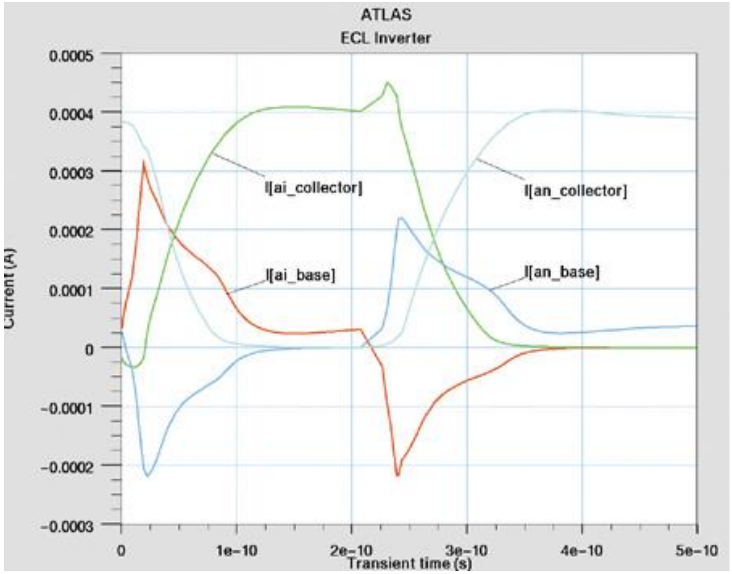




Atlas: MixedMode / Circuit Simulation

- Simulate physics-based devices in combination with compact analytical models in a circuit environment
- Any combination of Atlas 2D/3D modules
- Devices simulated with a SPICE netlist circuit description
- Wide range of SPICE models available
- Unlimited number of physical devices or compact model elements with MixedModeXL





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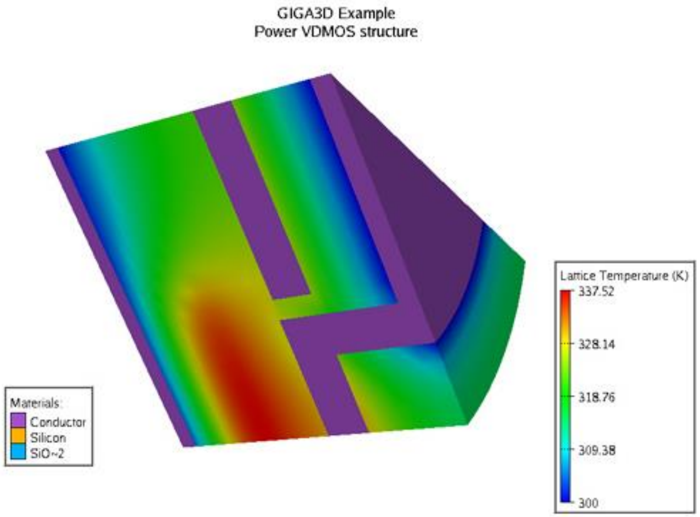
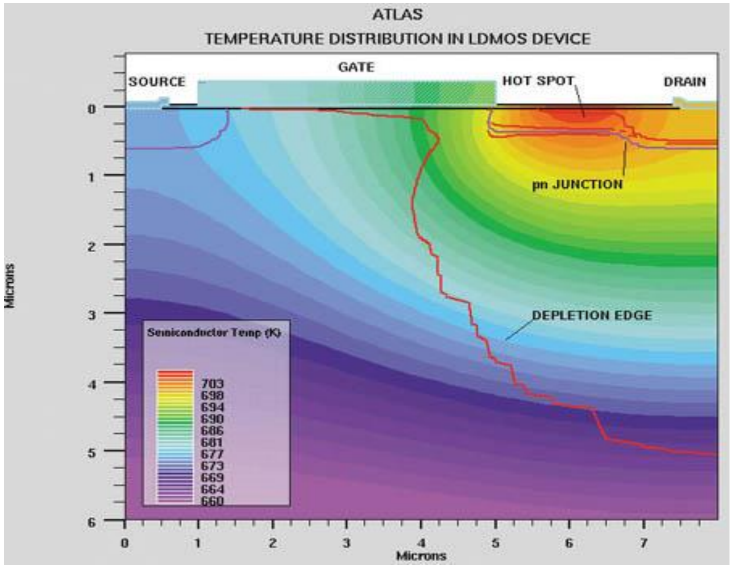
Atlas: GIGA – Electro-Thermal

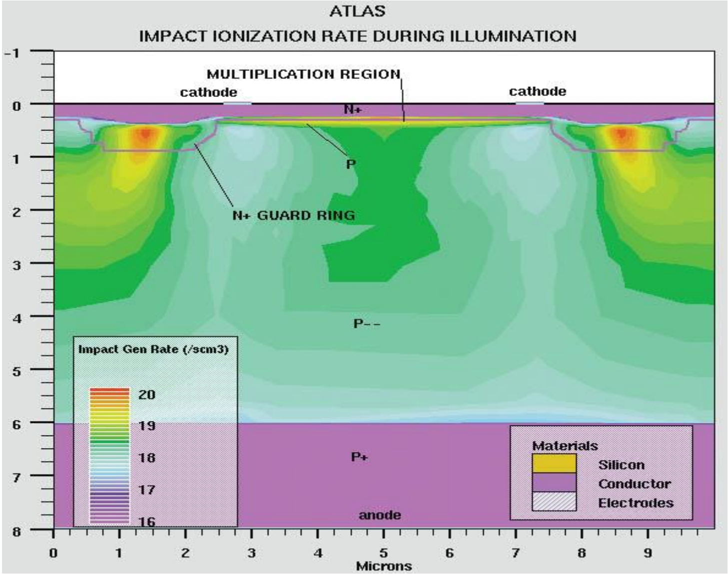
- Wachutka's thermodynamically rigorous model for Joule heating, Generation and Recombination and Peltier-Thomson effects
- Dependence of material and transport parameters on lattice temperature
- Specify heat-sinks, thermal impedances, and ambient temperatures.
- Compatible with both the drift-diffusion and energy balance transport models

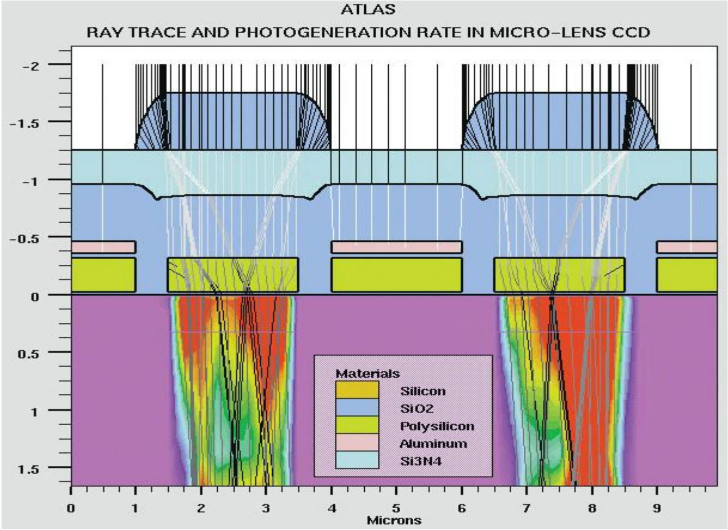




Atlas: Luminous – Optoelectronic Module

- Model light absorption and photogeneration in devices
- Arbitrary topologies, internal and external reflections and refractions, polarization dependencies and dispersion
- Mono-chromatic or multi-spectral optical sources
- DC, AC, and transient response in the presence of arbitrary optical sources

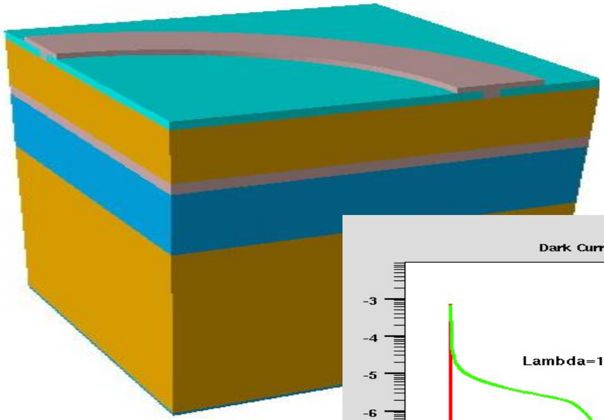


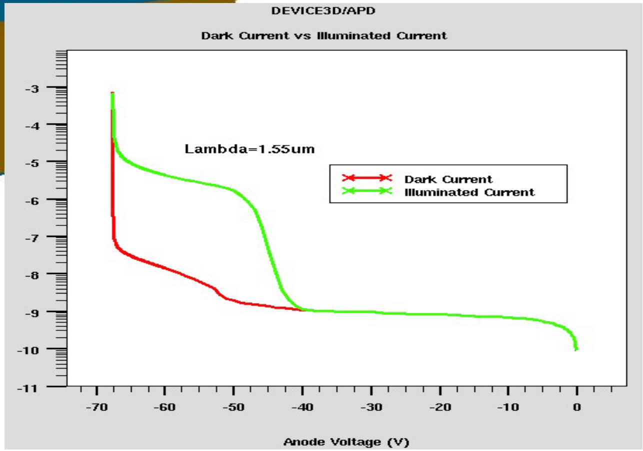


Atlas: Luminous – Optoelectronic Module

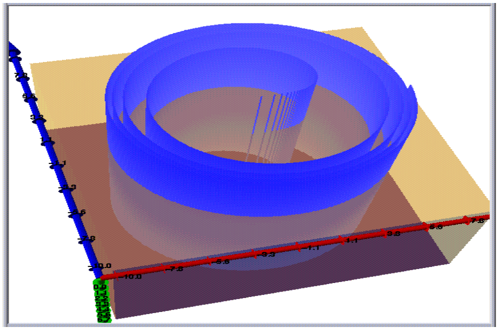
Light propagation algorithm options:

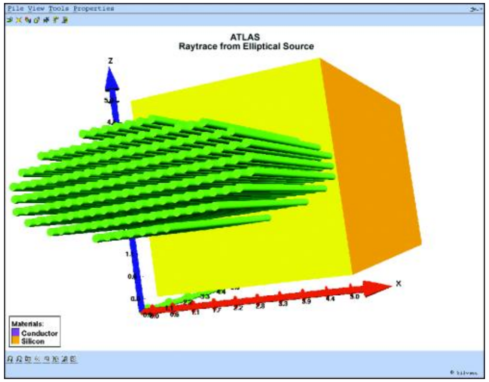
- Ray Tracing Method (RTM)
- Transfer Matrix Method (TMM)
- Beam Propagation Method (BPM)
- Finite Difference Time Domain (FDTD)





- Uniform and Gaussian illumination
- Circular and elliptical optical source
- User defined optical source





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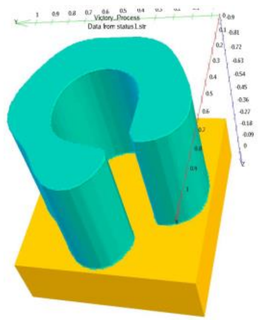
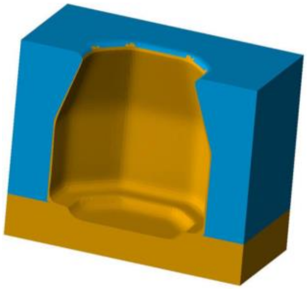
The Victory Suite

Victory: Process Mode

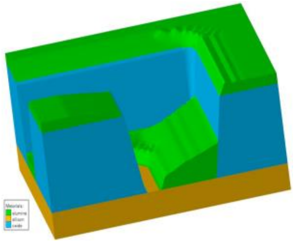
- Multi-particle and flux models for physical deposition and etching with substrate material re-deposition
- Open Modelling Interface – import your own models
- Monte Carlo implant simulation
- 3D oxidation (including stress)



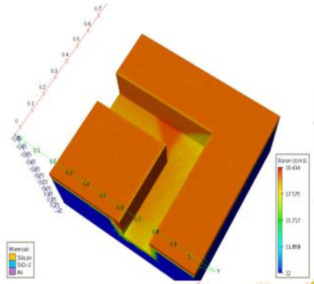
3D Geometrical Etching

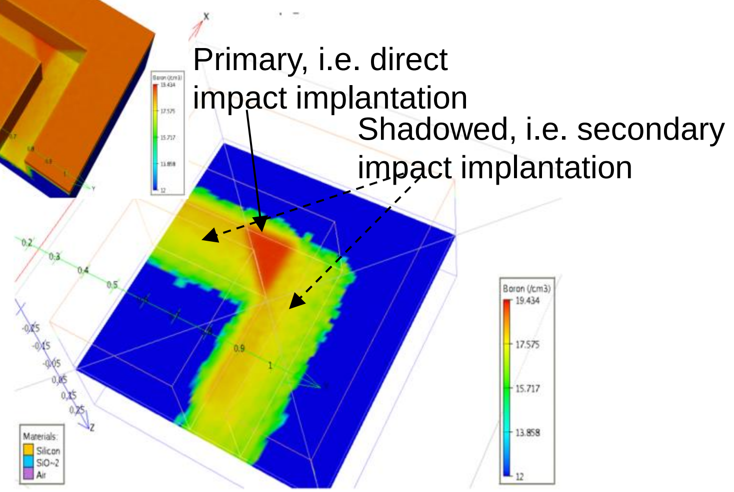


Physical Ion Milling Etching



Ion beam deposition with tilted beam

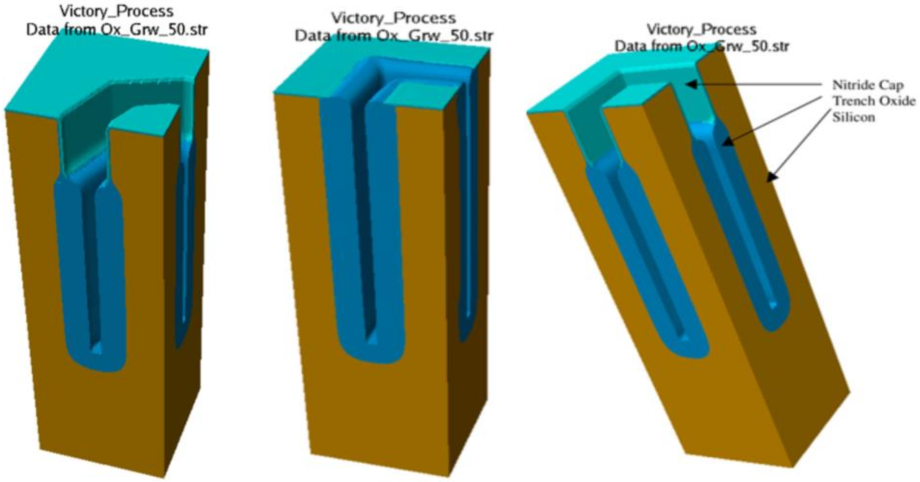




Monte Carlo trench implantation angled at 50^{O} with twist along structure's diagonal

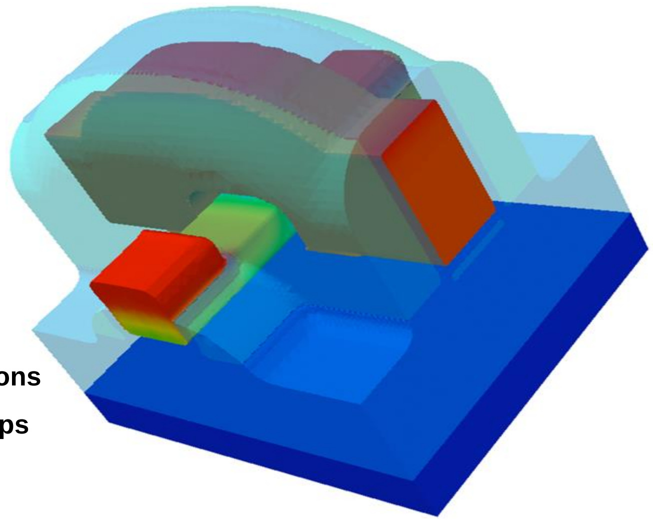
Victory: Process Mode

- Automatic meshing and Adaptive Mesh Refinement
- Multi-threading
- Mirroring
- Adaptive doping refinement
- Comprehensive set of 3D diffusion models: Fermi, three-stream, five-stream



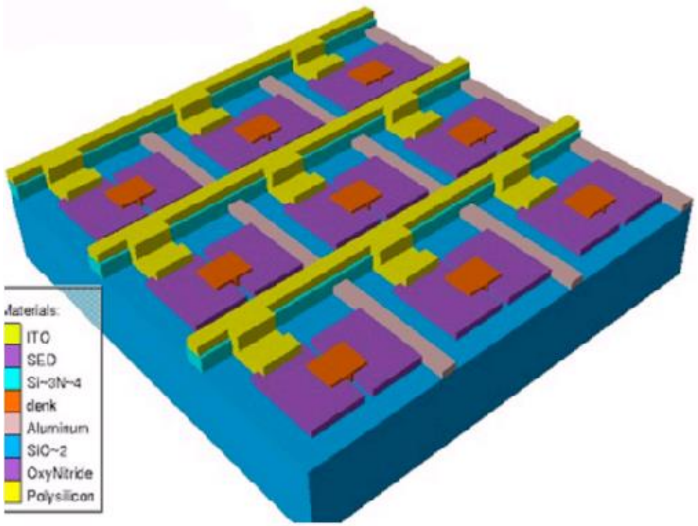
28nm FINFET

- **20 etch/depo steps**
- **3 Monte Carlo ion implantations**
- **4 oxidation and diffusion steps**
- **~800,000 mesh points**
- **< 2 hours on 8 CPU's**

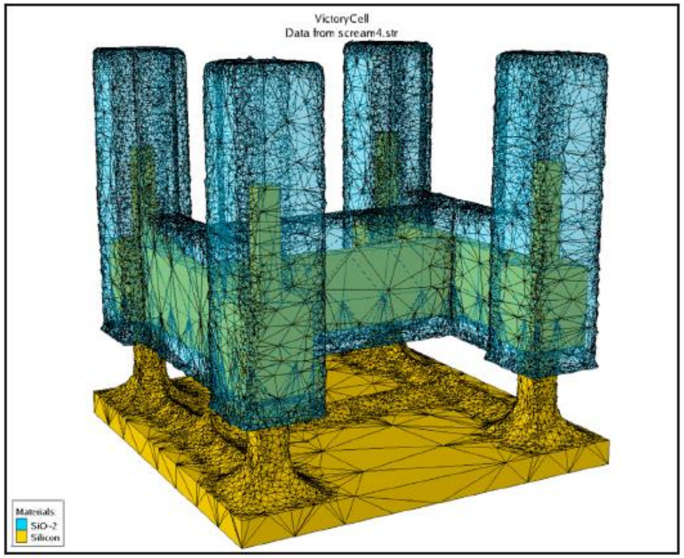


Victory: Cell Mode

- Fast, layout-driven 3D process simulator specifically designed for large structures
- Layout-driven mesh generation
- User-controlled mesh placement
- Easy to learn and user-friendly SUPREM-like syntax



Flat panel LCD and TFT circuits.



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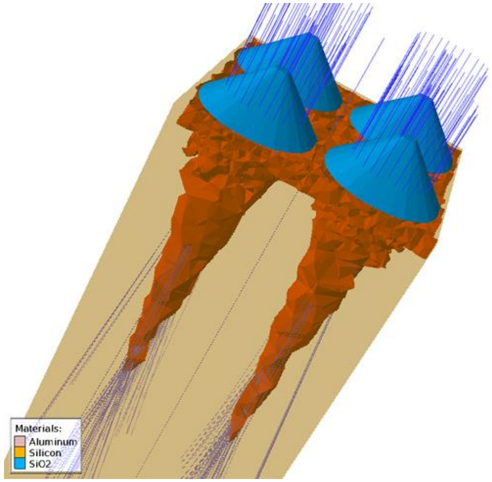
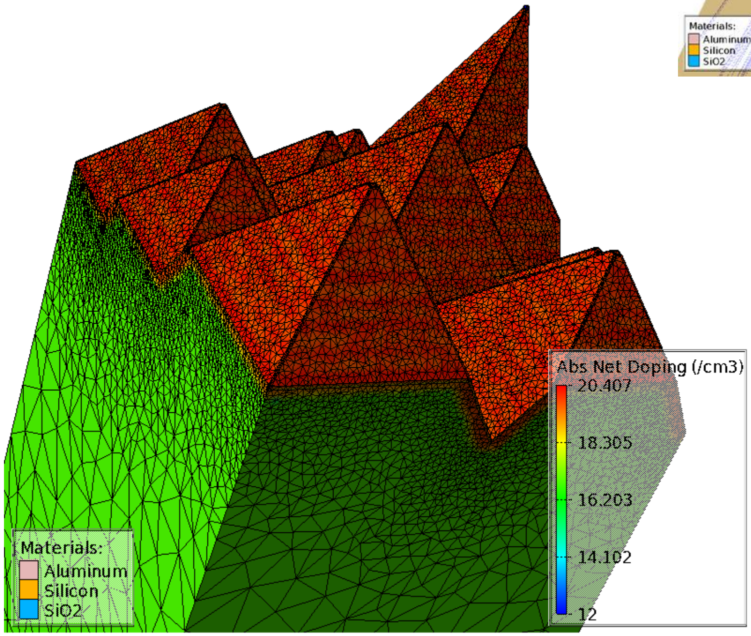
Victory: Cell Mode

- Mask Layout-based Processing
- In-deck mask definition and manipulation
- Multi-threaded
- Unstructured mesh





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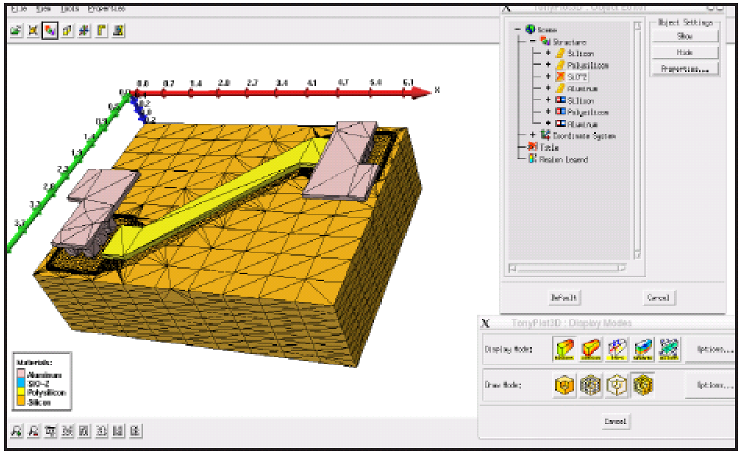
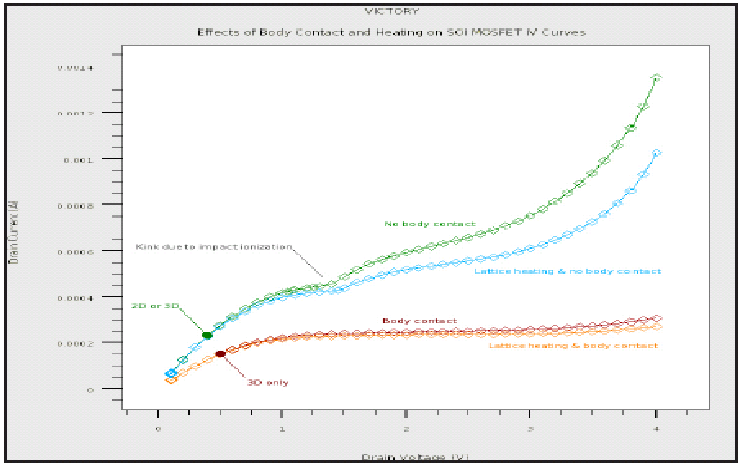
Victory: Device Simulator

- Tetrahedral meshing for fast and accurate simulation of complex 3D geometries
- DC, AC and transient analysis for silicon, binary, ternary, quaternary and organic material devices
- Customizable material database
- Stress-dependent mobility and bandgap models



Diagonal MOSFET structure with the oxide layer removed to show the polysilicon and metalization layers.



IdVd 3D SOI NMOSFET simulation with body contact showing the kink suppression effect.

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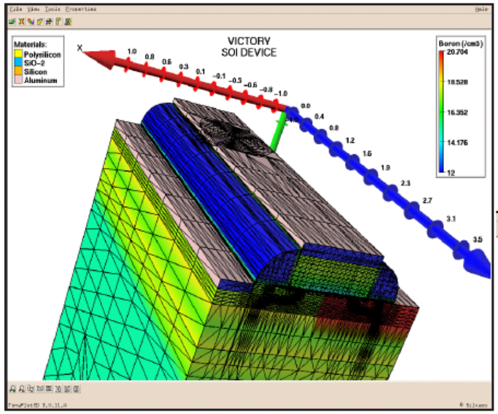
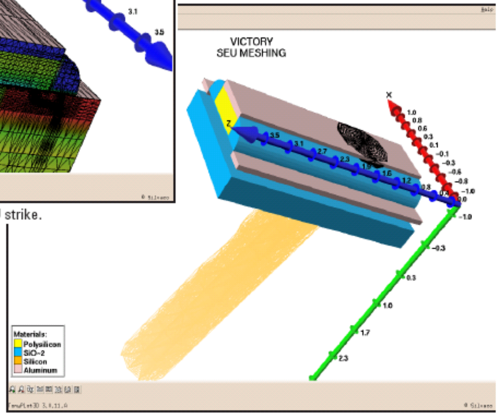
Victory: Device Simulator

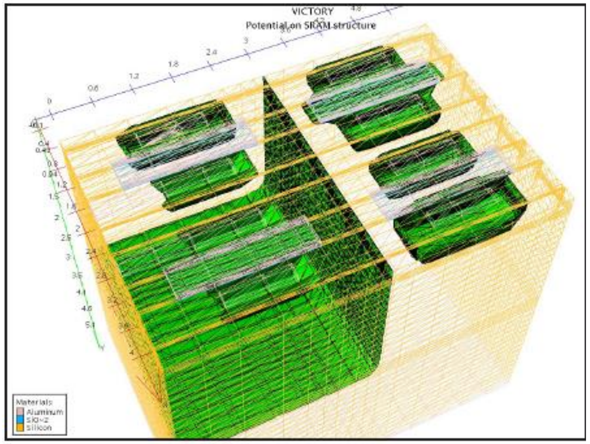
- Customisable physical models
- Drift-diffusion and energy balance transport equations
- Self-consistent simulation of self-heating effects including heat generation, heat flow, lattice heating, heat sinks and temperature dependent material parameters
- Multi-threaded
- Atlas-compatible



SOI device showing cylindrical meshing for the SEU strike.



The SEU strike volume was refined with a circular mesh in order to accurately capture charge generation along the length of the track. This has all been achieved without dramatically increasing the number of mesh points.



Electrostatic potential isocontour for the SRAM cell.

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Interactive Utility Tools

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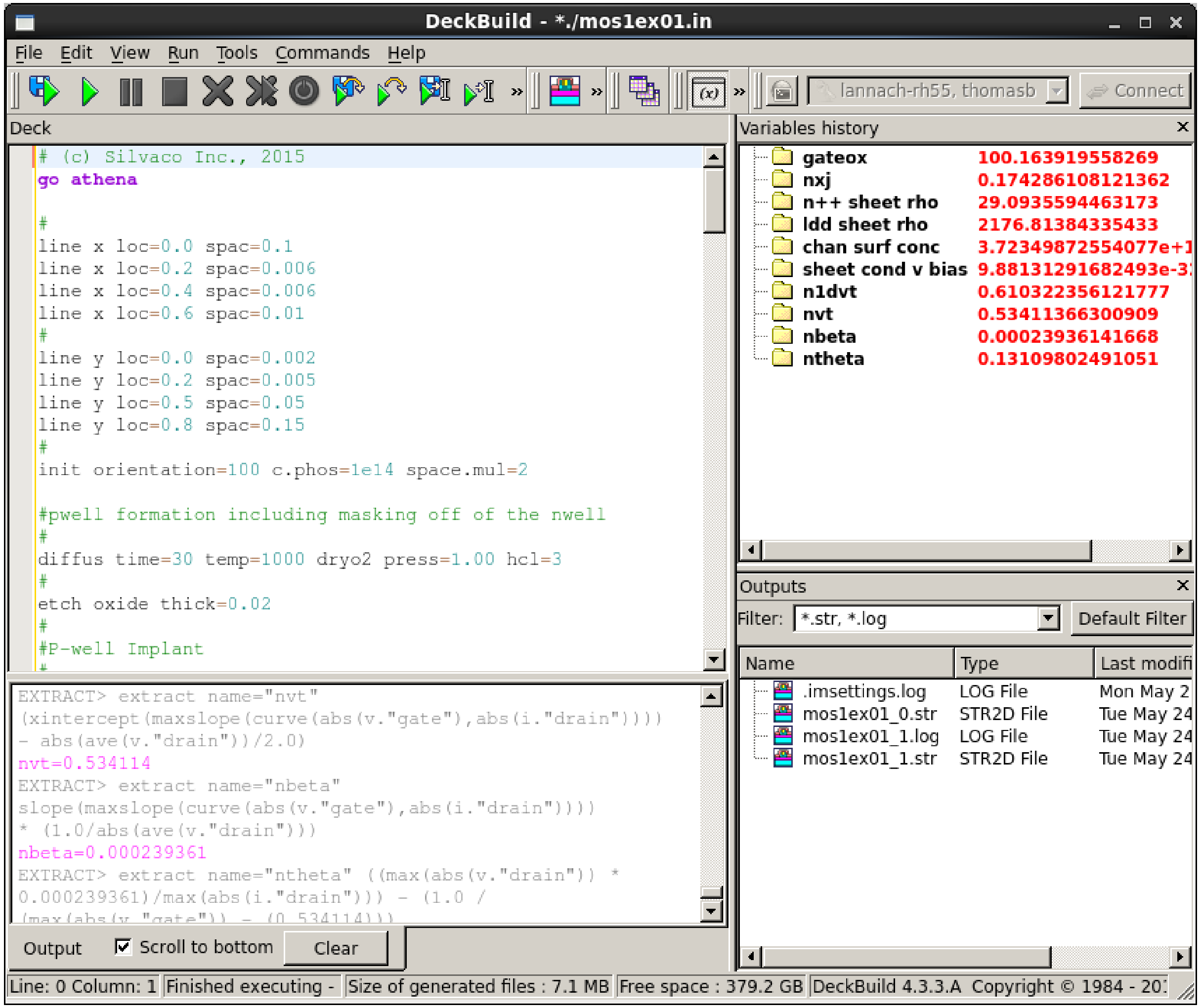
GUI for programme debugging & execution

- Fully documented and searchable examples database
- Quick launch of interactive tools: through toolbars or right clicking on file names
- Remote execution of simulations; utilize local graphics hardware for visualization
- Contextual highlighting of deck and run-time output syntax
- Separate Outputs and Variables panels to track variables and files
- Common look & feel in both Windows and Linux operating systems



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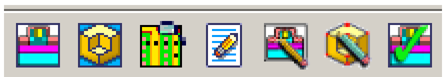
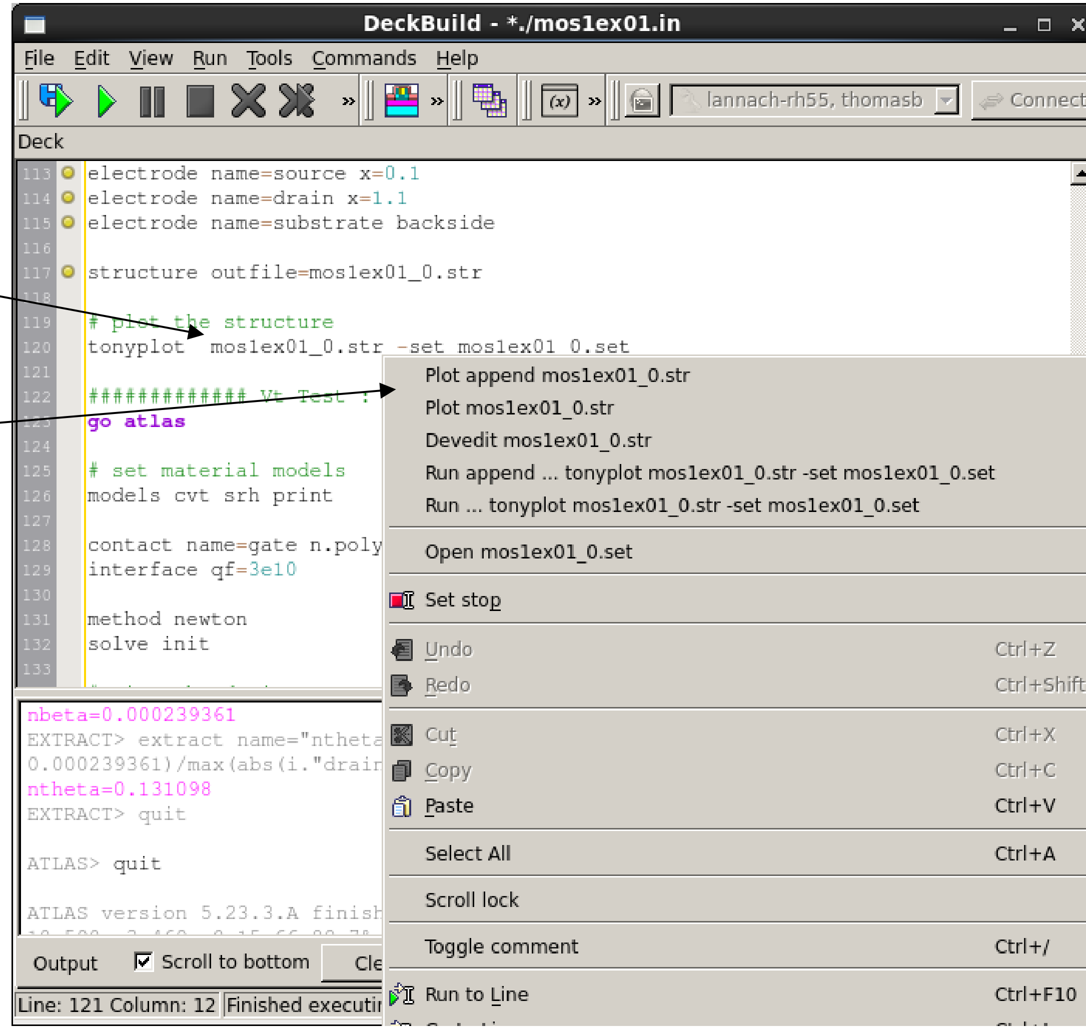
GUI for programme debugging & execution

- Quick launch of interactive tools through toolbars

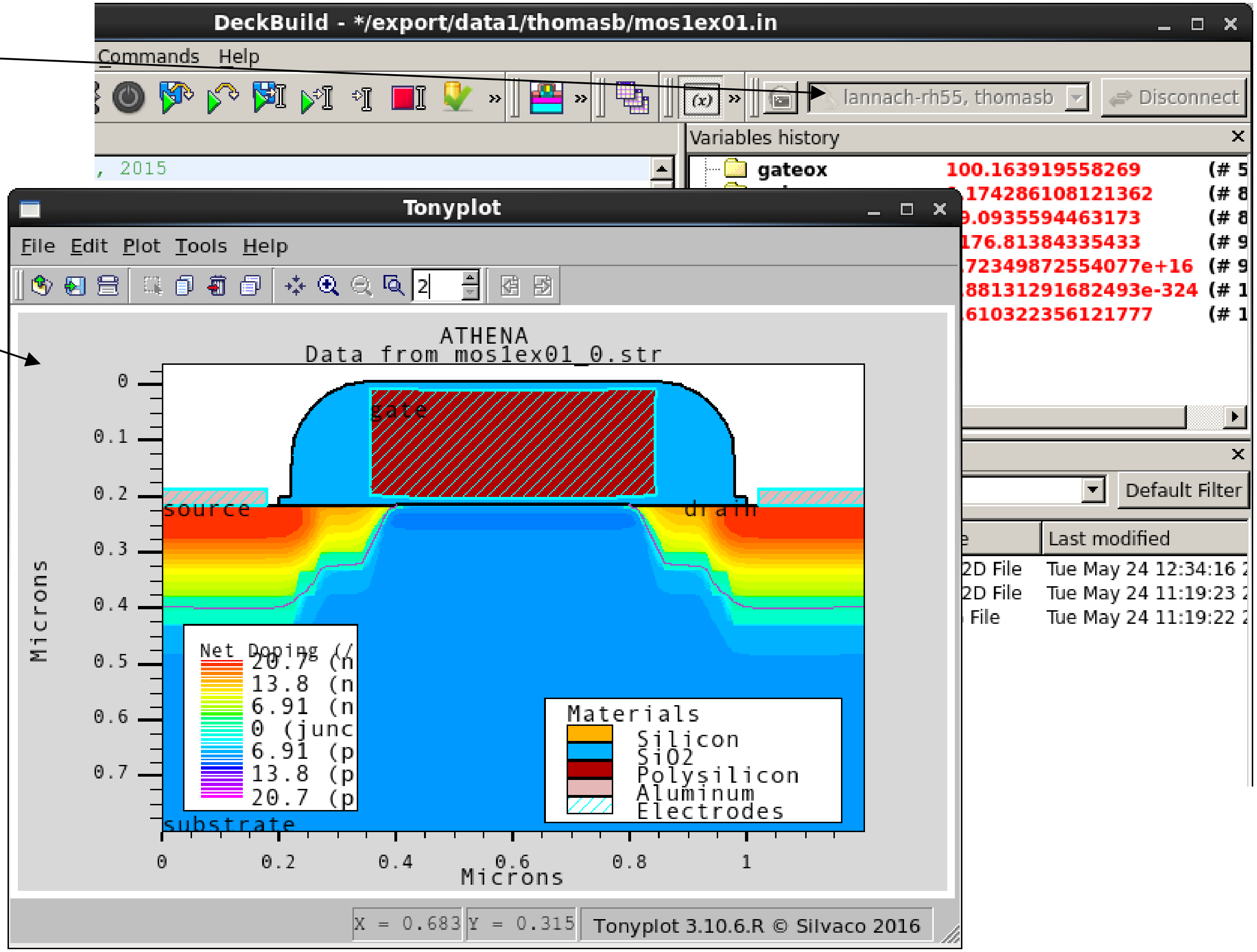


- Right click on a deck line to open file in plotting tool
- Offer options to append a plot to a previously started tool or start a new instance of the tool
- Extension sensitive:
  - .str(2D)/.log in Tonyplot2D
  - .str(3D) in Tonyplot3D
  - .lay in MaskViews
  - .de in DevEdit or Sedit
  - .dat/.txt launch in Sedit or plot in TP2D



GUI for seamless software execution & visualisation

- simulator runs on remote machine
- Any visualization is run locally to utilize graphics hardware



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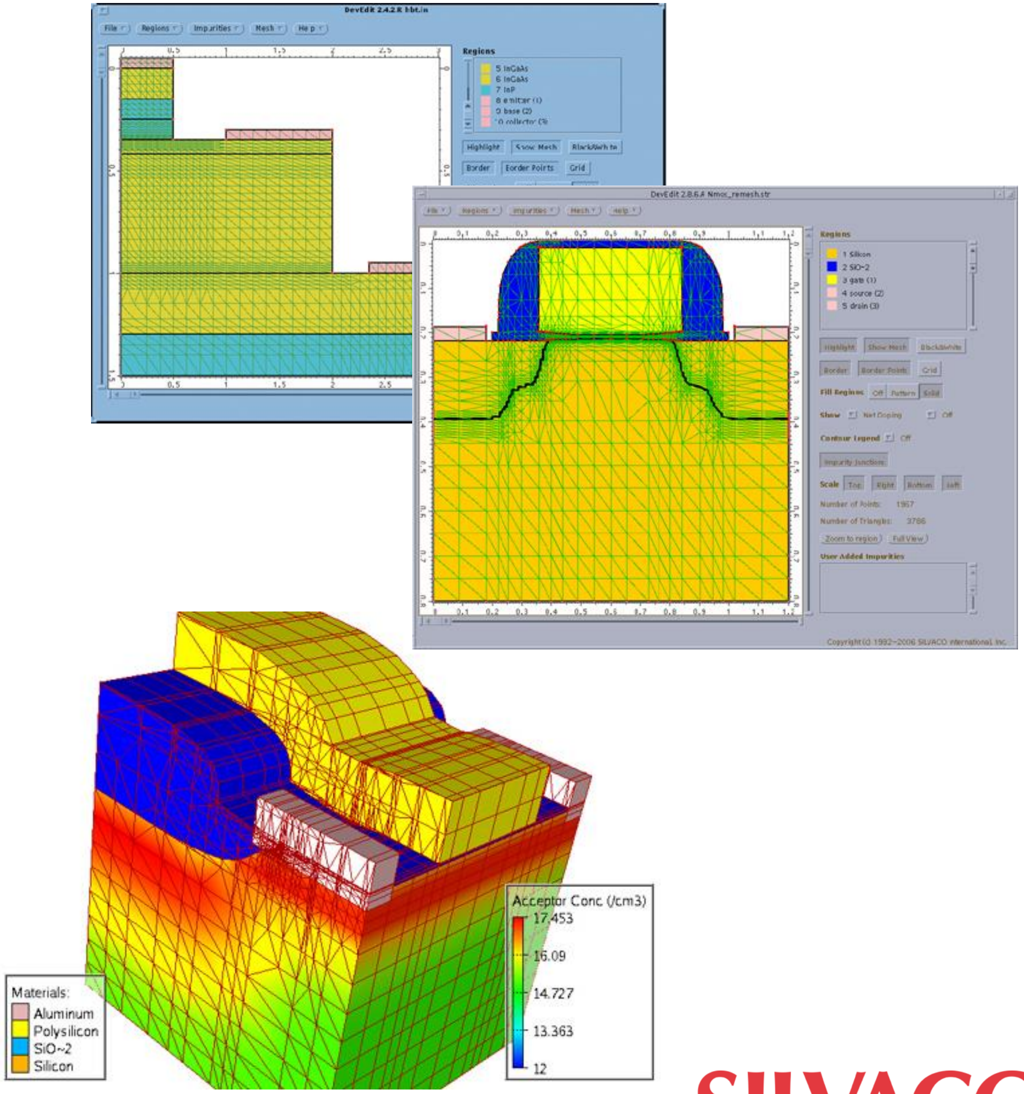
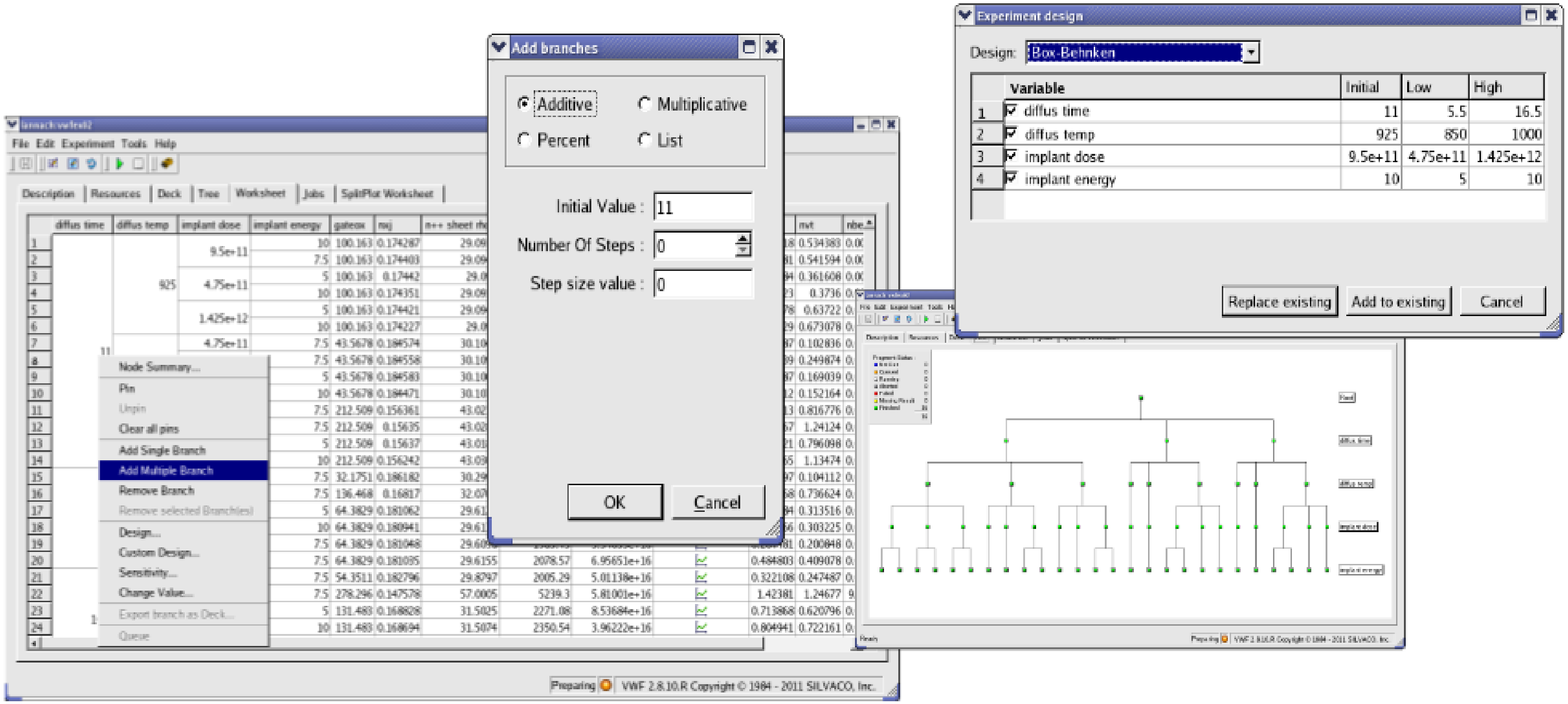
DevEdit: 2D / 3D Device & Mesh Editor

- Create a device from scratch, re-mesh or edit an existing device
- Parameterize and vary automatically with DeckBuild or VWF
- Mirroring, stretching, cloning and joining
- GUI to draw or edit devices directly
- Re-mesh on volume data
- Import 1D doping profiles



Automated utilities such as Virtual Wafer Fab (VWF) allow users to define a split lot experiment to probe available design space. Queuing system can be used to efficiently execute the calculations in parallel.



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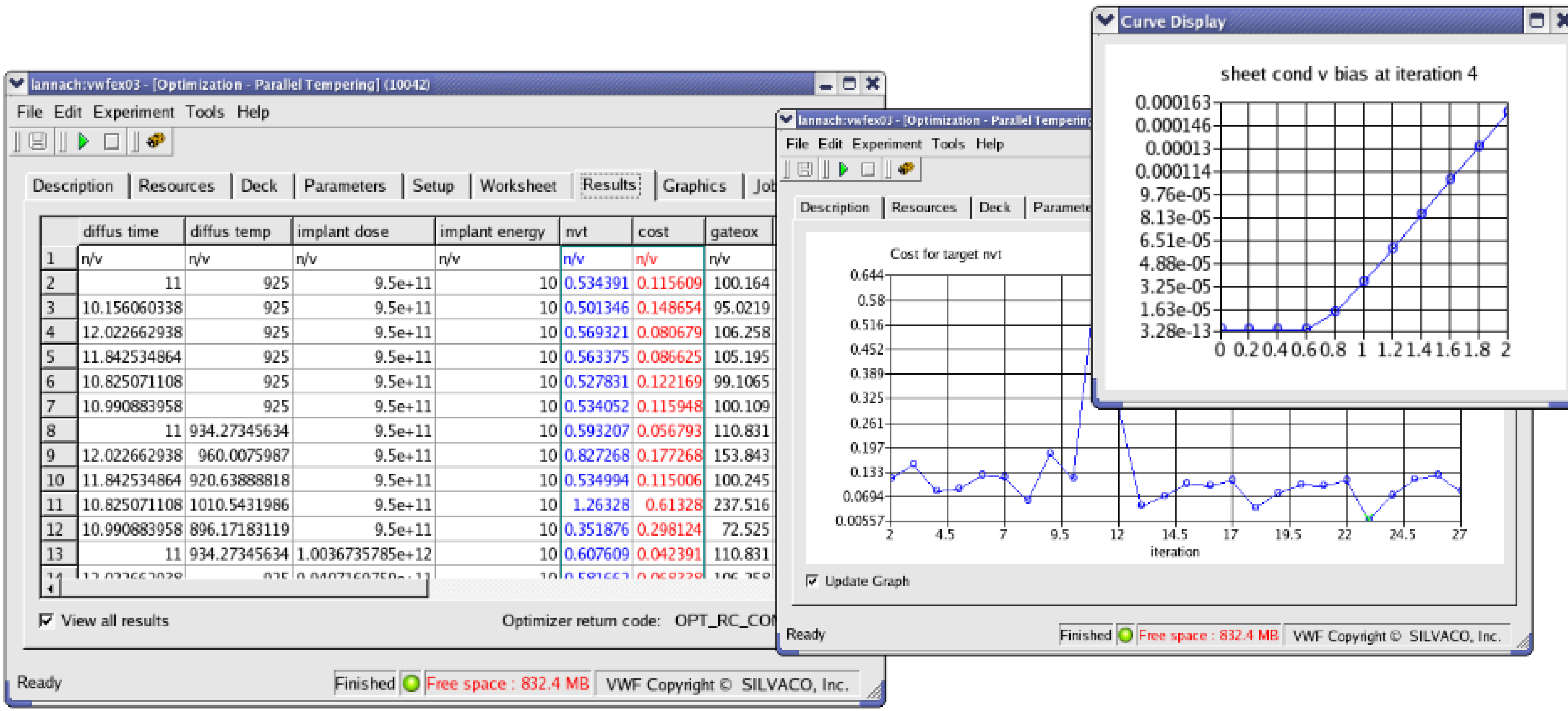
Further automation for optimizers allow users to "discover" optimal characteristics within the design space.



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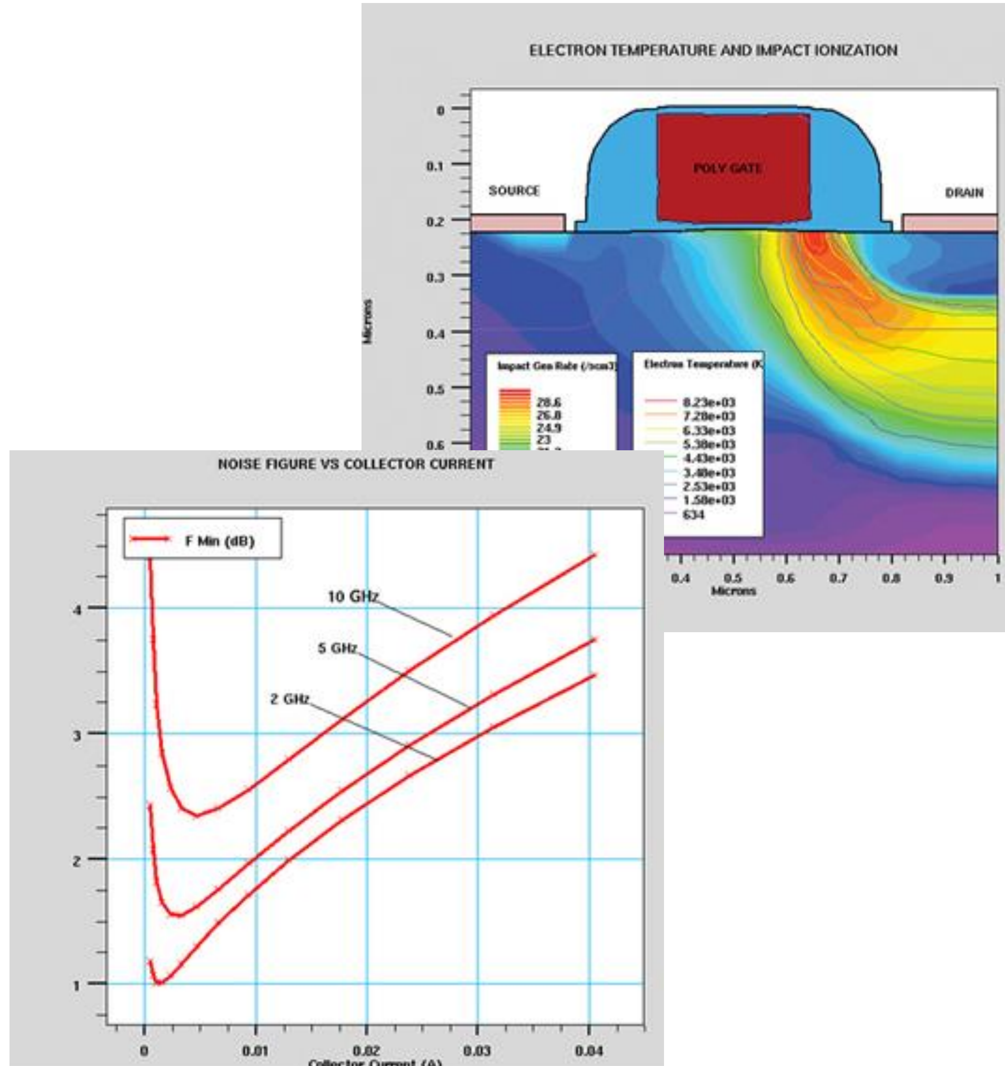
TonyPlot 2D: Interactive Visualisation Tool

- Supports 1D, 2D, meshed data, Smith and polar charts
- Export data for use in third party tools
- Measurement tools (probes, rulers, etc)
- Overlay plots
- Movie Mode
- Cut lines
- Function and Macro



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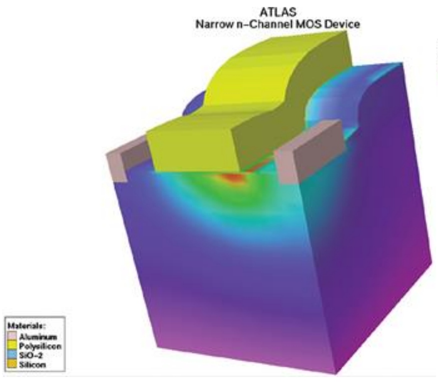
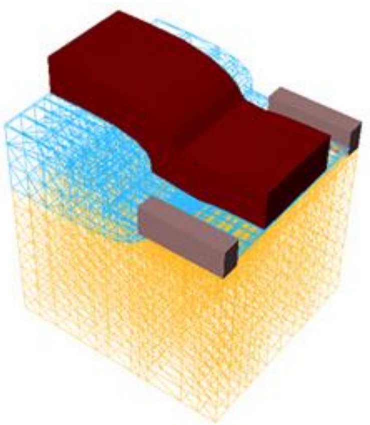
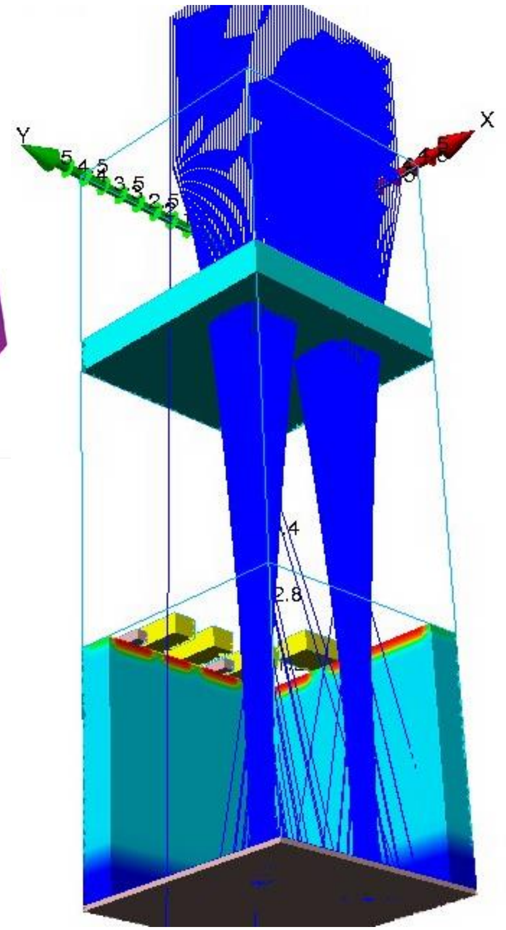
TonyPlot 3D: Interactive Visualisation Tool

- Graphical rotation around any axis (x, y, z), repositioning and zoom in/out
- Surface contours
- Isosurfaces
- Probe within the 3D structure
- Hide materials or regions
- Fully customizable
- Cut-plane: 2D slice exported to file or TonyPlot 2D







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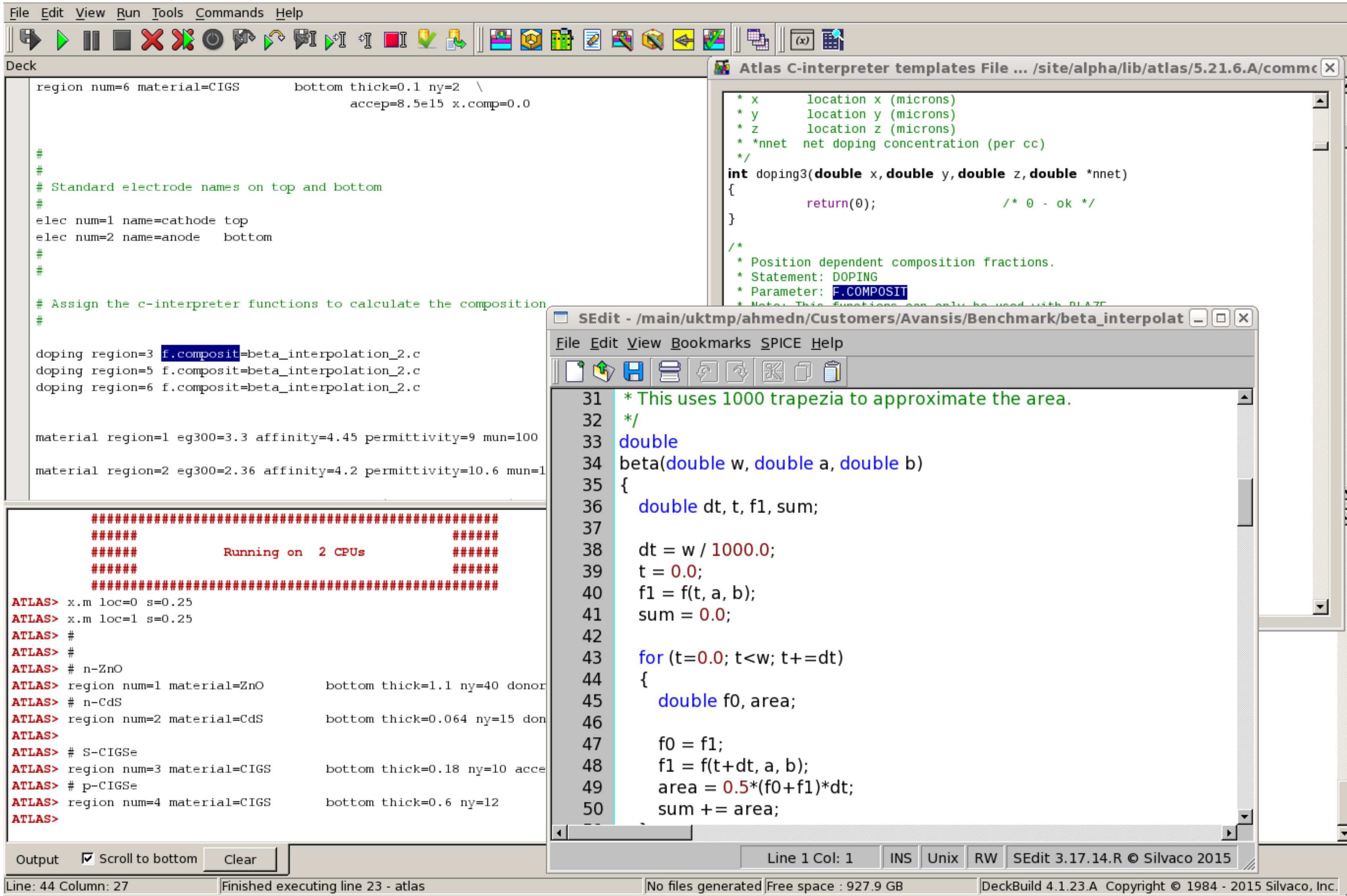
Flexible user defined c-functions



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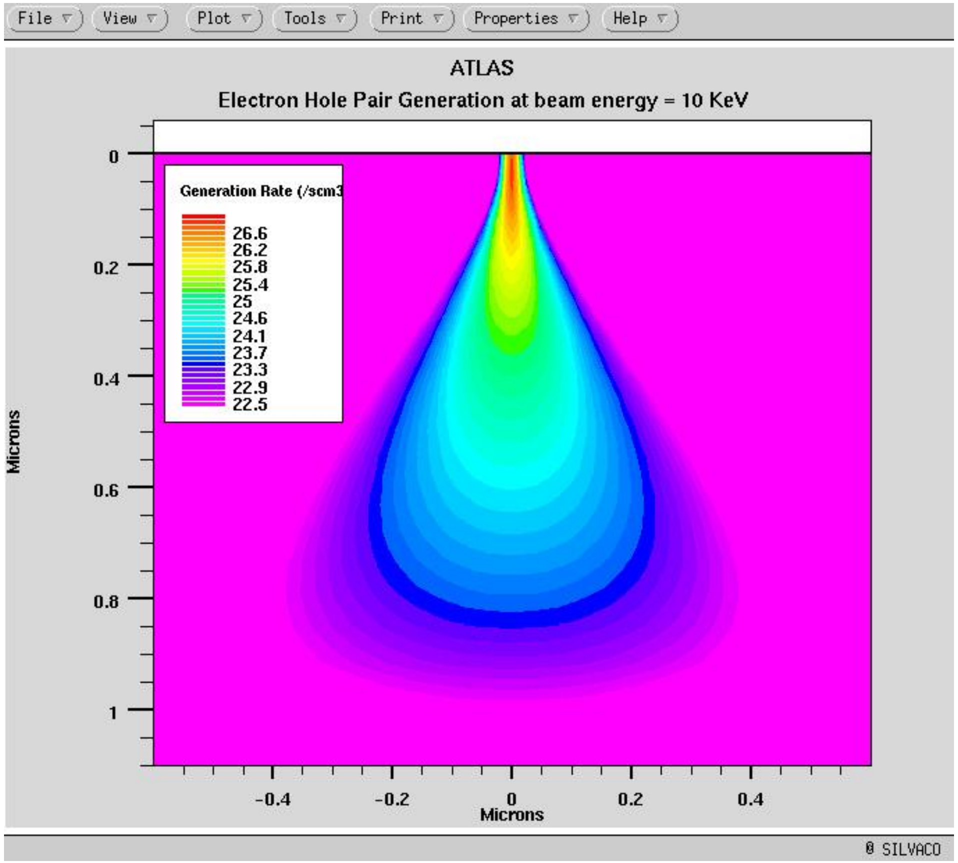
Flexible user defined c-functions (II)

```c
/*
 * Generation rate as a function of position
 * Statement: BEAM
 * Parameter: F.RADIATE
 * Arguments:
 * x          location x (microns)
 * y          location y (microns)
 * t          time (seconds )
 * *rat       generation rate per cc per sec.
 */
int radiate(double x,double y,double t,double *rat)
{
 double E=10; double l=1e-11; double Eg=1.08;
 double q=1.6022e-19; double beam_dia; double ei;
 double R; double A; double sigma_sq;
 double F; double G0; double Rnorm;

 /* Energy requires for formation of e-h pairs */
 ei = 2.596 * Eg + 0.714 ;

 /* Primary Electron Penetration Depth in cm */
 R = (3.98e-6) / 2.33 * pow(E, 1.75) ;

 /* Beam Diameter = 1% of R */
 beam_dia = 0.01 * R ;
```



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Conclusions

- Physical device simulations captures theoretical knowledge to provide essential insight. They can predict behaviour in the entire design space.

- TCAD simulations provides data that is difficult to measure to help speed up innovation and development cycles.

- Silvaco offers simulation tools for 2D and 3D process simulations as well as 2D and 3D device simulation.

- Simulation tools are complemented with user friendly interactive tools.

- Users have access to extensive resources to help them maximise the return out of their simulation effort.