SILVACO

# Complex device design using predictive modelling

Ahmed Nejim
R&D Projects Director

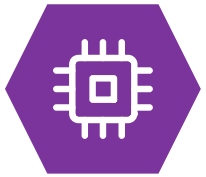
CS International - Brussels 18th April 2023

# Silvaco at a Glance

**600+**
Customers
Worldwide

**200+**
University Customers
Worldwide

**260+**
Employees



**#1**
TCAD and Modeling
for **Flat Panel, Power**

Solutions for
**Display, EV Power, SoC, IoT,**
**Fab Process Optimization**

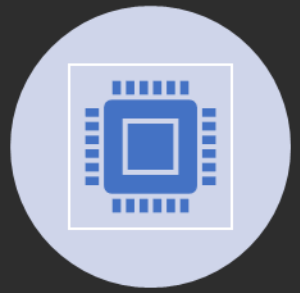
Deep Industry &
Academic
**Collaborations**

# De-risking technology development

To develop technology, we need design tools.

Automation design software sits at the heart of this development. Essential part of the supply chain.

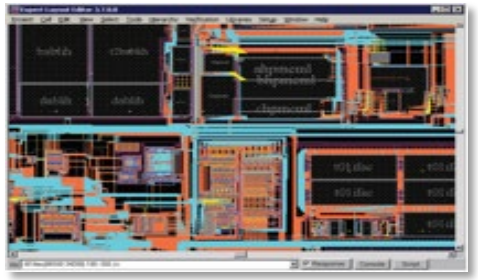
Predictive modelling is attractive; however, it comes at a great cost!



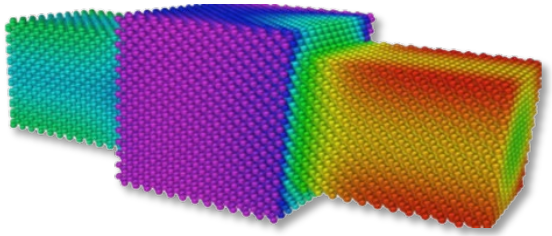
Move to circuits and system design will happen when devices “just work”.

# Silvaco's Solution Spectrum

Systems



Transistors



Atoms

Design IP

Analog
Custom

TCAD

Number of Devices

1

10K

10M

# Power Device Technology

## Market, R&D Drivers

- **New Device Geometries**
  - Exploiting 3D material properties to maximize performance/power density
  - Novel layouts to increase device density

- **Next Generation Materials**
  - SiC, GaN - Inherently better performance to challenge existing silicon-based designs
  - New electrical and fabrication behaviors to understand and improve

# Power Device Technology

## Market, R&D Drivers

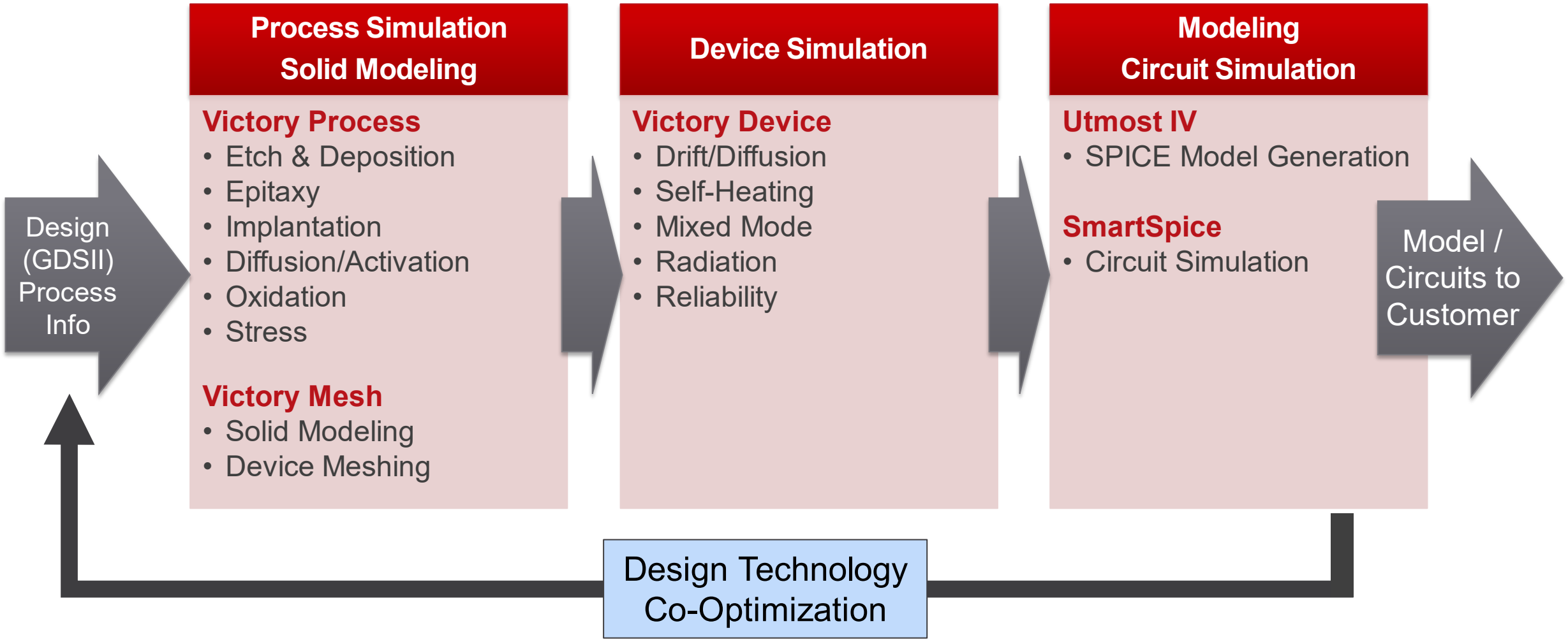
- **High Demand for Power Devices**
  - Higher volume applications (e.g., Electric Vehicles) require scaling of semiconductor technologies with high yield

- **Reliable by Design**
  - In-depth physics understanding required to meet standards of end use applications (e.g., Automotive, Mil/Aero/Space)

# Challenges & Silvaco Solutions

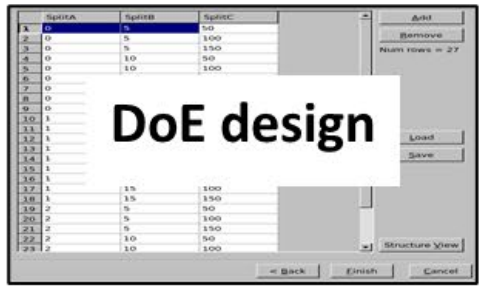
| Challenges | | Solutions | |
|---|---|---|---|
| • X,Y,Z current flow by design<br>• Large area, multi-cell, multi-finger designs | 3D Technology Design | Victory 2D/3D integrated Solution | • High capacity, Multi-threading<br>• GDSII driven, 2D/3D TCAD solution |
| • Maturing manufacturing for “new materials” | Next Generation Materials | Coverage of Today’s & Tomorrow’s Materials | • Decades of WBG experience<br>• Open model and material database |
| • Self heating, in-circuit operation, environment and aging effects | Multi-Physics Operation | Drift-Diffusion + Integrated Modules | • Self-Heating, TCAD+SPICE<br>• Reliability and Radiation models |
| • Engineering splits increase<br>• Manufacturing and test time increases | Engineering Cost / Time to Market | Design / Technology Co-Optimization | • TCAD proven to shorten time to market<br>• Explore new ideas and splits |
| • Tech detail capture needed<br>• New engineers learn from experienced technologists | "Digital Twin” / Knowledge Transfer | Process/Device of Record in TCAD | • Capture concept to product<br>• Enable learning of physics, visualization |

# Victory TCAD Solution for Power Devices

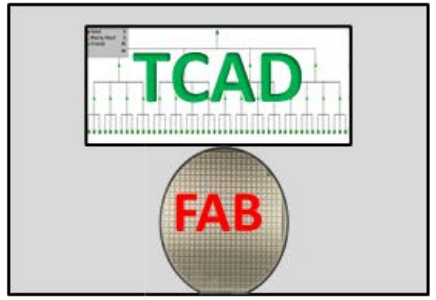


# Accelerating Fab Engineering with TCAD powered ML

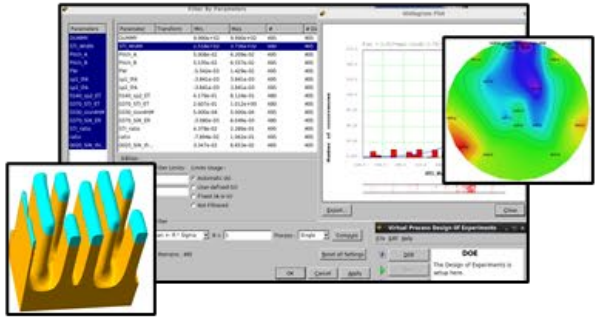
## Optimized Sampling




## Experiment

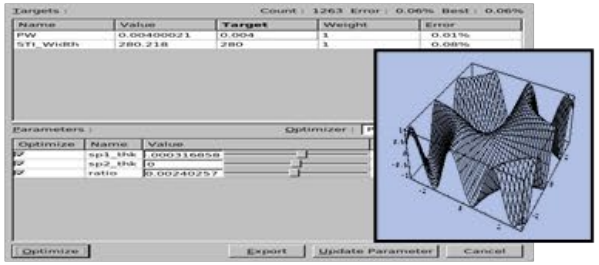



## Data analysis, visualization



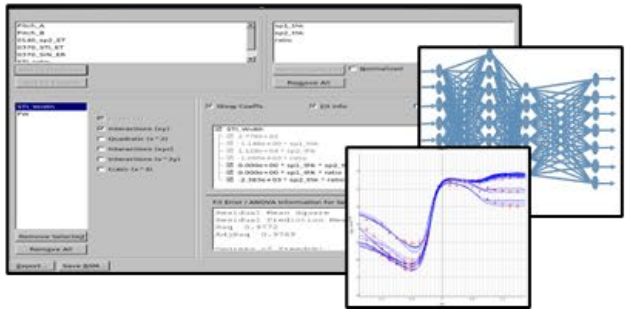
ML-based Incremental sampling

## Model-based Global Sizing



Good Model

## Supervised ML for Nonlinear Modeling



# **Victory Process** for Si & SiC Power Devices

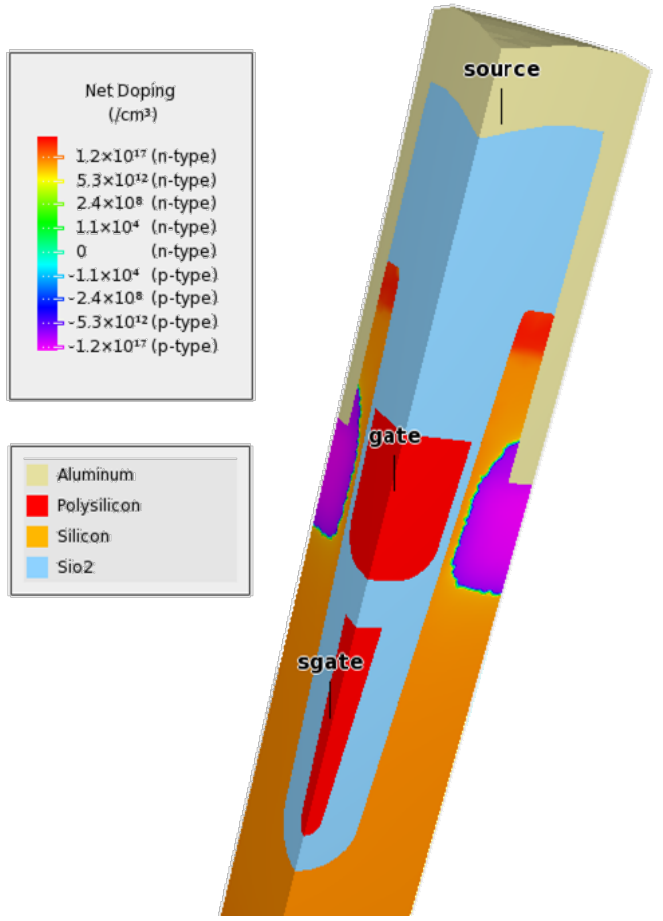
Virtualize your process flow. Optimize the next generation power devices through virtual fabrication

## Full 2D/3D TCAD Process Solution

- Build, debug, calibrate in fast 2D
- Easy transition to realistic 3D for full 3D technology design
- Seamless integration into Device Simulation

## Process simulation for Si and SiC

- Etch & Deposition
- Implantation
- Dopant Activation
- Oxidation
- Open Model Library and Material database
    - Allows for user customizability

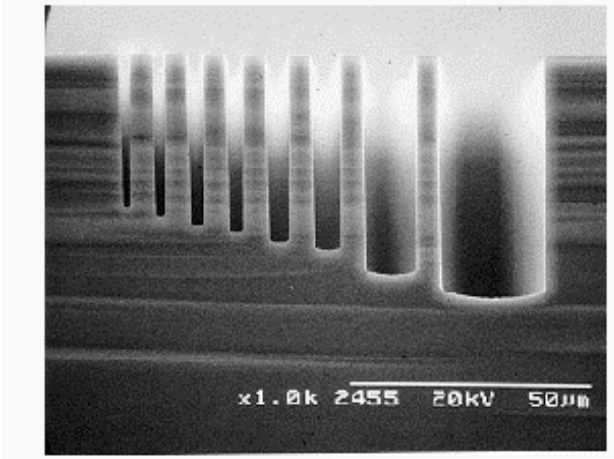


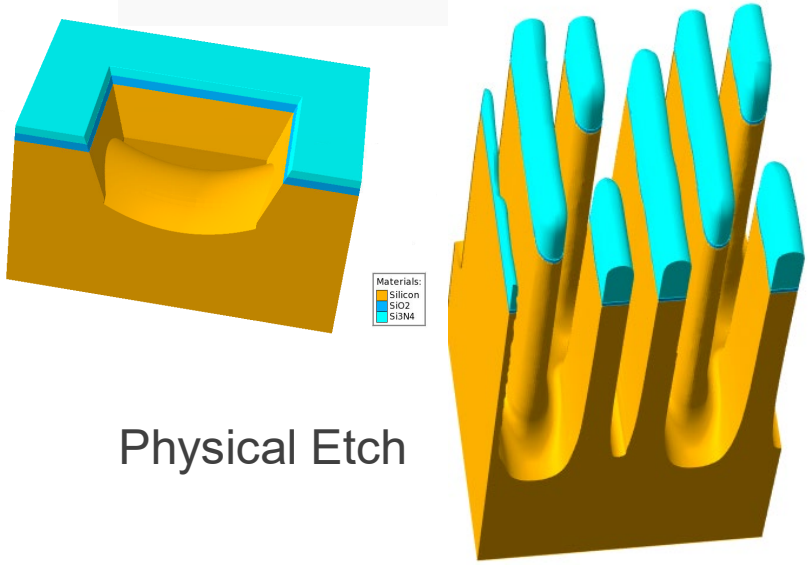

Silicon Split Gate Trench UMOSFET from Victory Process

# Etch & Deposition for Next Generation Devices

New power devices utilize multiple etch and deposition steps to produce trenches, spacers, and dielectric layers.  Capturing material geometry faithfully ensures TCAD simulation matches the fab.

- **GDSII driven TCAD,** connecting fab to TCAD
  - Import layout to use as masks for any process step
- **Simple geometric models** for fast simulating etch & deposition steps
  - Define etch/deposition thicknesses and a geometric model
- **Detailed physical models** for deeper understanding of your process steps
  - Define deposition/etch rates for each material
  - Sticking factors, flux parameters
  - Useful for understand visibility effects




Physical Etch

# Implantation Accuracy with Victory Process

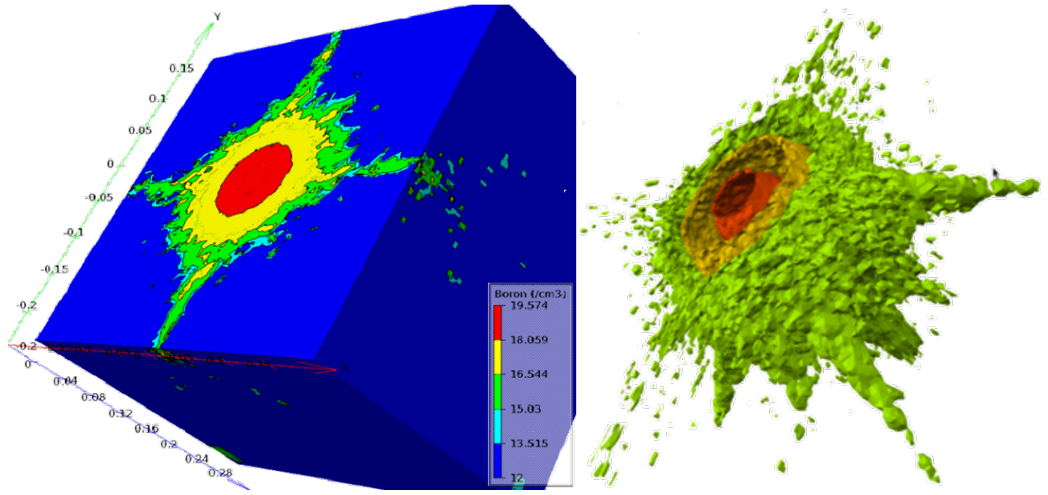
Fabrication processes include numerous implantations steps. Capturing physics-accurate implantation profiles allows optimization of process conditions for the best performing, high yield devices

## Physical Implantation via Monte Carlo Implantation

- User-Definable Implant Properties
  - Substrate type/orientation, wafer miscut, angle, dose and energy
- Well calibrated stopping within crystal channels and random direction
  - Crystal Damage & Scattering due to damage accumulation

## Empirical Methods to define doping in process

- Doping profiles by analytical distribution function
  - Quickly add Gaussian doping
- Doping profiles defined by external data files
  - Use SIMS profiles to build your TCAD process



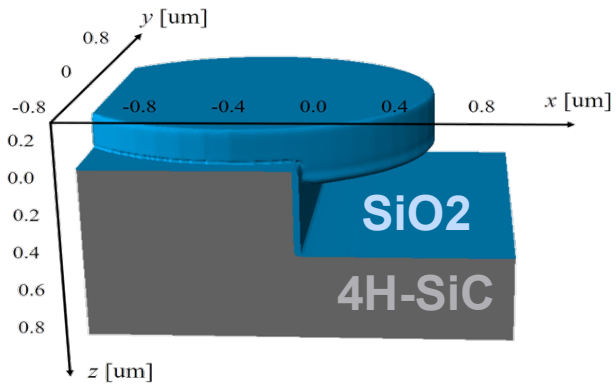

Implant distribution at the Silicon surface shows pronounced lateral channeling

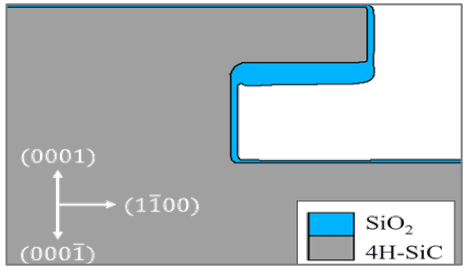
# Robust Oxidation Simulation

Simulation of 3D oxidation is a challenging numerical problem. Victory Process is capable of efficiently and accuracy modeling key oxidation steps for Silicon and Silicon Carbide devices.

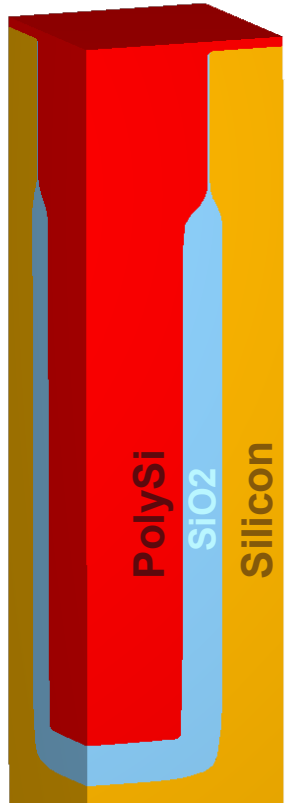
## Oxidation Simulations available for Si & SiC

- Well calibrated for Silicon & Silicon Carbide
- Fully 3D Anisotropic Oxidation Model for 4H-SiC
  - Each crystal plane will have separate oxidation rates
  - Well calibrated to experimental results
  - Useful for understanding oxidation in trench devices




Anisotropic Oxidation Effects for 4H-SiC




LOCOS Oxidation for Silicon Power Device

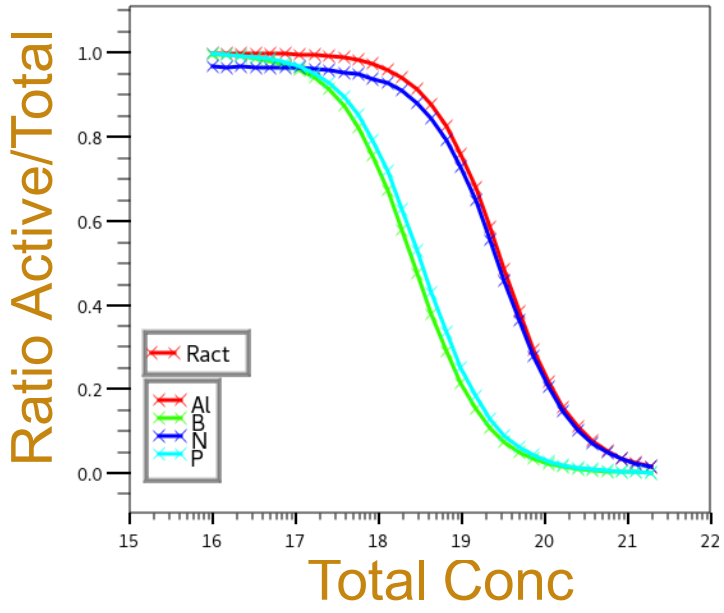
# Electrical Activation During Fabrication

Incomplete activation of dopants can dictate device performance, especially in Silicon Carbide. Modeling electrical activation as part of process simulation captures dopant concentrations accurately

## Dopant Activation Models calibrated for both Si & SiC

- Two major activation models: Empirical and Transient
  - **Empirical:** Instantaneous relationship between active and non-active concentrations
  - **Transient:** Adds transient partial differential equation to the empirical model

- **Table Method** for inserting user input data
  - Allows users to incorporate proprietary or new experimental activation data with ease




Activation Ratio vs Concentration for 4H-SiC at 1700C

# **Victory Device** for Si & SiC Power Devices

## Victory Device meets the breadth and depth of power device simulation needs

**Simulate DC, AC and transient electrical simulation**
- Understand how your device performs in any scenario

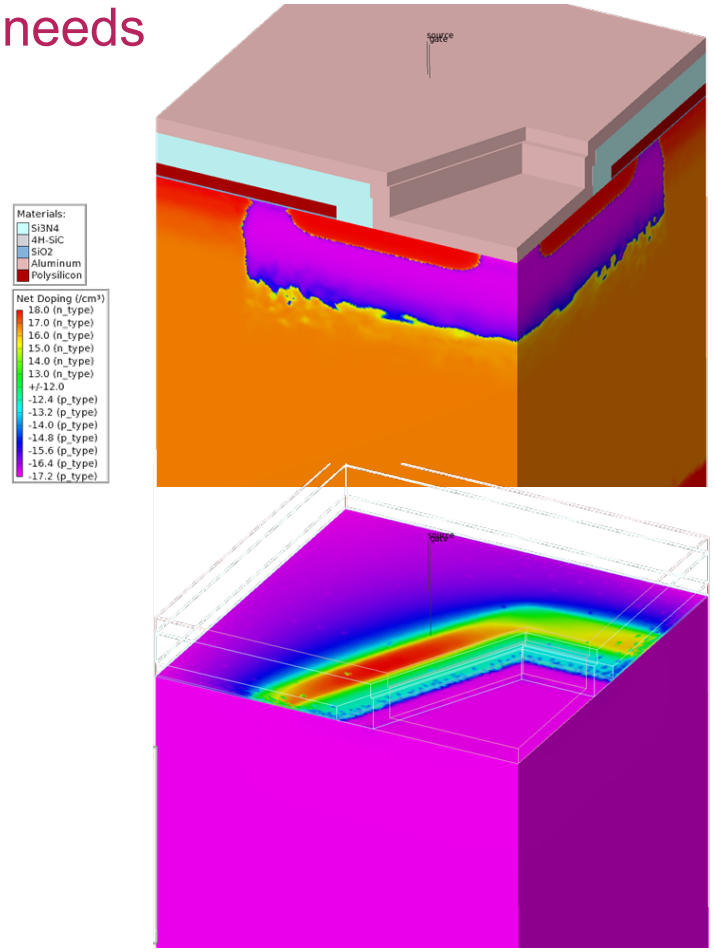
**Self-Heating Simulation**
- Gain insight into self-heating effects that influences electrical physics

**Reliability and Radiation**
- Simulate device degradation due to electrical stress, as well as radiation effects (TID, DD, SEB)

**MixedMode circuit/device simulation**
- Simulate TCAD devices within a SPICE circuit

**User-customizable physical models & material parameters**
- Calibrate any simulated device to your experimental data
- Novel wide bandgap materials can be simulated by adjusting the physical parameters

**Advance numerical solvers and methods**
- Multithreaded simulations and numerical extended precision available for the more difficult simulations




Anisotropic Mobility of SiC HexFET

# Summary

- **Multiscale flow**
  - Automated flow from process to circuit design.
  - Multiphysics is essential for mature technology design.

- **Design Space Exploration**
  - TCAD & EDA tools are essential for optimizing technology performance.
  - Increasing complexity requires advanced numerical methods.

- **Ramping up R&D**
  - Design software provides insight.
  - Generate deep understanding of technology potential.
  - Safeguard company knowledge and IP.

# Silvaco is leading the way for next generation Power Device Technology simulation