Exploring Methods for Adequate Simulation of Sub-100nm Devices

Victor Moroz and Norbert Strecker, Synopsys Inc., USA
Martin Jaraiz, University of Valladolid, Spain

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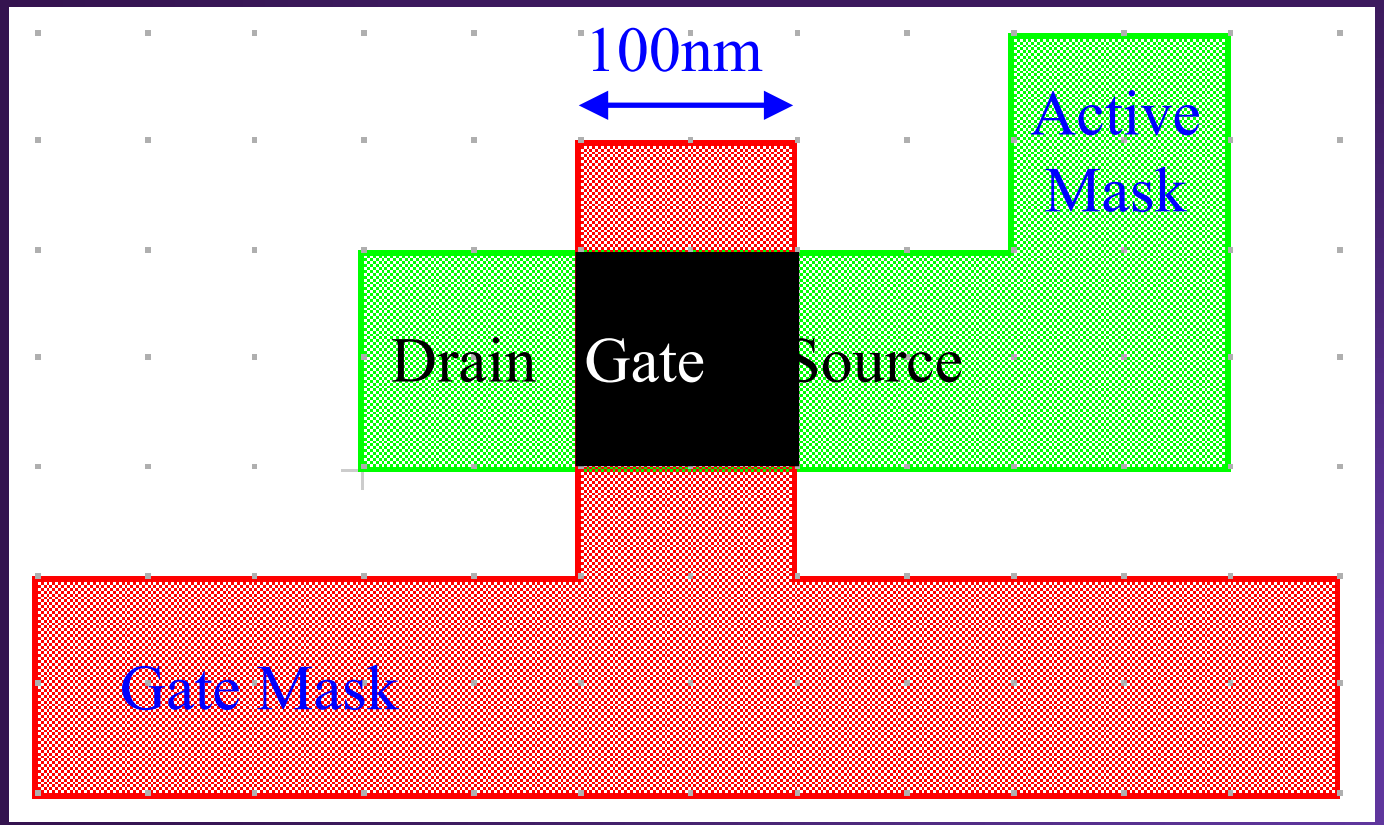
Outline

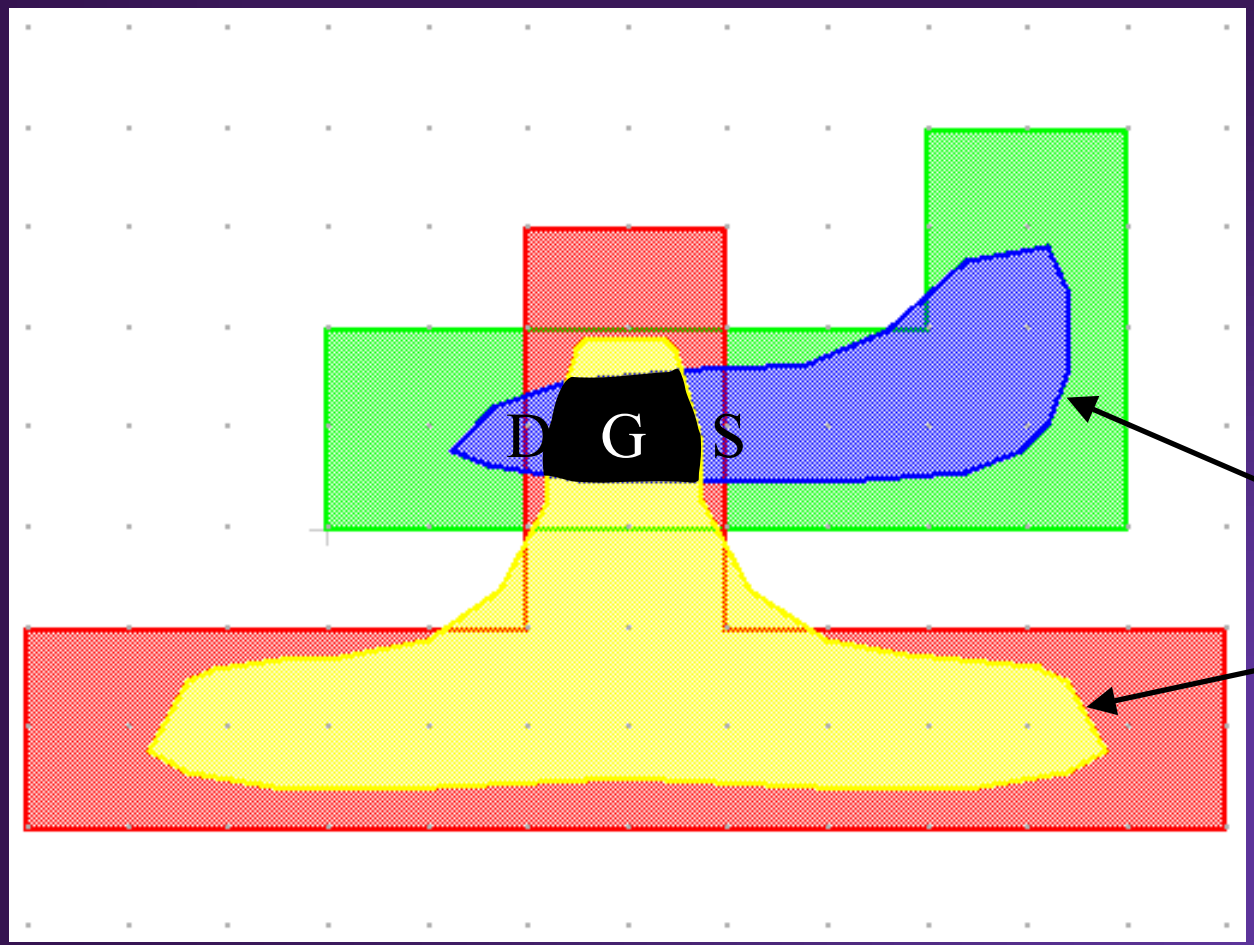
- **Photolithography:**
  - Optical proximity effects
  - OPC
- **3D Process Simulation:**
  - Continuum
  - Atomistic
  - Stress
- **3D Device Simulation:**
  - Rectangular vs. OPC vs. atomistic

Layout of a 100 nm nMOSFET



Rectangular channel with W/L=100nm/100nm

Distorted Image on Photoresist



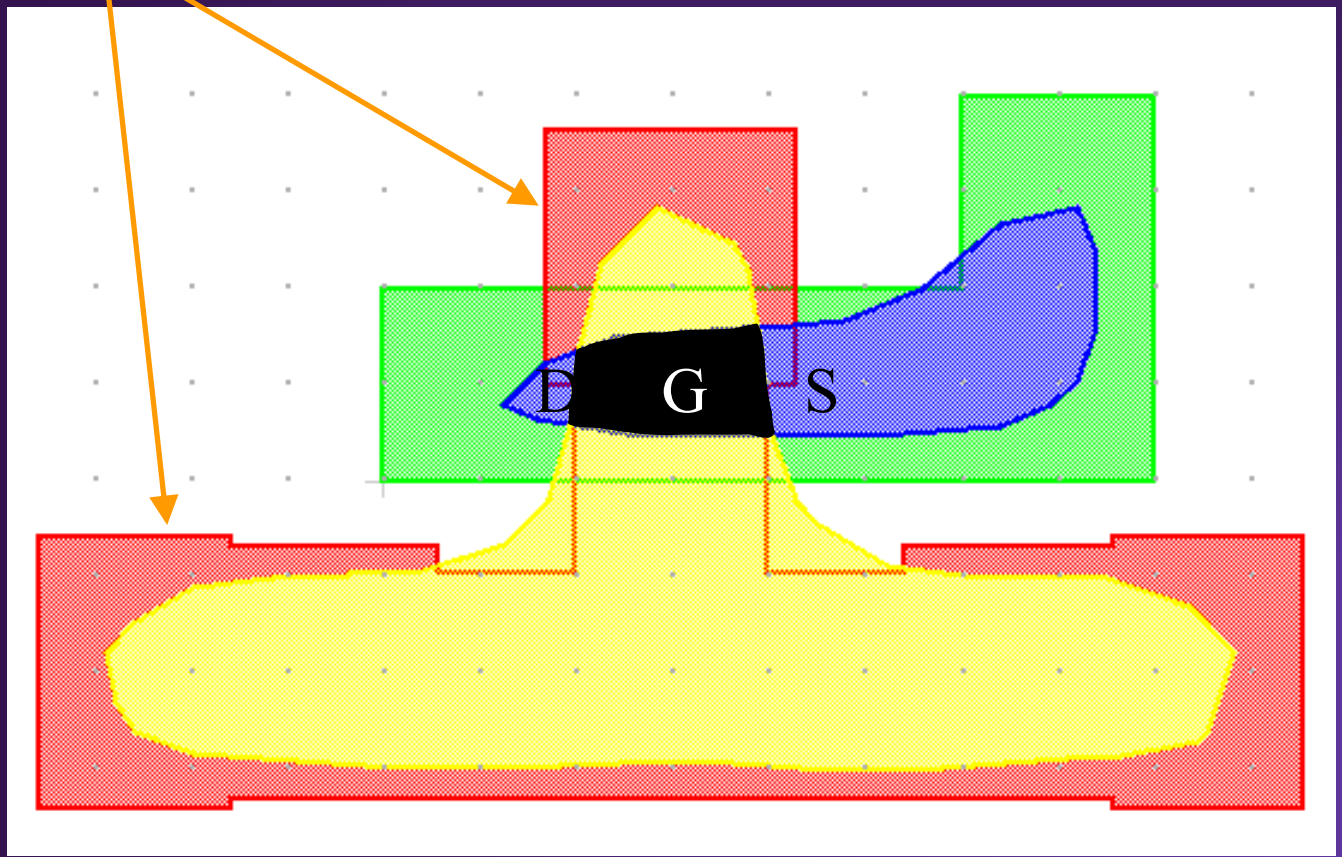
Lithography:
Canon @193nm
simulated by
Prospector

Image

Need OPC!

OPC for the Gate Mask

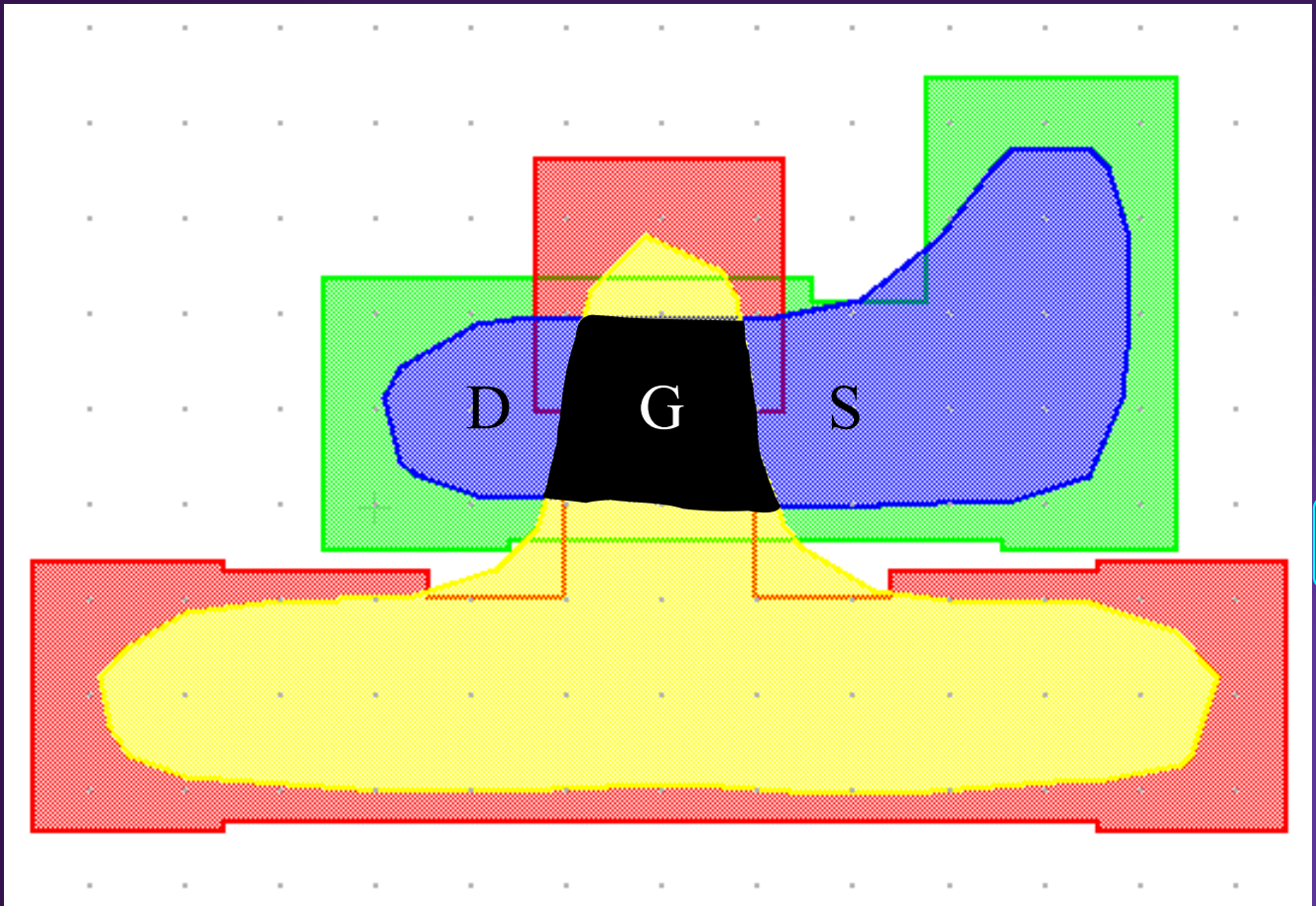
Serifs automatically generated by Prospector



Channel is still too distorted

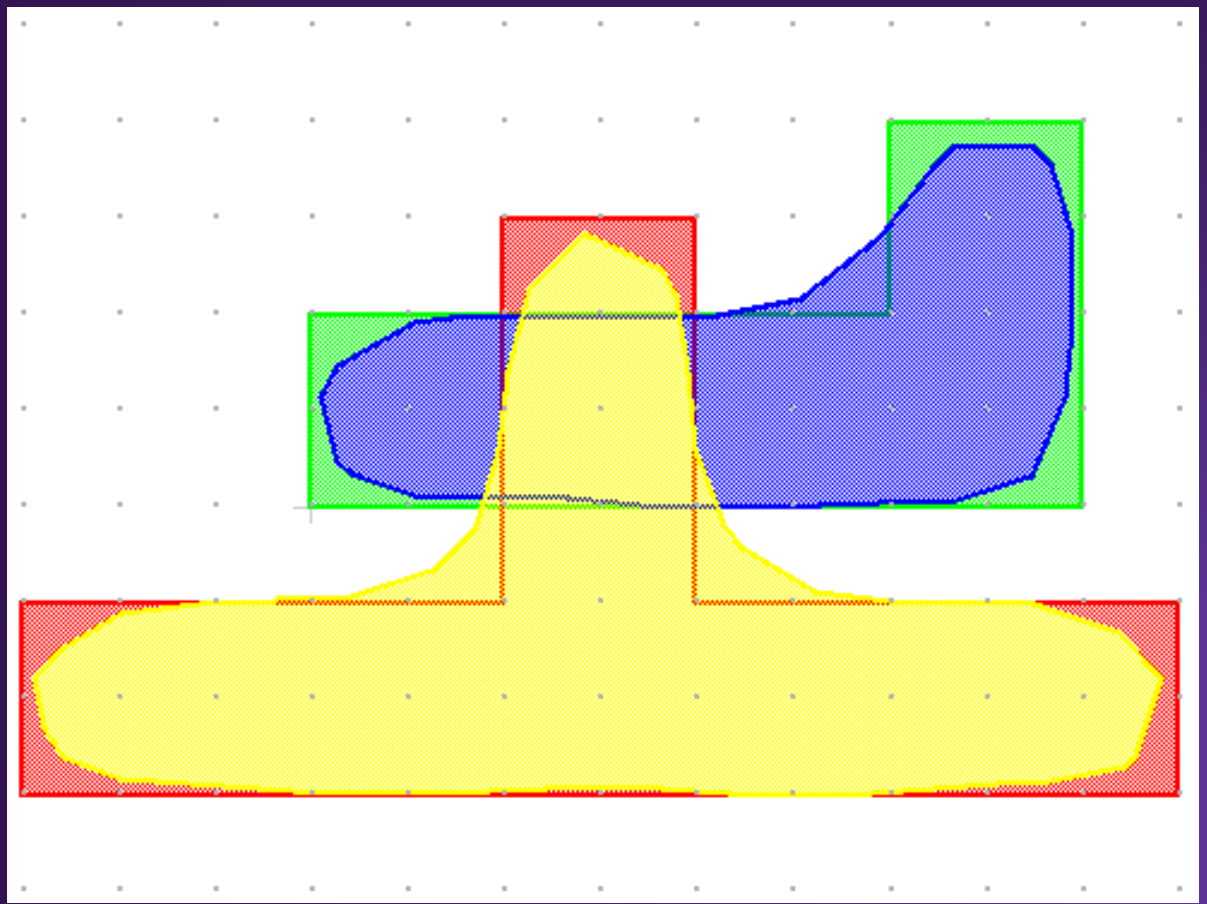
Need to OPC the Gate Mask!

OPC for both Gate and Active Masks



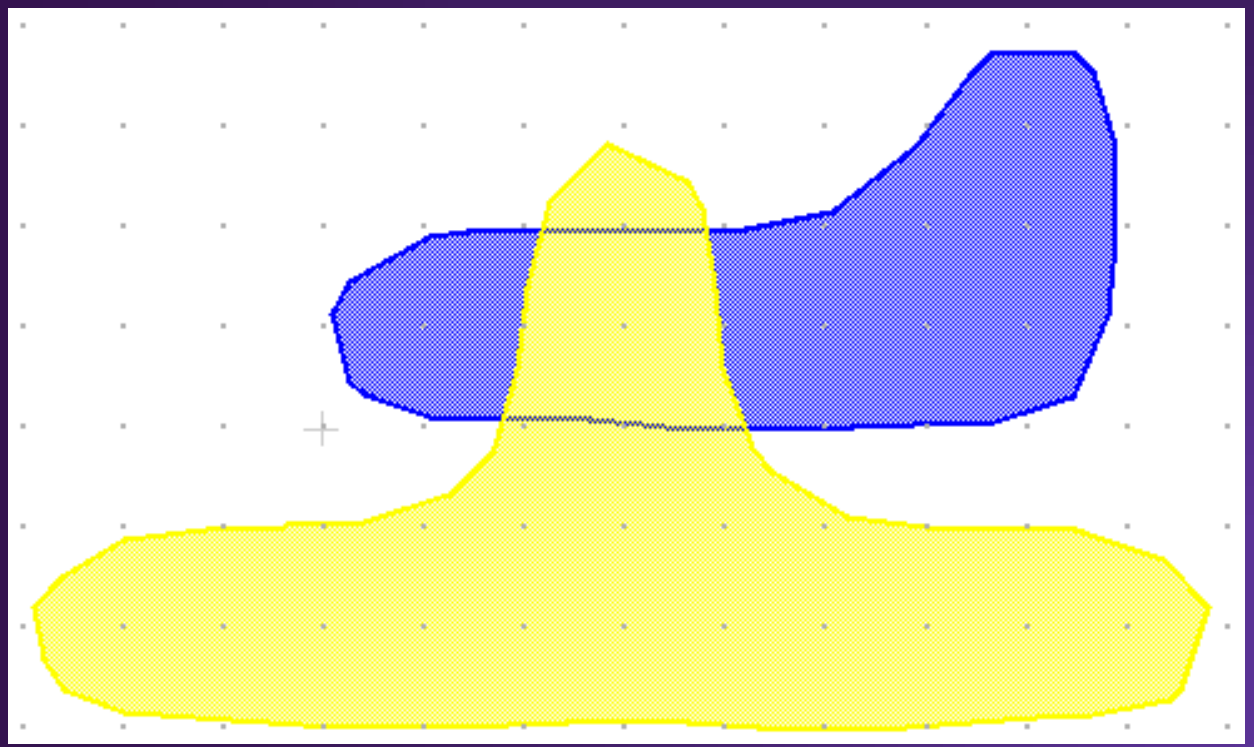
- Nominal W/L sizes reproduced, while some distortions remain
- Distortions can be completely eliminated at the expense of increased chip area!

Silicon Layout vs. Design Layout



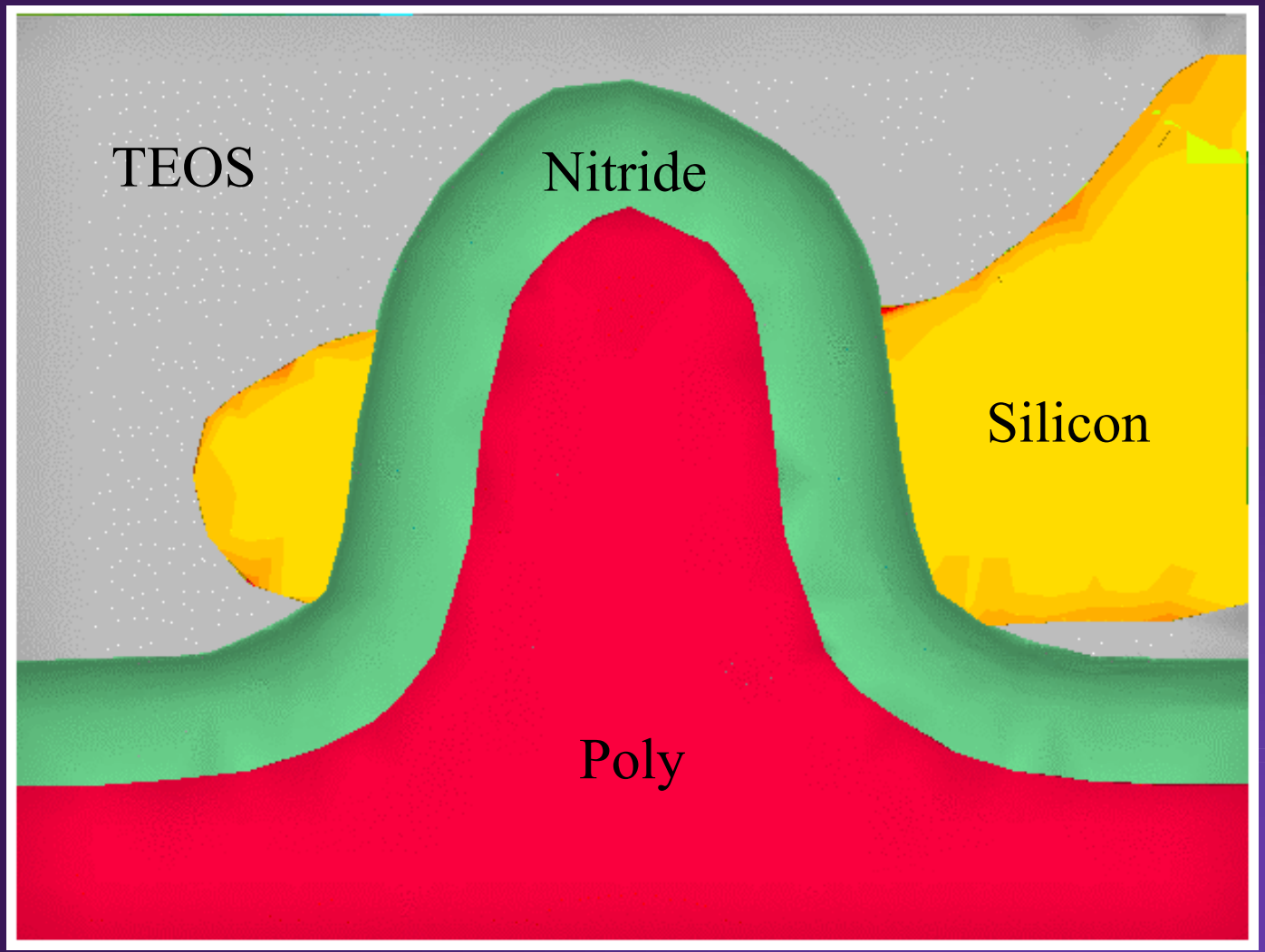
- Inherently 3D geometry requires 3D simulation
- Asymmetric geometry requires simulating entire device rather than a quarter or half

Realistic Masks for Process Simulation

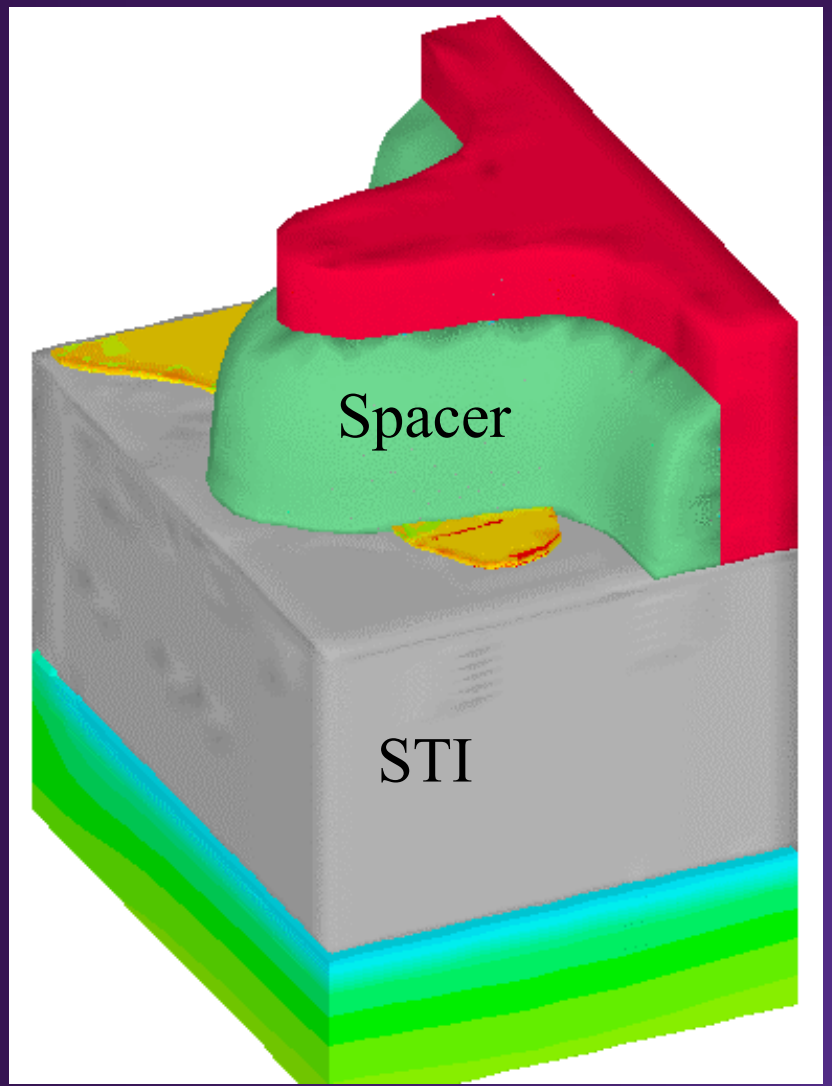


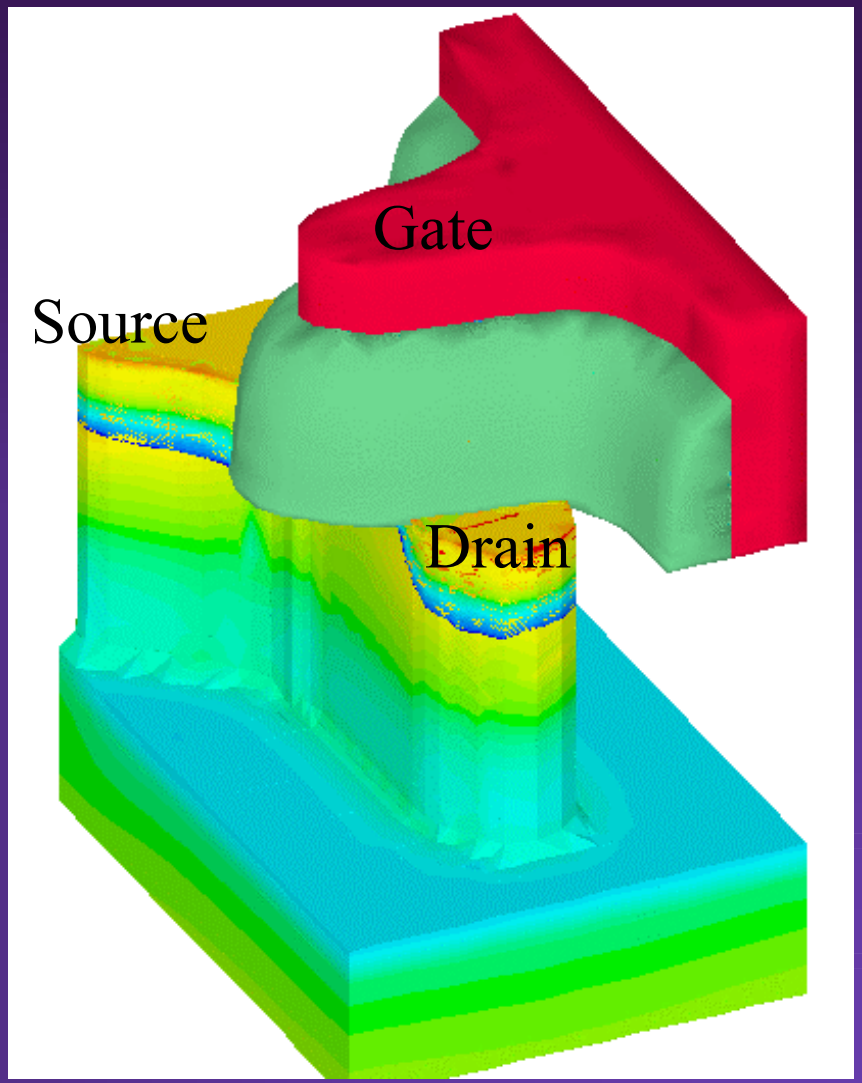
Images on photoresist (i.e. “silicon layout”) are saved as mask files in Prospector and then transferred to Taurus-Process for the etch modeling

Process Simulation: Top View

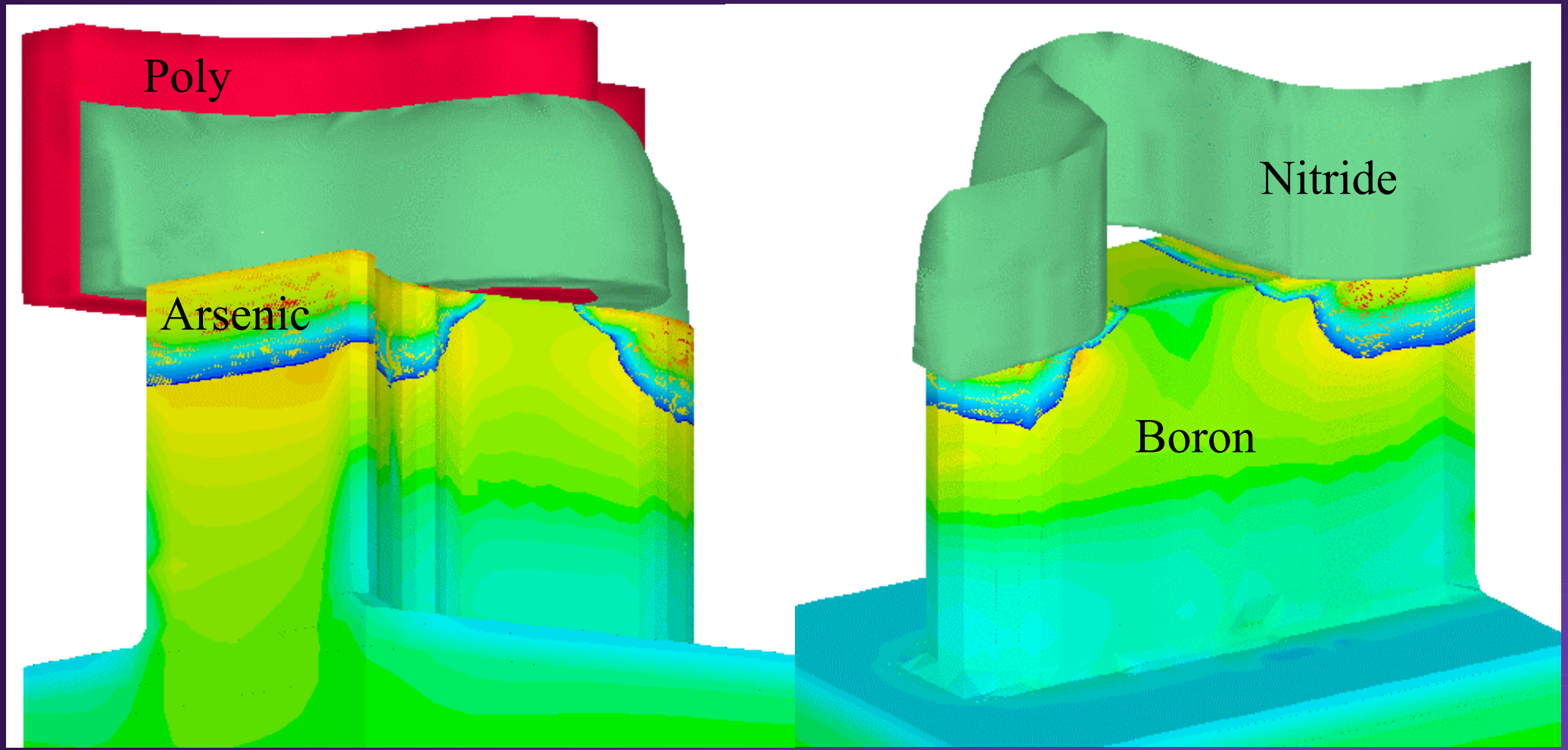


Geometry

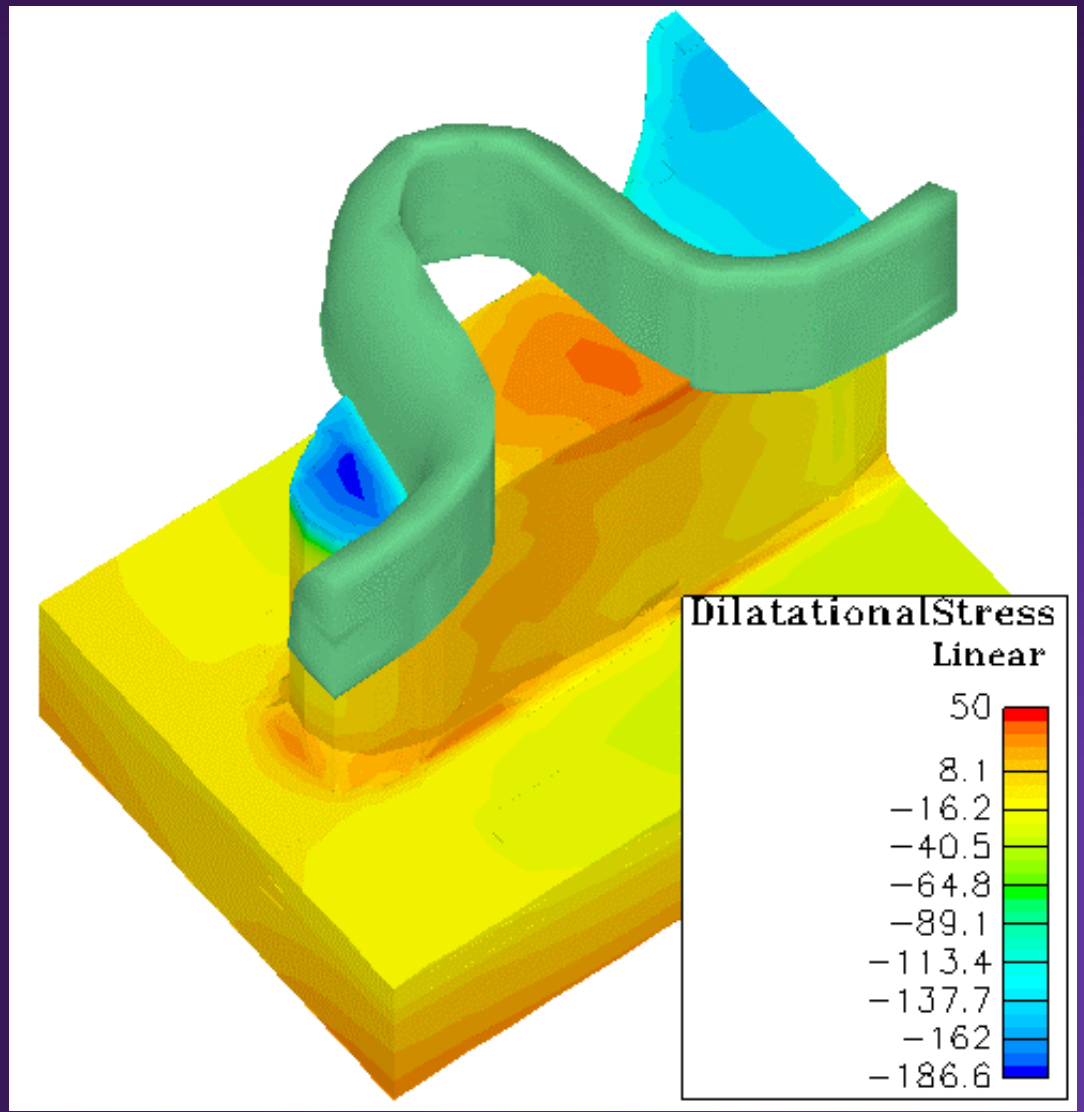




Doping: Arsenic and Boron Profiles

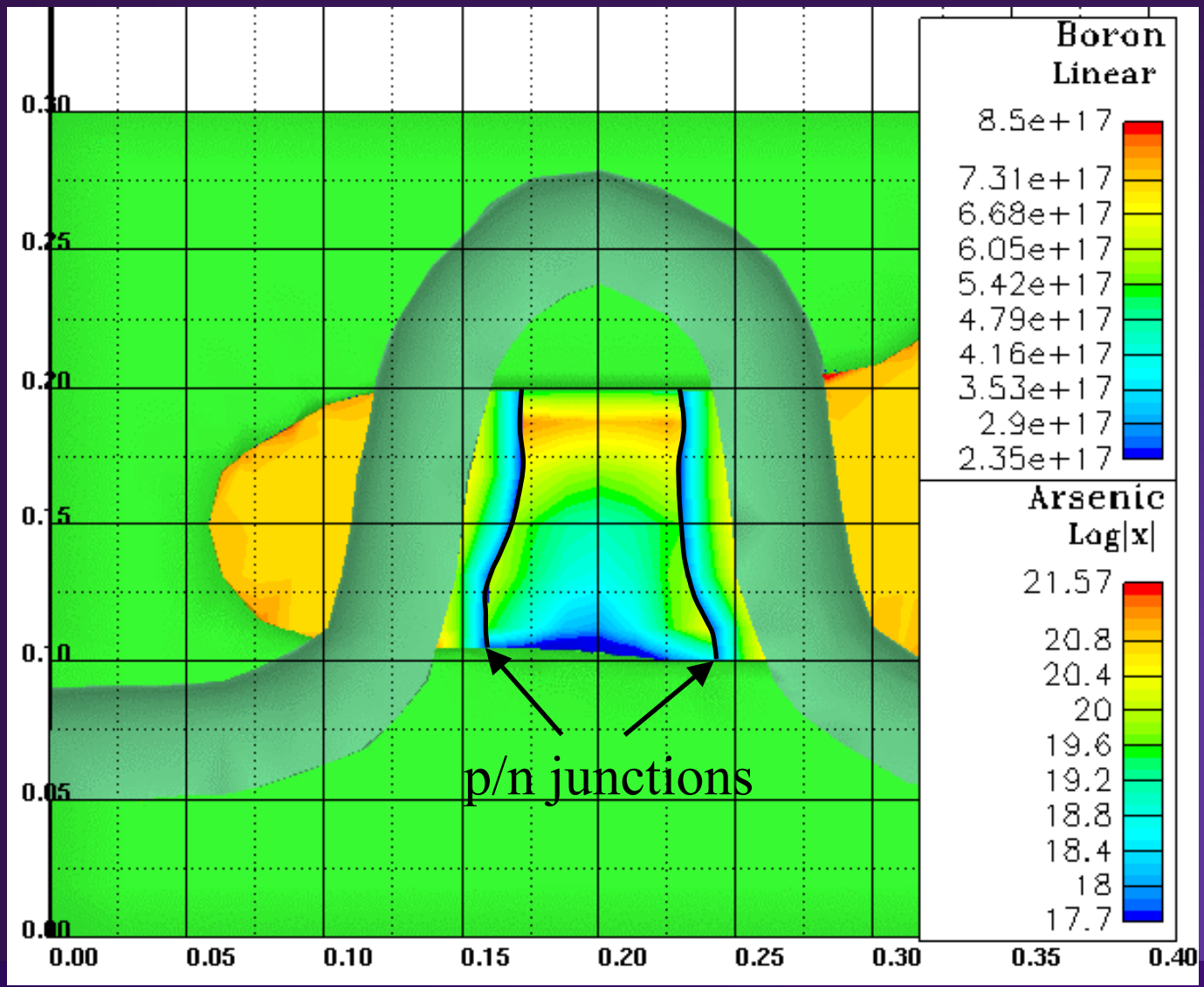


Stress Distribution After the Process Flow



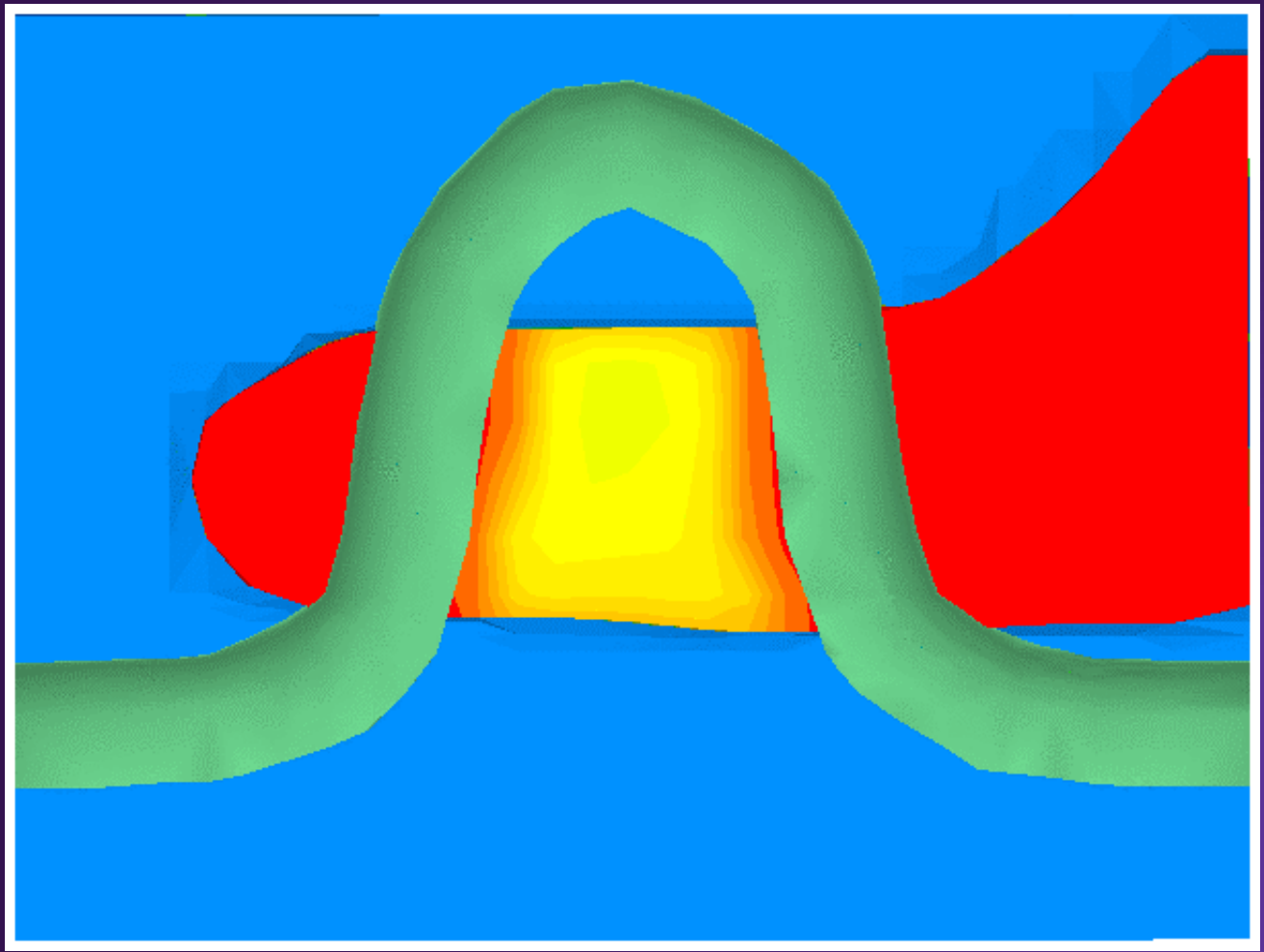
Stress impacts carrier mobility and junction leakage current through the band gap variation

Doping: Top View



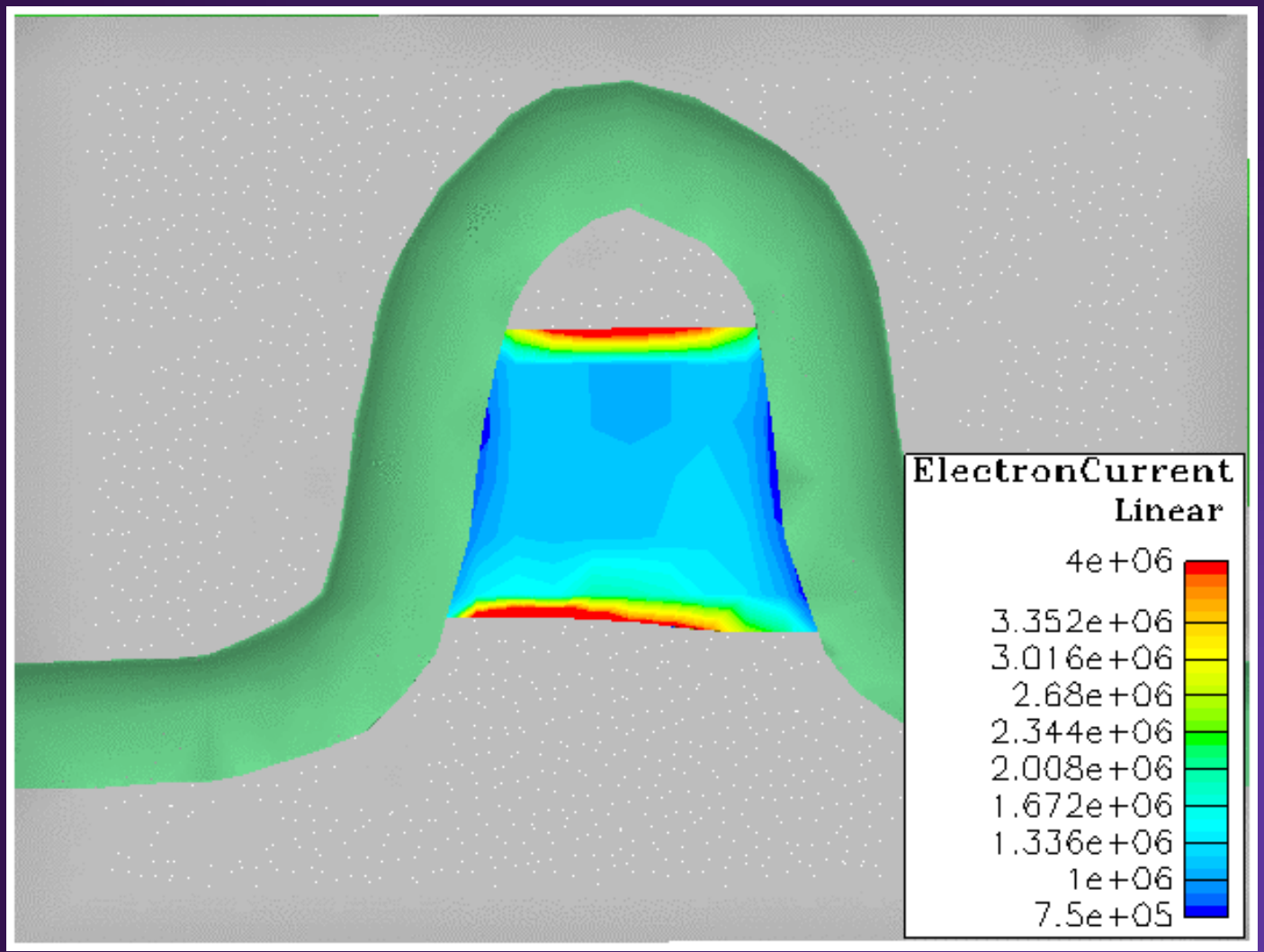
- Electrical channel length varies from 60 to 85nm across the channel
- Due to the tilted implants, boron concentration is higher where the channel is short

Device Simulation: Carriers in Channel



- Boron nonuniformity overcompensates the channel length variation effect
- This is determined by specific process flow and geometry

Current Density in the Channel



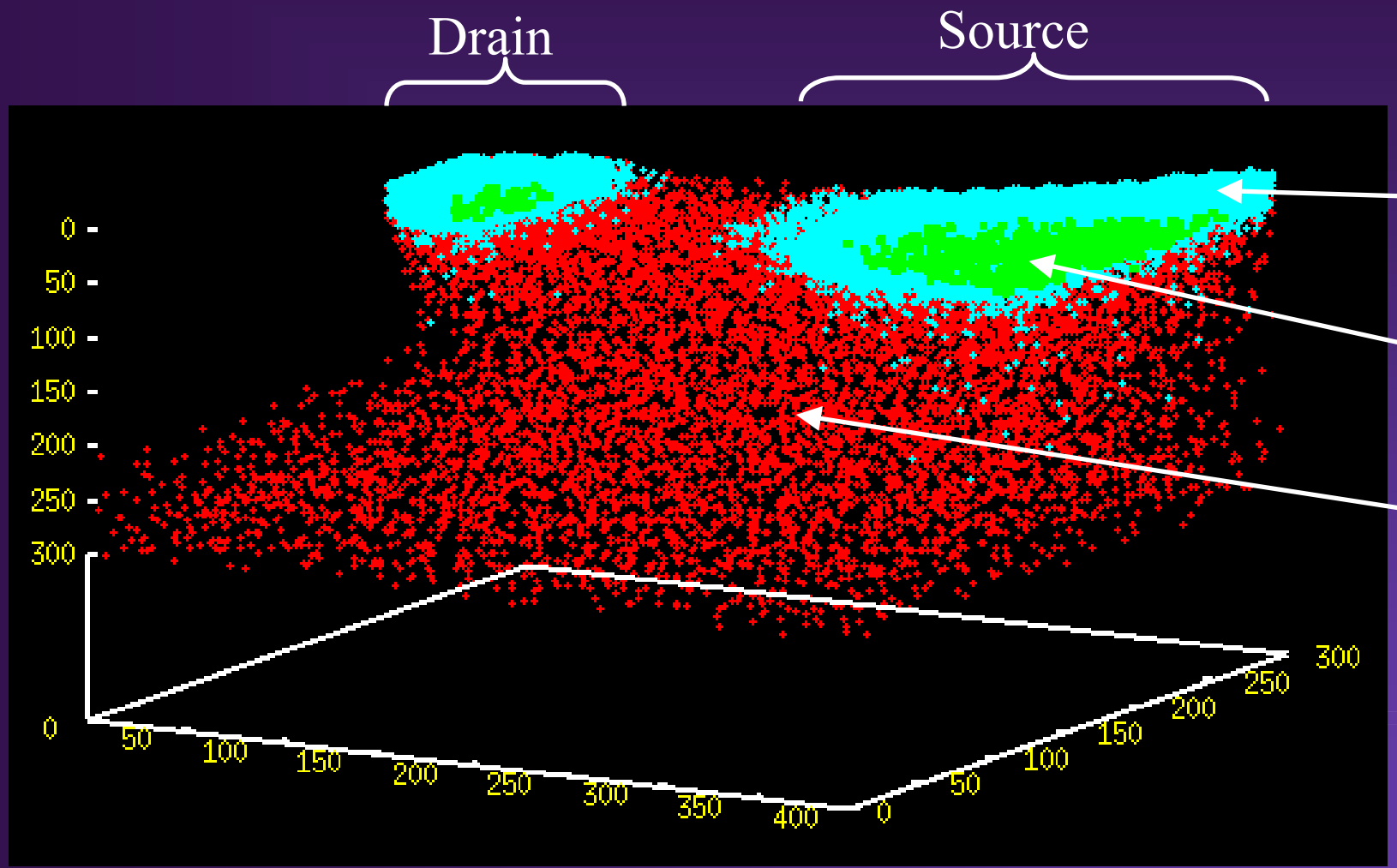
- Current is much higher at the STI corners
- Within the channel, the current density varies by a factor of 2

Atomistic Process Simulation

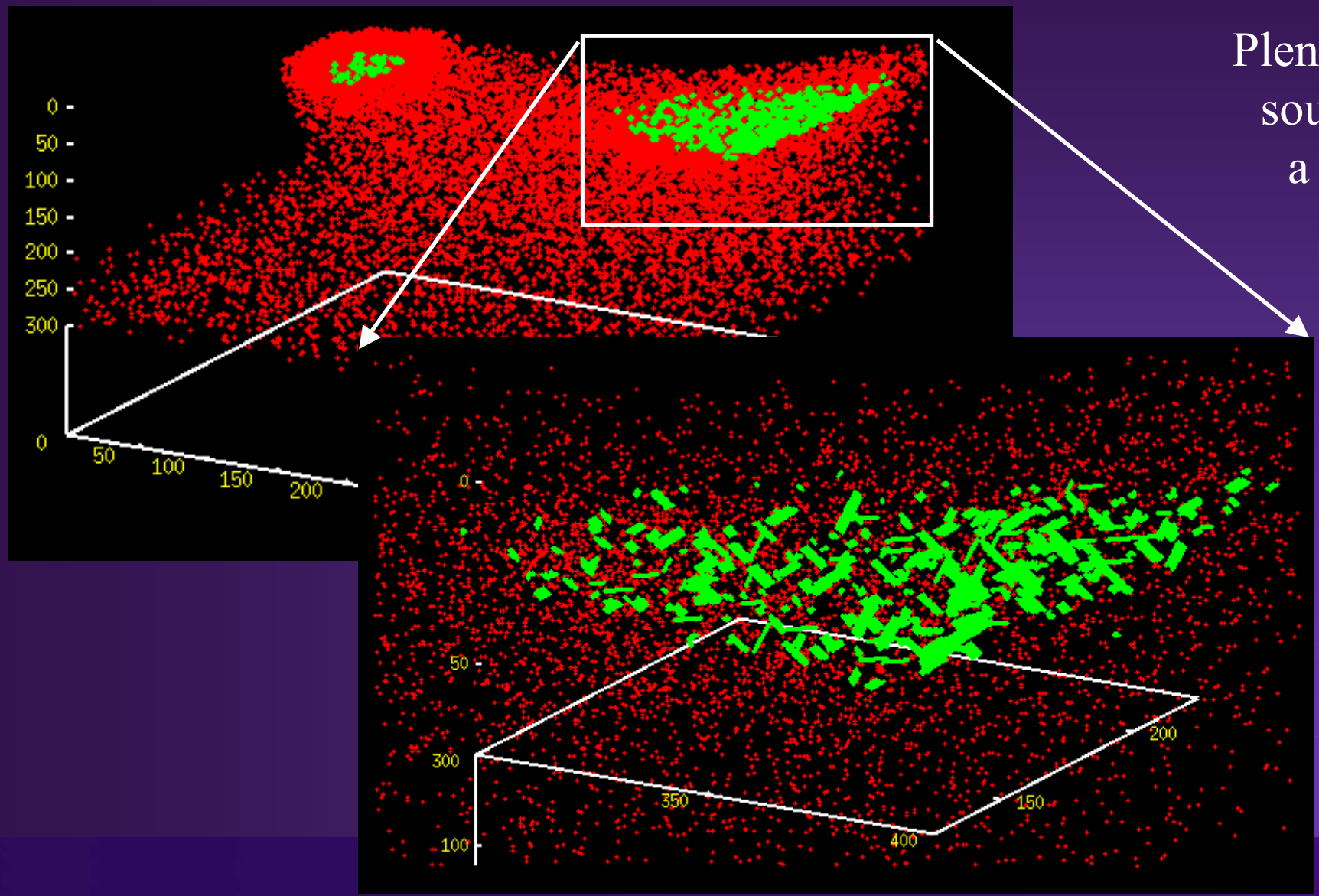
- Deposition, etching and implantation steps are performed in Taurus-Process using continuum approach, where dopants are represented in terms of concentrations.

- The geometry, defect and doping profiles are then transferred to kinetic Monte Carlo diffusion simulator DADOS. Concentrations are converted into the locations of individual particles.

Dopants and Defects in DADOS

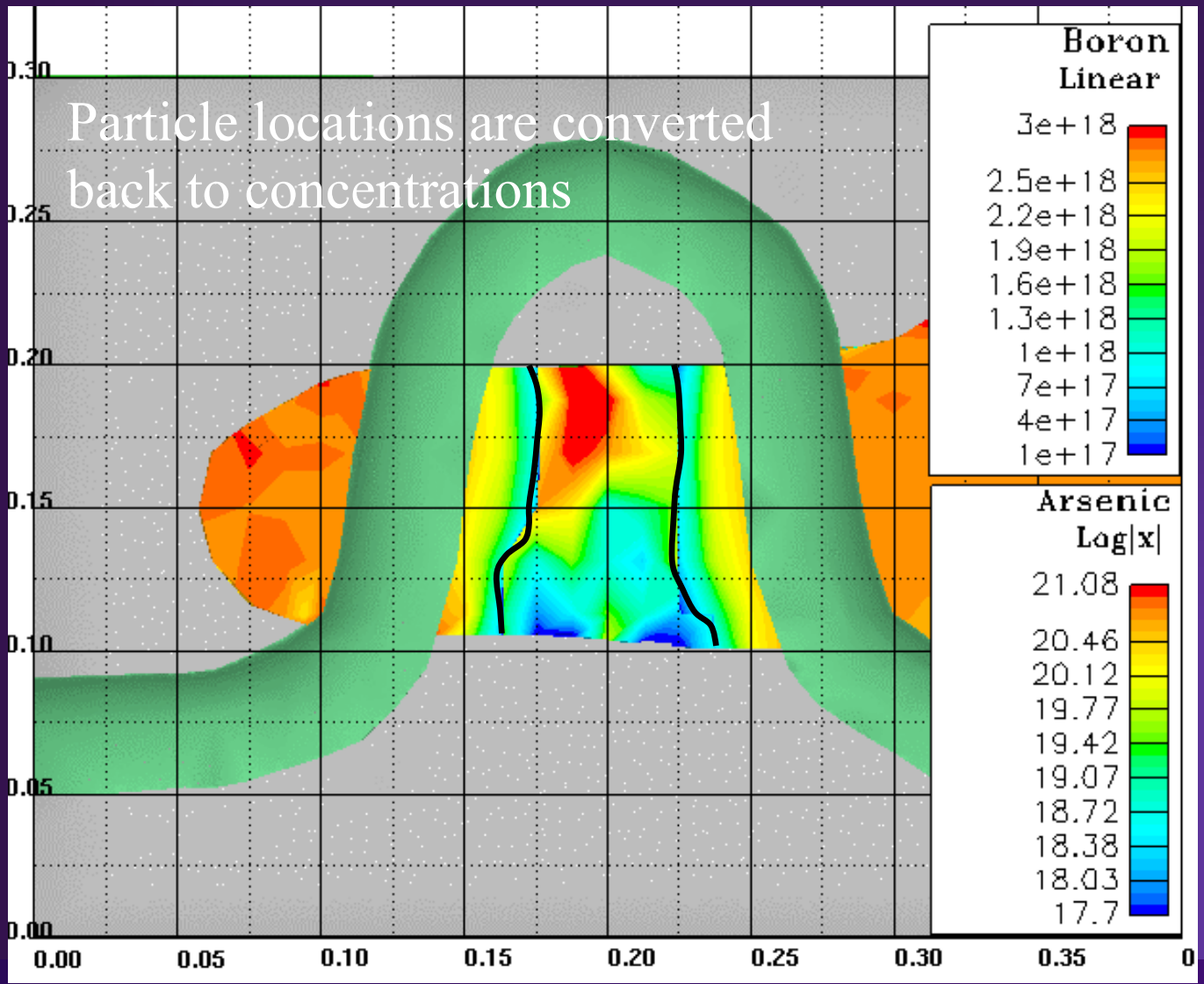


{311} Extended Defects: Zoom In



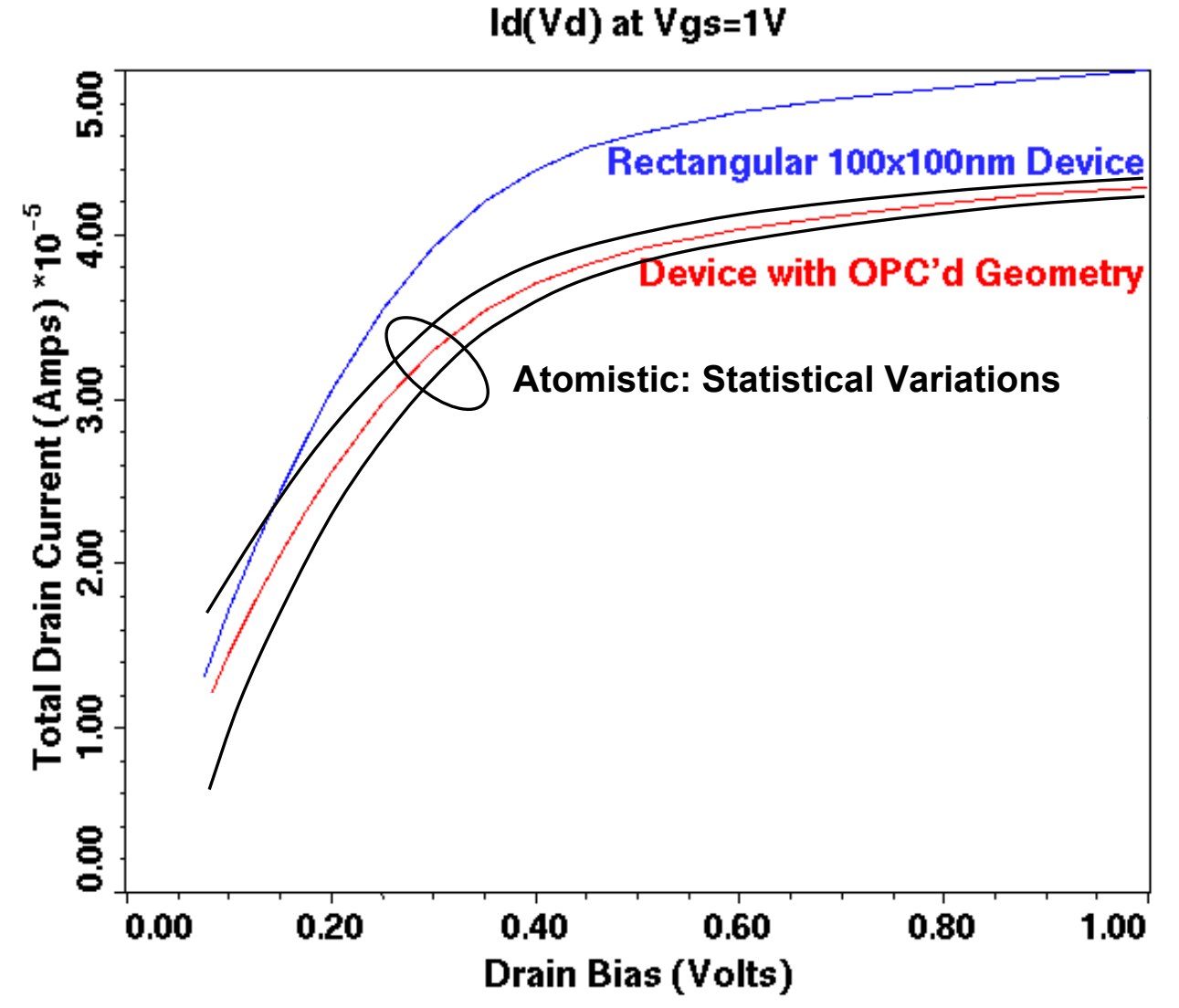
Plenty defects in source, but just a few in drain

Atomistic Doping: Top View



- Channel doping variation is much higher than in continuum mode
- S/D doping is close to the continuum mode because of large number of atoms

Comparing IV Curves



Conclusions

- The following effects are becoming increasingly important:
  - Optical proximity effects
    - Image distortions in optical lithography
    - OPC helps, but rounding remains at corners and line ends
  - 3D
    - Non-rectangular shapes
    - Non-uniform profiles due to the tilted implants
    - Overlapping stress fields from STI, spacer, and other corners
  - Atomistic
    - More accurate defect formation and dopant activation modeling
    - Finite number of particles in the devices
    - Statistical variations from device to device