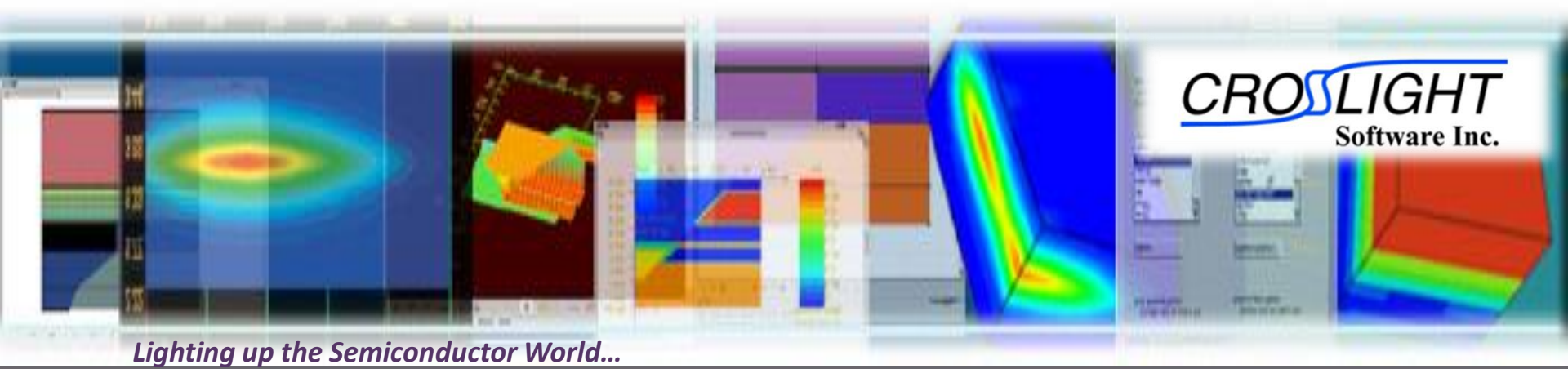


Lighting up the Semiconductor World…

Practical New Approach to 3D TCAD Simulations

By: Simon Li, Fred Y. Fu, Lisa Li and Kentaro Uehara

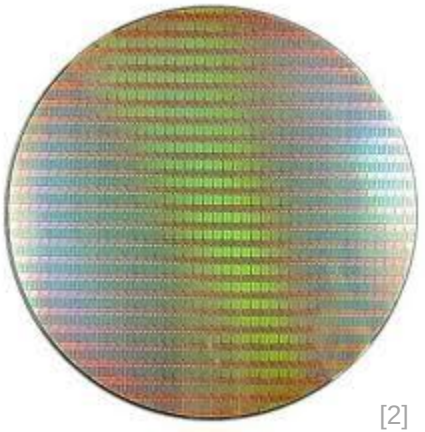
What is TCAD?

TCAD stands for "Technology Computer Aided Design" where a software tool is used to simulate the semiconductor process technology and a device's electrical, thermal and optical properties

Why TCAD?

TCAD can boost productivity and increase efficiency for semiconductor technology development in Foundries, IDMs and even fabless companies. TCAD is like Virtual Fabrication and Testing of semiconductors

[1]



[2]

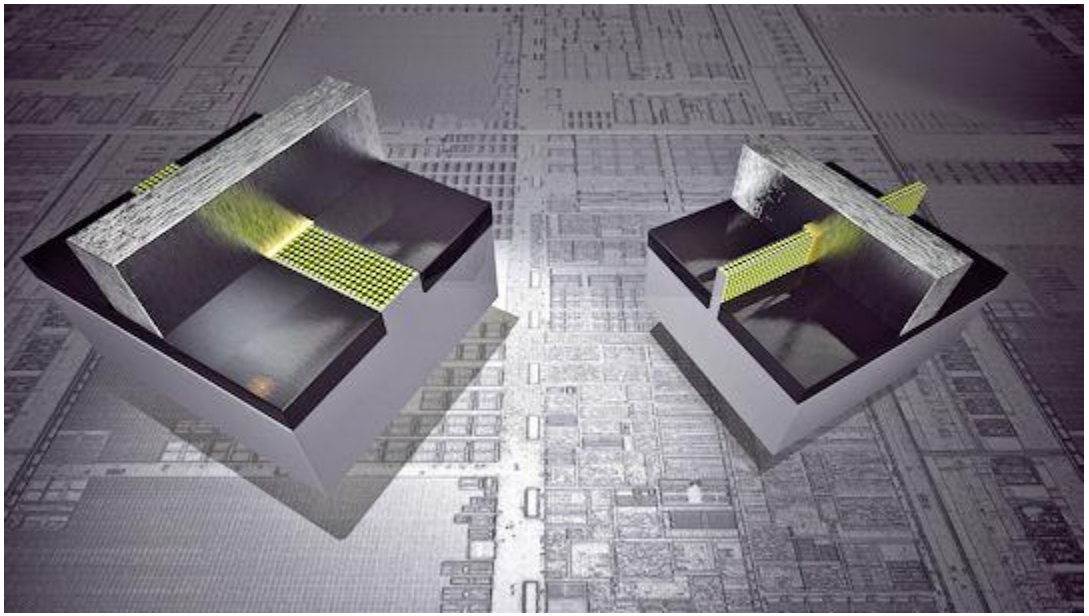
Why 3D TCAD?

For decades, TCAD has been limited to 2D, because:

- Lack of computing power for the simulator
- Device structures have little variations in the third dimension

Nowadays 3D simulation is increasingly important:

- Pronounced three dimensional effect
- Better understanding of device physics



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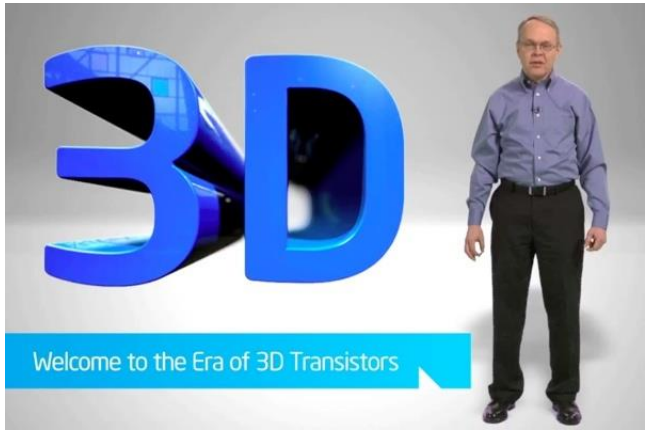
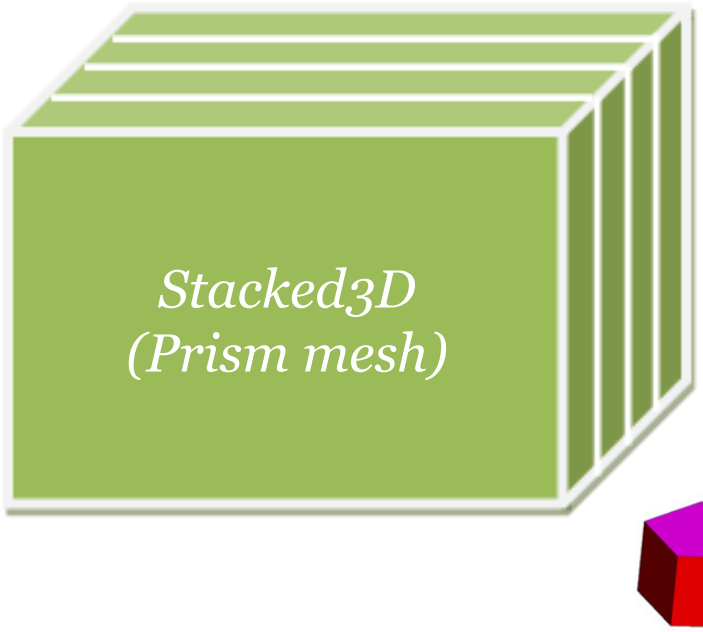


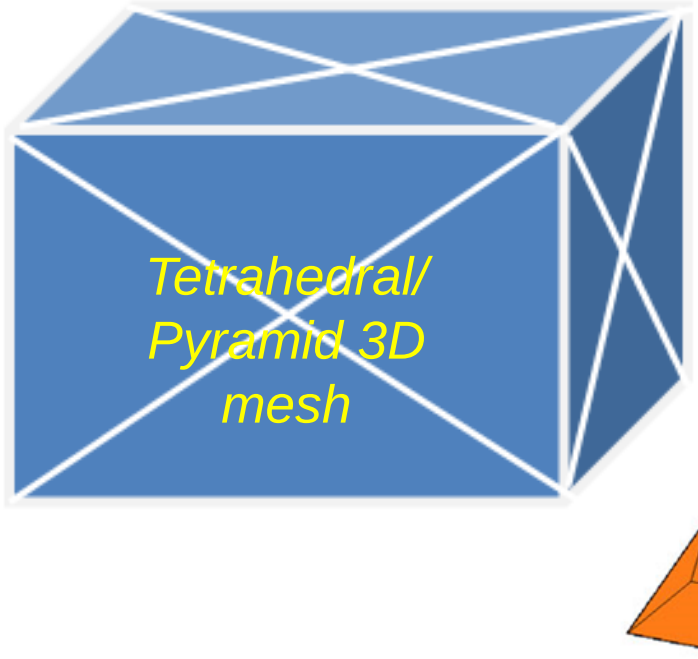
[4]

Intel's latest 22nm Ivy Bridge processor featuring 3D FINFET

Contents

3D TCAD Mesh Generation





Prism Mesh

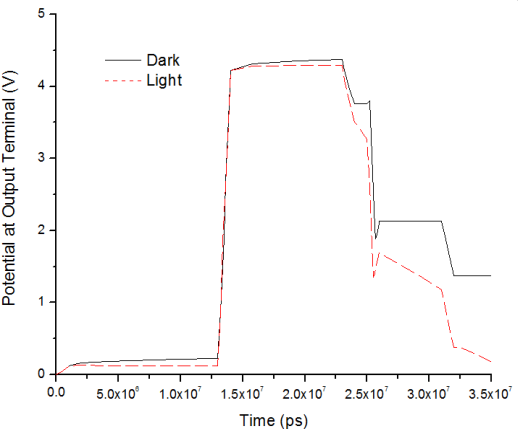
- ☑ Higher Efficiency
- ☑ Easier to build and control
- ☑ Directly extract 2D planes
- ☑ Better convergence
- ✗ Relatively new

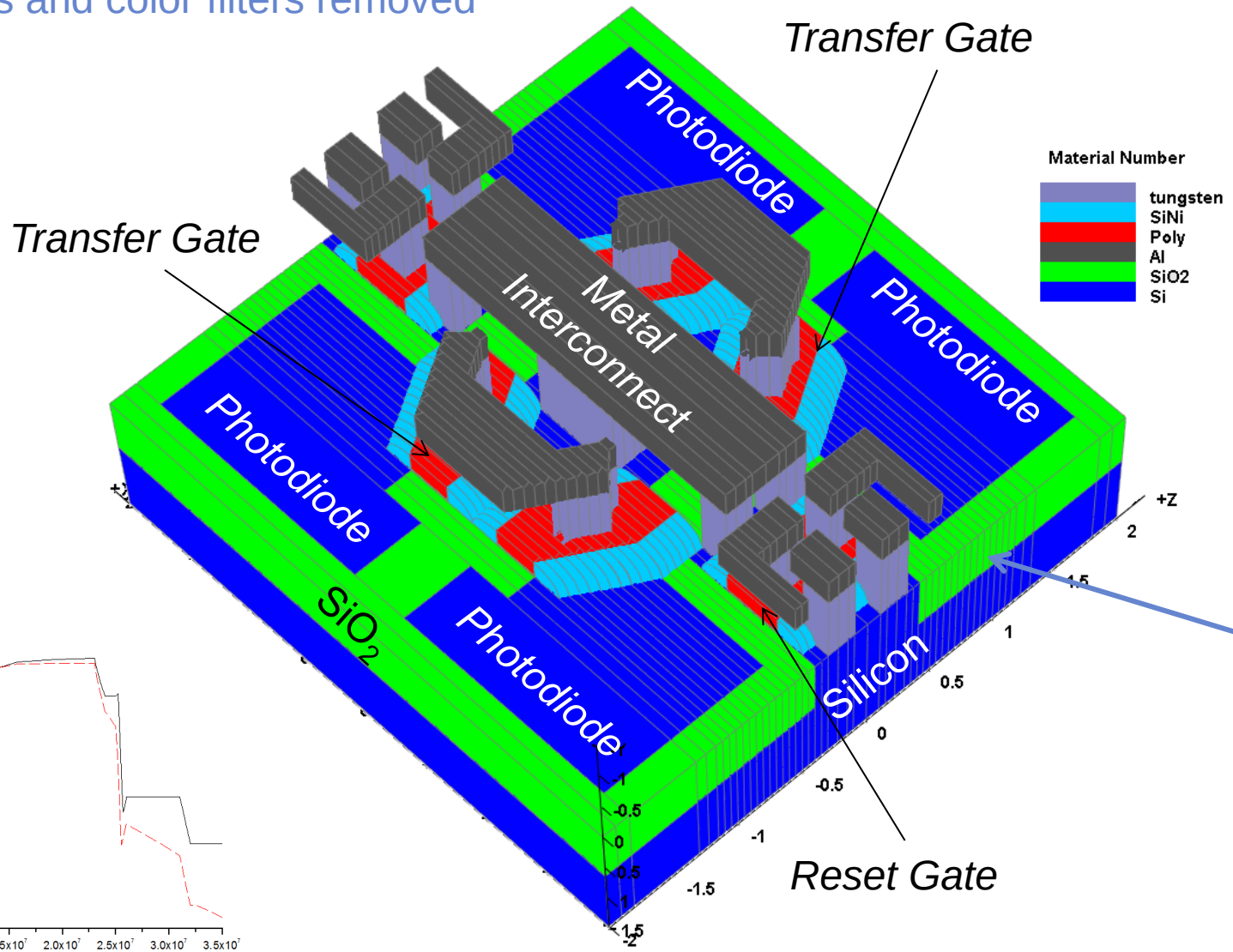
Tetrahedral Mesh

- ☑ Relatively mature
- ☑ Available from many vendors
- ✗ Less efficient
- ✗ Difficult to control
- ✗ Convergent problems

Example: CMOS Image Sensor

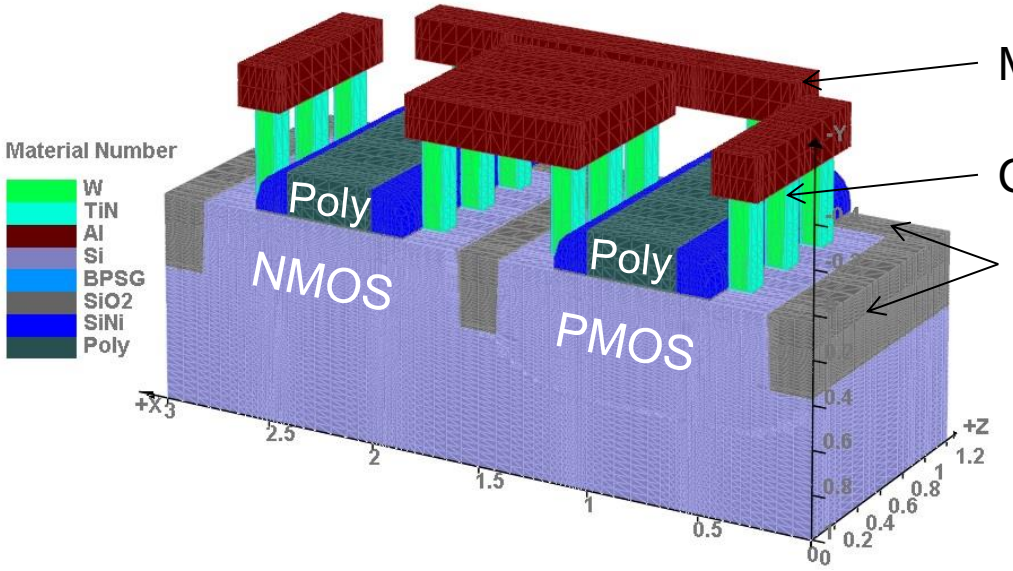
With lens and color filters removed





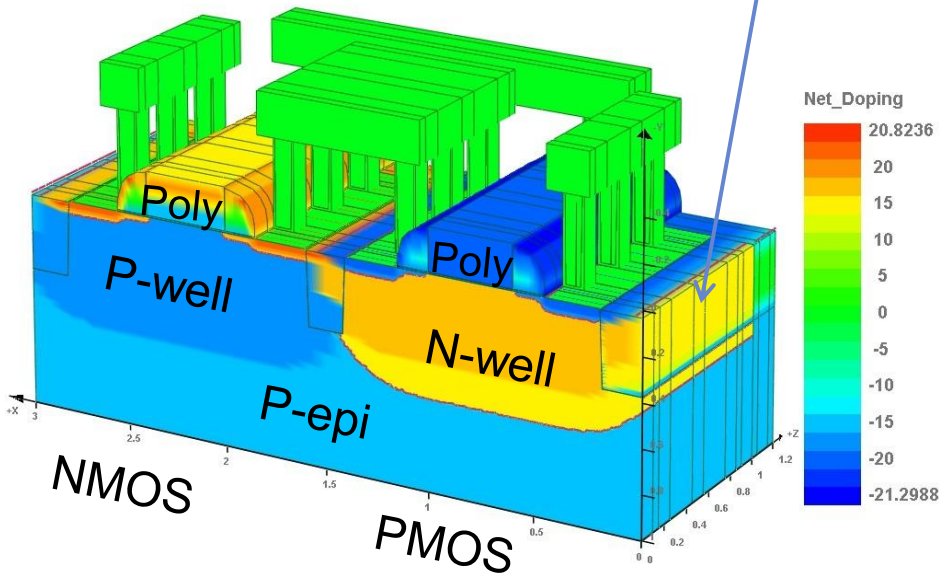
[6]

Example: CMOS Process Flow



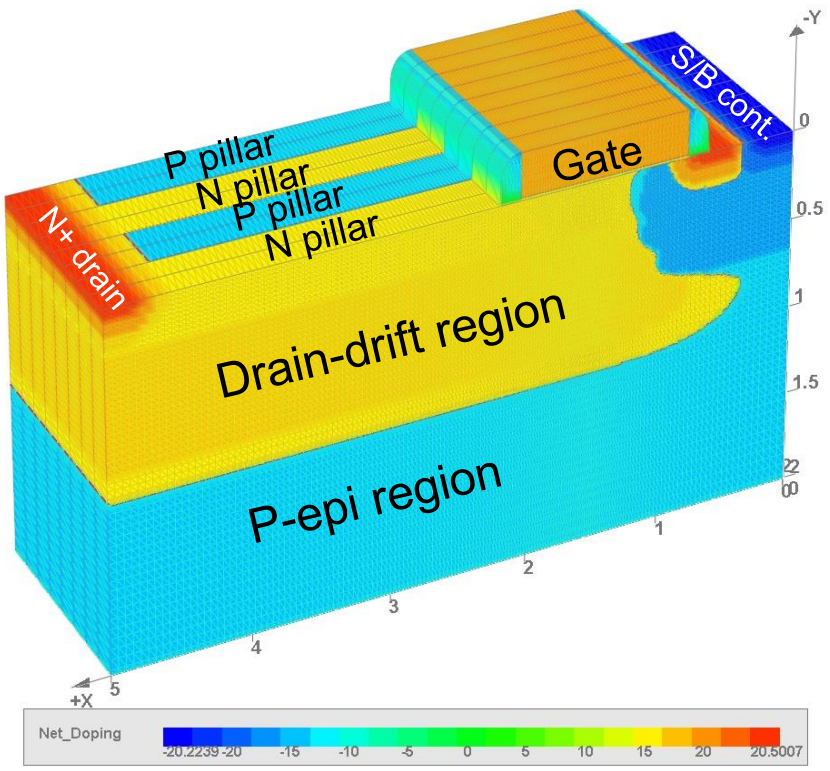
Stacked Planes

NMOS and PMOS are grown side by side and isolated by STI



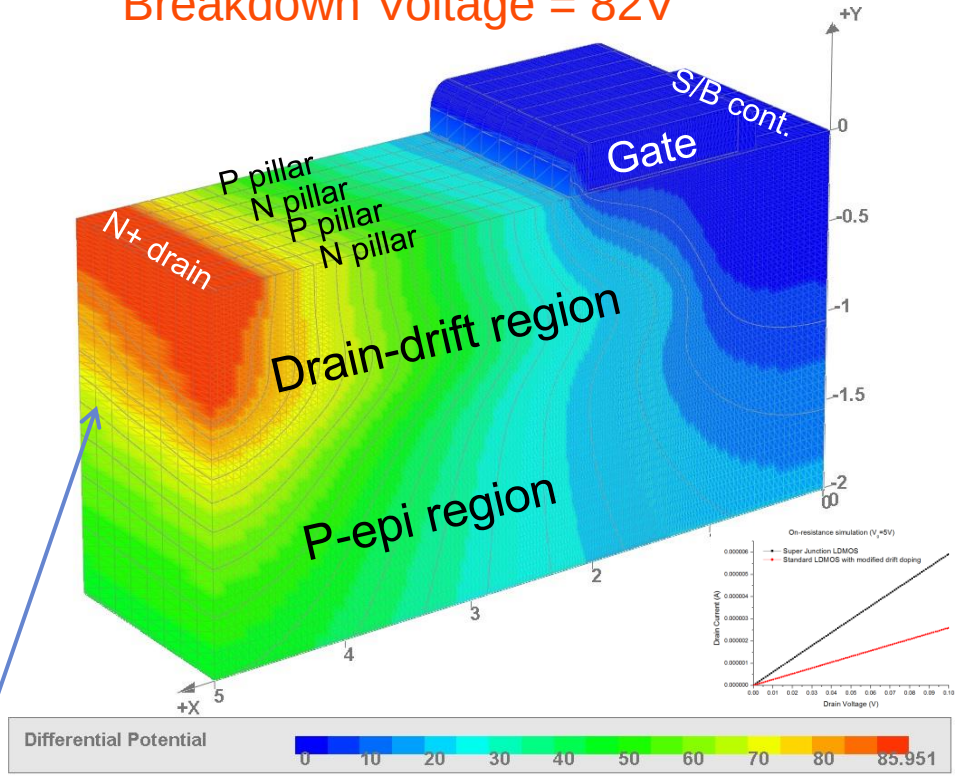
Example: Super Junction LDMOS

Super Junction LDMOS can achieve lower on-resistance with the same breakdown voltage as conventional LDMOS



Net doping concentration plot

Breakdown Voltage = 82V



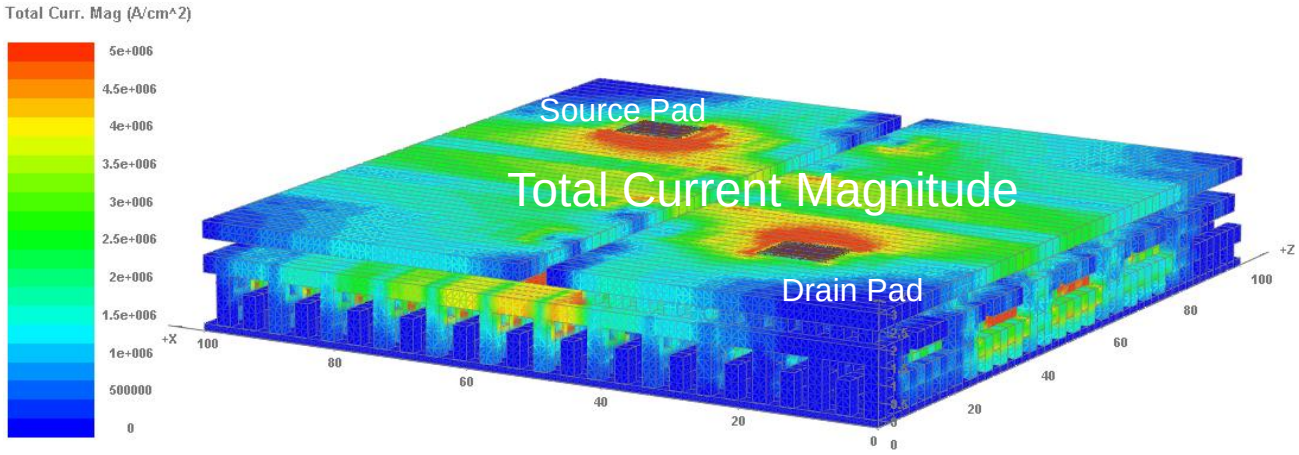
Potential plot after breakdown

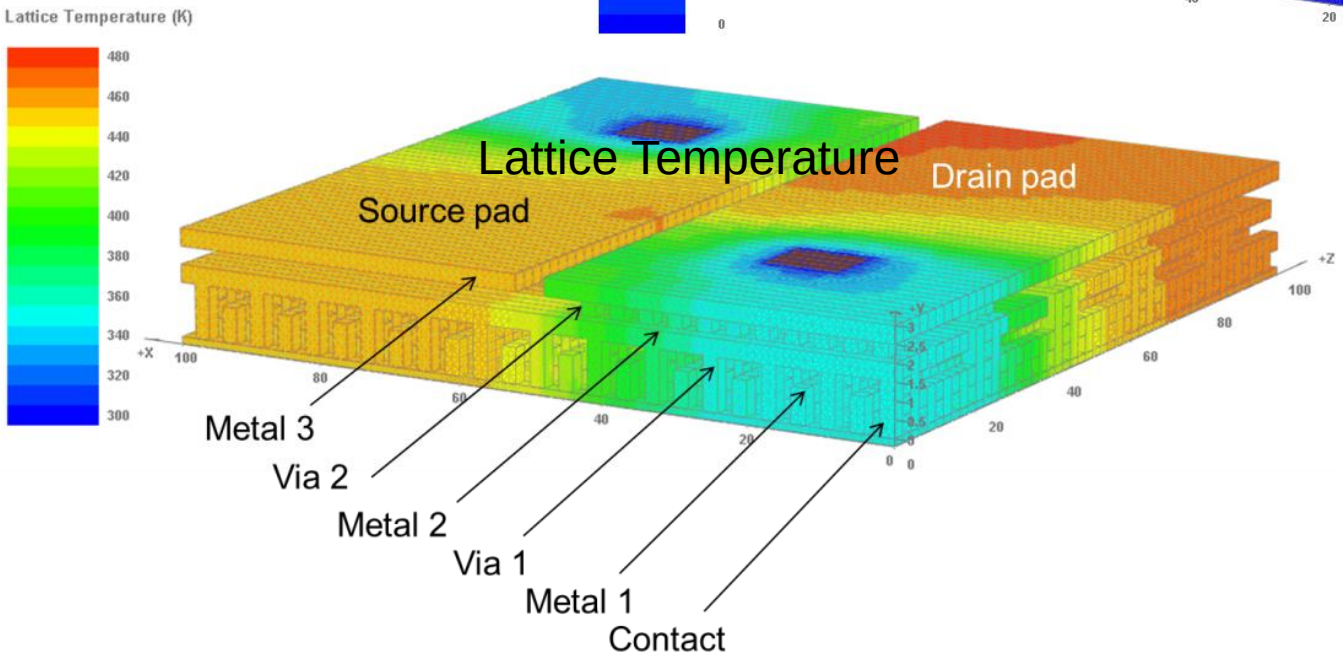
Stacked Planes

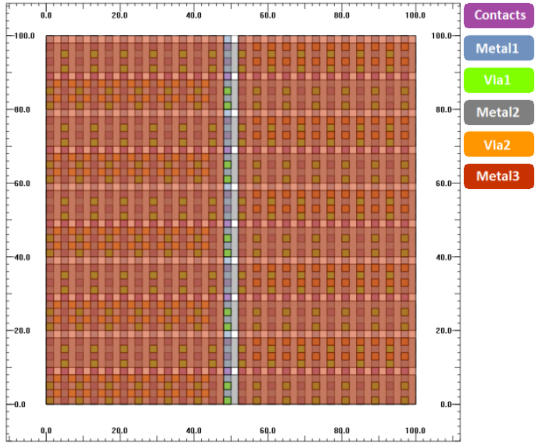
Example: Complex Interconnect

Interconnect current magnitude and lattice temperature distribution at high current bias

Total Mesh points: 110,000
Total stacked planes: 100

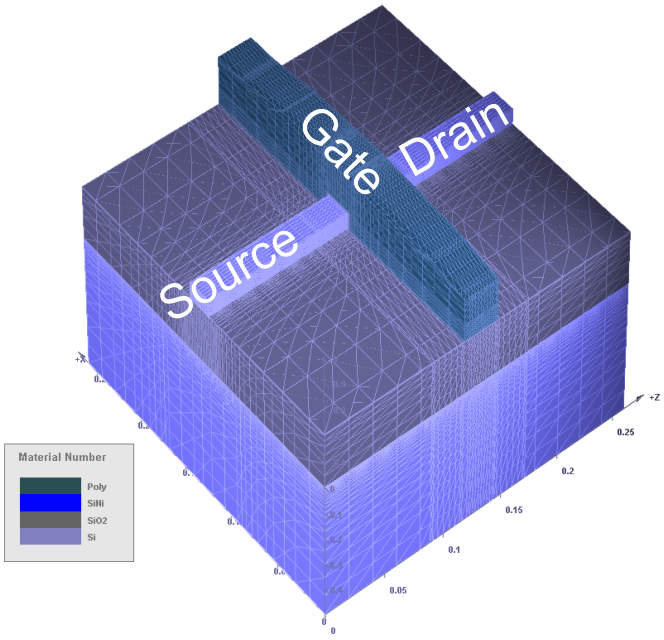


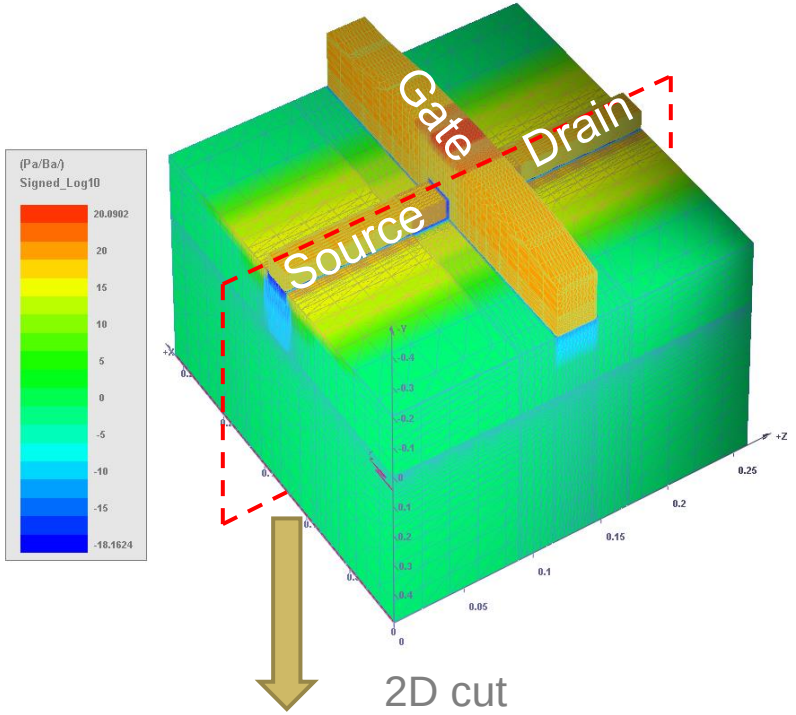


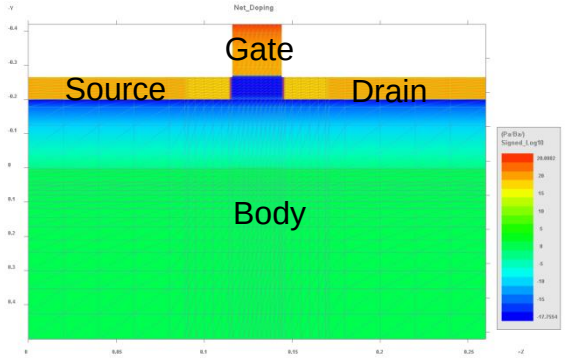


Example: FINFET with NEGF

A simple FINFET is simulated with Non-Equilibrium Green's Function (NEGF)

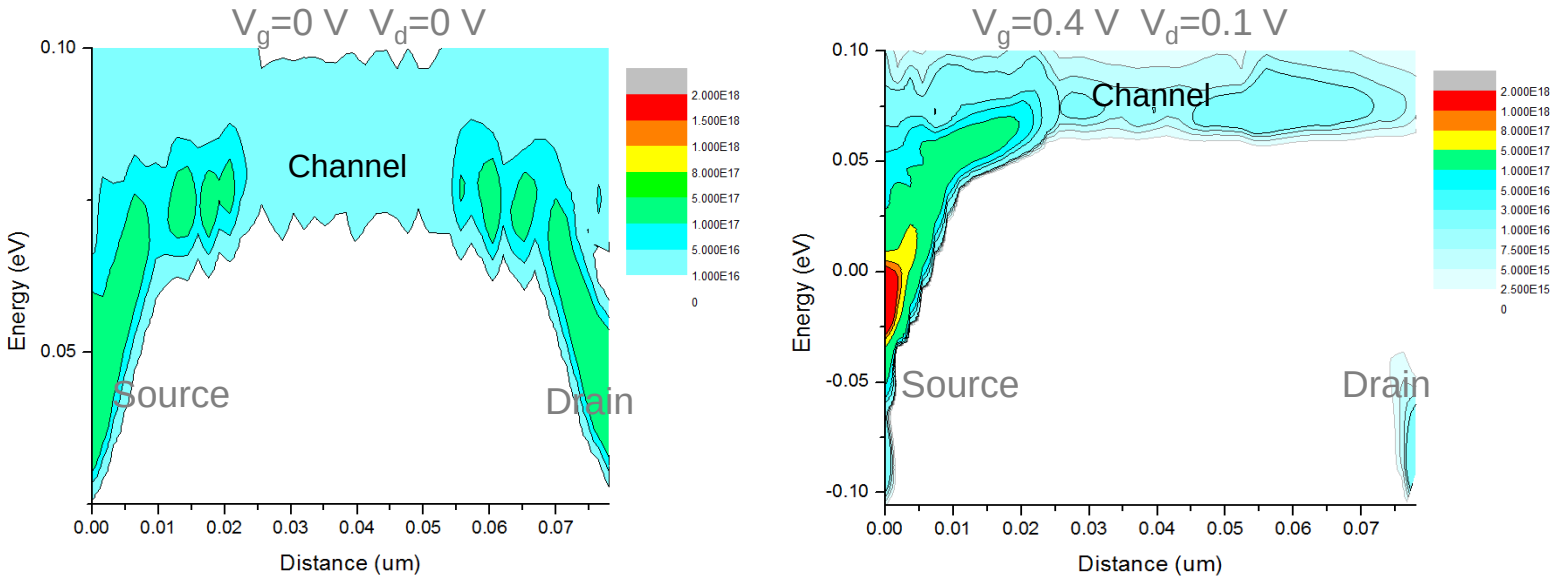






Example: Simple FINFET with NEGF

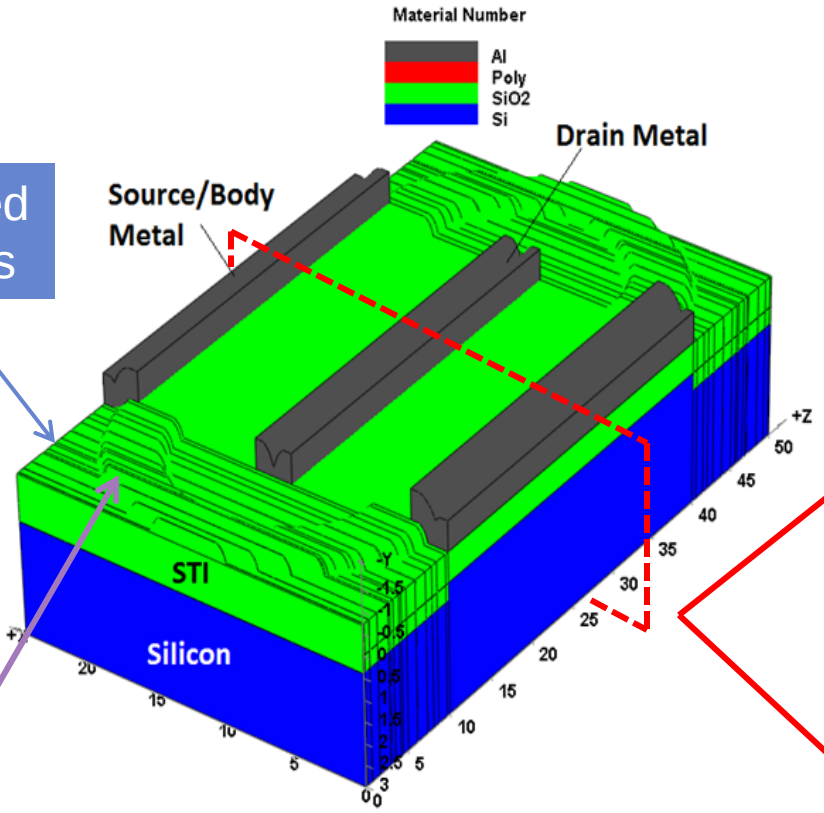
- The device is divided into classical drift-diffusion (DD) region (mainly in vicinity of source/drain contacts) and quantum ballistic transport (QBT) region in the channel
- NEGF (Non-Equilibrium Green's Function) model is employed in QBT region
- Poisson's equation solver is used in both DD and QBT regions

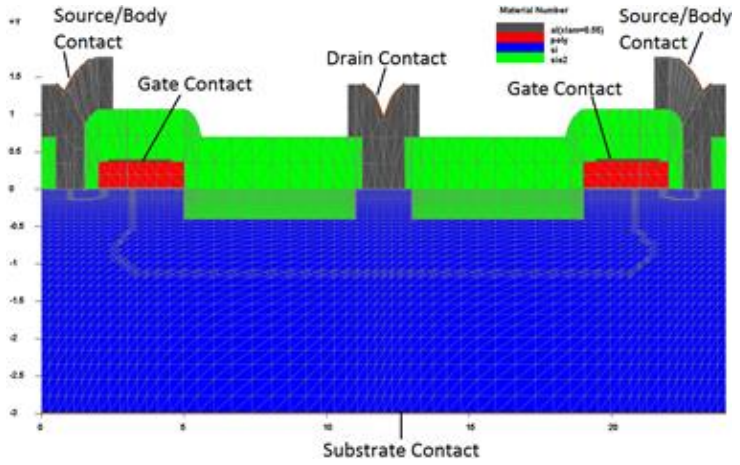


Electron density of val=1 sub=1 along the channel. As V_d increases, more electrons will be injected from source to drain by ballistic transport.

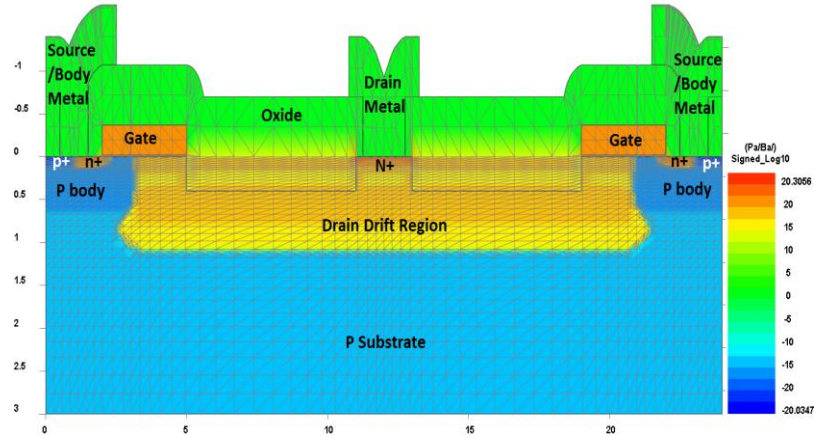
Example: Racetrack LDMOS

Stacked Planes





Materials plot from 2D cut



Net doping plot from 2D cut

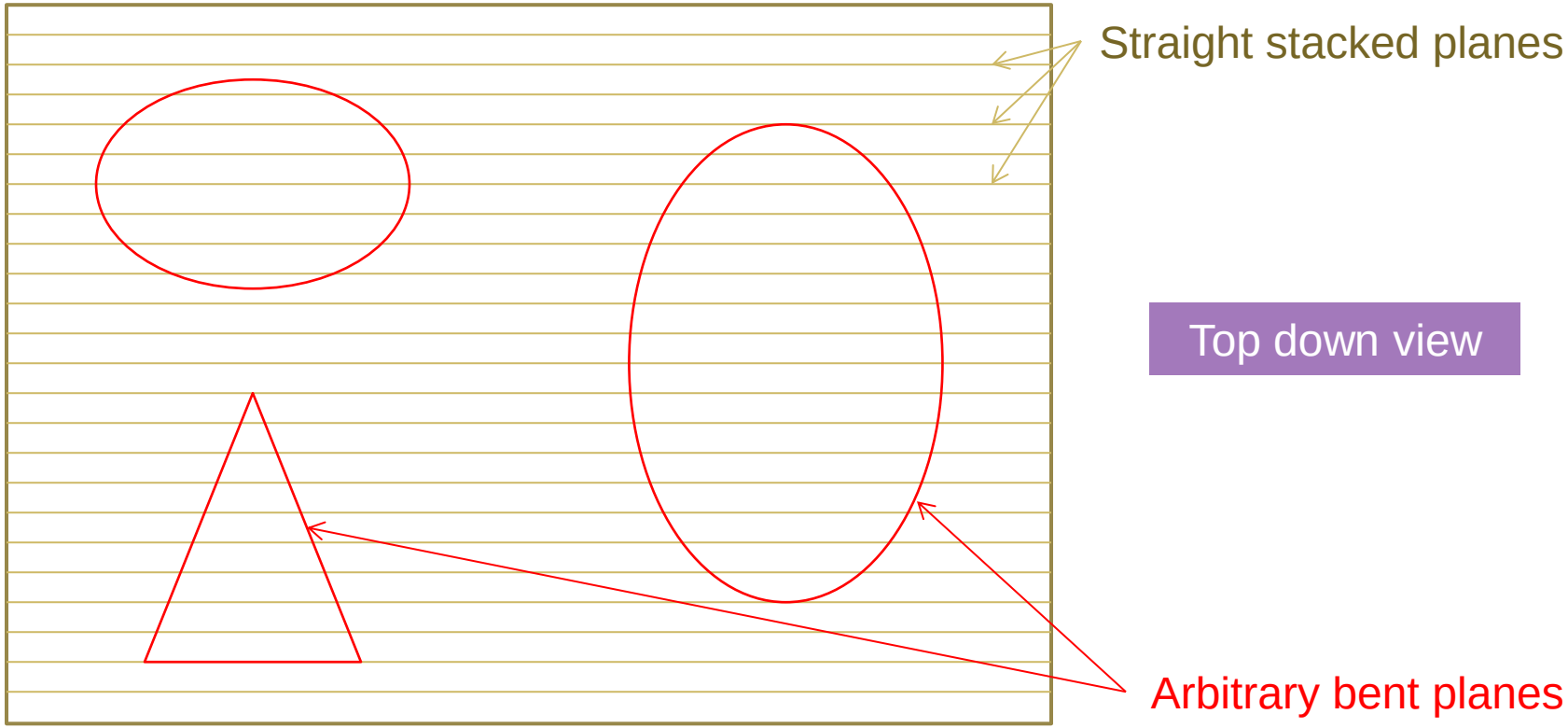
LDMOS with racetrack shaped gate: curved areas are not very smooth even though there are many stacked planes

[6]

Contents

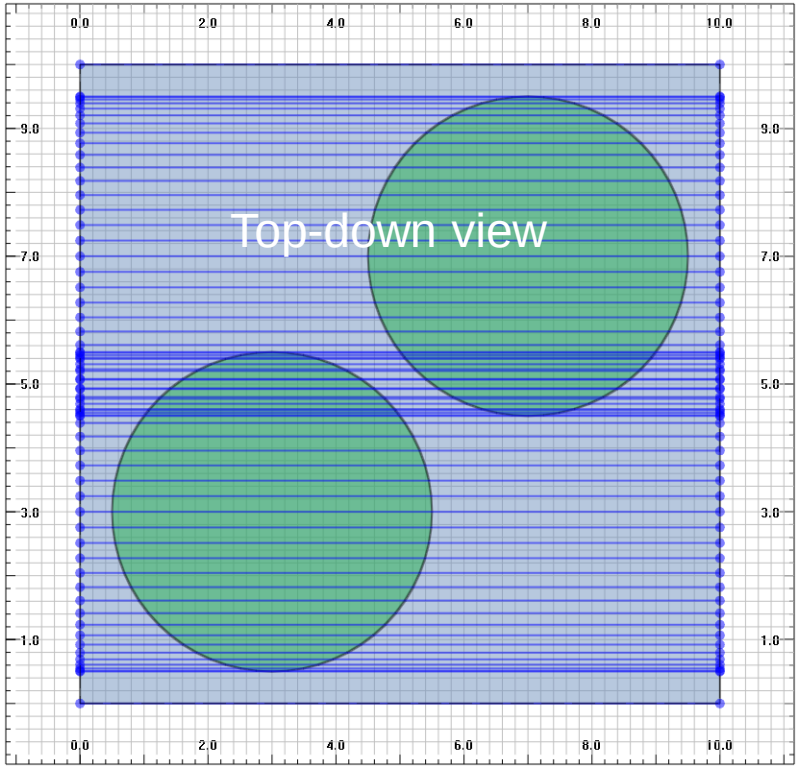
Bent Planes

While straight stacking planes are good at handling rectangular shaped structures, they can be inefficient for curvatures. For arbitrary and curved structures, a novel method is to apply a new kind of planes called bent planes inserted between straight planes. These bent planes greatly optimize the mesh design in the Z direction

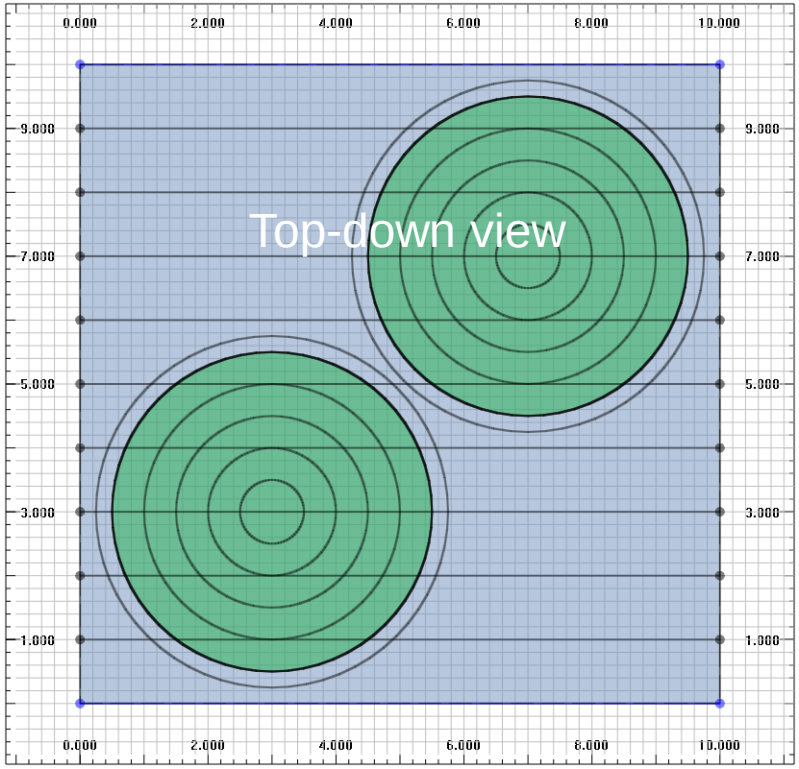


Bent Planes

Straight planes + bent planes solution can help reduce the total mesh and avoid the unnecessarily dense mesh locations in the straight planes only method

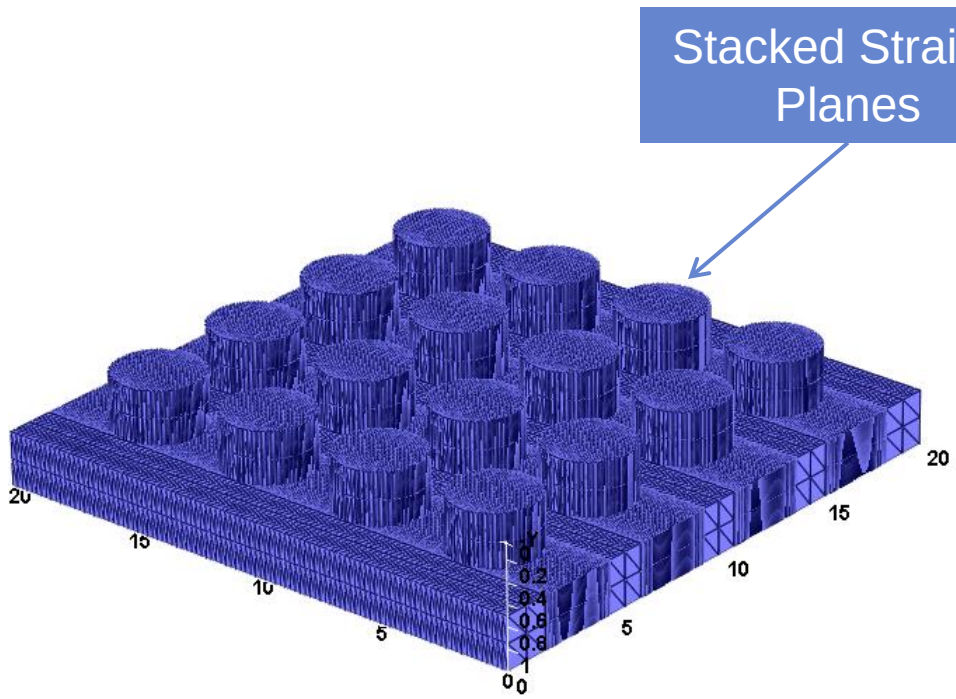


With straight planes only (75)
Mesh size: 33000

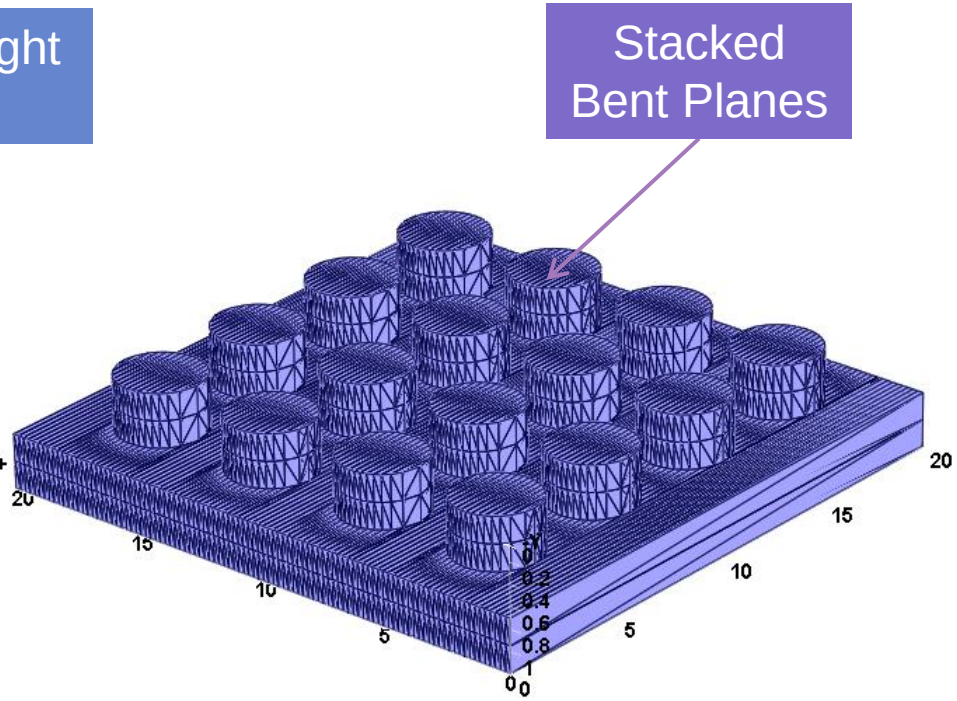


Straight planes (9) + bent planes (12)
Mesh size: 4800

Example: Array of Silicon Pillars



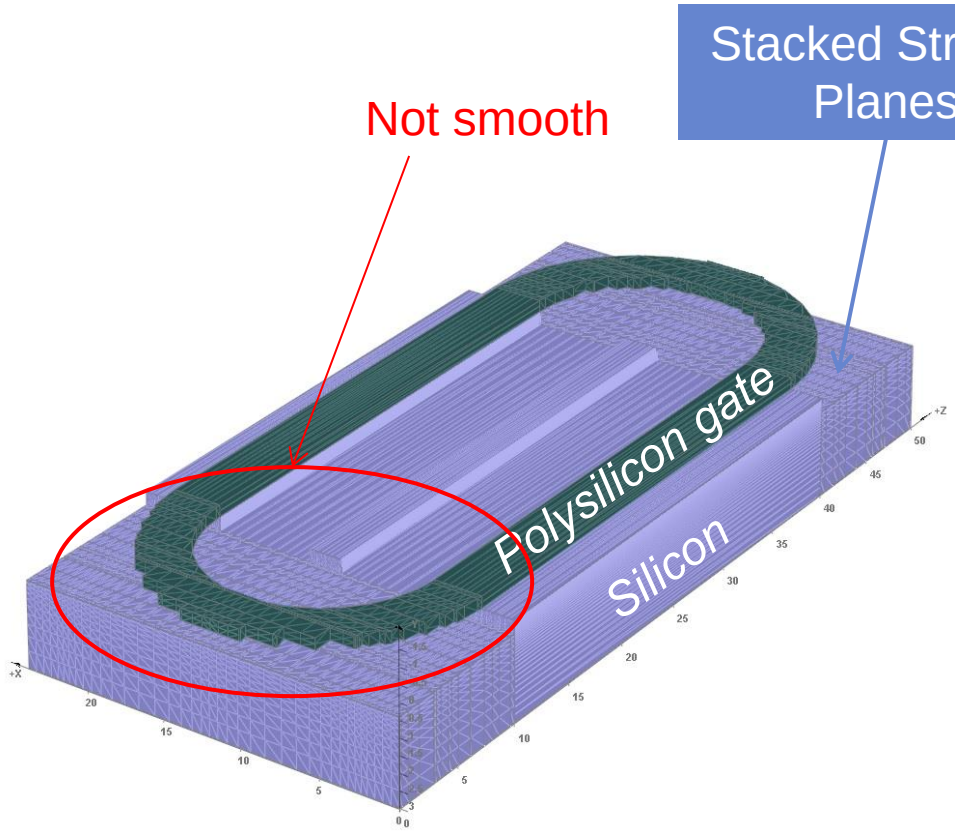
- Total Mesh Count: 52682
- Straight planes: 134
- Process Simulation time: 50 minutes



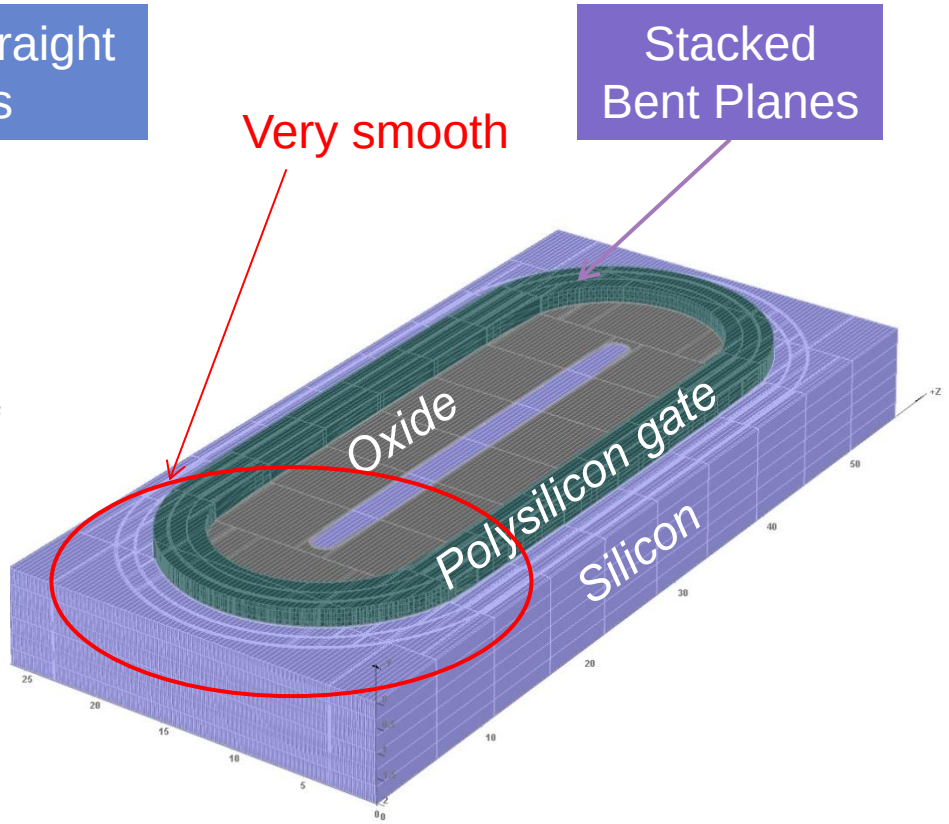
- Total Mesh Count: 4958
- Planes: 2 straight+ 16 bent planes
- Process Simulation time: 2 minutes

[6]

Example: Racetrack LDMOS

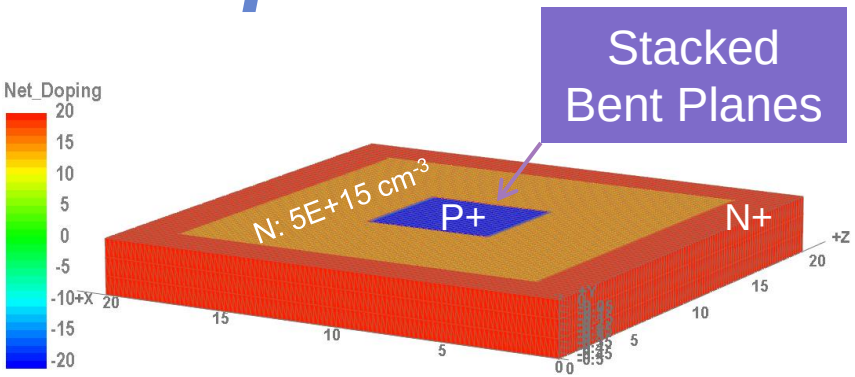


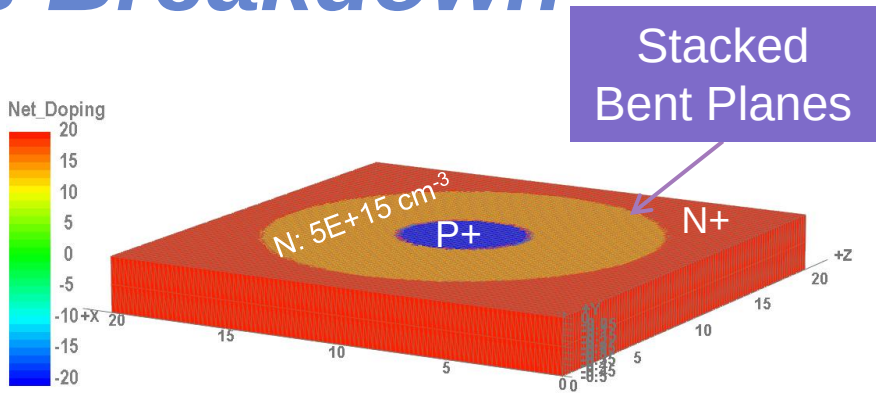
Structure with straight stacked planes only (with oxide and metal layers removed)

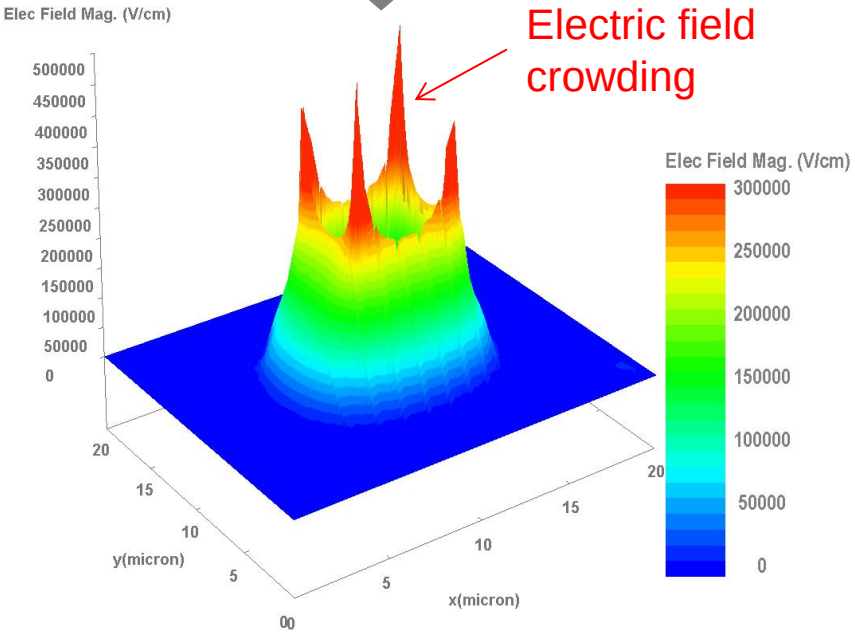


Structure with straight and bent planes (with metal layers removed)

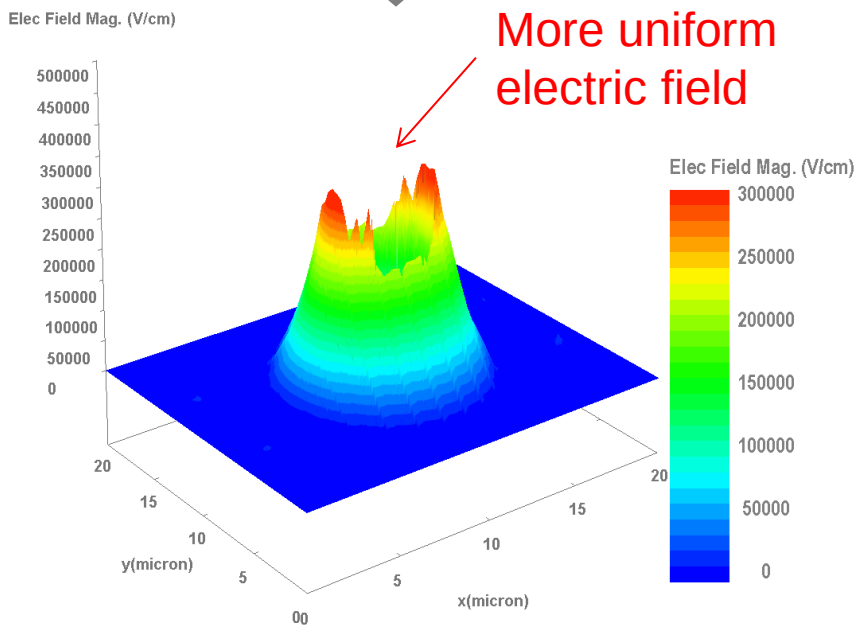
Example: 3D Diodes Breakdown





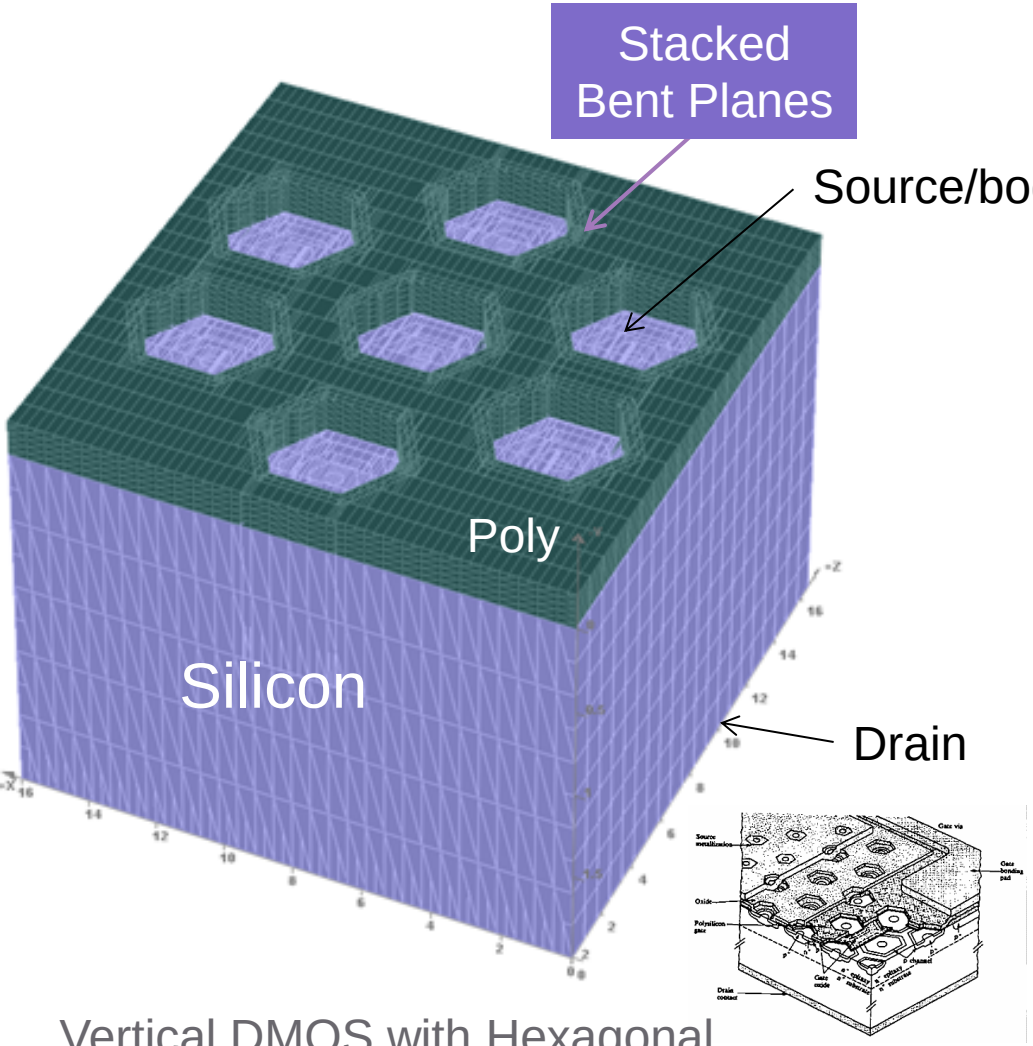


Breakdown Voltage= 50V

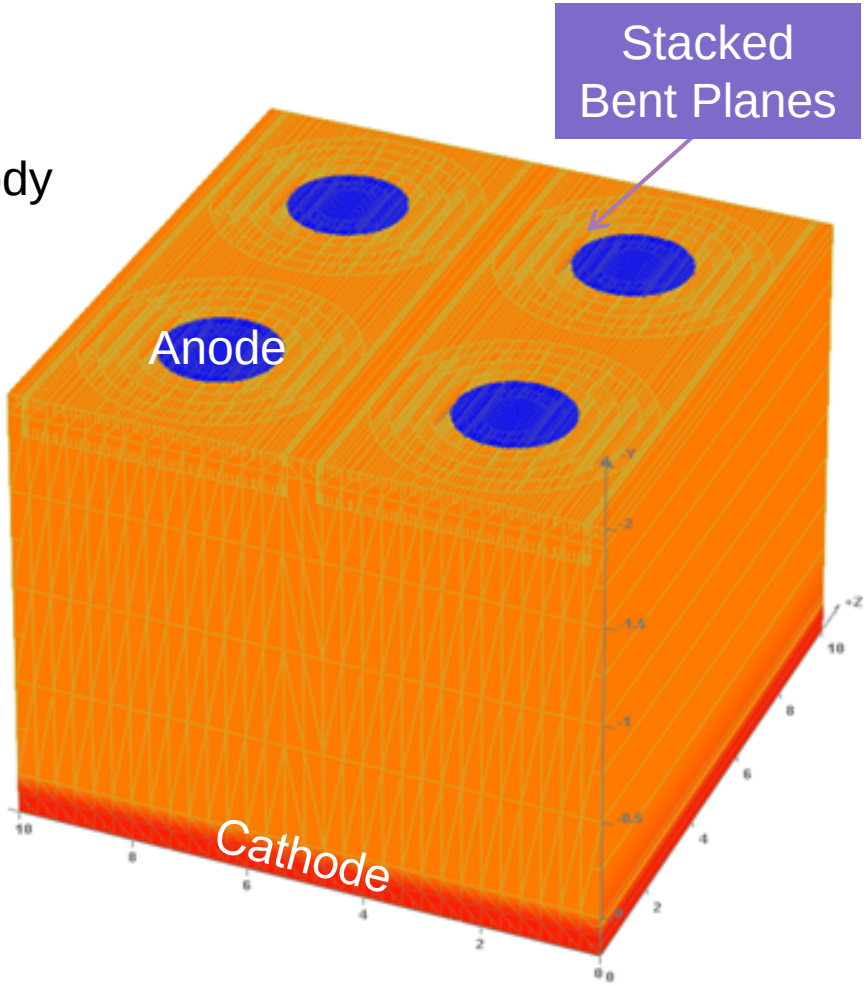


Breakdown Voltage= 67V

Example: Vertical DMOS and Diode



Vertical DMOS with Hexagonal shaped gates

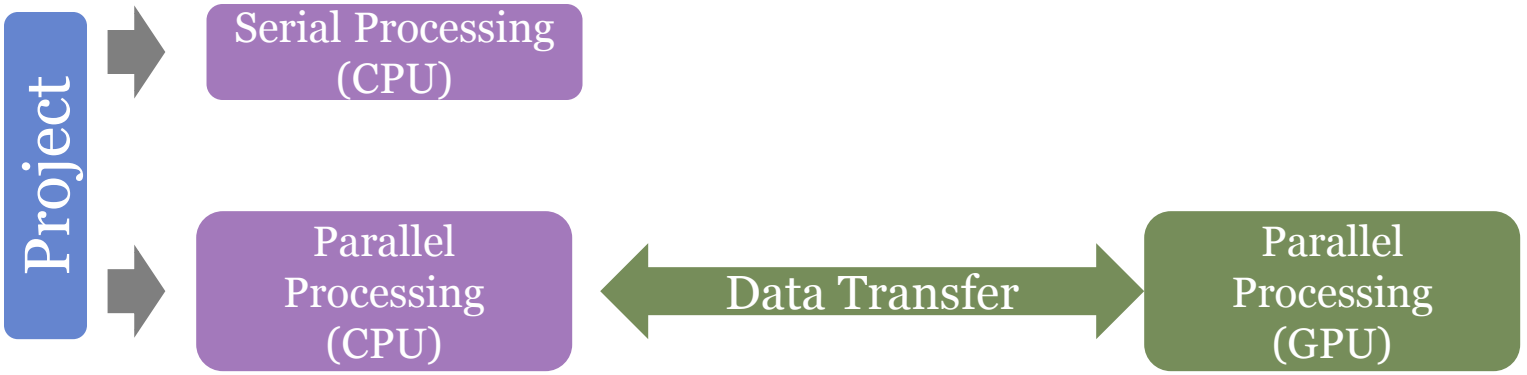


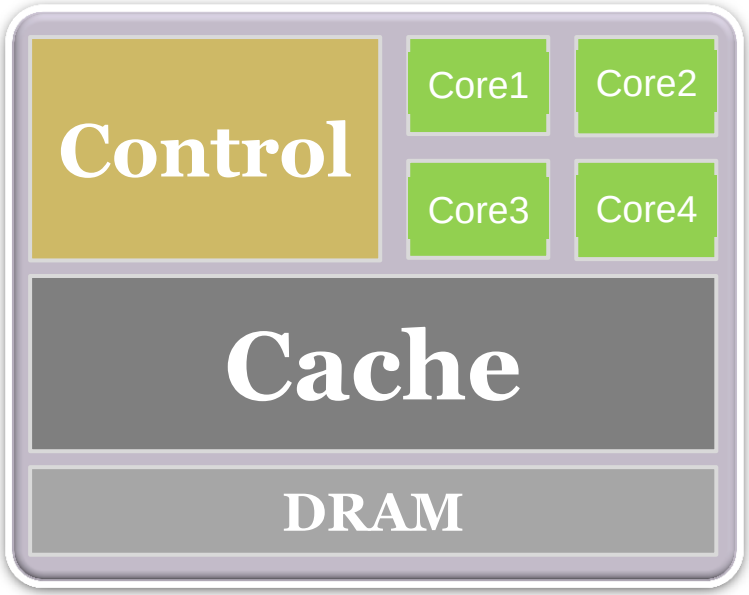
Vertical diodes structure

http://www.irf.com/technical-info/guide/device.html

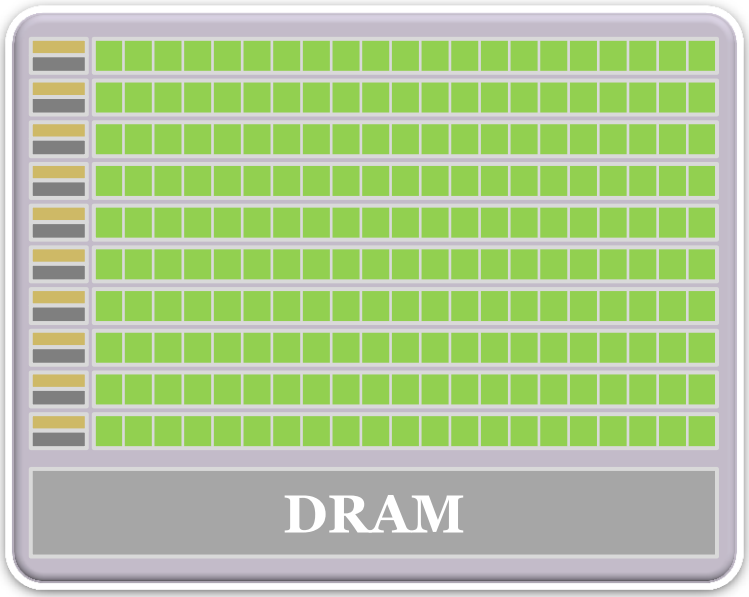
Contents

GPU Simulation





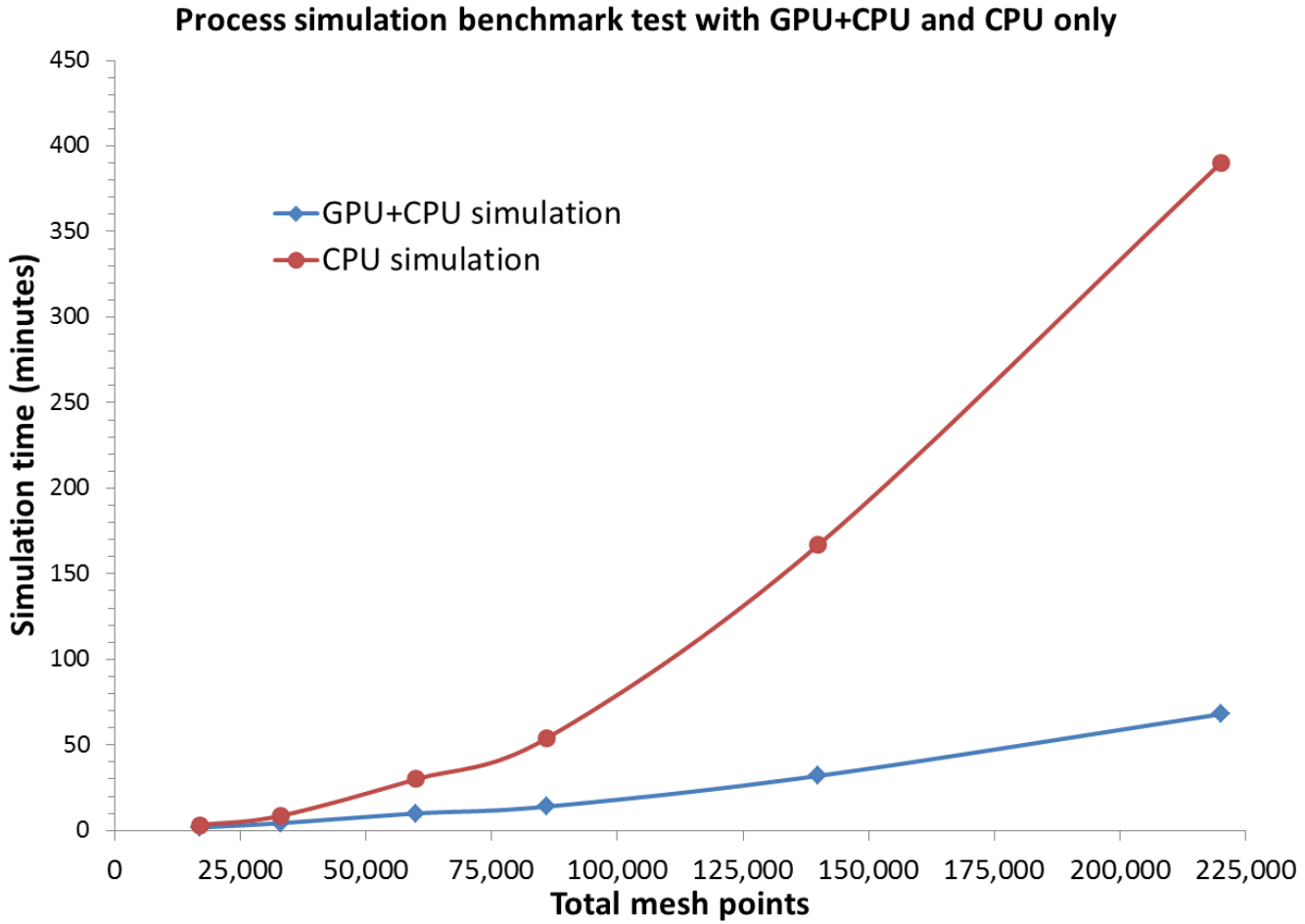
Simplified CPU Architecture



Simplified GPU Architecture

GPU Simulation Benchmark

GPU (Graphic Processing Unit) simulation enables large scale parallels simulation to greatly reduce simulation time



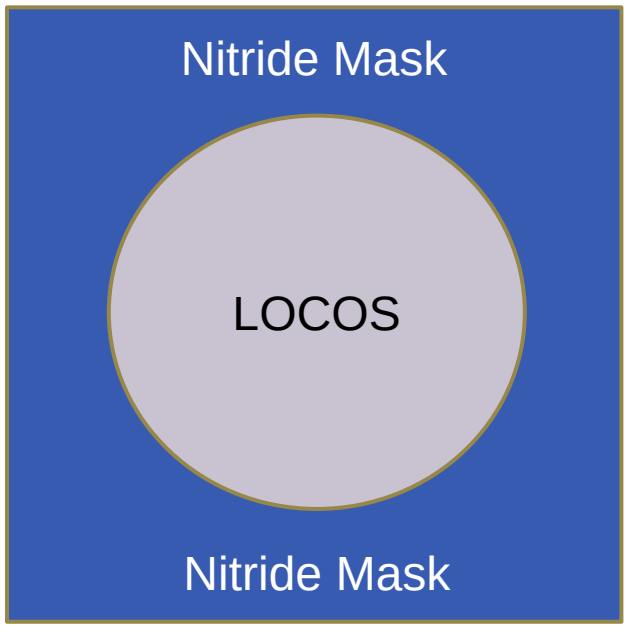
Intel core i7 3770 with 32 G memory and 64bit Windows 7 OS. GPU: NVidia Geforce GTX 690

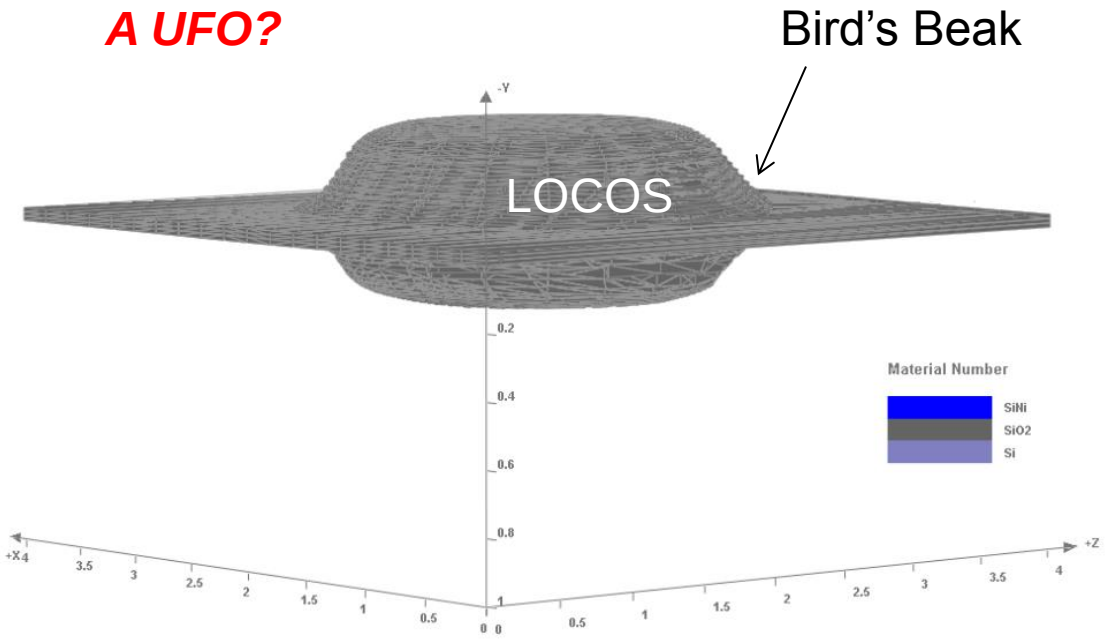
GPU Simulation:

FDTD (Finite-difference time-domain) simulation of light propagation and optical intensity from top of a lens

Example: 3D Circular LOCOS Growth

LOCOS: Local Oxidation of Silicon, simulated with GPU



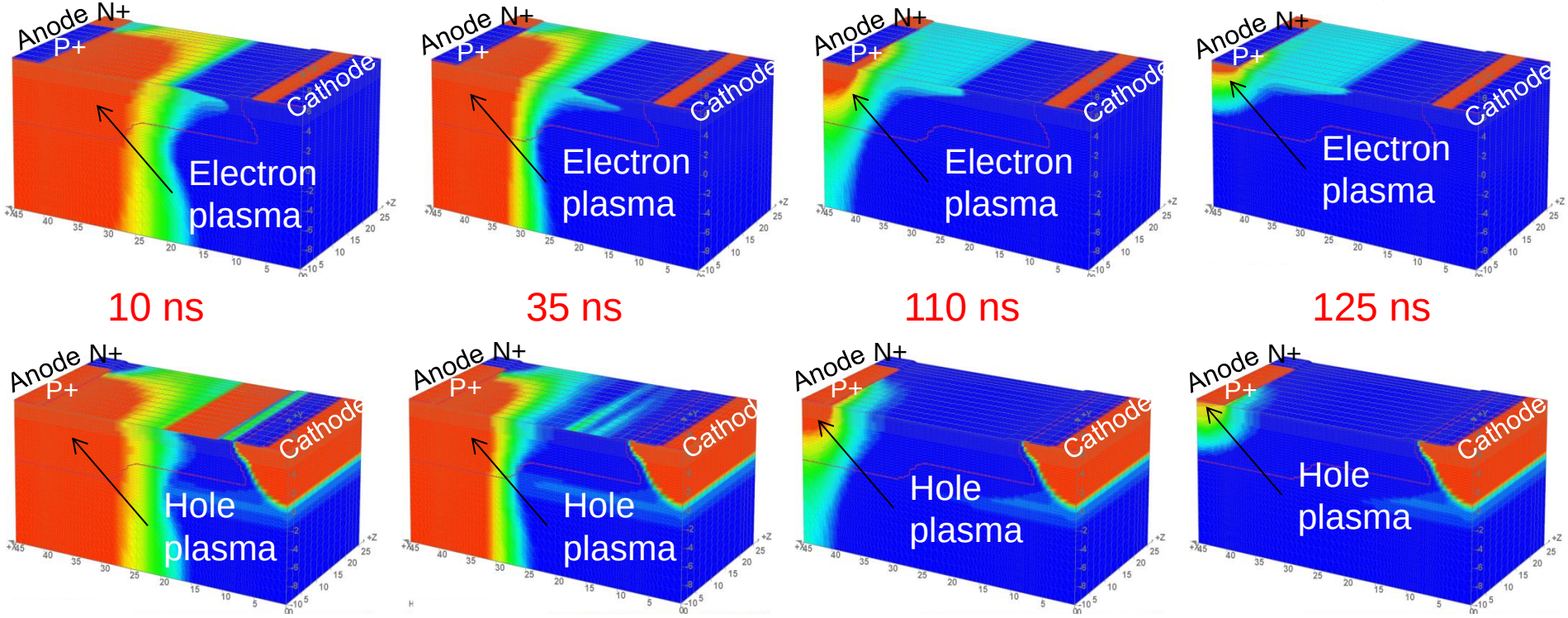


Oxidation and diffusion are the most time consuming steps in a semiconductor process simulation. Fortunately, it is possible to make the simulation job done in parallel. GPU simulation of oxidation and diffusion greatly reduces the total simulation time

Example: LIGBT Switch-off Transient

Transient simulation of a segmented anode Lateral Insulated Gate Bipolar Transistor (LIGBT) with GPU

Electron plasma diminishing in the silicon overtime



Hole plasma diminishing in the silicon overtime

Summary

Practical new approaches for 3D TCAD simulation:

- ✓ Prism mesh instead of conventional pyramid mesh for less convergent issues and more efficient mesh generation
- ✓ Bent planes are created for curvatures and arbitrary shapes in the Z direction
- ✓ GPU simulation can dramatically reduce simulation time

* CPU: i7-3770, GPU: NVidia Geforce GTX 690, Memory: 32 G

Devices	Mesh size	Process simulation time (GPU)	Device simulation time (GPU)
3D E-field	35,000	20 minutes	1.1 hours
LIGBT	167,000	2 hours	35 hours
Super Junction LDMOS	177,000	4.25 hours	55 hours

About Crosslight

A Canadian company with 20 years of history

The world's first commercial TCAD for laser diode

The world's No.1 provider of optics and photonics TCAD

The world's most advanced stacked planes 3D TCAD

CROSSLIGHT
Software Inc.

Reference

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