EE724 Tutorial

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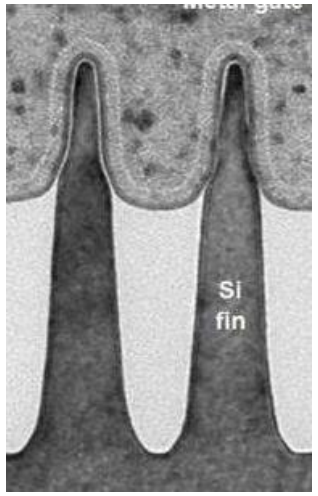
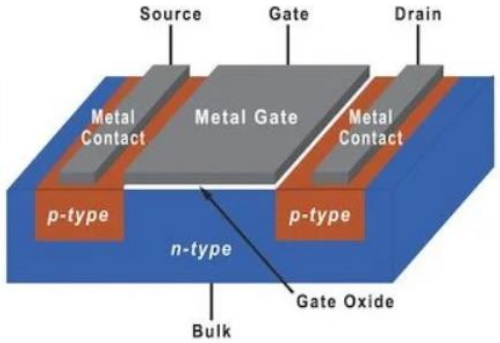
Content

- Introduction FinFET
- TCAD?
  - Why and how to use
  - 3D and 2D FinFET analysis
- FinFET designing for performance improvement
- Takeaways

Introduction to FinFET

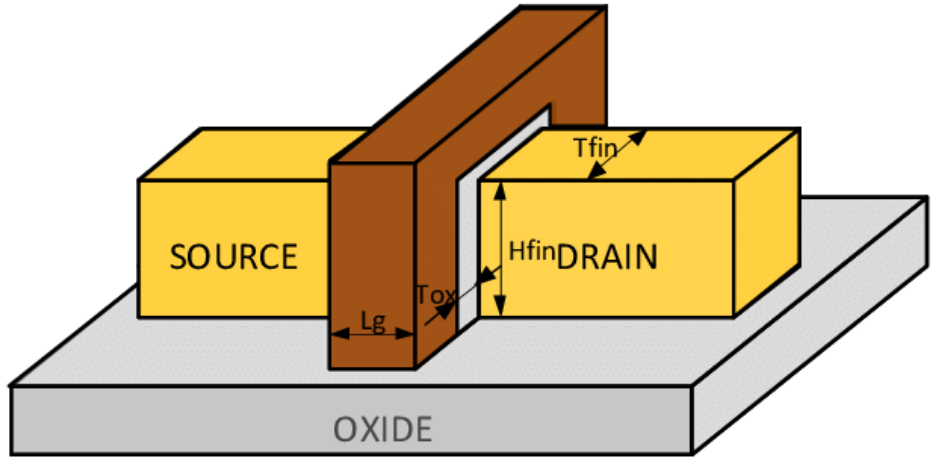
FinFET TEM

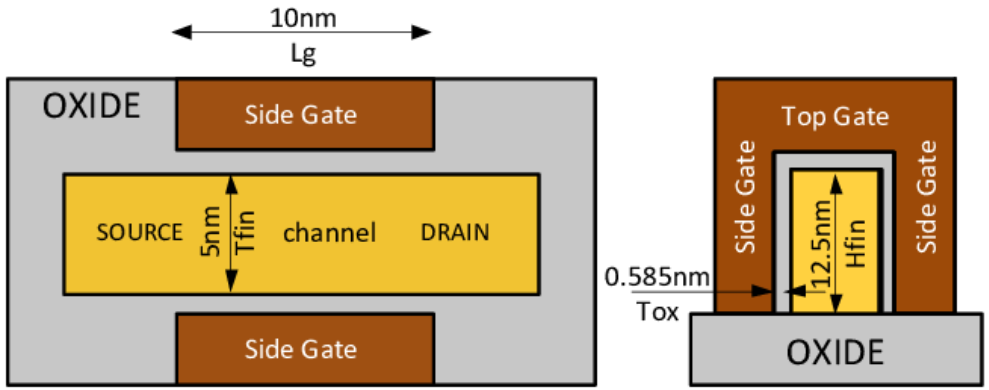




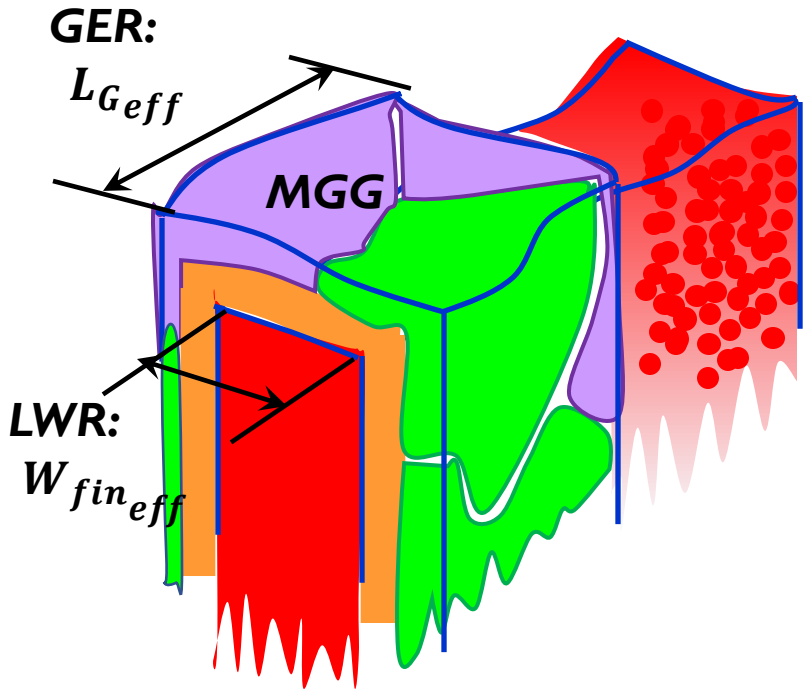
Planar MOSFET

FinFET schematic and cross-section





FinFET with variability



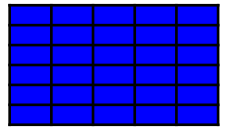
How do you simulate?

LER: Line Edge Roughness
LWR: Line Width Roughness
GER: Gate Edge Roughness
MGG: Metal Gate Granularity

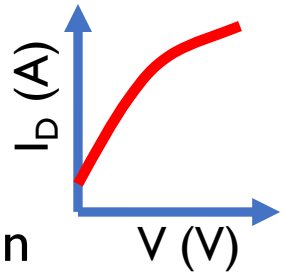
Simulate real-world device → TCAD

TCAD: Why, What, How

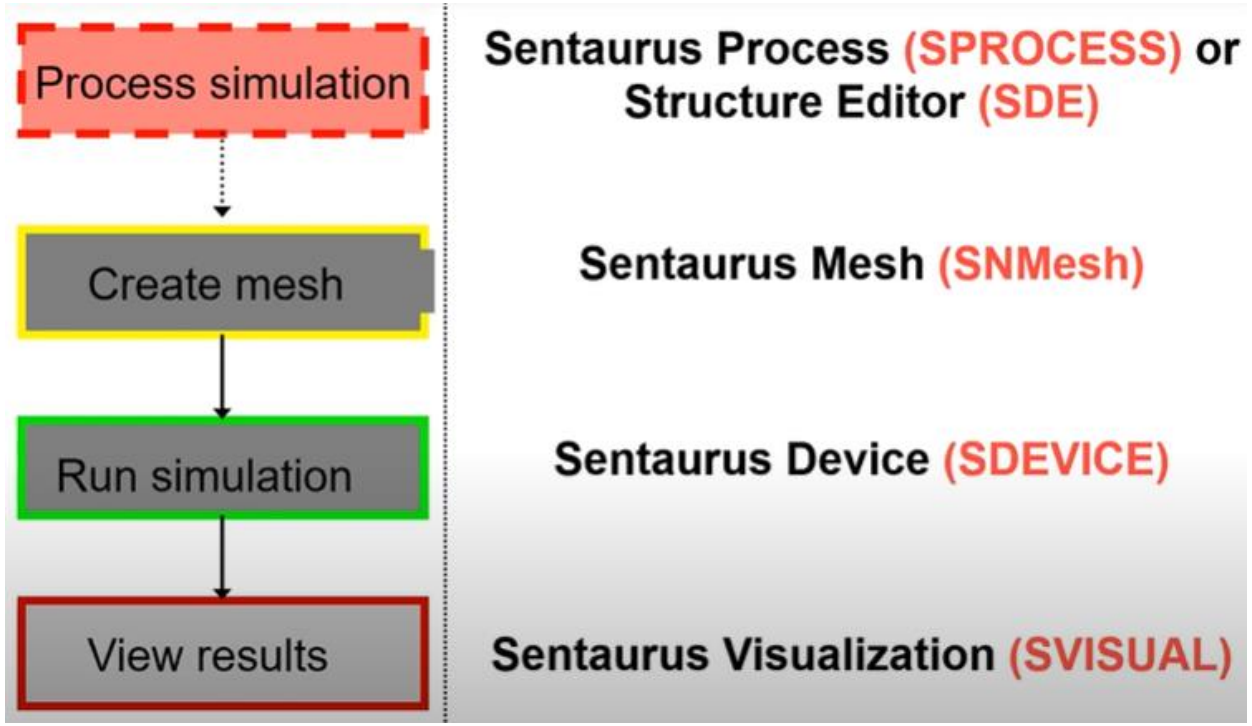
- TCAD: Enables R&D for upcoming technology
- Solves fundamental, physical, and partial differential equations (Drift-Diffusion, Poisson, etc.) for discretized geometries



- Define equation: Physics to solve
- Boundary condition: Electrode potential
- Solve equation at each mech point

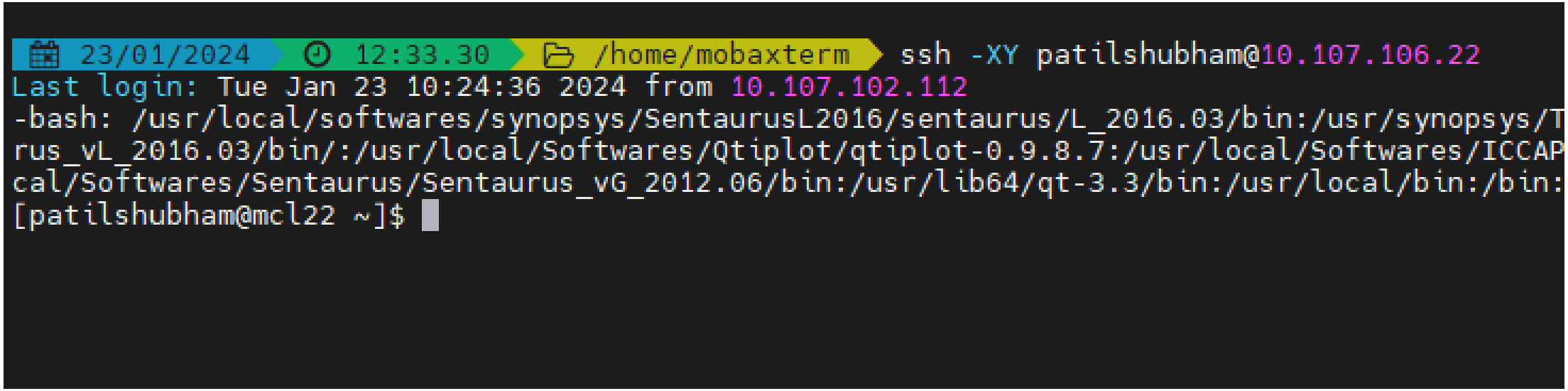


- Files
  - .tdr – Structural information
  - .plt – Device characteristic information



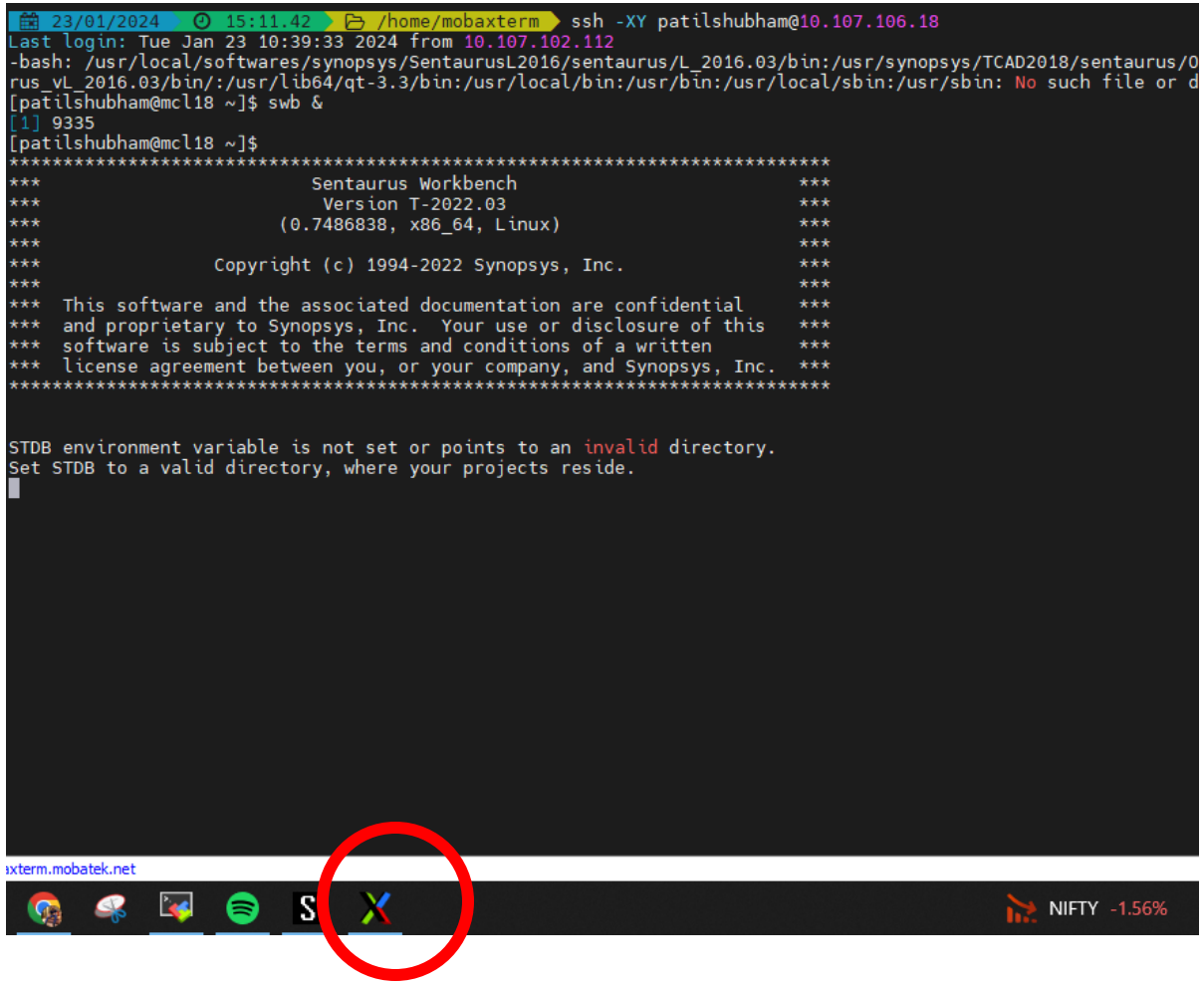
How to start TCAD

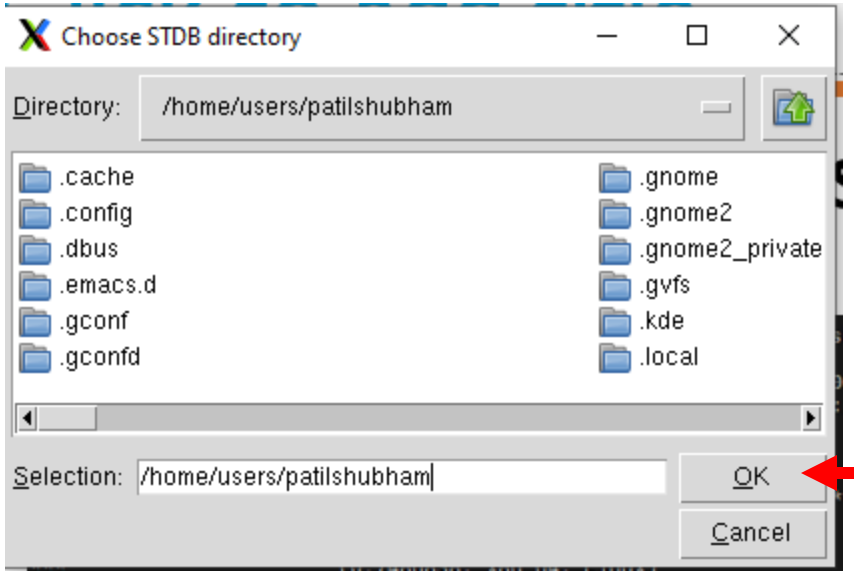
- Download and install MobaXterm
- Start new session
  - Write command: ssh -XY username@10.107.106.22
  - Press enter
    - Usernames: Find in the sheet
  - Password: Same as username



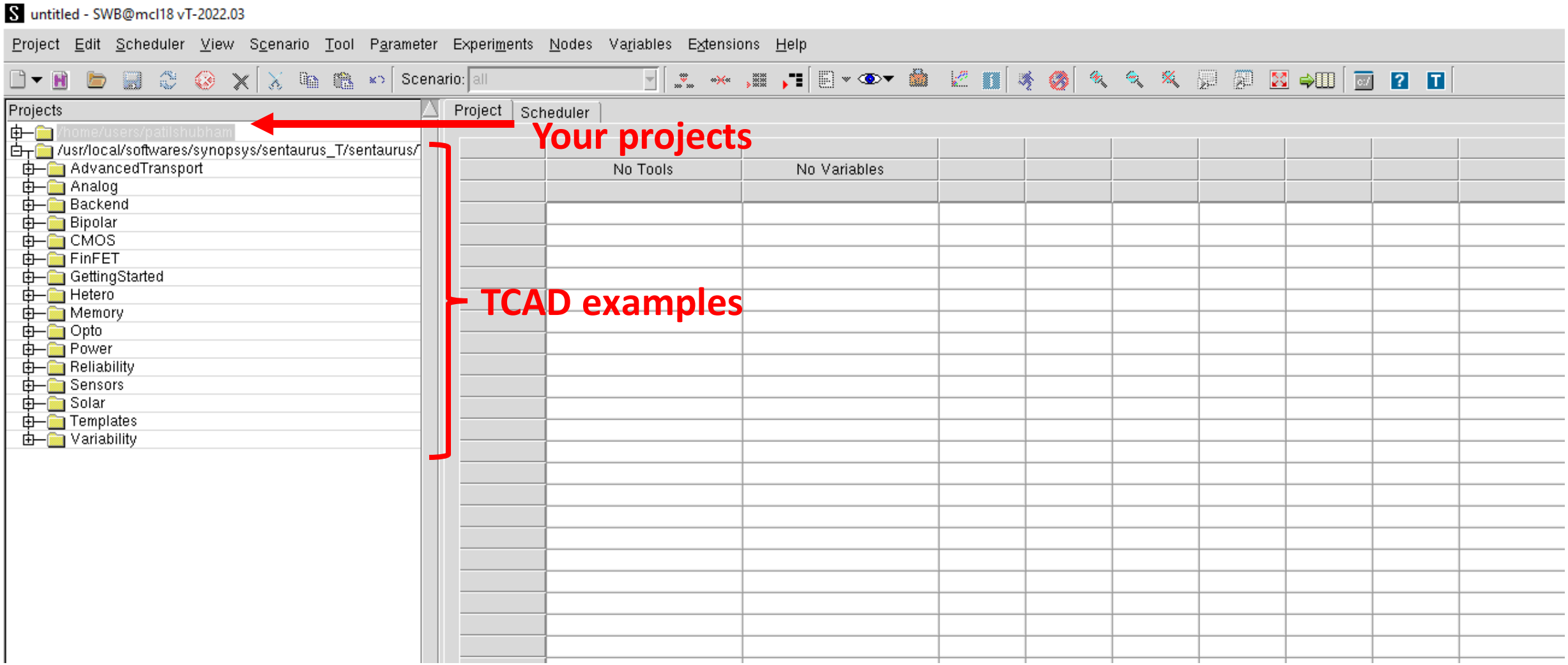
SWB

- Write: swb & Press enter
- Set working directory



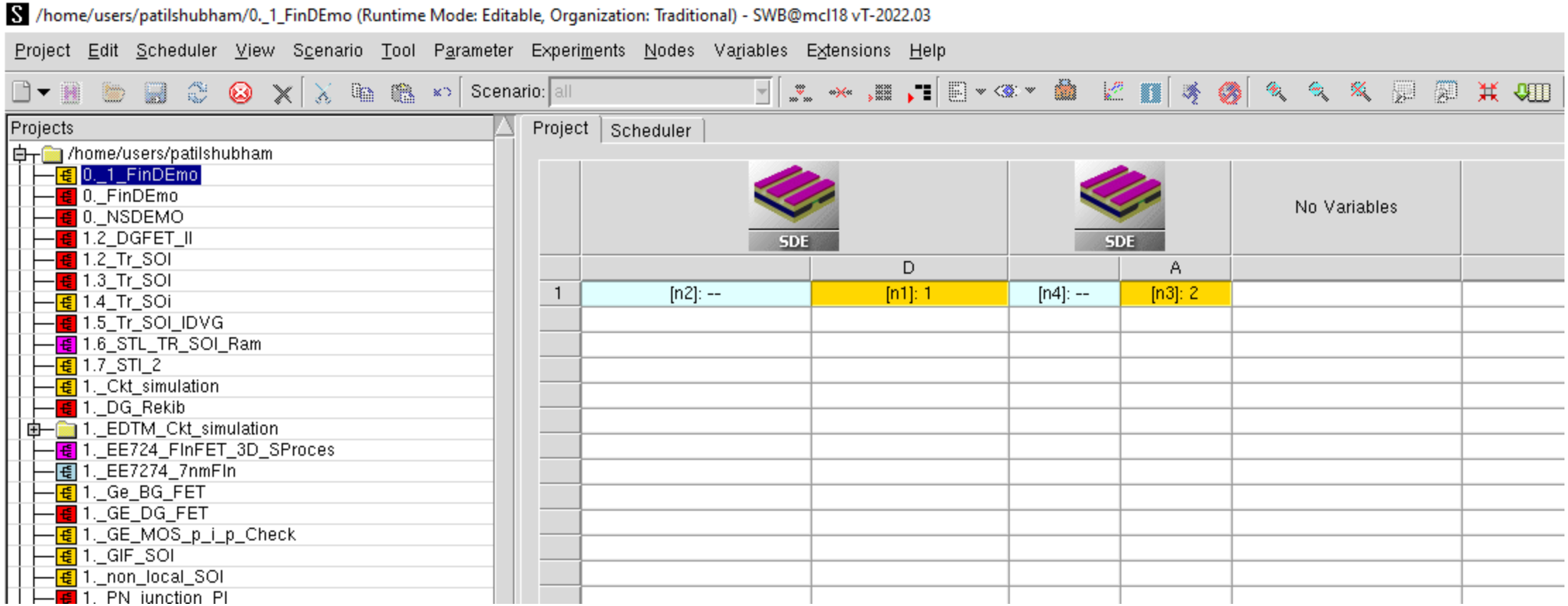


SWB environment

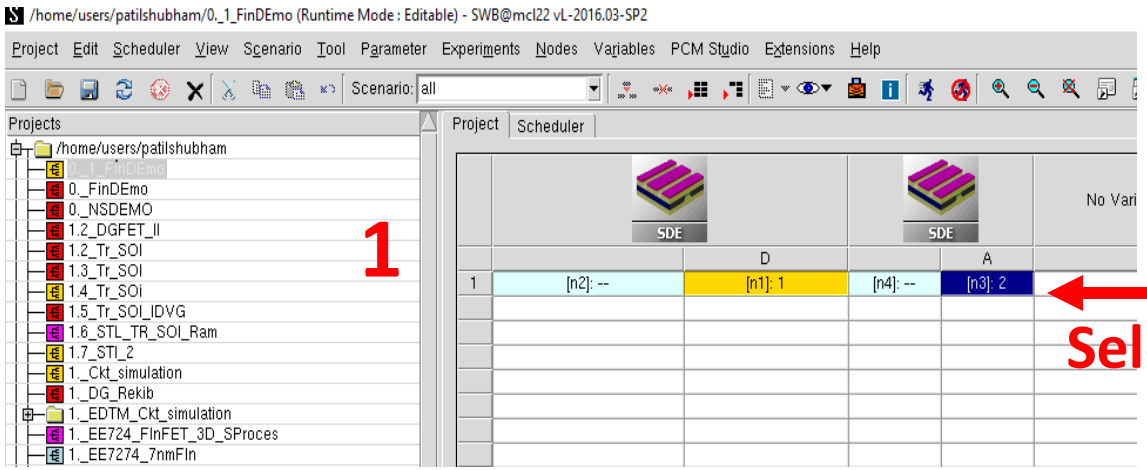


One project: FinFET

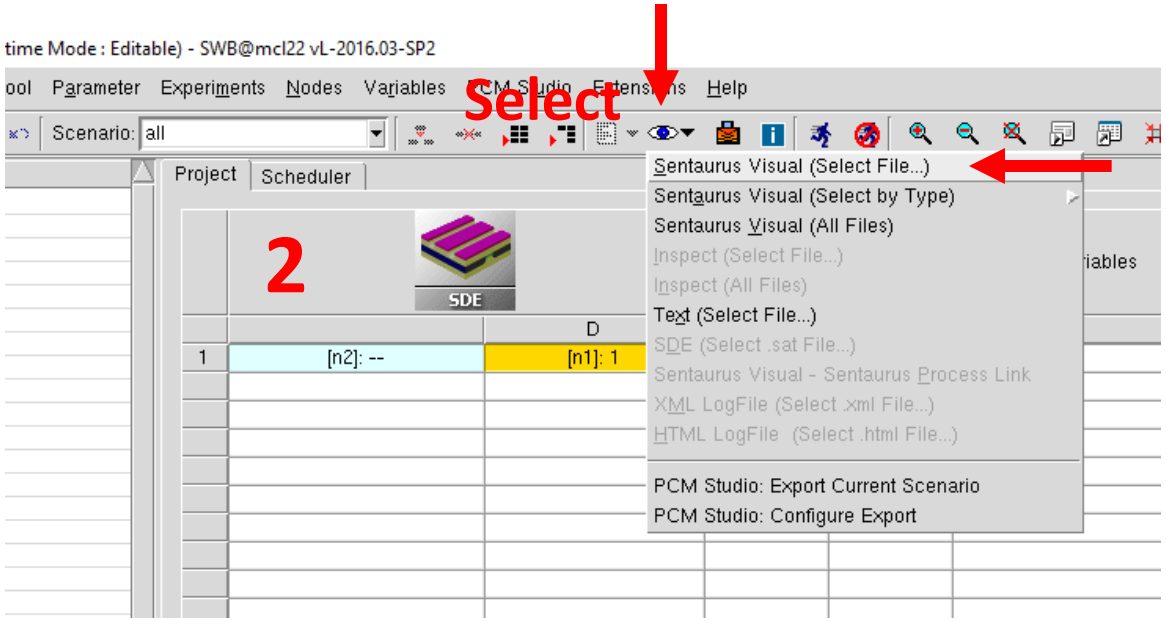
- In home, you will find the **0._1_FinDEmo** project. Double click to open

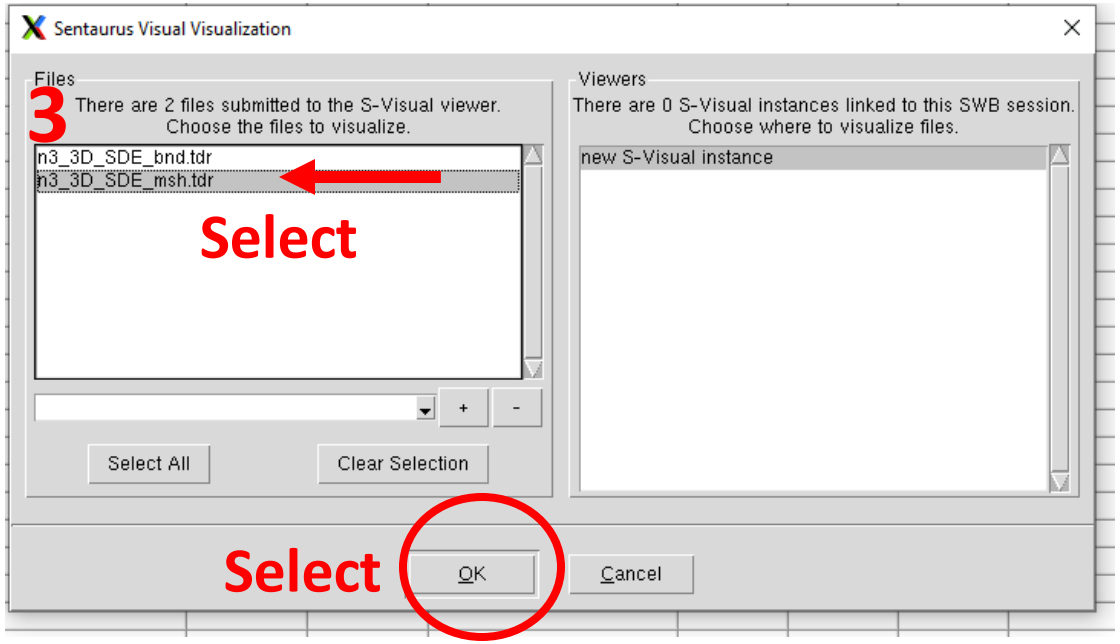


Open TDR

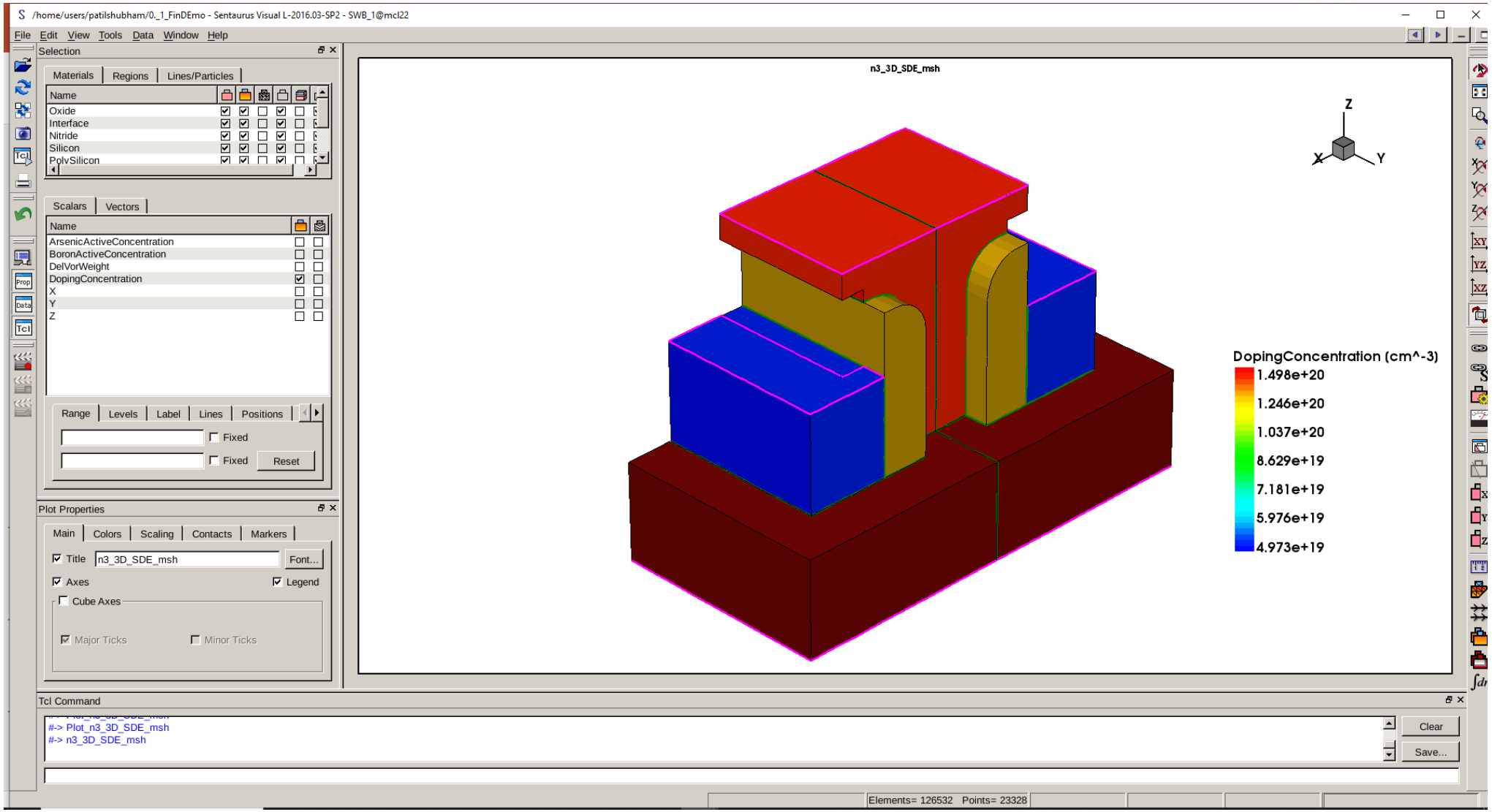


Select





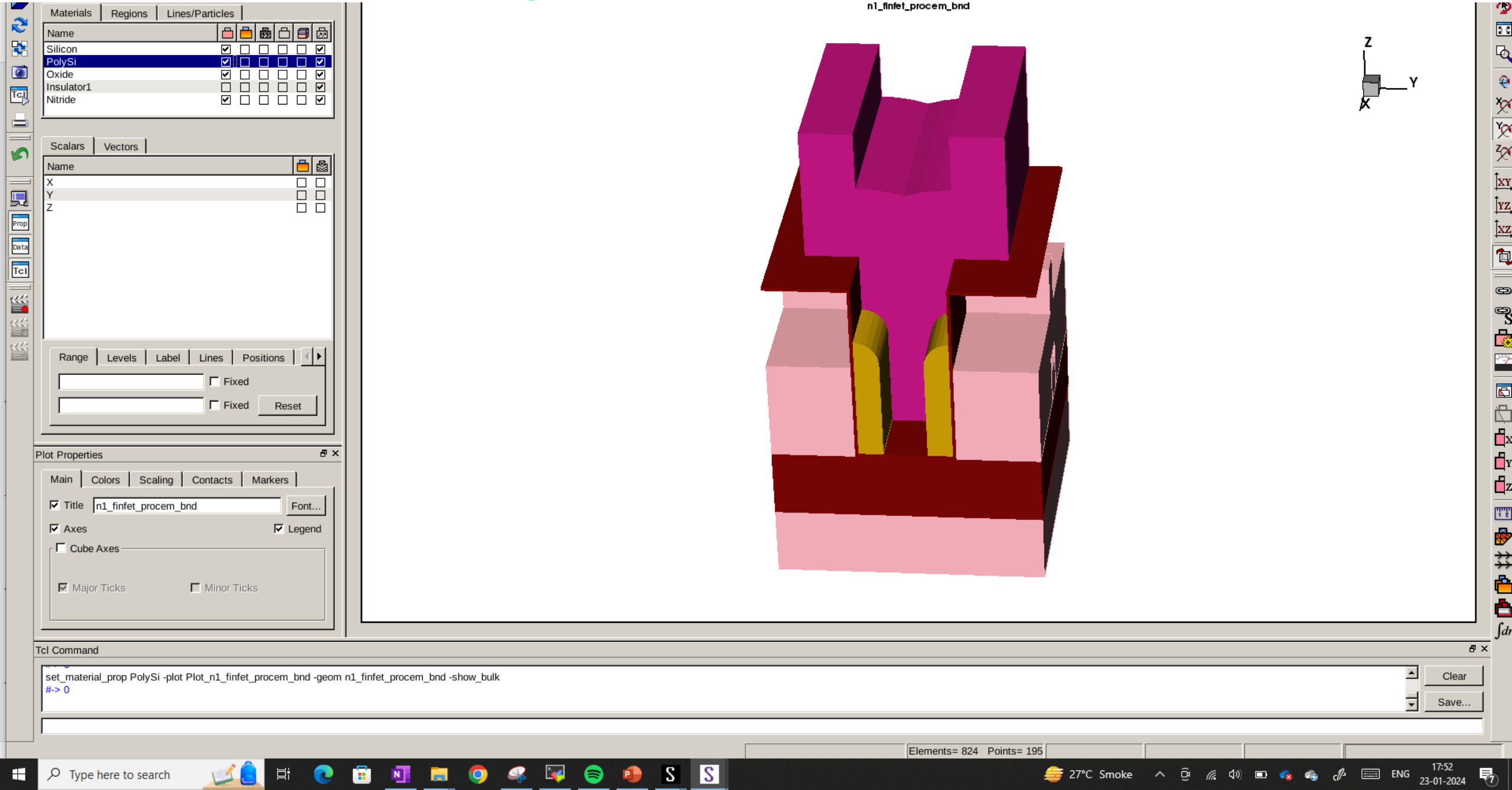
FinFET in TCAD



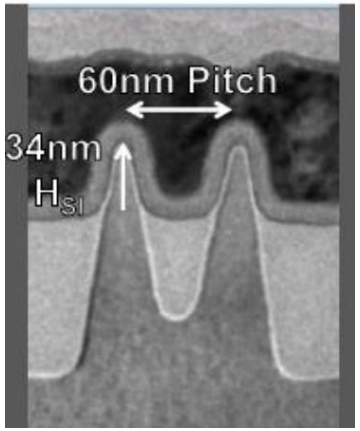
Rotation for view

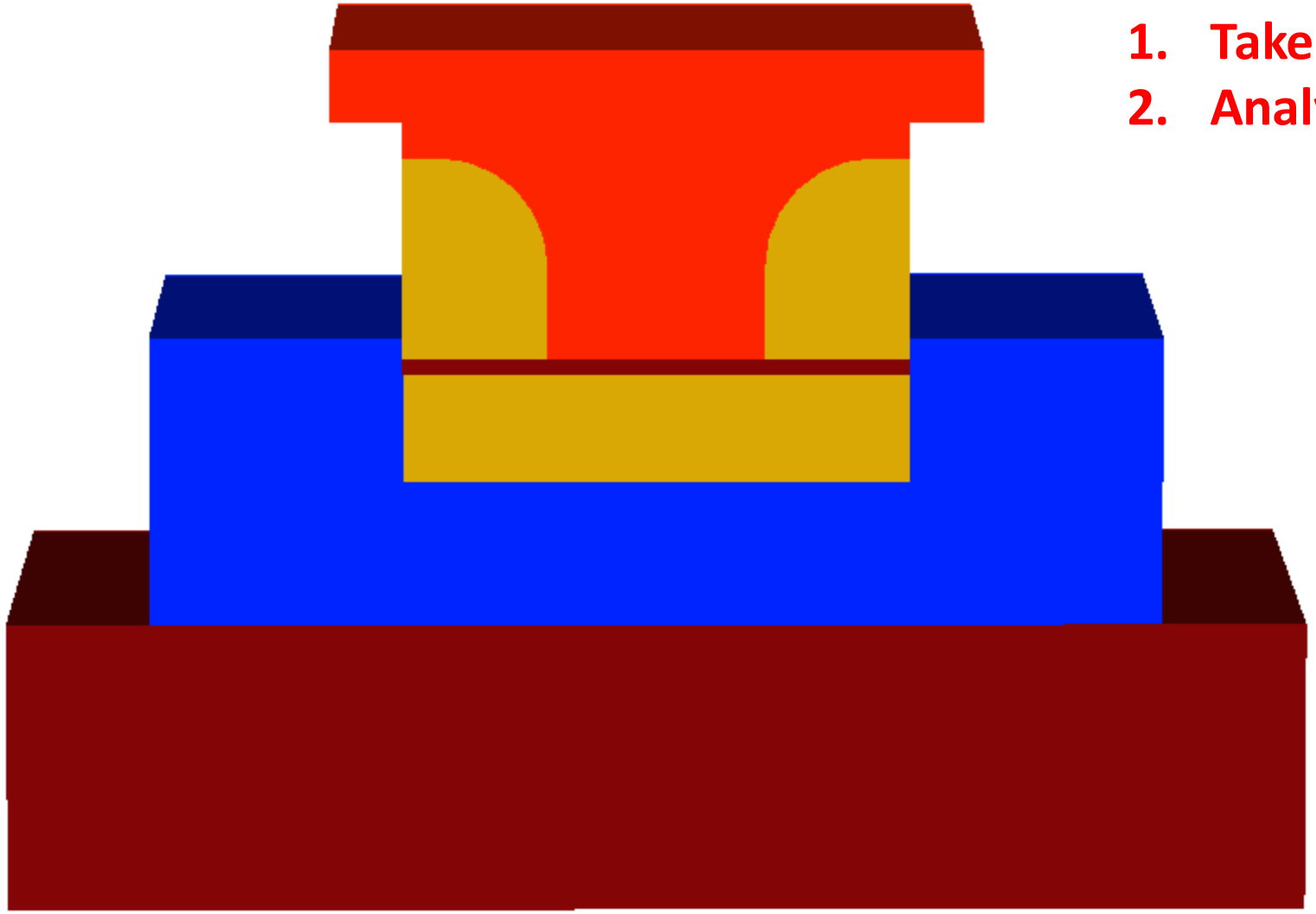
Cutline

FinFET: Fabrication steps



Device Research: Virtual Fab solution

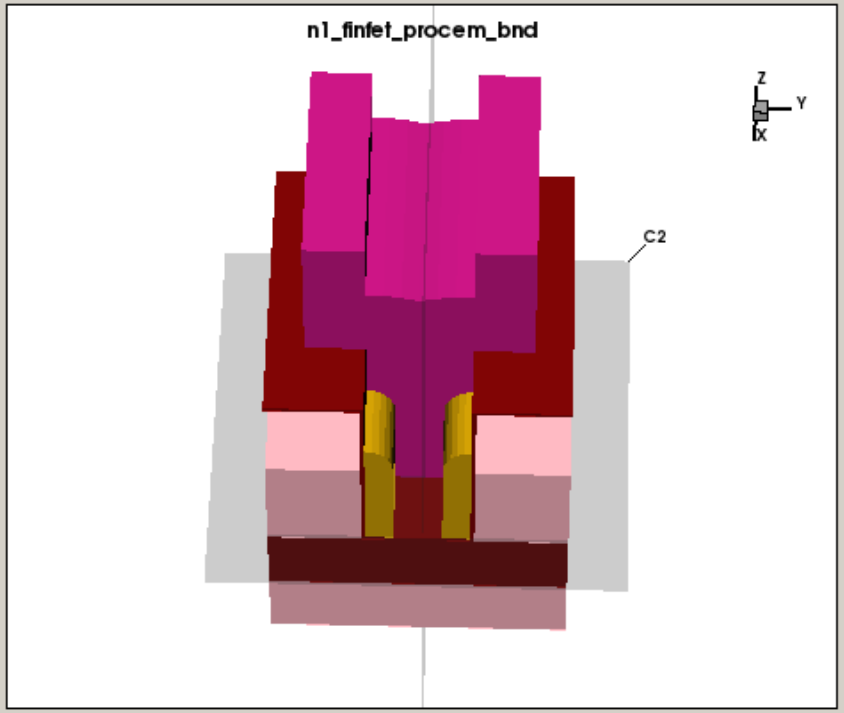


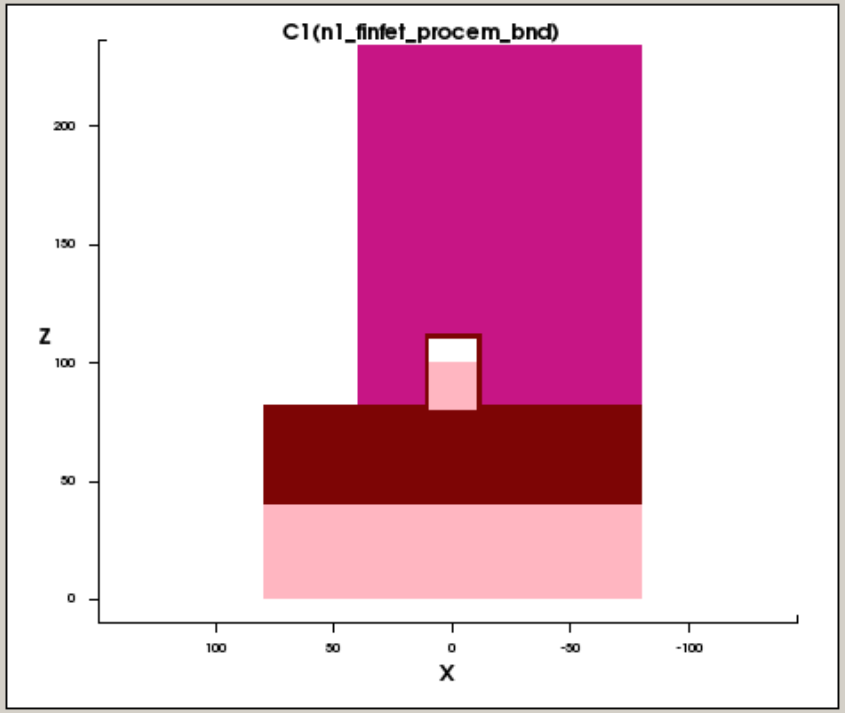


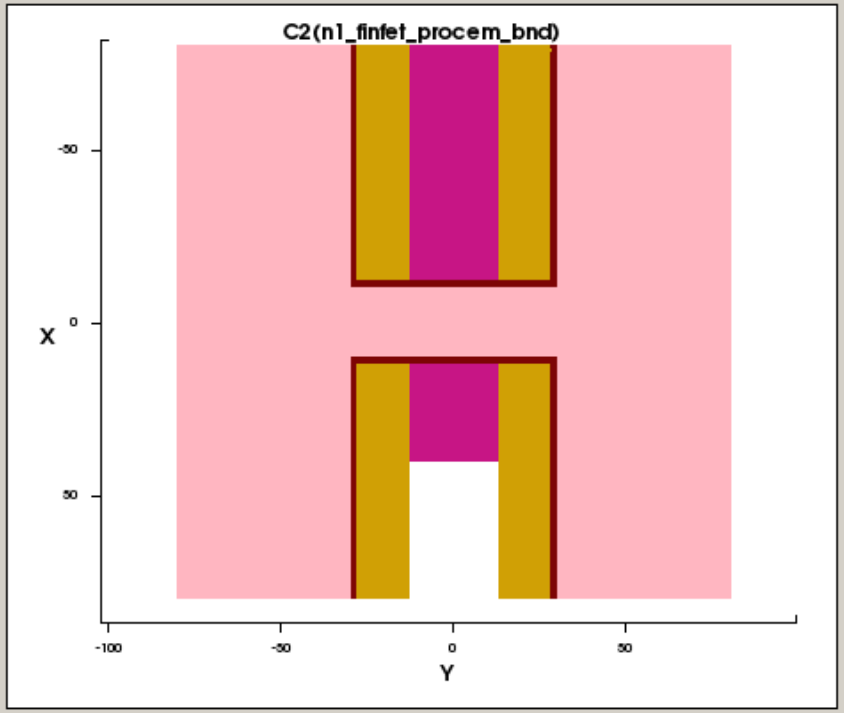
1. Take cutlines
2. Analyse structure

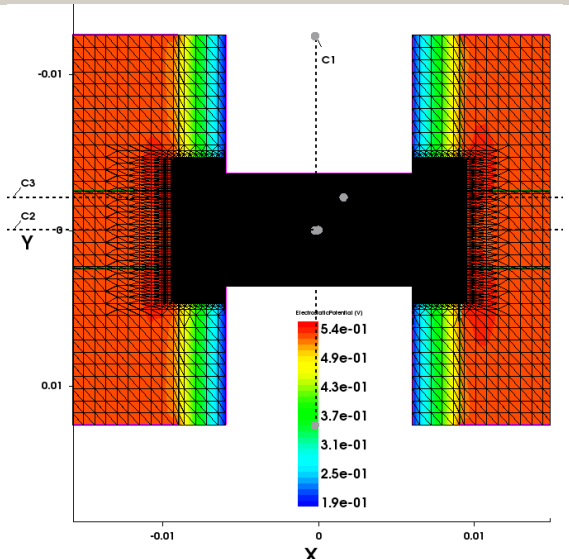
FinFET structure

3D → 2D FinFET

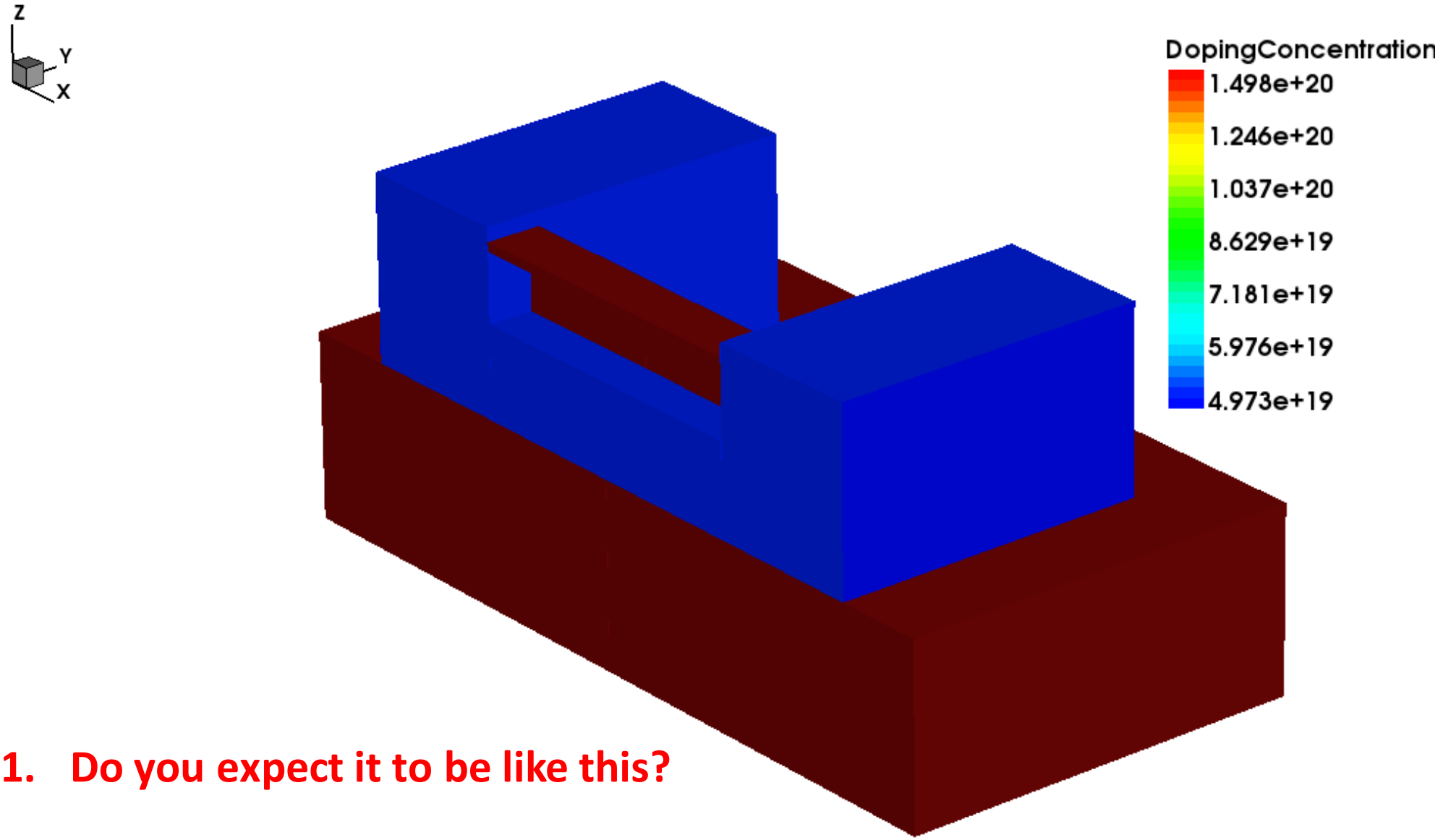

n1_finfet_procem_bnd
Z
Y
X
C2


C1(n1_finfet_procem_bnd)
200
150
100
50
0
Z
100
50
0
-50
-100
X


C2(n1_finfet_procem_bnd)
-50
0
50
X
-100
-50
0
50
Y

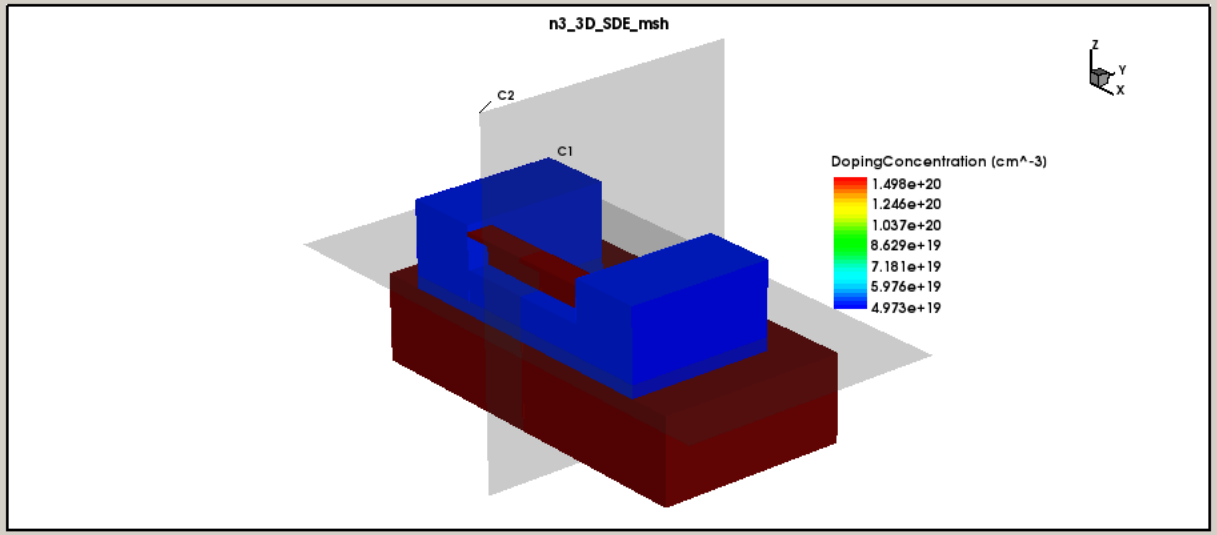

C1
C3
C2
Y
-0.01
0.01
5.4e-01
4.9e-01
4.3e-01
3.7e-01
3.1e-01
2.5e-01
1.9e-01
-0.01
0
0.01
X

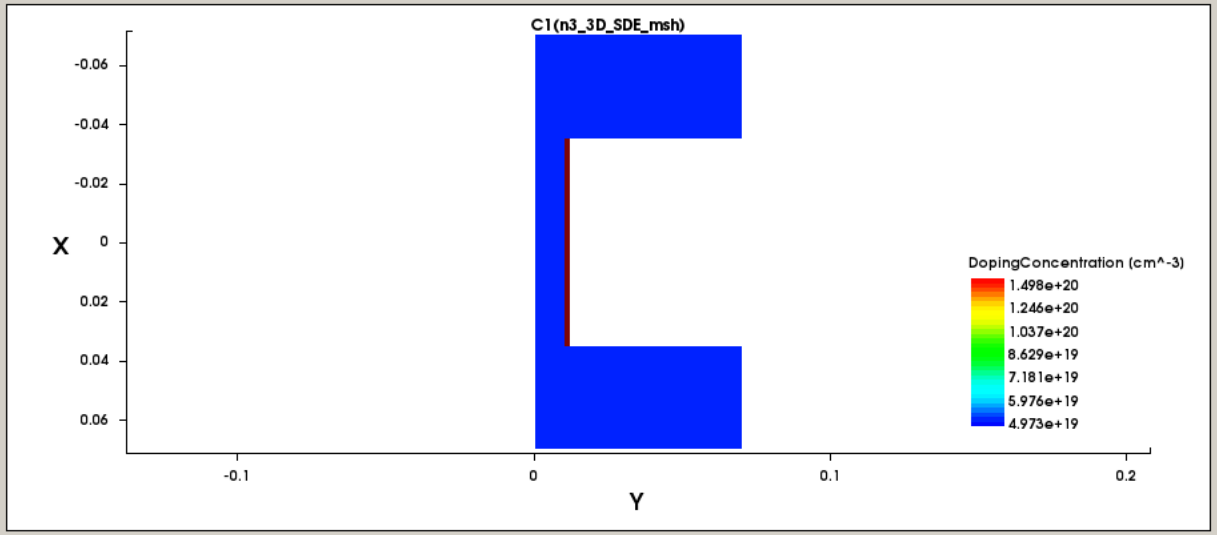
FinFET: Is something weird?

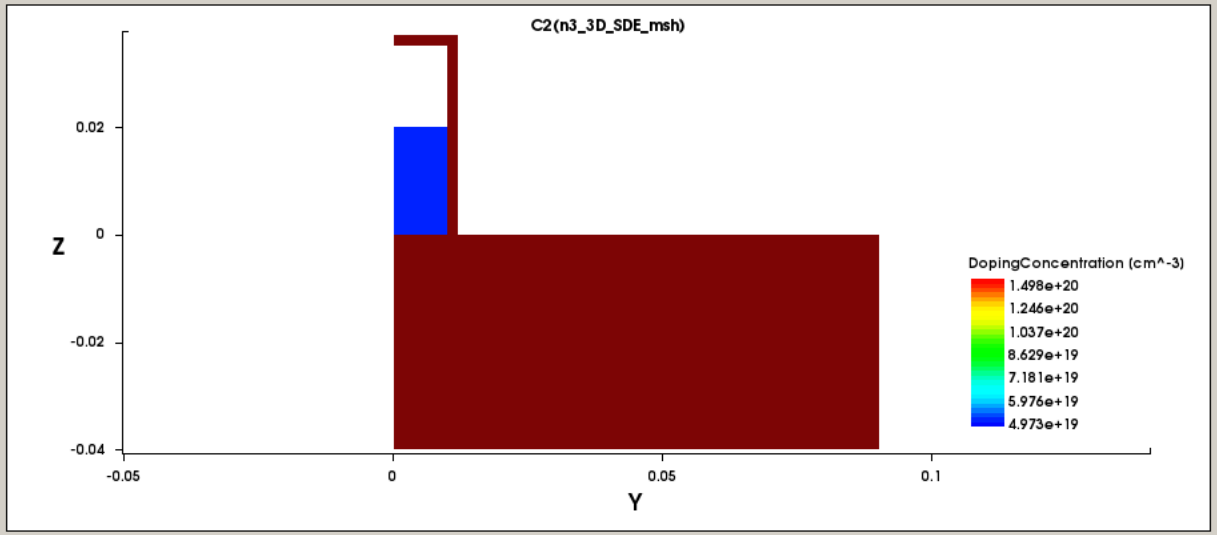


1. **Do you expect it to be like this?**

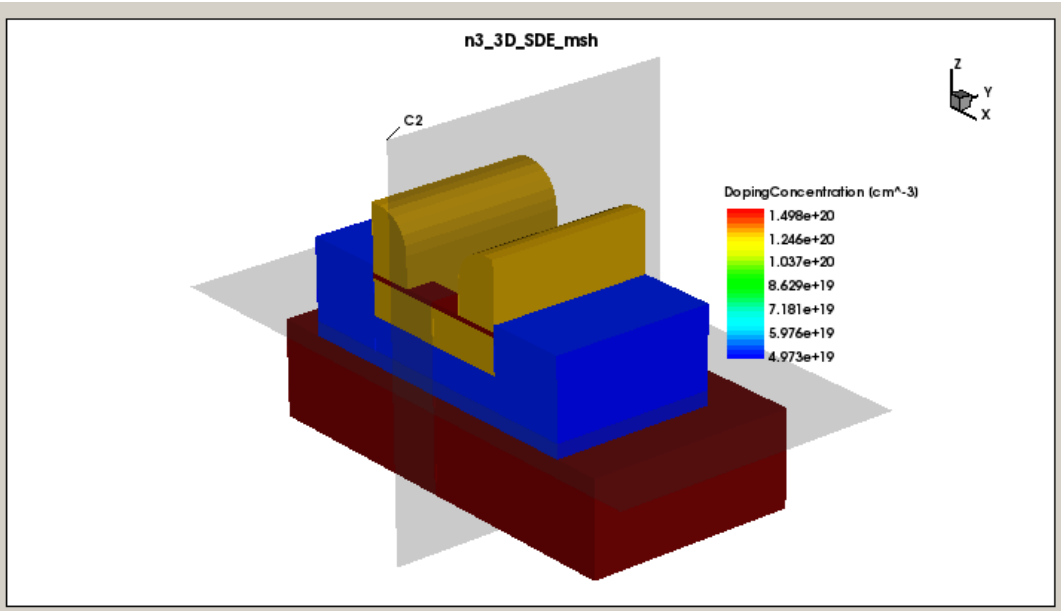
FinFET: 2D view

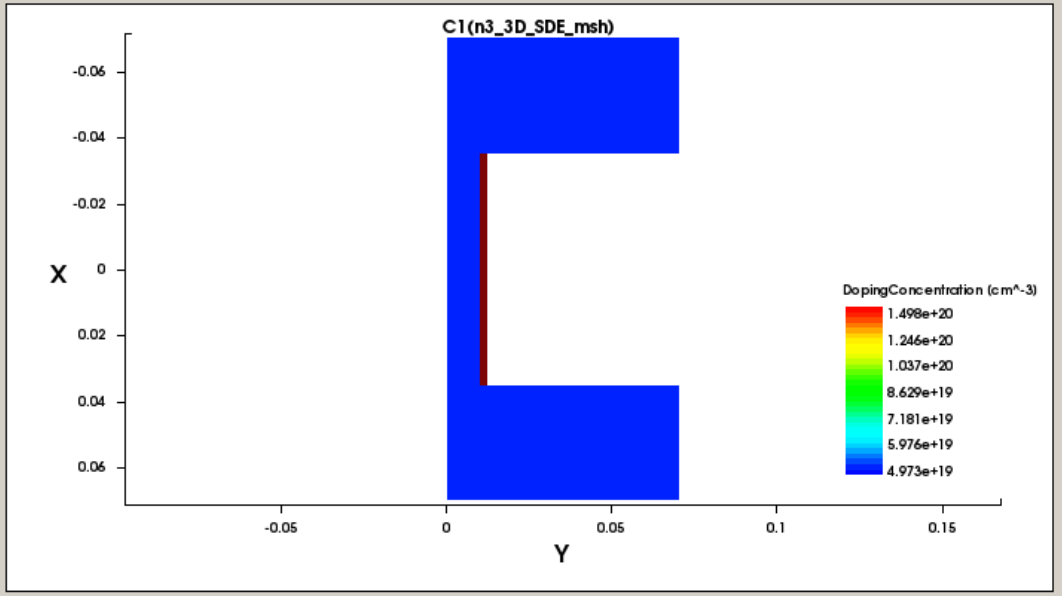


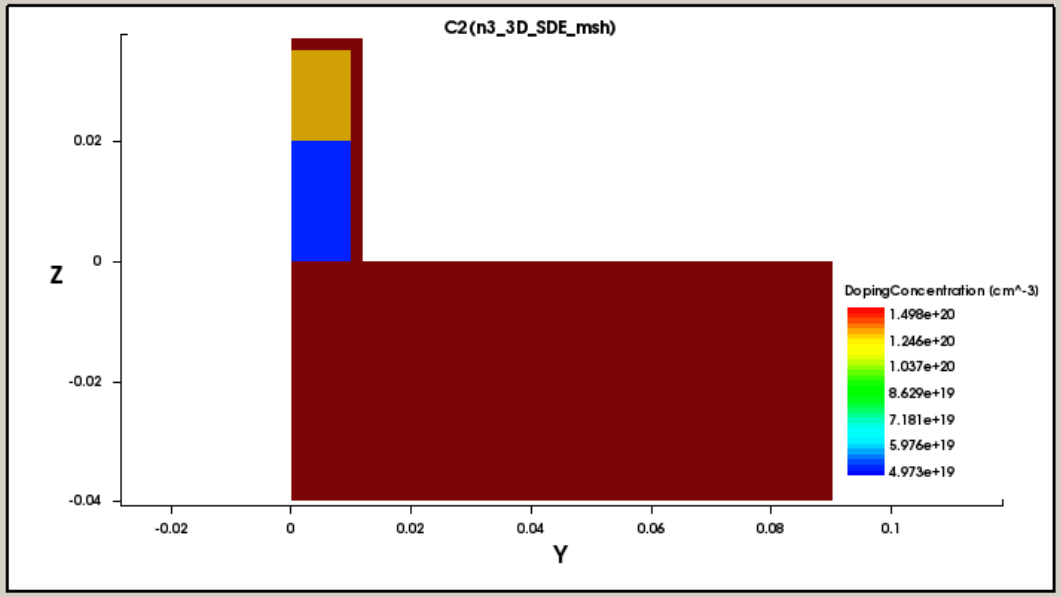




FinFET: 2D view







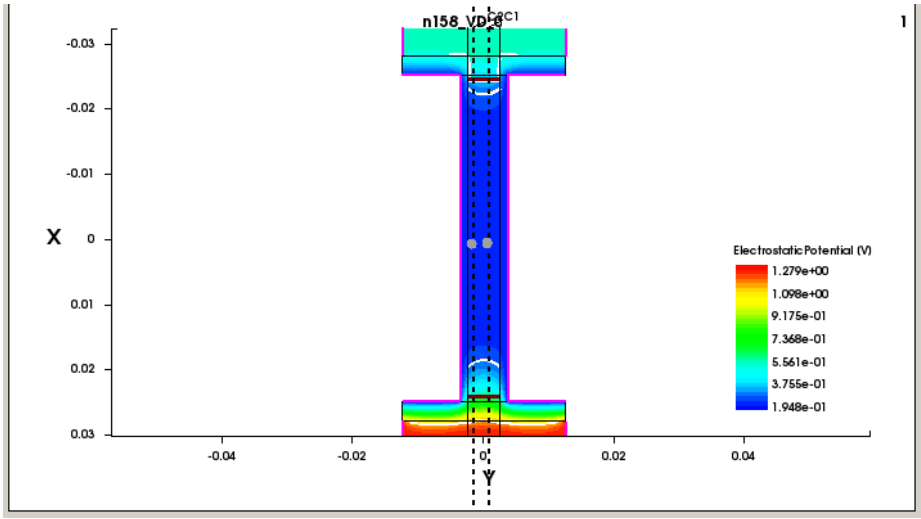
1. Is it something you expected?
2. If yes, why?
3. If no, what changes are needed?

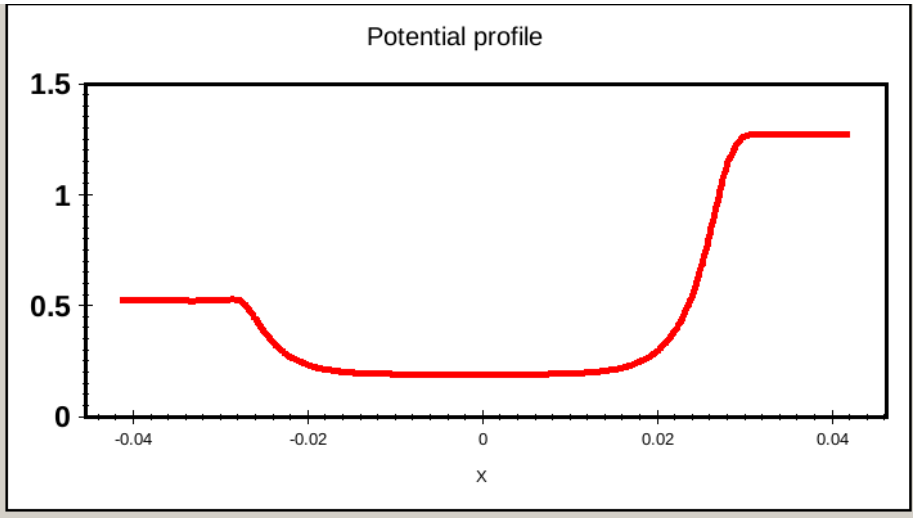
FinFET: Simulation questions

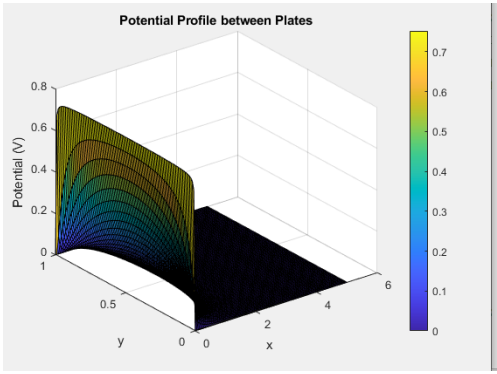
- Think:
  - What are the two types of boundary conditions?
  - In the half-fin model, what are the boundary condition
- Pair:
  - Why are the advantage/disadvantage of the half fin model?
    - Simulation cheaper
    - Spatial design variations can't be captured
      - Design with maybe different doping profiles, and workfunction
  - For a case where S/D is at zero bias, can a smaller simulation space suffice e.g. quarter fin model?
    - No, can’t replicate

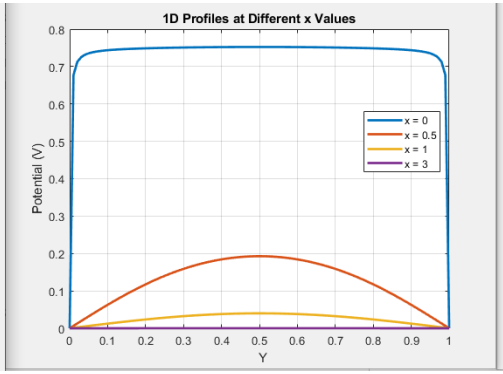
2D FinFET: Potential profile comparison vs. MATLAB

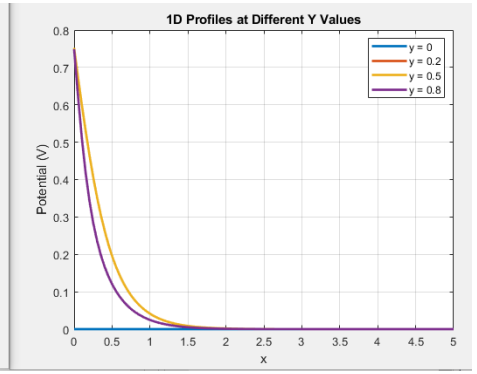
$V_G = 0$
$V_D = 0.75$

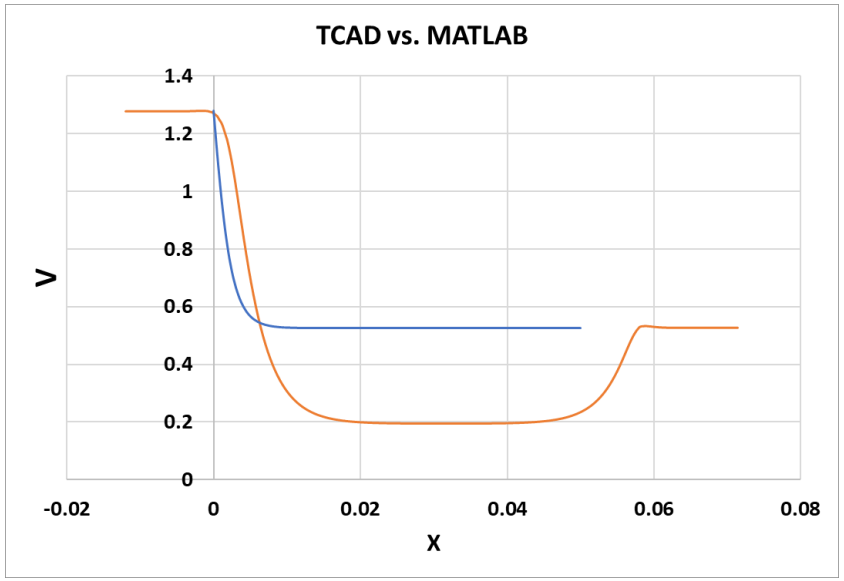




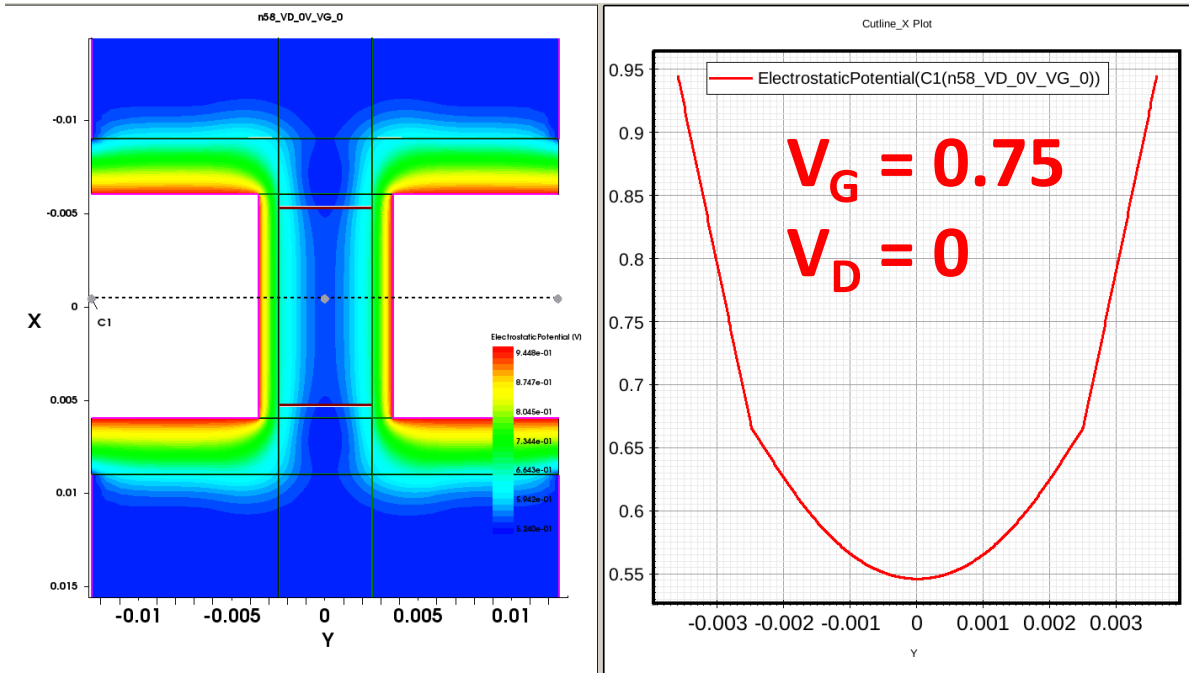


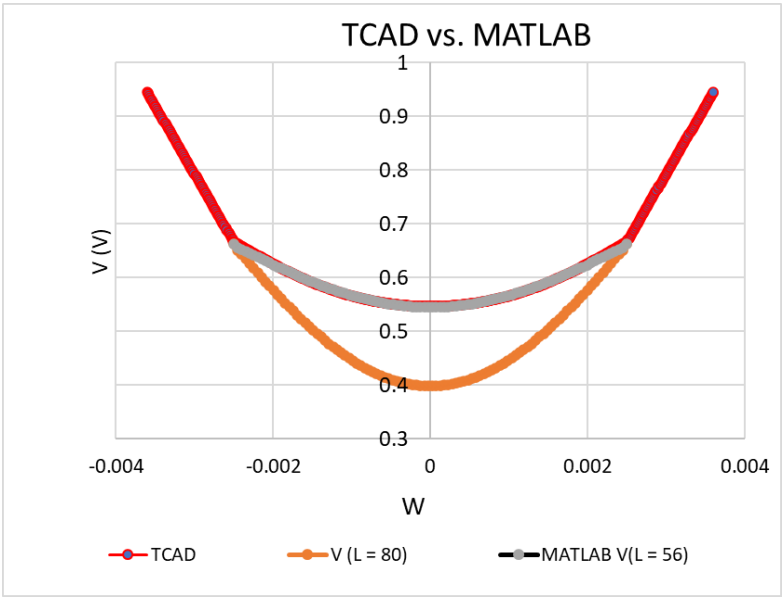






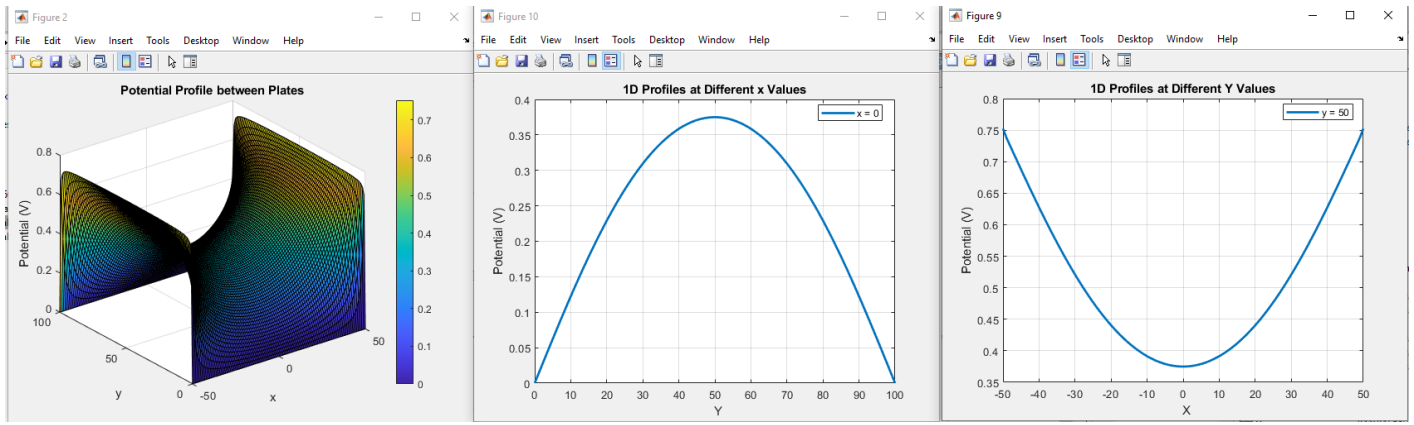
2D FinFET: Potential profile comparison vs. MATLAB

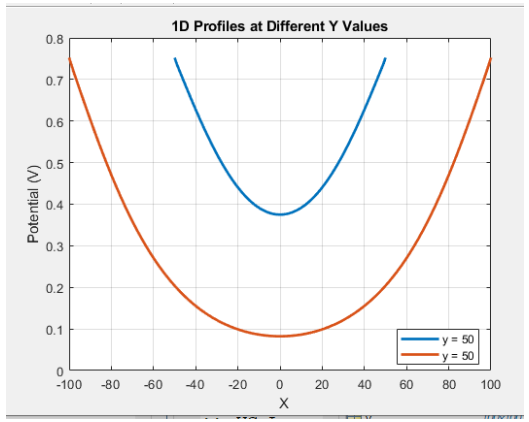




Decay -> f(X)

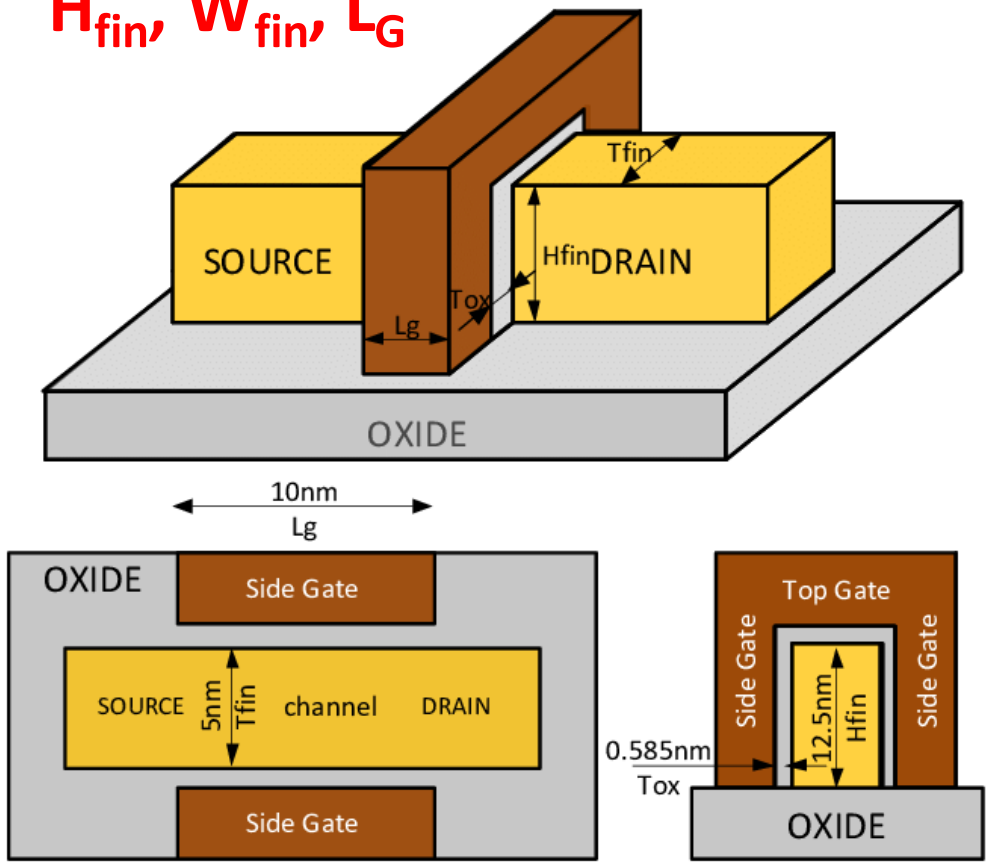
With proper scaling the dimension we can achieve this





FinFET design: Designer perspective

H_{fin}, W_{fin}, L_G

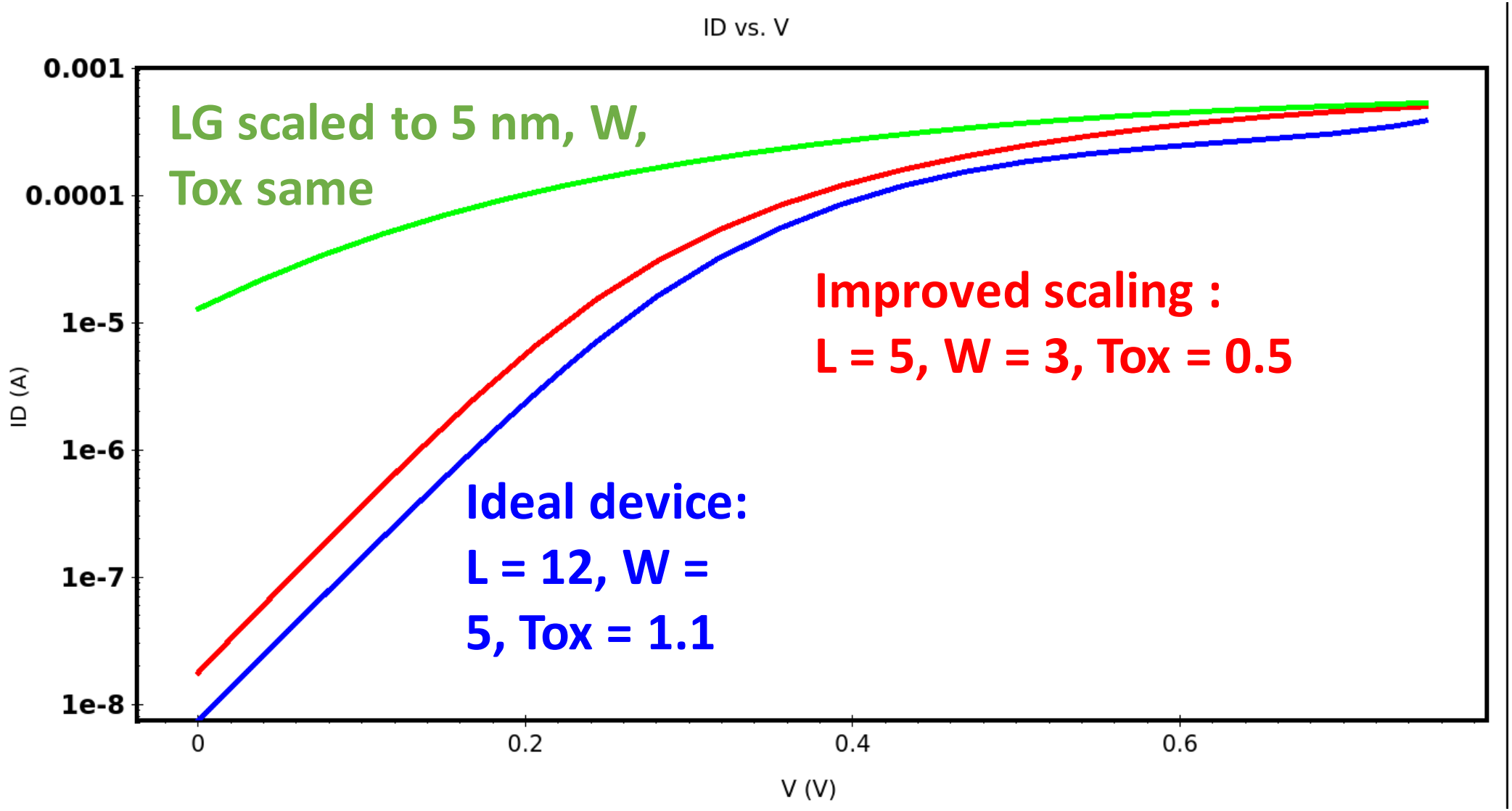


$$I_D = \mu * C_{ox} * \frac{W}{L} * (V_{GS} - V_T)$$

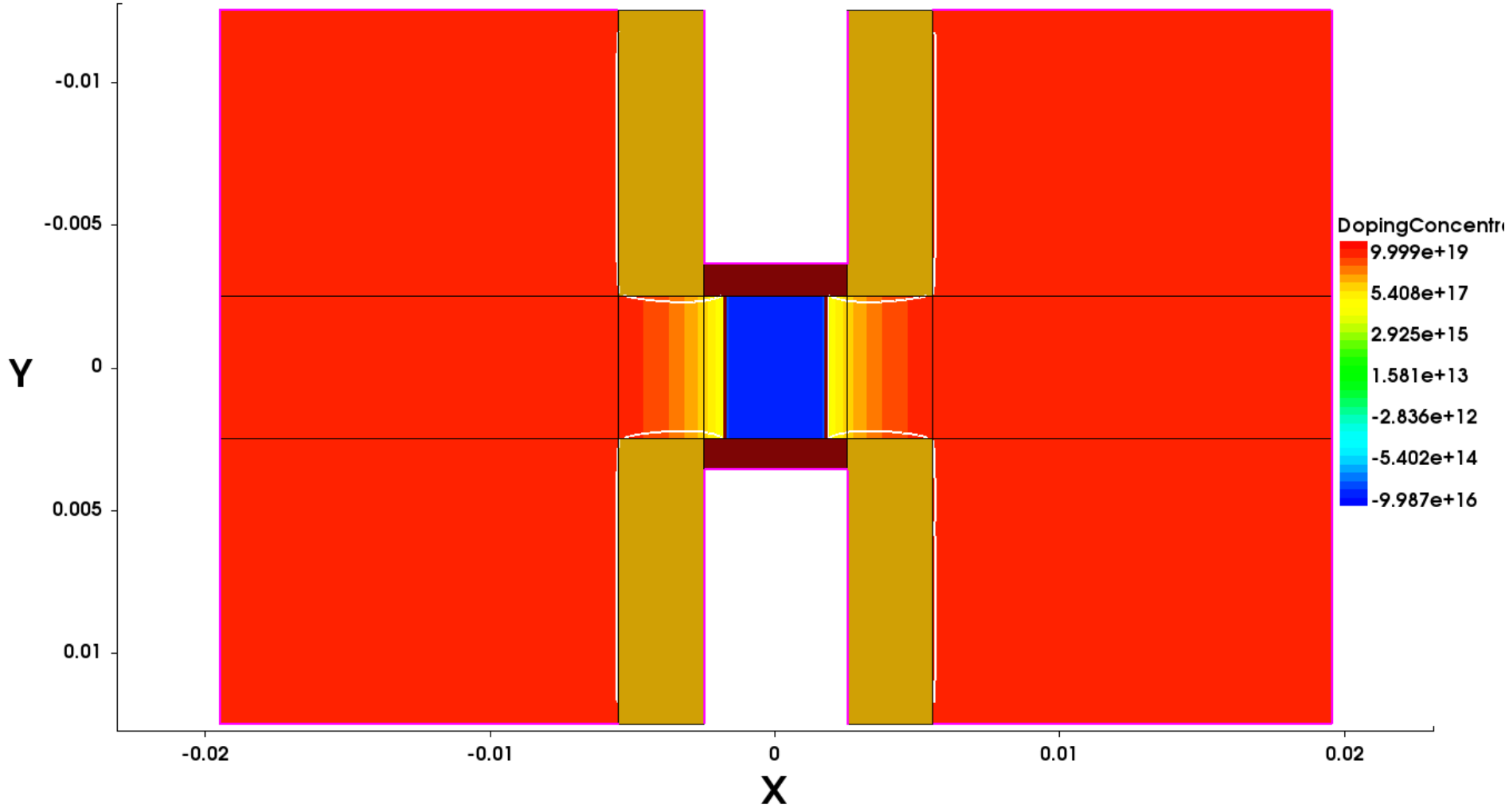
$$V_T = f(N_{channel})$$

- Now you understand the FinFET
- Suppose you are a device engineer, how will you improve the FinFET performance?
  1. What are the parameters to be considered for performance improvement?
     - On-current, OFF current, SS, DIBl
     - What about parasitic capacitance?
  2. How to do it?
     - L_G scaling: is it only enough?
       - Draw EBD for long and short LG
     - L_G and W: Will the performance improve
     - What about T_{OX} ?
       - Can you keep on scaling it?
       - What about the gate leakage current>
     - L_G, W, H, and Tox

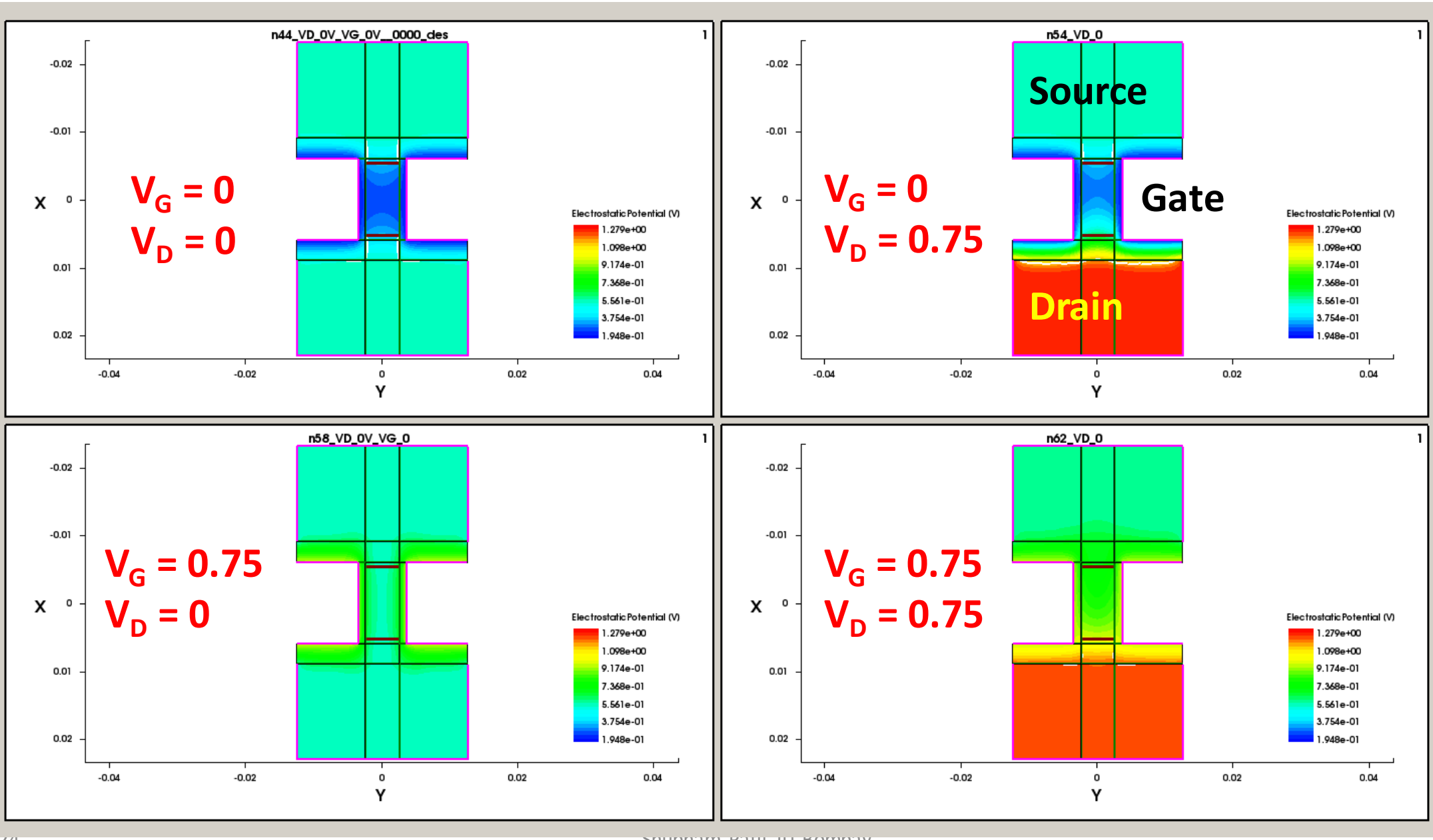
FinFET design: Designer perspective



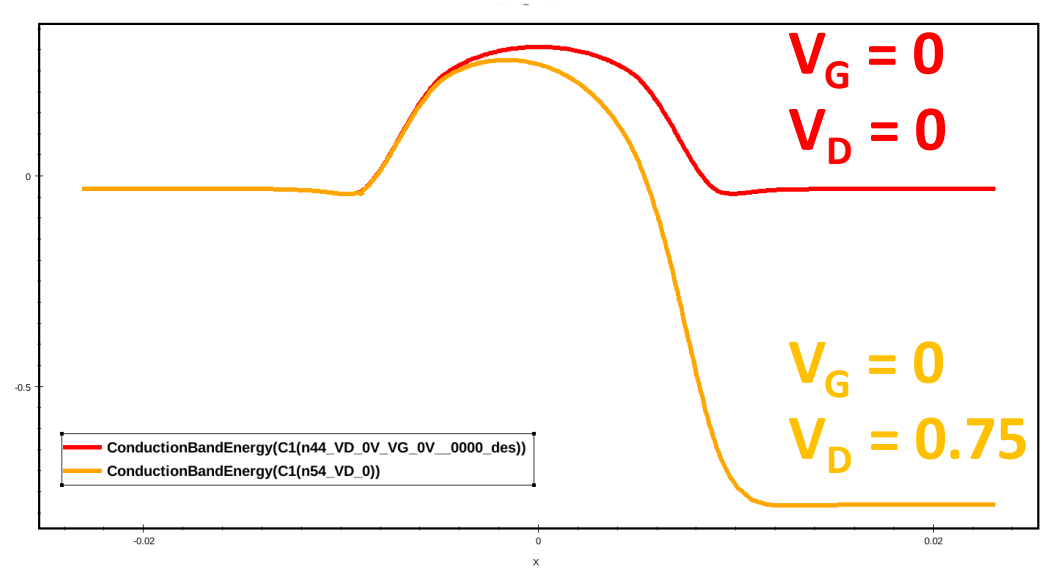
2D FinFET

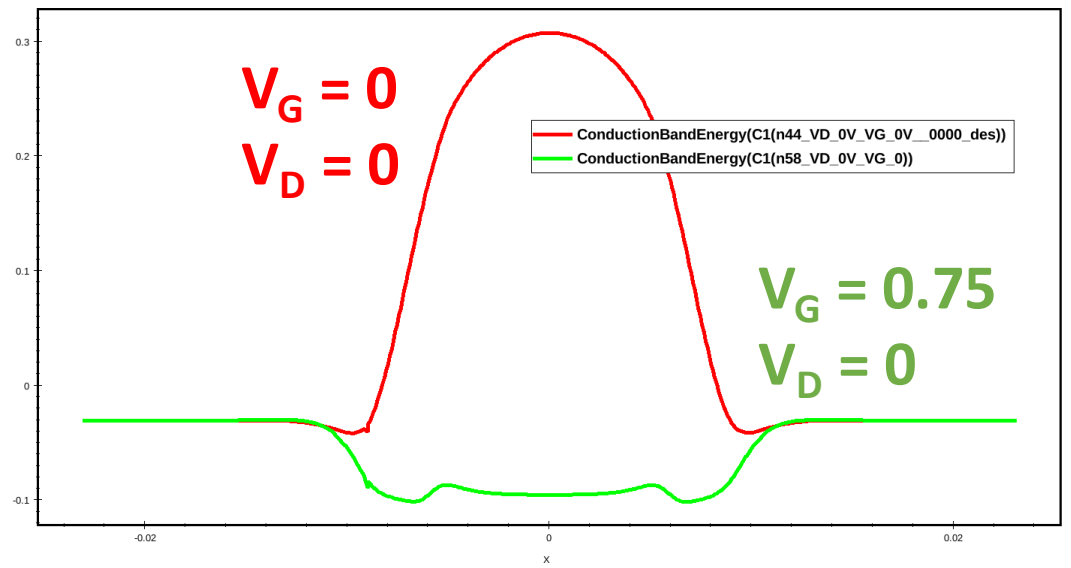

-0.01
-0.005
0
0.005
0.01
Y
-0.02
-0.01
0
0.01
0.02
X
DopingConcentr
9.999e+19
5.408e+17
2.925e+15
1.581e+13
-2.836e+12
-5.402e+14
-9.987e+16

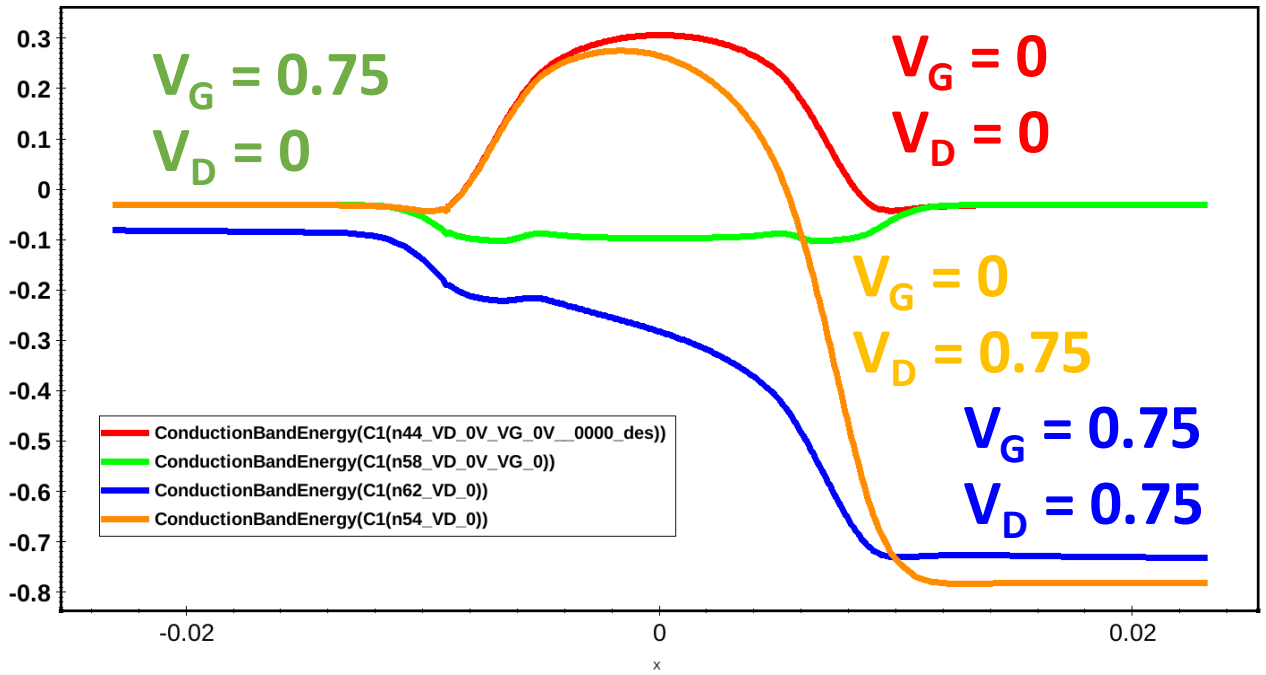
Draw conduction band profiles?



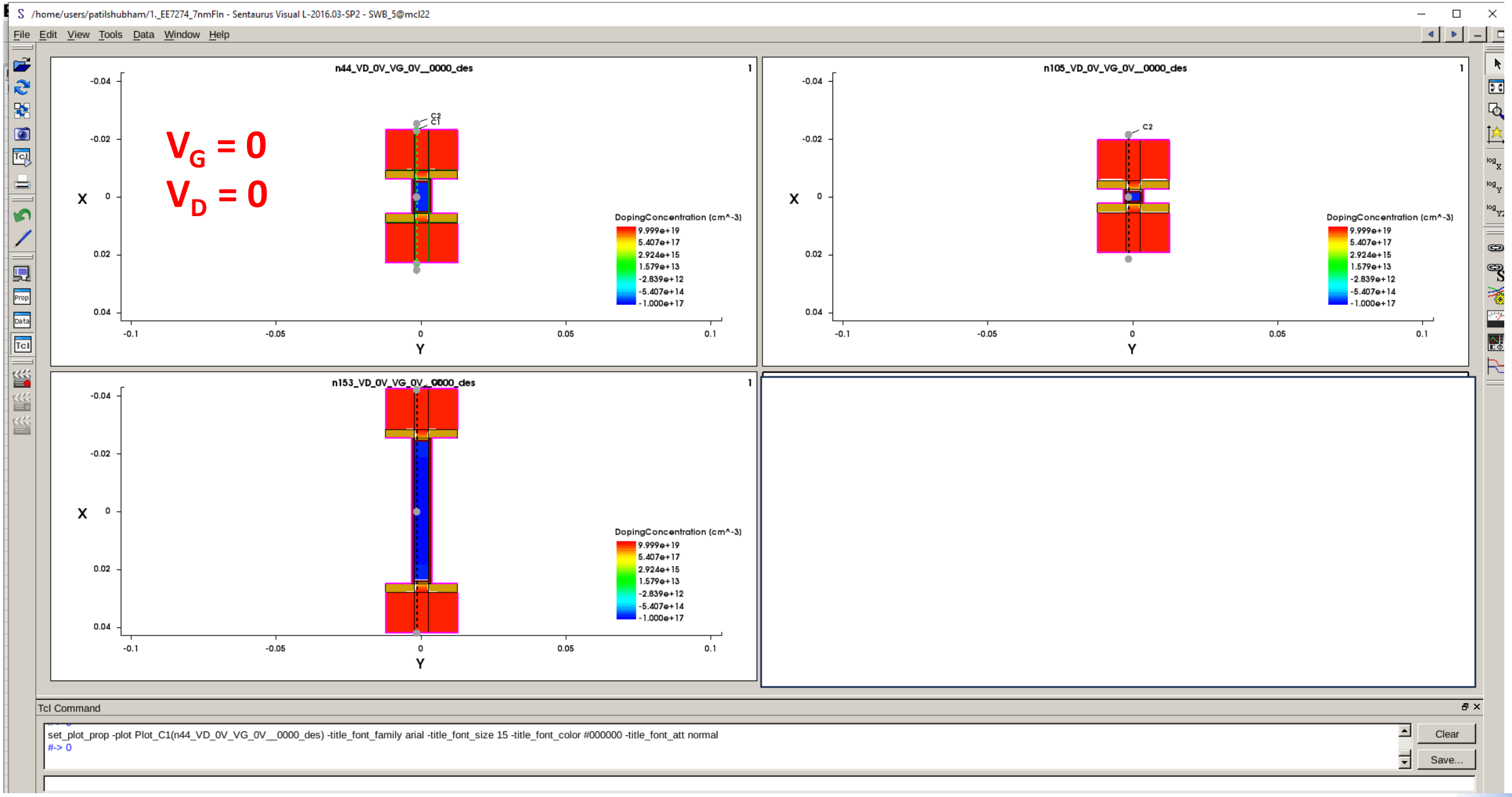
FinFET: EBD


$V_G = 0$
$V_D = 0$
$V_G = 0$
$V_D = 0.75$
ConductionBandEnergy(C1(n44_VD_0V_VG_0V__0000_des))
ConductionBandEnergy(C1(n54_VD_0))
x

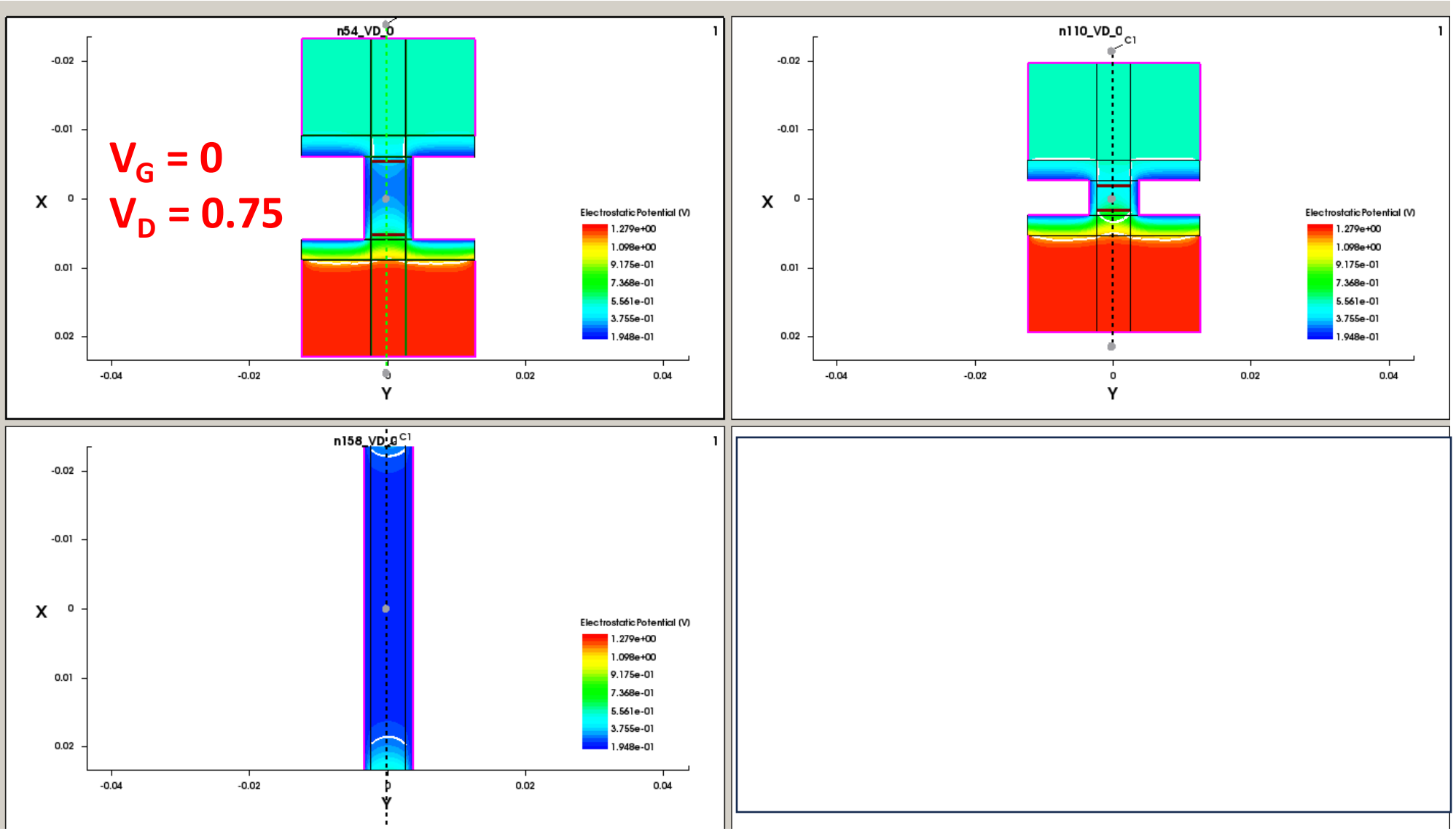

$V_G = 0$
$V_D = 0$
$V_G = 0.75$
$V_D = 0$
ConductionBandEnergy(C1(n44_VD_0V_VG_0V__0000_des))
ConductionBandEnergy(C1(n58_VD_0V_VG_0))
x


$V_G = 0.75$
$V_D = 0$
$V_G = 0$
$V_D = 0$
$V_G = 0$
$V_D = 0.75$
$V_G = 0.75$
$V_D = 0.75$
ConductionBandEnergy(C1(n44_VD_0V_VG_0V__0000_des))
ConductionBandEnergy(C1(n58_VD_0V_VG_0))
ConductionBandEnergy(C1(n62_VD_0))
ConductionBandEnergy(C1(n54_VD_0))
x

FinFET: L_G scaling impact



FinFET: L_G scaling impact



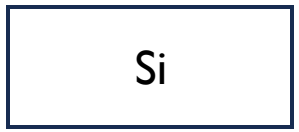
TCAD SDE: Commands

MOSFET: Sde file for reference

- Define BOX

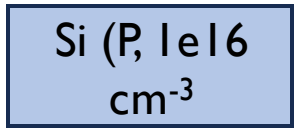
(sdegeo:**create-rectangle** (position 0 0 0) (position L W 0) "**Germanium**" "R.Sub")

  - Germanium: Replace your material (Silicon, Oxide, HfO2, Nitride…)
  - R.Sub: Dummy name for the box, works as its identity



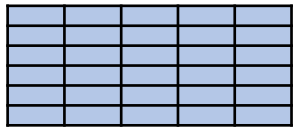
- Define doping in BOX

(sedr:define-constant-profile "Const.Sub“ "BoronActiveConcentration" 1e16)
(sedr:define-constant-profile-region "PlaceCD.Sub" " Const.Sub " "R.Sub")



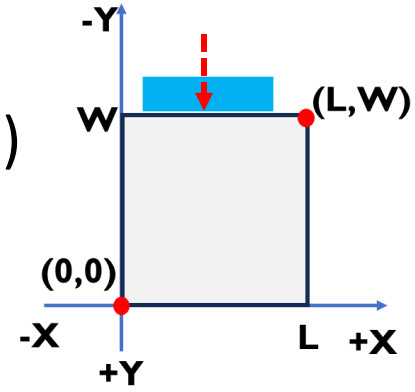
- Meshing in BOX

(sedr:define-refinement-size "size_R.Sub2 " 0.01 0.01 00.01 0.002 0.005 0.005)
(sedr:define-refinement-placement "Place_R.Sub" " size_R.Sub2 " " R.Sub ")



- Contact

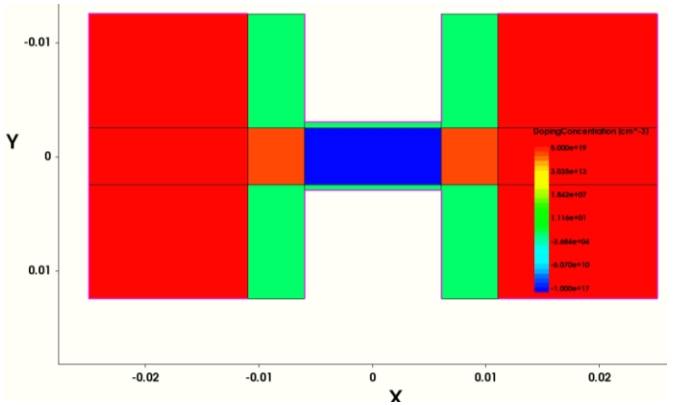
(sdegeo:**set-contact** (find-edge-id (position (/ L 2) W 0.0)) "drain")



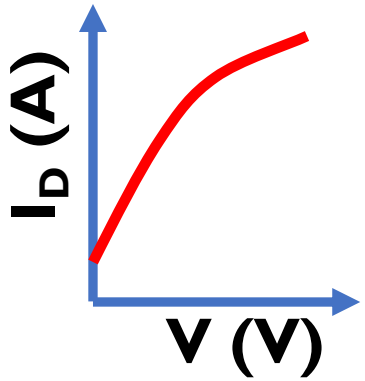
- Save TDR: (sde:build-mesh "SOI_n@node@")

TCAD Sdevice File

- Syntax: _____.cmd



- Section
  - File: I/p and o/p files
  - Electrode: All the contacts (Source, Drain, Gate …)
  - Physics: All models for simulation (Transport, Fermi, Recombination/Generation, Mobility models)
  - Plot: Variables to be visualized (V, E, I, n_e, n_h)
  - Math: Control for the solver (Iterations, accuracy, method…)
  - Solve: Simulation condition (Ramping of voltages)



[TCAD Sentaurus Hands-on Tutorial: Sentaurus Workbench and Structure Editor and SVisual]

MOSFET: Sdevice File for reference

Learnings

- Working with TCAD
- Visualize TDR and analyze 3D and 2D structure
  - Electrostatic profiles
- FinFET Device designing
  - Scaling
  - EBD

Thank You

Stay cool