

# TCAD for electronic devices part 1

Microelectronics devices, sensors and  
MEMS

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# Synopsys TCAD tutorial – part 1

- Introduction to Synopsys simulation programs
- Numerical simulation of semiconductor resistive structures
- Getting started:
  - Start PC with **linux** OS
  - Download this guide and the script files from the course website:  
[\*\*http://webapps.unitn.it/geco/\*\*](http://webapps.unitn.it/geco/)
  - Open a terminal/console

# Part 1: SWB

# Sentaurus Workbench (SWB)

To launch SWB: type command “swb &” at the terminal

The screenshot displays the Sentaurus Workbench (SWB) interface. On the left, the 'Projects' pane shows a tree view of project files, including folders like 'Analog', 'Backend', 'Bipolar', 'CMOS', 'FinFET', 'GettingStarted', 'Hetero', 'Memory', 'Opto', 'Power', 'Sensors', 'Solar', 'Templates', 'Variability', and 'SRAM\_Variability'. A red box highlights this pane, with the label 'Projects' written below it. The main workspace is a grid. A red box labeled 'Tools' highlights the top toolbar, which contains a 'No Tools' button. A red box labeled 'Variables' highlights the grid area below the toolbar. A red arrow points from the 'Tools' box to the 'Select DB Tool' dialog box on the right. The 'Select DB Tool' dialog box shows a list of tools categorized by function: 'SENTAURUS PROCESS SIMULATION, STRUCTURE GENERATION' (including SPROCESS, PROPOSD, SPTOPD, SOE, SINTERCO, SLITHO), 'SENTAURUS GRID GENERATION' (including SMESH), 'SENTAURUS DEVICE SIMULATION' (including SDEVICE, EMW, SCAND), 'SENTAURUS VISUALIZATION' (including SVISUAL, INSPECT), 'EXTRACTION' (including RAPHAEL), 'UTILITIES' (including TDX, SHELL, TOLSH, MY TOOL), 'TAURUS PROCESS AND DEVICE SIMULATION' (including TSUPREM4, MEDICI), and 'PROCESS EMULATION' (including SPX). To the right of the dialog box, the labels 'SPROCESS', 'SDE', 'SDEVICE', and 'SVISUAL' are listed, corresponding to the categories in the dialog box. At the bottom of the screen, a status bar shows various tool states: none, queued, ready, pending, running, done, failed, aborted, virtual, pruned, orphan, and folded.

**Projects**

**Tools**

**Variables**

**SPROCESS**

**SDE**

**SDEVICE**

**SVISUAL**

Project Edit Scheduler View Scenario Tool Parameter Experiments Nodes Variables PCM Studio Extensions Help

Scenario: all

Projects

- /u/vryvkin/STDB
  - Applications\_Library
    - Bipolar
      - HBT\_BV
      - HBT\_DC
      - HBT\_RF
    - SiGeHBT\_processing
    - CMOS
      - CMOS\_130\_TS4SD
      - CMOS\_processing
      - KMC
      - NMOS\_SSE
    - FinFET
      - FTPApplicationNotes
      - GettingStarted
    - Hetero
      - HEMT\_BV
      - HEMT\_DC
      - HEMT\_RF
    - Memory
      - SONOS\_Memory
    - Opto
      - EEL\_1D
      - Raytracer\_Detector\_EQE
      - Raytracer\_Detector\_IV
    - Power
      - IGBT
      - LDMOS\_processing
      - SiC\_Schottky\_Diode
      - Thyristor
    - SPTOP0
      - 45nmCMOS\_sptopo\_Intg
    - sptopo3d\_examples
    - sptopo\_examples
    - tmp

Project Scheduler

Family Tree

Variable Values

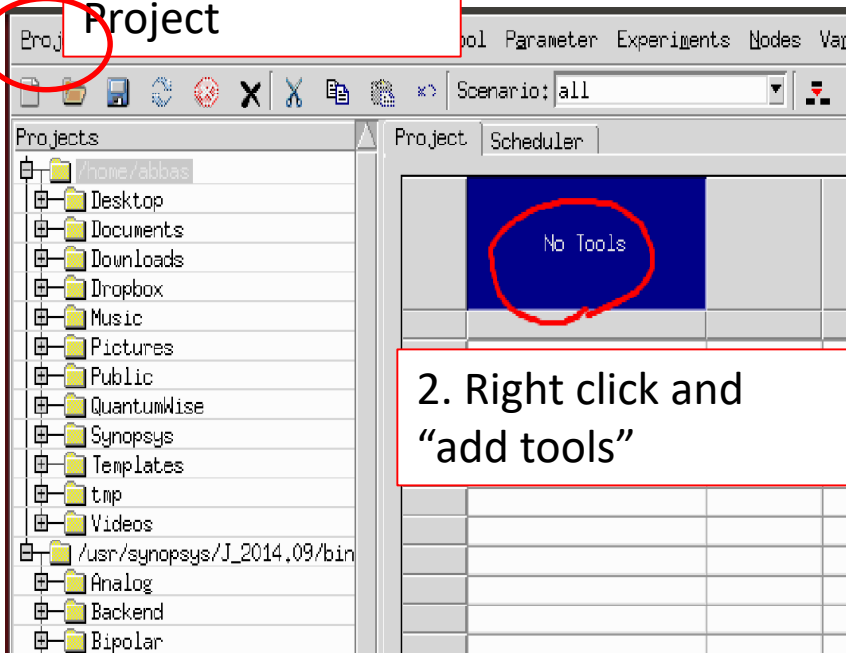
	sde	IdVg_lin	PlotIdVg_lin	IdVg_sat	PlotIdVg_sat	Vtgm	VtLin	IdLin					
Type	Igate	Vdd	Vdlin	IdVg_lin	IdVg_sat								
1	nMOS	0.045	--	1.2	0.05	1	--	--	1	--	0.16	0.282	6.494e-05
2		0.065	--	1.2	0.05	1	--	--	1	--	0.411	0.375	5.697e-05
3		0.09	--	1.2	0.05	1	--	--	1	--	0.426	0.386	5.018e-05
4		0.13	--	1.2	0.05	1	--	--	1	--	0.417	0.368	4.318e-05
5		0.25	--	1.2	0.05	1	--	--	1	--	0.404	0.344	3.174e-05
6	--	1.0	--	1.2	0.05	1	--	--	1	--	0.388	0.297	1.220e-05
7	pMOS	0.045	--	1.2	0.05	1	--	--	1	--	-0.234	-0.242	3.623e-05
8		0.065	--	1.2	0.05	1	--	--	1	--	-0.447	-0.354	2.825e-05
9		0.09	--	1.2	0.05	1	--	--	1	--	-0.476	-0.383	2.248e-05
10		0.13	--	1.2	0.05	1	--	--	1	--	-0.473	-0.377	1.735e-05
11		0.25	--	1.2	0.05	1	--	--	1	--	-0.457	-0.354	1.072e-05
12		1.0	--	1.2	0.05	1	--	--	1	--	-0.329	-0.320	3.212e-06

done queued ready pending running done failed aborted virtual pruned orphan folded

***Different color indicates different status of the node***

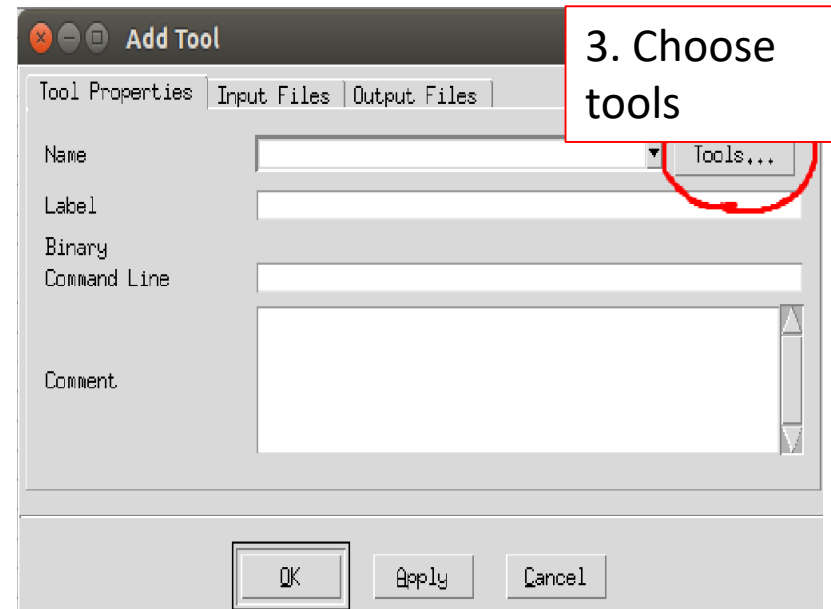
# Create New Project and Add tools

1. Project > New  
Project



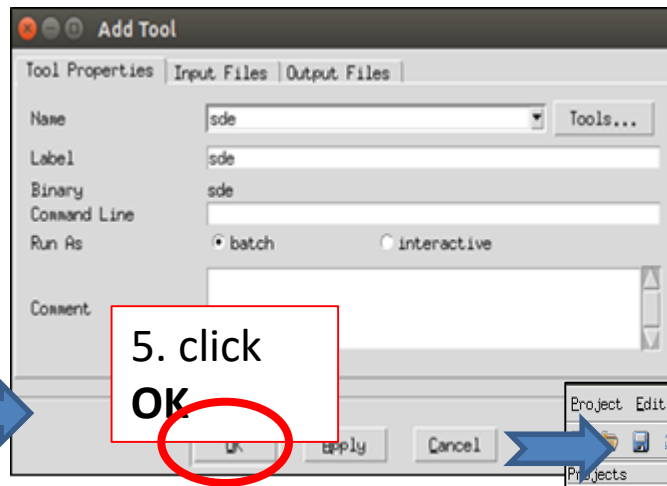
2. Right click and  
“add tools”

3. Choose  
tools

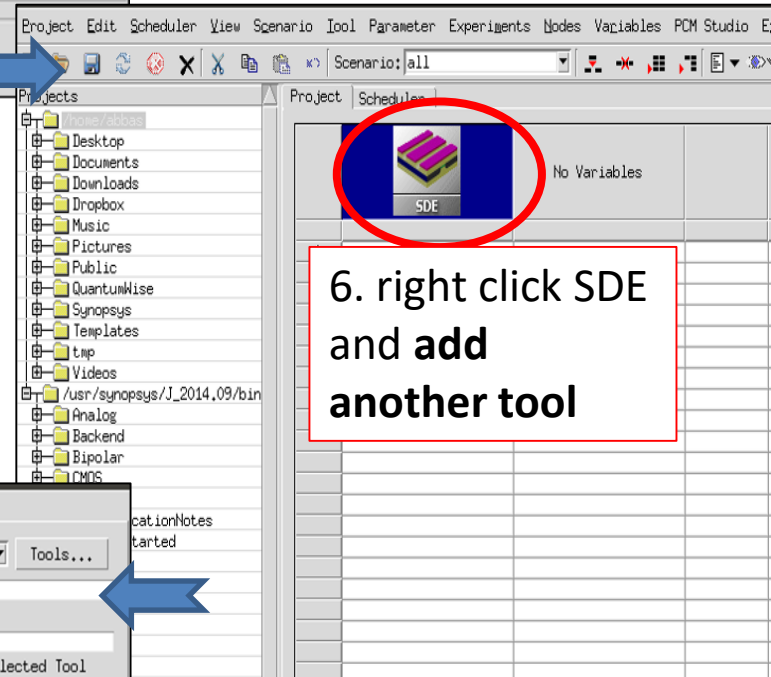




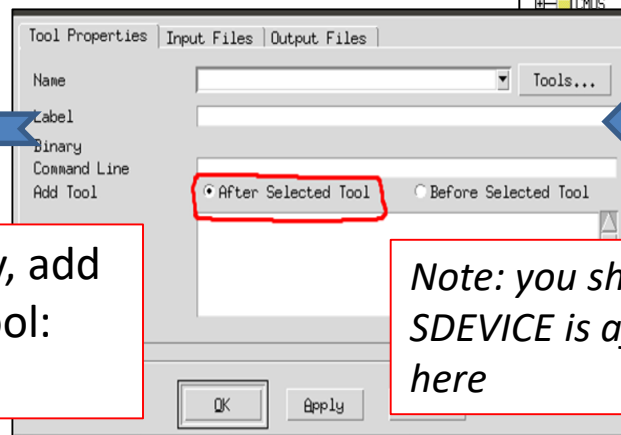
4. Choose  
**SDE**  
and click  
**OK**



5. click  
**OK**



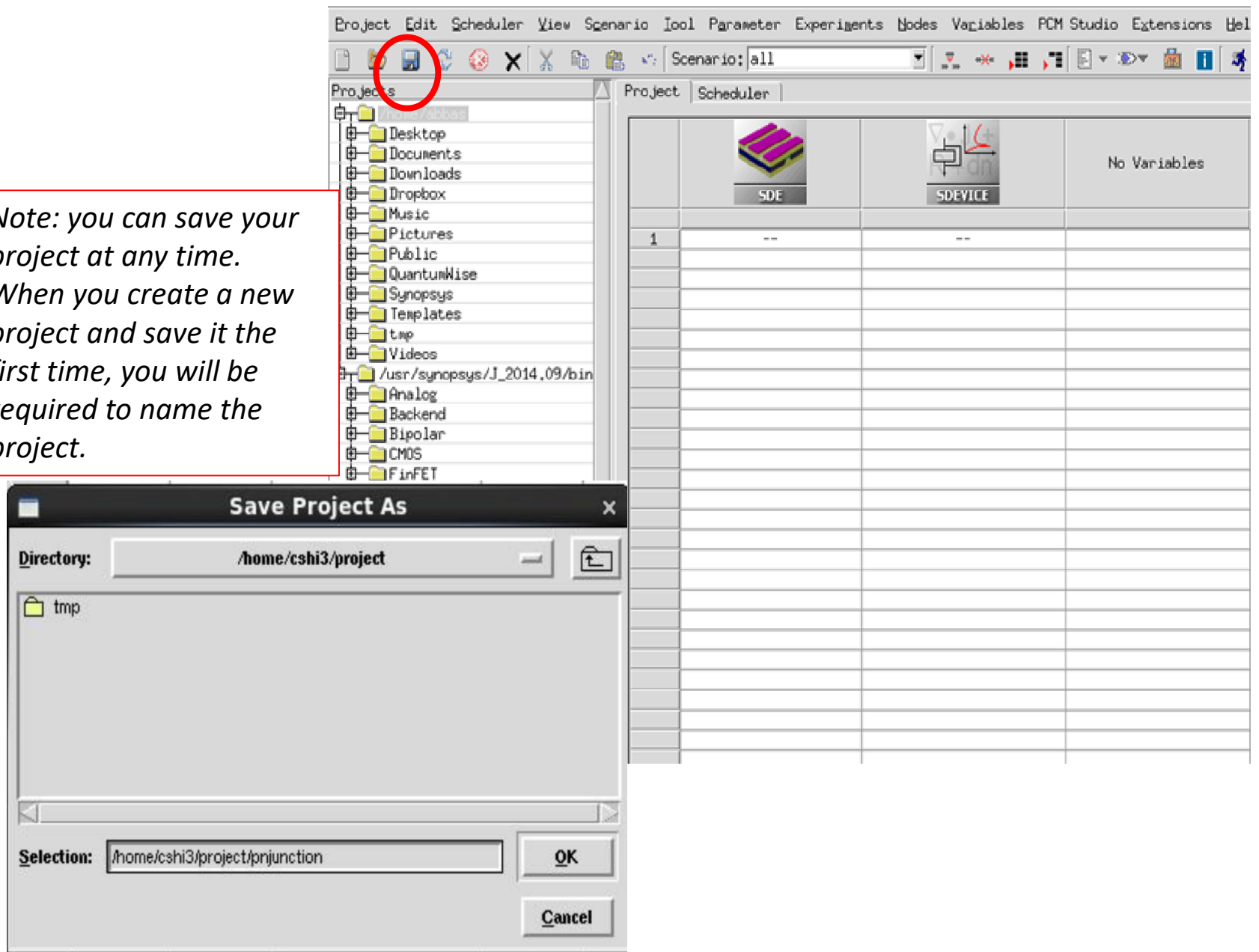
6. right click SDE  
and **add**  
**another tool**



7. Similarly, add  
another tool:  
**SDEVICE**

*Note: you should make  
SDEVICE is after SDE  
here*

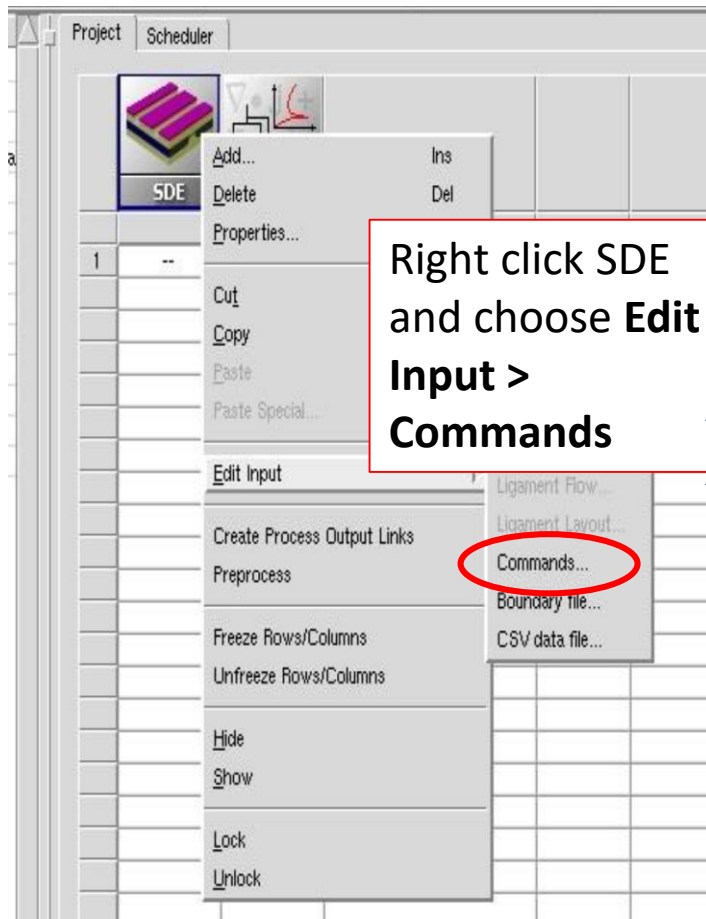
*Note: you can save your project at any time.  
When you create a new project and save it the first time, you will be required to name the project.*



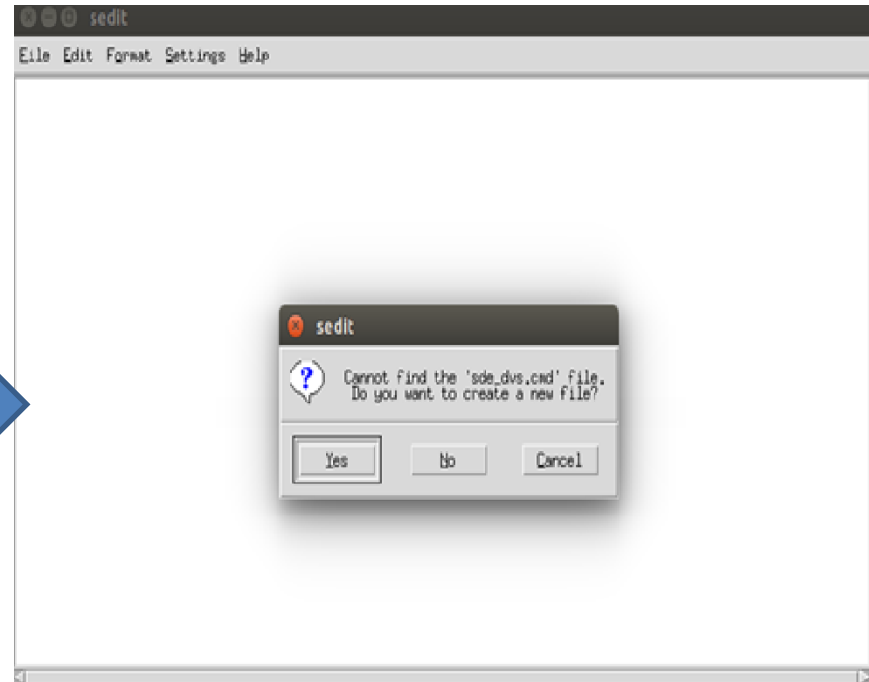


## Part 2: SDE

# Sentaurus Device Editor (SDE): using the command interface



Right click SDE  
and choose **Edit  
Input >  
Commands**



```
;;  
;; Example 1: silicon resistance  
;;
```

### ;; Define geometry

```
(sdegeo:create-rectangle (position 0 0 0) (position 100 100 0) "Silicon" "substrate")
```

### ;; Defines contact names and placements

```
(sdegeo:define-contact-set "C1" 4 (color:rgb 1 0 0) "##" )  
(sdegeo:set-current-contact-set "C1")  
(sdegeo:set-contact-edges (list (car (find-edge-id (position 1 0 0)))) "C1")  
(sdegeo:define-contact-set "C2" 4 (color:rgb 0 1 0) "##" )  
(sdegeo:set-current-contact-set "C2")  
(sdegeo:set-contact-edges (list (car (find-edge-id (position 1 100 0)))) "C2")
```

### ;; Defines the doping profiles

```
(sdedr:define-constant-profile "Substrate_prof_def" "BoronActiveConcentration" 1e15)  
(sdedr:define-constant-profile-region "Substrate_prof_plac" "Substrate_prof_def"  
"substrate")
```

### ;; Defines the mesh discretization rules

```
(sdedr:define-refeval-window "Global_ref_win" "Rectangle" (position 0 0 0) (position 100  
100 0))  
(sdedr:define-refinement-size "Global_ref_def" 5 2 0 5 2 0 )  
(sdedr:define-refinement-placement "Global_ref_plac" "Global_ref_def" "Global_ref_win" )
```

### ; saves the model file and the mesh file

```
(sde:save-model "p@node@")  
(sde:build-mesh "snmesh" "-a -c boxmethod" "n@node@")
```

Create a square silicon region

Define the contacts

Define the doping

Define the mesh

Save the file and build the mesh

# Part 3: SDEVICE

```
Math {
  Extrapolate
  Derivatives
  Iterations=30
}
```

**MATH SECTION**  
*About calculation issue*

**Right Click the SDEVICE tool, Edit Input > Command**  
**Paste the command files.**

```
Electrode {
  { Name="C1" Voltage=0}
  { Name="C2" Voltage=0}
}
```

**ELECTRODE SECTION**

**Plot Section**  
*What parameter will be showed in the XXX.tdr output file*

```
File {
  grid = "@tdr@"
  current = "@plot@"
  plot = "@tdrdat@"
}
```

**FILE SECTION**  
*The input file(from SDE)*  
*Sometimes you may need parameter files.*  
*Output file*  
*XXX.tdr----- Device figure*  
*XXX.plt----- Plot file*  
*XXX.log, XXX.out----log files*

```
Plot {
  eDensity hDensity
  TotalCurrent/Vector
  eCurrent/Vector hCurrent/Vector
  ElectricField/Vector Potential
  Doping
}
```

**Solve Section**  
*How to simulate the device*

```
Physics{
  Temperature = 300
}
```

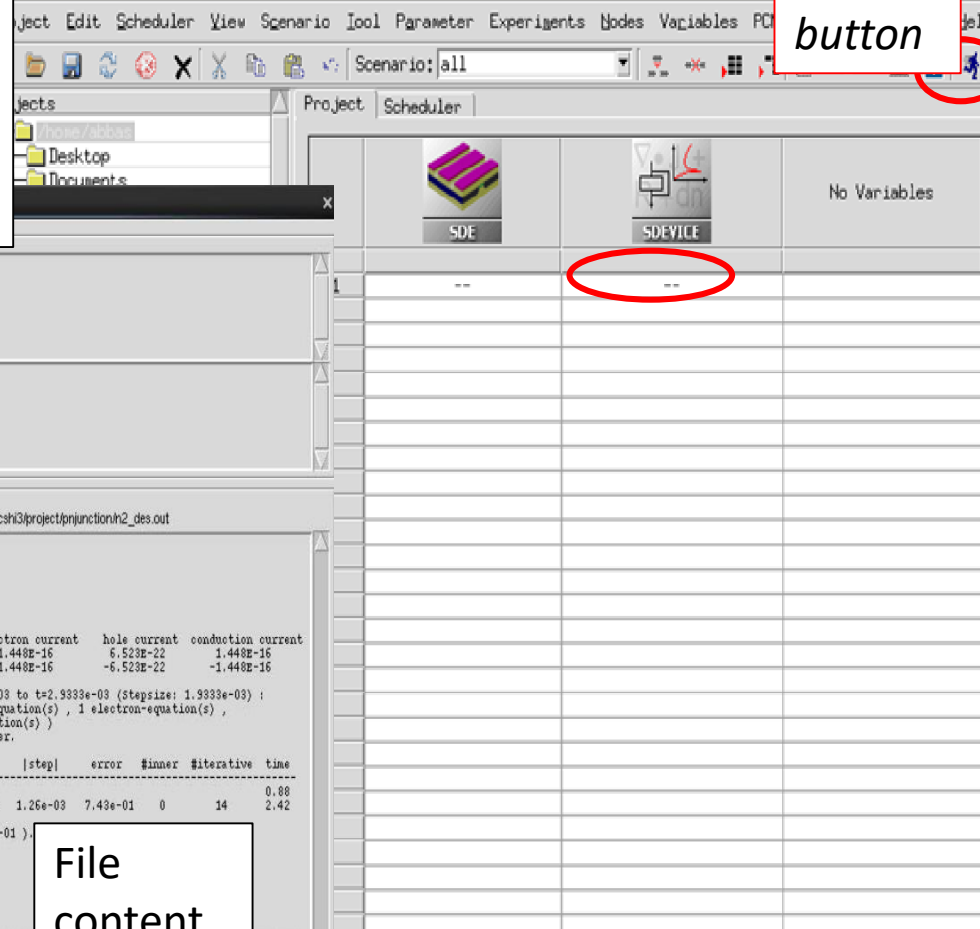
**PHYSICS SECTION**  
*What models will be used*

```
Solve {
  Poisson
  Coupled{ Poisson Electron Hole }
  Quasistationary(
    InitialStep=0.1 MinStep=1e-6
    MaxStep=0.1
    Goal{ Name="C1" Voltage=1 }
  ) { Coupled { Poisson Electron Hole } }
}
```

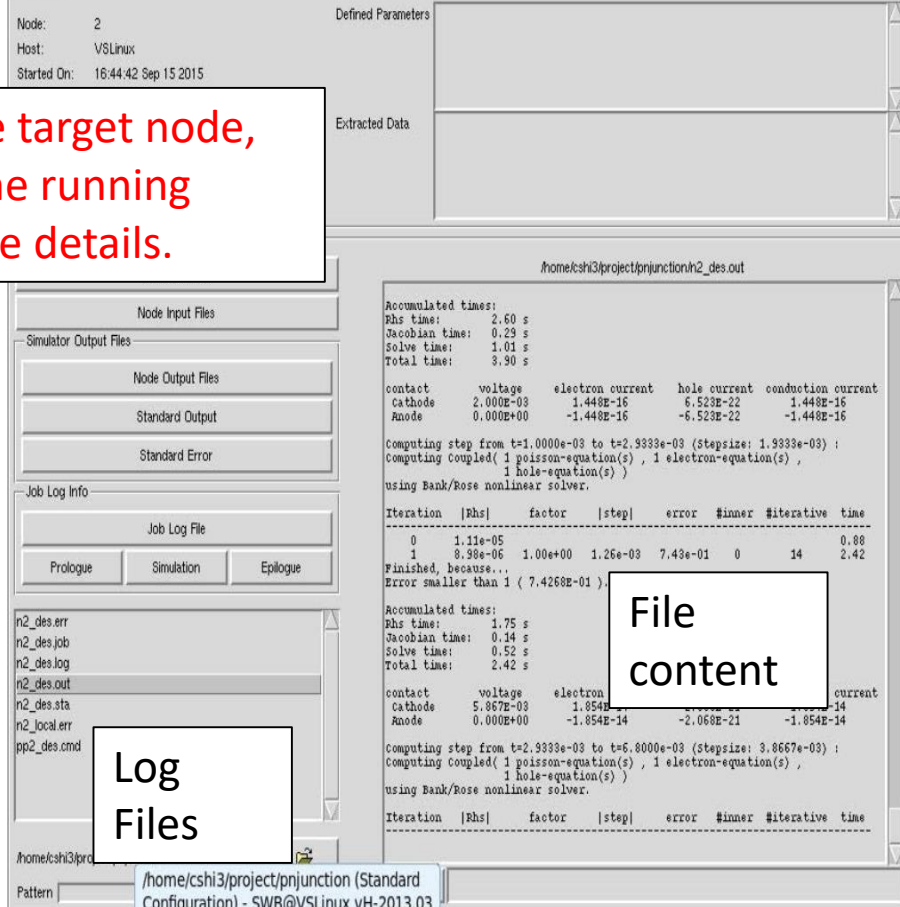
When you finish it, save the command file and close it.

Use “**Ctrl+R**” to run the project. Or Choose the **target node**(I figured it out in this figure), and click “**run button**”.

run  
button



Double click the target node, you can track the running status with more details.



Log  
Files

File  
content

If something is wrong in the simulation, you can try to check the XXX.out and XXX.err to debug.

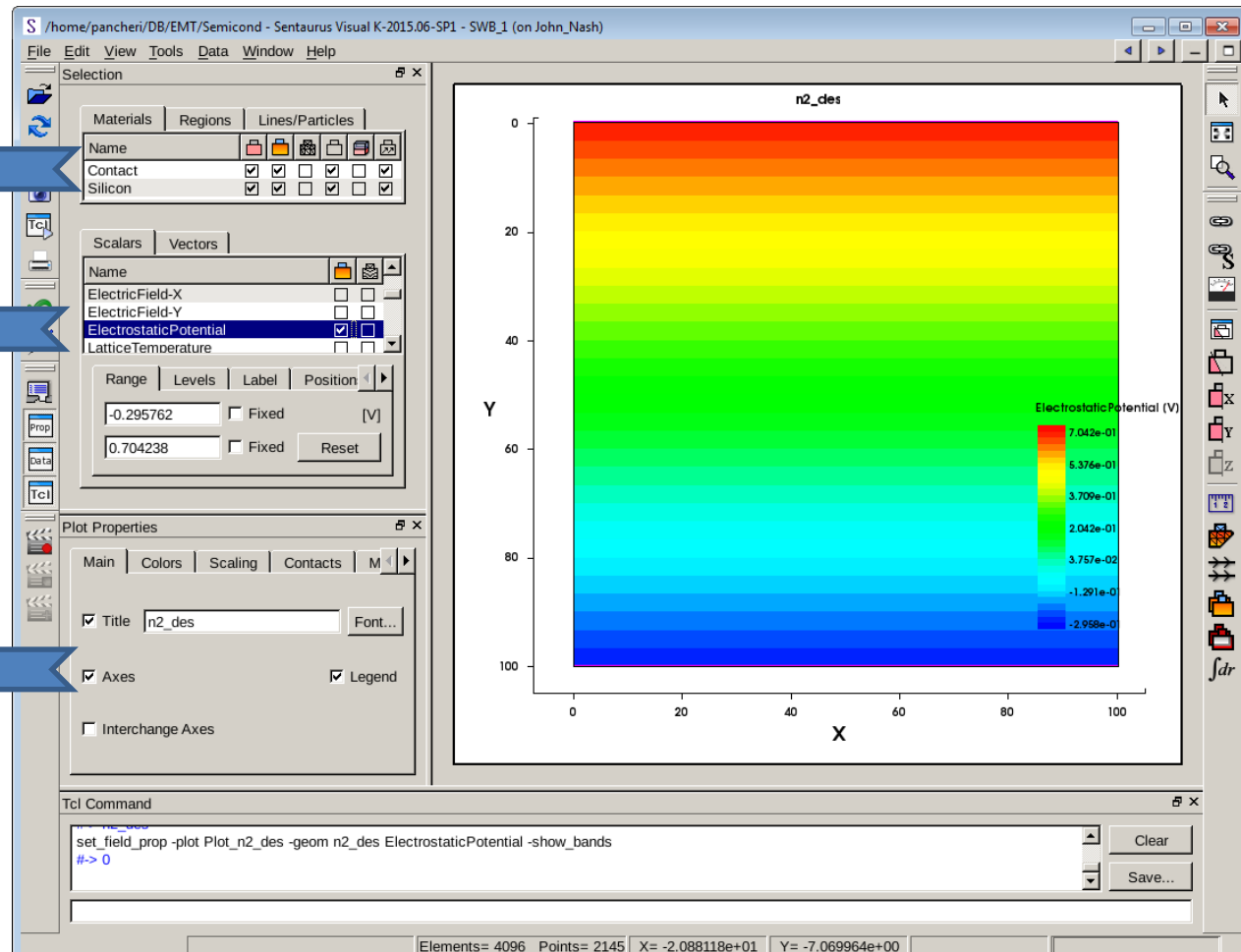
# Part 4: SVISUAL

XXX.tdr output file:  
Show the device  
figure.

Choose different region  
or contacts or material to  
show

Choose what parameter  
you'd like to see (you have  
to define them in Physic  
Section in SDEVICE code  
as we mentioned above)

The Plot Properties



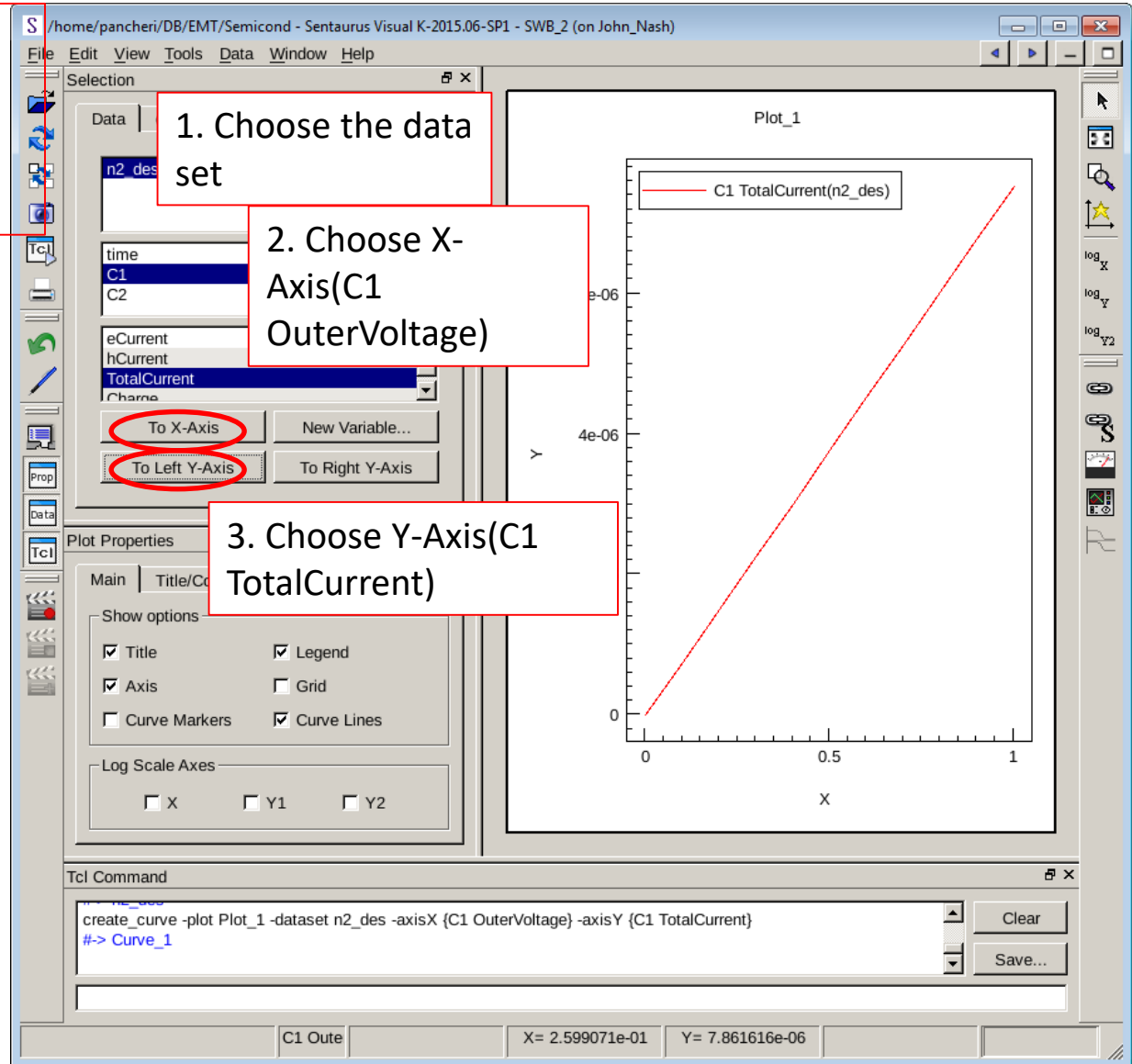


XXX.plt output file:  
Show the plot  
curve.

Notes:

**You can only choose  
one X-Axis value.**

But you can choose  
many Y-Axis to plot  
several curves in the  
same graph



# Where to get help

In sentaurus workbench: open reference manuals

The image shows the Synopsys Sentaurus Workbench interface. The top menu bar includes Project, Edit, Scheduler, View, Scenario, Tool, Parameter, Experiments, Nodes, Variables, PCM Studio, Extensions, and Help. The Help menu is open, and the question mark icon is highlighted with a red box and an arrow. Below the Help menu, the Adobe Reader window is open, displaying the 'front.pdf' file. The document title is 'front.pdf - Adobe Reader'. The document content is the 'Reference manuals' page for 'TCAD Sentaurus' by Synopsys. The page features a grid of links to various manuals, with several links highlighted by red boxes: 'Sentaurus Workbench', 'Sentaurus Process', 'Sentaurus Structure Editor', 'Sentaurus Device', and 'Sentaurus Visual'. The page also includes a sidebar with 'Tutorials', 'References and Examples', and 'Applications Library'. The version 'Version G-2012.06' is displayed at the bottom.

untitled - SWB@localhost.localdomain vK-2015.06-SP1

Project Edit Scheduler View Scenario Tool Parameter Experiments Nodes Variables PCM Studio Extensions Help

Scenario: all

Projects

- Yhome/pancheri/DB
- Course
- EMT
- LFMAPS.tar.gz
- LFMAPS
- PIXFEL
- SEED
- SSSC
- tmp
- /usr/synopsys/K\_2015.06-SP1/tcad/current
- Analog
- Backend
- Bipolar
- CMOS
- FinFET
- FTPApplicationNotes
- GettingStarted
- Hetero
- Memory
- Opto
- Power
- Sensors
- Solar
- Templates
- Variability

front.pdf - Adobe Reader

File Modifica Vista Finestra ?

1 / 1 69.9%

Strumenti Firma Commento

Reference manuals

SYNOPSYS®

TCAD Sentaurus

Framework	Process Simulation	Device Creation	Device Simulation
<a href="#">Sentaurus Workbench</a>	<a href="#">Sentaurus Process</a>	<a href="#">Sentaurus Structure Editor</a>	<a href="#">Sentaurus Device</a>
Calibration Kit Inspect Ligament Optimizer Sentaurus Data Explorer	Advanced Calibration for Process Simulation Sentaurus Interconnect Sentaurus Topography Sentaurus Topography 3D	Mesh Generation Tools	Advanced Calibration for Device Simulation Compact Models Sentaurus Device Electromagnetic Wave Solver Sentaurus Device Monte Carlo Solvers
<a href="#">Sentaurus Visual</a>			
Tecplot SV Utilities			

Tutorials

- TCAD Sentaurus Tutorial Tips & Tricks

References and Examples

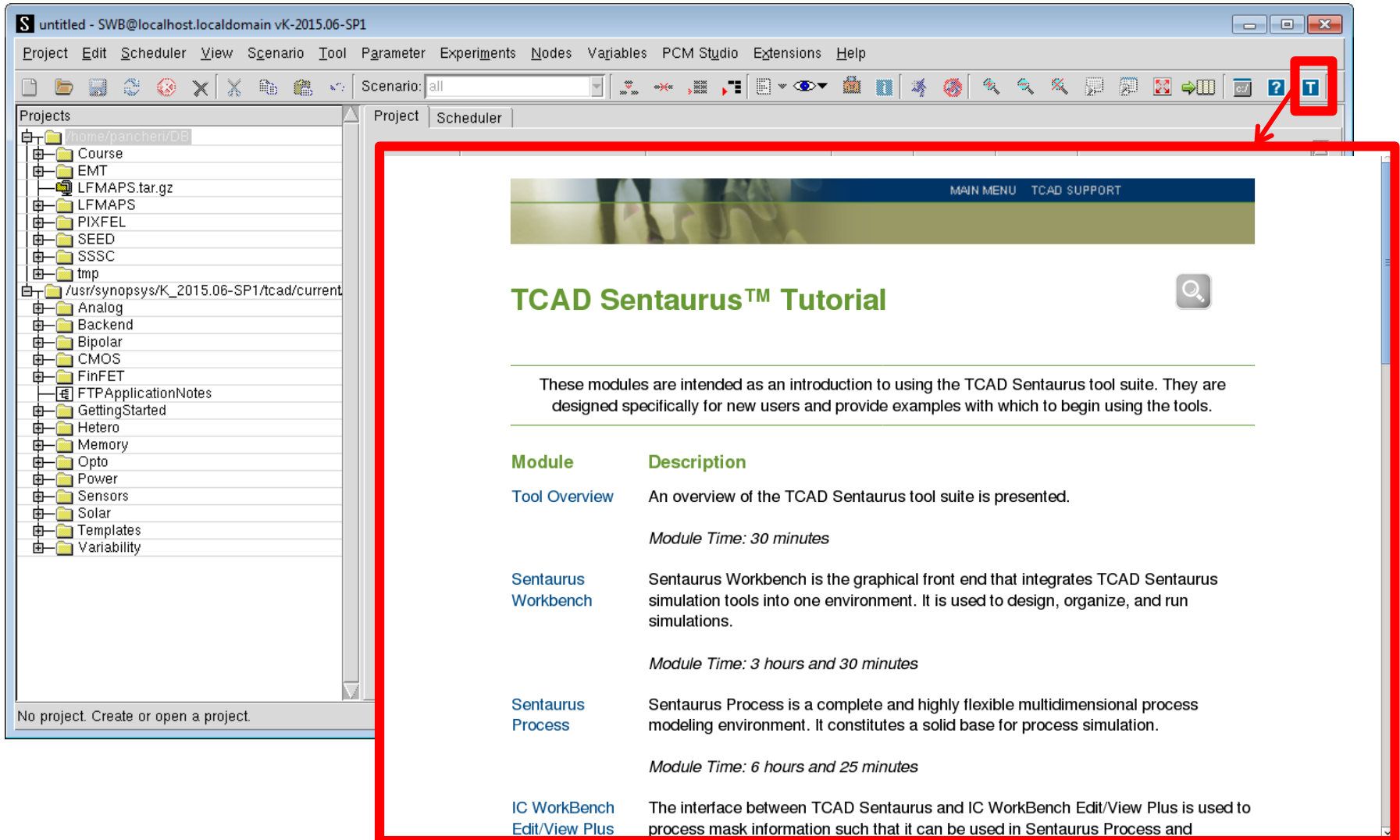
- Applications Library
- Tecplot 360™ User's Manual
- Tecplot 360™ Scripting Guide
- Release Notes
- SolvNet® Application Notes
- Product Names and Binaries

Version G-2012.06

No project. Create or open a project.

# Where to get help

In sentaurus workbench: open tutorial



untitled - SWB@localhost.localdomain vK-2015.06-SP1

Project Edit Scheduler View Scenario Tool Parameter Experiments Nodes Variables PCM Studio Extensions Help

Scenario: all

Projects

- Yhome/pancheri/DB
  - Course
  - EMT
  - LFMAPS.tar.gz
  - LFMAPS
  - PIXFEL
  - SEED
  - SSSC
  - tmp
- /usr/synopsys/K\_2015.06-SP1/tcad/current
  - Analog
  - Backend
  - Bipolar
  - CMOS
  - FinFET
  - FTPApplicationNotes
  - GettingStarted
  - Hetero
  - Memory
  - Opto
  - Power
  - Sensors
  - Solar
  - Templates
  - Variability

No project. Create or open a project.

Project Scheduler

MAIN MENU TCAD SUPPORT

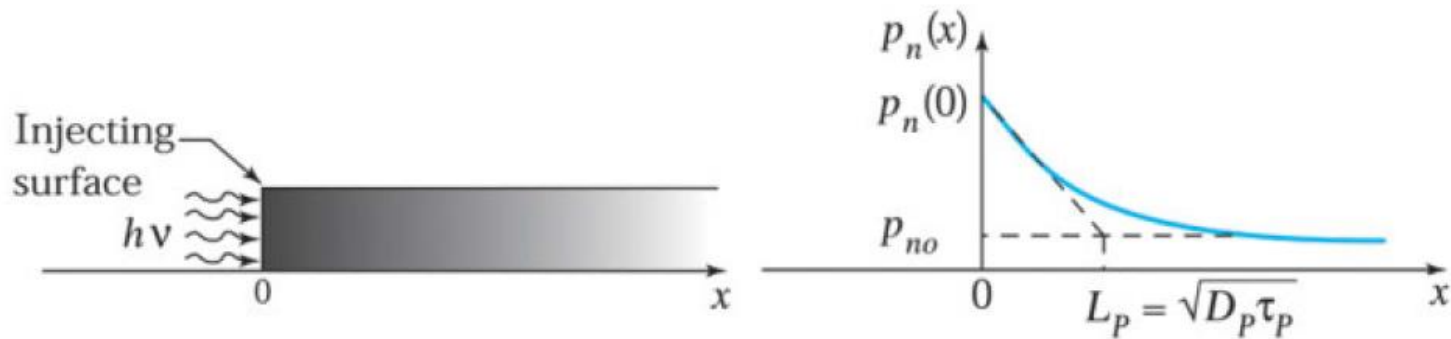
## TCAD Sentaurus™ Tutorial

These modules are intended as an introduction to using the TCAD Sentaurus tool suite. They are designed specifically for new users and provide examples with which to begin using the tools.

Module	Description
<a href="#">Tool Overview</a>	An overview of the TCAD Sentaurus tool suite is presented.  <i>Module Time: 30 minutes</i>
<a href="#">Sentaurus Workbench</a>	Sentaurus Workbench is the graphical front end that integrates TCAD Sentaurus simulation tools into one environment. It is used to design, organize, and run simulations.  <i>Module Time: 3 hours and 30 minutes</i>
<a href="#">Sentaurus Process</a>	Sentaurus Process is a complete and highly flexible multidimensional process modeling environment. It constitutes a solid base for process simulation.  <i>Module Time: 6 hours and 25 minutes</i>
<a href="#">IC WorkBench Edit/View Plus</a>	The interface between TCAD Sentaurus and IC WorkBench Edit/View Plus is used to process mask information such that it can be used in Sentaurus Process and

# Example 4.

Minority carrier injection on one side



Using optical generation to inject the carriers.

In the example: p-type silicon doped with  $N_A = 10^{14}$  acc./cm<sup>3</sup>

Monitoring electron concentration decay

$$D_n = 35 \text{ cm}^2/\text{s} \quad \tau_n = 10 \text{ } \mu\text{s}$$

$$L_n = \sqrt{35 \times 10 \times 10^{-6}} = 187 \text{ } \mu\text{m} \quad \rightarrow \quad \text{Silicon length} = 1\text{mm}$$

# Example 4. Geometry

Device is divided in 2 regions:

- left: from 0 to 10  $\mu\text{m}$ : where optical generation takes place
- right: from 10  $\mu\text{m}$  to 1mm, no optical generation

```
;; Define geometry
```

```
(sdegeo:create-rectangle (position 0 0 0 ) (position 10 1 0 )  
"Silicon" "left" )  
(sdegeo:create-rectangle (position 10 0 0 ) (position 1000 1 0 )  
"Silicon" "right" )  
(sdegeo:insert-vertex (position 2 0 0 ))  
(sdegeo:insert-vertex (position 998 0 0 ))
```

```
;; Define the doping profiles
```

The two regions have the same doping

```
(sdedr:define-constant-profile "Substrate_prof_def"  
"BoronActiveConcentration" 1e14)  
(sdedr:define-constant-profile-region "leftSubstrate_prof_plac"  
"Substrate_prof_def" "left")  
(sdedr:define-constant-profile-region "rightSubstrate_prof_plac"  
"Substrate_prof_def" "right")
```

# Example 4. Command file

```
Physics{  
    Temperature = 300  
    Recombination(SRH( DopingDep ))  
}
```

Includes SRH model (standard lifetimes expressed by Scharfetter equation)

```
Physics (Region = "left") {  
    Optics (  
        OpticalGeneration (SetConstant (Value = 1e18))  
    )  
}
```

Optical generation activated in the left region

```
Plot {  
    eDensity hDensity  
    TotalCurrent/Vector eCurrent/Vector hCurrent/Vector  
    ElectricField/Vector Potential  
    eLifetime hLifetime SRH  
    Doping  
}
```

Plots also lifetime and SRH recombination

```
Solve {  
    Poisson  
    Coupled{ Poisson Electron Hole }  
}
```

Steady-state simulation

# Plotting results

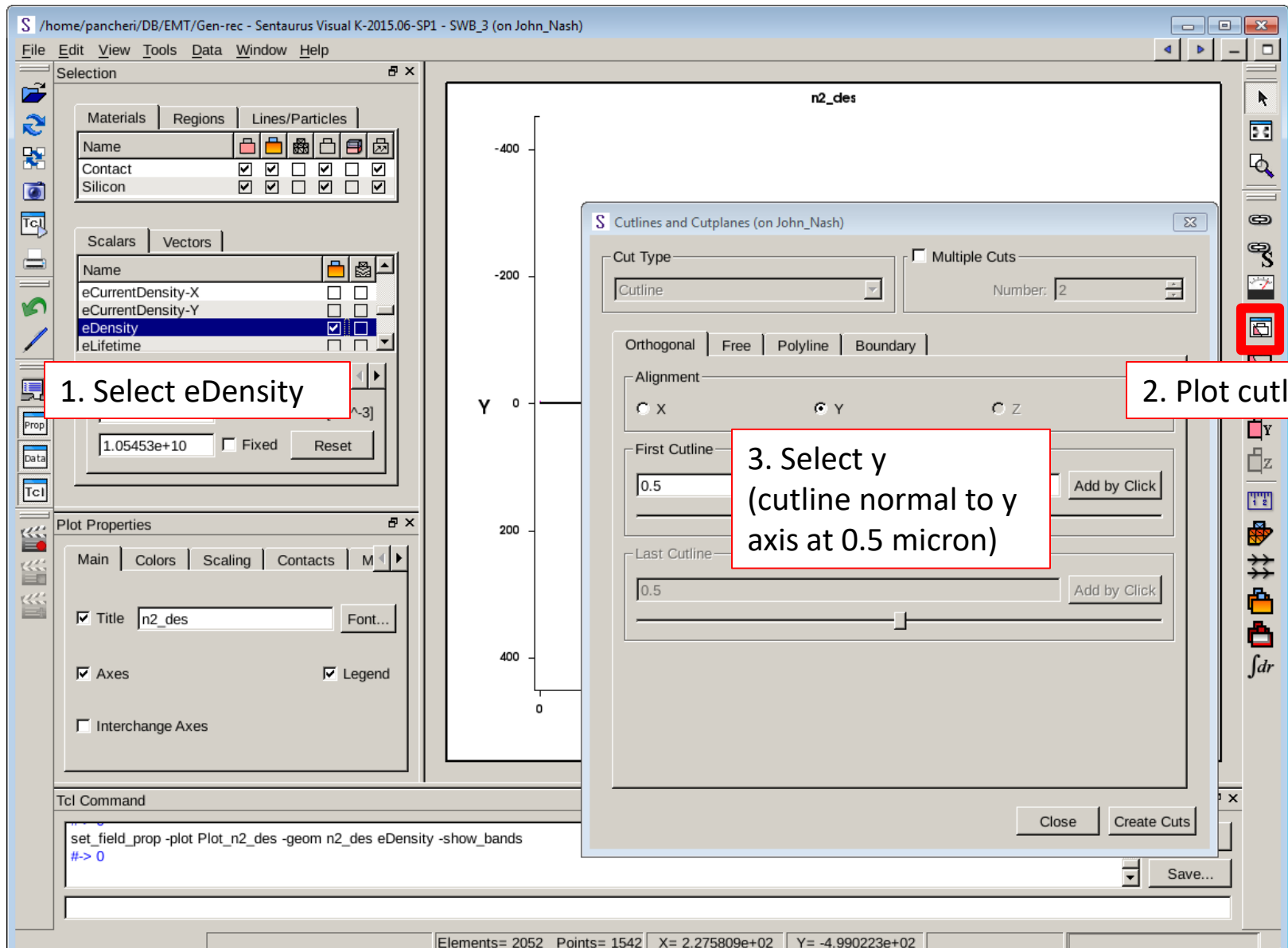
The screenshot displays the Synopsys S-Studio interface in 'Runtime Mode: Editable'. The main window shows a project tree on the left with folders like 'Course', 'EMT', and 'Diode1'. A context menu is open over the 'Diode1' folder, with the 'Visualize' option selected. A red box labeled '1. Right-click' points to the 'Diode1' folder. The context menu includes options like 'Copy', 'Paste', 'Edit Value', 'Modify Multiple Parameter Values...', 'Set Variable Value...', 'Preprocess', 'Run...', 'Quick Run...', 'Abort', 'Visualize', 'Quick Visualize', 'Node Explorer', and 'View Output'. A red box labeled '2. Choose Sentaurus visual (select file...)' points to the 'Visualize' option. A 'Sentaurus Visual Visualization' dialog box is open in the foreground, showing a list of files with 'n2\_des.tdr' selected. A red box labeled '3. Select n2\_des.tdr' points to 'n2\_des.tdr'. The dialog box also shows a list of viewers and buttons for 'Select All', 'Clear Selection', 'OK', and 'Cancel'. The status bar at the bottom indicates the simulation status: 'ing', 'running', 'done', 'failed', 'aborted', 'virtual', 'pruned', 'orphan', and 'folded'.

1. Right-click

2. Choose Sentaurus visual (select file...)

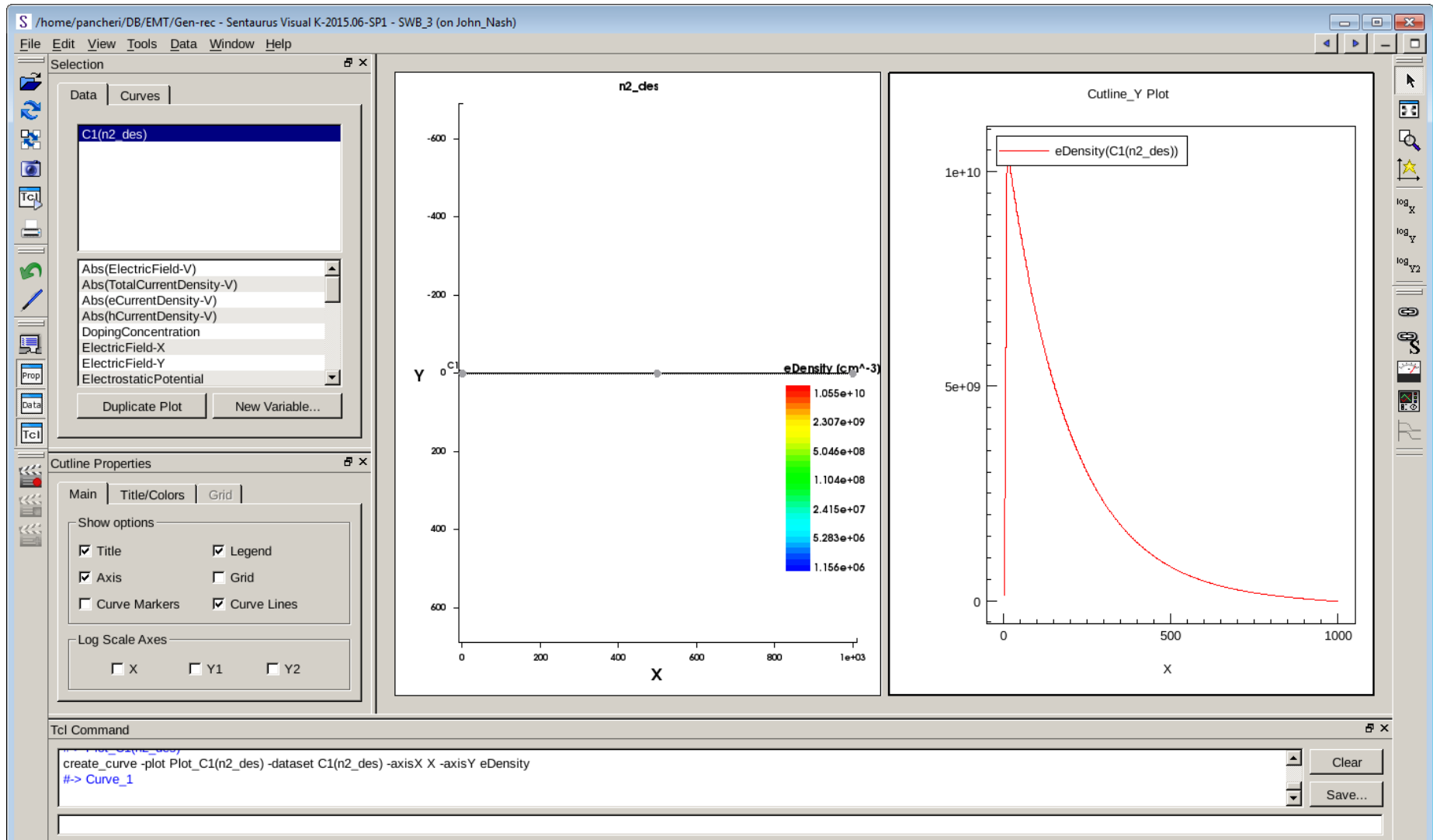
3. Select n2\_des.tdr

# Plotting results: svisual





# Plotting results: electron concentration



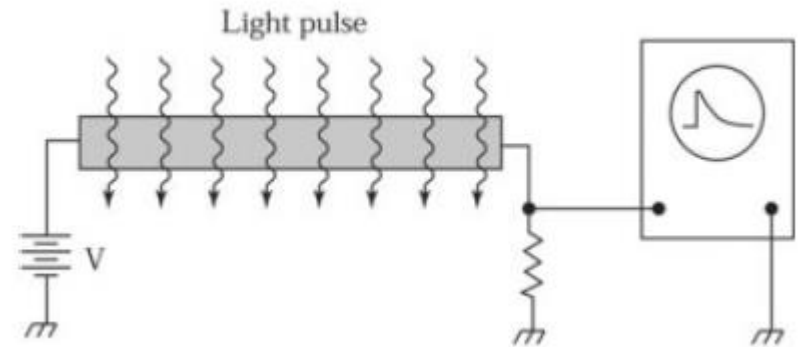
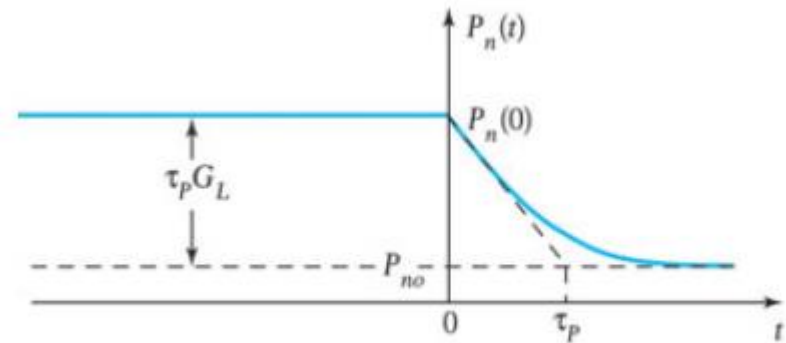
# Example 5.

Photoconductivity decay

In the example: p-type silicon doped  
with  $N_A = 10^{14}$  acc./cm<sup>3</sup>

Monitoring electron concentration time  
decay, applying a light pulse

$\tau_n = 10 \mu\text{s}$  → Simulation time 100  $\mu\text{s}$



# Example 5. Geometry

Device is divided in 2 regions:

- left: from 0 to 10 um: where optical generation takes place
- right: from 10um to 1mm, no optical generation

```
;; Define geometry
```

```
(sdegeo:create-rectangle (position 0 0 0 ) (position 10 1 0 )  
"Silicon" "left" )  
(sdegeo:create-rectangle (position 10 0 0 ) (position 1000 1 0 )  
"Silicon" "right" )  
(sdegeo:insert-vertex (position 2 0 0 ))  
(sdegeo:insert-vertex (position 998 0 0 ))
```

```
;; Define the doping profiles
```

The two regions have the same doping

```
(sdedr:define-constant-profile "Substrate_prof_def"  
"BoronActiveConcentration" 1e14)  
(sdedr:define-constant-profile-region "leftSubstrate_prof_plac"  
"Substrate_prof_def" "left")  
(sdedr:define-constant-profile-region "rightSubstrate_prof_plac"  
"Substrate_prof_def" "right")
```

# Example 5. Command file 1

```
Solve {  
    Poisson  
    Coupled{ Poisson Electron Hole }  
  
    Quasistationary(  
        InitialStep=0.1  MinStep=1e-6 MaxStep=0.1  
        Goal{ Name="C1" Voltage=0.1 }  
    ) { Coupled { Poisson Electron Hole } }  
    Save(FilePrefix="bias01V")  
}
```

Steady state simulation

Saves a state file at the end of the simulation

# Example 5. Command file 2

```
Physics{
  Temperature = 300
  Recombination(SRH( DopingDep ))

  Optics (
    OpticalGeneration (
      SetConstant (Value = 1e18)
      TimeDependence (
        WaveTime = (10e-6, 50e-6)
        WaveTSigma = 1e-9
      )
    )
  )
}
Solve {
  Load(FilePrefix="bias01V")
  Transient(
    InitialTime=0.0
    FinalTime=100e-6
    InitialStep=0.2e-6
    MaxStep=0.2e-6
    MinStep=1e-9
    Increment=1.5
    Plot { Range = (0 100e-6) Intervals =10}
  ) { Coupled { Poisson Electron Hole} }
}
```

Optical generation defines optical pulse

Transient solution, starting from the  
Saved state file

Plots 10 intermediate state  
files

# Plotting results

The screenshot shows the S-Studio interface with the following components:

- Project List:** A tree view on the left showing the project hierarchy. The 'Gen-rec' project is selected.
- Project Scheduler:** A table in the center showing the project schedule. The 'Gen-rec' project is highlighted in yellow.
- Context Menu:** A right-click menu is open over the 'Gen-rec' project. The menu items include: Copy, Paste, Edit Value, Edit Properties..., Modify Multiple Parameter Values..., Set Variable Value..., Preprocess, Run..., Quick Run..., Abort, Visualize, Quick Visualize, Node Explorer, View Output..., and Clean Up Node Output....
- Sentry Visual Visualization Dialog:** A dialog box is open in the foreground. It has two panes: 'Files' and 'Viewers'. The 'Files' pane shows two files: 'n2\_des.plt' and 'n3\_des.plt'. The 'Viewers' pane shows 'new S-Visual instance'. The 'Files' pane is highlighted with a red box.

Annotations and steps:

1. Right-click
2. Choose Sentry Visual (select file...)
3. Select n3\_des.plt

# Plotting results: svisual

