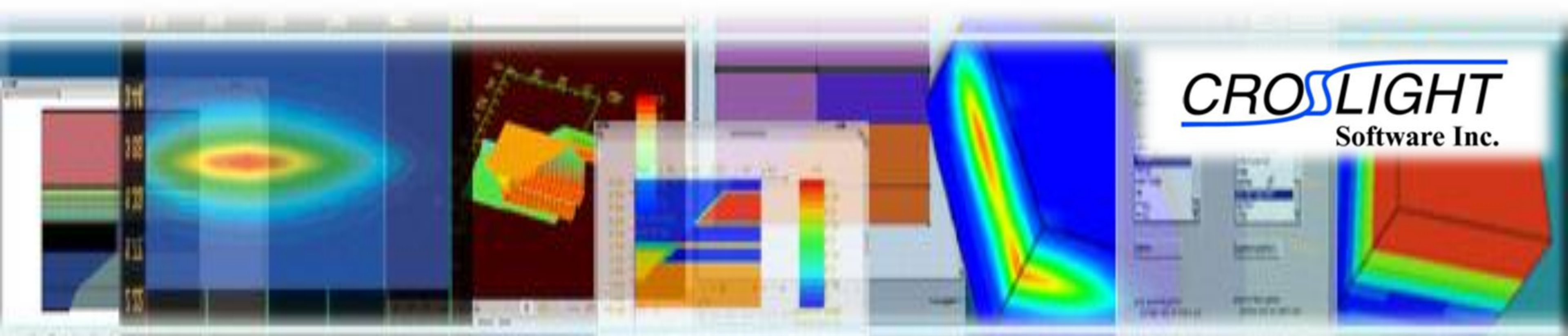


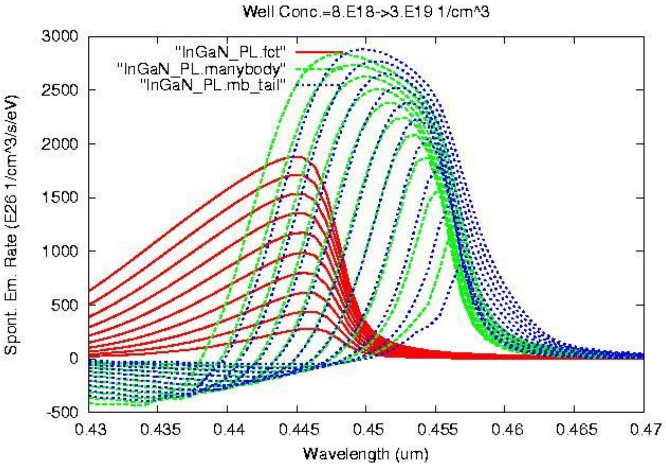
Lighting up the Semiconductor World…

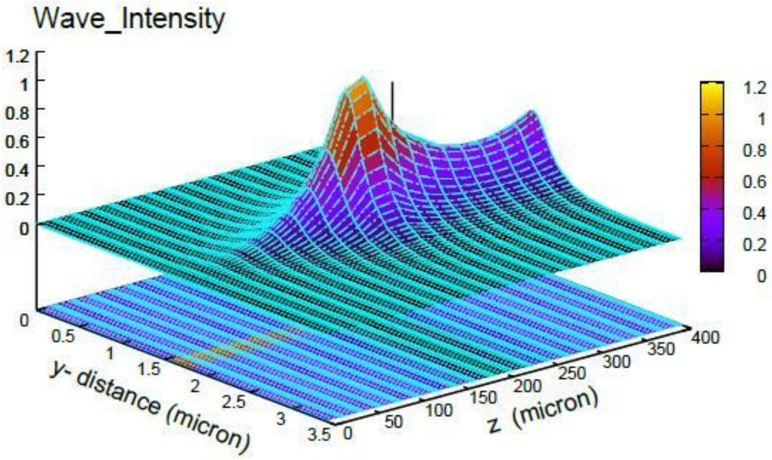
Semiconductor Device Engineering and Crosslight TCAD

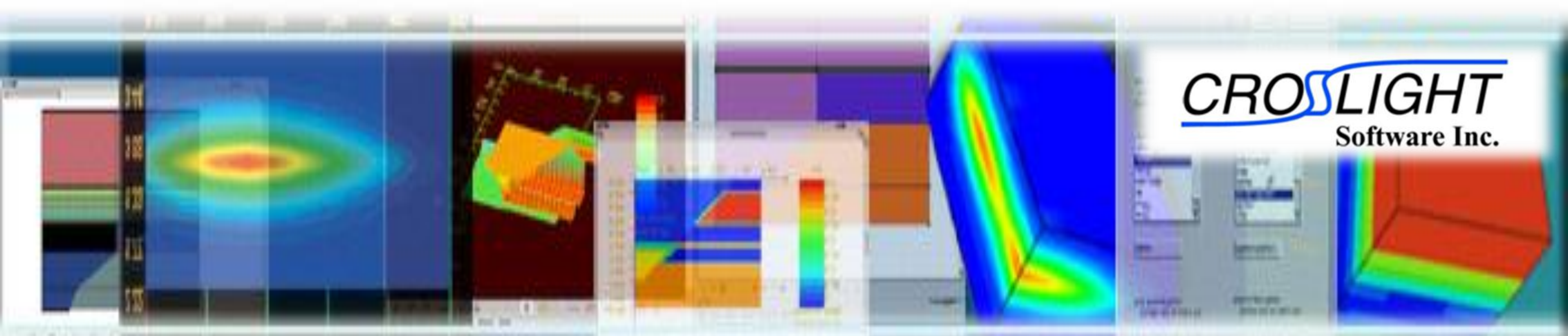
What is TCAD?

- TCAD stands for Technology Computer Aided Design, it is a software tool for device engineers and professionals to look into the device physics and its electrical thermal and optical performance.

- Unlike IC CAD, TCAD uses physical models and Finite Element Method (FEM) to simulate the semiconductor device behavior. IC CAD is using compact models (semi-empirical math equations)







Lighting Up the Semiconductor World:

About Crosslight TCAD

A Glimpse

- A leading TCAD provider since 1993
- The world's No.1 TCAD simulator for optics and photonics application
- The world's first commercial TCAD for Laser Diode
- Customer list extends to hundreds of companies, research institutions and universities world wide.
- Complete product portfolio for 2D/3D semiconductor device simulation
- *Café-time Simulator*. Windows based, user friendly GUI makes simulation more enjoyable.

Crosslight Global Offices

Vancouver Office

Japan Office

South Korea

China Office

Vancouver Headquarter

Shanghai Office

Japan Office

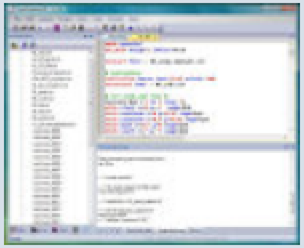
Taiwan Distributor

China Distributor

Korea Distributor

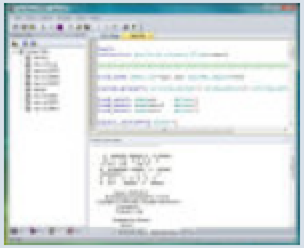
India and Southeast Asia Distributor (Future)

Product Portfolio For Microelectronics Application



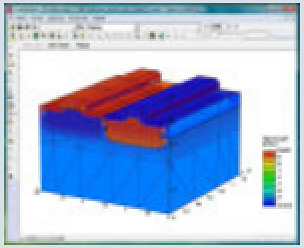
CSuprem ---- Advanced Semiconductor Process Simulator TCAD --- Windows based

- 2D/3D Capable
- Quasi-3D/full 3D
- plane-stacked 3D to ensure flexibility and efficiency



APSYS ---- Advanced Semiconductor Device Simulator TCAD ---- Windows based

- 2D/Full 3D Capable
- Band-Engineering based
- MQW, Impact Ionization

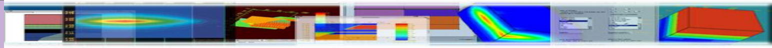


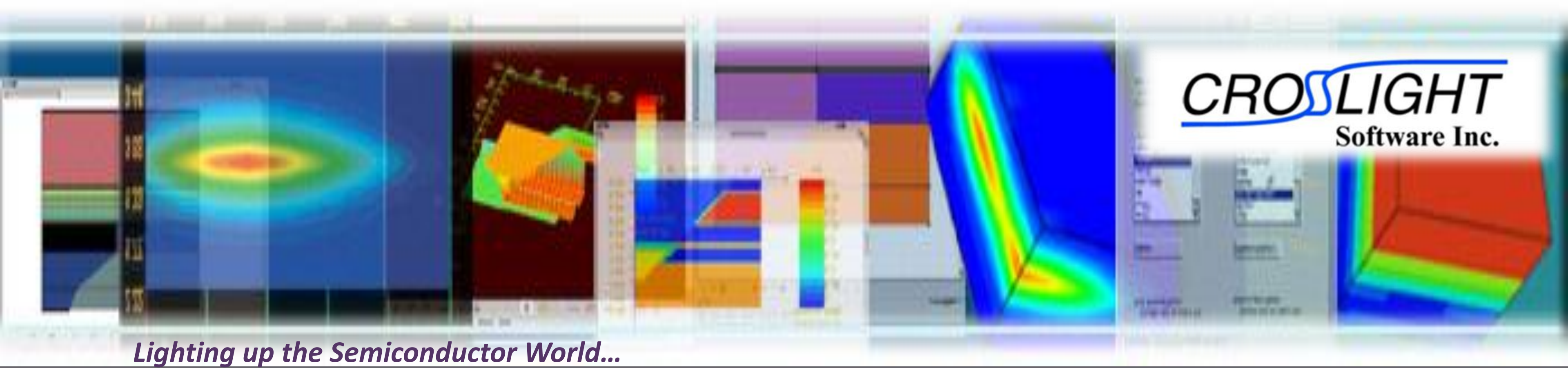
CrosslightView ---- Graphic User Interface (GUI) --- Windows based

- 2D/3D Rotation
- 3D meshing
- Automatic MOSFET Threshold Extraction

CSUPREM Features

- Originated from Stanford University’s Suprem IV, 2D/3D capable
- Innovative simulation tools to ensure a fast and seamlessly transfer from process to device simulation
- Stacked3D technology enables ultra efficient 3D structure combined with powerful and easy to use 3D editor to provide class leading 3D simulation experience
- Windows based and user friendly Graphic User Interface (GUI)
- AutoTCAD for generating a series of simulations from parameter variations, perfect for overnight simulations
- Embedded easy 2D/3D setup tool, grammar check tool, *point and show* wizard help and tutorial movies for a jump start





3D Simulation of Semiconductor Devices Using *MaskEditor*

About3D Simulation

Why 3D?

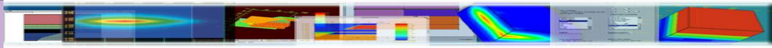
- Device is 3D in nature, lots of devices need 3D simulation for better accuracy. For example, Superjunction LDMOS, metal interconnect, etc.

Do you need 3D Simulation?

- Does your device have variation along the third (z) dimension ?
- Do you want to examine some peripheral behavior of the device, like fringe current at the corner of race-track shaped gate?
- Does your device have a special shape from top down view? (like CMOS Image Sensor, or HEXFET)?

Challenges for 3D Simulation:

- Extremely time consuming. As hard as it may be to believe, traditional 3d simulation time may be longer than the actual fabrication time for large power semiconductor devices.
- Difficult to build the structure and optimize the mesh.

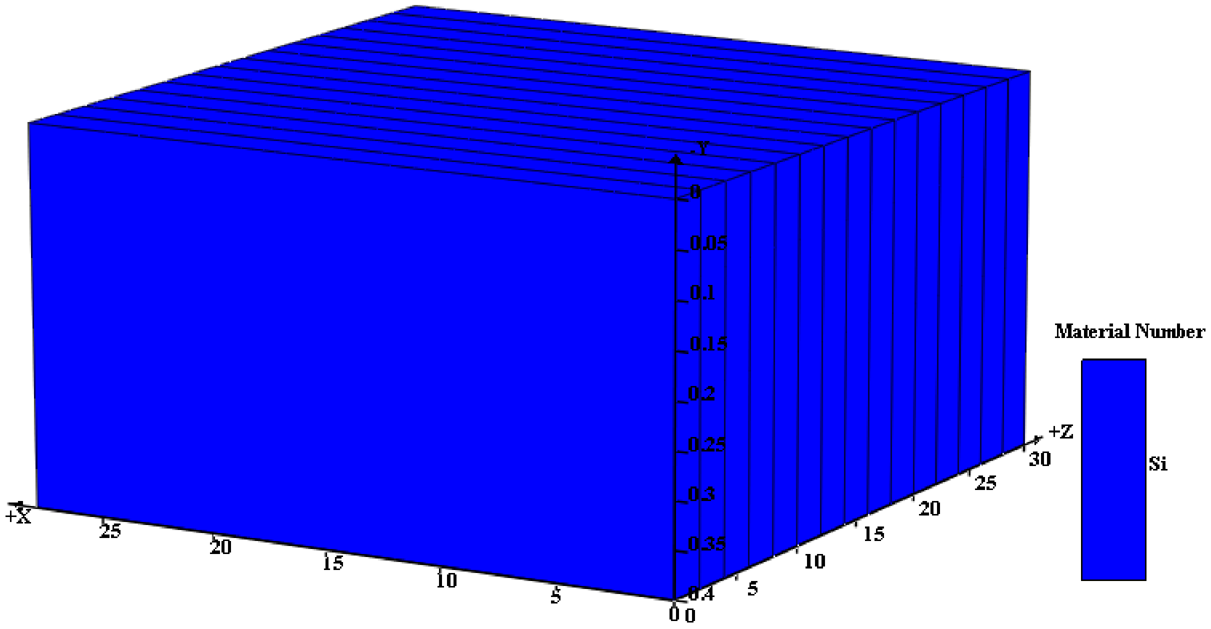


Crosslight's Approach of 3D Simulation

Stacked3D

- Crosslight has developed a unique 3D simulation package. Instead of traditional approach, which basically starts from bulk (conventional 3D FEM), Crosslight starts from 2D planes, and stacks them to form the 3D structure.

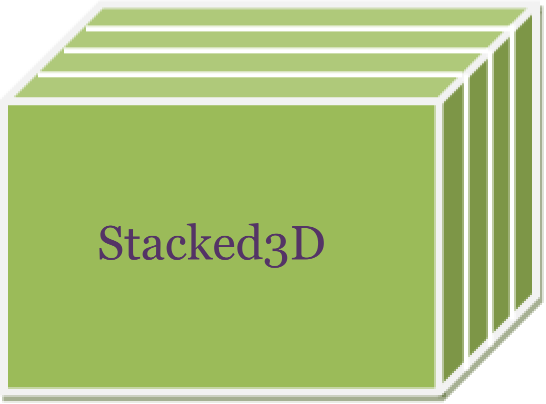
Stacked3D Example:

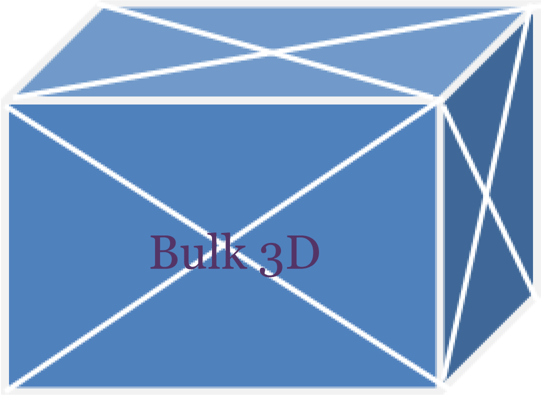


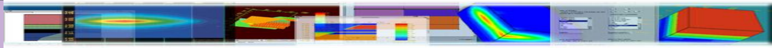
Advantages of Stacked3D

Stacked3D Advantages

- Highly Efficient, generally less mesh points required, mesh density can easily be varied
- Easy to build: It starts from 2D planes
- Easy to optimize mesh. The mesh can be optimized for individual planes
- Increased 3D success rate from successful 2D simulation
- Directly extract 2D planes and 2D simulation

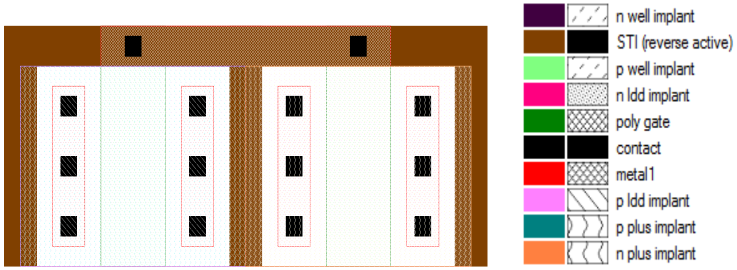


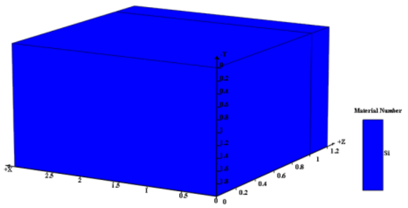




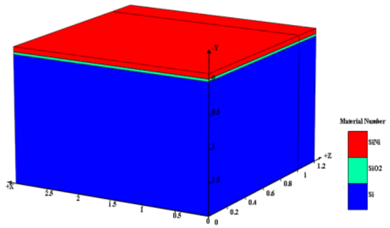
Simulation Examples:

CMOS Process Flow

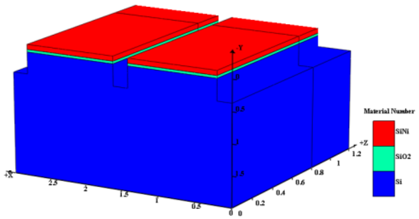




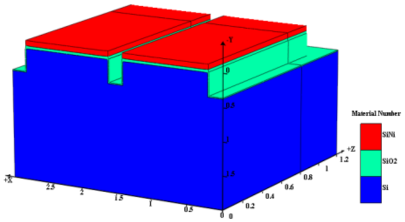
1. Substrate



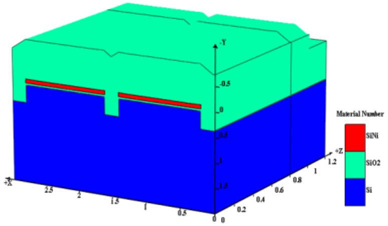
2. Pad Ox and Nitride



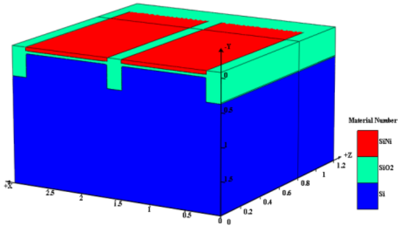
3. STI plasma etch



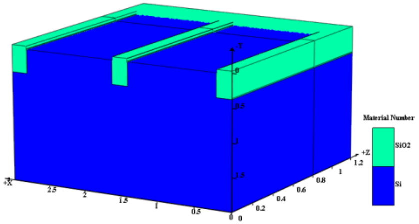
4. STI thermal liner oxide



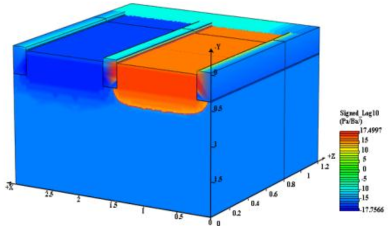
5. STI HDP fill



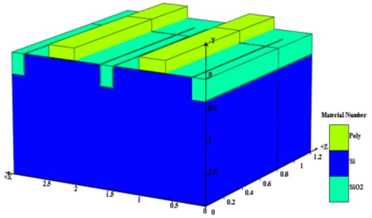
6. CMP Nitride layer



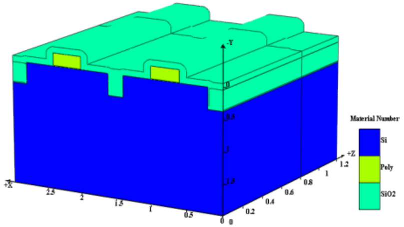
7. Chemical strip



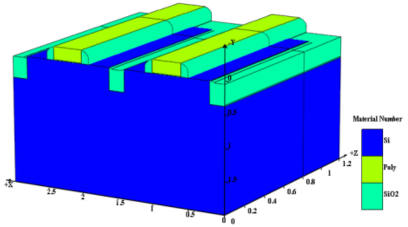
8. Well implants & drives



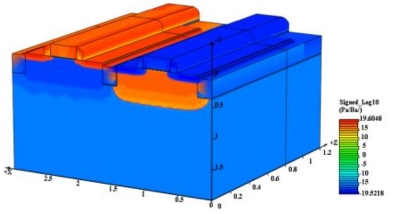
9. Poly deposit



10. Spacer deposit



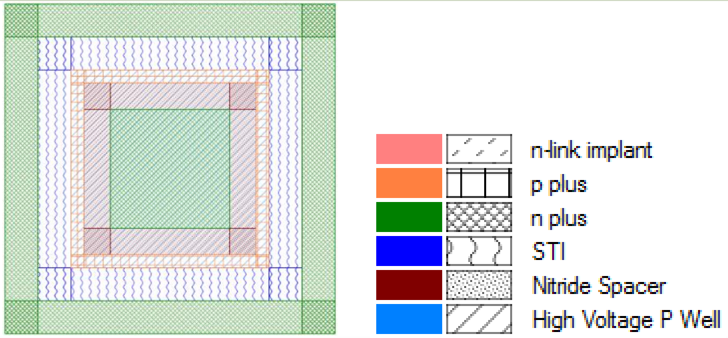
11. Spacer etch

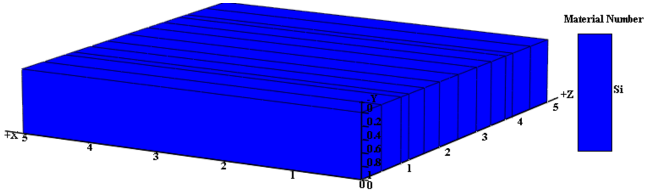


12. FEOL result: doping

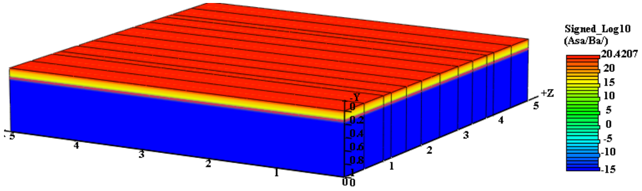
Simulation Examples:

NPN BJT

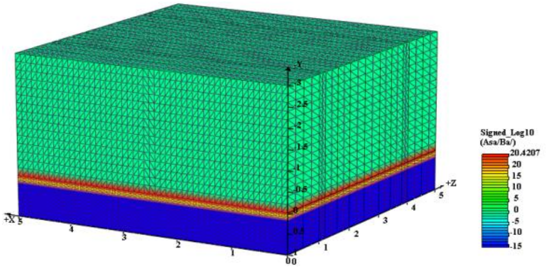




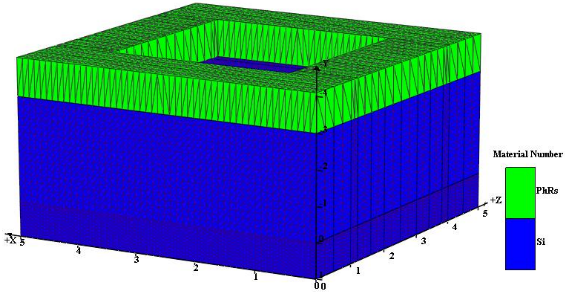
1. Substrate



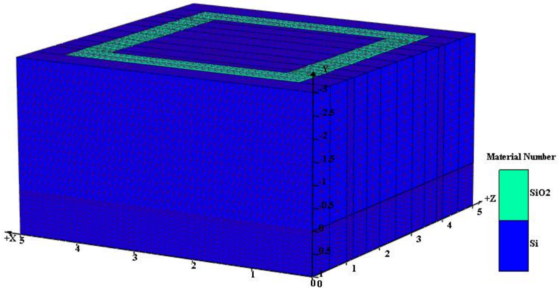
2. Buried Layer



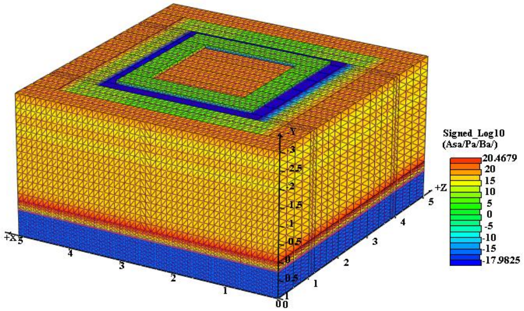
3. Epi Layer



4. Base Mask



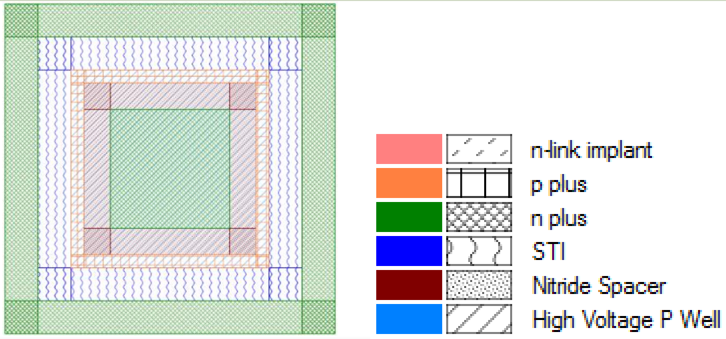
5. STI fill

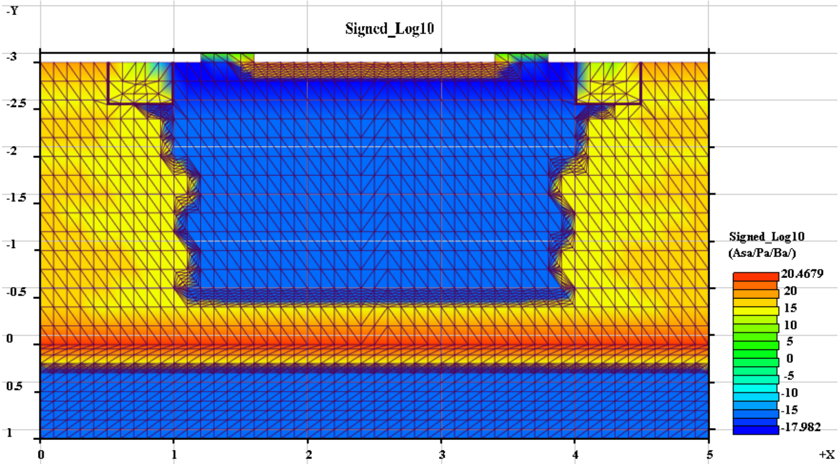


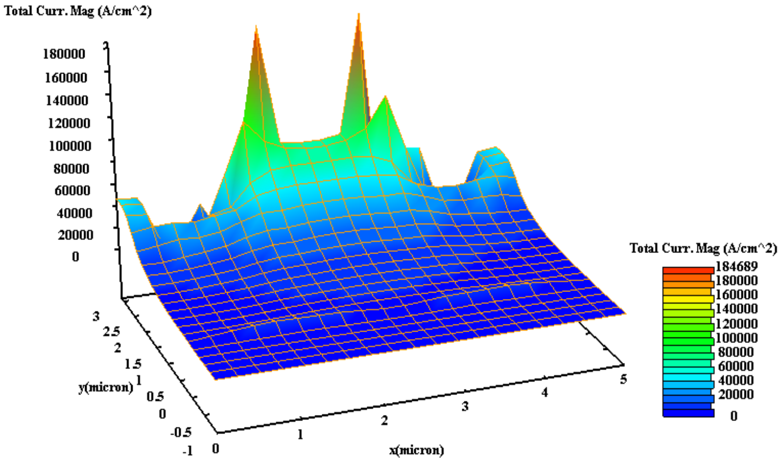
6. Final net doping

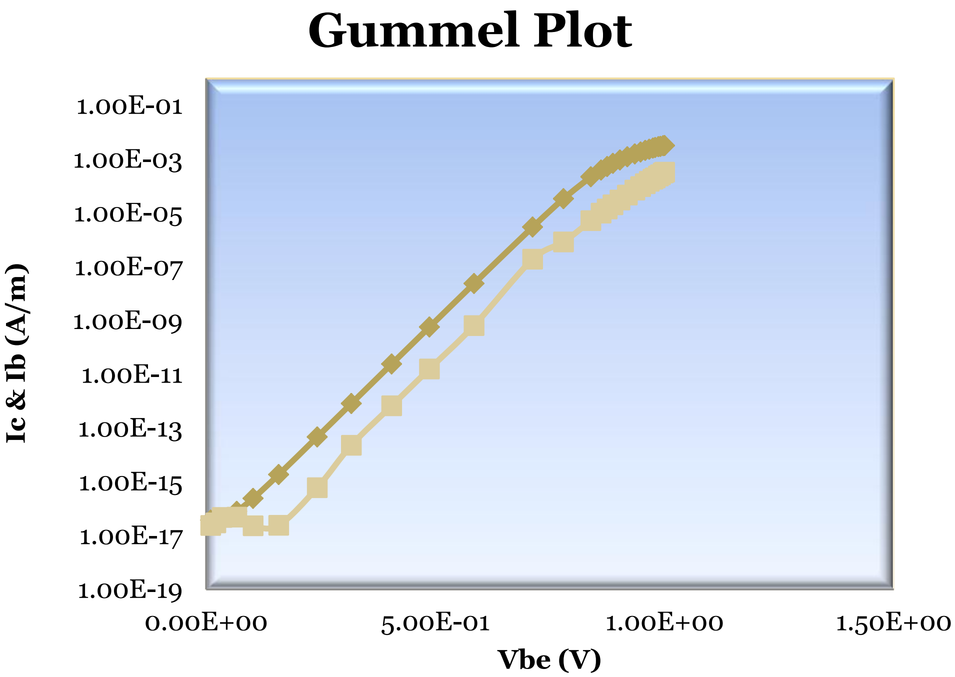
Simulation Examples:

NPN BJT (Continued)



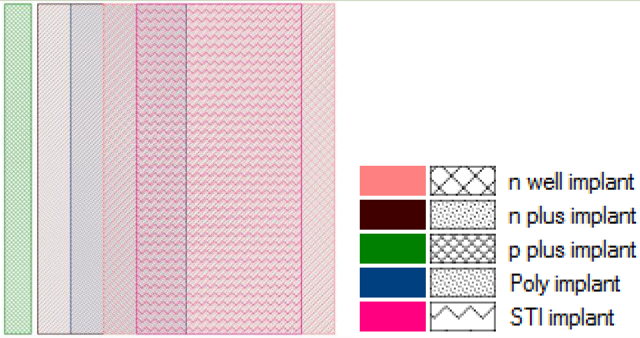


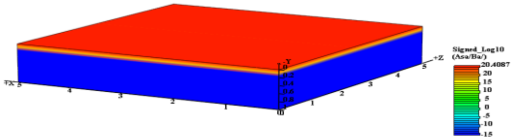




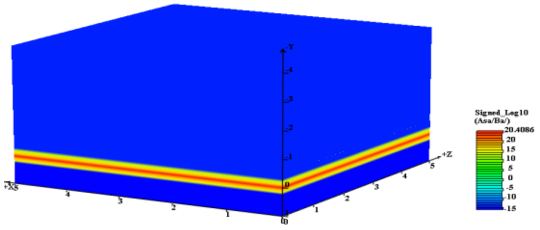
Simulation Examples:

LDMOS

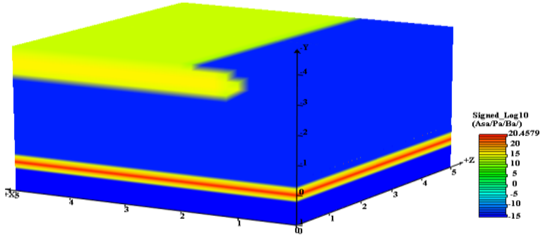




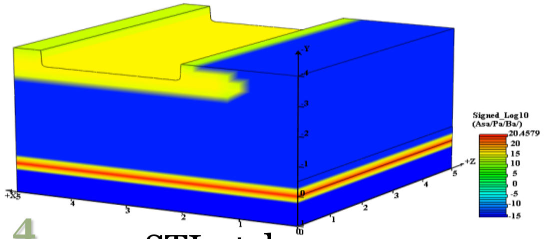
1 Sub+NBL



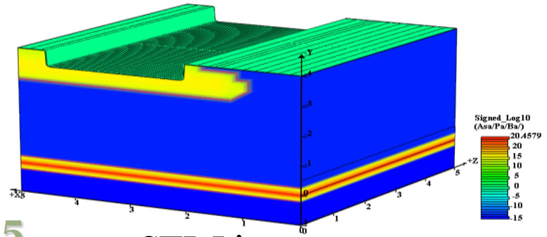
2 Epi-Layer



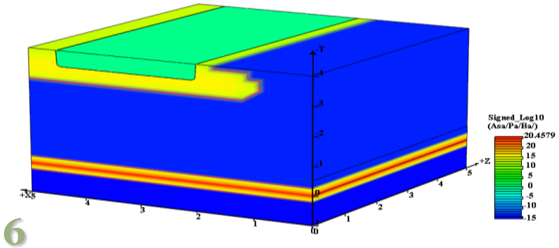
3 N well Implant



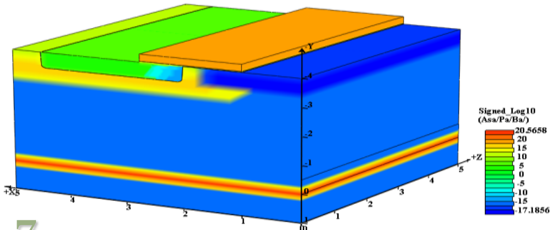
4 STI-etch



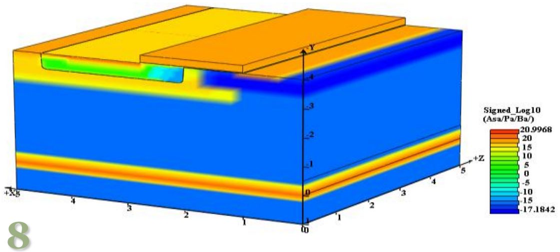
5 STI-Liner



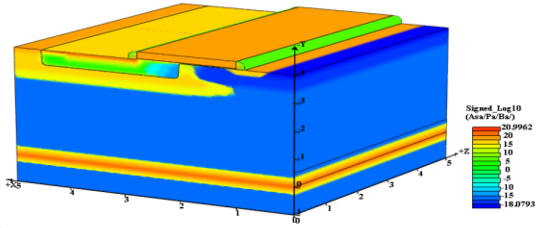
6 STI-Fill



7 Poly Gate



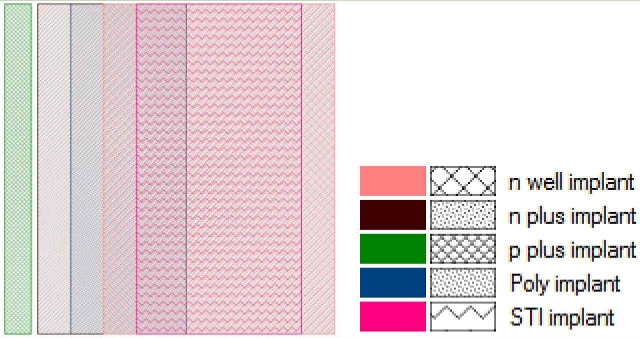
8 NLDD

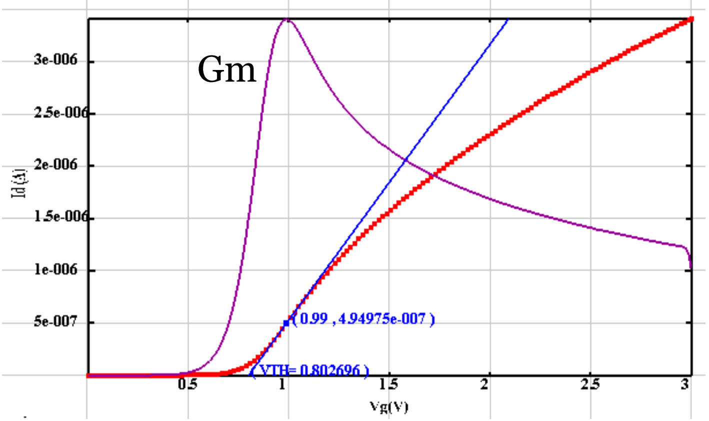


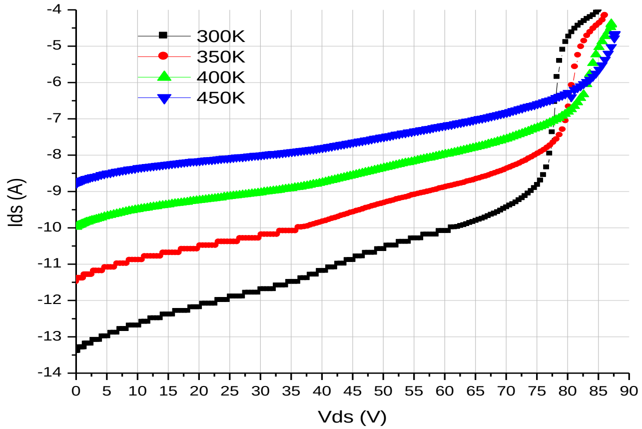
9 Spacer Etch +Regrid

Simulation Examples:

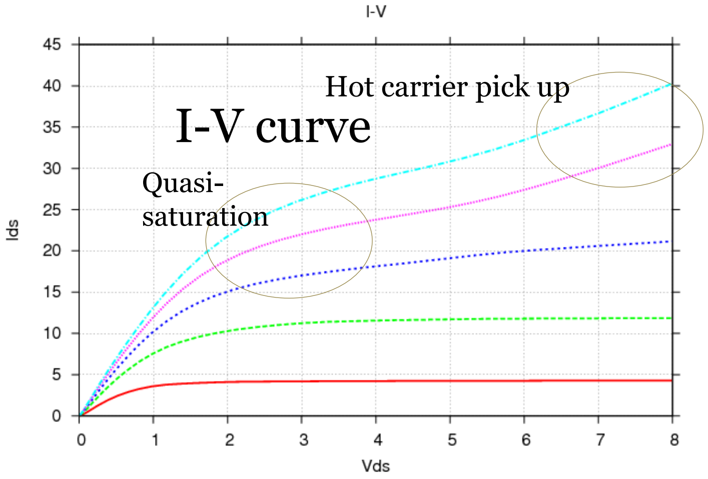
LDMOS (Continued)

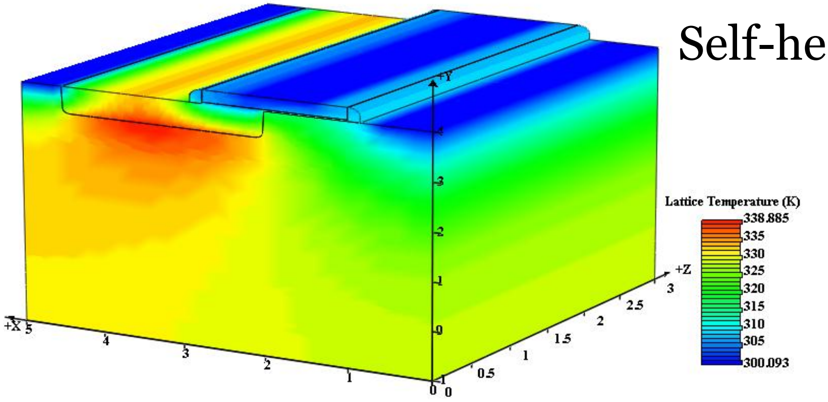






BV @ different Temperatures

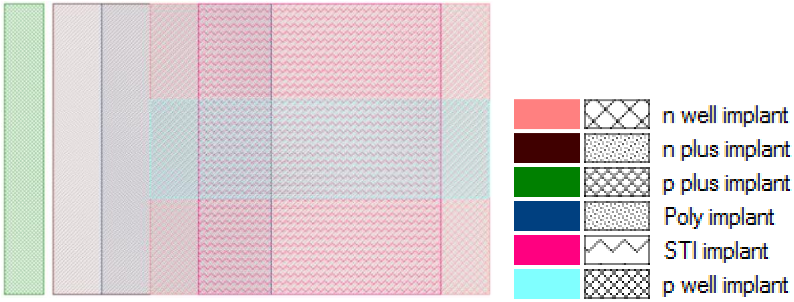


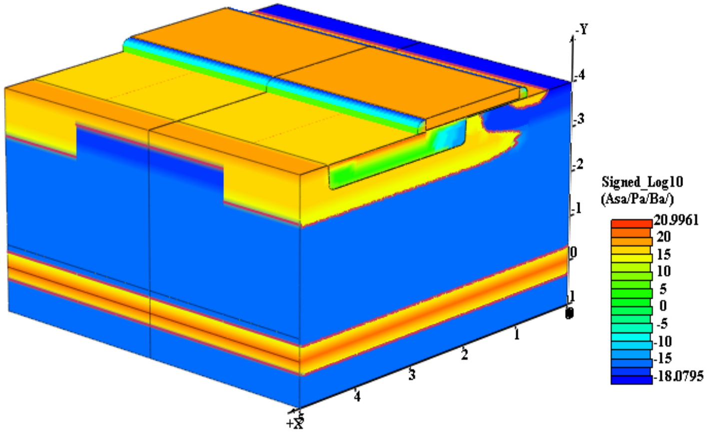


Self-heating

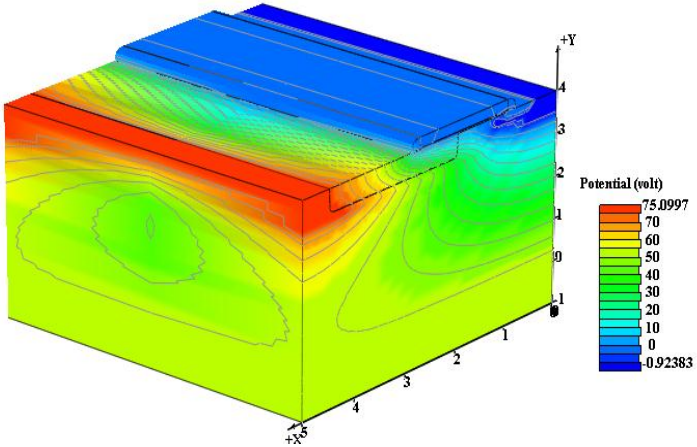
Simulation Examples:

SuperJunction LDMOS

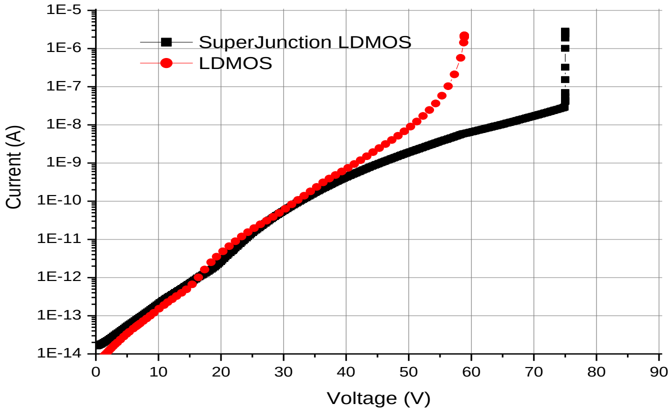


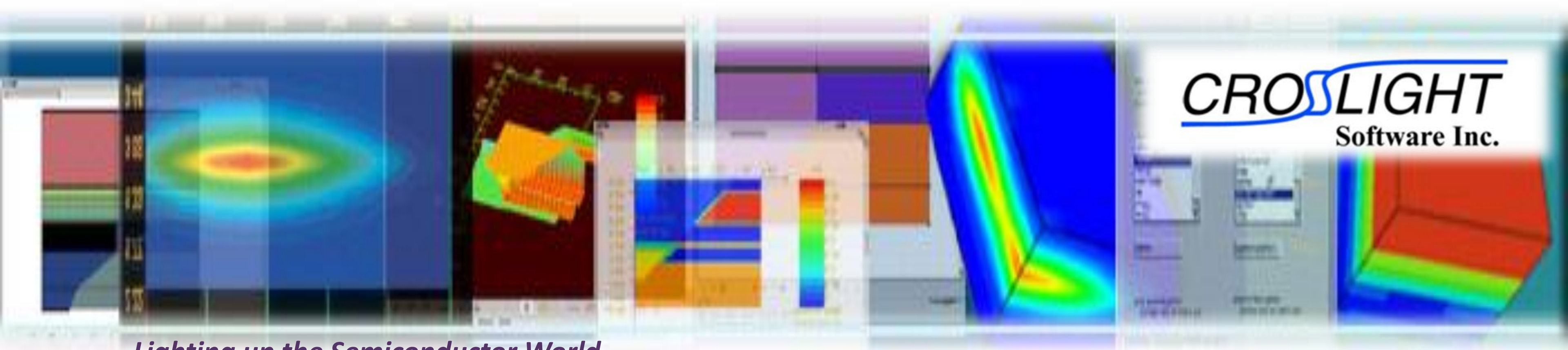


SJ LDMOS Net Doping



SJ LDMOS Potential lines





Lighting up the Semiconductor World…

2D Simulation of MOSFET Threshold Voltage Using AutoTCAD

A New Batch Testing and Design of Experiments Tool

What is Design of Experiments for TCAD?

- Suppose you are a device engineer, responsible for the design a MOSFET

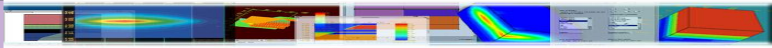
- Now, you have a target for threshold voltage, for example, 1.2V. You want to know how to choose the gate oxide thickness and body(channel) doping

- For gate oxide, suppose you have two choices, one is 25nm, the other is 35nm, while for body doping, you have two choices for both energy and dose

- Windows based and user friendly Graphic User Interface (GUI)

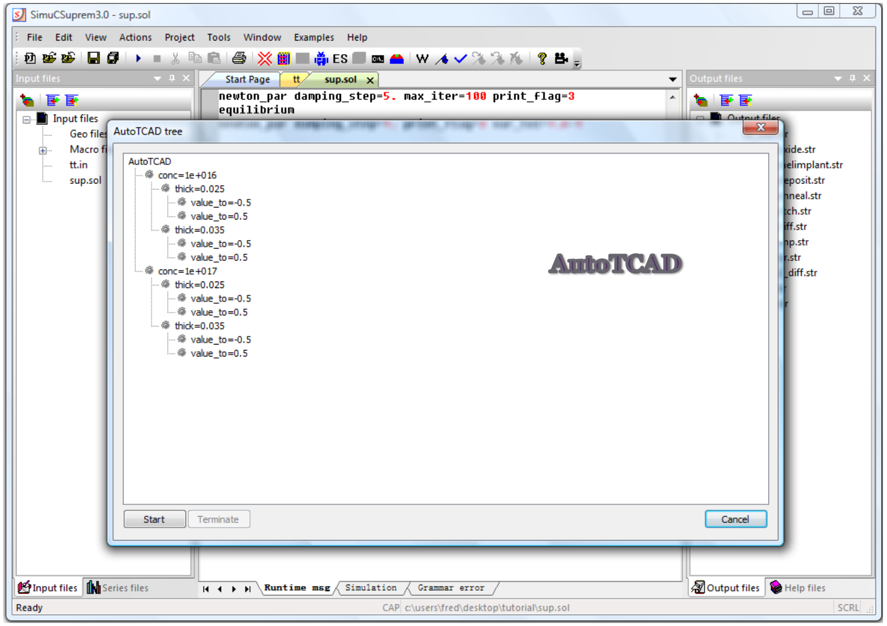
- AutoTCAD for generating a series of simulations from parameter variations, perfect for overnight simulations

- Embedded easy 2D/3D setup tool, syntax check tool, *point and show* wizard help and tutorial movies for a jump start



AutoTCAD Features

- Works together with CSUPREM and APSYS to deliver an easy to use Design of Experiments from process to device simulations.
- Tree structure with color indicators to monitor the simulation status.
- Direct extract important parameters like Vt, BV, Rdson, etc. (under development, will be available in near future)



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equilibrium
```

```
AutoTCAD
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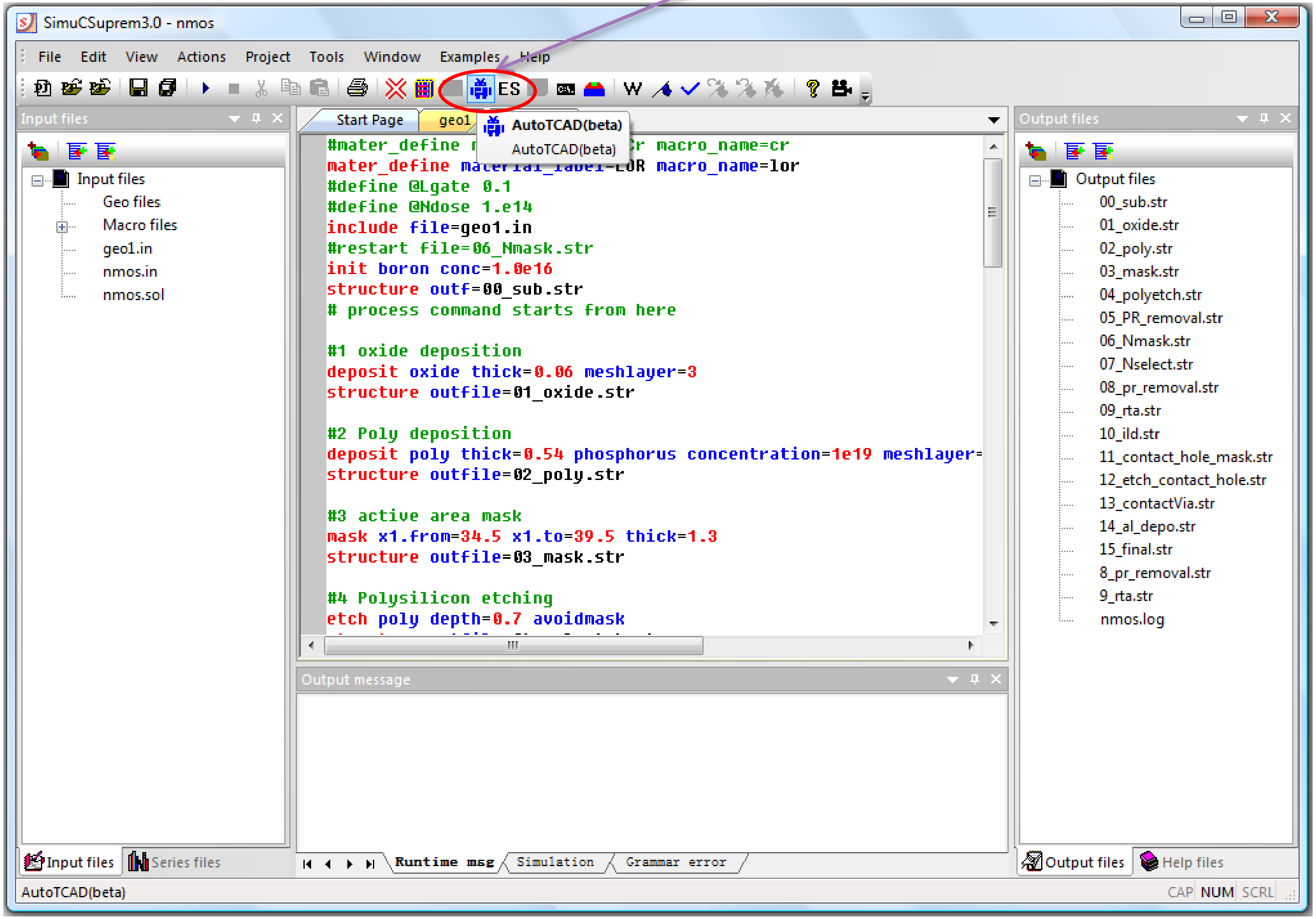
      value_to=0.5
    thick=0.035
      value_to=-0.5
      value_to=0.5
  conc=1e+017
    thick=0.025
      value_to=-0.5
      value_to=0.5
    thick=0.035
      value_to=-0.5
      value_to=0.5
```

c:\users\fred\desktop\tutorial\sup.sol

Where is AutoTCAD?

I am here!
Look for the Robot Icon



```
#mater_define r                 Cr macro_name=cr
mater_define material_label=LOR macro_name=lor
#define @Lgate 0.1
#define @Ndose 1.e14
include file=geo1.in
#restart file=06_Nmask.str
init boron conc=1.0e16
structure outf=00_sub.str
# process command starts from here

#1 oxide deposition
deposit oxide thick=0.06 meshlayer=3
structure outfile=01_oxide.str

#2 Poly deposition
deposit poly thick=0.54 phosphorus concentration=1e19 meshlayer=
structure outfile=02_poly.str

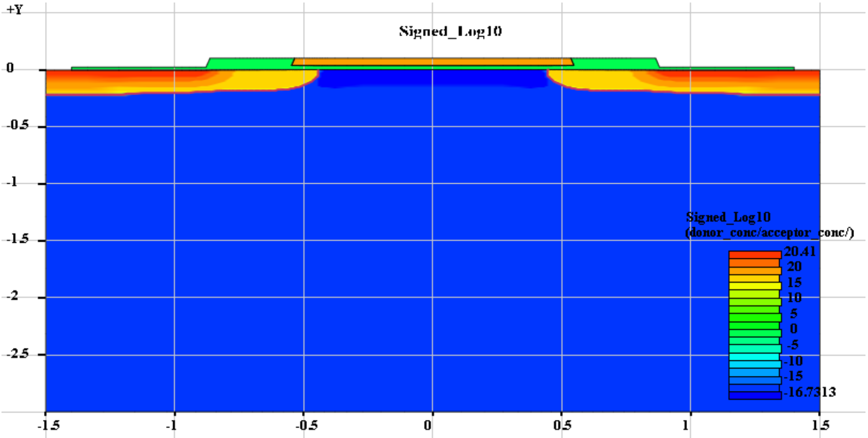
#3 active area mask
mask x1.from=34.5 x1.to=39.5 thick=1.3
structure outfile=03_mask.str

#4 Polysilicon etching
etch poly depth=0.7 avoidmask
```

A Simple Example for Threshold Voltage Simulation Using AutoTCAD

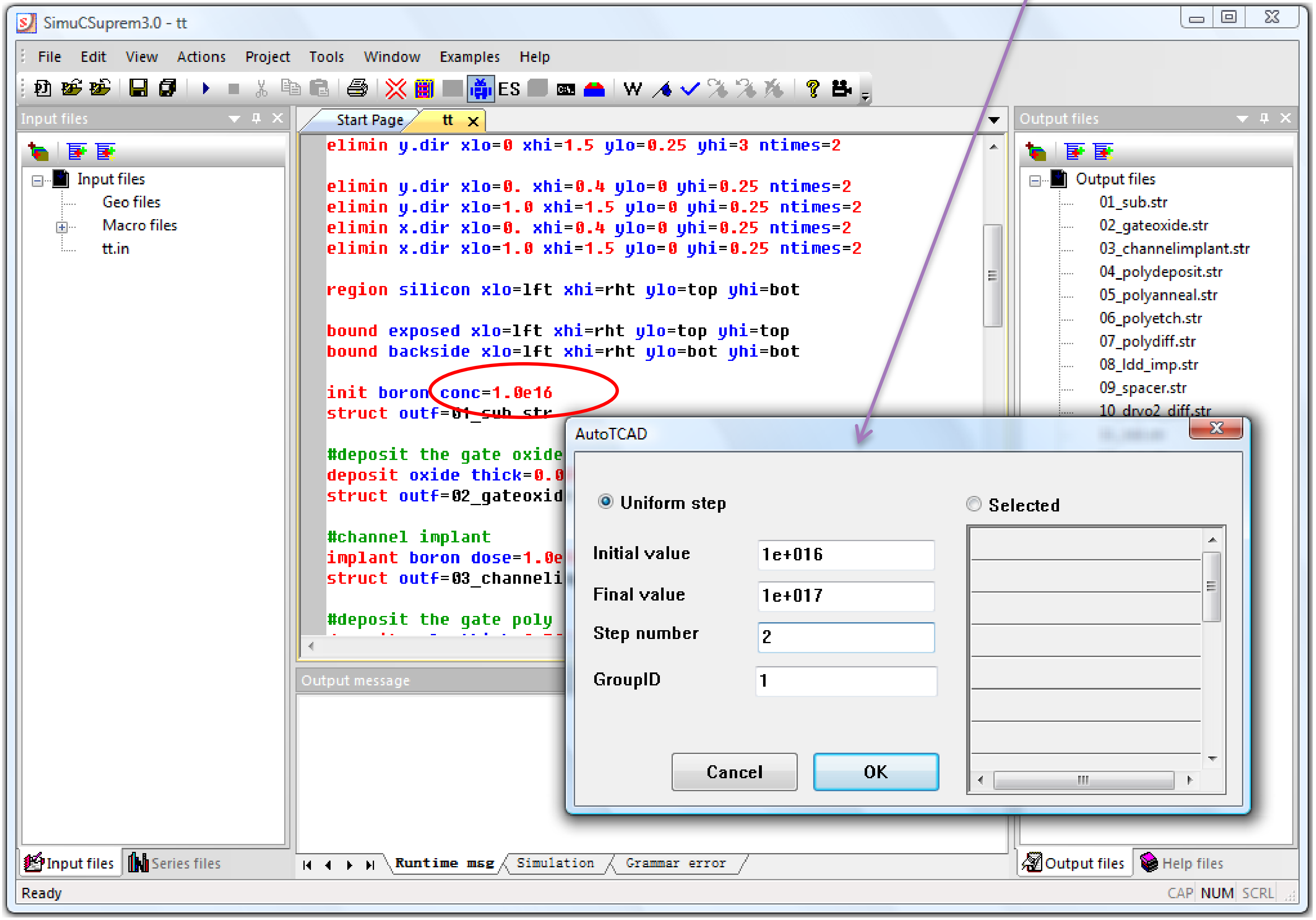
- Process simulation parameters to experiment:
  - Boron doping in the body/substrate
  - Gate Oxide thickness

- Device simulation parameters to experiment:
  - Voltage on the body contact (body bias)



Step 1a. Choose the parameters and values for Process Simulation: boron doping

2 variations



```
elimin y.dir xlo=0 xhi=1.5 ylo=0.25 yhi=3 ntimes=2

elimin y.dir xlo=0. xhi=0.4 ylo=0 yhi=0.25 ntimes=2
elimin y.dir xlo=1.0 xhi=1.5 ylo=0 yhi=0.25 ntimes=2
elimin x.dir xlo=0. xhi=0.4 ylo=0 yhi=0.25 ntimes=2
elimin x.dir xlo=1.0 xhi=1.5 ylo=0 yhi=0.25 ntimes=2

region silicon xlo=lft xhi=rht ylo=top yhi=bot

bound exposed xlo=lft xhi=rht ylo=top yhi=top
bound backside xlo=lft xhi=rht ylo=bot yhi=bot

init boron conc=1.0e16
struct outf=01_sub.str

#deposit the gate oxide
deposit oxide thick=0.0
struct outf=02_gateoxid

#channel implant
implant boron dose=1.0e
struct outf=03_channeli

#deposit the gate poly
```

● Uniform step ○ Selected

Initial value: 1e+016

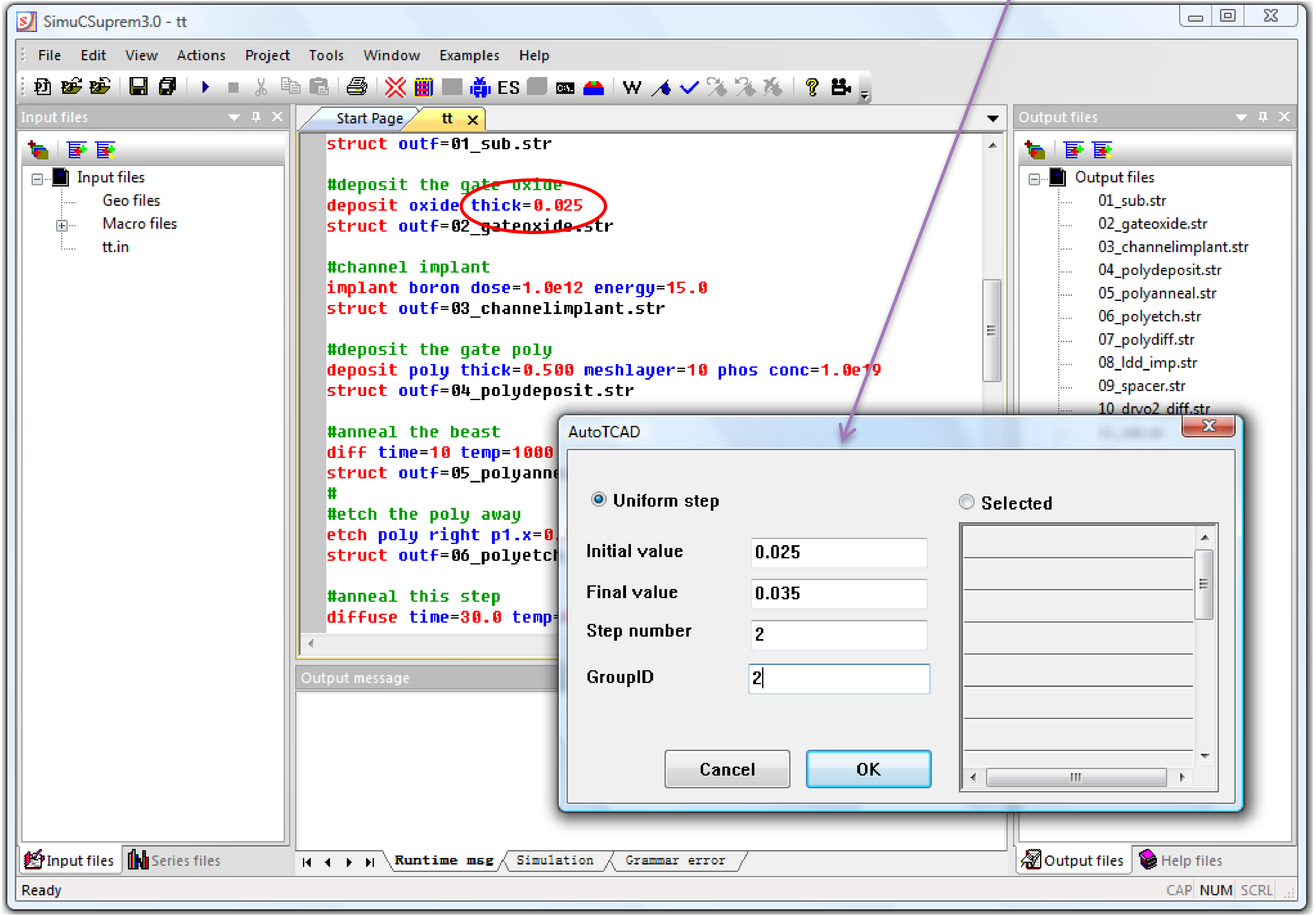
Final value: 1e+017

Step number: 2

GroupID: 1

Step 1b. Choose the parameters and values for Process Simulation: oxide thickness

2 variations



```
struct outf=01_sub.str

#deposit the gate oxide
deposit oxide thick=0.025
struct outf=02_gateoxide.str

#channel implant
implant boron dose=1.0e12 energy=15.0
struct outf=03_channelimplant.str

#deposit the gate poly
deposit poly thick=0.500 meshlayer=10 phos conc=1.0e19
struct outf=04_polydeposit.str

#anneal the beast
diff time=10 temp=1000
struct outf=05_polyanne
#
#etch the poly away
etch poly right p1.x=0.
struct outf=06_polyetch

#anneal this step
diffuse time=30.0 temp=
```

AutoTCAD

● Uniform step ○ Selected

Initial value: 0.025

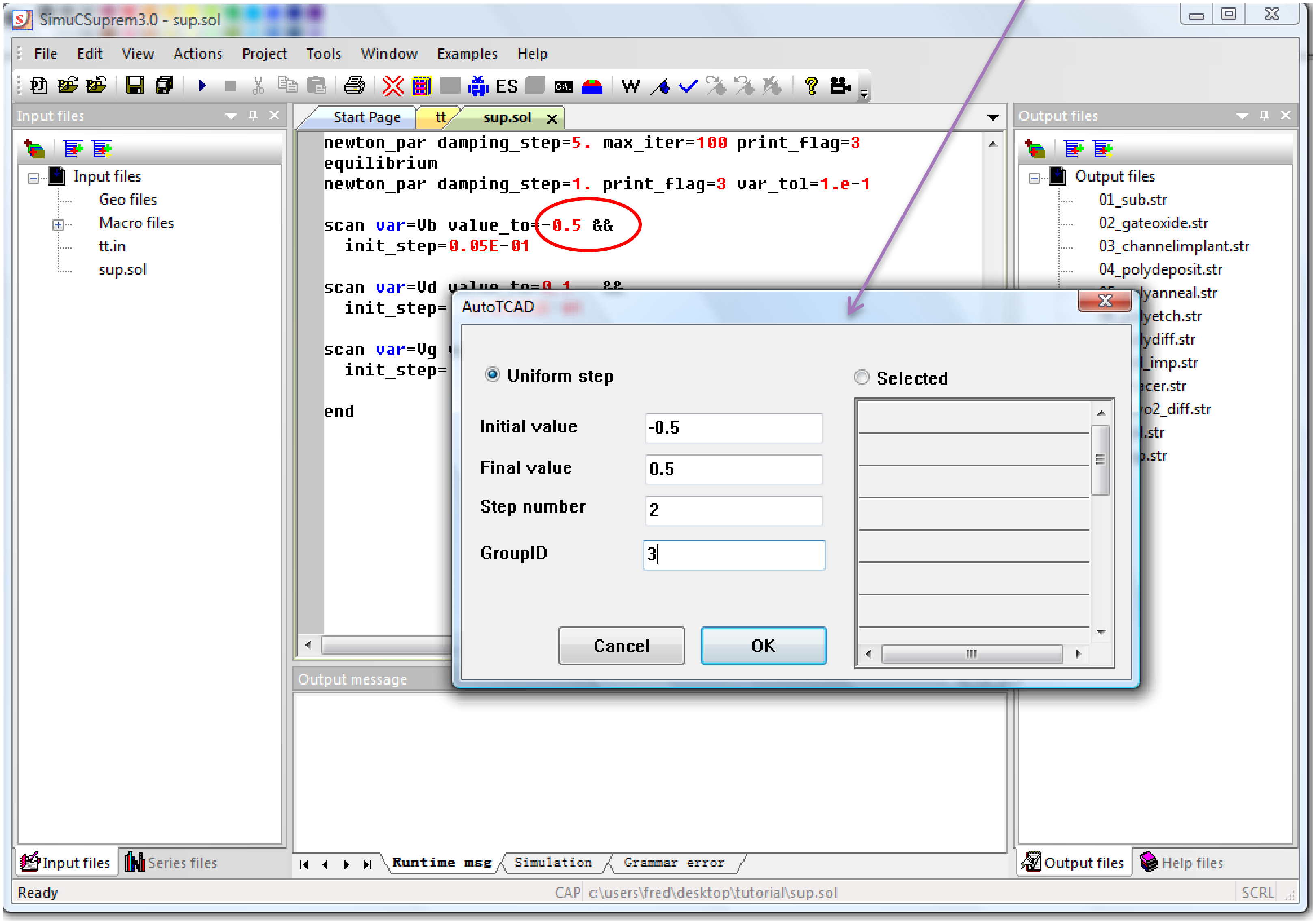
Final value: 0.035

Step number: 2

GroupID: 2

Step 2. Choose the parameters and values for Device Simulation: Body bias

2 variations



```
newton_par damping_step=5. max_iter=100 print_flag=3
equilibrium
newton_par damping_step=1. print_flag=3 var_tol=1.e-1

scan var=Vb value_to=-0.5 &&
  init_step=0.05E-01

scan var=Vd value_to=0.1  &&
  init_step=

scan var=Vg
  init_step=

end
```

AutoTCAD

● Uniform step ○ Selected

Initial value: -0.5

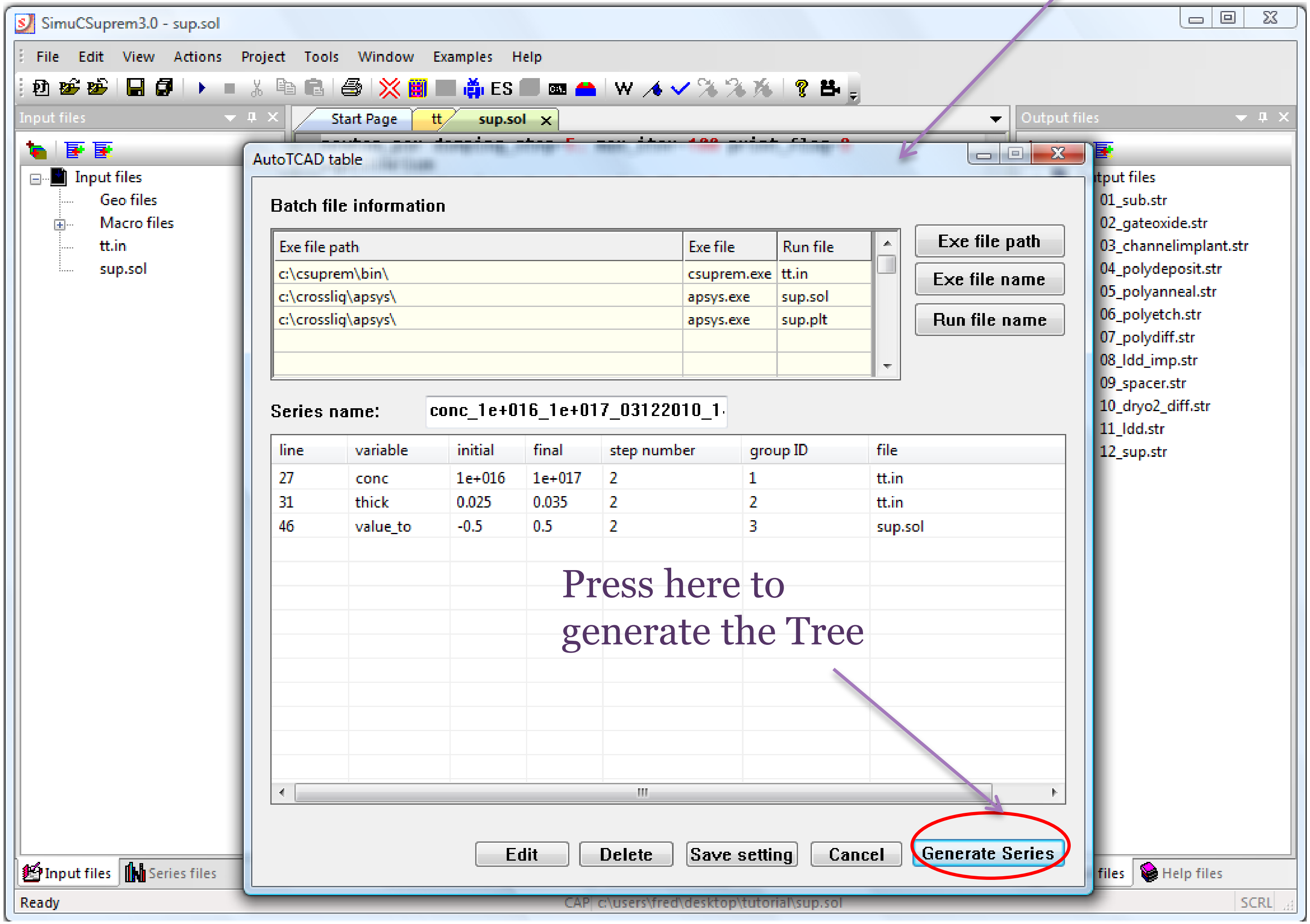
Final value: 0.5

Step number: 2

GroupID: 3

Step 3. AutoTCAD table summarizes the Variables from both process and device Simulation

AutoTCAD Table



Input files
- Geo files
- Macro files
- tt.in
- sup.sol

Output files
- 01_sub.str
- 02_gateoxide.str
- 03_channelimplant.str
- 04_polydeposit.str
- 05_polyanneal.str
- 06_polyetch.str
- 07_polydiff.str
- 08_ldd_imp.str
- 09_spacer.str
- 10_dryo2_diff.str
- 11_ldd.str
- 12_sup.str

Batch file information

Exe file path	Exe file	Run file
c:\csuprem\bin\	csuprem.exe	tt.in
c:\crossliq\apsys\	apsys.exe	sup.sol
c:\crossliq\apsys\	apsys.exe	sup.plt

Series name: conc_1e+016_1e+017_03122010_1

line	variable	initial	final	step number	group ID	file
27	conc	1e+016	1e+017	2	1	tt.in
31	thick	0.025	0.035	2	2	tt.in
46	value_to	-0.5	0.5	2	3	sup.sol

c:\users\fred\desktop\tutorial\sup.sol

Press here to generate the Tree

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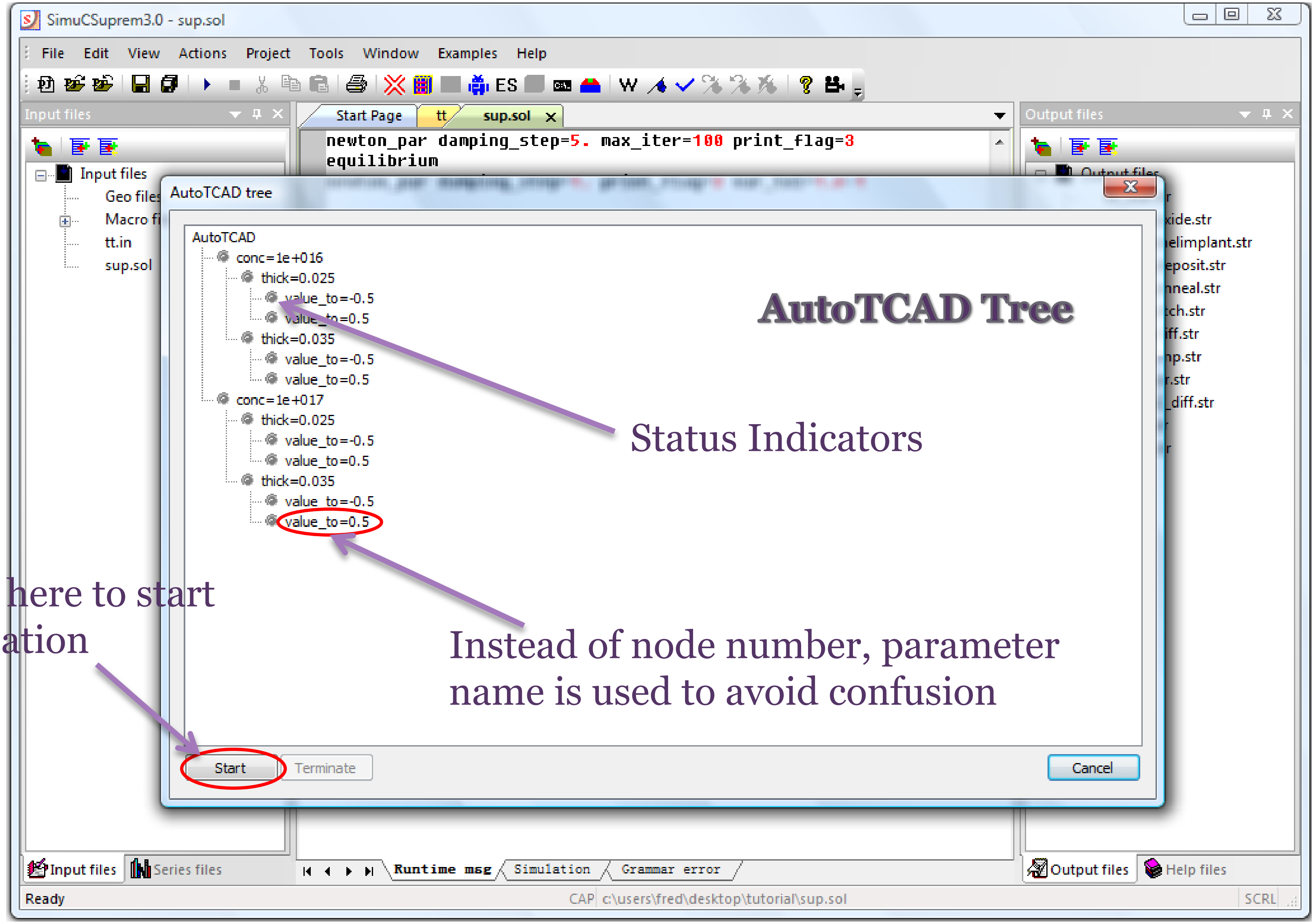
Step 4. AutoTCAD Tree Generated from the table.



```
newton_par damping_step=5. max_iter=100 print_flag=3
equilibrium
```

```
AutoTCAD
  conc=1e+016
    thick=0.025
      value_to=-0.5
      value_to=0.5
    thick=0.035
      value_to=-0.5
      value_to=0.5
  conc=1e+017
    thick=0.025
      value_to=-0.5
      value_to=0.5
    thick=0.035
      value_to=-0.5
      value_to=0.5
```

AutoTCAD Tree

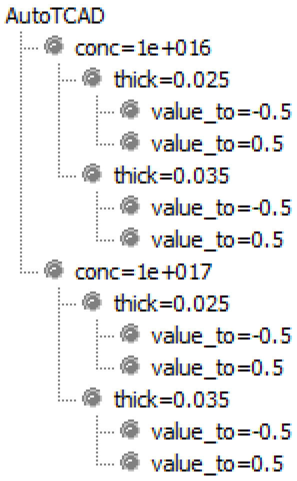
Status Indicators

Press here to start simulation

Instead of node number, parameter name is used to avoid confusion

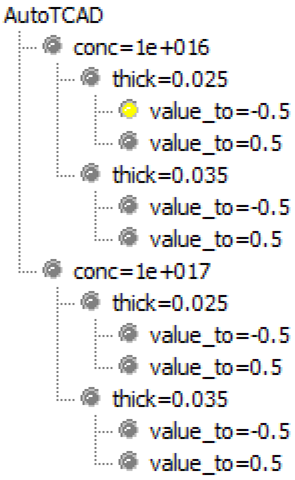
Step 5. AutoTCAD Batch Simulation

- All nodes at idle mode



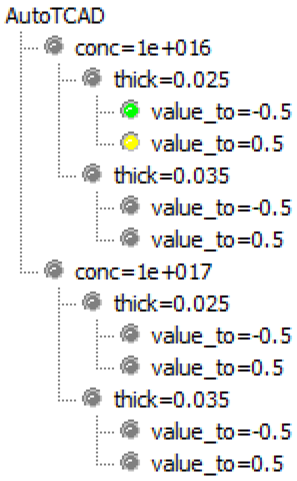
- AutoTCAD
  - conc=1e+016
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5
  - conc=1e+017
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5

- First node is under simulation mode



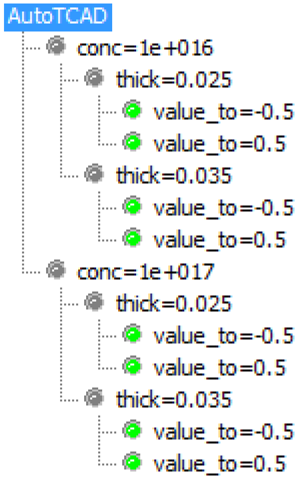
- AutoTCAD
  - conc=1e+016
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5
  - conc=1e+017
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5

- First node simulation has successfully finished, second node is in simulation mode



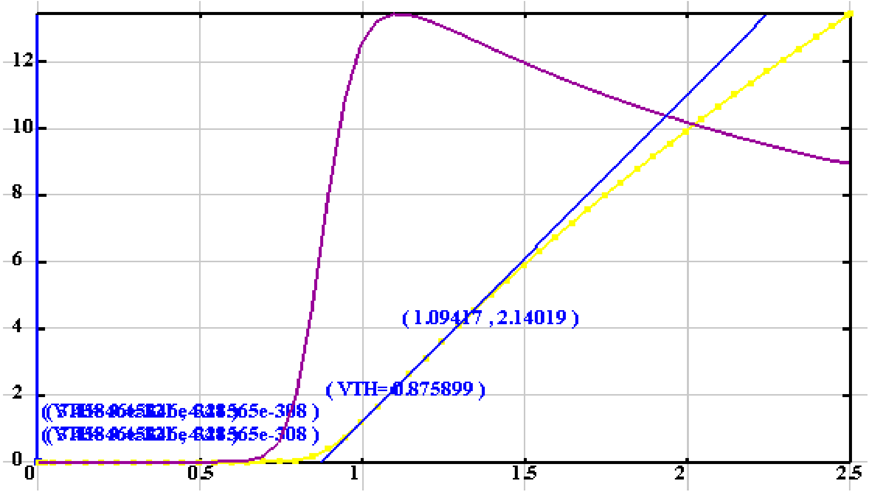
- AutoTCAD
  - conc=1e+016
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5
  - conc=1e+017
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5

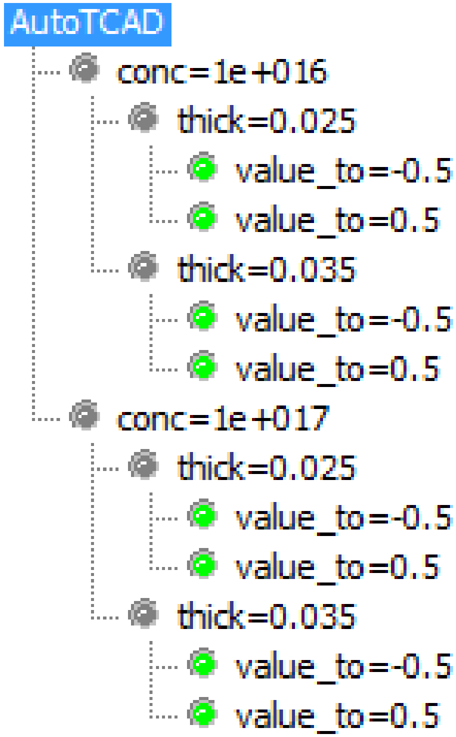
- All nodes have successfully finished



- AutoTCAD
  - conc=1e+016
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5
  - conc=1e+017
    - thick=0.025
      - value_to=-0.5
      - value_to=0.5
    - thick=0.035
      - value_to=-0.5
      - value_to=0.5

Auto Extraction of Threshold Voltage by CrosslightView





- AutoTCAD
  - conc=1e+016
    - thick=0.025
      - value_to=-0.5 Vt=0.876V
      - value_to=0.5 Vt=0.486V
    - thick=0.035
      - value_to=-0.5 Vt=1.16V
      - value_to=0.5 Vt=0.653V
  - conc=1e+017
    - thick=0.025
      - value_to=-0.5 Vt=1.56V
      - value_to=0.5 Vt=0.793V
    - thick=0.035
      - value_to=-0.5 Vt=2.142V
      - value_to=0.5 Vt=1.072V

Ongoing improvements and near future releases

- Full release of AutoTCAD, with direct extraction of important parameters like BV, VT and Rdson in a couple of weeks. (The parameter extraction capability is ready, and is now being implemented to the AutoTCAD GUI)

- New Release of SimuCenter, the most powerful GUI from Crosslight. SimuCenter will act as a central hub to connect all the functions of Crosslight's products, and make the simulation experience even more enjoyable

- Codeless Simulation. Iconize process steps and device simulation steps

- GPU-based solver to further accelerate 3D power semiconductor device simulation

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