

STANDARD OPERATING PROCEDURES FOR FABRICATION PROCESS SIMULATIONS

(using Silvaco TCAD – Ssuprem3 (1D) and ATHENA (1D/2D))

***** NOTE: These instructions assume access to Silvaco TCAD software.
For installation media, please see cleanroom manager or director*****

General Information:

- Deckbuild is the general input and output interface for Silvaco (for all TCAD modules)
 - The top half of the Deckbuild window is the command input
 - Type in program “statements” here or create in a text editor, then go to File, Open, to import
 - The bottom half of the Deckbuild window is where program execution and “extract” information is listed as the program runs
 - To execute a program , hit Run (the light green colored button close to the top left corner) and the execution/results will be generated in the bottom half of the Deckbuild screen
- TonyPlot is the graphical plotting program
 - Simulation results do NOT automatically load into this program when a simulation is complete
 - The general command to save results into a file that can be opened in a spreadsheet program as well as directly from TonyPlot is:
 - struct outfile=results.str
 - The direct command to start TonyPlot with current simulation results is simply:
 - TonyPlot
 - Combining these two commands in a program will both export the results to a file than can be opened directly from TonyPlot (without having to re-run an input program), and opens the result immediately in TonyPlot.

**Please follow these instructions to perform simulations
using either Ssuprem3 or ATHENA**

- Click start
- Go to programs
- Go to Silvaco (or simply click on the Silvaco shortcut icon if it is on the Desktop)
- Go to Deckbuild
- Type the program in the input window or open saved input program
 - NOTE: sample programs are included below
- Click Run (The light green button)
- The output window (bottom pane) shows the resulting data that is generated from the program
- If included in the program, TonyPlot will start up minimized to the taskbar
- Click TonyPlot to open the window showing the graphical simulation results
- Numerous examples are given under Examples, Ssuprem3 examples and Athena examples.

Sample Ssuprem3 Program

****NOTE**** This sample program includes command statements (in BOLD) necessary for simulating ONE DIMENSIONAL oxide growth, ion implantation, extracting oxide thickness and extracting sheet resistance. (“#” at the beginning of a statement allows the user to insert comments into the program – these are highlighted in blue only for emphasis. “\” at the end of a line allows the continuation of a statement on the next line. Please refer to the Ssuprem3 manual for additional programming syntax and a more complete examination of simulation resources)

```

go ssuprem3
TITLE SIMULATION OF Oxidation Followed by Ion Implantation

# The following statement defines wafer information
# including orientation, background concentration, and
# simulation mesh properties (thickness (depth) and density)
INITIALIZE <100> SILICON c.phosphorus=1e15 Thick=4 \
XDX=1.0 DX=.005 SPACES=150

# Ion implantation statement
IMPLANT boron DOSE=1E13 ENERGY=100

# Oxide growth statement
DIFFUSION TEMP=1000 TIME=30 NITROGEN
DIFFUSION TEMP=1000 TIME=120 WETO2
DIFFUSION TEMP=1000 TIME=20 NITROGEN

# Sample extract oxide thickness statement
extract name="oxide" thickness material="SiO~2" mat.occno=1

# SamSilvaco SOPle extract sheet resistance statement
extract name="sheetres" sheet.res material="Silicon" \
mat.occno=1 region.occno=1

# The following command lists layers and the properties
# associated with each
PRINT LAYERS

# Plot the data
TonyPlot -ttitle "Ion Implantation Followed by Oxide Growth"

Quit

```

The values for the oxide thickness and sheet resistance can be found in output window module (items in bold have been highlighted for illustrative purposes).

```

                S S U P R E M 3
                Version 5.8.0.R
                Date Wed Dec 11 18:28:51 CST 2002
                Copyright 1990-2000 SILVACO International
                All rights reserved

We acknowledge the contribution of the following collaborative partners:

                Stanford University
                University of Texas in Austin

SSUPREM3> TITLE SIMULATION OF Oxidation Followed by Ion Implantation
*****
SIMULATION OF Oxidation Followed by Ion Implantation
*****
SSUPREM3> # The following statement defines wafer information
-----
The following statement defines wafer information
-----

```

```

SSUPREM3> # including orientation, background concentration, and
-----
including orientation, background concentration, and
-----
SSUPREM3> # simulation mesh properties (thickness or depth and density)
-----
simulation mesh properties (thickness or depth and density)
-----
SSUPREM3> INITIALIZE <100> SILICON c.phosphorus=1e15 Thick=4 \
> XDX=1.0 DX=.005 SPACES=150
SSUPREM3> # Ion implantation statement
-----
Ion implantation statement
-----
SSUPREM3> IMPLANT boron DOSE=1E13 ENERGY=100
Implantation parameters for impurity BORON Energy = 1.000E+02 keV
The default value(7 degrees) used for the tilt angle.
The default value(30 degrees) used for the rotation angle.
Parameters for E>80 keV are from MIT (single pearson with long tail).

Layer   Material   RP,microns   DRP,microns   Skewness   Kurtosis
1       SILICON    3.2370E-01   1.0430E-01    -0.38      12.

SSUPREM3> # Oxide growth statement
-----
Oxide growth statement
-----
SSUPREM3> DIFFUSION TEMP=1000 TIME=30 NITROGEN
SSUPREM3> DIFFUSION TEMP=1000 TIME=120 WETO2
SSUPREM3> DIFFUSION TEMP=1000 TIME=20 NITROGEN
SSUPREM3> # Sample extract oxide thickness statement
-----
Sample extract oxide thickness statement
-----
SSUPREM3> save struct outfile=AIA03804
SSUPREM3>
EXTRACT> init infile="AIA03804"
EXTRACT> extract name="oxide" thickness material="SiO~2" mat.occno=1
oxide=5861.6 angstroms (0.58616 um)
EXTRACT> # Sample extract sheet resistance statement
EXTRACT> extract name="sheetres" sheet.res material="Silicon" mat.occno=1
region.occno=1
sheetres=3948.11 ohm/square
EXTRACT> # The following command lists layers and the properties
EXTRACT> # associated with each
EXTRACT> quit
SSUPREM3> PRINT LAYERS

```

```

layer      material type      thickness  dx  dxmin top  bottom  orientation
no.        (microns) (microns) node  node  or grainsize
  2        OXIDE              0.5862  0.0100  0.0010  848   860
  1        SILICON           3.7421  0.0050  0.0010  861   1000      <100>

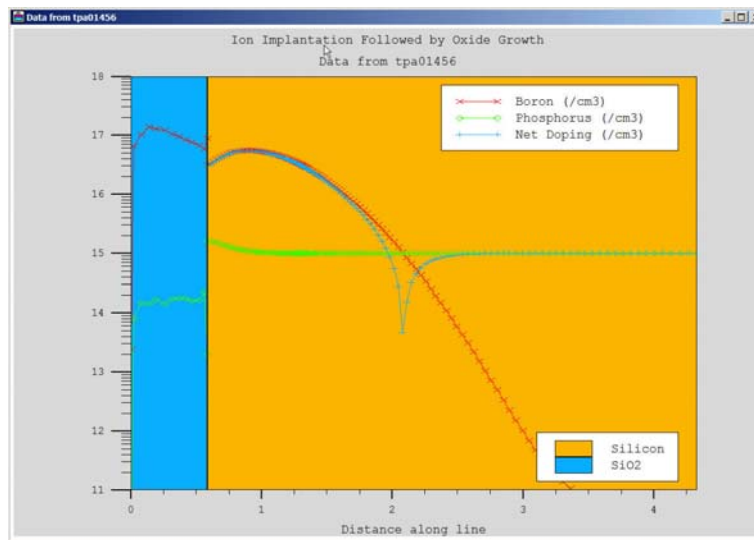
                          Integrated Dopant
layer      Net              Total
no.        active          chemical          active          chemical
           (1/cm^2)      (1/cm^2)         (1/cm^2)      (1/cm^2)
  2        0.0000E+00    -5.7003E+12     0.0000E+00    5.7182E+12
  1        -3.8096E+12  -3.8096E+12     4.5817E+12    4.5817E+12
sum        -3.8096E+12  -9.5099E+12     4.5817E+12    1.0300E+13

                          Integrated Dopant
layer      BORON              PHOSPHORUS
no.        active          chemical          active          chemical
           (1/cm^2)      (1/cm^2)         (1/cm^2)      (1/cm^2)
  2        0.0000E+00    5.7093E+12     0.0000E+00    8.9604E+09
  1        4.1957E+12    4.1957E+12     3.8604E+11    3.8604E+11
sum        4.1957E+12    9.9049E+12     3.8604E+11    3.9500E+11

                          Junction Depths and Integrated Dopant
                          Concentrations for Each Diffused Region
layer      region  type  junction depth  net act  total chem
no.        no.    type  (microns)      Qd (1/cm^2)  Qd (1/cm^2)
  2        1      n      0.0000        0.0000E+00  5.7182E+12
  1        2      p      0.0000        4.0188E+12  4.3409E+12
  1        1      n      1.4995        2.0899E+11  2.3419E+11

SSUPREM3> # Plot the data
-----
Plot the data
-----
SSUPREM3> save struct outfile=tpc03804
SSUPREM3> TonyPlot -ttitle "Ion Implantation Followed by Oxide Growth"
SSUPREM3> Quit
    
```

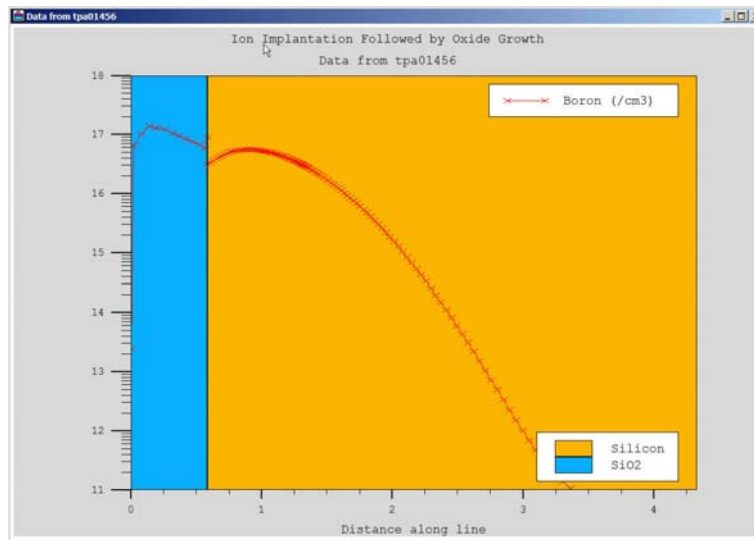
The TonyPlot results from this sample program are shown in the image below:



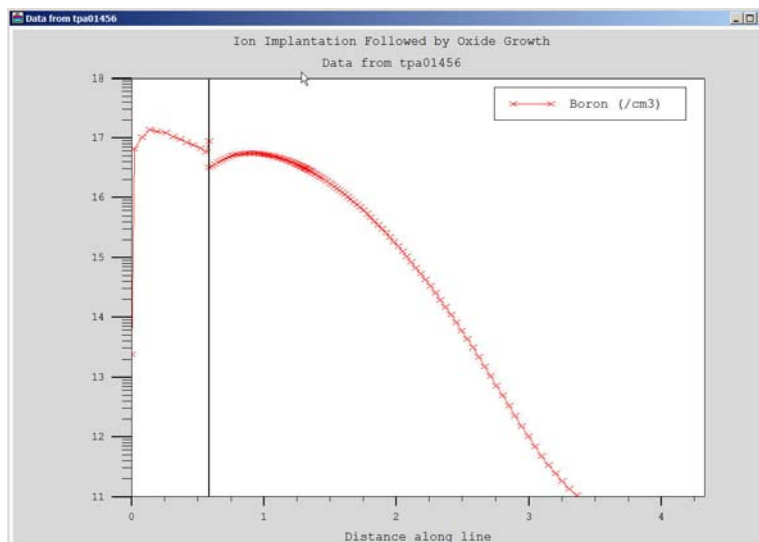
This figure shows the Tonyplot of the doping profiles after ion implantation and oxide growth, including concentrations of Boron (implanted), Phosphorus (background impurity), and the net doping.

Individual profiles of the dopants can also be extracted from the Tonyplot as follows.

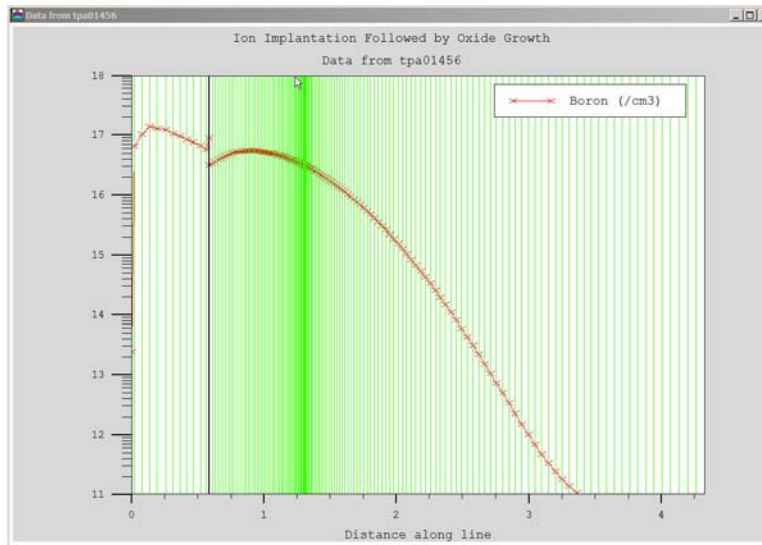
- Click Plot
- Go to Display
- Select the dopant of interest
- Click Apply
- The plot window will update and include only the dopant atom(s) chosen



- The colored regions can be removed by clicking the region button followed by Apply



- The current mesh definition can now be shown by clicking the mesh icon followed by Apply



Sample ATHENA Program

This sample program includes command statements (in BOLD) necessary for simulating both ONE and TWO DIMENSIONAL processes, including (but not limited to) oxide growth, ion implantation, extracting oxide thickness and extracting sheet resistance. (“#” at the beginning of a statement allows the user to insert comments into the program – these are highlighted in blue only for emphasis. “\” at the end of a line allows the continuation of a statement on the next line.)

```

go athena

#TITLE: Simple Boron Anneal

#the x dimension definition
line x loc = 0.0 spacing=0.1
line x loc = 0.1 spacing=0.1

#the vertical definition
line y loc = 0 spacing = 0.02
line y loc = 2.0 spacing = 0.20

#initialize the mesh
init silicon c.phos=1.0e14

#perform uniform boron implant
implant boron dose=1e13 energy=70

#perform diffusion
diffuse time=30 temperature=1000

#extract junction depth
extract name="xj" xj silicon mat.occno=1 x.val=0.0 junc.occno=1

#plot the final profile
TonyPlot

#save the structure
structure outfile=sample.str

quit

```

Note the inclusion of x and y dimension definitions. This is how to specify the meshing in the x and y directions. (the 1D program needed to only specify a mesh in one dimension)

The values for the oxide thickness and sheet resistance can be found in the output window module (items in bold are highlighted for illustrative purposes).

```

A T H E N A

Version 5.6.0.R

Copyright (c) 1989 - 2002 SILVACO International
All rights reserved

We acknowledge the contribution of the following collaborative
partners:

```

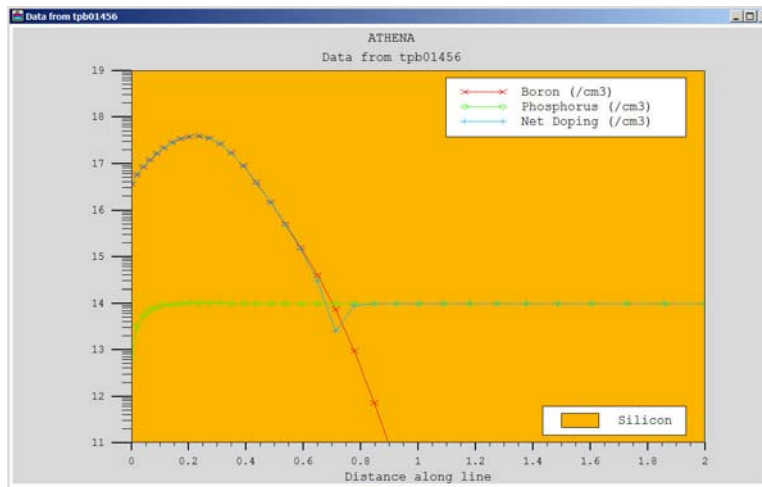


```

Stanford University
University of Texas at Austin
MCNC Center for Microelectronic Systems Technologies
University of California at Berkeley
Harris Semiconductor
CNET-Grenoble (France Telecom)
EPSRC supported Ion Beam Centre at the University of Surrey
=====
ATHENA                          : Enabled
SSUPREM4                         : Enabled
  Silicide material               : Enabled
  BCA Ion Implant                 : Enabled
ELITE                             : Enabled
  Monte Carlo Deposit            : Enabled
OPTOLITH                         : Enabled
FLASH                            : Enabled
C Interpreter                     : Enabled
Adaptive Meshing                  : Enabled
=====
                It is now Mon Apr 11 11:26:04 2005
                Athena 5.6.0.R is executing on "MEGACRUNCH"
Loading model file 'C:\Silvaco\lib\athena\5.6.0.R\common\athenamod'... done.
ATHENA> #TITLE: Simple Boron Anneal
ATHENA> #the x dimension definition
ATHENA> line x loc = 0.0 spacing=0.1
ATHENA> line x loc = 0.1 spacing=0.1
ATHENA> #the vertical definition
ATHENA> line y loc = 0 spacing = 0.02
ATHENA> line y loc = 2.0 spacing = 0.20
ATHENA> #initialize the mesh
ATHENA> init silicon c.phos=1.0e14
ATHENA> #perform uniform boron implant
ATHENA> implant boron dose=1e13 energy=70
ATHENA> #perform diffusion
ATHENA> diffuse time=30 temperature=1000
Solving time (hh:mm:ss.t) 00:00:00.0 + [1.e-00 sec] [100. %] [np 66]
Solving time (hh:mm:ss.t) 00:00:00.0 + [9.9e-0 sec] [9900. %] [np 66]
Solving time (hh:mm:ss.t) 00:00:00.0 + [0.1 sec] [10101.%] [np 66]
Solving time (hh:mm:ss.t) 00:00:00.1 + [90.148 sec] [90148.%] [np 66]
Solving time (hh:mm:ss.t) 00:01:30.2 + [220.70 sec] [244.82%] [np 66]
Solving time (hh:mm:ss.t) 00:05:10.9 + [450. sec] [203.89%] [np 66]
Solving time (hh:mm:ss.t) 00:12:40.9 + [450. sec] [100. %] [np 66]
Solving time (hh:mm:ss.t) 00:20:10.9 + [450. sec] [100. %] [np 66]
Solving time (hh:mm:ss.t) 00:27:40.9 + [139.04 sec] [30.898%] [np 66]
Solving time (hh:mm:ss.t) 00:30:00.0
ATHENA> #extract junction depth
ATHENA> struct outfile=AIa01456
ATHENA>
EXTRACT> init infile="AIa01456"
EXTRACT> extract name="xj" xj silicon mat.occno=1 x.val=0.0 junc.occno=1
xj=0.700554 um from top of first Silicon layer X.val=0
EXTRACT> #plot the final profile
EXTRACT> quit
ATHENA> struct outfile=tpb01456
ATHENA> TonyPlot
ATHENA> #save the structure
ATHENA> structure outfile=sample.str
ATHENA> quit


```

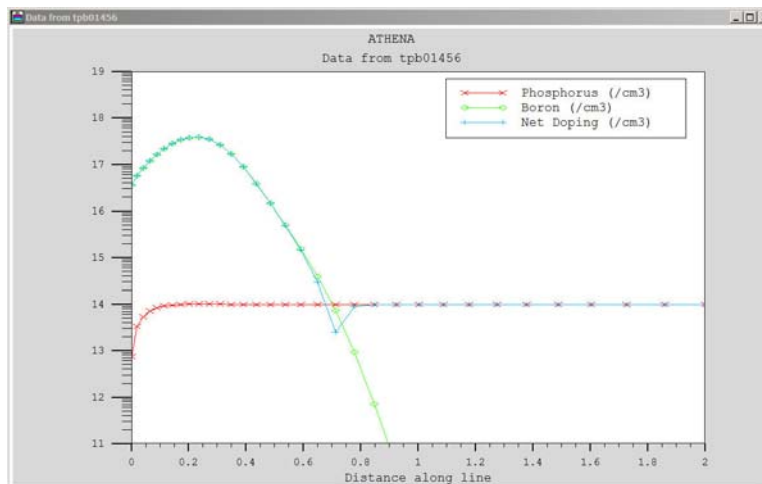
The TonyPlot results from this sample program are shown in the image below:



This figure shows the doping profile after ion implantation and subsequent diffusion that acts as a drive-in step.

Since the diffusion step produces no appreciable oxide, the results indicate that there is only one layer, so the background color can be moved to make the plot a little easier to read as follows.

- Click Plot
- Go to Display
- Clicking the mesh coloring icon  followed by Apply
- The TonyPlot window will be updated with no colored background as shown below



The preceding program can be changed to a TWO DIMENSIONAL program by adding the argument “two.d” to the initialization command in the program.

```

go athena

#TITLE: Simple Boron Anneal

#the x dimension definition
line x loc = 0.0 spacing=0.1
line x loc = 0.1 spacing=0.1

#the vertical definition
line y loc = 0 spacing = 0.02
line y loc = 2.0 spacing = 0.20

#initialize the mesh
init silicon c.phos=1.0e14 two.d

#perform uniform boron implant
implant boron dose=1e13 energy=70

#perform diffusion
diffuse time=30 temperature=1000

#extract junction depth
extract name="xj" xj silicon mat.occno=1 x.val=0.0 junc.occno=1

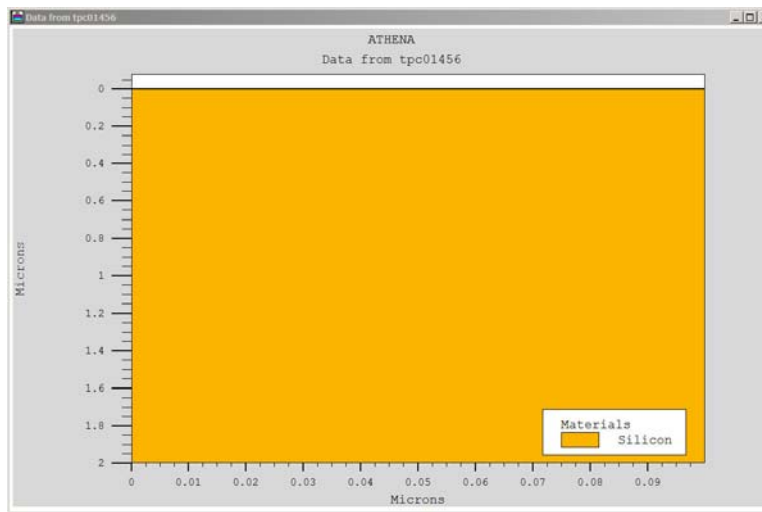
#plot the final profile
TonyPlot

#save the structure
structure outfile=sample.str



quit

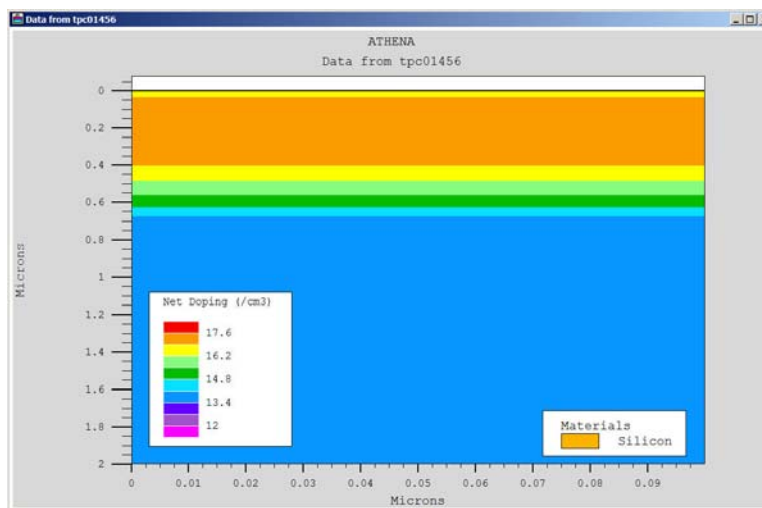
```

The extract results remain the same, however the TonyPlot window indicates a 2D result as shown below.






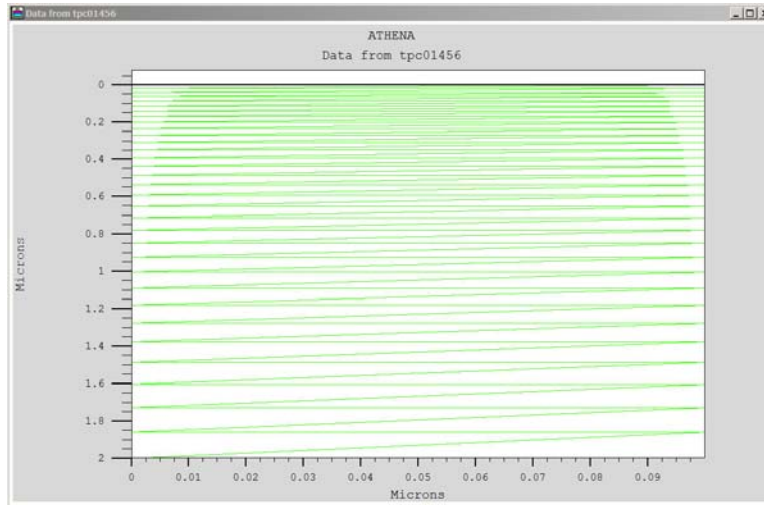
The doping profile is not shown by default in this 2D result. To show the doping profile:

- Click Plot, Display
- Click the Layer Color icon  followed by Apply to remove the layer coloring
- Click the icon shown here  and click on Contours . . .
- Change the Quantity value to indicate which impurity you wish to visualize (in this case Boron) and click “Apply”, then OK, OK
- The TonyPlot window show a color profile of the doping results




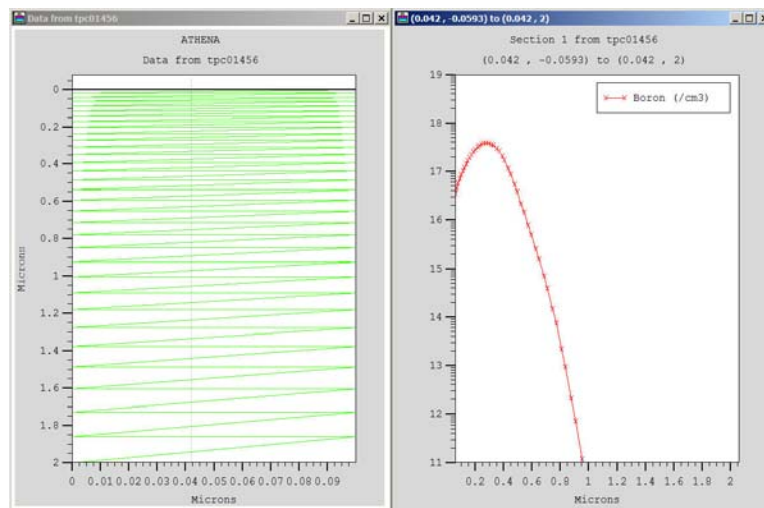
The mesh used can be visualized by:

- Click Plot, Display
- Click the Layer Color icon  followed by Apply to remove the layer coloring (if not performed in the previous step)
- Click the Contour Icon  followed by Apply to remove contour coloring
- Click the Mesh Icon  followed by Apply to show mesh
 - This step can be performed to visualize the mesh prior to the addition of simulation steps to a program



1D plots of concentration (similar to what is generated when Ssuprem3 is used instead of ATHENA) can be extracted from 2D results by:

- Click Tools, Cutline
- Choose the vertical line icon 
- Click the left mouse button and drag a line vertically from top to bottom through the device then release the mouse
- TonyPlot will be updated with an extracted 1D plot of the information available along the extracted line (most commonly doping concentration) as shown below.



Final Notes:

SSuprem3 Module:

- Command Line Statements begin on page 57 of the manual “ssuprem3_um.pdf”

ATHENA Module:

- Chapter 2 is a tutorial and a good way to begin learning the syntax of ATHENA
- Command Line Statements begin on page 251 of the manual “athena_users.pdf”
 - NOTE: There are some differences between the current Deckbuild interface and the one presented in some sections of this manual.
- Many more capabilities than shown in this SOP [etching (wet, dry), deposition, lithographic steps (hard/soft bake)] left up to the user to investigate

Deckbuild Program

- Overview of DeckBuild can be found in the manual “pcitools.pdf”

Extract Command Syntax:

- Arguments for this statement can be found in the manual “pcitools.pdf” starting on page 49

TonyPlot Program

- Overview of TonyPlot can be found in Chapter 3 of the manual “pcitools.pdf” starting on page 79
- Data files (ascii based) from other software packages can be loaded into TonyPlot
- Athena output files “*.str” can be opened in spreadsheet programs, however interpretation of the Silvaco data format in these files is left up to the user (find column of x data and y data and plot in your program)

v.1 Chakry
2003
v.2 TJR, Jr.
2005