Tutorial

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SAN JOSE STATE UNIVERSITY

Electrical Engineering Department

Getting Started with Synopsys TCAD tools

PROCESS INTEGRATION AND IC DESIGN GROUP SAN JOSE STATE UNIVERSITY

A tutorial guide for using Synopsys TCAD tools

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Acknowledgements:

I would like to thank all the folks at Synopsys that made this work possible.

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Chapter 1: Starting the Sentaurus TCAD Tutorials

Opening the tools in a webbrowser

Synopsys has on-line training that can be accessed from a web browser. There are a few typos here and there, but it should be easy to follow. The tutorials are quite lengthy so give yourself plenty of time to complete them. If you already know a TCAD tool and process engineering you probably can reduce your completion time from the estimated completion time in half.

1. First log (ssh or vnc) in remotely or at a Unix station and star a terminal

2. Start a web browser (Figure 1).

3. Go to File... Open File (Figure 2).

4. Click on Filesystem in the left control area of Figure 3.

5. Click on apps in the right control area of Figure 3.

6. Click on apps, synopsys, TCAD, tcad, current, Example_Library, Sentaurus_Training (Figure 4).

7. Double Click on main_menu.html (Figure 4).

8. The web browser should look like Figure 5. Bookmark the page by going to Bookmarks.. Book mark this page (Figure 6).

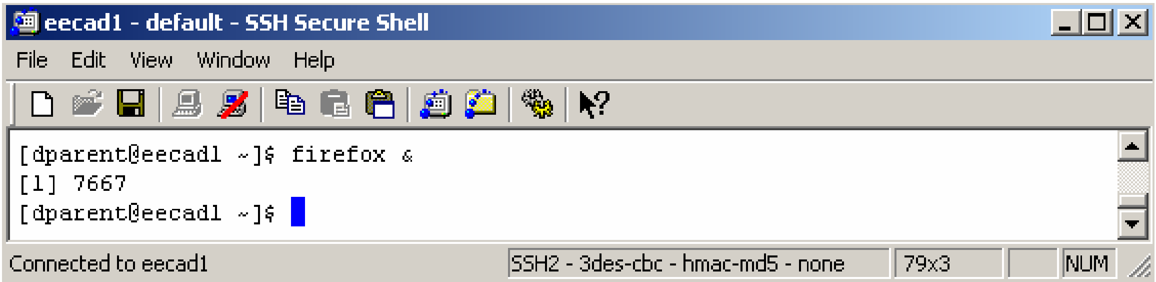

Figure 1. Starting a Web Browser.

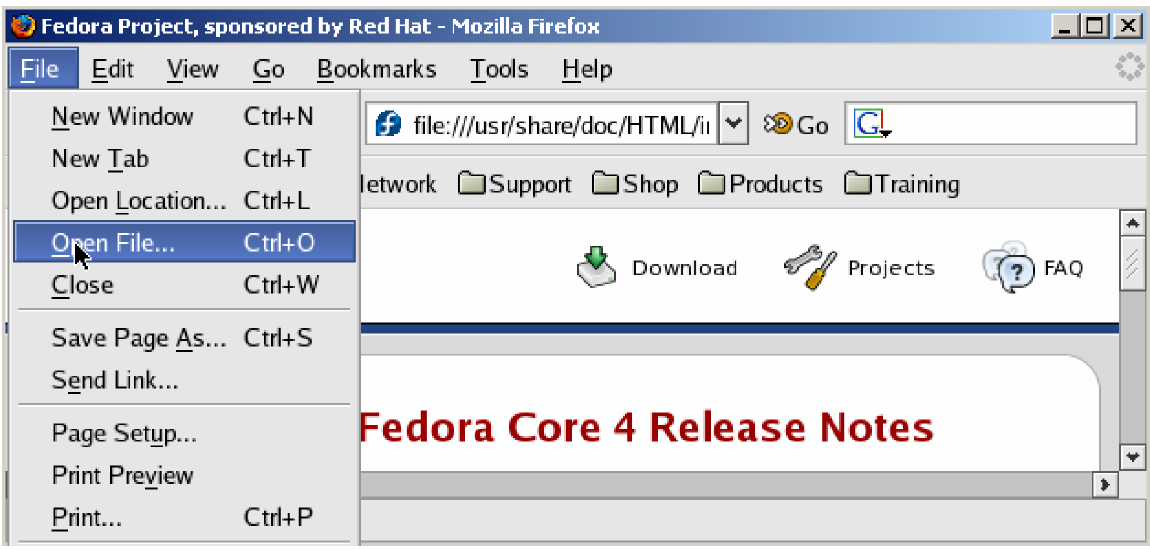

Figure 2: Open a file in a Web Browser.

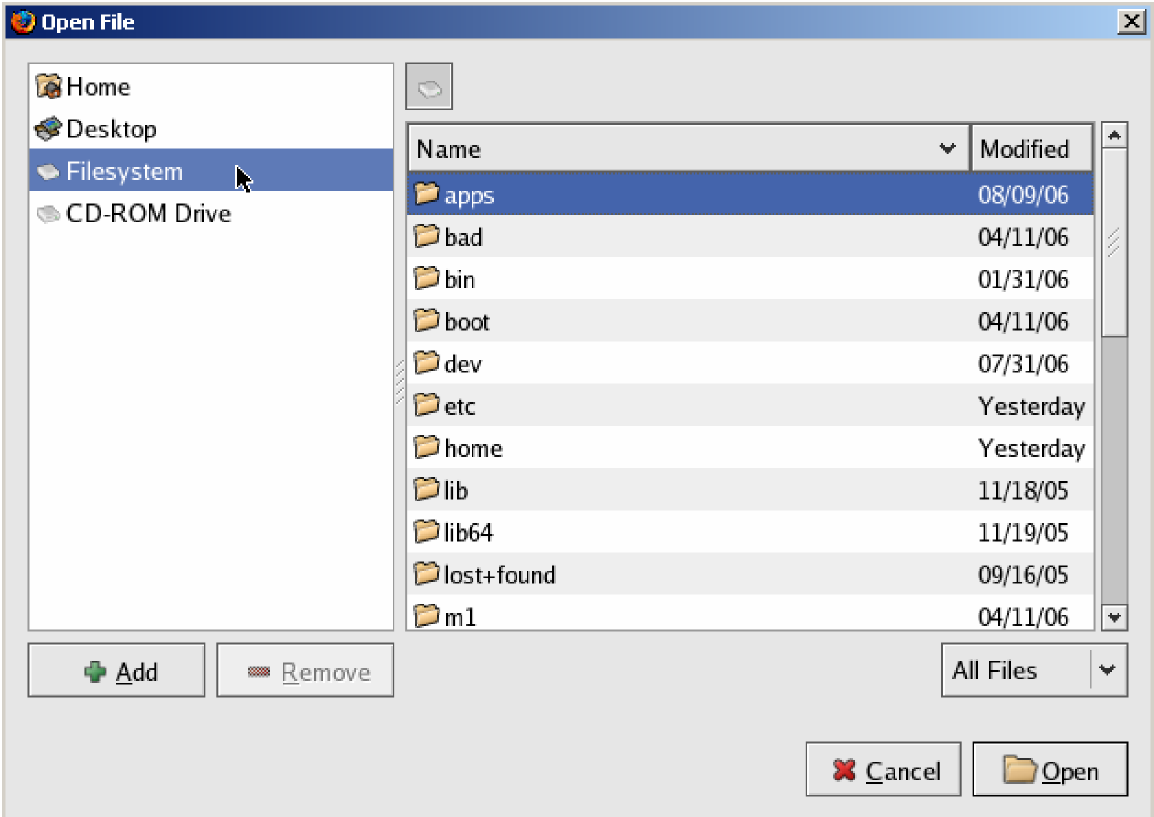

Figure 3: Open a file (Filesystem).

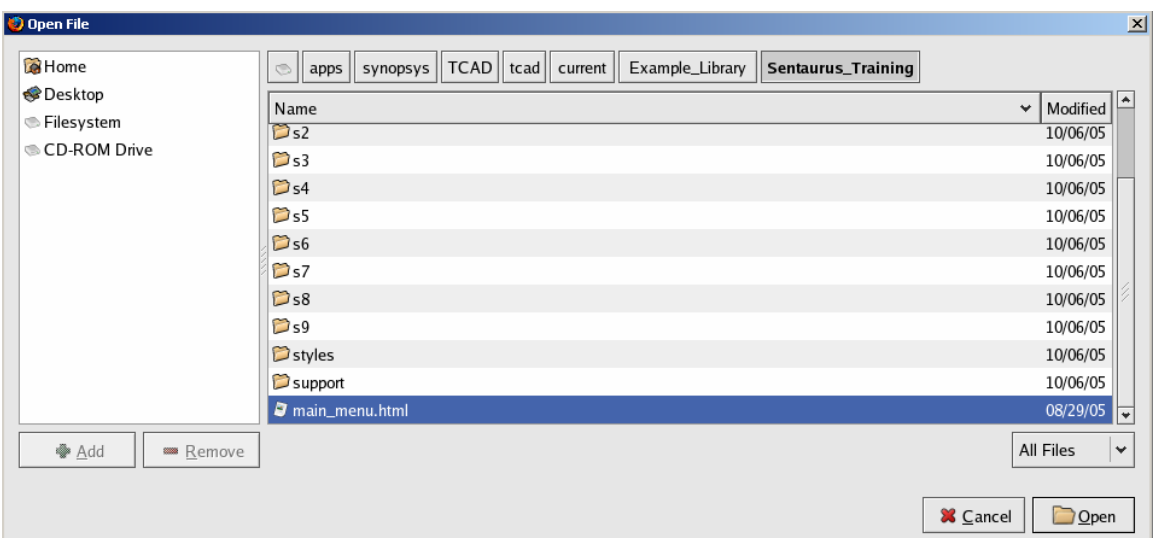

Figure 4: Location of Sentaurus Training.

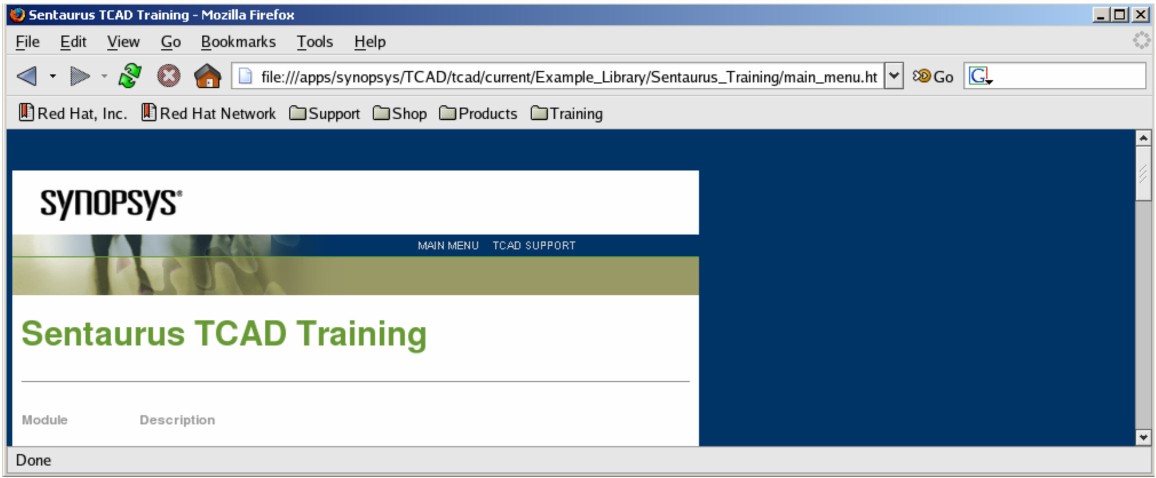

Figure 5: Main Menu of Sentaurus Training.

Figure 6: Bookmark this page.

Doing the tutorials:

I recommend doing the tutorials slightly out of order. You should probably do chapter 2 first if you hav enver seen TCAD before. Sentaurus Work bench is great but for novices it is at too high a level to understand why you are doing what you are doing, and what a time saver it is. D o the tutorials in this order:

1. Tool Overview
2. Ligament
3. Sentaurs Process
4. Sentaurus Structure editor
5. Sentaurus Device
6. Inspect
7. Techplot SV (use tecplot_sv –mesa on our machines).
8. Sentaurus Workbench
9. TCL
10. Noffse3D

Chapter

2

Chapter 2: Simple Example Showing How Ligedit, Sentaurus Process, Sentaurus Structure Editor, Sentaurus Device, Tecplot, and Inspect work

Diode Example:

We will simulate the fabrication steps and electrical characteristics of a simple N+/P diode using a P substrate and an diffused N+ layer.

It is easier to keep all the files for a project inside a directory inside a directory called sentaurus (Figure 7).

1. $ **mkdir sentaurus**
2. $ **cd sentaurus**
3. $ **mkdir diode**
4. $ **cd diode**
5. $ **pwd**

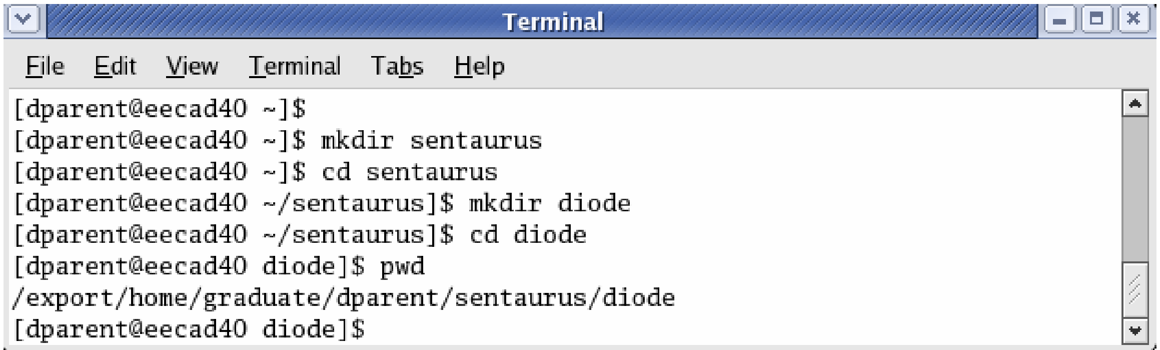

Figure 7: Creating a Project Directory.

Creating Layers and shape with s Prolyt Mask Layer editor:

We are going to first draw the Mask View of the Diode.

1. Type **prolyt &** at the command line.

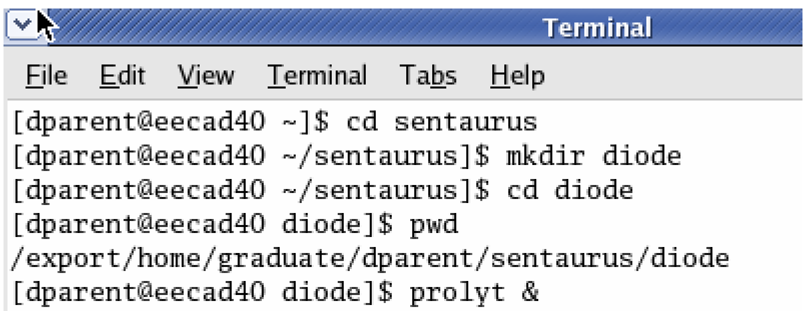

Figure 8: Starting prolyt.

2. Click OK on the Layout dimensions pop-up that is in front of the Layout editor (Figure 9).

3. There are three layers we are interested in the NDIFF layer, which will be used to selectively dope the p-substrate n-type, the CC layer wich will be a via connecting the Metal1 layer to the substrate through an oxide layer, and the Al metal Layer M1. We have to add these three layers to the editor.

   a. Double click on the layer INIT on the left hand side or the editor, a pop-up should appear (Figure 10).

   b. In the Edit Layers pop-up change the name of INIT to NDIFF (Figure 11), and the color of NDIFF to green (Figure 12). Click on **Modify** to update your changes (Figure 12).

   c. In the Edit Layers pop-up change the name of NDIFF (Figure 13) to CC, and the color of Black to green (Figure 14). Click on **NEW** to update your changes (Figure 12). Repeat this for the M1 layer to be blue.

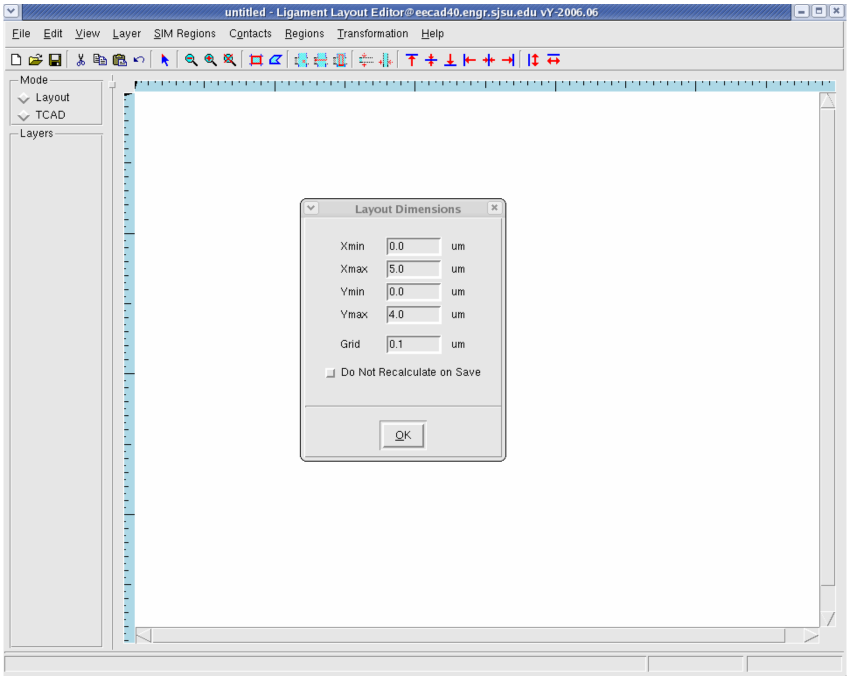

Figure 9: Starting the Layout Editor.

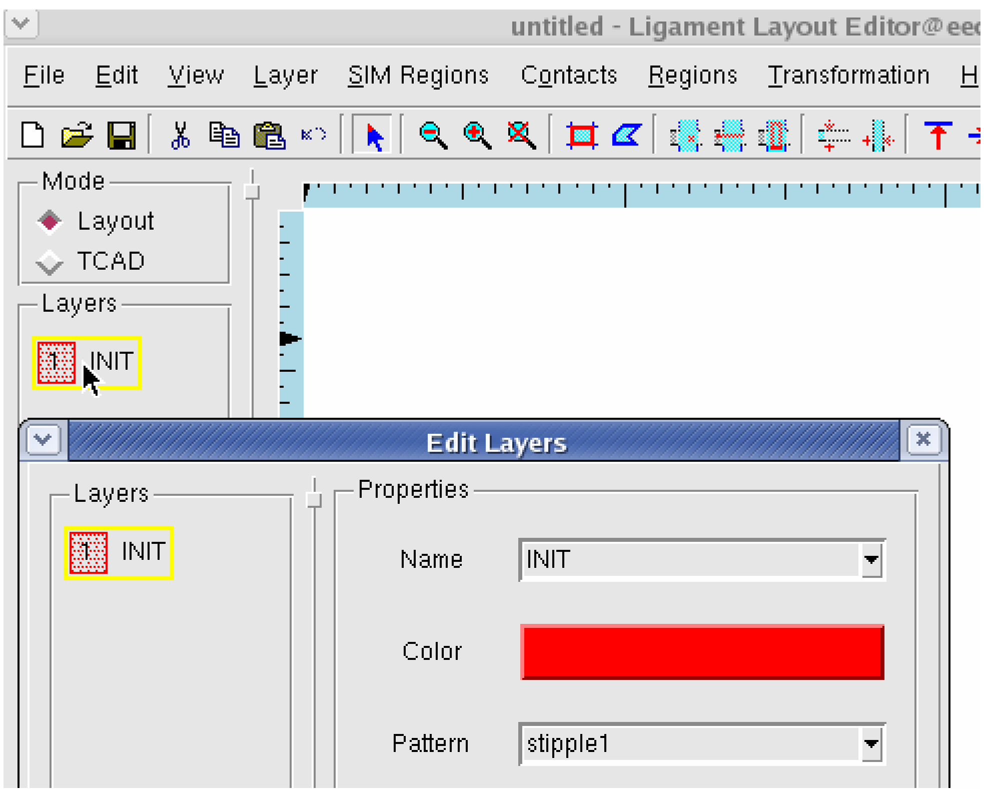

Figure 10: Editing Layers.

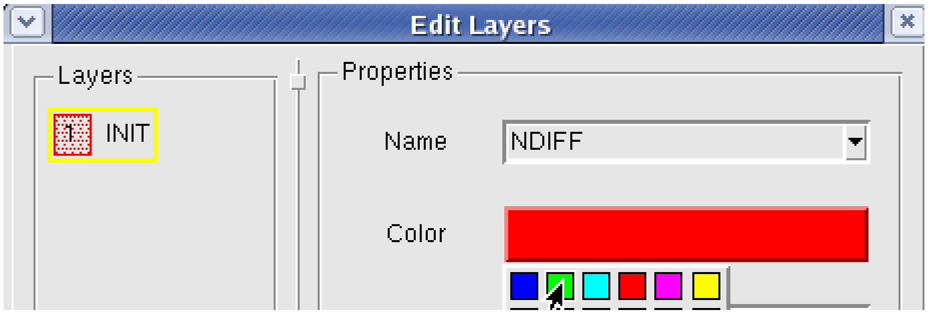

Figure 11: Changing the Layer name to NDIFF.

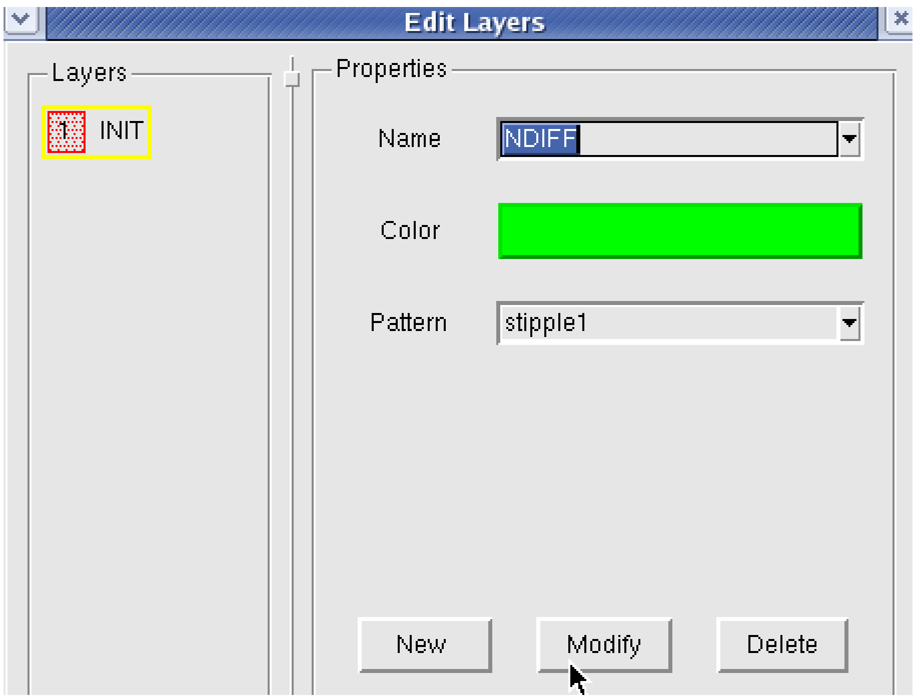

Figure 12: Changing the Color of the NDIFF Layer.

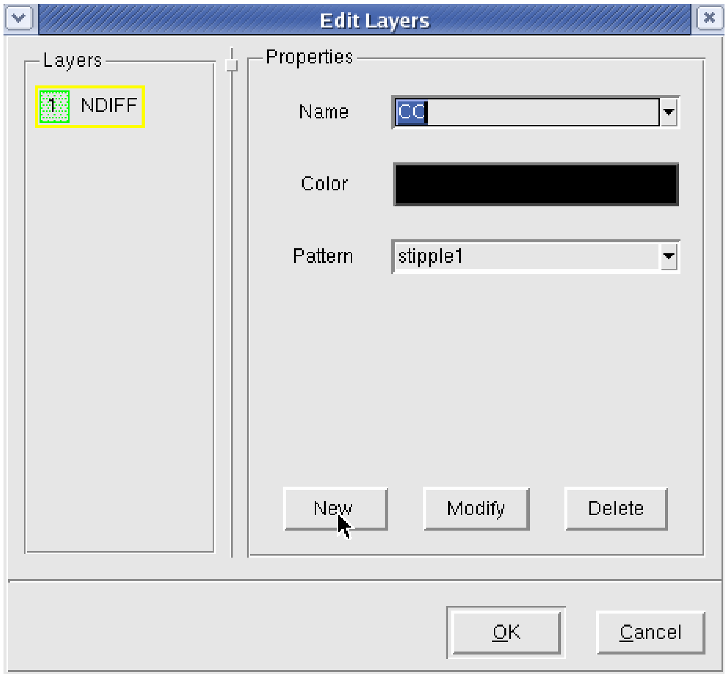

Figure 13: Adding a Contact or Via Layer (CC).

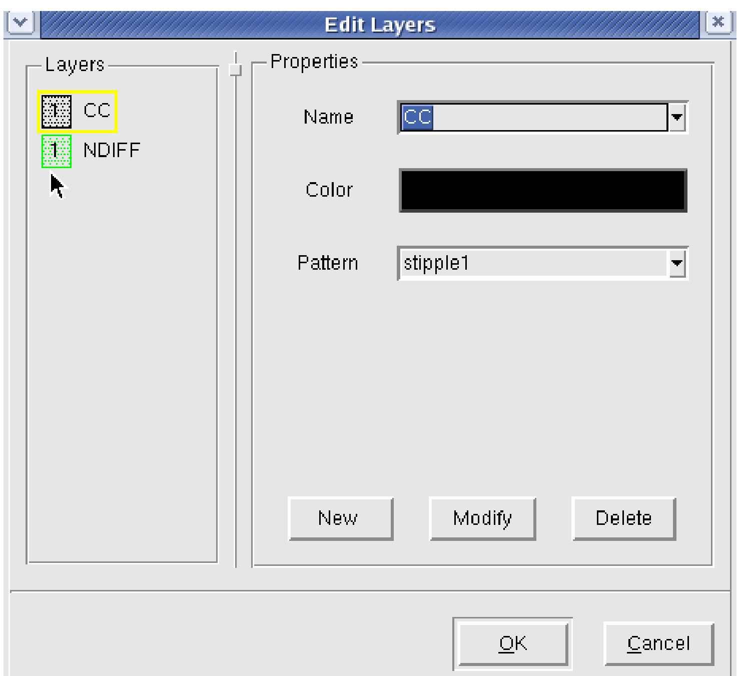

Figure 14: Results of adding the CC Layer.

4. Your Layout editor should look like Figure 15.

5. To add an area of NDIFF click on NDIFF in the selection area and click on the add a new rectangle icon (Figure 16).

6. Draw a rectangle of any shape or size in the editor window (Figure 16).

7. To edit the coordinates click on the select an existing object icon (Figure 17), and then double click on the rectangle you wish to edit (Figure 17).

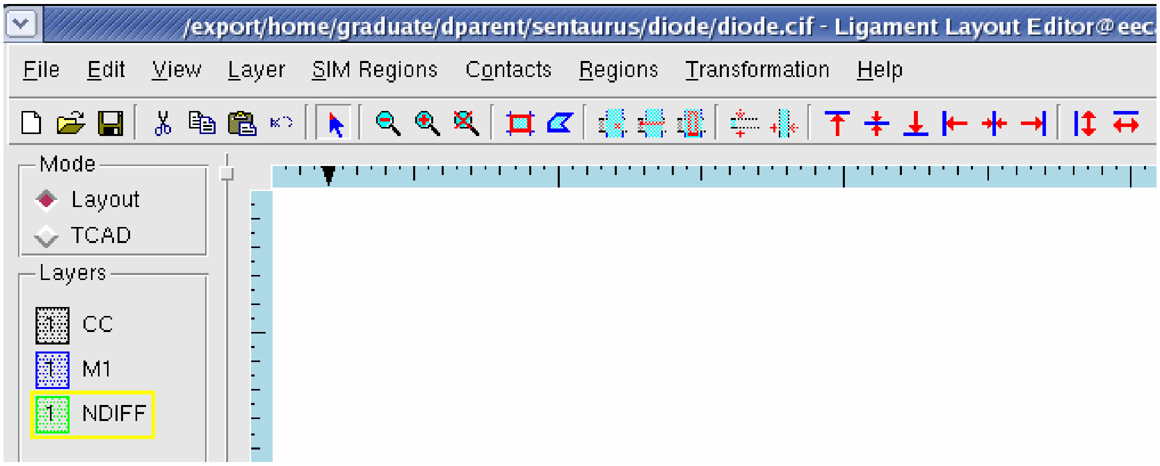

Figure 15: View of the Layout Editor with all three layers.

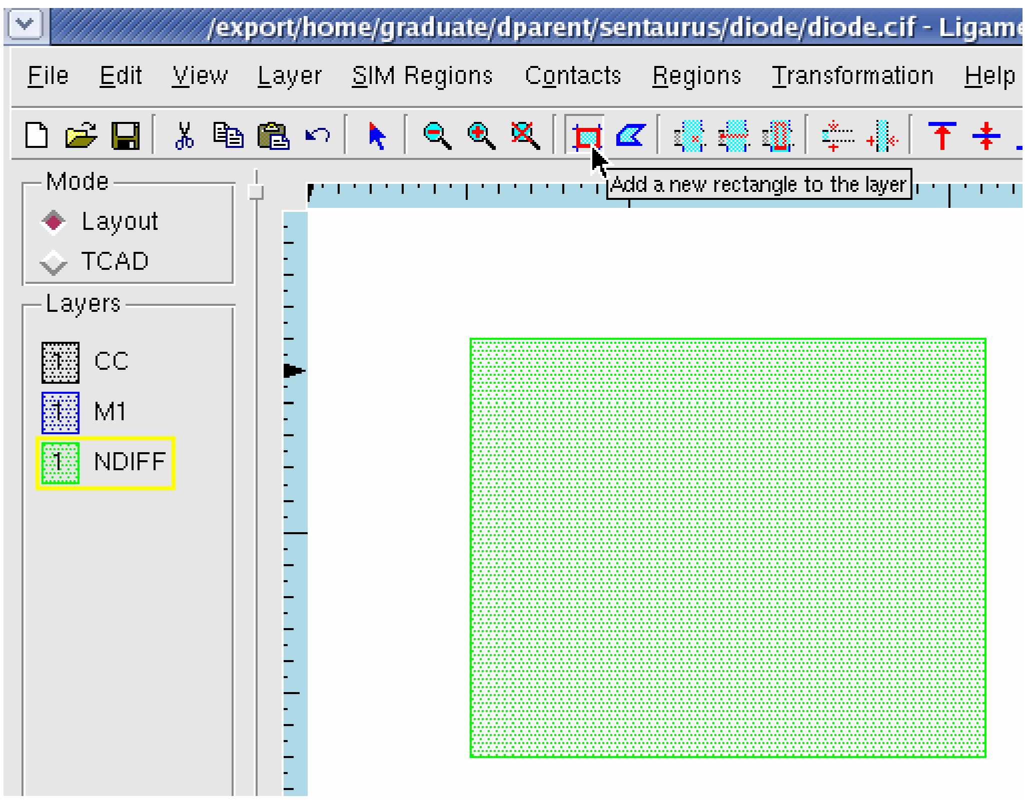

Figure 16: Drawing rectangle.

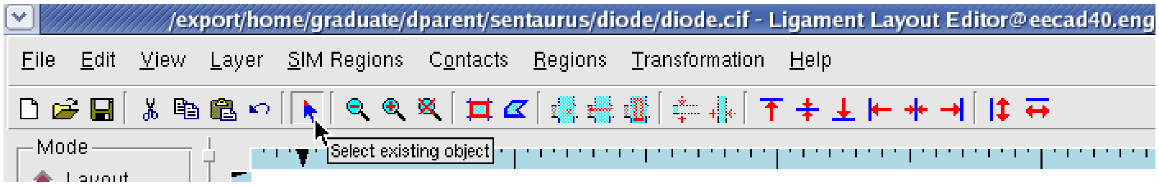

Figure 17: Selecting the selection tools to edit the NDIFF Rectangle.

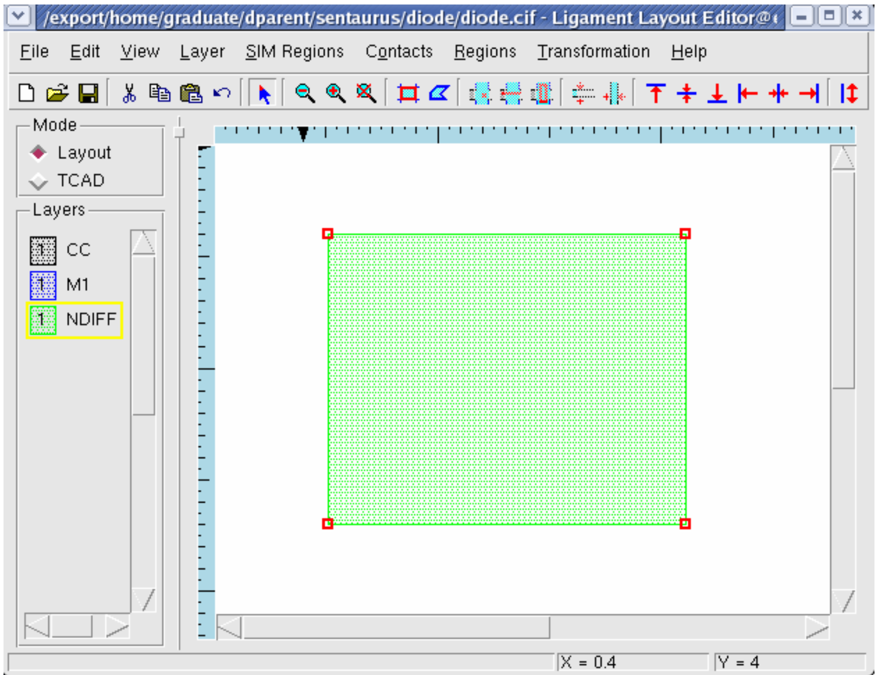

Figure 18: Selecting the NDIFF rectangle.

8. Double click the upper left hand corner of the rectangle and edit its value to **0,4** (Figure 19Figure 20). The corner is moved according to (Figure 20).

9. In a similar manner edit the lower left corner to be 0,0 (Figure 21).

10. In a similar manner edit the lower right corner to be 4,0 (Figure 22).

11. In a similar manner edit the upper right corner to be 4,4 (Figure 22).

12. Save you work by going to file… Save All (Figure 23). Save the file as **diode.lyt**.

13. After saving you will notice all your shapes will disappear (Figure 24Figure 24). Just click on where the shapes should be and they will re-appear (Figure 25).

14. Add a M1 rectangle at coordinates (.5,.5), (.5,3.5), (3.5,.5), (3.5,3.5) (Figure 26).

15. Add a CC rectangle at coordinates (1,1), (1,3), (3,1), (3,3) (Figure 26).

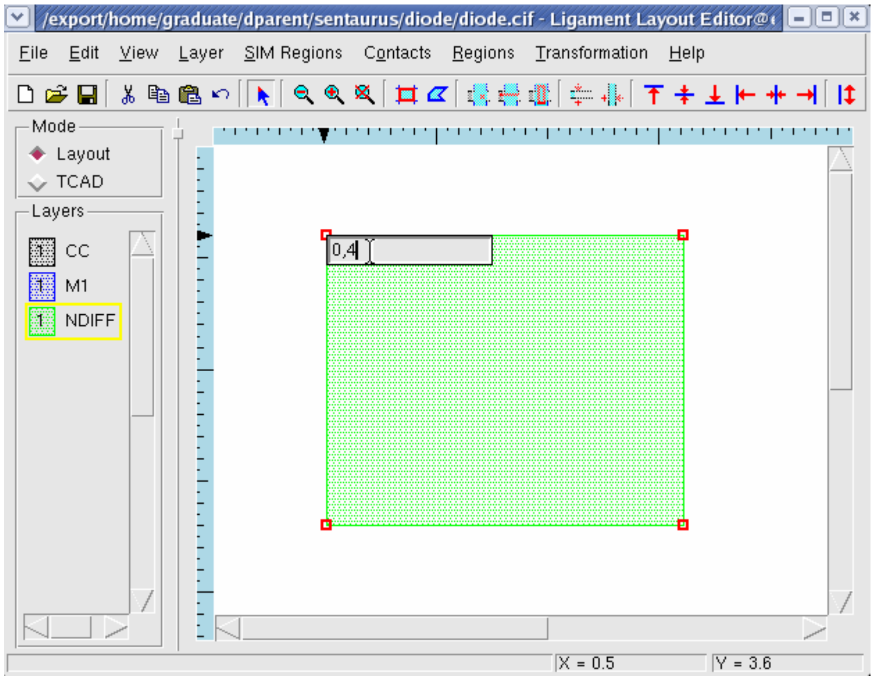

Figure 19: Editing the coordinates of the up left corner.

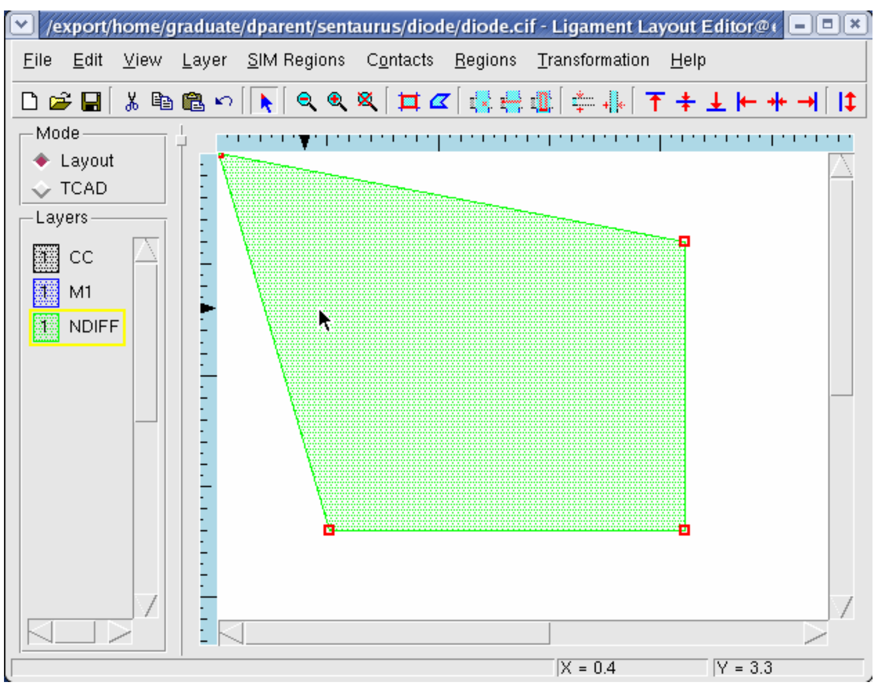

Figure 20: Results of the edit. (Results will vary.)

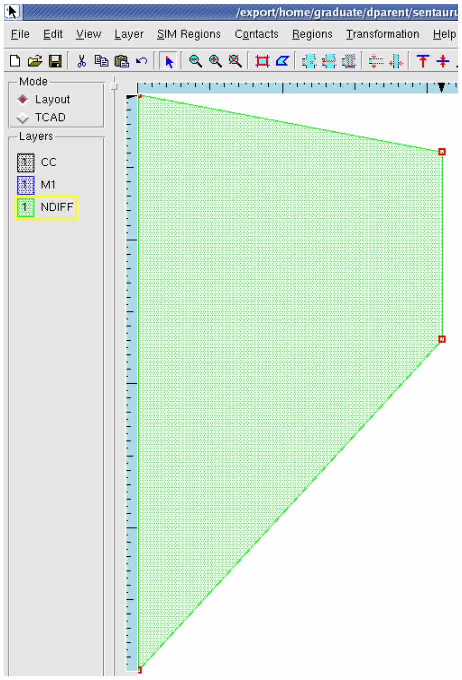

Figure 21: Results of setting the lower left corner to x=0 and y=0.

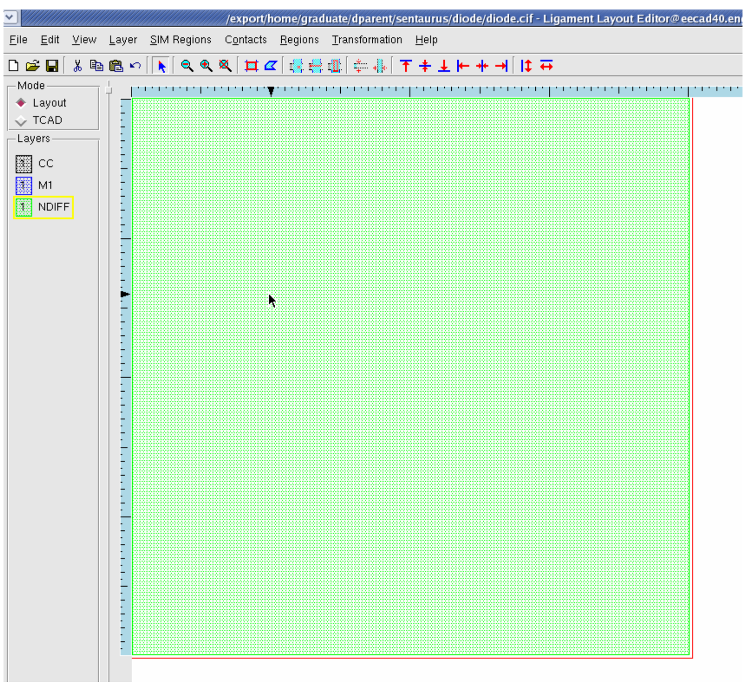

Figure 22: Results of setting the rectangle coordinates to (0,0), (0,4), (4,4) and(4,0).

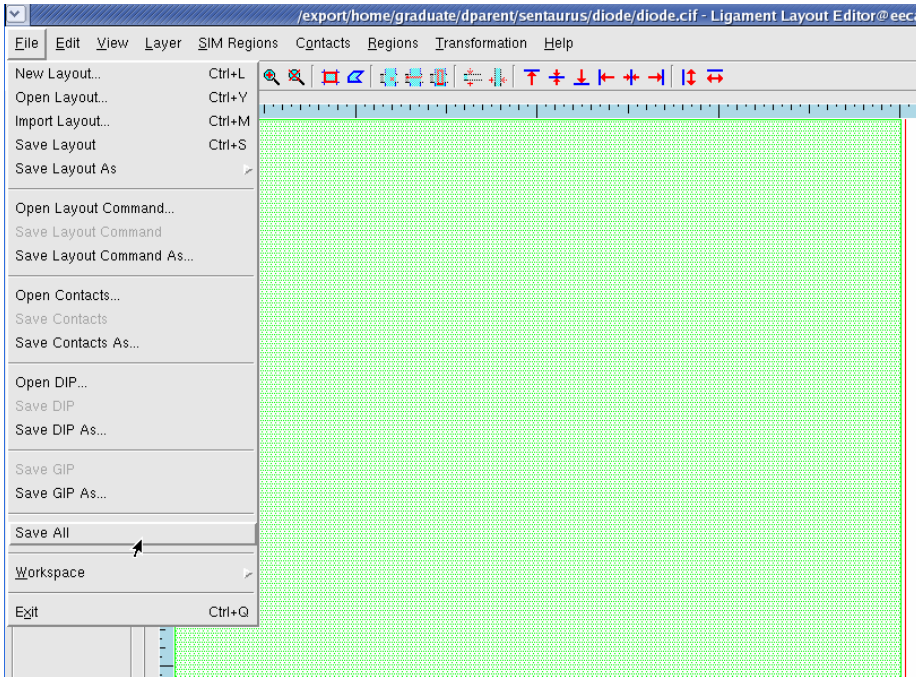

Figure 23: Saving your results.

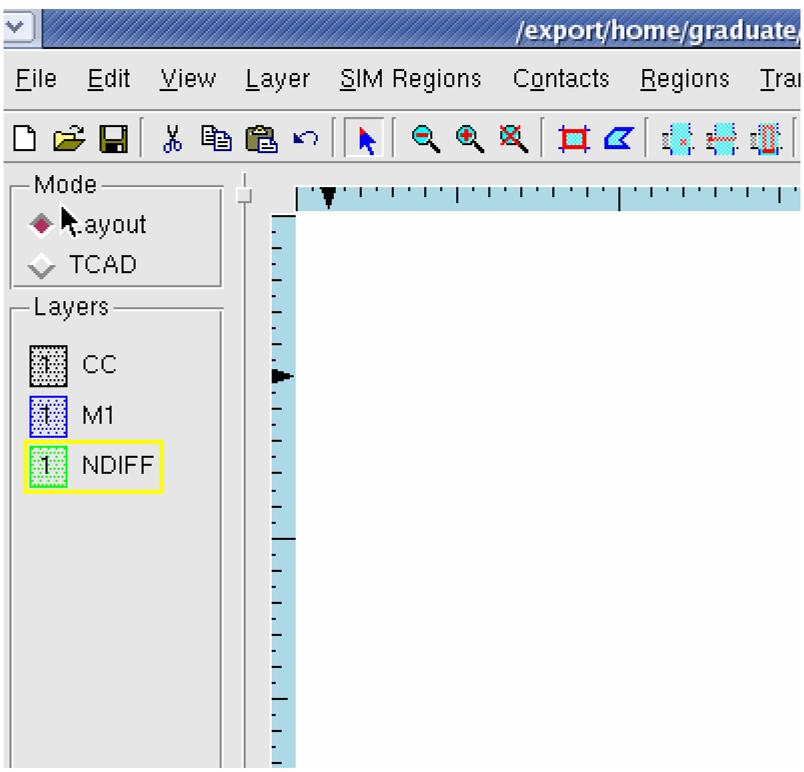

Figure 24: Layers seem to disappear after saving.

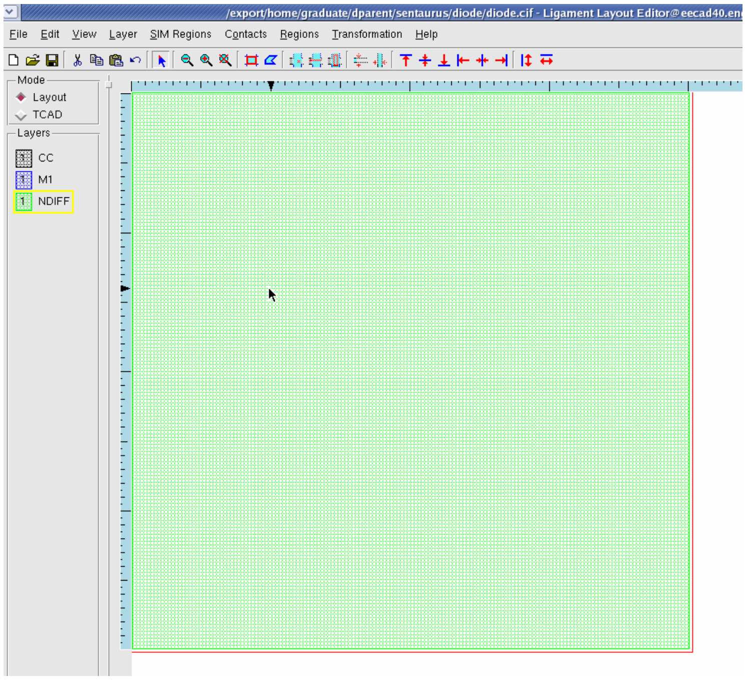

Figure 25: Clicking on shapes to bring them back into view.

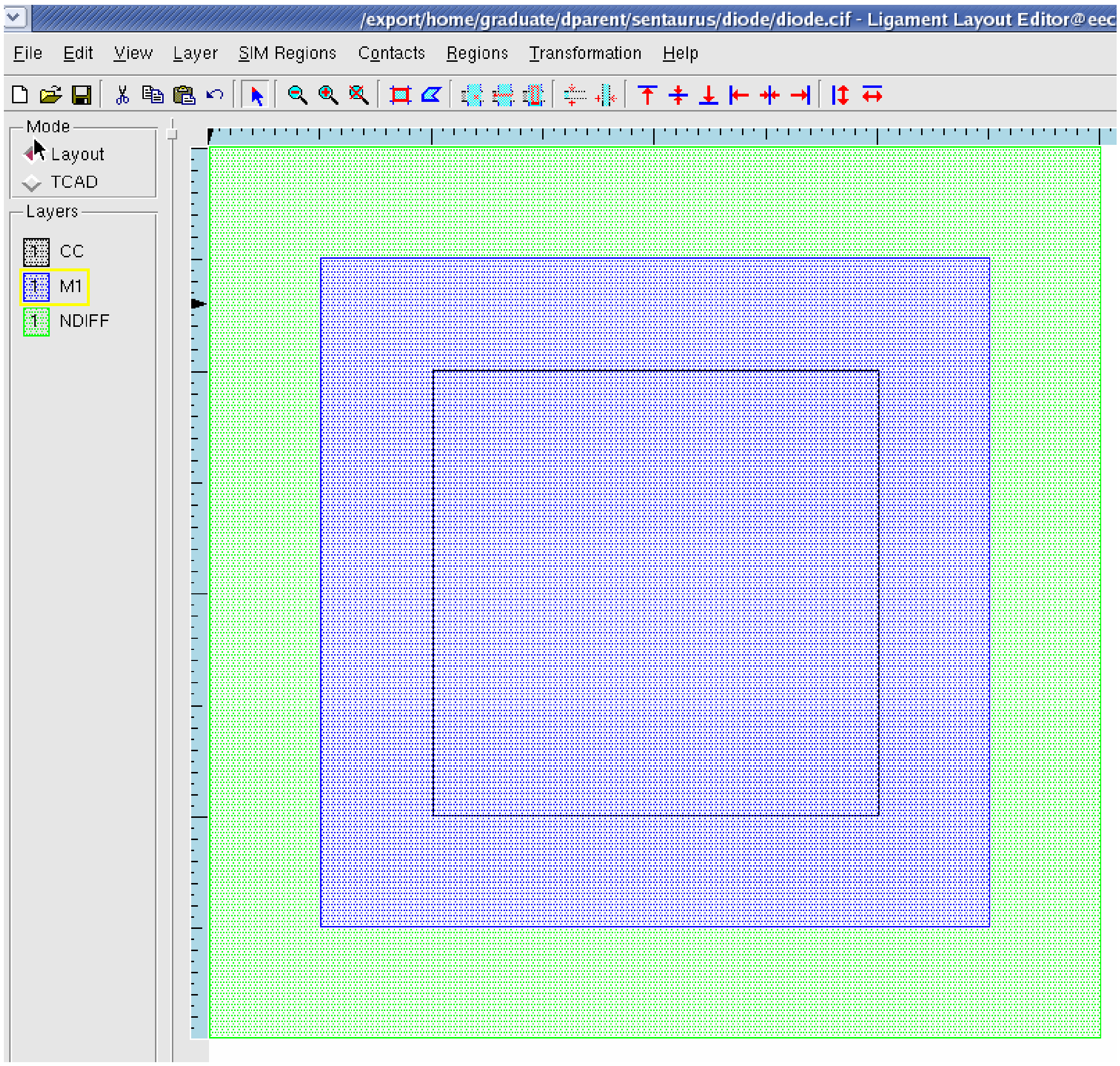

Figure 26: Adding M1 and CC shapes.

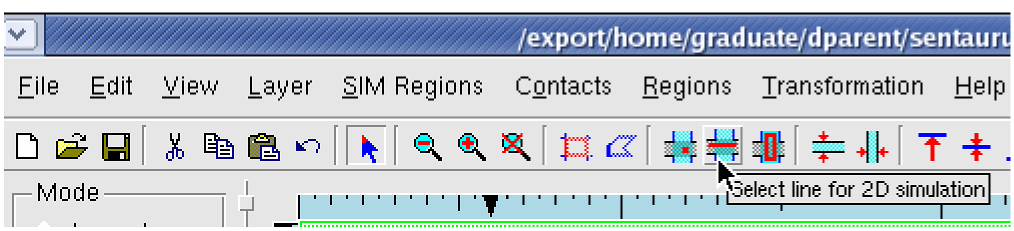

Figure 27: Setting a 2-D cross section for simulation.

16. Now we would like to simulate a 2-D cross section of the device. We only want to process half of the device to save simulation time. Click on TCAD in the upper left corner of the editor and the select line for 2-D cross section icon (Figure 27).

17. Draw the line according to Figure 28.

18. Save your work!

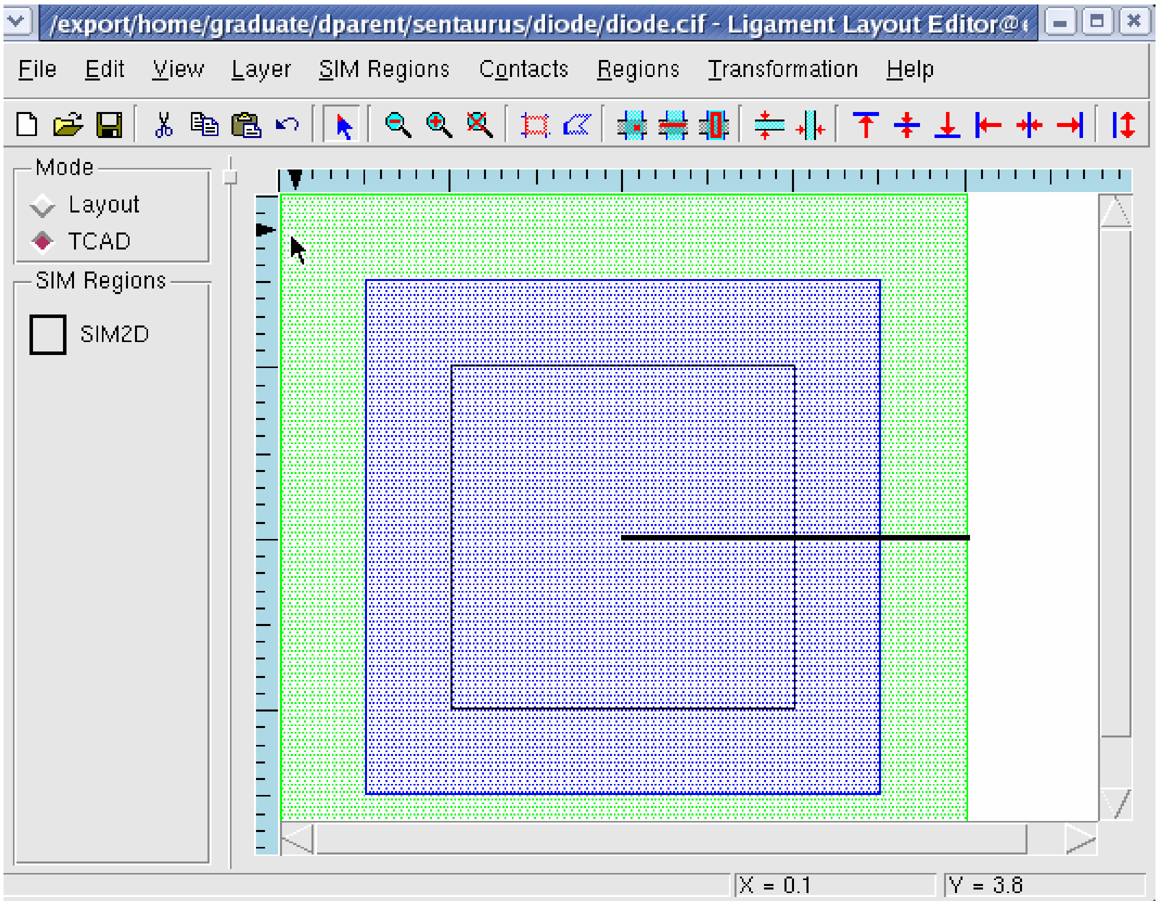

Figure 28: A line representing half of the diode structure.

Creating a Process Flow with Ligedit:

In the previous section we defined the masks for three layers NDIFF, CC and M1. IN this section we will use that mask information in the process run deck and we will simulate the 2-D cross section area we choose SIM2D.

1. In your diode directory, start the Ligedit editor by typing **Ligedit &** at the command line (Figure 29). The editor should start (Figure 30).

2. Add a Process Header by going to Edit… Add Process Header (Figure 31).

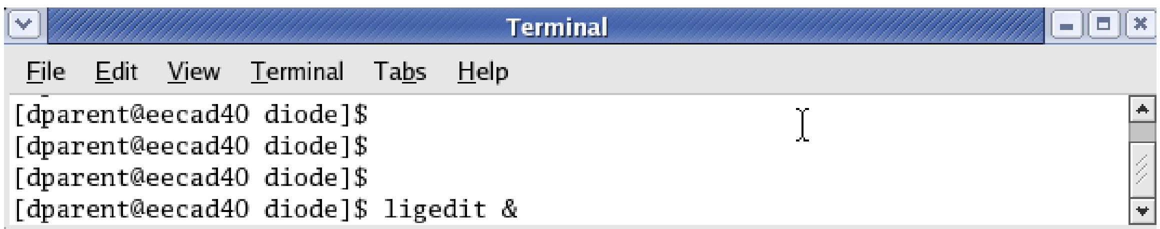

Figure 29: Starting Ligedit.

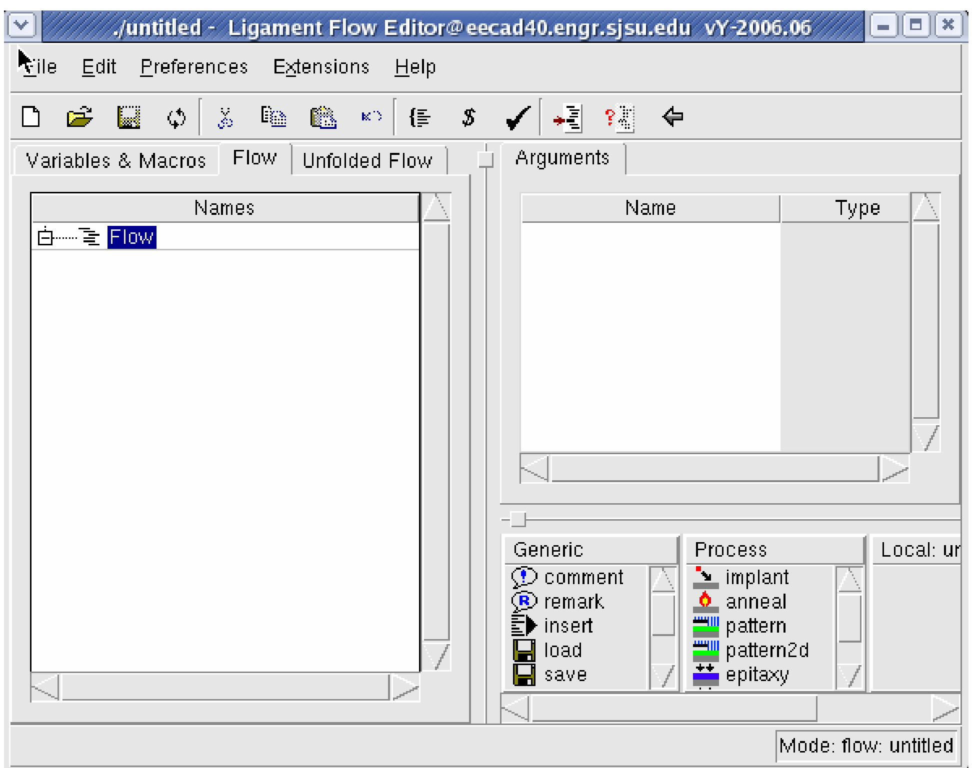

Figure 30: Ligedit GUI.

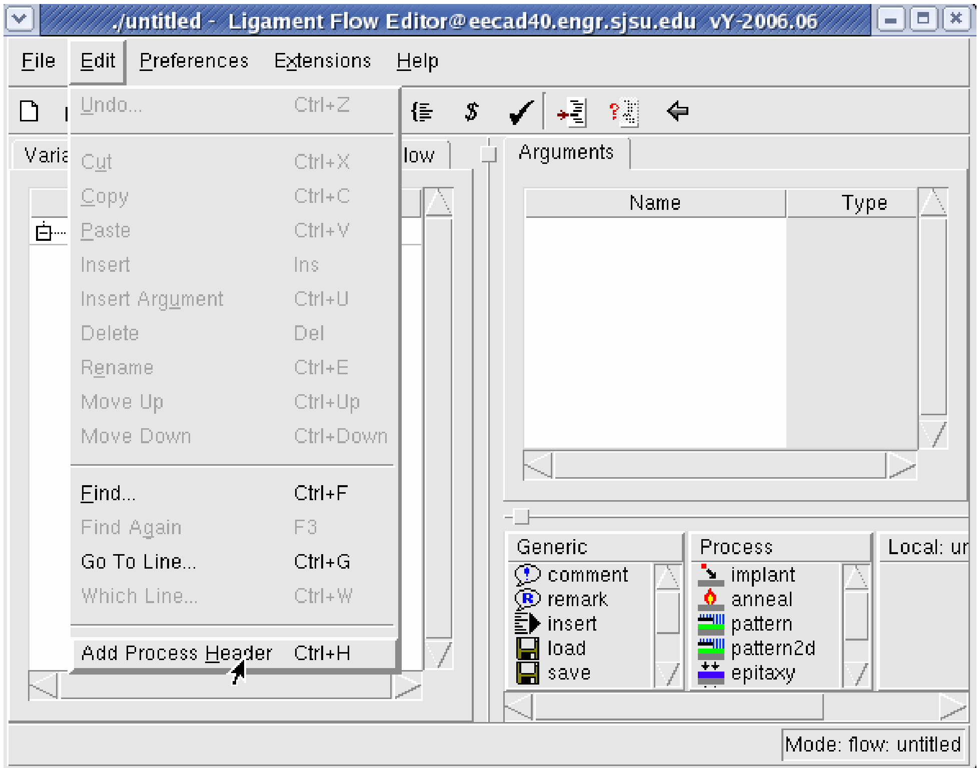

Figure 31: Adding a Process Header.

3. Double Click on environment and the title (Figure 32), and set the title to Diode (Figure 32).

4. Double lick on simulator and set it to sprocess (Figure 33).

5. Double click on output and save it to diode (Figure 34). This saves all output files ad @diode@.

6. Double Click on Graphics and set it to false. This makes sure plots do not pop-up during simulation (Figure 35).

7. Click on Substrate and double click on dopant type and set it to Boron (Figure 36).

8. Double click on concentration and set it to 1e16 with a unit of /cm3 (Figure 37).

9. Read in the mask data by going to File.. Open Layout (Figure 38). Select the file you created in the previous section (Figure 39).

10. To assign the region click on environment, and then double click on region, Select SIM2D from the pop-up (Figure 40).

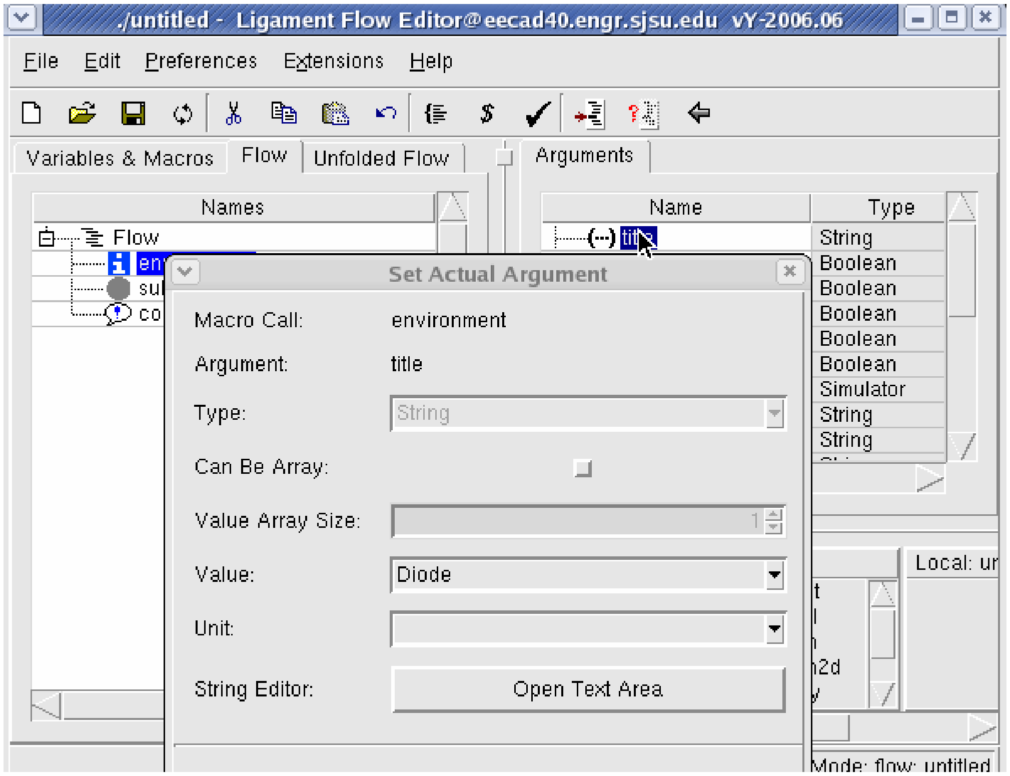

Figure 32: Setting the value of the Title.

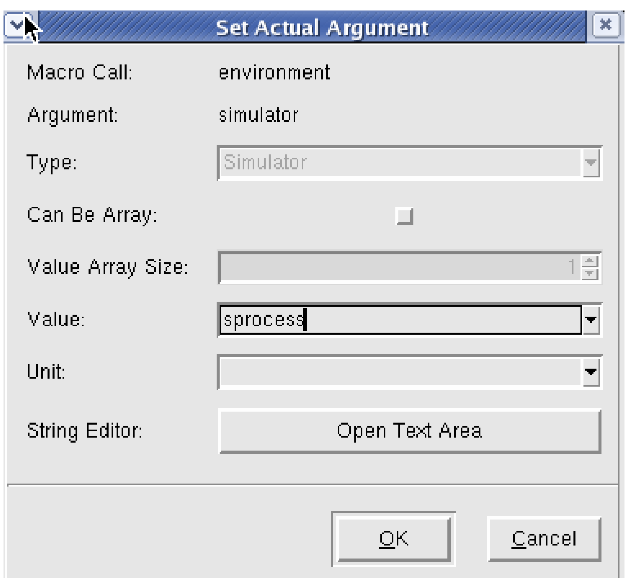

Figure 33: Setting the argument of the simulator to sprocess.

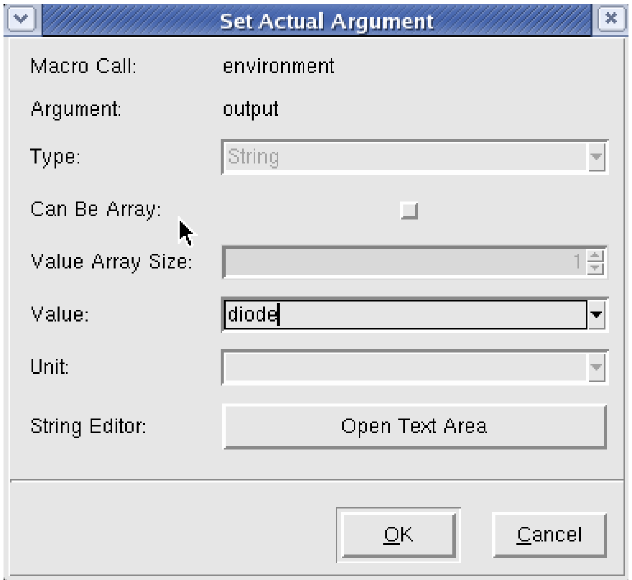

Figure 34: Setting the output argument.

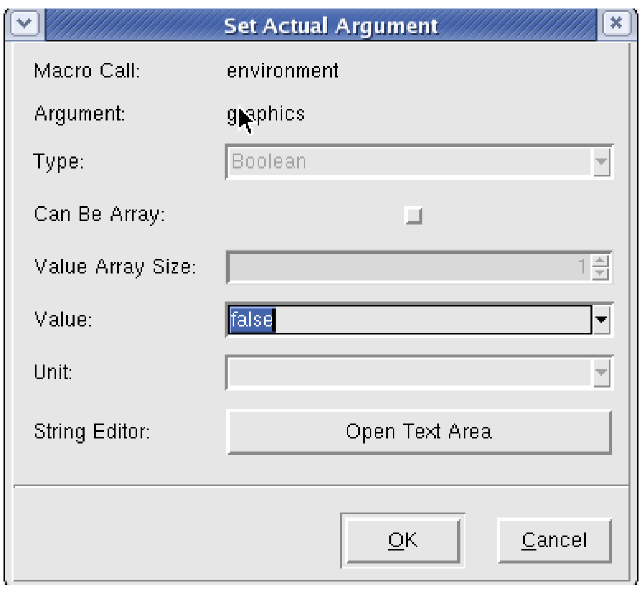

Figure 35: Setting the graphics environment to false.

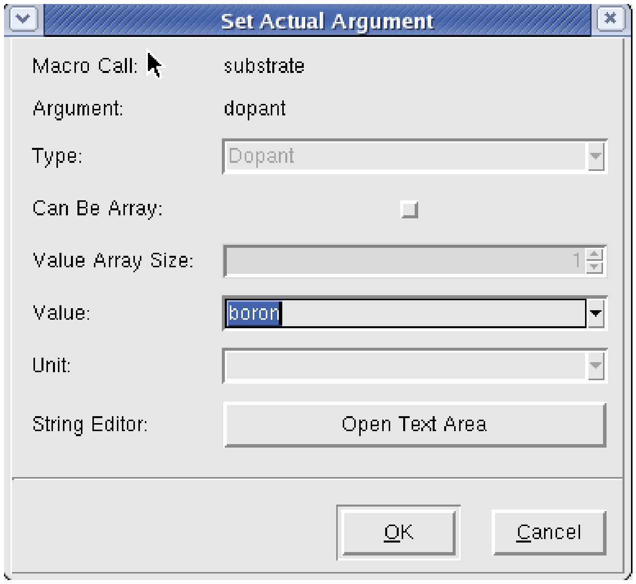

Figure 36: Setting the substrate doping type to boron.

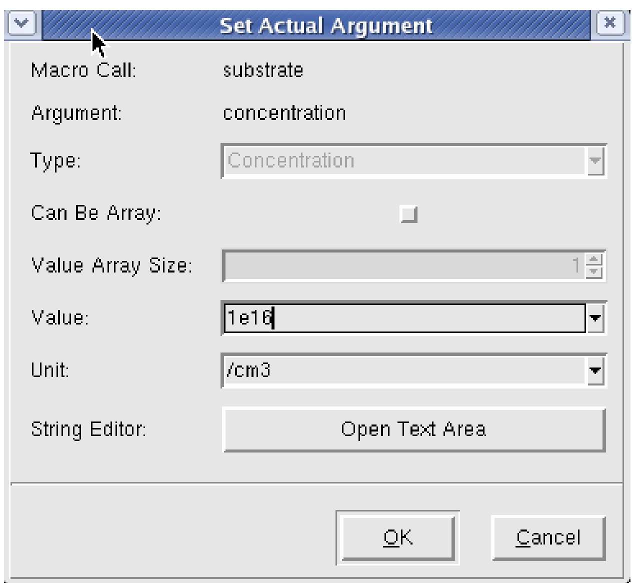

Figure 37: Setting the substrate concentration.

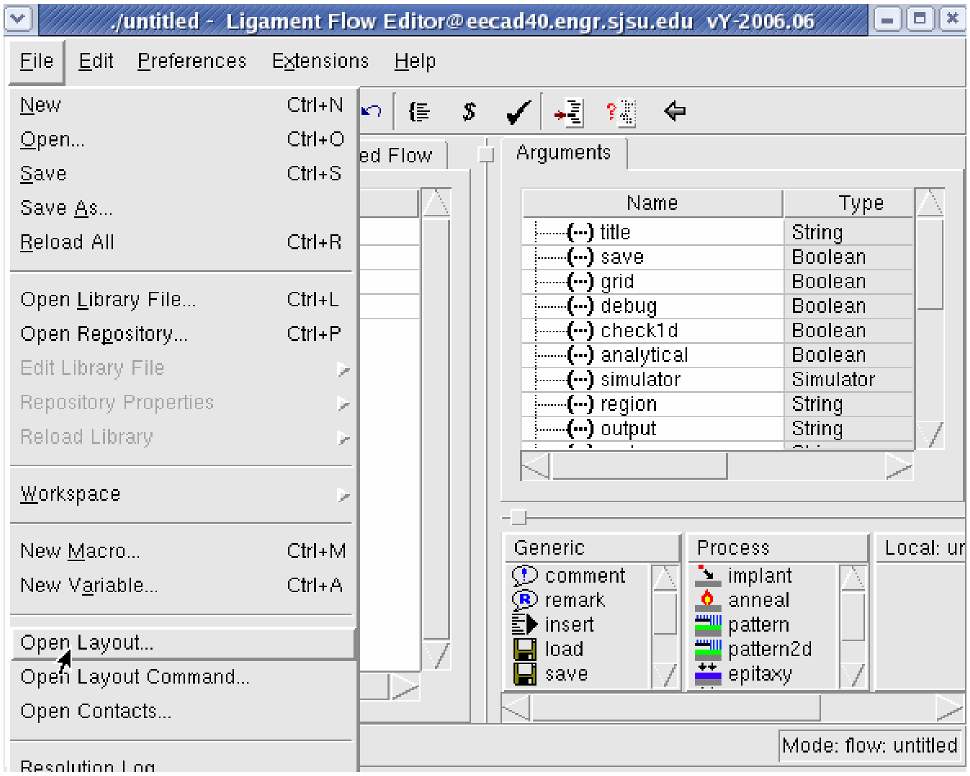

Figure 38: Opening the Layout view for the mask pattern steps.

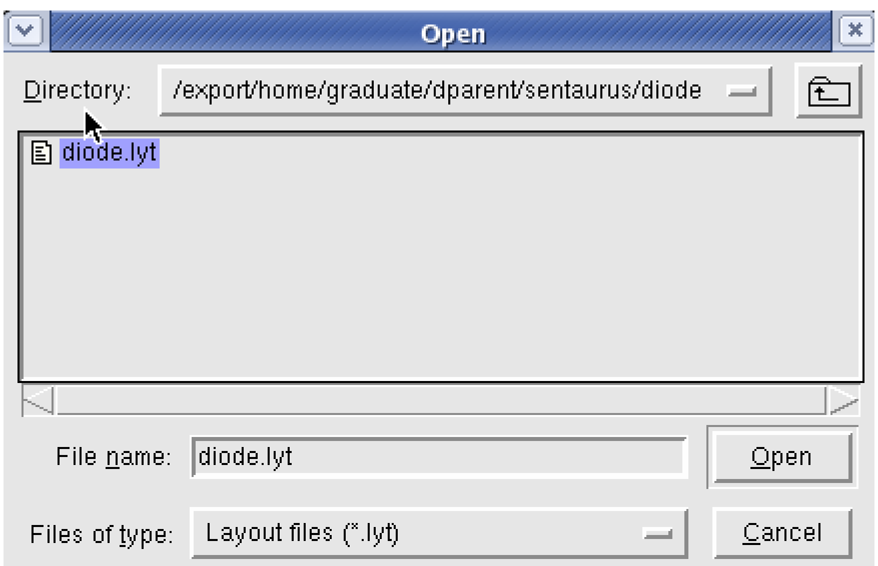

Figure 39: Selecting the proper layout file.

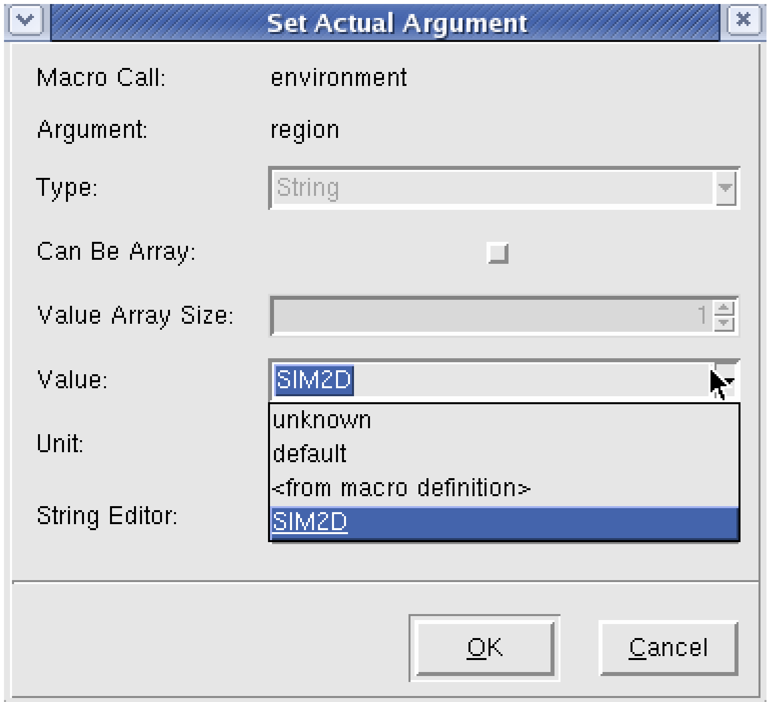

Figure 40: Selecting the proper 2-d cross section.

11. Click on the translate current flow icon (Figure 41). You should see the run deck that has been created by the gui. The simulation is x from 0 to 5 microns (up and down) and y from 0 to 2 microns (left and right). The simulation is 5 microns deep by default.

12. Check to see if the syntax is acceptable for sprocess by clicking on check translated flow (Figure 42).

13. Save this sprocess run deck by going to File… Save translated flow (Figure 43).

14. Save the files as diode_fps.cmd (Figure 44).

15. Click on the Go back to editor icon (Figure 45).

16. Save this GUI-Run deck (not the same thing as an sprocess run deck), by going to File… Save as (Figure 46). Call the file diode_lig.cmd.

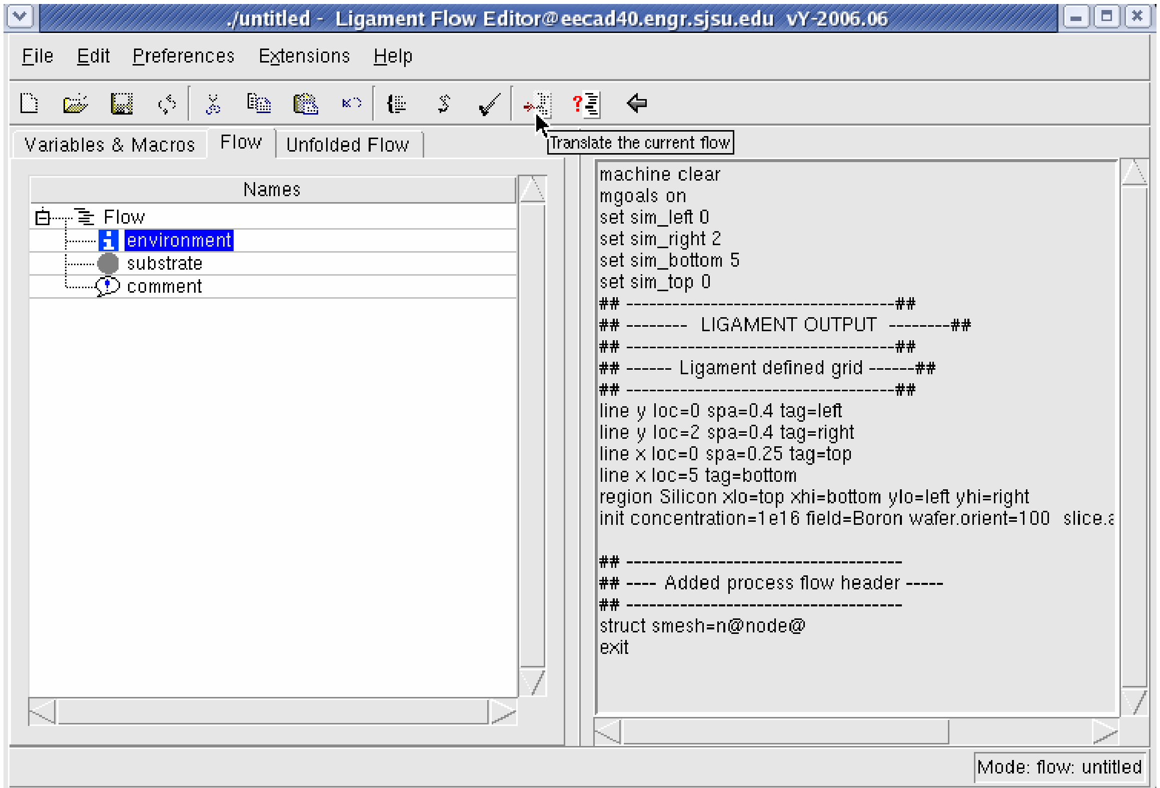

Figure 41: Translated flow into sprocess.

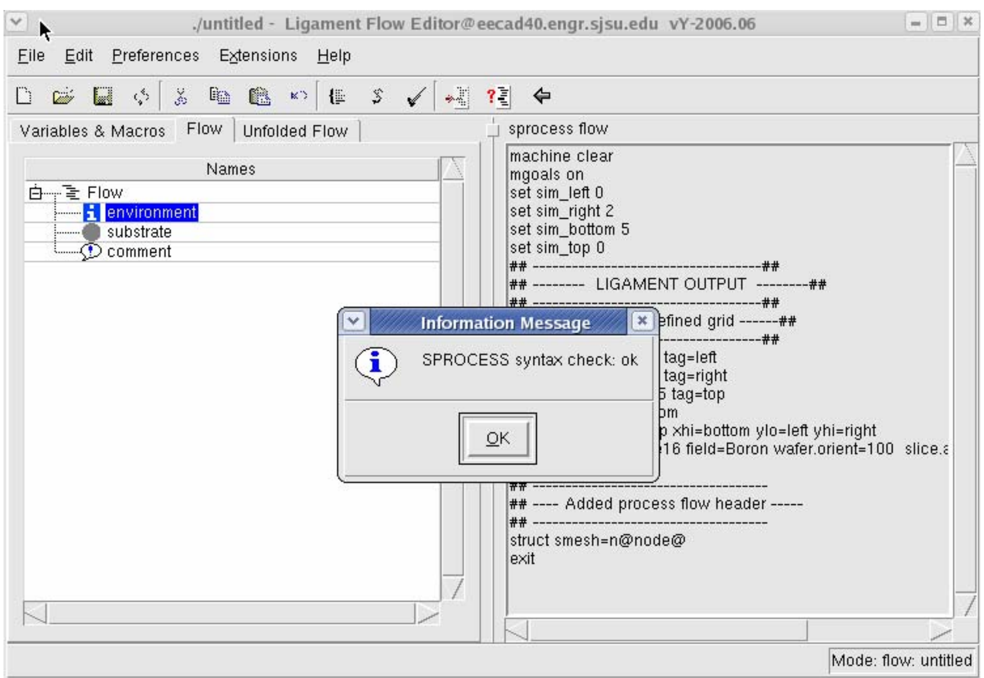

Figure 42: Checking the syntax for the sprocess deck.

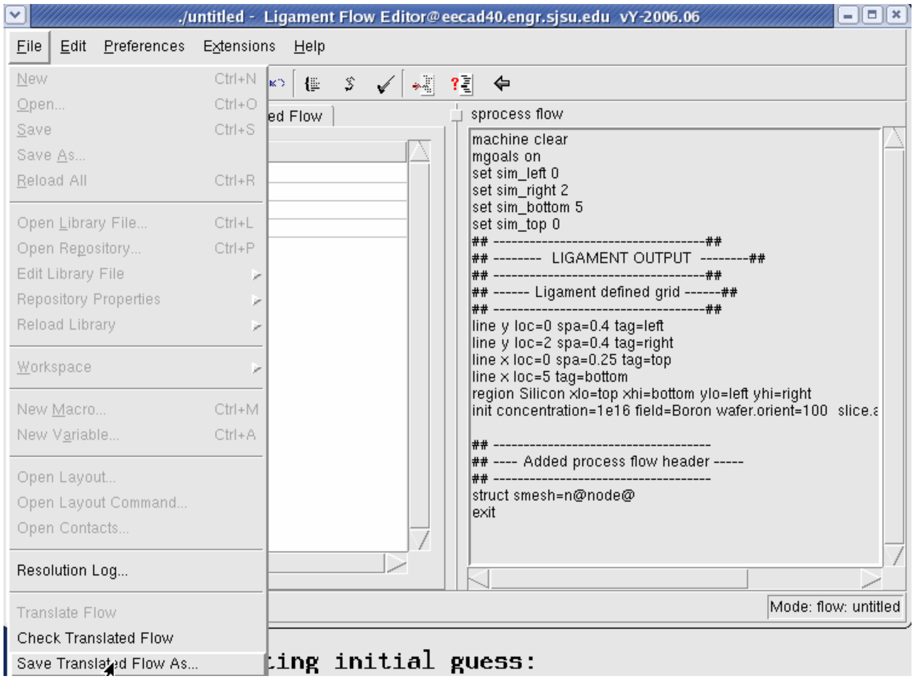

Figure 43: Saving the translated sprocess flow.

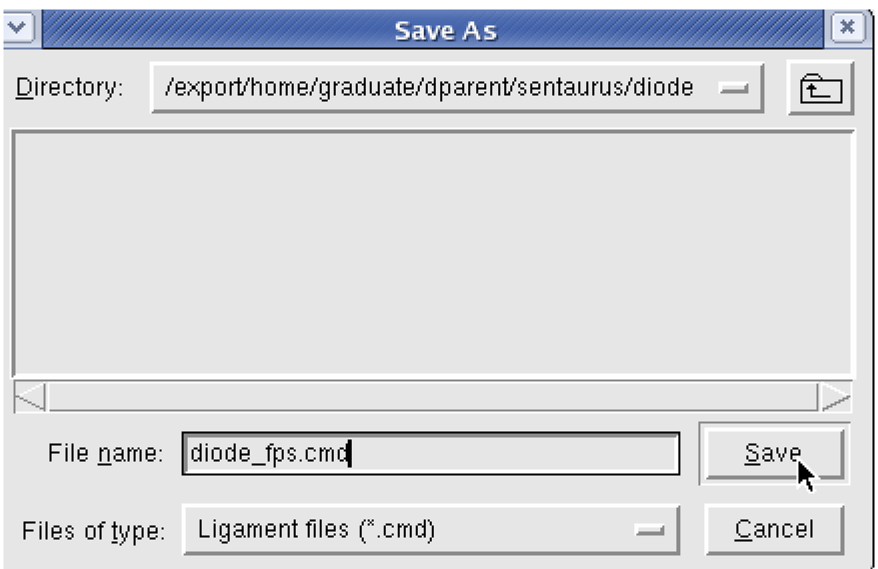

Figure 44: File name for process flow.

Figure 45: Going back to the GIU editor.

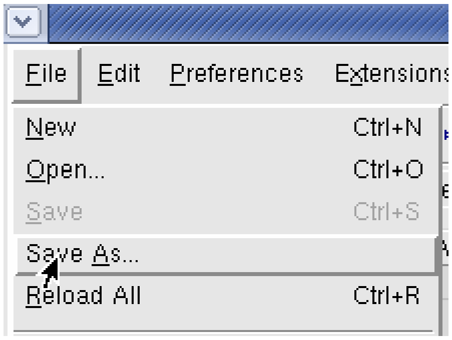

Figure 46: Saving the Gui run deck.

Running sprocess and viewing results in tecplot.

1. In your diode directory type**: sprocess diode_fps.cmd** (Figure 47). The simulator should start and eventually end with a successful message (Figure 48).

2. To view you substrate definition (that is all we have done so far) type **tecplot_sv –mesa &** (Figure 49).

3. The Tecplot viewer should appear (Figure 50). If it doe not you probably forgot the –mesa when invoking it.

4. Go to File load (Figure 51) and a read Synopsys file pop-up should appear (Figure 52).

5. Highlight diode_bdn.tdr (Boundary file) and diode_fps.tdr (doping information) and click add (Figure 53), then OK.

6. Two pink rectangles should appear (Figure 54). There is not much data because we just defined the substrate. We did no processing.

7. Exit Tecplot.

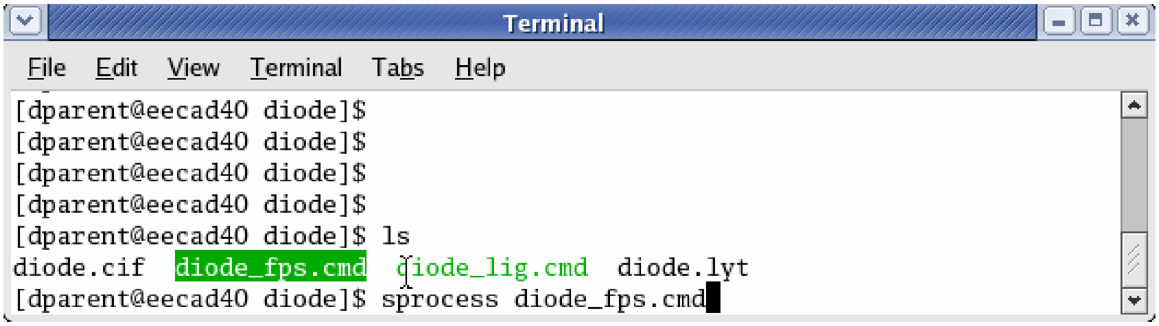

Figure 47: Running the process deck.

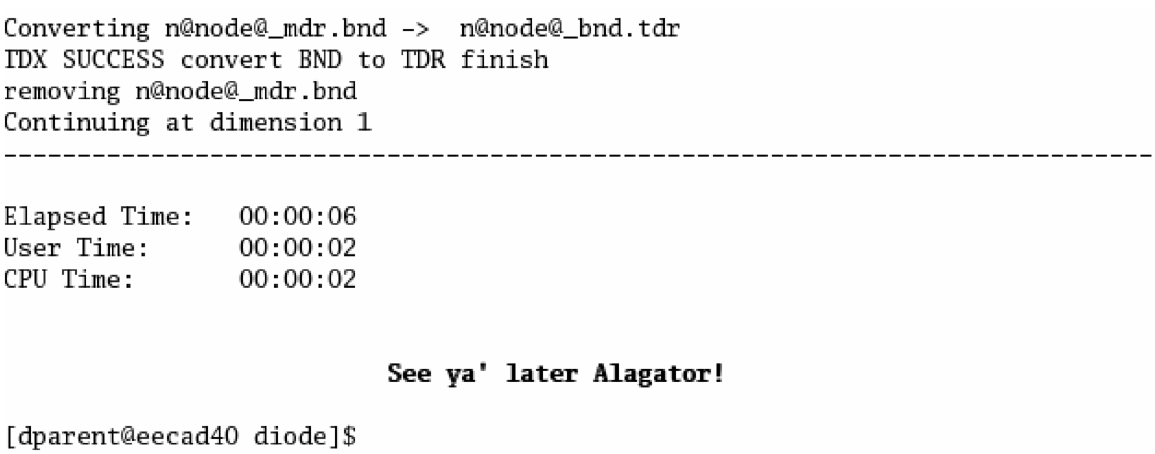

Figure 48: Sprocess completes sucessfully.

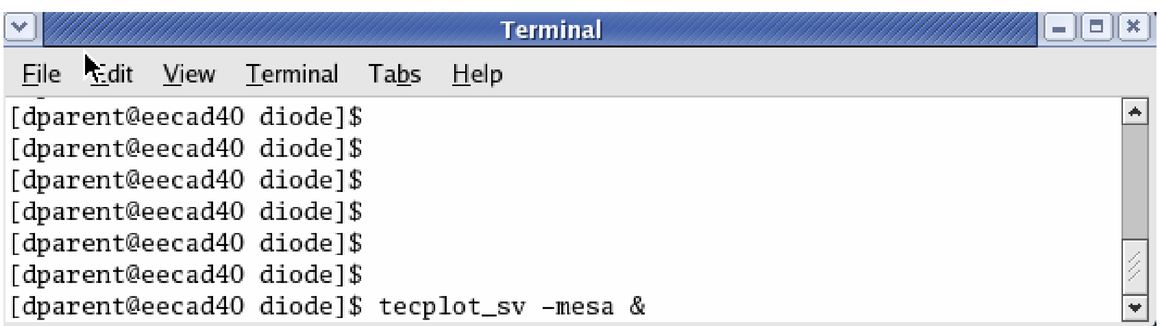

Figure 49: Plotting results.

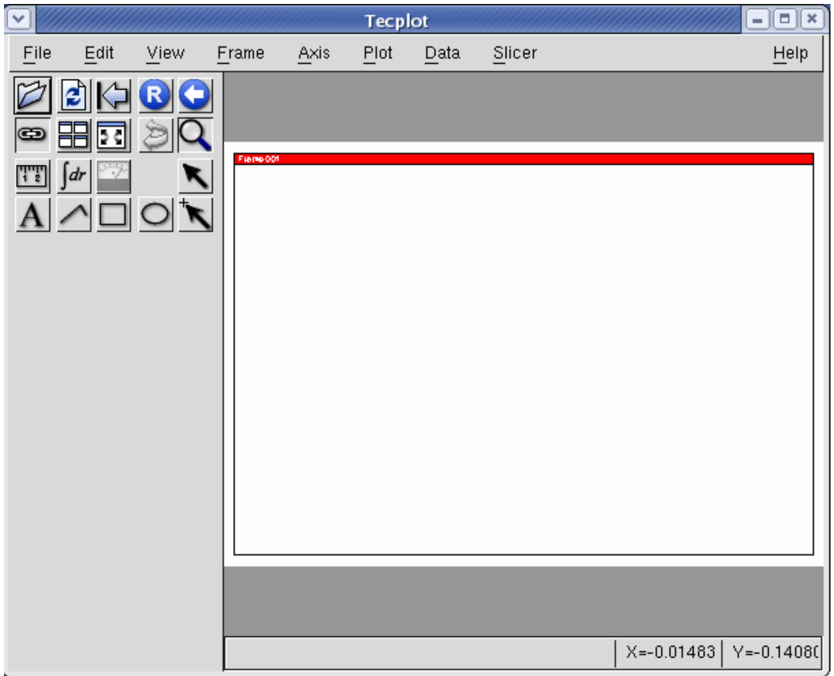

Figure 50: Techplot.

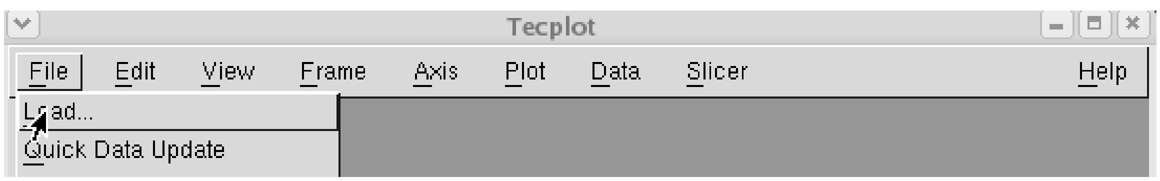

Figure 51: Loading the files to be plotted.

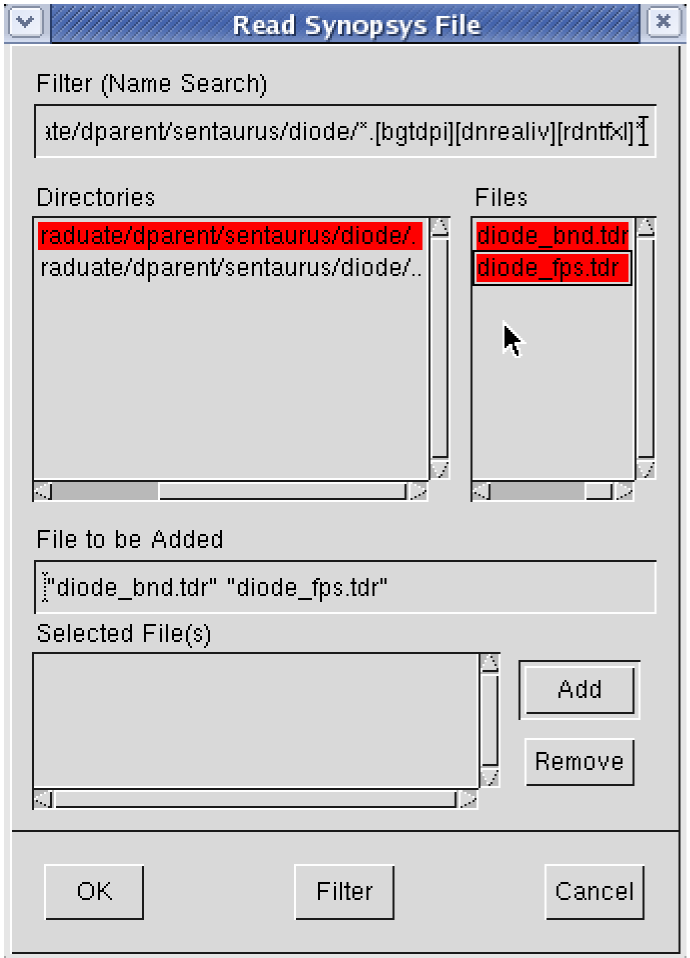

Figure 52: adding data to tecplot.

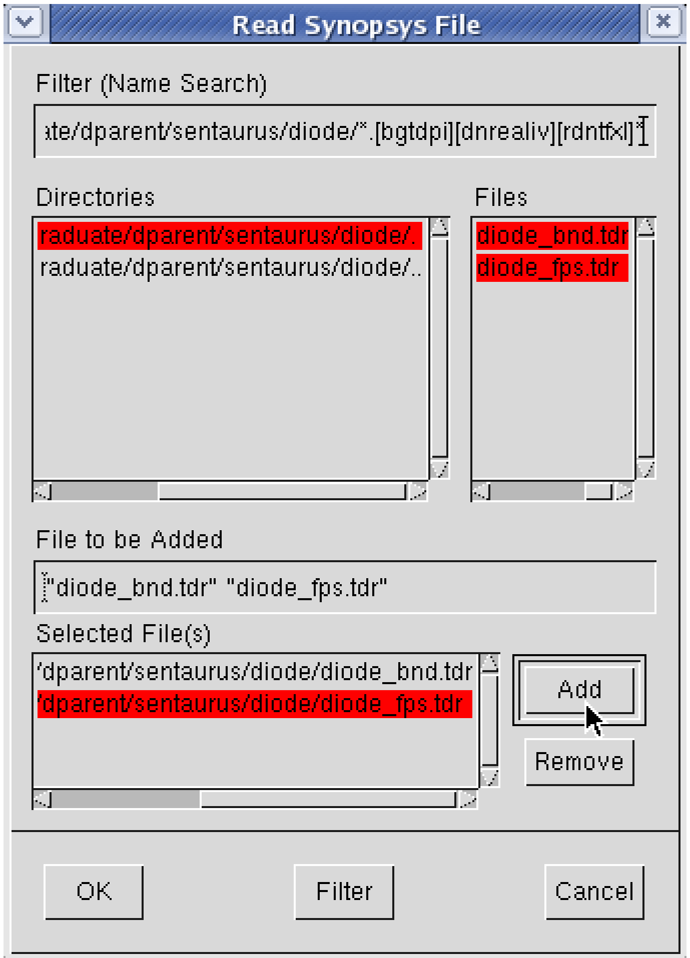

Figure 53: Adding data to tecplot.

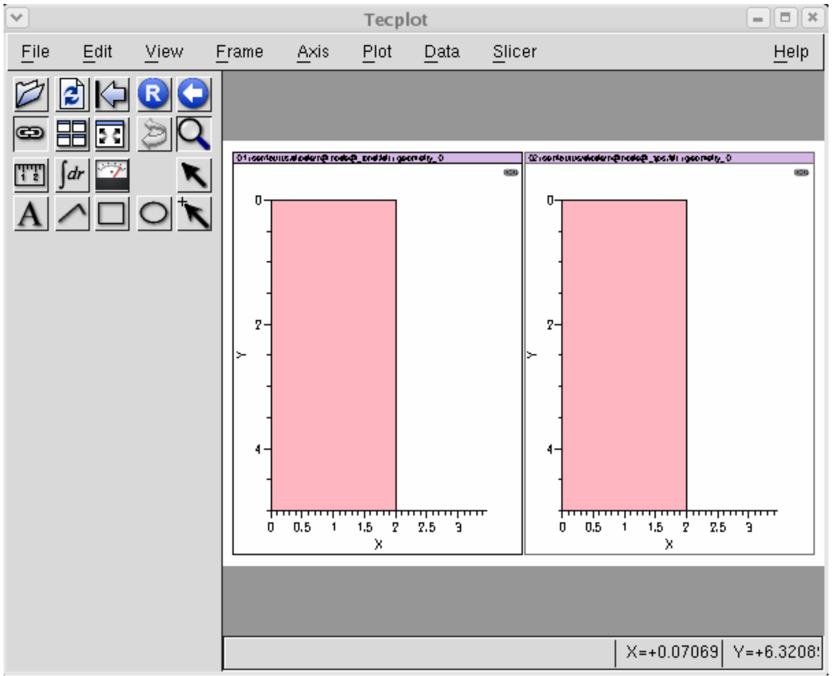

Figure 54: Results of setting substrate.

8. Add an Spin On Glass (SOG) oxide layer that will be used for the dopant source by going back to the ligedit (Figure 55) GUI, and copying a deposit command(Figure 56) and pasting it after the comment (Figure 57, Figure 58).

9. Set the material to Oxide (Figure 59), the thickness to 3000 Angstroms (Figure 60), the dopant to phosphorus (Figure 61), and the concentration to 5e21 /cm3 (Figure 62). Save your GUI ligament flow.

10. Translate the flow (Figure 63) and save it as didoe_fps.cmd, and view your results in tecplot (Figure 64). Exit tecplot when you are done viewing. You can see the didoe_fps.tdr file is now meshed properly.

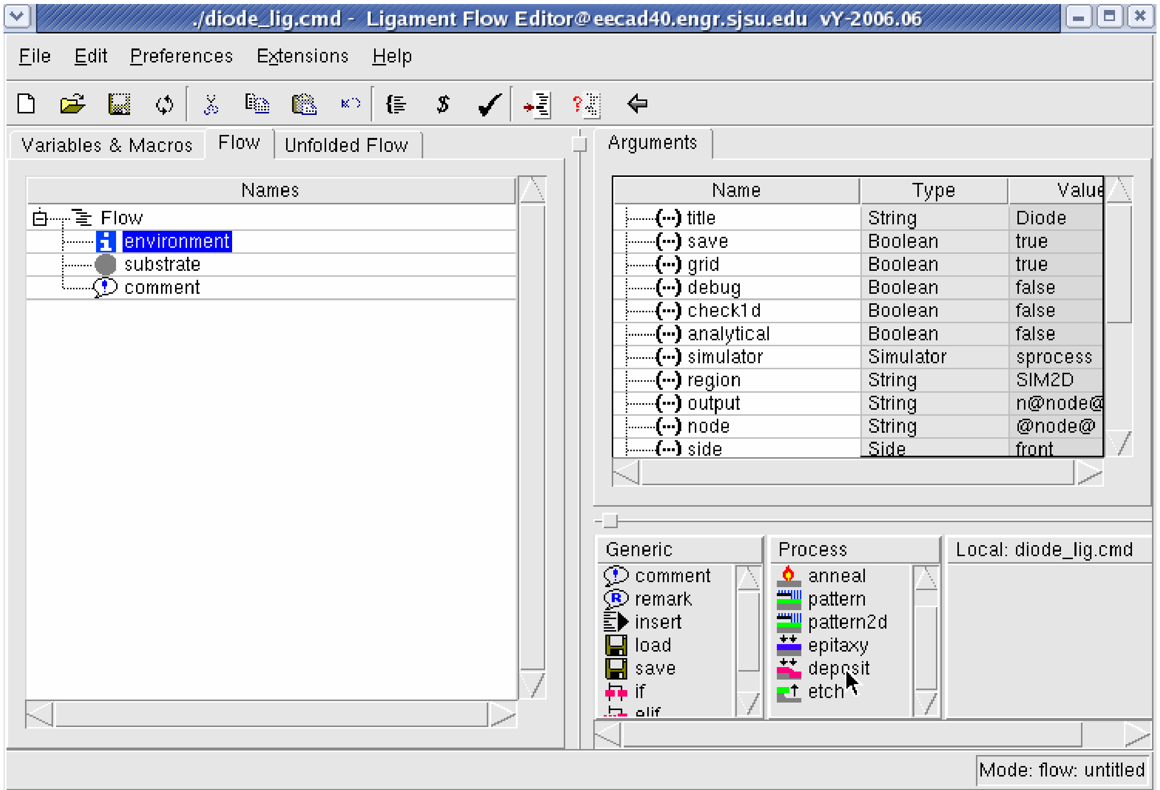

Figure 55: Adding a deposit step.

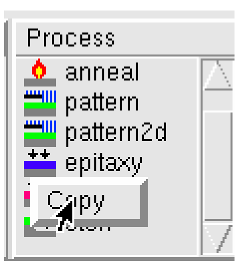

Figure 56: Copy a Deposit step.

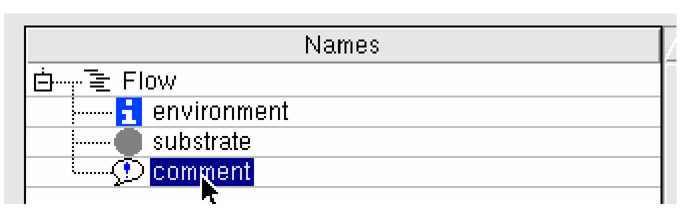

Figure 57: Pasting a Deposit step after comment..

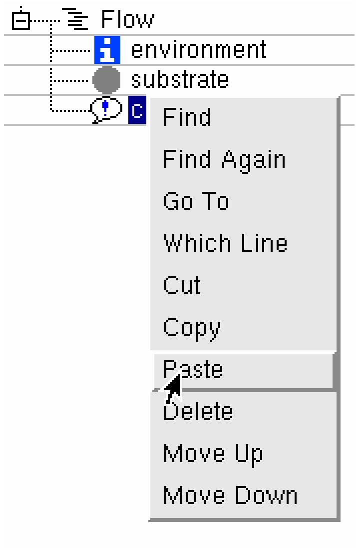

Figure 58: Past the step.

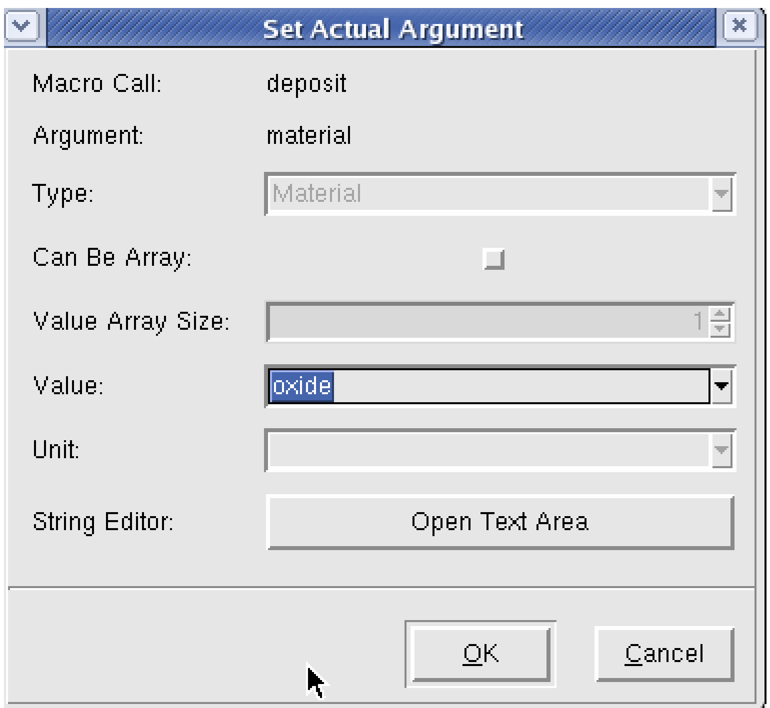

Figure 59: Set the Material type to oxide.

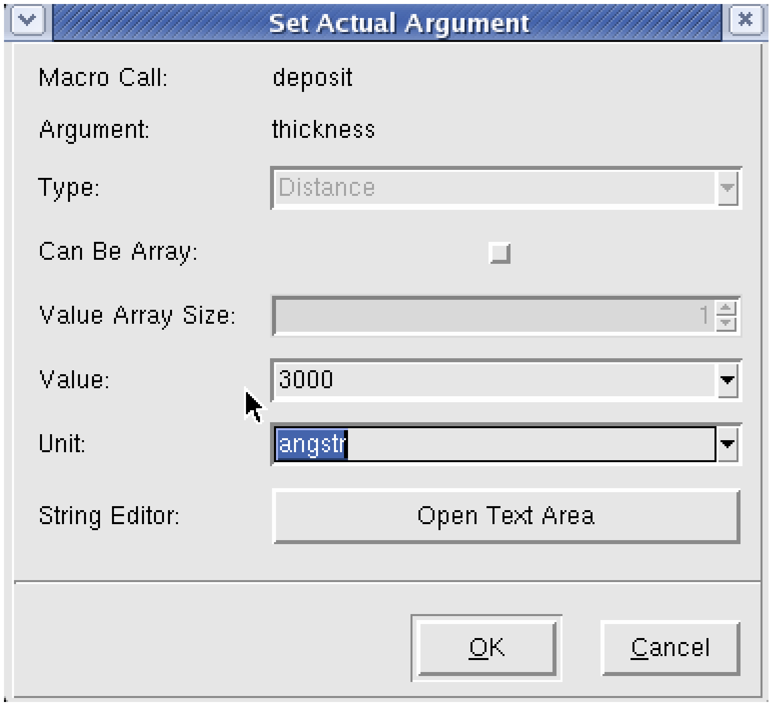

Figure 60: Set the thickness to 3000A.

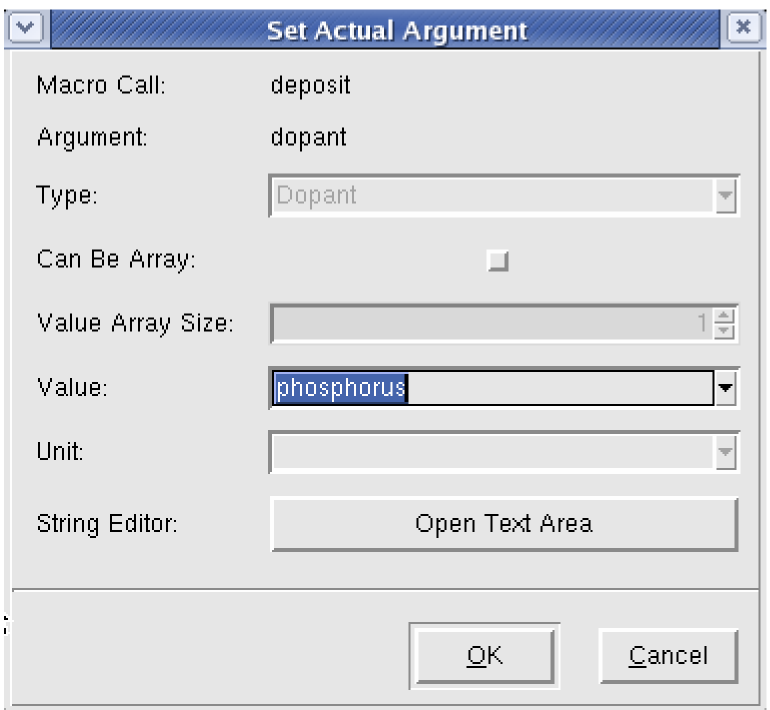

Figure 61: Setting the doping type to P.

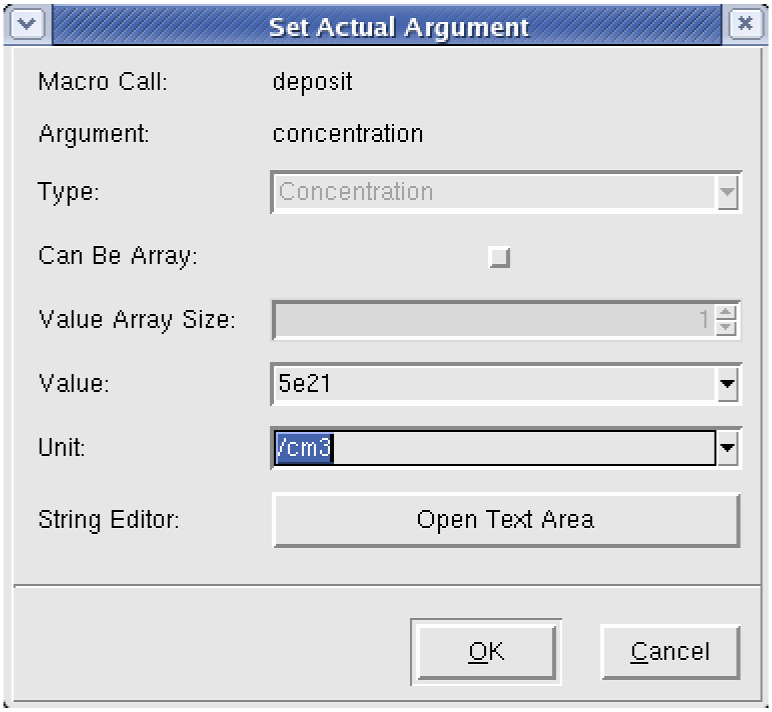

Figure 62:Setting the concentration.

```
machine clear
mgoals on
set sim_left 0
set sim_right 2
set sim_bottom 5
set sim_top 0
## ---------------------------------------##
## --------  LIGAMENT OUTPUT  --------##
## ---------------------------------------##
## ------ Ligament defined grid ------##
## ---------------------------------------##
line y loc=0 spa=0.4 tag=left
line y loc=2 spa=0.4 tag=right
line x loc=0 spa=0.25 tag=top
line x loc=5 tag=bottom
region Silicon xlo=top xhi=bottom ylo=left yhi=right
init concentration=1e16 field=Boron wafer.orient=100  slice.angle=[CutLine2D 0 0 2 0]

## -----------------------------------------
## ---- Added process flow header -----
## -----------------------------------------
deposit material = {Oxide} type = isotropic  Phosphorus conc=5e21 rate = {1.0} time=0.3
struct smesh=diode
```

Figure 63: Translated flow.

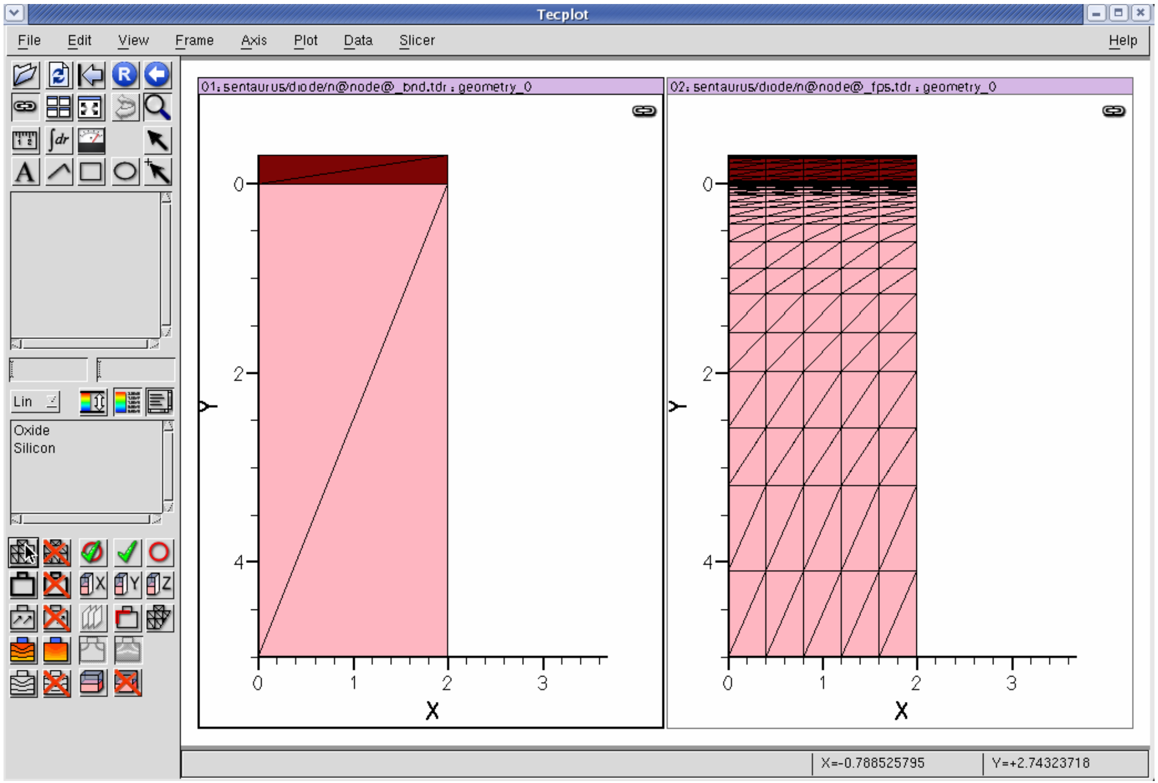

Figure 64: Results of sprocess.

11. To diffuse the Phosphorous into the p-type Si add an anneal step, by copying it from the process area to the Flow area. Change the time to 60 min (Figure 65). And the temperature to 900 degC (Figure 66).

12. Translate the flow (Figure 67), check the syntax and save as diode_fps.cmd.. Savehte GUI version as well. Run the process deck and view the results (Figure 68).

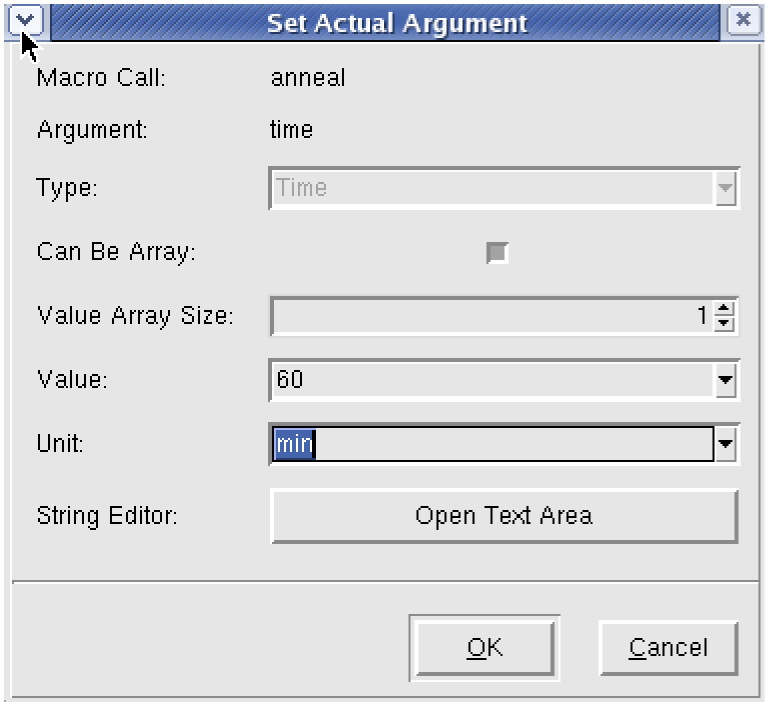

Figure 65: Add and anneal step (time =60 min.).

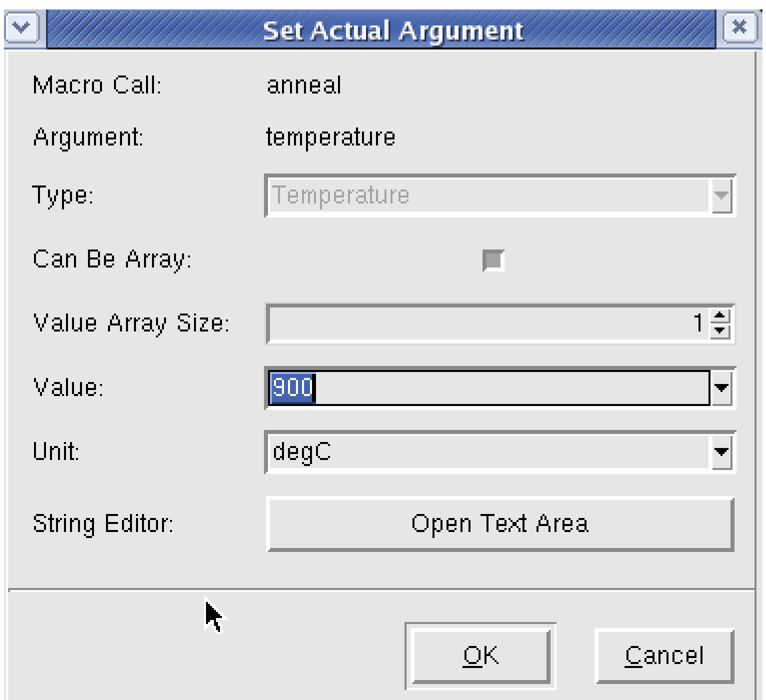

Figure 66: Setting the temperature.

Note: Due to a typo, and the fact that the original doc was lost, I had to make sure the last lines were properly coded (struct smesh=diode). As a result it looks pasted in.

```
machine clear
mgoals on
set sim_left 0
set sim_right 2
set sim_bottom 5
set sim_top 0
## ------------------------------------##
## --------  LIGAMENT OUTPUT  --------##
## ------------------------------------##
## ------ Ligament defined grid ------##
## ------------------------------------##
line y loc=0 spa=0.4 tag=left
line y loc=2 spa=0.4 tag=right
line x loc=0 spa=0.25 tag=top
line x loc=5 tag=bottom
region Silicon xlo=top xhi=bottom ylo=left yhi=right
init concentration=1e16 field=Boron wafer.orient=100  slice.angle=[CutLine2D 0 0 2 0]

## ------------------------------------
## ---- Added process flow header -----
## ------------------------------------
deposit material = {Oxide} type = isotropic  Phosphorus conc=5e21 rate = {1.0} time=0.3
temp_ramp name=tempramp_1_2 time=60 temp=900
diffuse temp_ramp=tempramp_1_2
struct smesh=diode
exit
```

Figure 67: Translated flow after anneal.

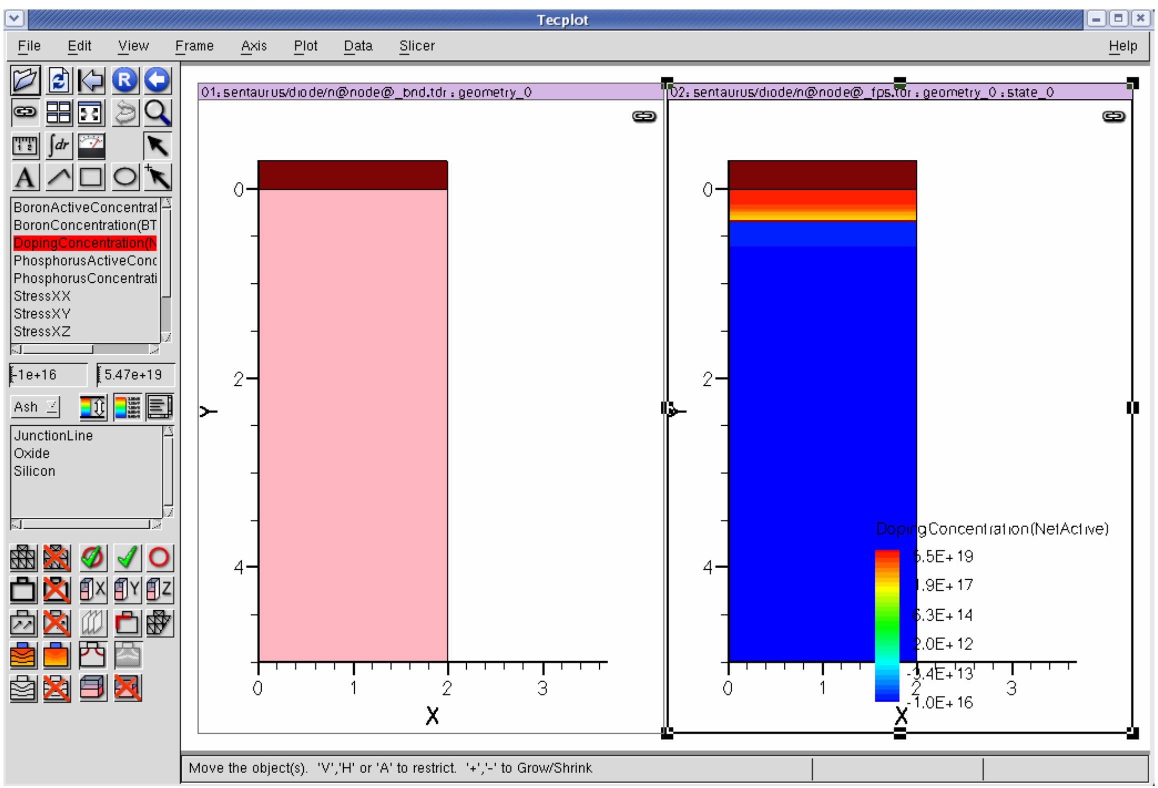

Figure 68: Annealed results.

13. Add a pattern step the the process area after the anneal step. Set the Layer to CC (Figure 69), the polarity to dark_field(Figure 70), and the thickness to 1 um(Figure 71).

14. Translate (Figure 72), check and save, run sprocess and view your results in tecplot (Figure 73).

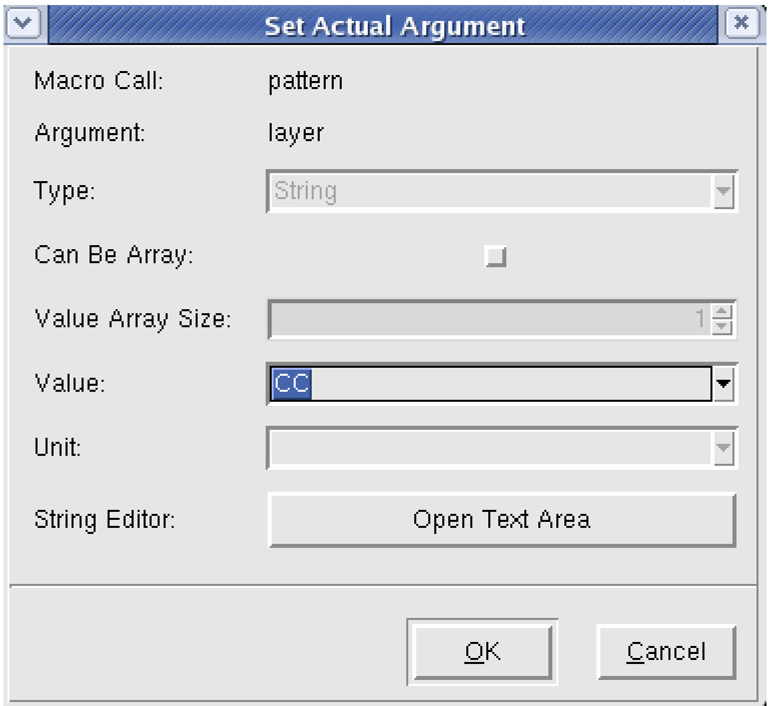

Figure 69: Setting the Layer argument of a pattern step.

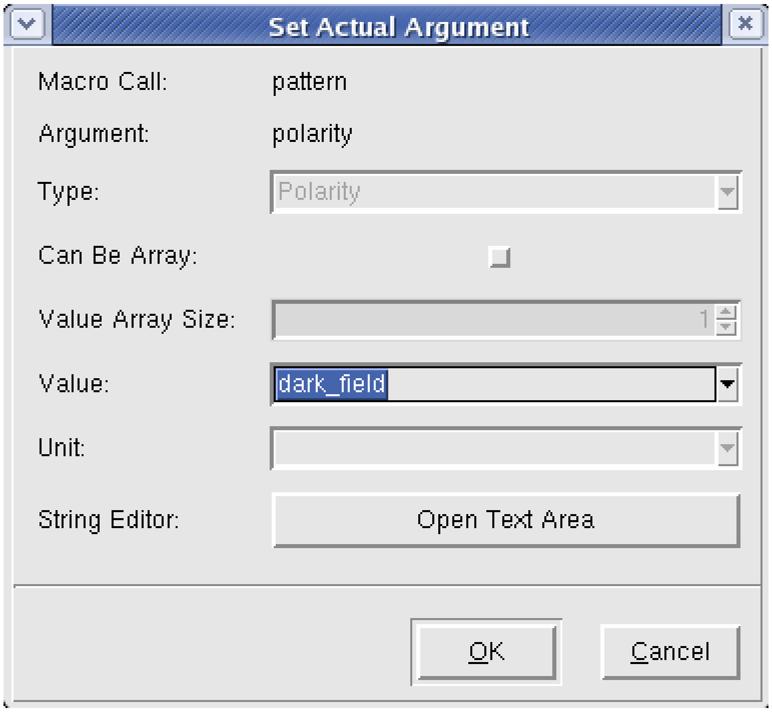

Figure 70: Setting the polarity of the mask step.

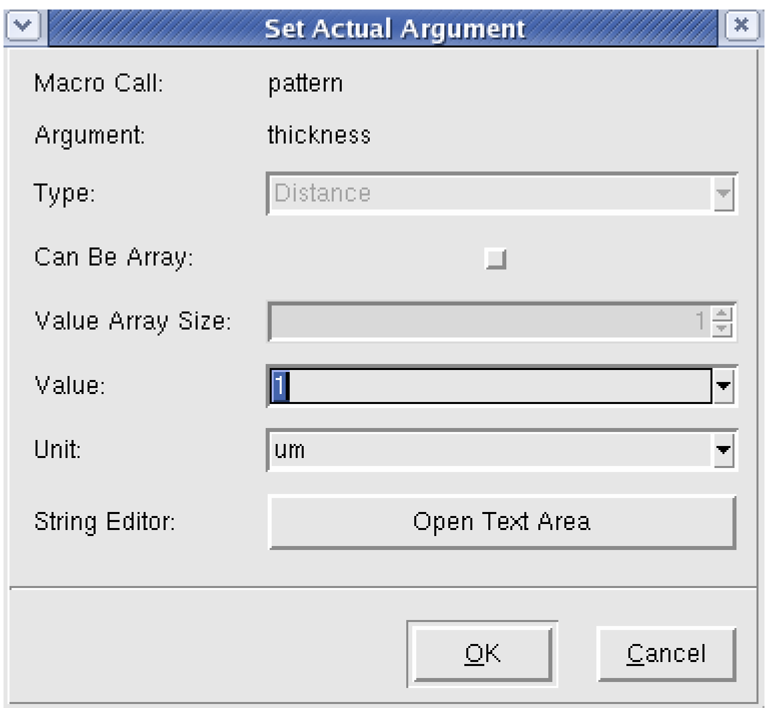

Figure 71: Setting the thickness of the PR.

```
machine clear
mgoals on
set sim_left 0
set sim_right 2
set sim_bottom 5
set sim_top 0
## -----------------------------------##
## --------  LIGAMENT OUTPUT  --------##
## -----------------------------------##
## ------ Ligament defined grid ------##
## -----------------------------------##
line y loc=0 spa=0.4 tag=left
line y loc=2 spa=0.4 tag=right
line x loc=0 spa=0.25 tag=top
line x loc=5 tag=bottom
region Silicon xlo=top xhi=bottom ylo=left yhi=right
init concentration=1e16 field=Boron wafer.orient=100  slice.angle=[CutLine2D 0 0 2 0]

## ------------------------------------
## ---- Added process flow header -----
## ------------------------------------
deposit material = {Oxide} type = isotropic Phosphorus conc=5e21 rate = {1.0} time=0.3
temp_ramp name=tempramp_1_2 time=60 temp=900
diffuse temp_ramp=tempramp_1_2
mask name=mask_1_2 segments = {1.0 2.1 } negative
photo mask=mask_1_2 thickness=1
struct smesh=diode
exit
```

Figure 72: Translated flow after pattern step.

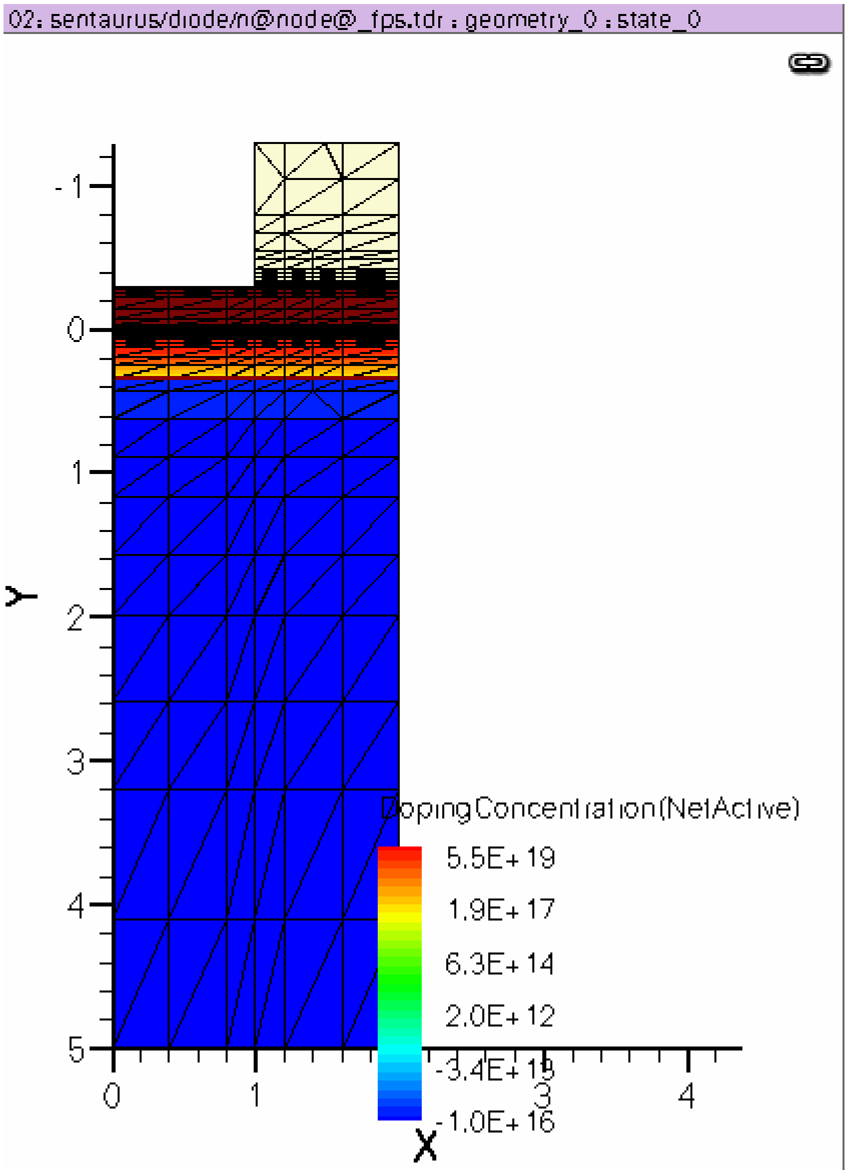

Figure 73: Sprocess results.

15. Add an etch step after the previous pattern step. Set the material to Oxide (Figure 74), Overetch to 10 (Figure 75), and the type to anisotropic (Figure 76).

16. Translate (Figure 77), check and save, run sprocess and view your results in tecplot (Figure 78).

17.

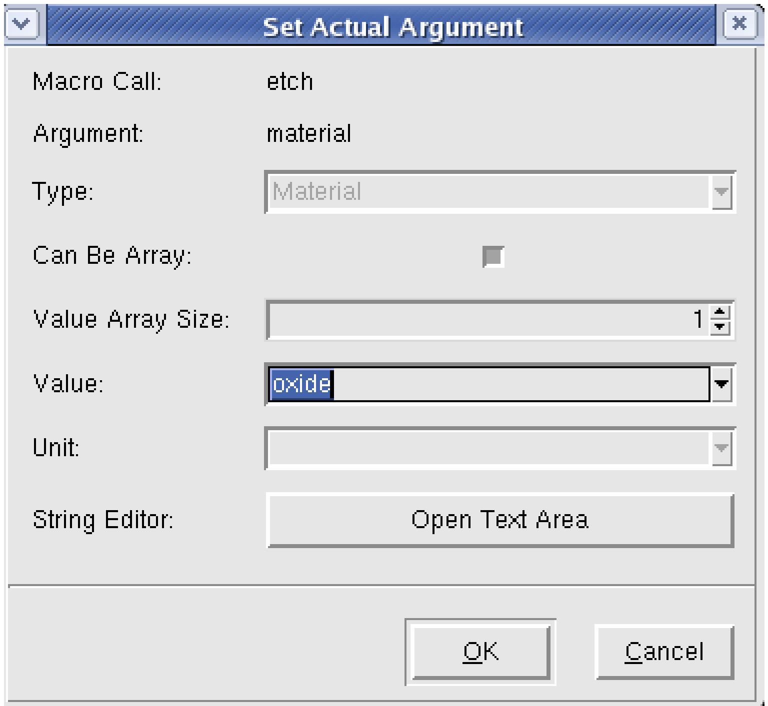

Figure 74: Setting the etch step for oxide.

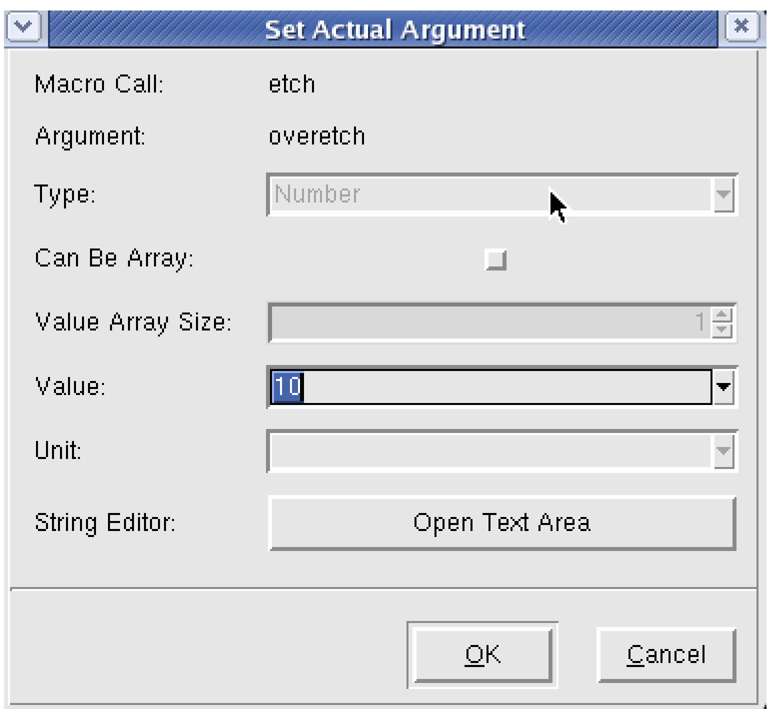

Figure 75: Setting the over etch.

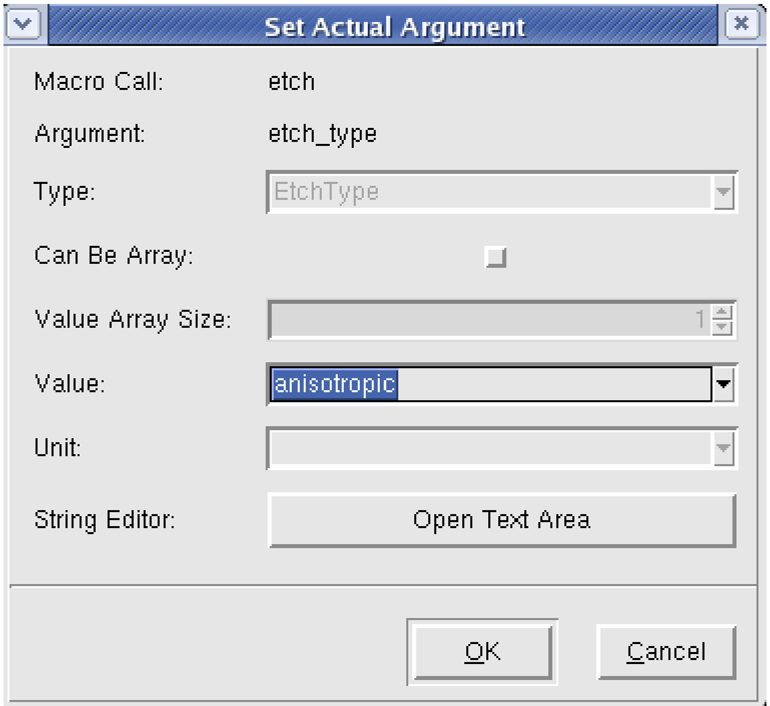

Figure 76: Setting the etch type.

```
photo mask=mask_1_2 thickness=1
etch material = {Oxide} type=anisotropic rate = {10.0} time=1.1
```

Figure 77: Translated flow after etch step.

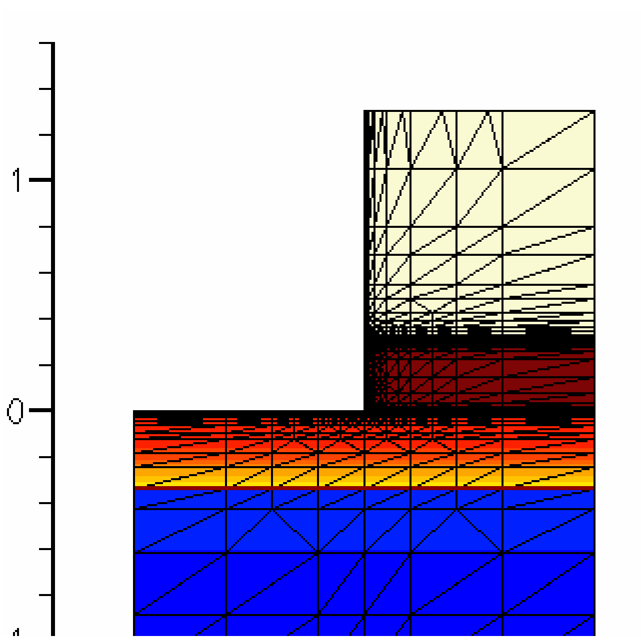

Figure 78: Sprocess results after oxide window etch step.

18. Etch of the photoresist by adding and Etch step to the etch step you just did. Set the material to photoresist (Figure 79), the type to strip (Figure 80). Translate the flow (Figure 81), check the syntaxt, and save. Save GUI flow too. Run in sprocess and view results (Figure 82).

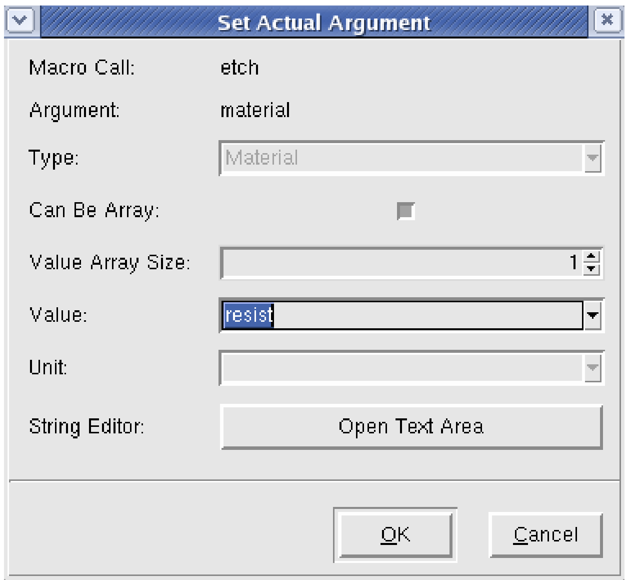

Figure 79: Setting etch step for resist.

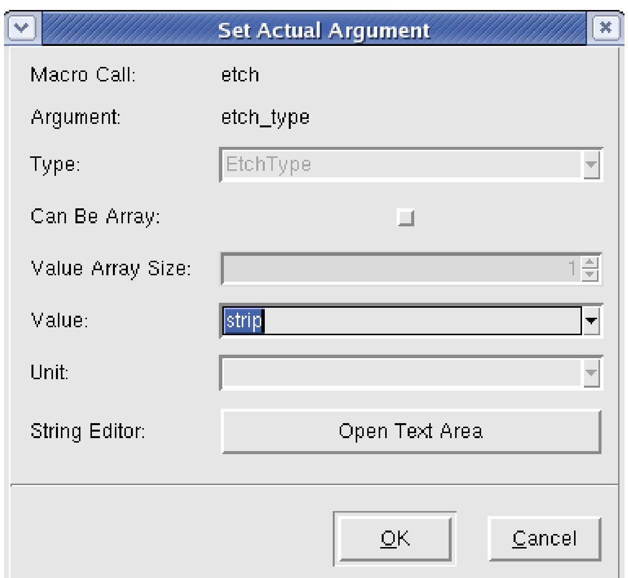

Figure 80: Stripping resist.

```
etch material = {Oxide} type=anisotropic rate = {10.0} time=1.1
strip Photoresist
```

Figure 81: Translated flow after PR strip.

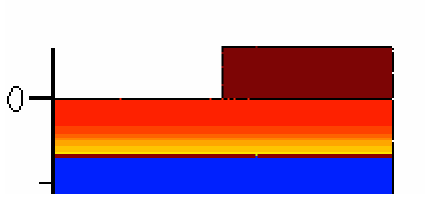

Figure 82: Results after PR strip.

19. Add an Aluminum Layer by adding a deposit step to the last etch step and setting the material to AL (Figure 83), and the thickness to 2500 Angstroms (Figure 84). Translate (Figure 85). Check and save the the flow and run in sprocess. View the results (Figure 86).

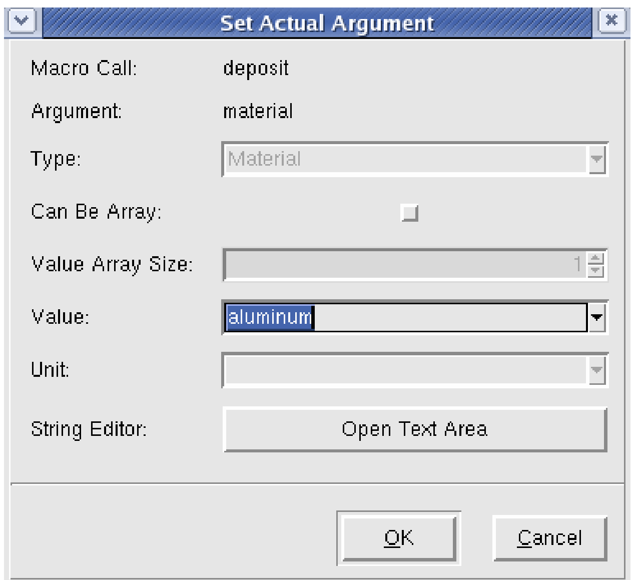

Figure 83: Deposit AL

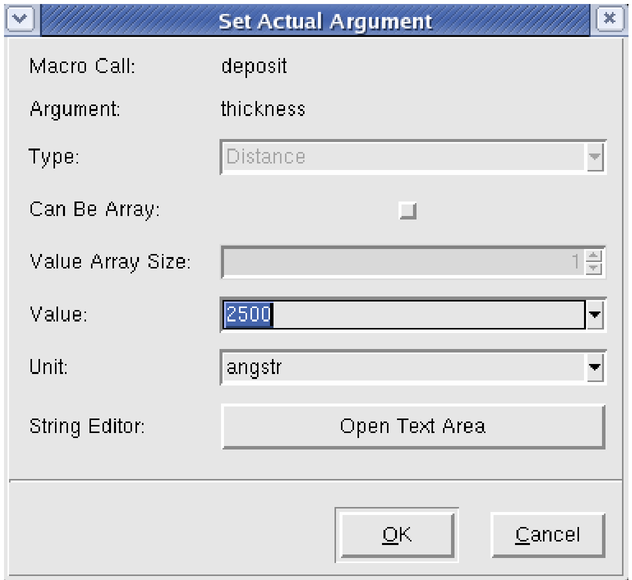

Figure 84: Setting AL thickness.

```
deposit material = {Aluminum} type = isotropic  rate = {1.0} time=0.25
```

Figure 85: Translated AL deposition FLow.

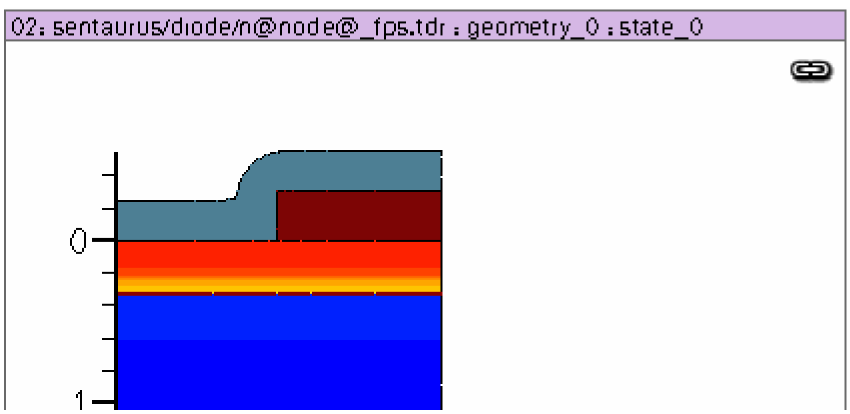

Figure 86: Results of AL deposition..

20. Pattern the the M1 layer by adding a pattern statement. Set the layer to M1 (Figure 87), the polarity to light_field (Figure 88), and the thickness to 1um (Figure 89).

21. Translate (Figure 90) Check and save the flow and run in sprocess. View the results (Figure 91).

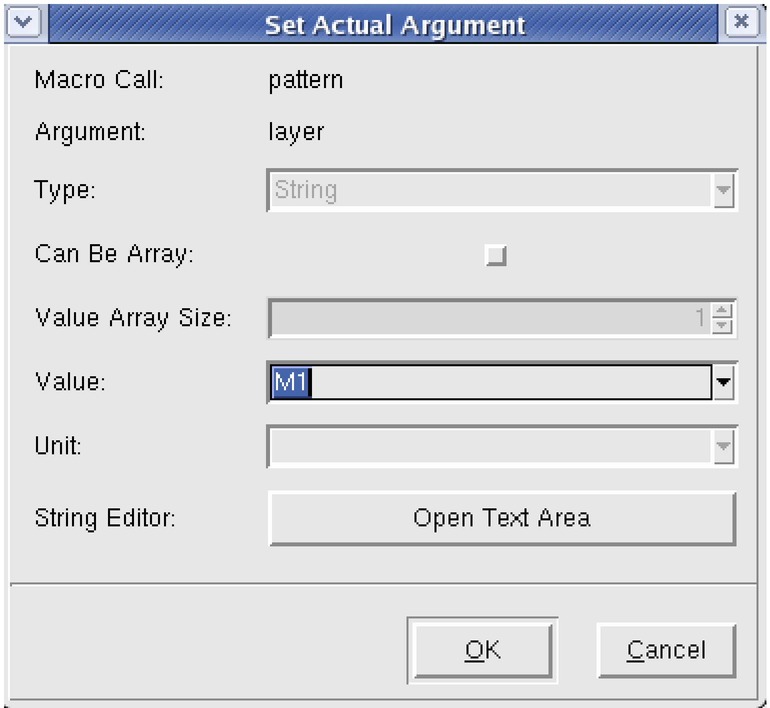

Figure 87: Pattern the M1 layer.

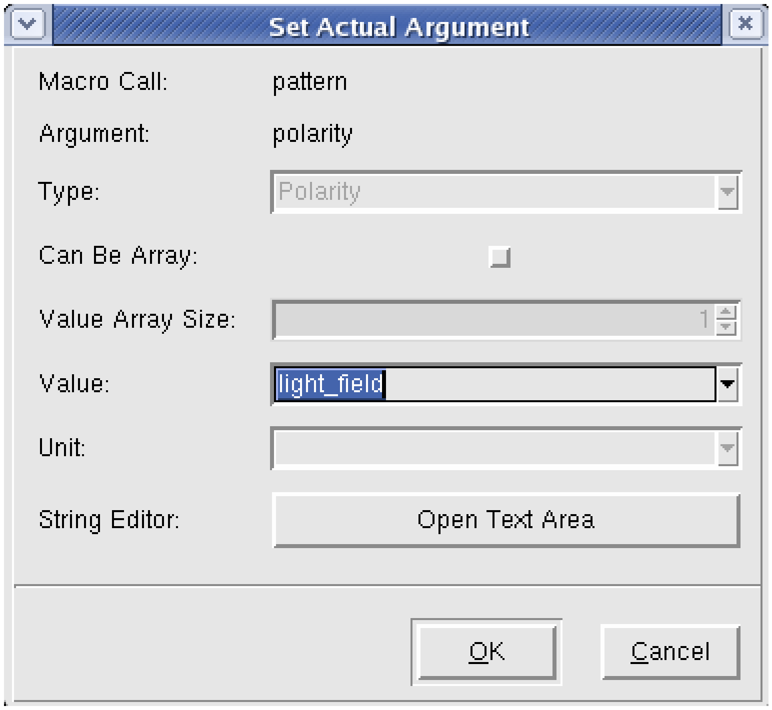

Figure 88: Setting Polarity.

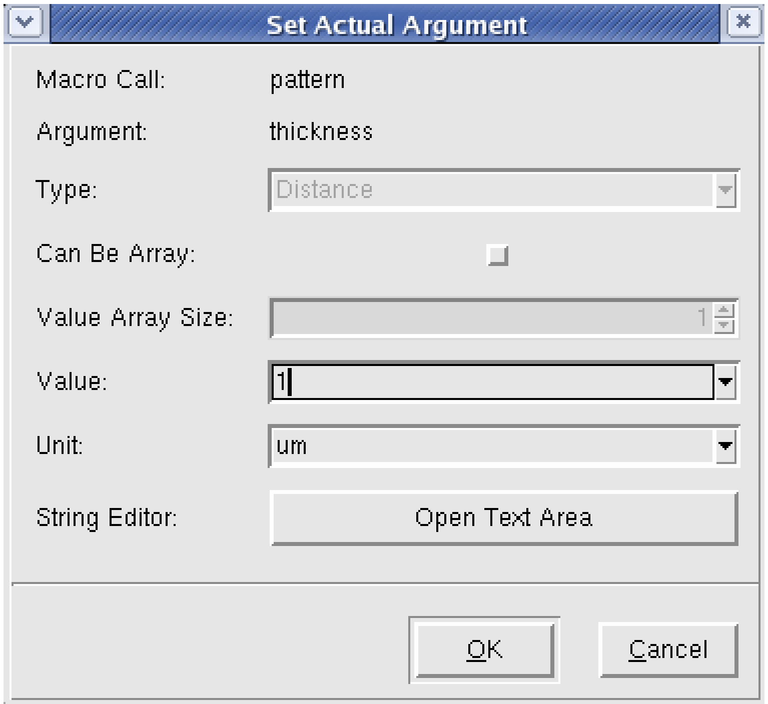

Figure 89: Setting thickness.

```
mask name=mask_1_3 segments = {-0.1 1.5 } negative
photo mask=mask_1_3 thickness=1
```

Figure 90 :Translated process flow.

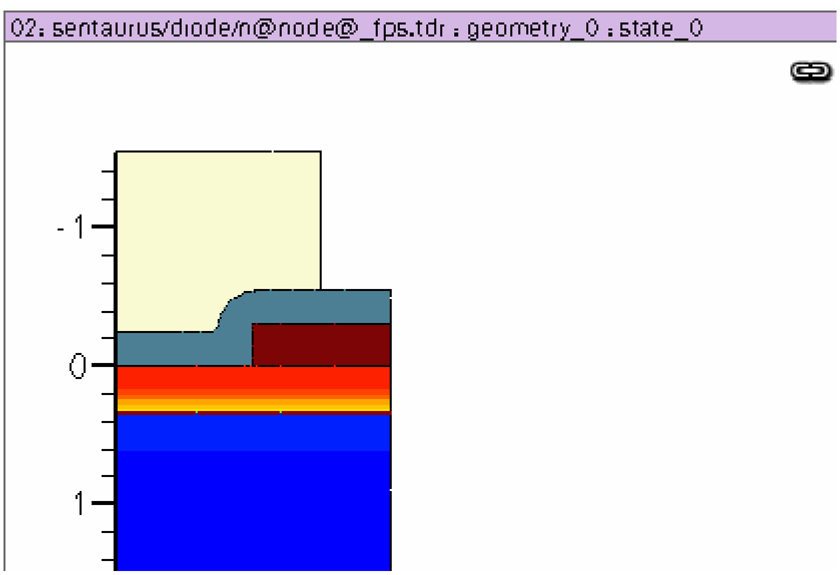

Figure 91: PRocess results for PR pattern.

22. Pattern the AL layer by adding an Etch statement. Set the material to AL (Figure 92), the type to anisotropic (Figure 93), and the overetch to 10 (Figure 94).

23.

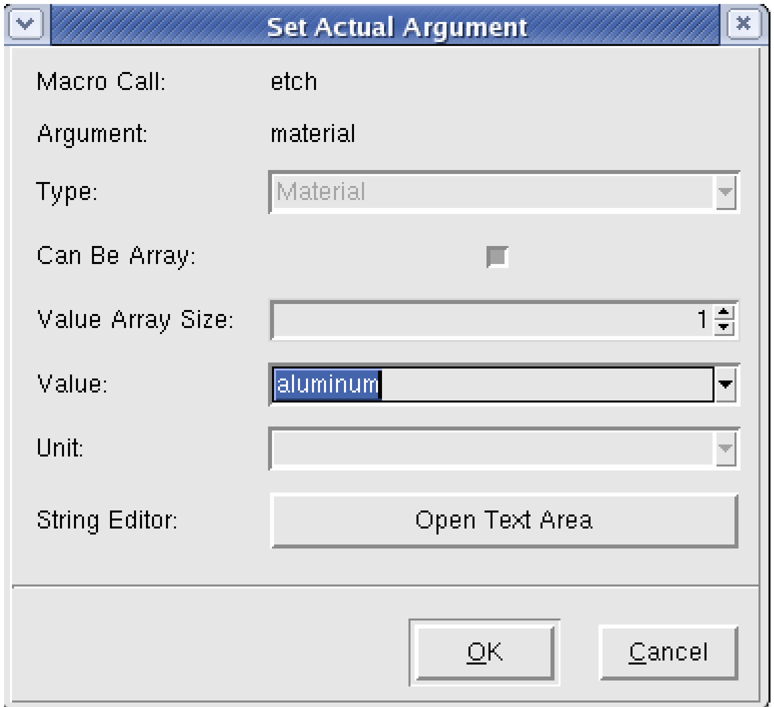

Figure 92: Setting the etch AL etch step.

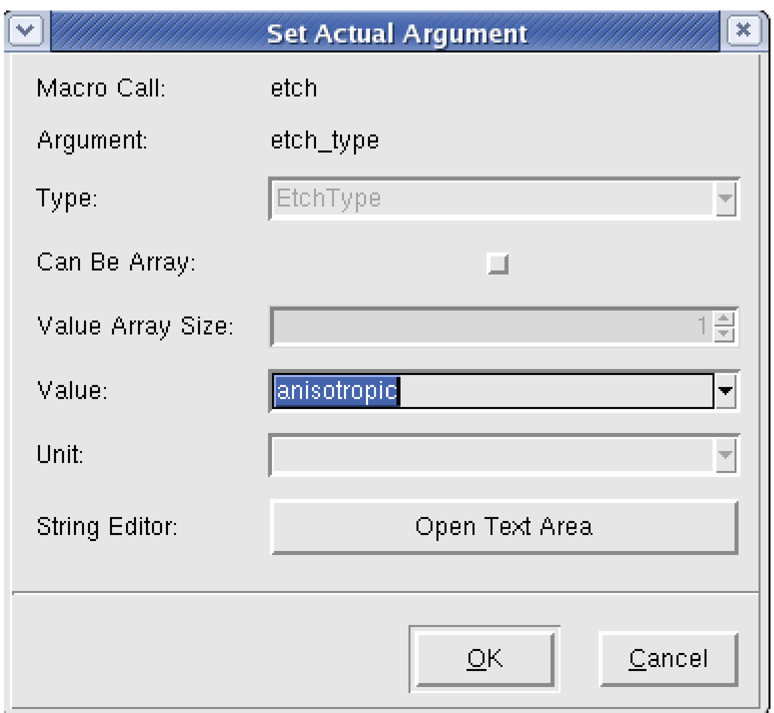

Figure 93: Setting type.

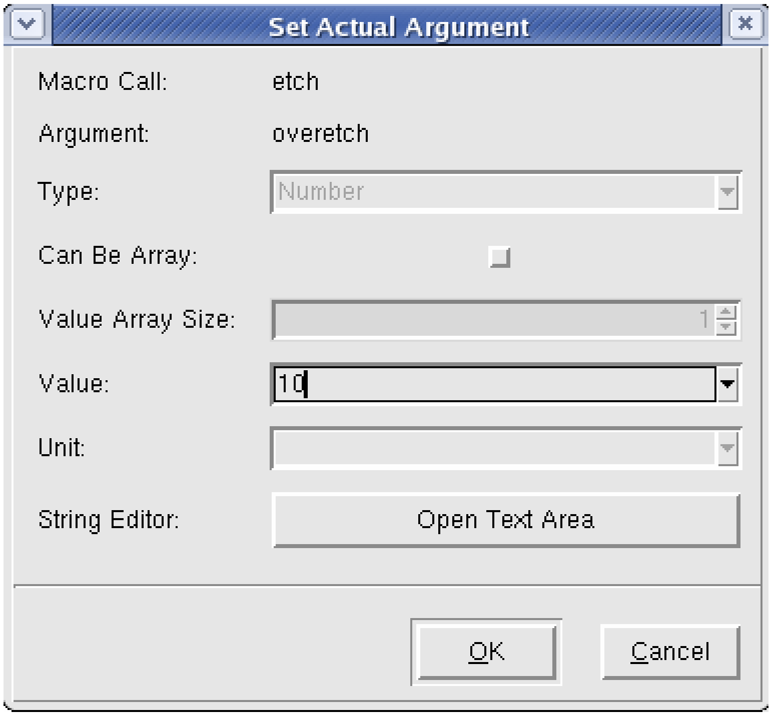

Figure 94: Setting over etch for Al.

```
etch material = {Aluminum} type=anisotropic rate = {10.0} time=1.1
```

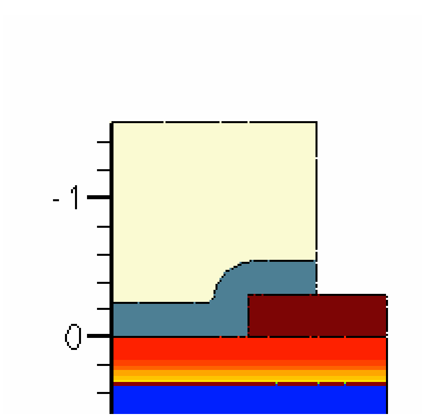

Figure 95: Sprocess Results for etch step.

24. Check t make sure your process window looks like Figure 96.

25. Add a photoresist strip step. Your results should look like Figure 97.

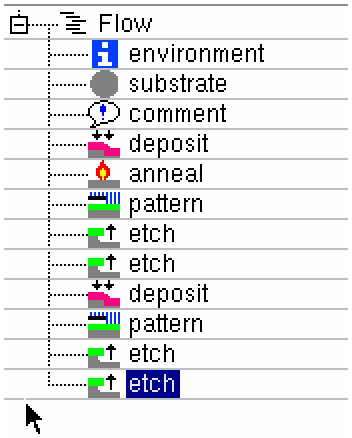

Figure 96: Process Window.

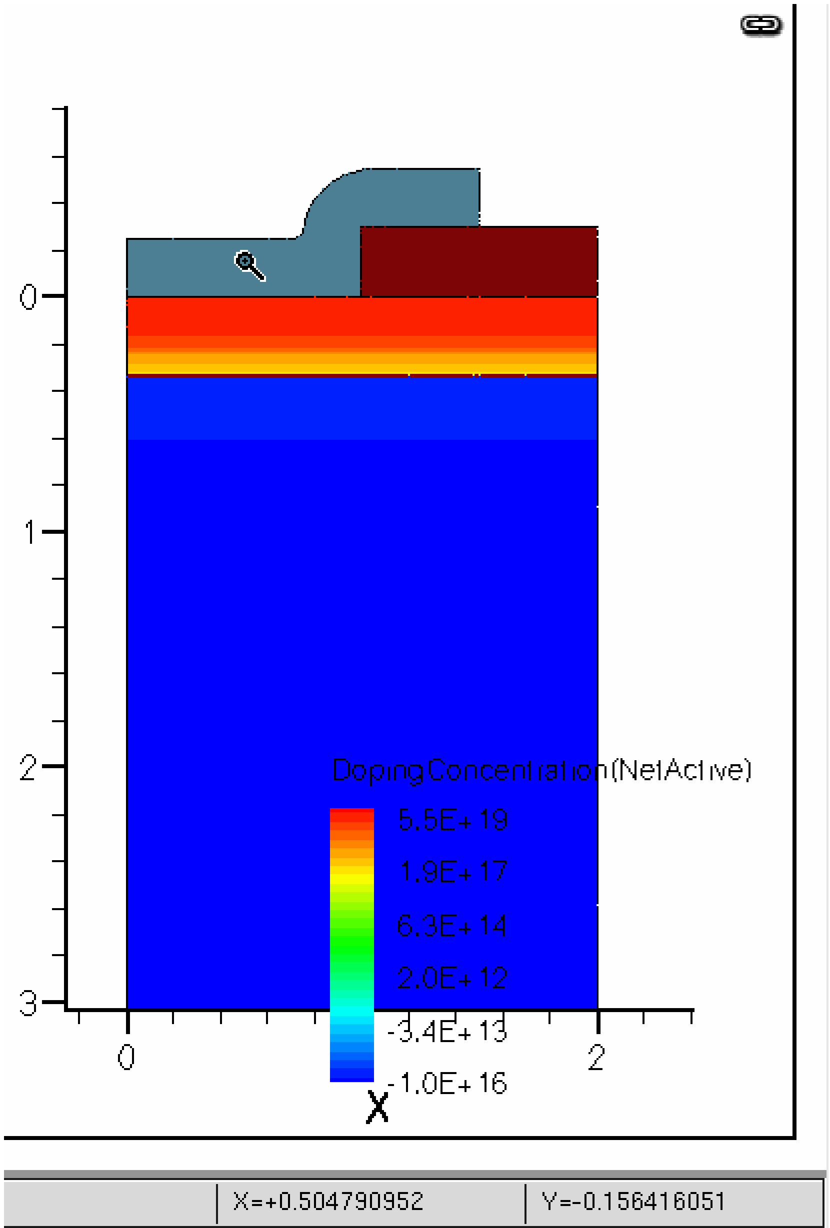

Figure 97: Complete device.

26. To make electrical contacts, add and insert macro call (Figure 98), double click on sprocess and open up the text area and fill in exactly as shown (Figure 99).

contact name=n_side point x=-.15 y=.5

contact name=p_side box silicon xlo=5 ylo=0 xhi=4.5 yhi=2

27. Translate (Figure 100) and run and view results (Figure 101). Notice how the AL layer has been replaced with a contact layer.

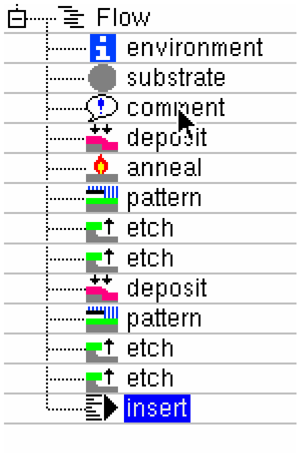

Figure 98: adding an insert macro call.

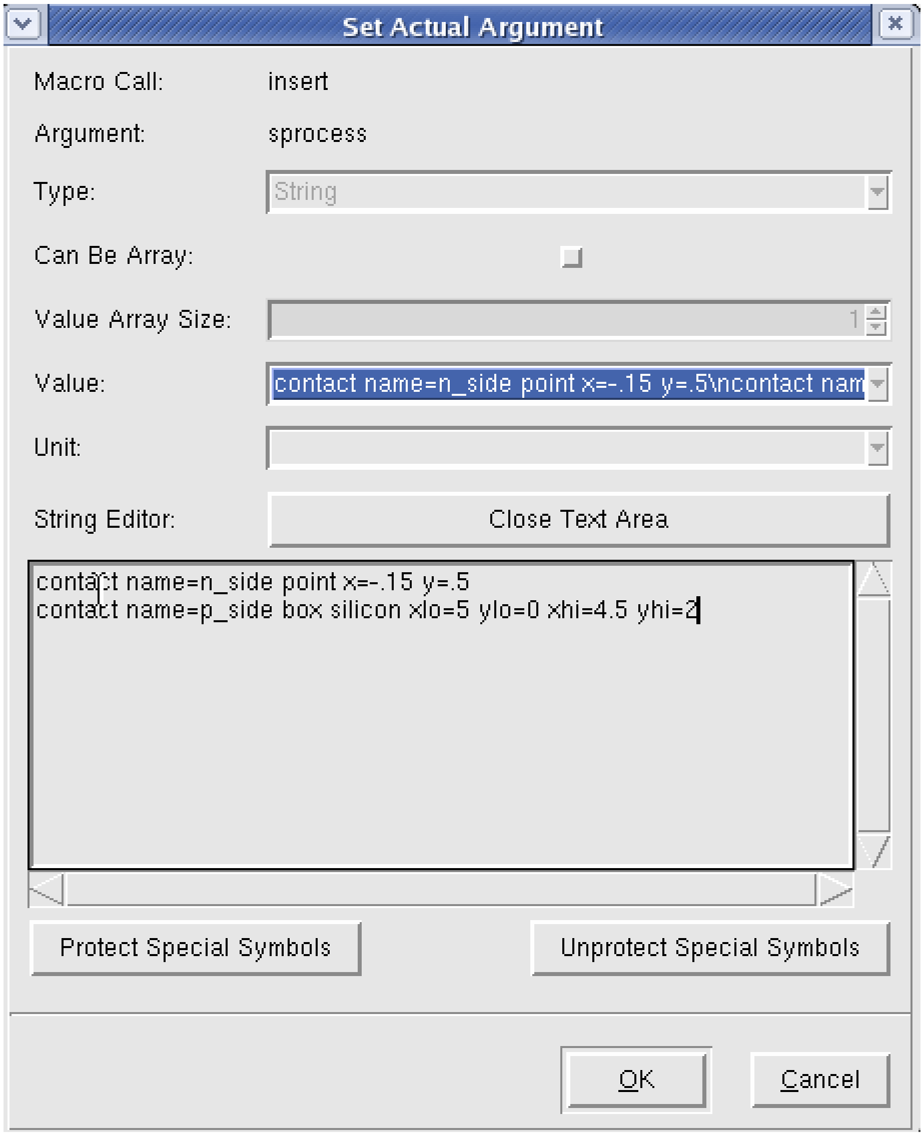

Figure 99: Setting the insert marco call for contacts.

```
contact name=n_side point x=-.15 y=.5
contact name=p_side box silicon xlo=5 ylo=0 xhi=4.5 yhi=2
```

Figure 100: Translated process flow.

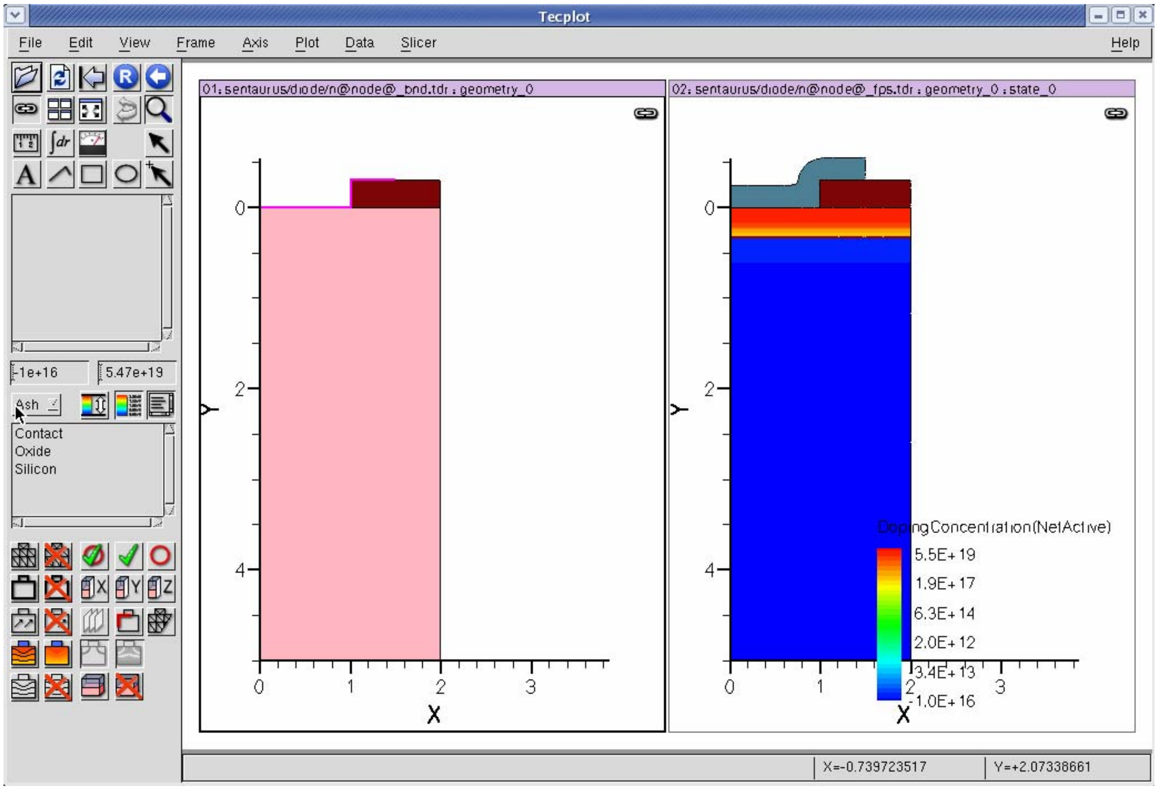

Figure 101: Results for contact step.

Using SDE to Build a mesh suitable for electrical simulation.

1. First you need to down load a tar file, untar it in your sentaurus directory. (See link below fig. 102.)

2. Copy the diode_dvs.cmd file into your diode directory. This file shas been edited to remesh your diode for electrical simulation. There are many things in this file that are just left over from the SWB example. At the very end the diode is reflected to get the full 4 microns. To view the file type **gedit diode_dvs.cmd** (Figure 102). Your results should look like (Figure 103).

3. To mesh your structure type sde –e –l diode_dvs.cmd (Figure 104). Your deck should run properly (Figure 104Figure 105).View the results in tecplot by looking at diode_msh.tdr (Figure 106). Notice how the mesh has been simplified (Figure 107)?

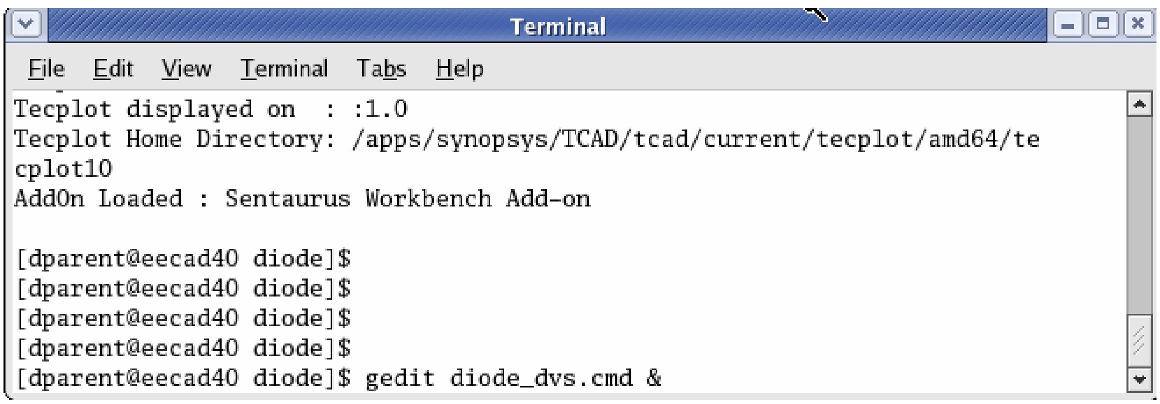

Figure 102: Viewing the file for Sentaurus structure editor.

The tar file is located at www.engr.sjsu.edu/dparent/ee221/diode_master.tar

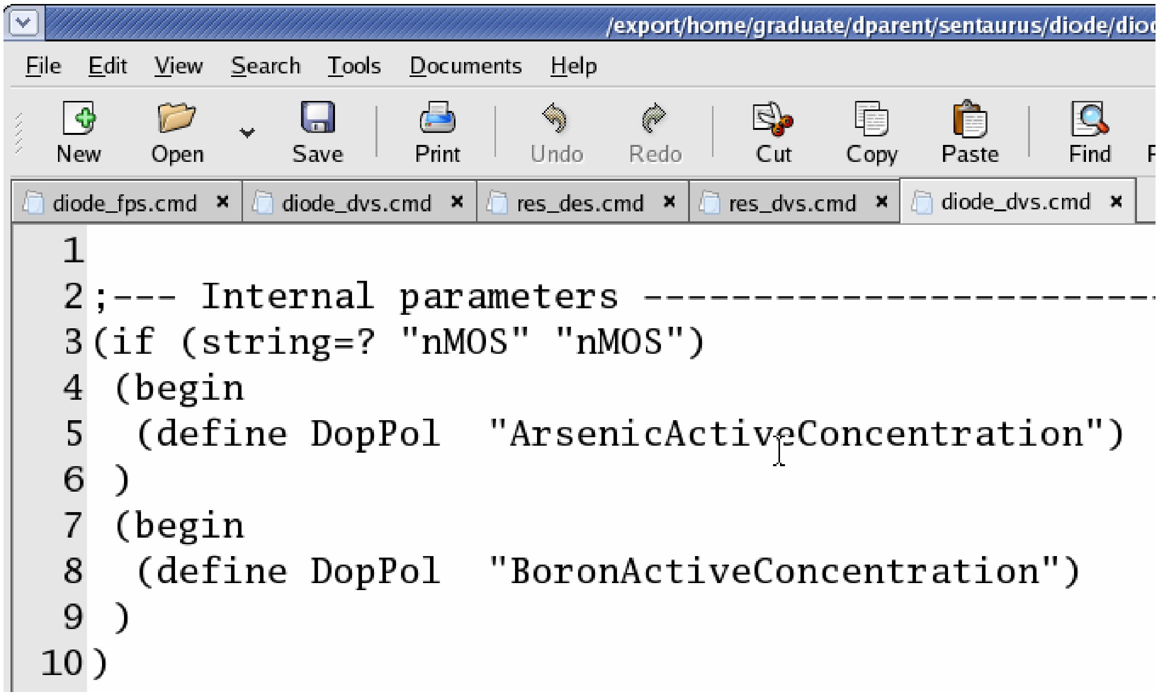

Figure 103: Sample Code from the didoe_dvs.cmd file.

Figure 104: Runiing SDE in bathc mode.

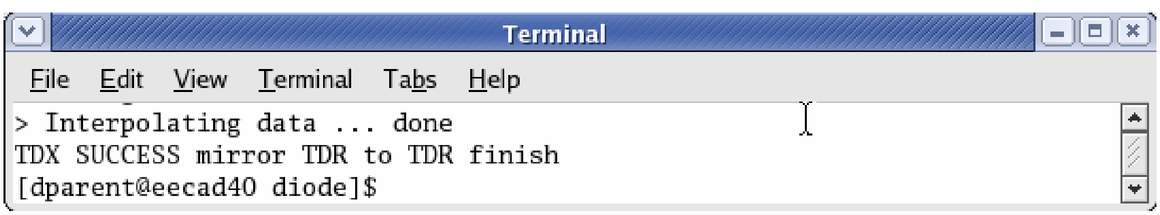

Figure 105: SDE exists properly.

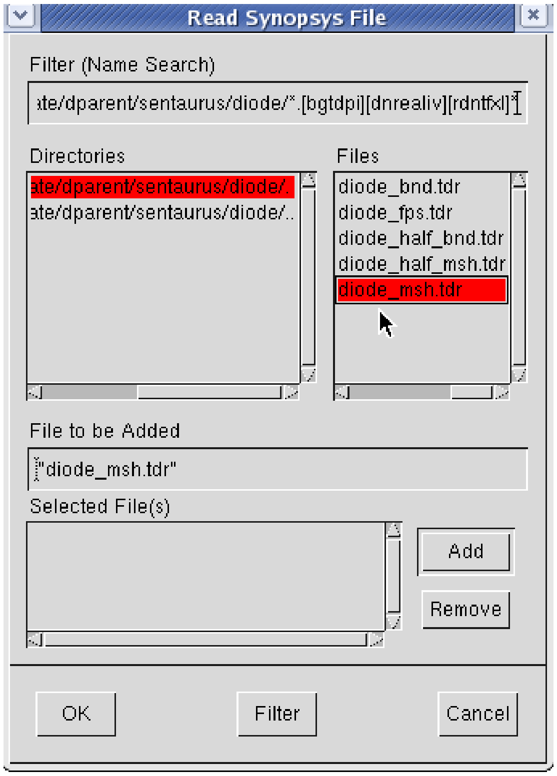

Figure 106: Plotting results.

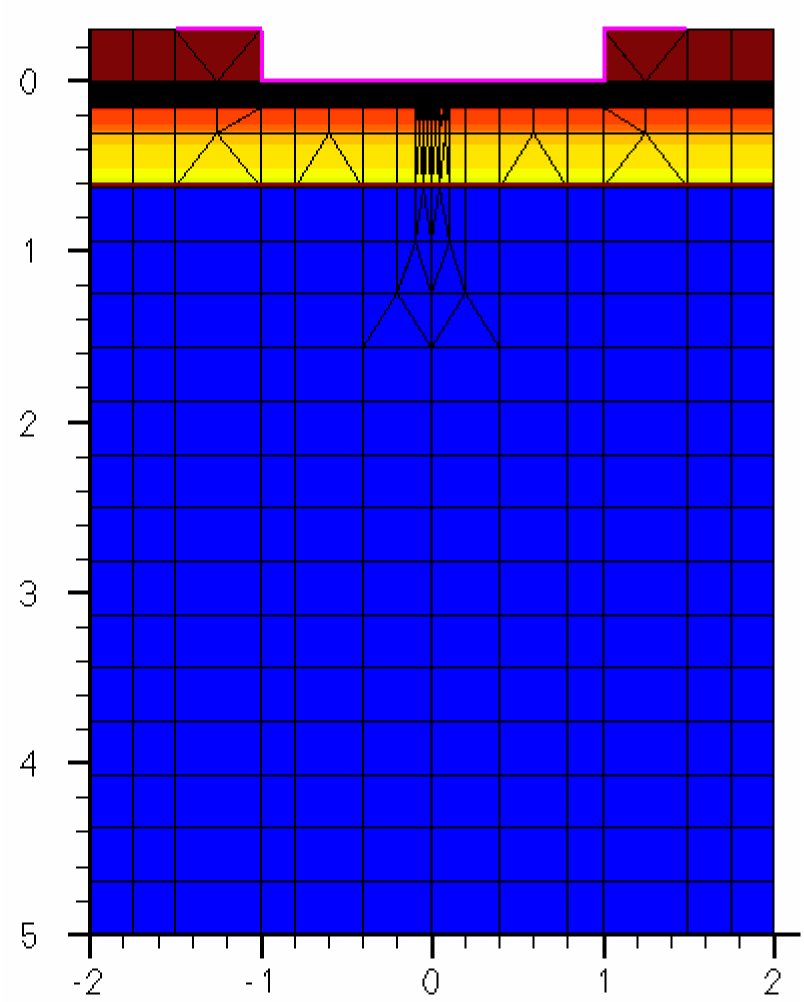

Figure 107: TecplotResults of SDE.

Running setaurus device to obtain electrical results:

1. Copy the file diode_des.cmd from the directory you downloaded. View it with gedit (Figure 108).

2. Run the deck by typing **sdevice diode_des.cmd** at the command line. It should exit properly (Figure 109).

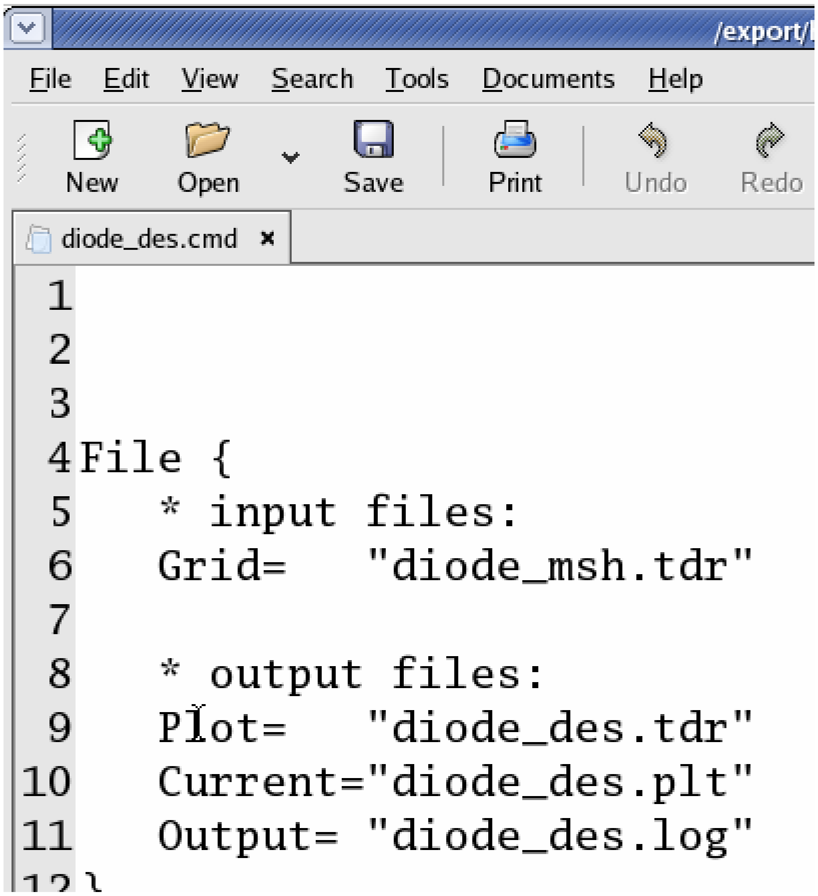

Figure 108: The Sdevcie run deck.

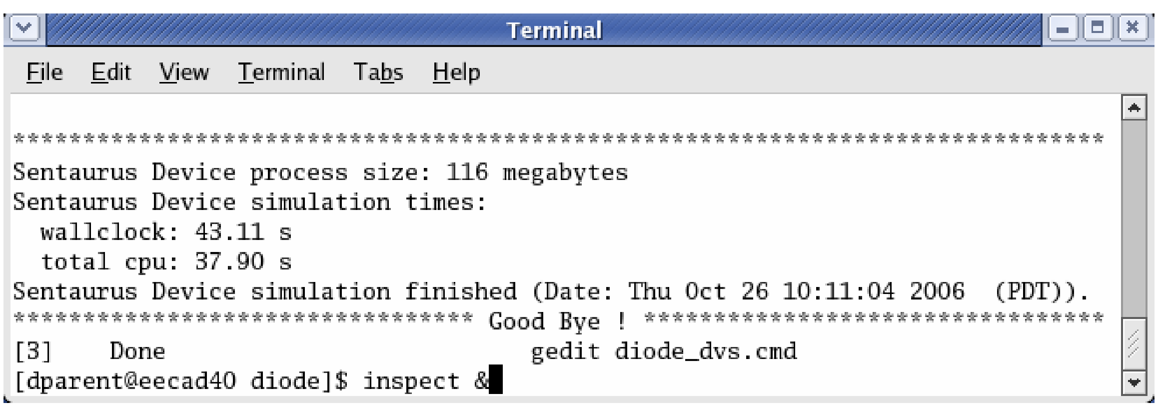

Figure 109: Sdevcie exiting properly and starting inspect.

.

Using inspect to view your electrical results:

1. Start inspect by typing inspect & at t command line (Figure 109).
2. Go to File.. Load and select diode_des.plt.
3. Click on p_side, OuterVoltageo x axis (Figure 110).
4. Click on n_side TotalCurrewnt and assign to left y-axis (Figure 111). You should see a forward biased diode's characteristics (Figure 112). Try plotting the y axis in log scale (Figure 113).

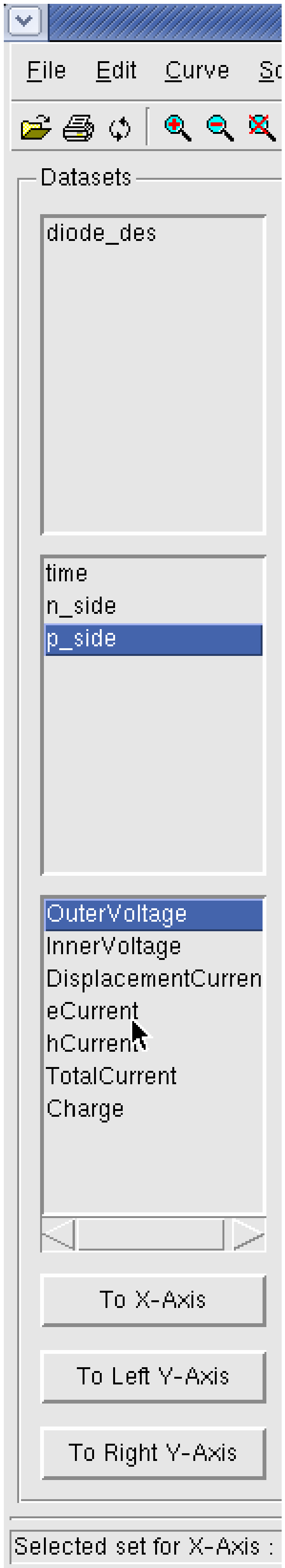

Figure 110: Assigning X-axis.

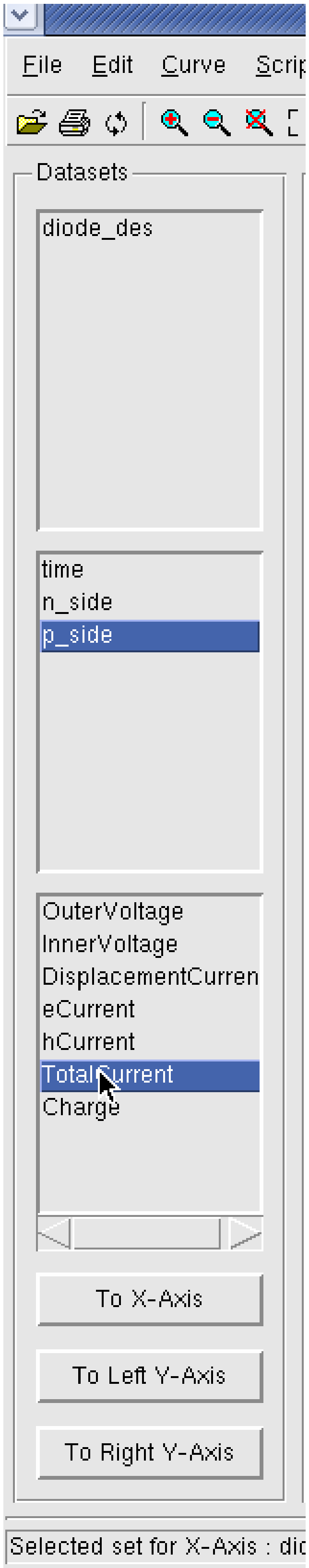

Figure 111: Assigning y-axis.

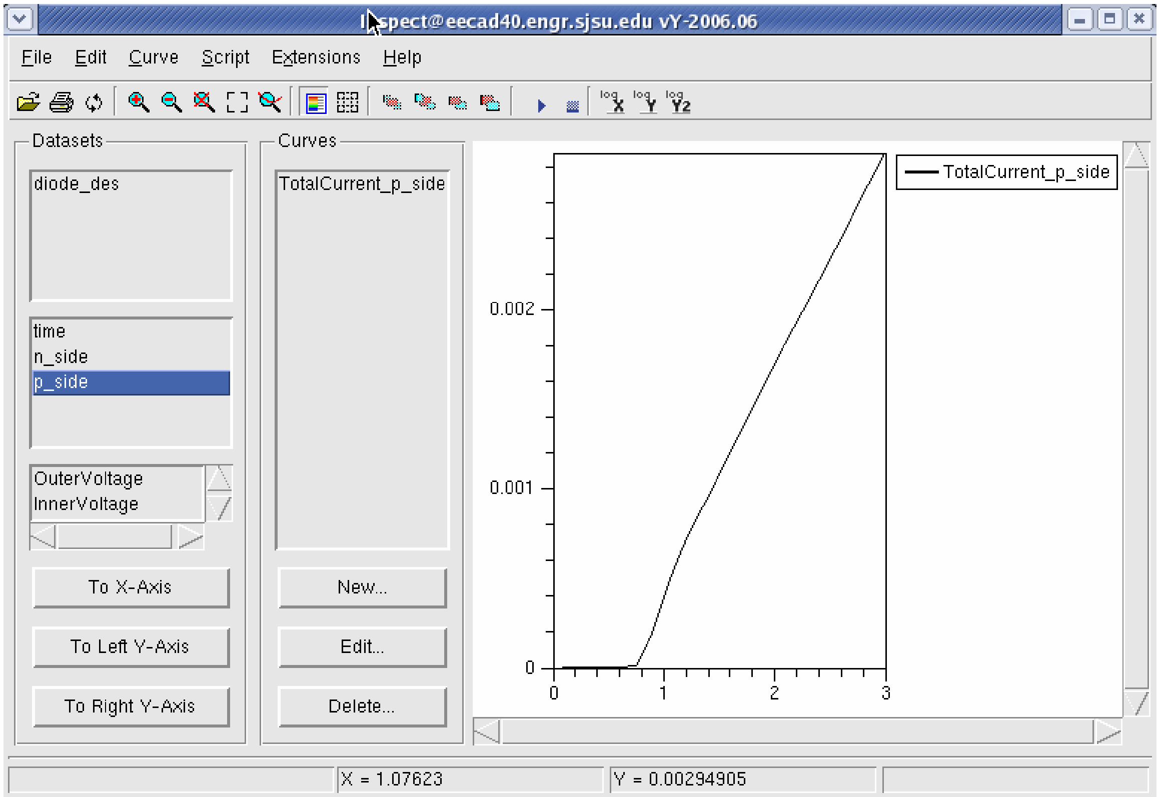

Figure 112: Electrical results of a forward biased diode.

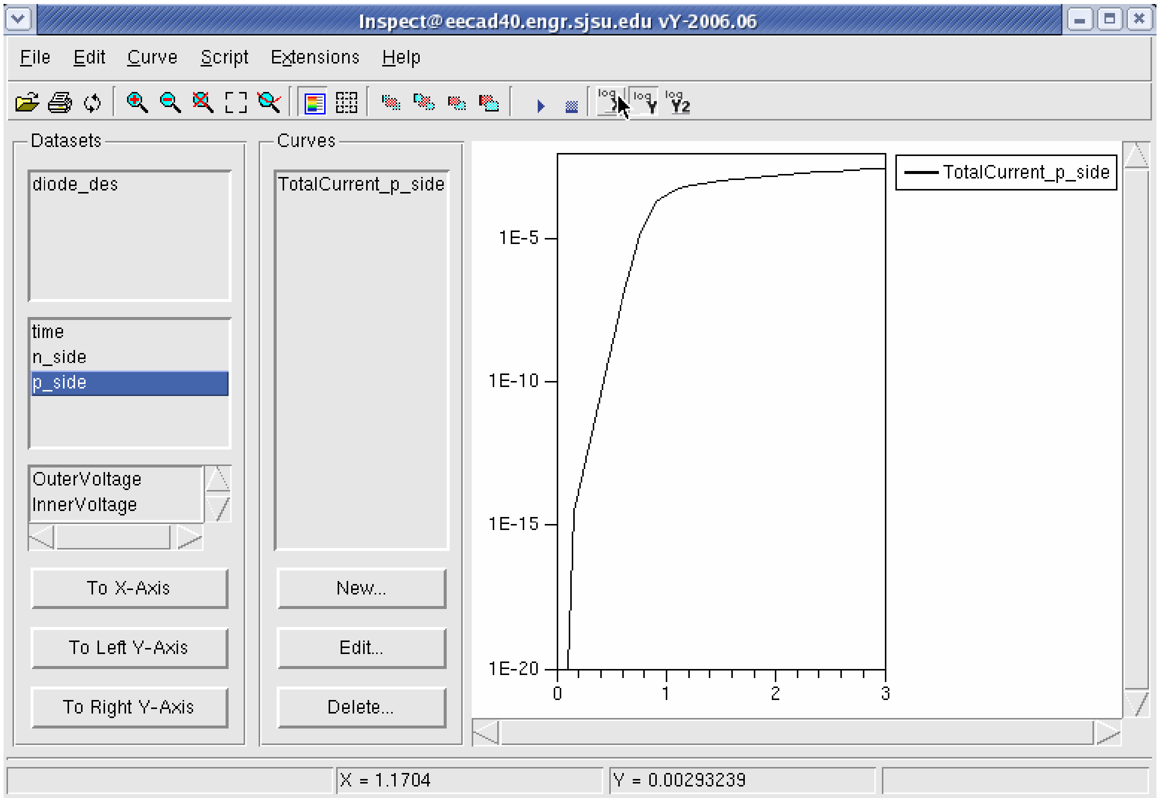

Figure 113: Forward bias diode Log scale.