EE 735 Assignment 5

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Q1) In this problem, to solve the given questions we had to modify the given code first for a N-doped Silicon bar of length 0.1um and thickness 0.1um.The N-type bar is doped with a doping density of 10^{16} cm^{-3}.Once the device mesh is generated by the SDE tool, we have to find the I-V characteristics of the bar by sweeping the voltage across the N-type bar from 0V to 3V for three different mobility models as given below-

a) Constant Mobility

b) Doping Dependence

c) High-field Saturation

First we define parameters of length “Ln” of N-type bar with a thickness “h”.

```
{
(define Ln 1e-1)
(define h 1e-1)
}
```

The N-type doping “Nd” is given as an user input parameter.

```
{
(define Nd @Nd@)
}
```

Next we define a rectangular region of same dimensions for N-type bar.

```
{
(sdegeo:create-rectangle (position 0 0 0) (position Ln h 0) "Silicon" "n_region")
}
```

The doping is uniform throughout the bar. This is ensured using the following.

{

(sedr:define-constant-profile "n_doping" "PhosphorusActiveConcentration" Nd)

(sedr:define-constant-profile-region "n_doping_profile" "n_doping" "n_region")

}

Contacts for applying voltages are defined using different colors and different names for both side of the bar i.e left and right are named “n_contactr” and “n_contactl”.

{

(sdegeo:define-contact-set "n_contactr" 4.0 (color:rgb 1.0 0.0 0.0) "##")

(sdegeo:define-contact-set "n_contactl" 4.0 (color:rgb 0.0 1.0 0.0) "||")

(sdegeo:define-2d-contact (find-edge-id (position 0 (/ h 2) 0)) "n_contactl")

(sdegeo:define-2d-contact (find-edge-id (position Ln (/ h 2) 0)) "n_contactr")

}

To find I-V charectaristics, we only use a global coarse mesh for this silicon bar. No fine meshing is required since there is no junction present in this case.The meshing step size is Ln/100 in the length and h/20 in the thickness of the bar.

{

(sedr:define-refeval-window "RefWin.Global" "Rectangle" (position 0 h 0) (position Ln 0 0))

(sedr:define-refinement-size "RefDef.Global" (/ Ln 100) (/ h 20) (/ Ln 100) (/ h 20) 1 1)

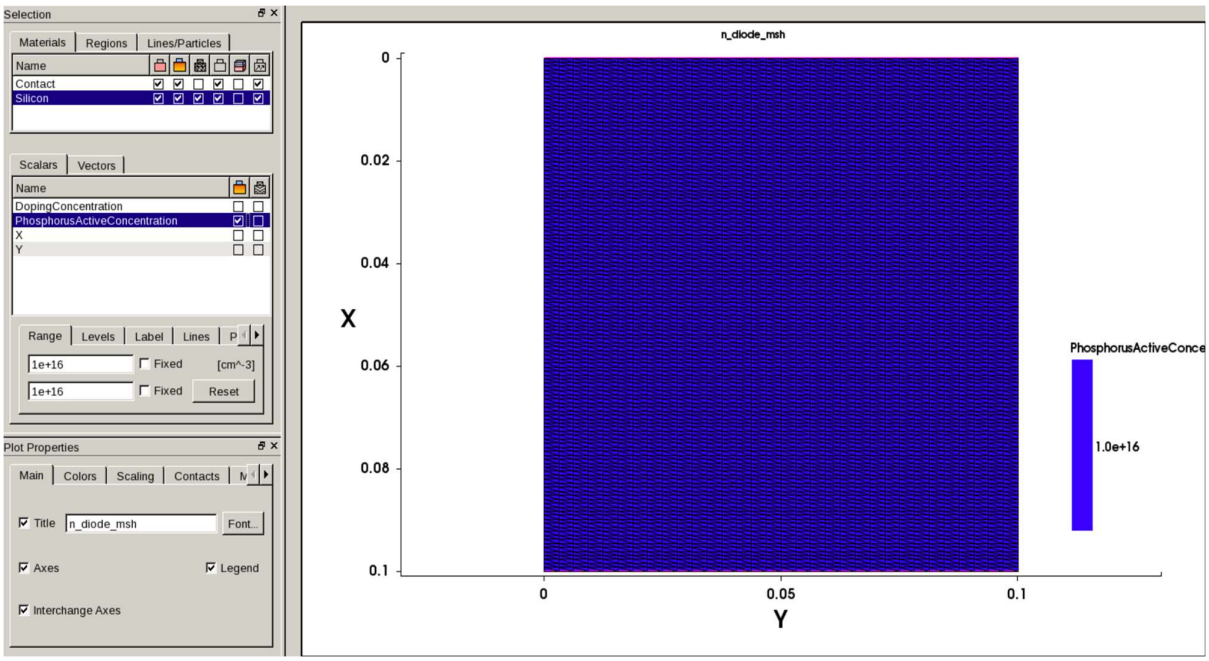
(sedr:define-refinement-placement "Place.Global" "RefDef.Global" "RefWin.Global")

}

Once the meshing dimensions and step sizes are defined, we can generate the mesh and simulate the I-V charectaristics using the SDEVICE tool.

```
{
(sde:build-mesh "snmesh" "" "n_diode")
}
```

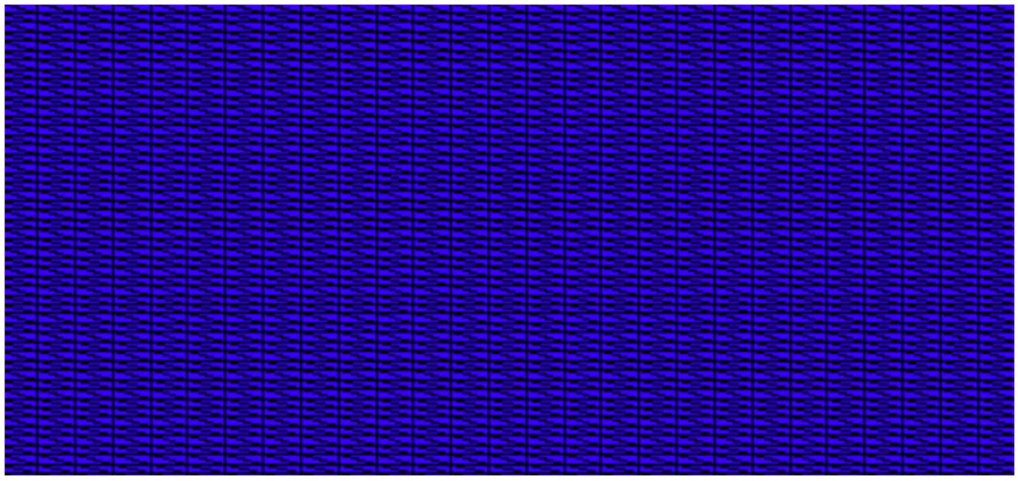
We can now open SVisual and open the file named “n_diode_mesh.tdr” and then check the mesh ON button to see the TCAD simulated device Structure showing Mesh points. The mesh looks like the picture below.



Zooming in we can see the exact structure of the mesh which appears to be small triangles stitched together.

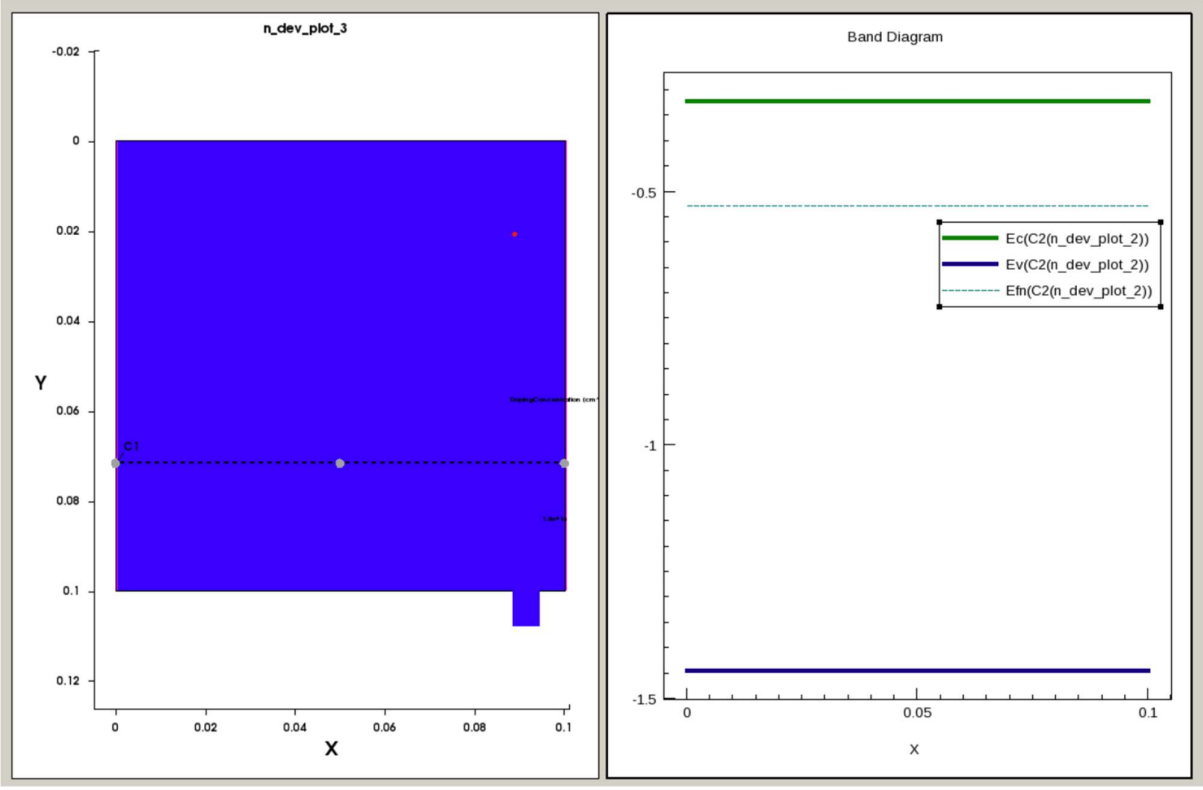
Observation:

The mesh structure turns out to be the same for all the three mobility models.

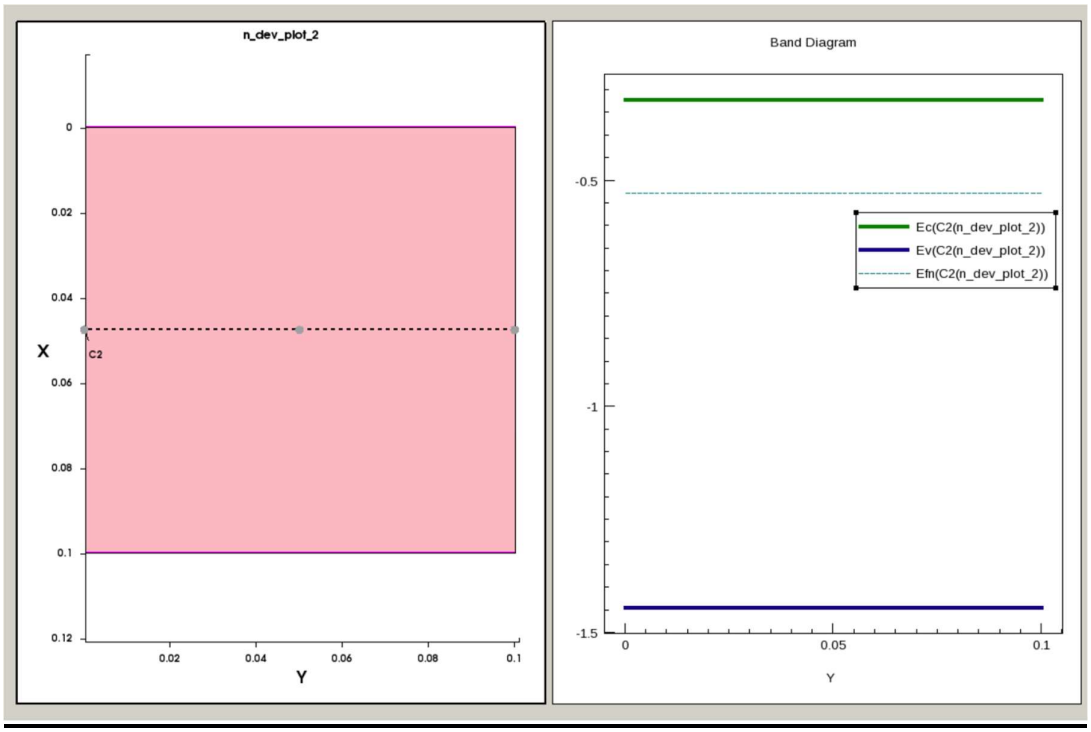


The band diagram at equilibrium can be found by opening the “n_dev_plot.tdr” file in SVisual and taking a X-cut on the N-type Si bar and then using the plot Band Diagram button on the right hand side of the toolbar. It is important to note that the Y-cut will not produce the band diagram at equilibrium since we are applying a voltage in that direction.

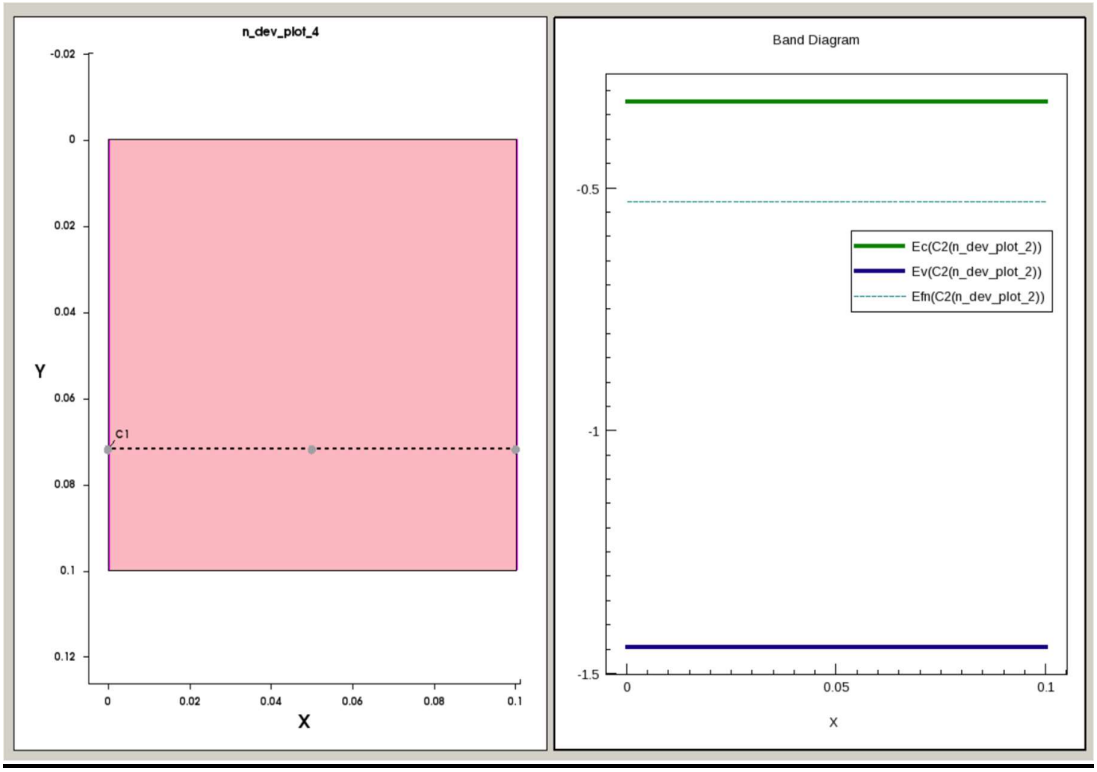
Constant Mobility Doping Model



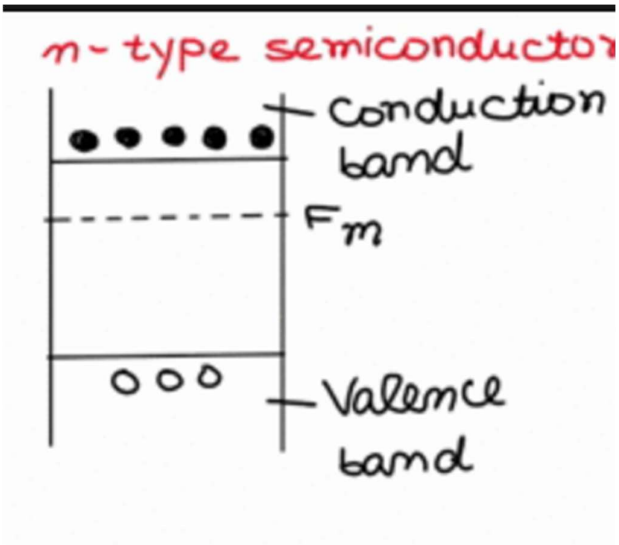
Doping Dependence Doping Model



High-field SaturationDoping Model

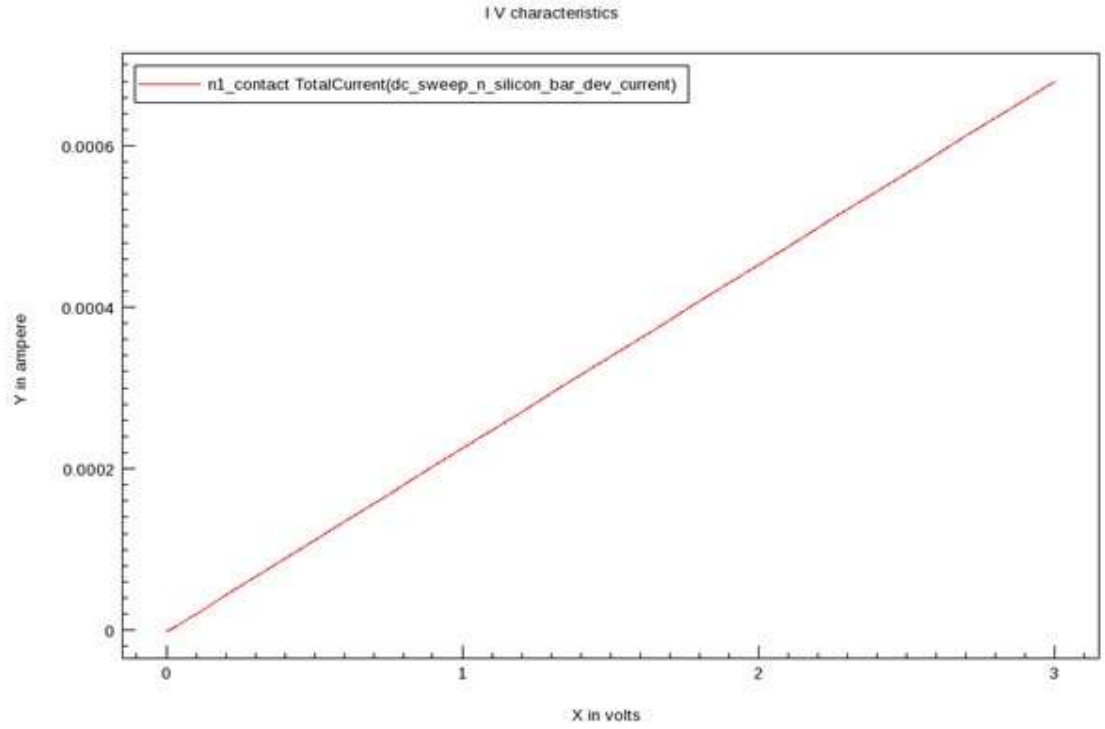


The Energy band diagram looks just like we expected for a N-type bar. The manual diagram is given below.

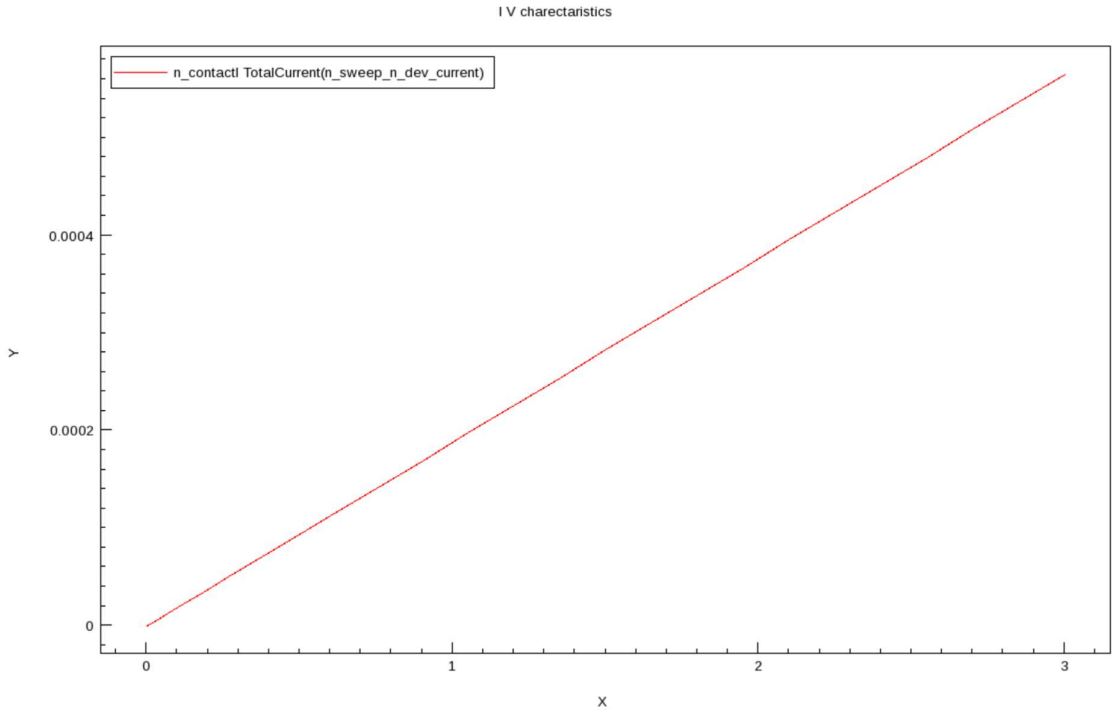


The I-V Charectaristics can be plotted only running the simulation using SDEVICE tool which takes the .tdr file from before as input and defines proper electrodes to run various practical numerical operations. The voltage is swept from 0V to 3V with an InitialStep= 0.01V, MaxStep of 0.05V and Minstep of 1.e-5 V. The plots came as follows for the different models.

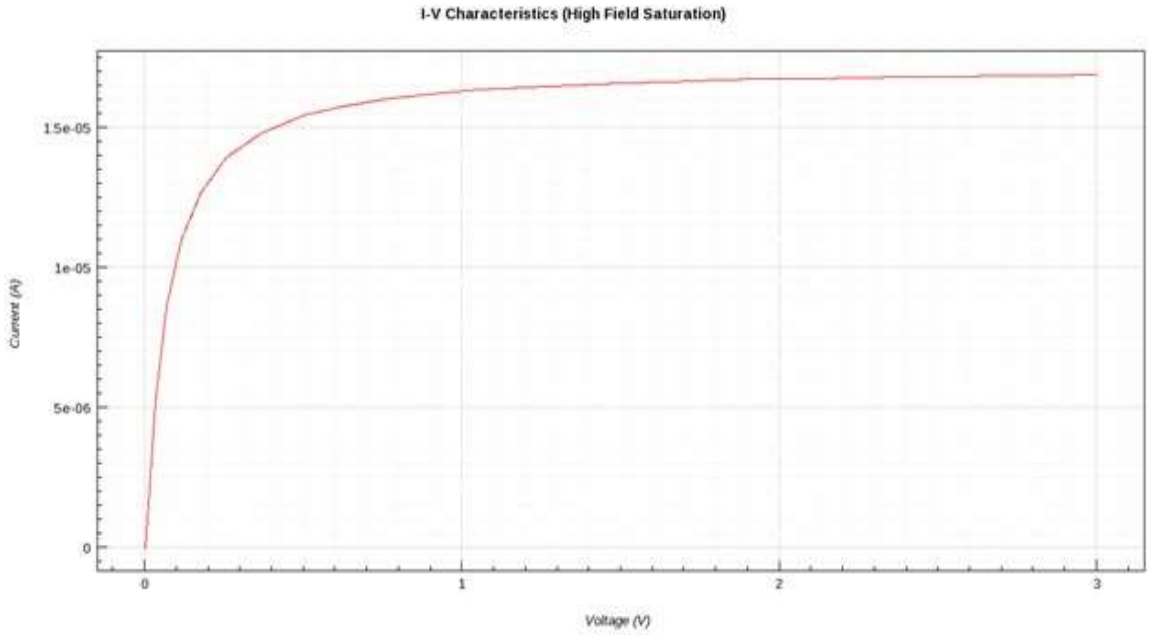
Constant Mobility Doping Model



Doping Dependence Doping Model



High-field Saturation Doping Model



Observation:

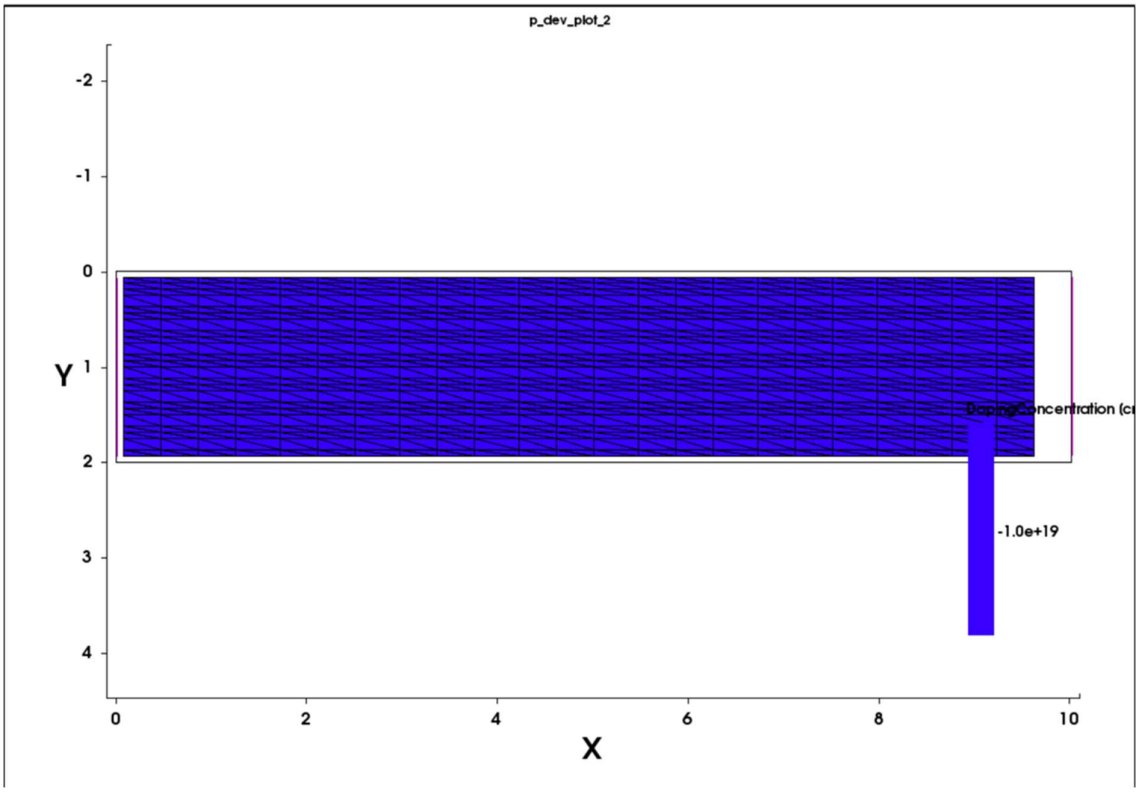
The Constant Mobilty and Doping dependence model give us the exact same current voltage charectaristics. This is due to the fact that there is uniform doping for this N-type bar which means that mobility is constant even for doping dependence model. The High field saturation model however shows that we get a much lower value of current for the same voltage applied. Also the current saturates at higher values of electric fields due to saturating values of mobility.

Q2) In this problem, to solve the given questions we had to modify the given code first for a P-doped Silicon bar of length 10um and width 2um.The P-type bar is doped with a doping density of 10^{19} cm^{-3}.Once the device mesh is generated by the SDE tool, we have to find the I-V characteristics of the bar by sweeping the voltage across the P-type bar from 0V to 3V by applying voltage on the left contact.

A contact may be made Ohmic or Schottky by modifying the Electrode part of the Code with “EqOhmic” or “Schottky Barrier” with given barrier voltage in eV.

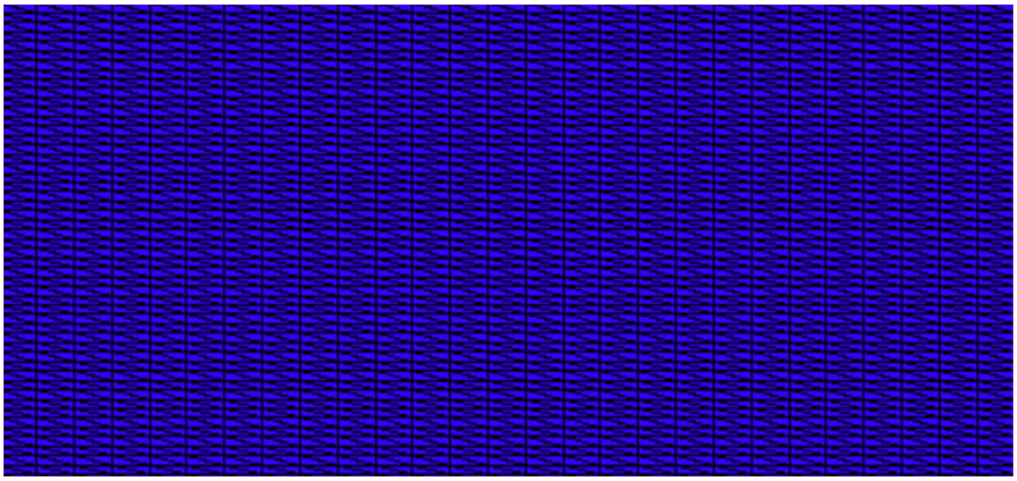
The code is almost same to the last problem except we define a P-type region by parameter “Lp” and the uniform doping density is for P-type dopant.

Once the meshing dimensions and step sizes are defined, we can generate the mesh and simulate the I-V charectaristics using the SDEVICE tool. We can now open SVisual and open the file named “p_diode_mesh.tdr” and then check the mesh ON button to see the TCAD simulated device Structure showing Mesh points. The mesh looks like the picture below.



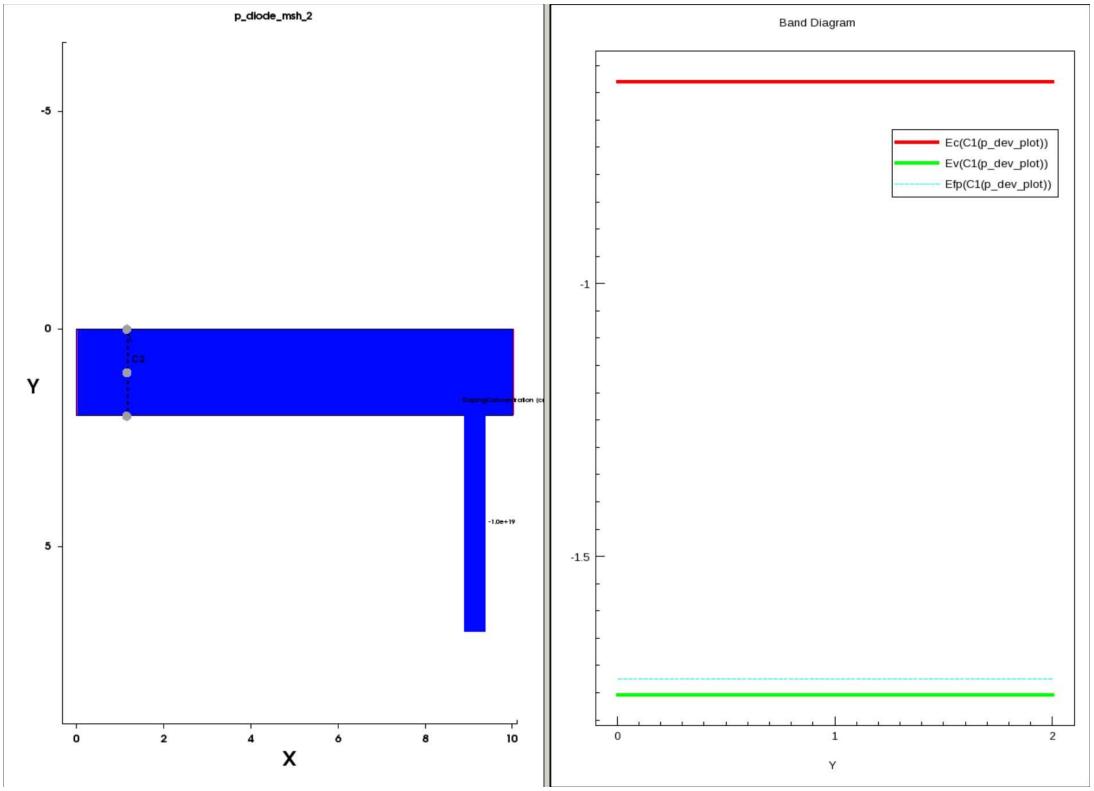
Zooming in we can see the exact structure of the mesh which appears to be small triangles stitched together.

Observation:
The mesh structure turns out to be the same for both the cases given in the question. Thus ohmic or Schottky contacts do not alter the mesh structure.

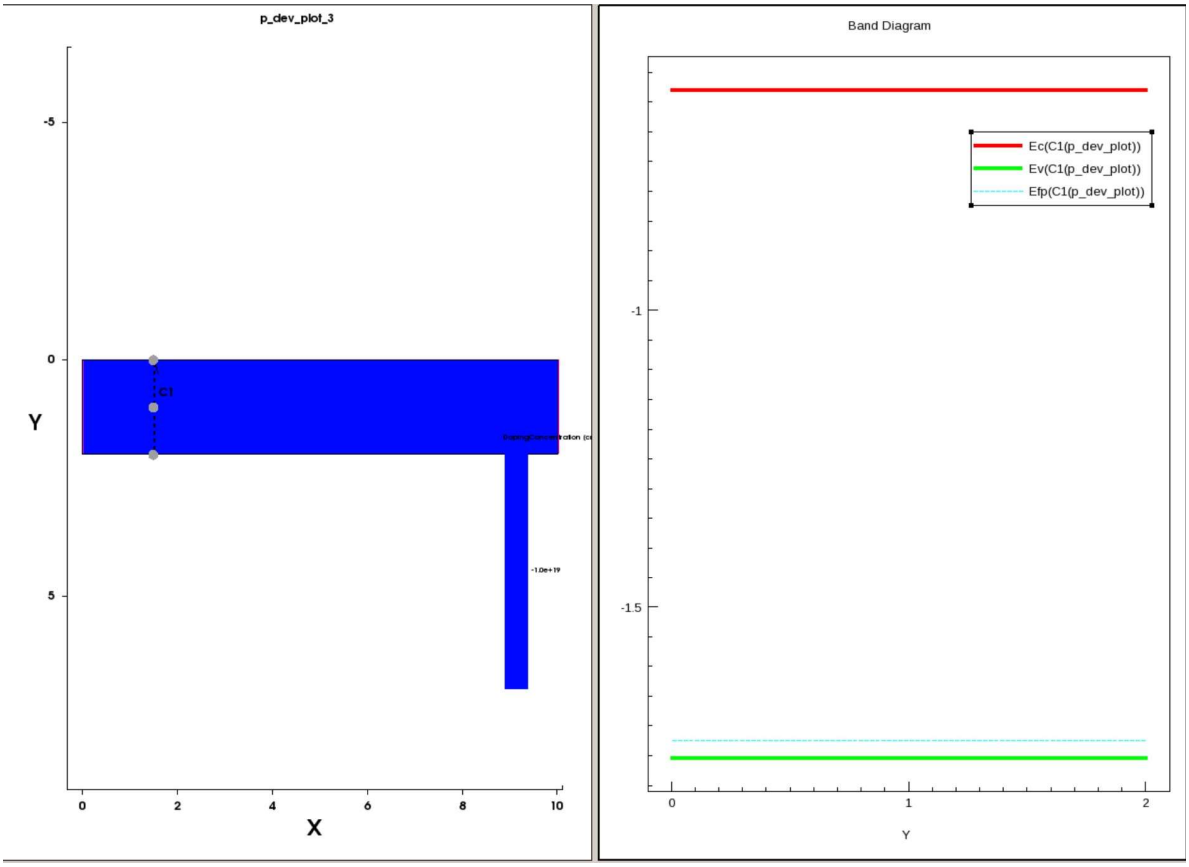


The band diagram at equilibrium can be found by opening the "p_dev_plot.tdr" file in SVisual and taking a X-cut on the P-type Si bar and then using the plot Band Diagram button on the right hand side of the toolbar. The plot of band diagram at equilibrium comes as follows.

Both sides Ohmic Contact

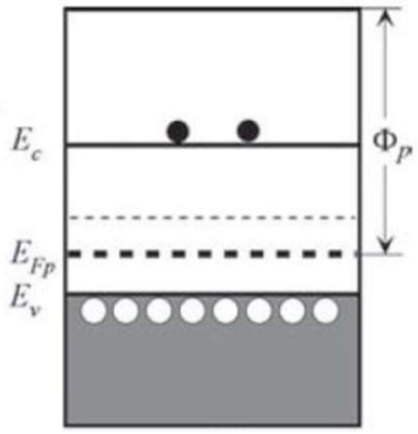


Left side is Ohmic right side is Schottky



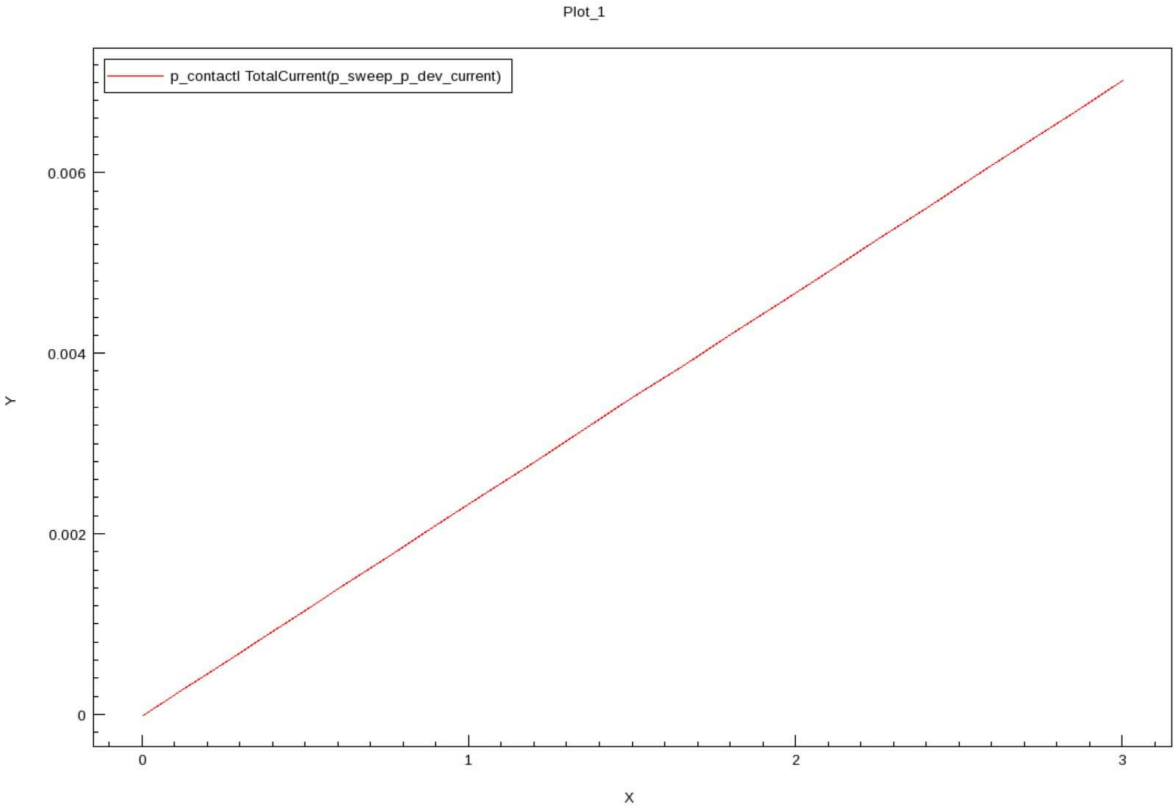
The contacts do not seem to alter the Energy Band diagram at equilibrium in any way. Hence both the plots appear to be exactly same.

The Energy band diagram looks just like we expected for a P-type bar. The manual diagram is given below.

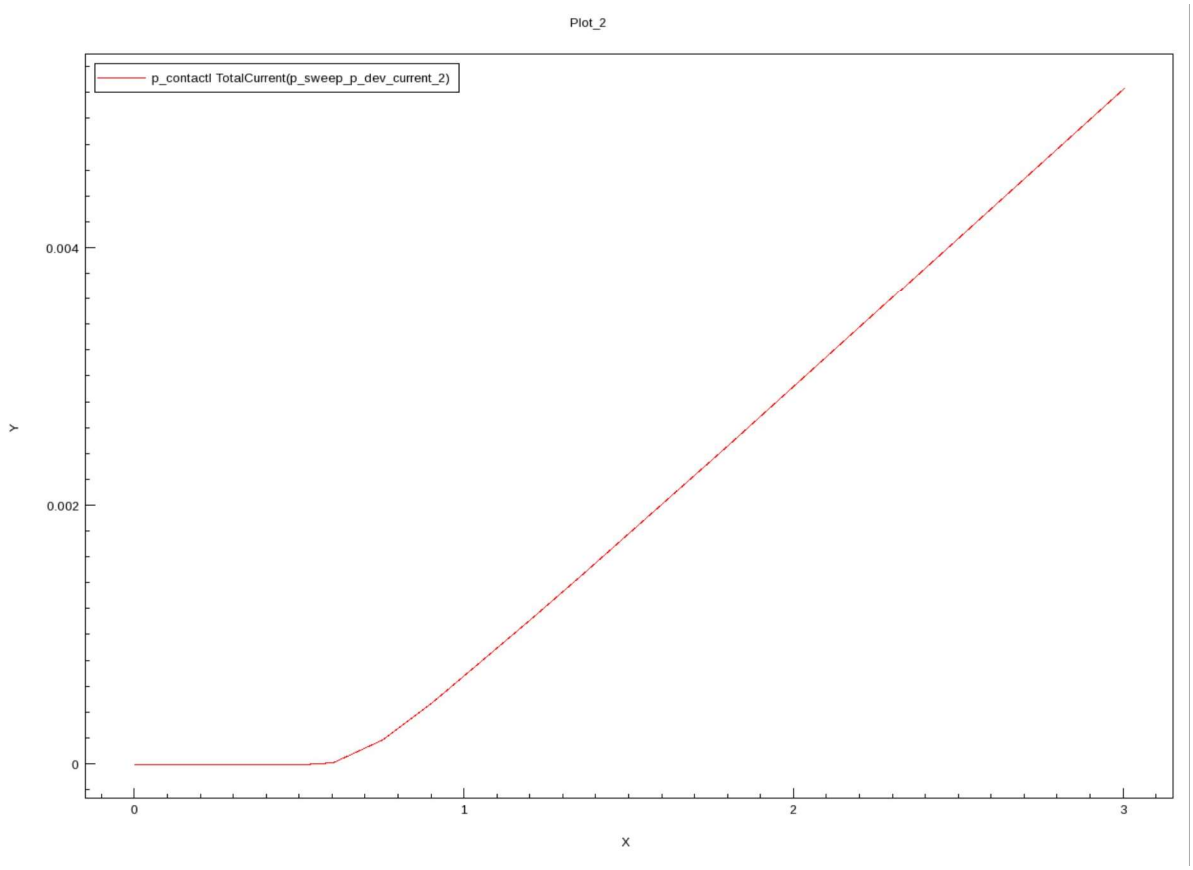


The I-V Charectaristics can be plotted only running the simulation using SDEVICE tool which takes the .tdr file from before as input and defines proper electrodes to run various practical numerical operations. The voltage is swept from 0V to 3V with an InitialStep= 0.01V, MaxStep of 0.05V and Minstep of 1.e-5 V. The plots came as follows for the different models.

Both sides Ohmic Contact



Left side is Ohmic right side is Schottky



Observation:

For Ohmic Contact we consider that the contacts do not bend or effect the Band Diagram in any way. These contacts are called “Ohmic” as they follow Ohm’s Law and allow bidirectional current passage.Since the contact do not affect the behavior of semiconductor, and the semiconductor itself behaves as a resistor (follows Ohm’s Law) as discussed in Question 1.

In Schottky Contact we consider behavior of Metal-Semiconductor junction similar to that of PN junction. The Energy Bands of the junction on both sides bend in equilibrium. This causes a built-in potential to arise in the structure.This structure acts like a Diode and allows conduction in single direction. Thus we can see that a certain voltage has to be applied to overcome this barrier potential so that current starts flowing in the silicon bar.

Q3) In this problem, to solve the given questions we had to modify the given code first for a NPN Silicon bar of length 1.3um and thickness 0.1um.The bar is doped with a doping density of 10^{19} cm^{-3} and 3e16 cm^{-3} of Arsenic on both sides with 10^{14} cm^{-3} of Boron in the middle.

We define the regions of NPN with values Ln and Lp and subsequently define the specific regions in the following manner.

```
{
(define Ln1 0.6) #Ln1 defined as 0.6 so that regions can be created easily
(define Lp 0.1)
(define Ln2 0.7)
#### Regions ####
(sdegeo:create-rectangle (position (* -1 Lp) 0 0) (position (* -1 Ln1) h 0) "Silicon" "n1_region")
(sdegeo:create-rectangle (position 0 0 0) (position (* -1 Lp) h 0) "Silicon" "p_region")
(sdegeo:create-rectangle (position 0 0 0) (position Ln2 h 0) "Silicon" "n2_region")
}
```

The doping “Nd1” ,“Nd2” and “Na” given as an user input parameter.

Constant doping regions, contacts and global course mesh are defined similar to the last two problems. Additionally due to the presence of junctions, we have to define a fine mesh for better results at the junction region. This fine mesh is defined as a rectangle around the junction region.

```
{
#### Junction fine mesh ####


(sedr:define-refeval-window "RefWin1.Dep" "Rectangle" (position (/ (* -1 Lp) 4) h 0) (position (/ Ln2 7) 0 0))
(sedr:define-refeval-window "RefWin2.Dep" "Rectangle" (position (/ (* -1 Ln1) 3) h 0) (position (* (* -1 Lp) (/ 3 4)) 0 0))
```

(sedr:define-refinement-size "RefDef1.Dep" (/ Ln1 500) (/ h 20) (/ Ln1 500) (/ h 20) 1 1)

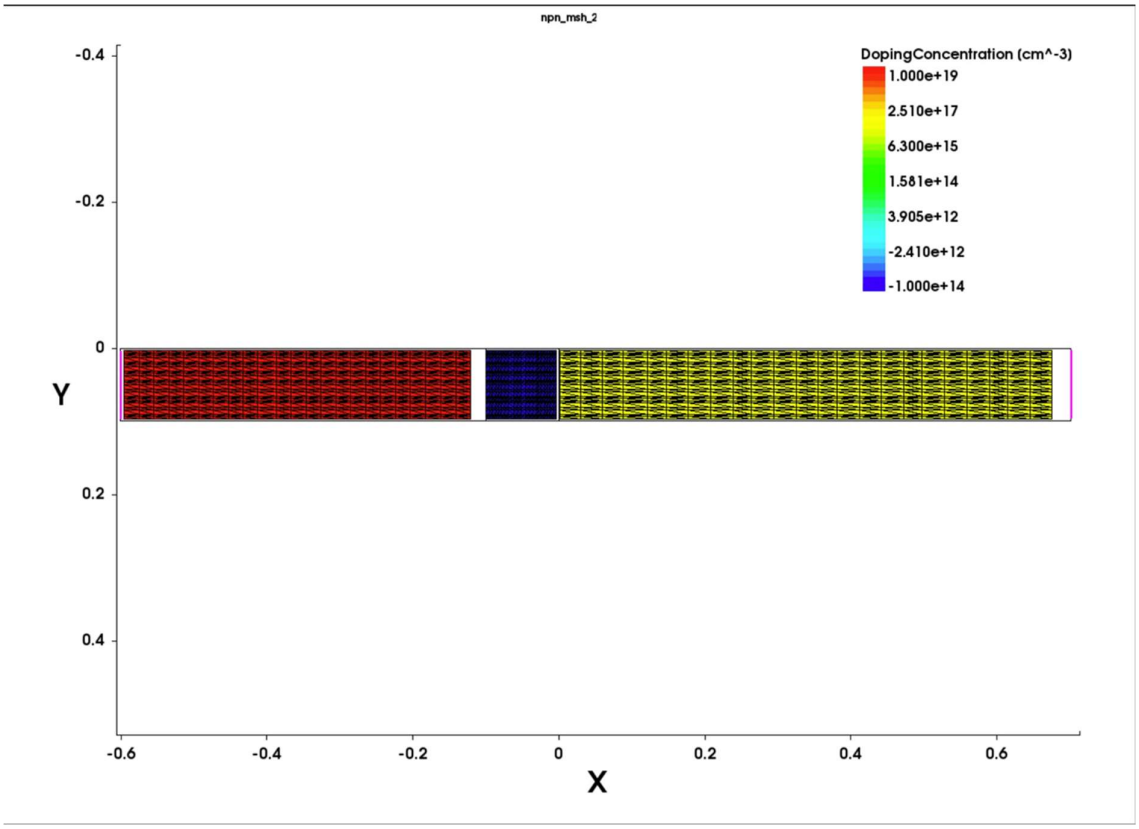
(sedr:define-refinement-size "RefDef2.Dep" (/ Ln1 500) (/ h 20) (/ Ln1 500) (/ h 20) 1 1)

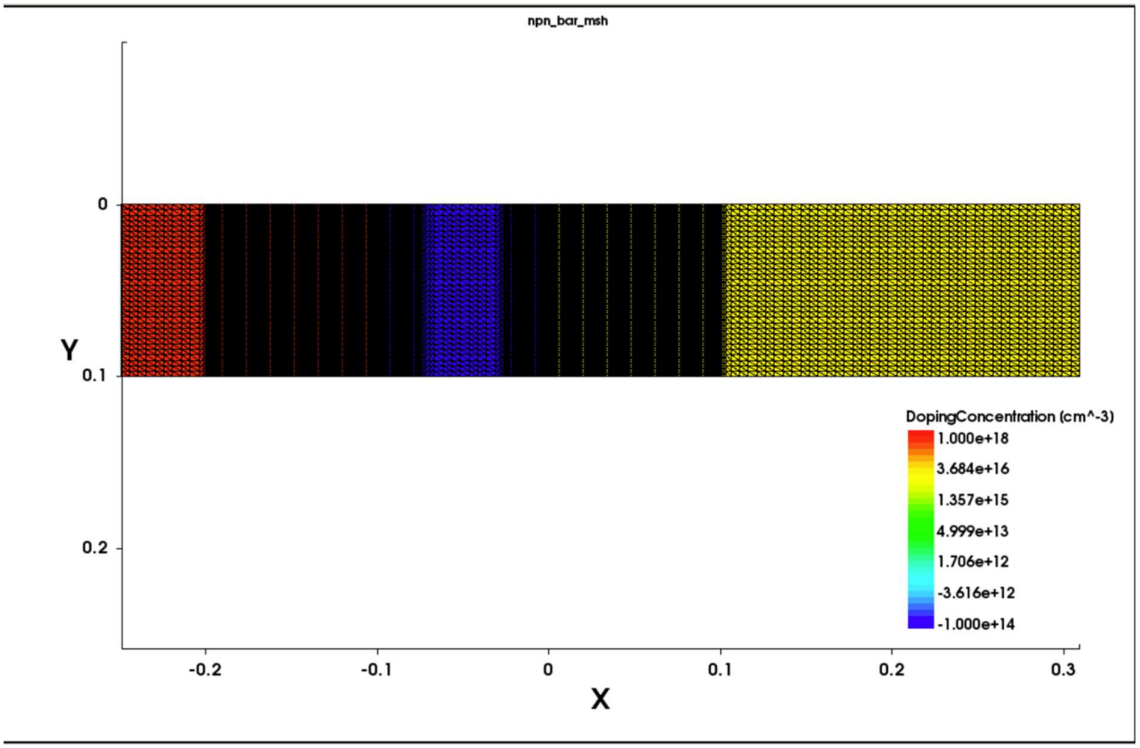
(sedr:define-refinement-placement "Place1.Dep" "RefDef1.Dep" "RefWin1.Dep")

(sedr:define-refinement-placement "Place2.Dep" "RefDef2.Dep" "RefWin2.Dep")

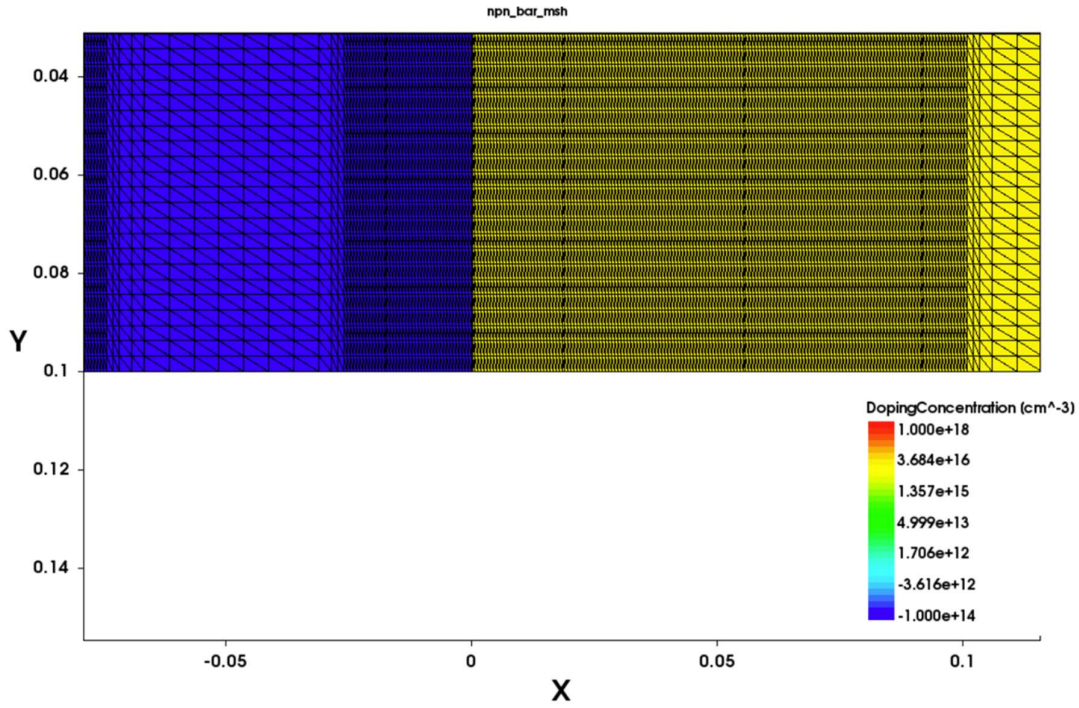
}

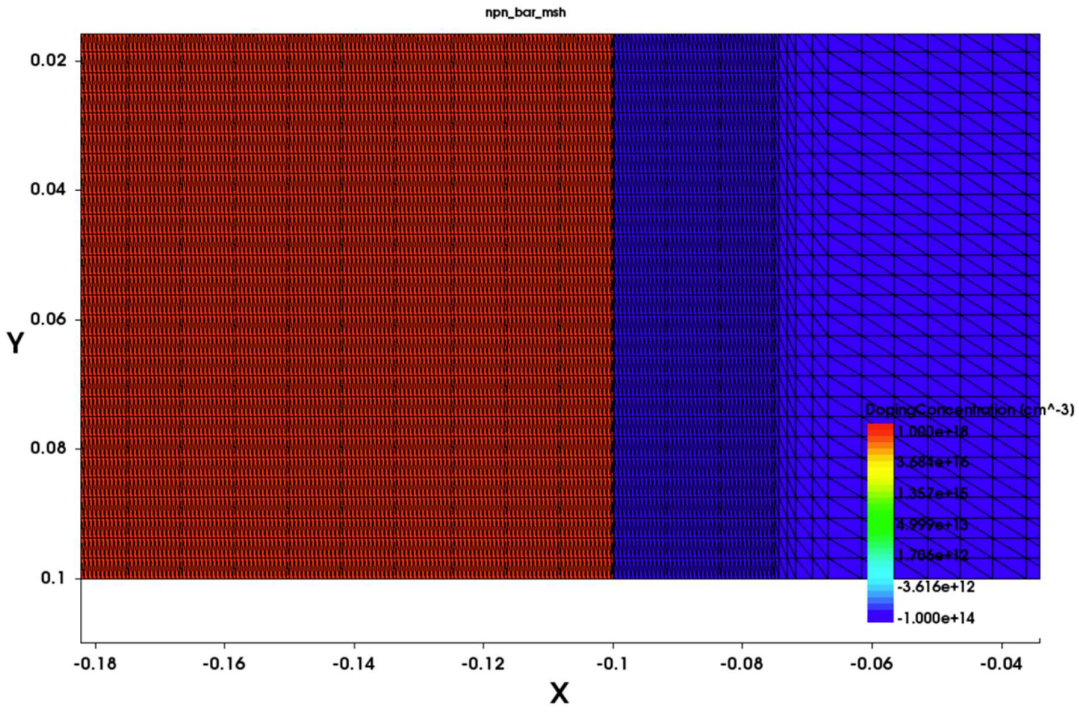
The device structure showing mesh points is as follows.





The black regions around the junction show the high density meshing that we defined earlier. A closer picture gives us the following figure of the mesh.

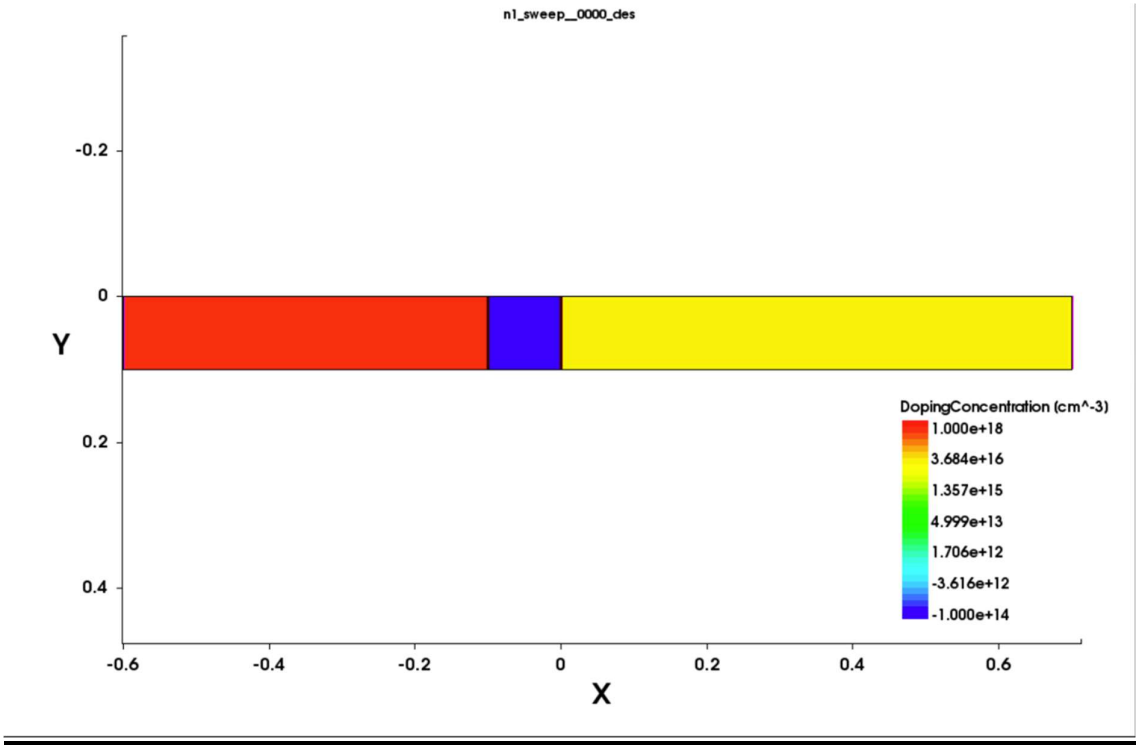




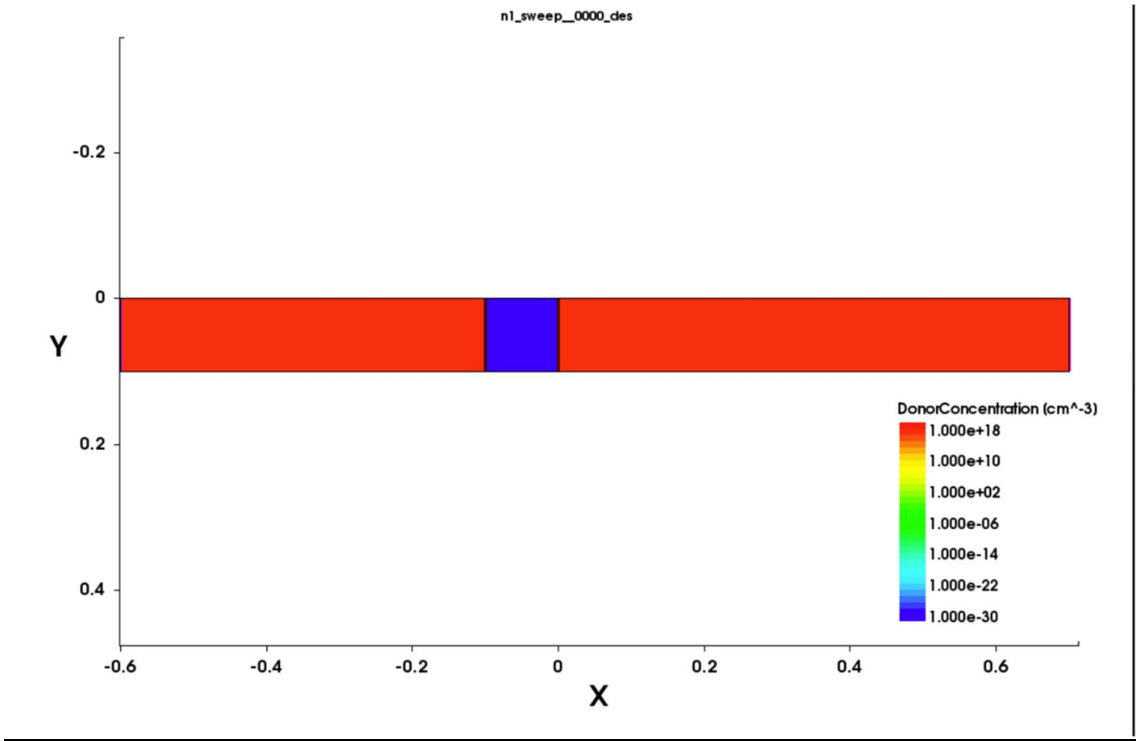
On zooming we can clearly observe the high density of meshing around the junctions.

The Plots for Doping Concentration, Donor ,Acceptor Concentration and Space Charge Density can be found by choosing the appropriate boxes from the left side of the toolbar.

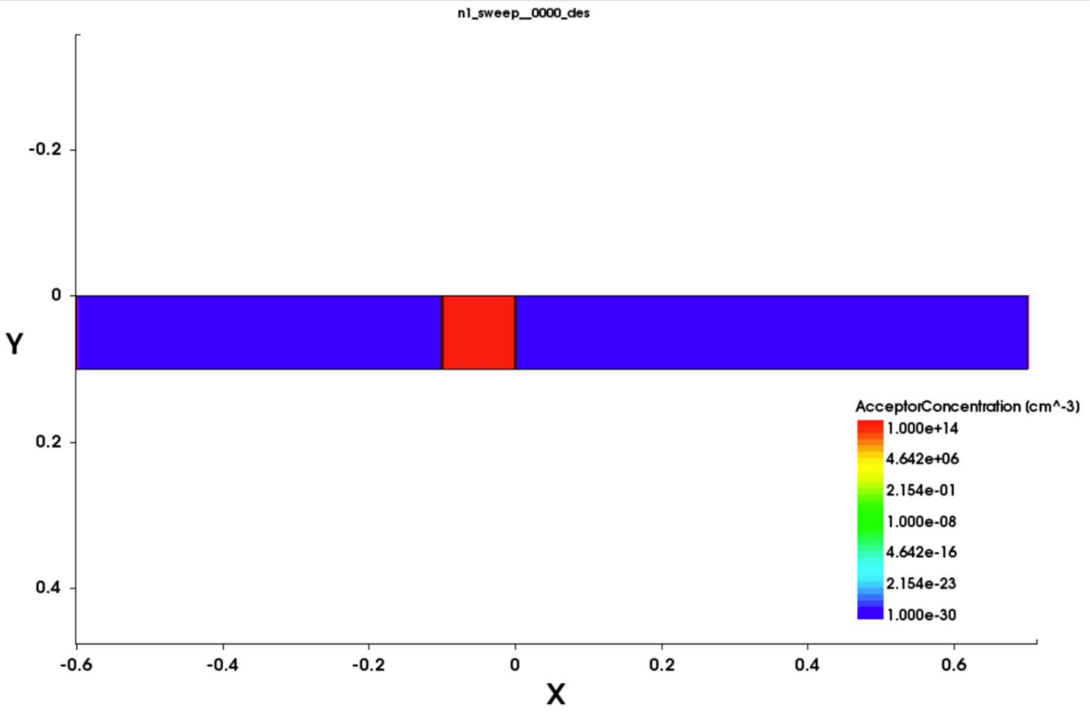
Doping Concentration across the NPN bar



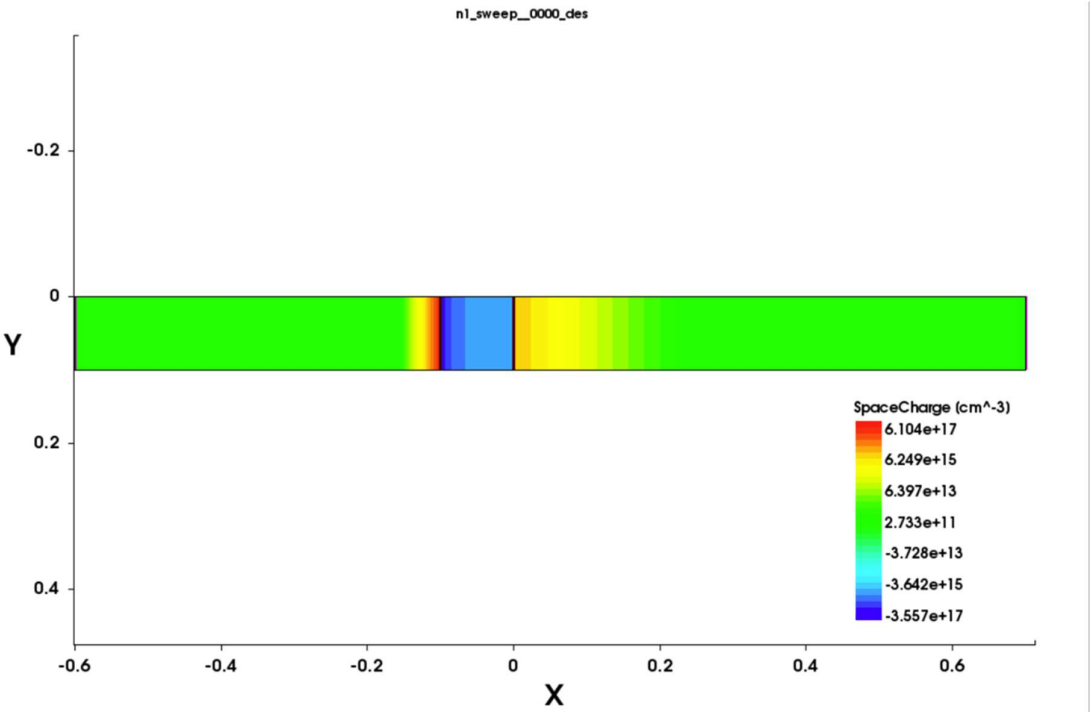
Donor Concentration



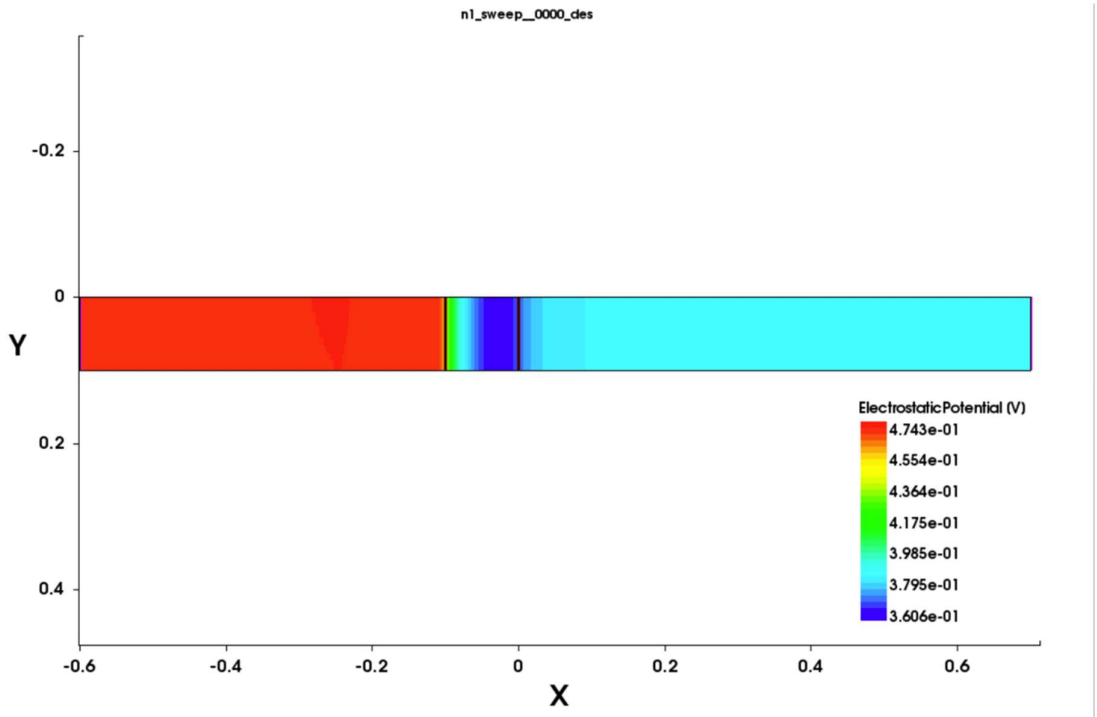
Acceptor Concentration



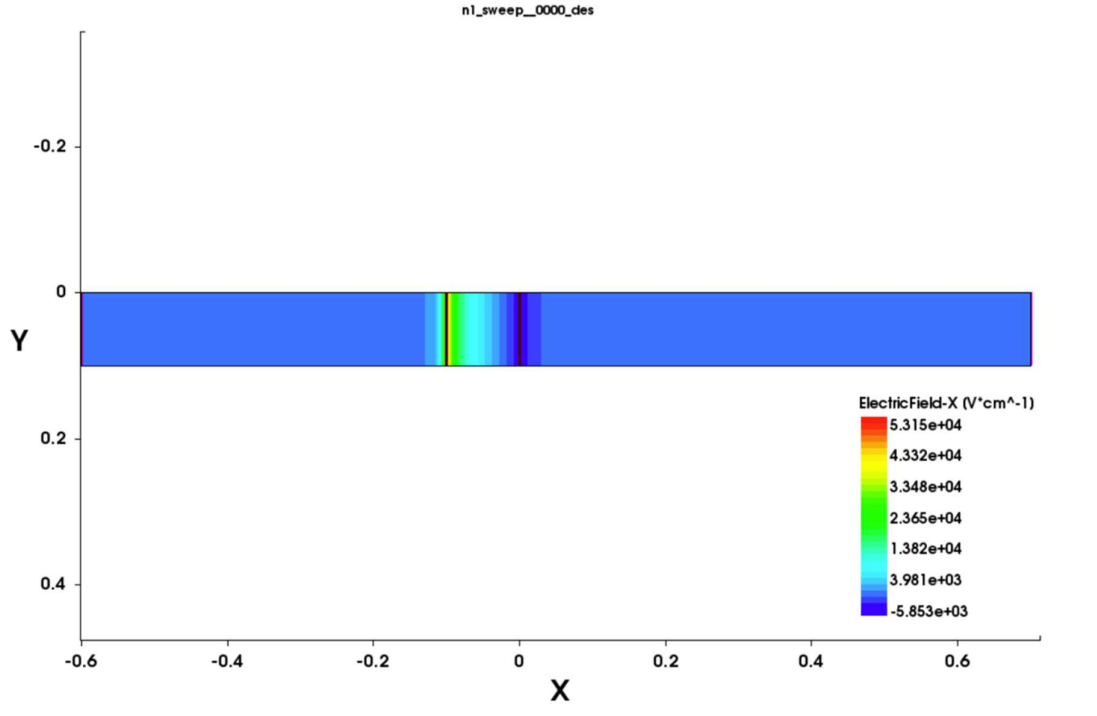
Space Charge Density

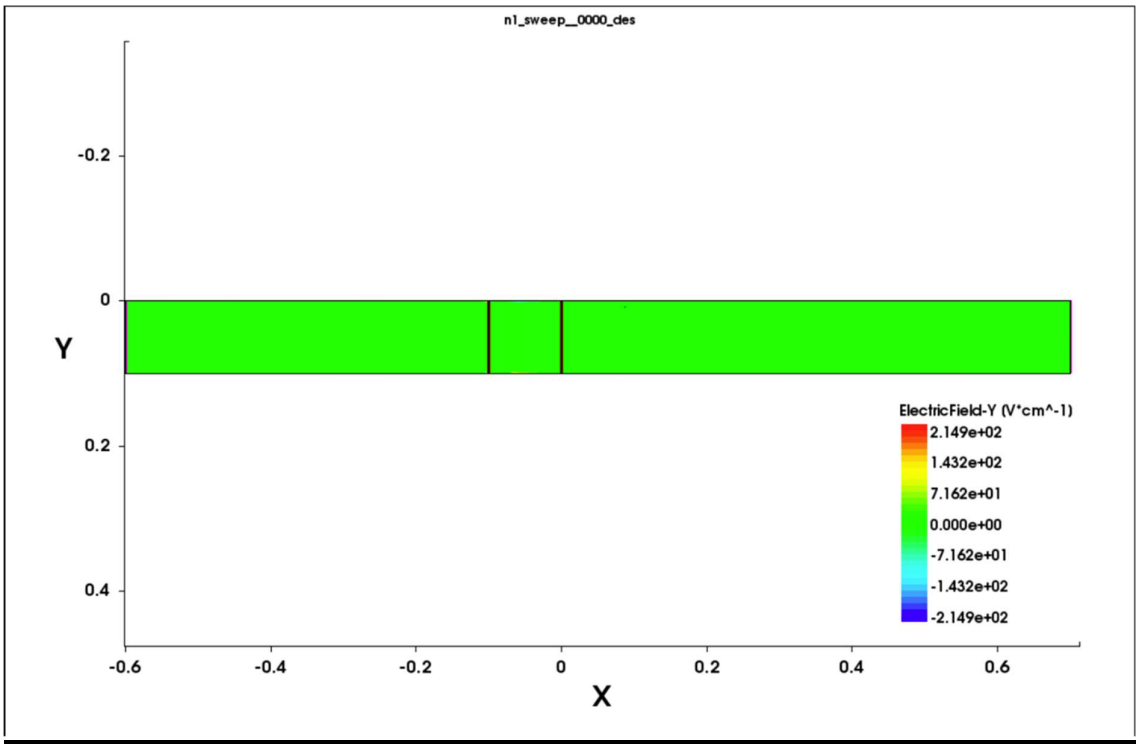


Electric Potential

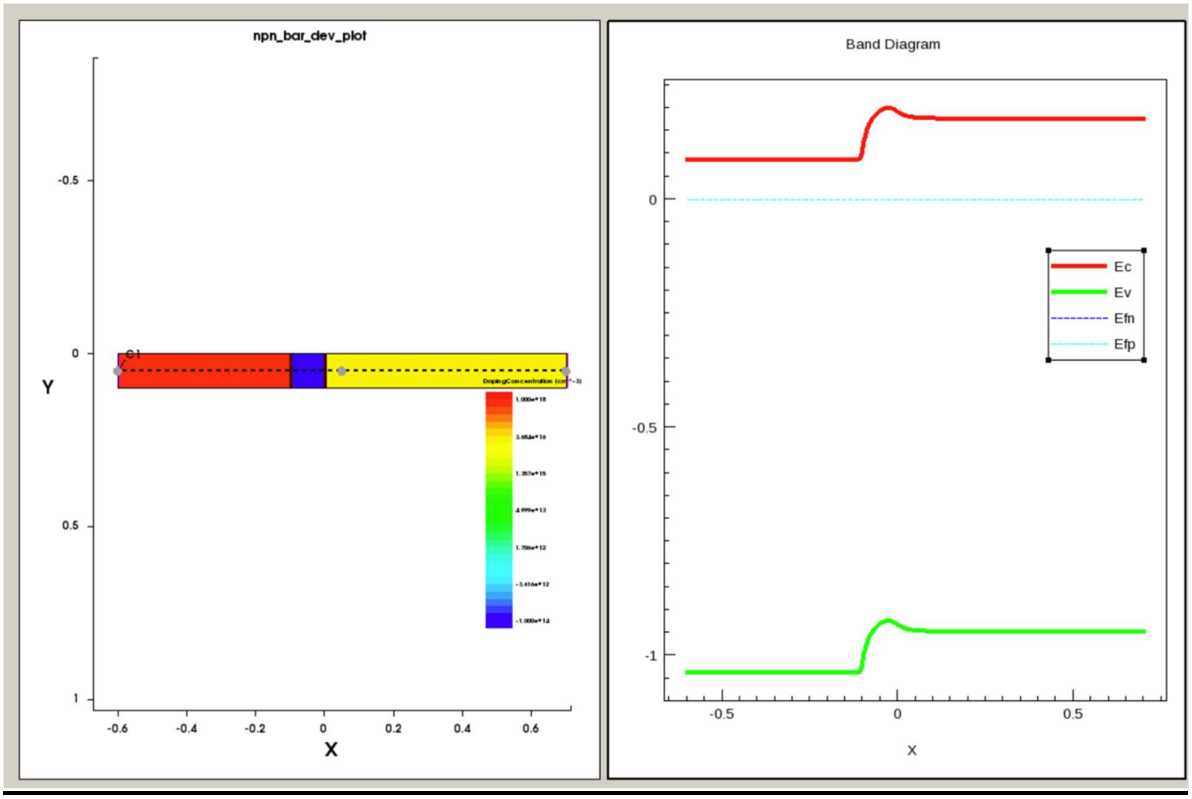


Electric Field(Both X and Y directions)





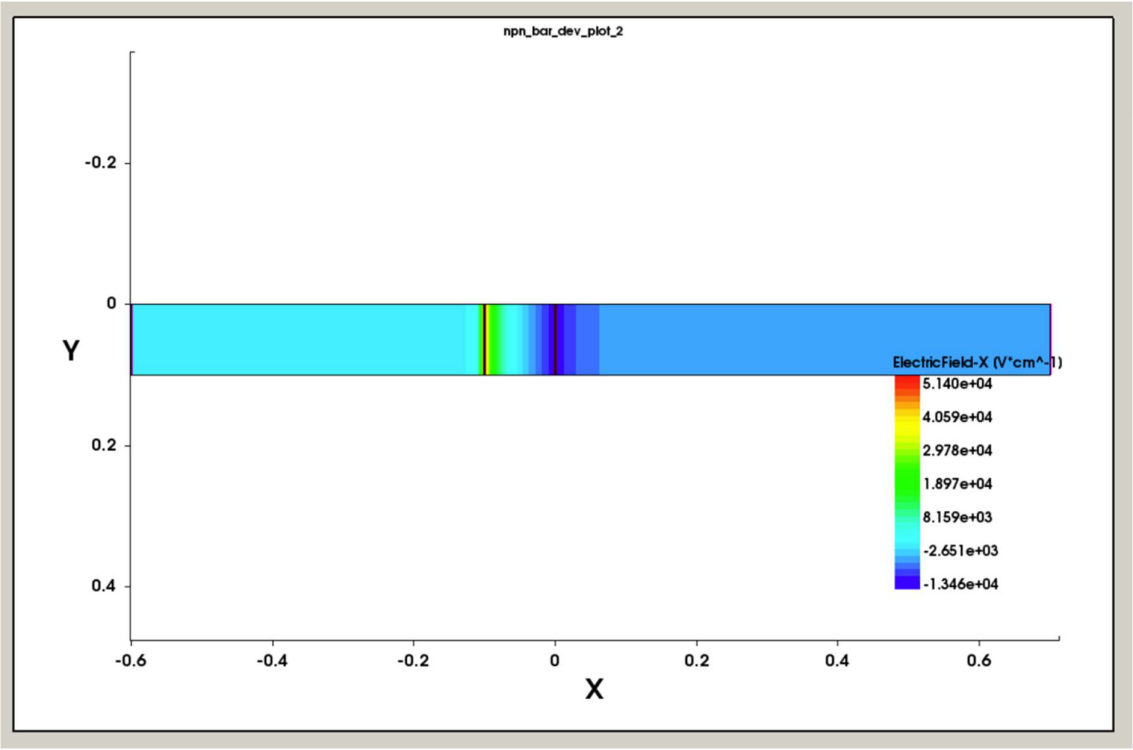
Energy Band Diagram at Equilibrium

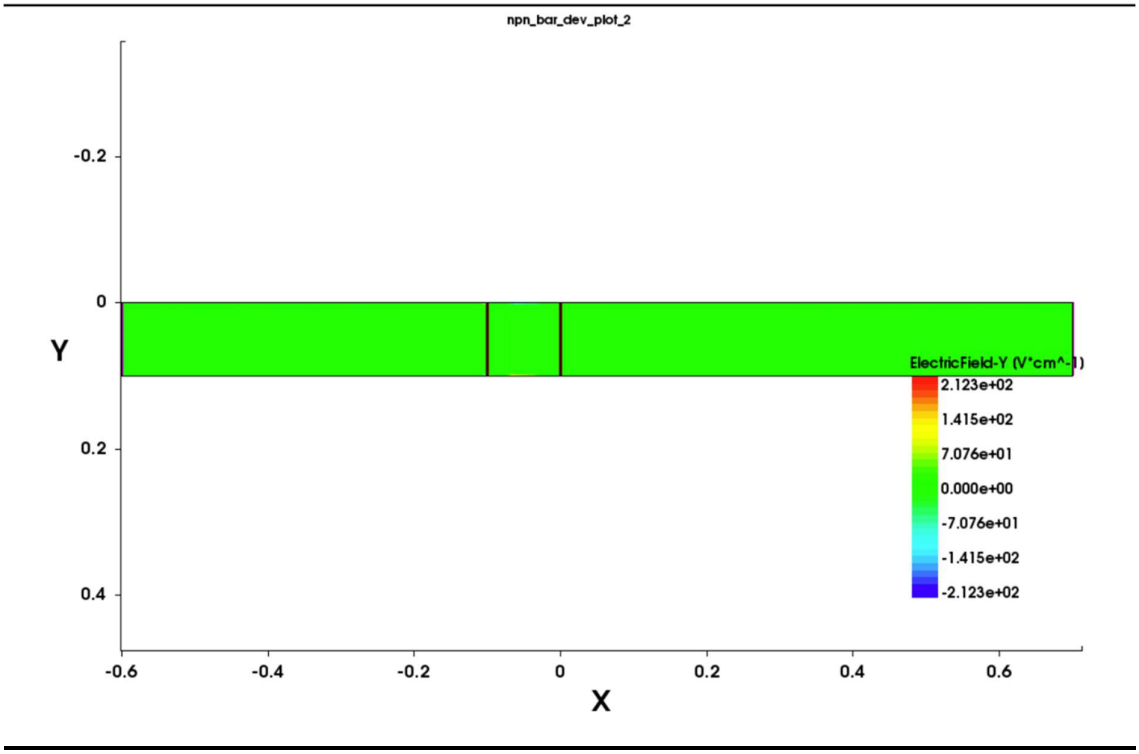


The fermi level being a straight line confirms the equilibrium condition.

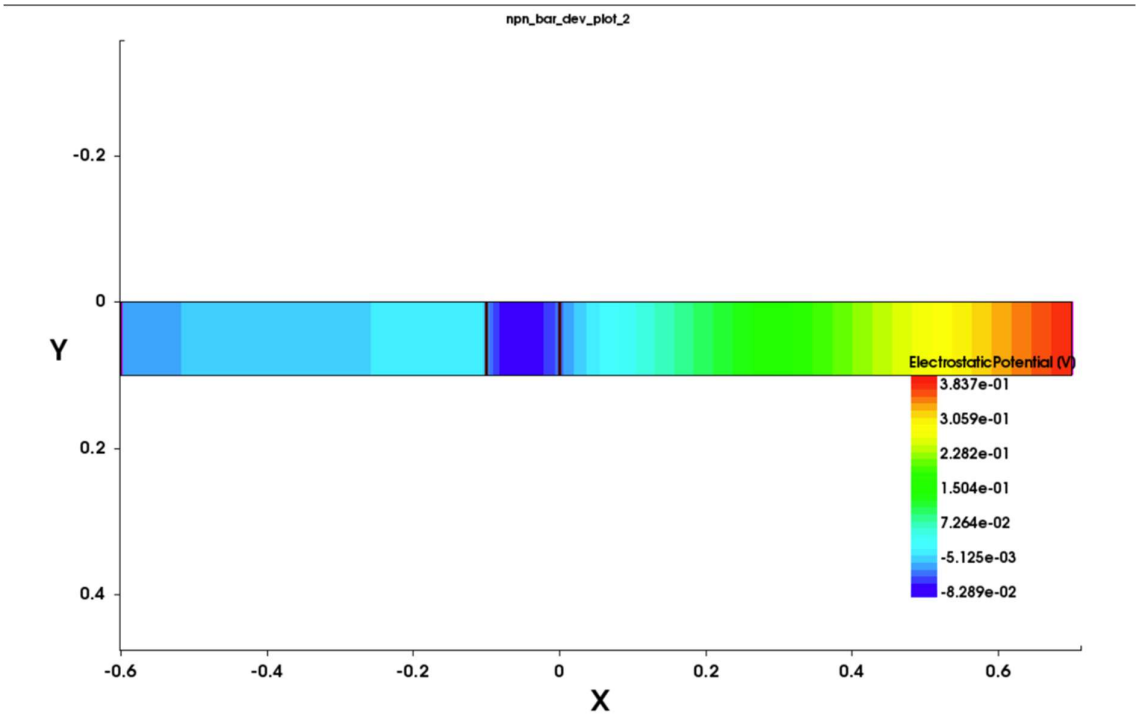
Now we will apply -0.5V at the left terminal and plot the Electric field, potential and band diagram.

Electric Field(Both X and Y directions)





Electric Potential



Energy Band Diagram