EE 735 Assignment 3

Name-Rajdeep Sinha

Roll- 23M1133

Q1)

Roll no- 23M1133

a=3,b=3

For Abrupt junction: Na=4e15 cm-3 , Nd=4*e15 cm-3;

For Linear junction: Na=Nd=4e15 cm-3;

To solve this problem using depletion approximation, we use the same method that we used in assignment 2. Without depletion approximation, we have to consider hole and electron densities on both sides and solve charge neutrality equation. The charge neutrality equation is

$$\rho = q(p - n + N_D - N_A)$$

where

$$p = n_i * \exp\left(-\frac{\Psi_i}{V_t}\right)$$

$$n = n_i * \exp\left(\frac{\Psi_i}{V_t}\right)$$

and psi(i) is the potential for the ith grid point of the PN Junction. We consider the following boundary conditions to solve the problem

V2 = Vth * ln(Nd/ni)

V1 = -Vth* ln(Na/ni)

Where V1 and V2 are boundary potentials at the extreme ends of the PN Junction.

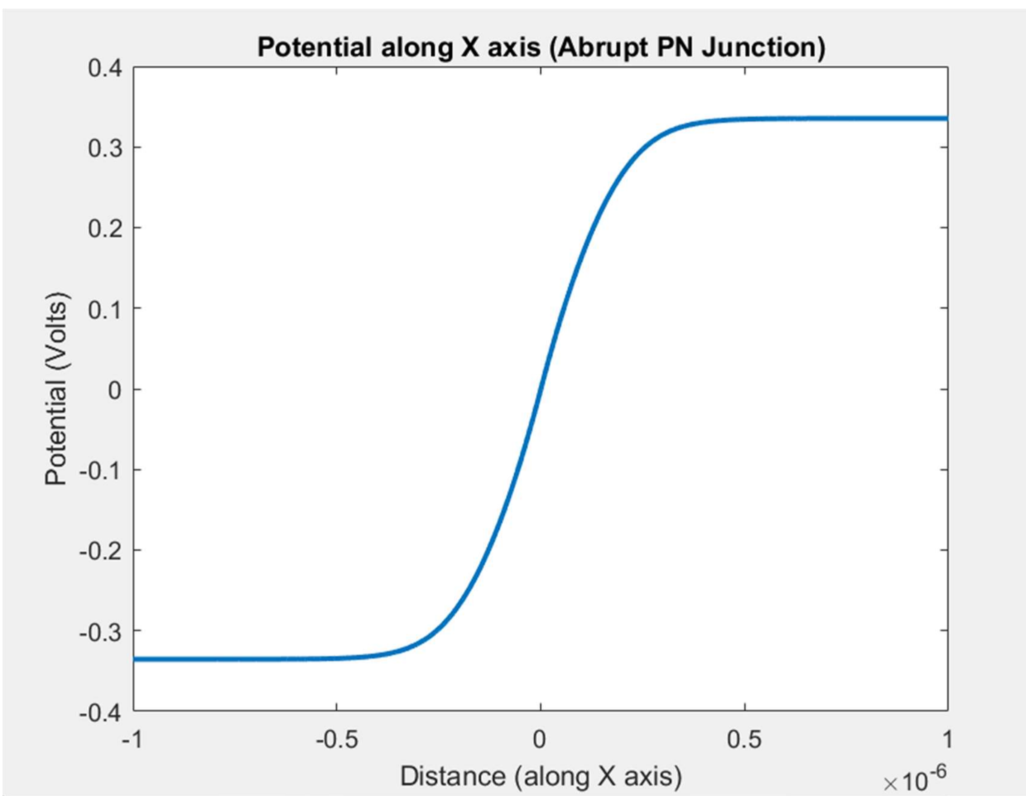
Using the finite difference matrix and charge matrix for both linear and abrupt junctions, we calculated potential at each grid point by solving the poisson equation using Newton Raphson method. The creation of a Jacobian matrix was critical in solving using this method. Inverting the Jacobian gave us deltaV which could be added with earlier matrix to get newer potential. This should be iterated enough number of times to get correct potential. In doing this I struggled with deltaV turning into a singular matrix due to very small values. To solve this , the linear junction case was done using LU decomposition method to create the inverse of jacobian matrix.

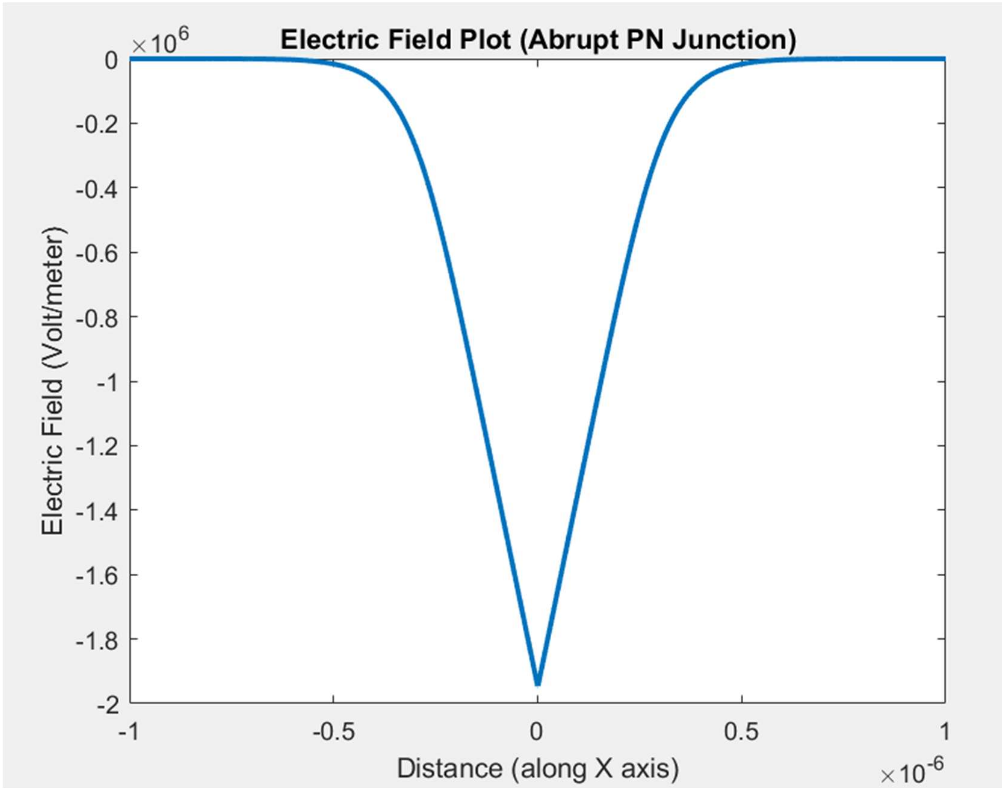
The electric field, potential and carrier concentrations were calculated and plotted once the potential was found.

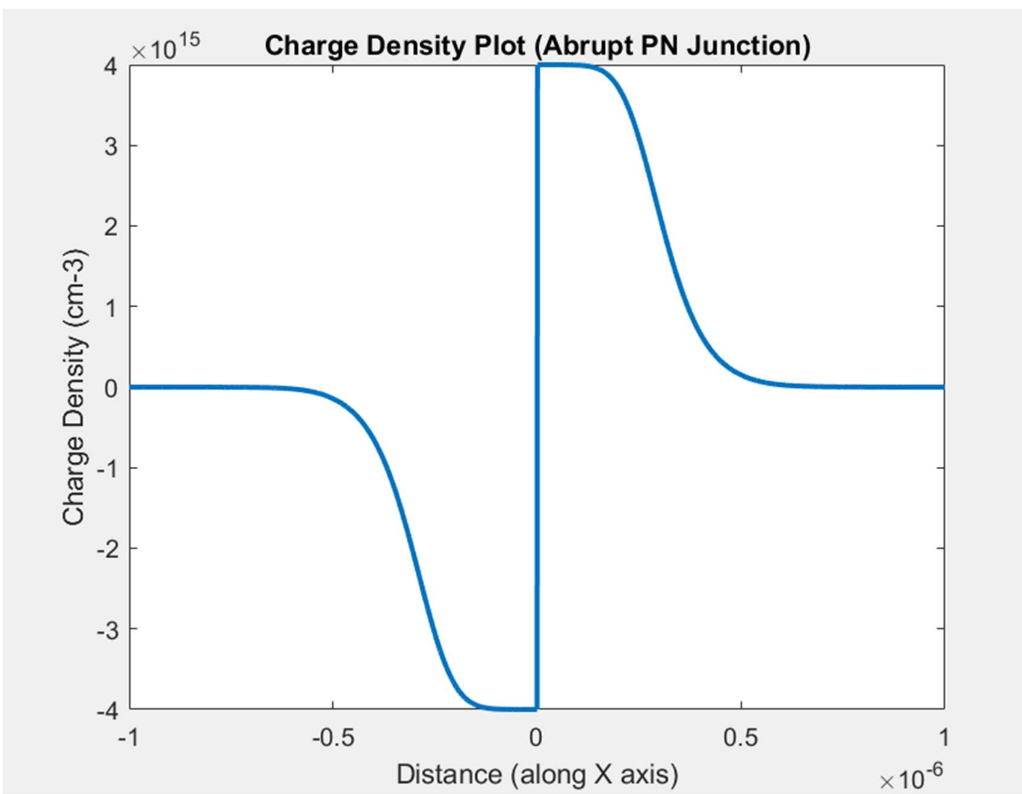
To plot the Energy Band diagram, conduction band, valence band, intrinsic fermi levels were defined on both the p and n side. Along with this, a device fermi level was also added. I have used to depletion approximation to find the fermi level on either side and then plot them in MATLAB.

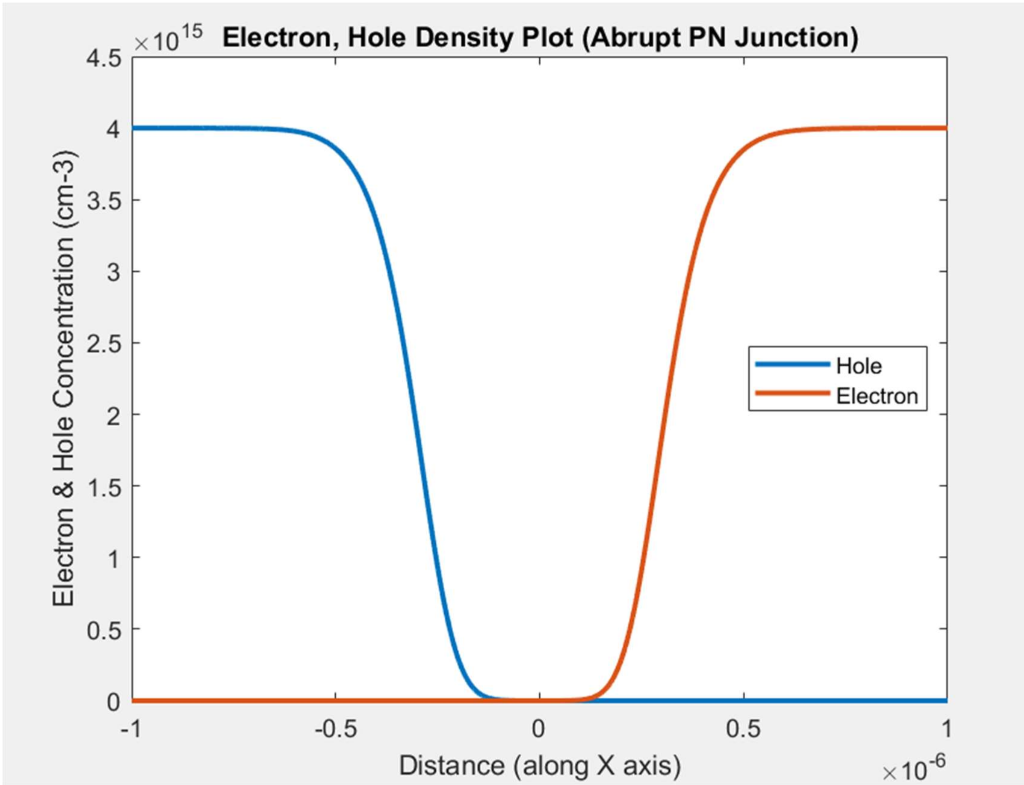
The plots obtained are provided below-

Abrupt Junction

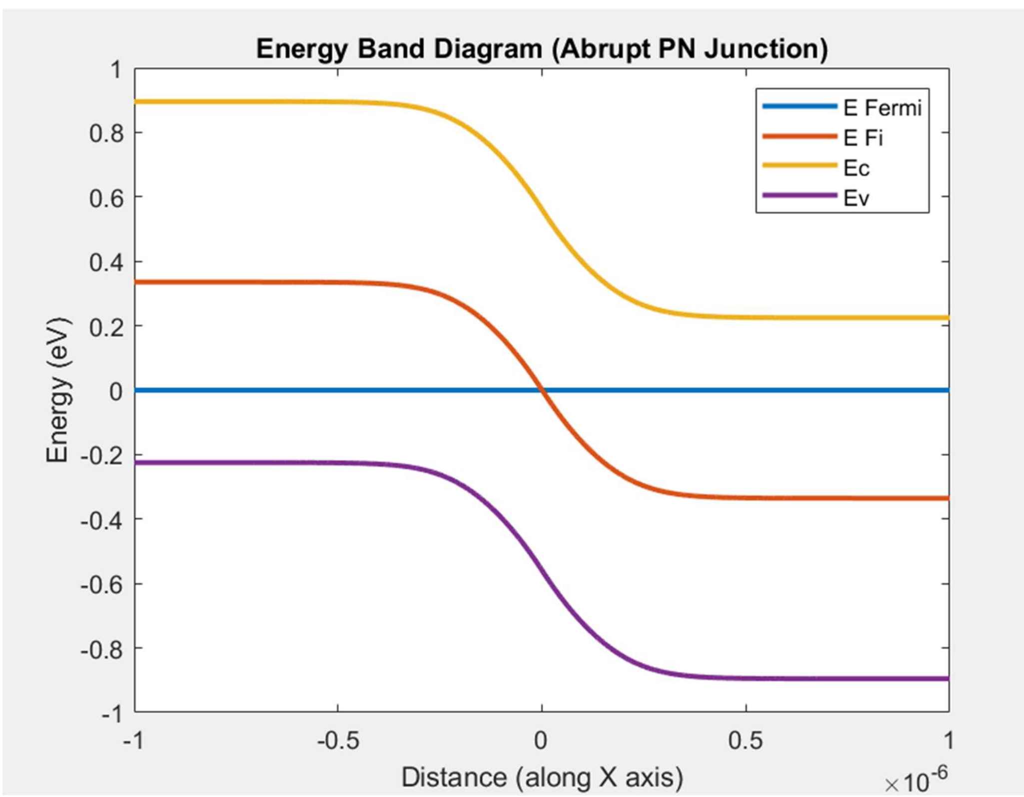



Electric Field Plot (Abrupt PN Junction)
×10^6
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
Electric Field (Volt/meter)
-1
-0.5
0
0.5
1
Distance (along X axis)
×10^-6

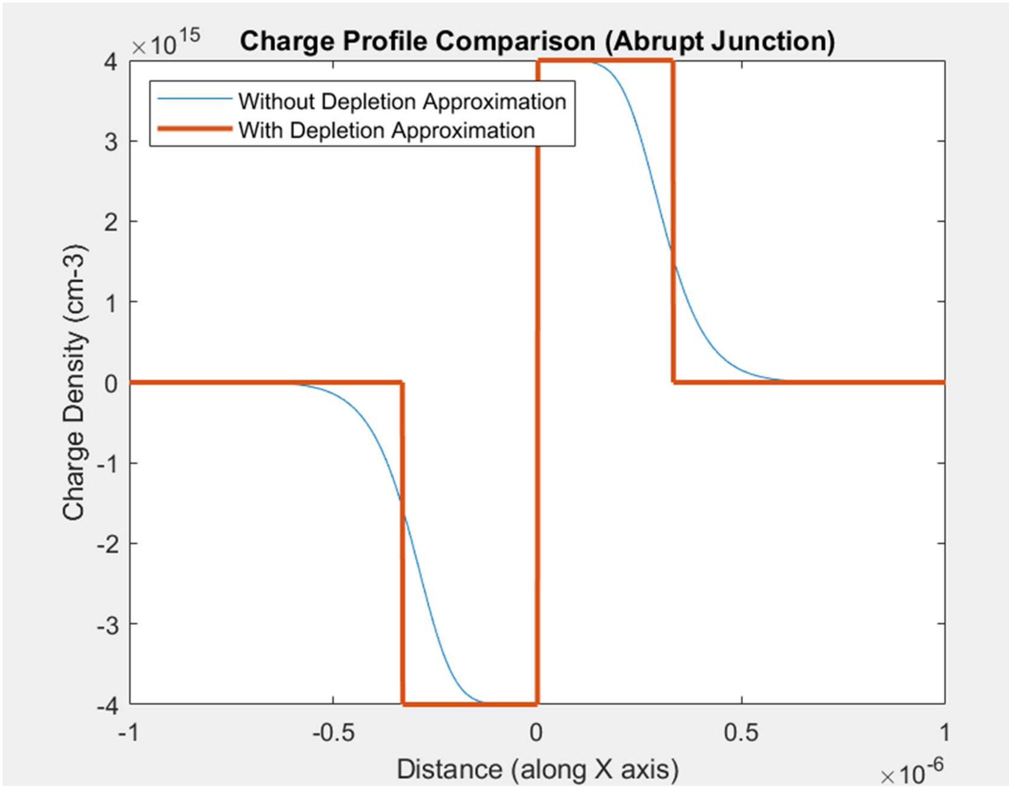

Charge Density Plot (Abrupt PN Junction)
×10^15
4
3
2
1
0
-1
-2
-3
-4
Charge Density (cm-3)
-1
-0.5
0
0.5
1
Distance (along X axis)
×10^-6

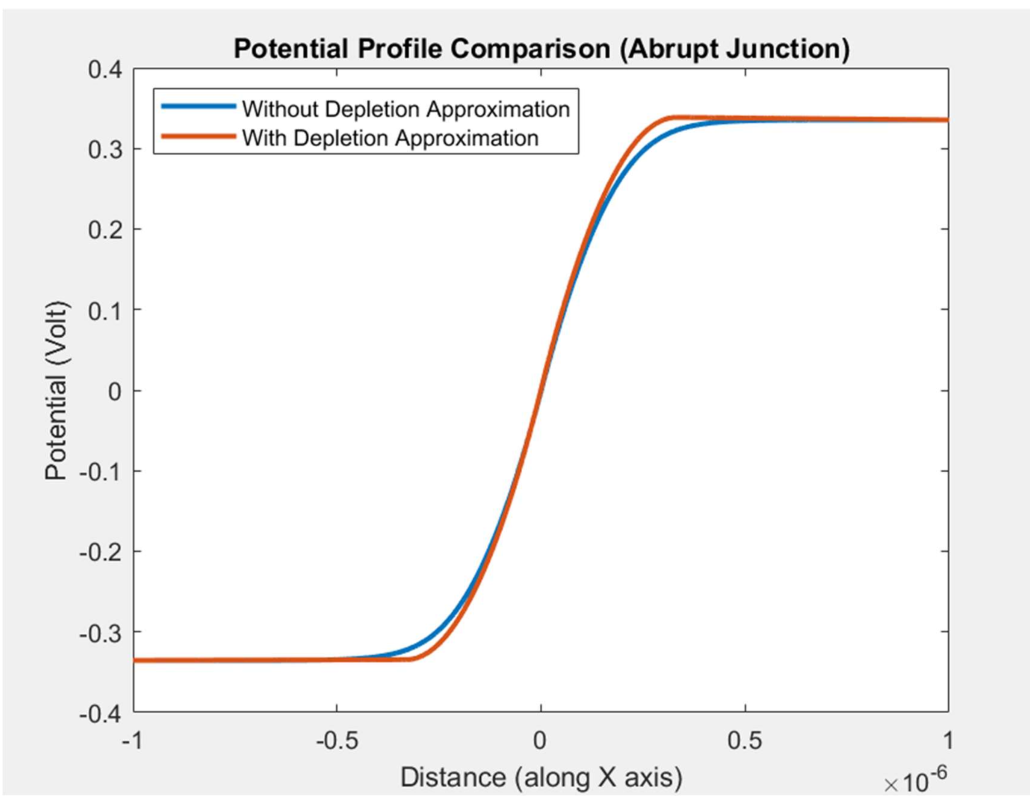


Electron, Hole Density Plot (Abrupt PN Junction)
×10^15
Electron & Hole Concentration (cm-3)
Hole
Electron
Distance (along X axis)
×10^-6

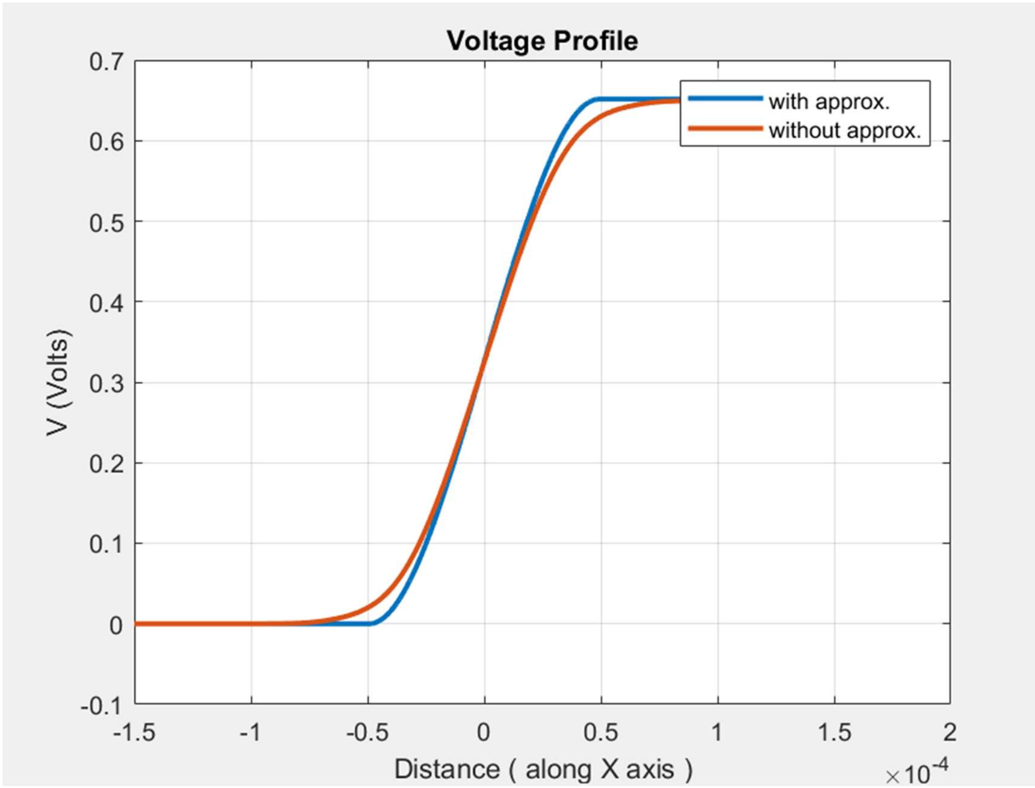


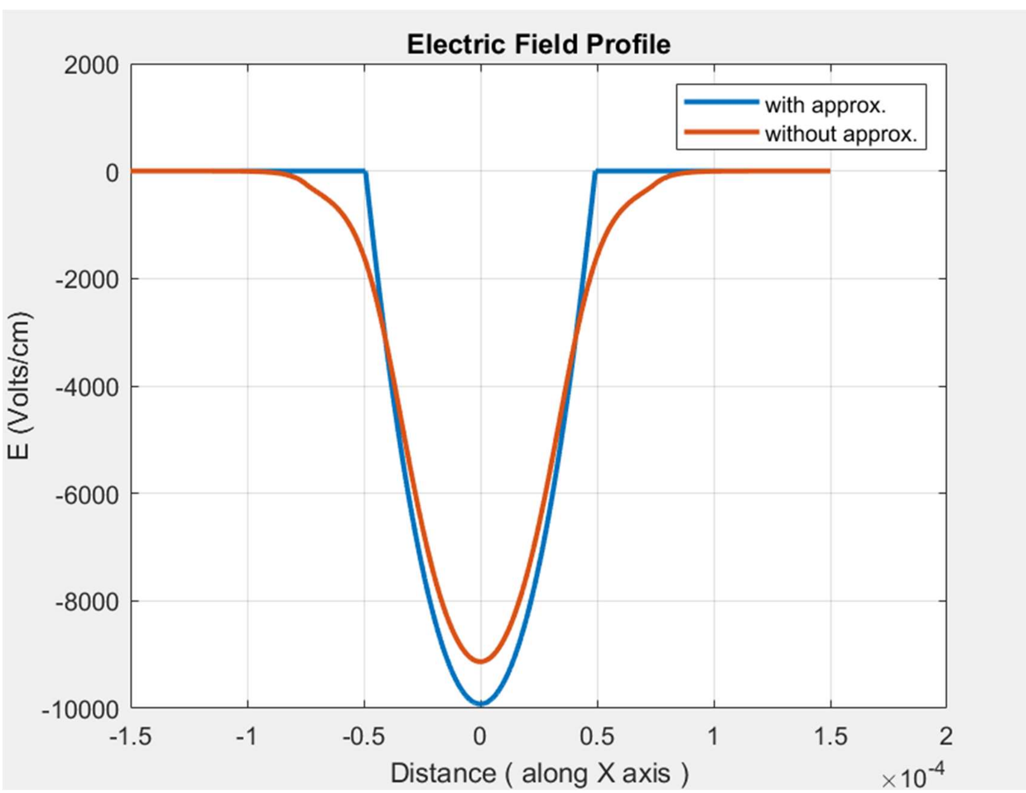
Energy Band Diagram (Abrupt PN Junction)
E Fermi
E Fi
Ec
Ev
Energy (eV)
Distance (along X axis)
×10^-6

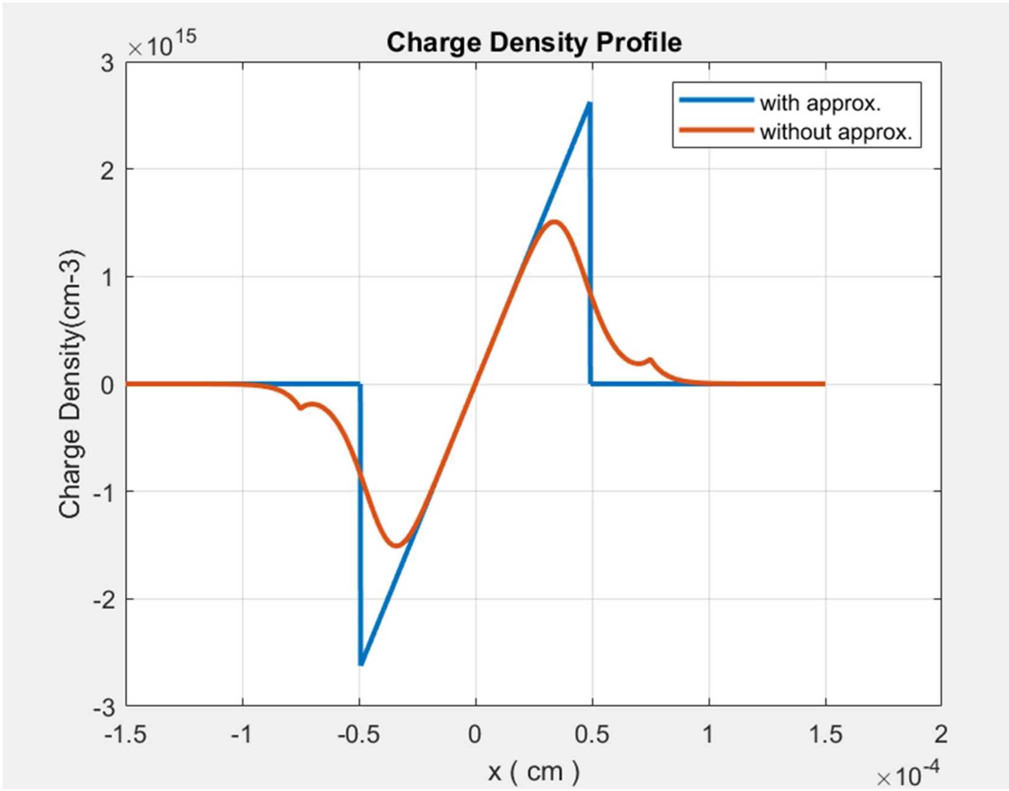

Charge Profile Comparison (Abrupt Junction)
Without Depletion Approximation
With Depletion Approximation
Charge Density (cm-3)
Distance (along X axis)
×10^15
×10^-6

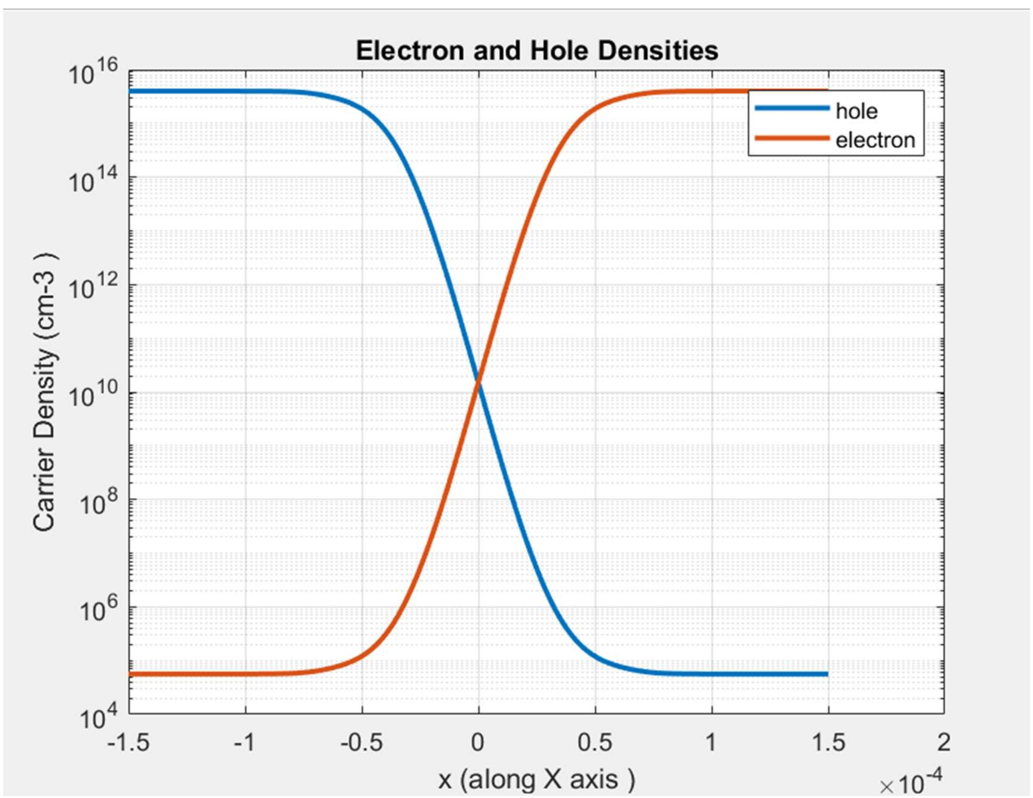

Potential Profile Comparison (Abrupt Junction)
Without Depletion Approximation
With Depletion Approximation
Potential (Volt)
Distance (along X axis)
×10^-6

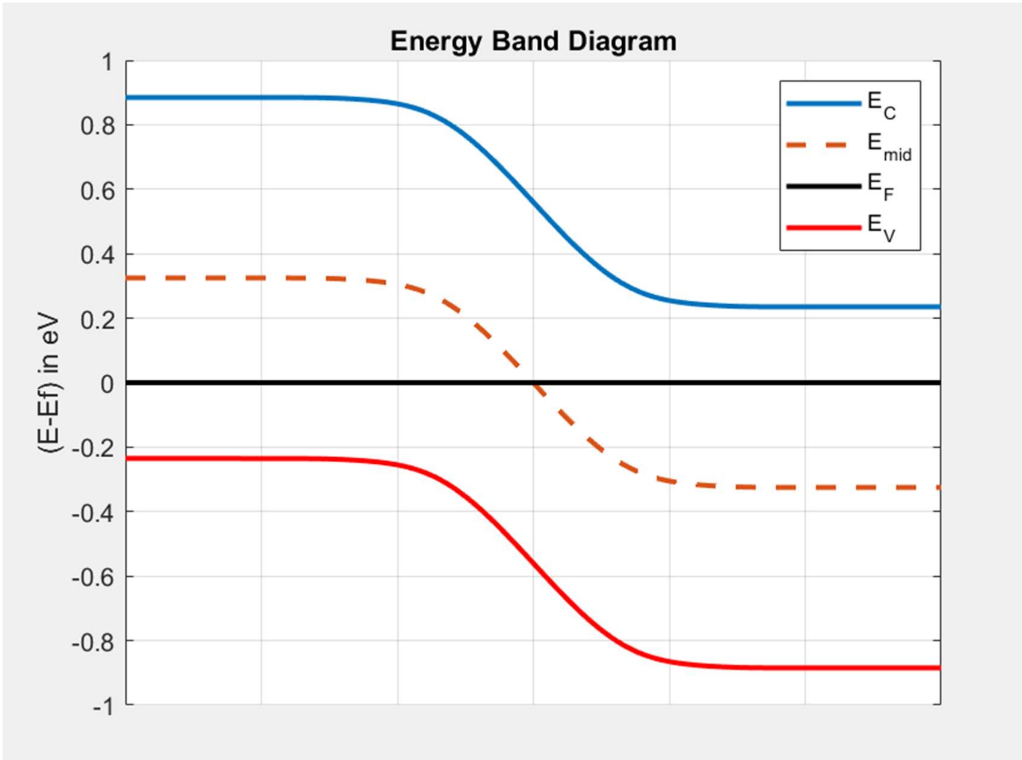
Linear Junction






Charge Density Profile
$\times 10^{15}$
Charge Density(cm-3)
3
2
1
0
-1
-2
-3
-1.5
-1
-0.5
0
0.5
1
1.5
2
x (cm)
$\times 10^{-4}$
with approx.
without approx.


Electron and Hole Densities
Carrier Density (cm-3)
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
-1.5
-1
-0.5
0
0.5
1
1.5
2
x (along X axis)
$\times 10^{-4}$
hole
electron



Energy Band Diagram
(E-Ef) in eV
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
E_C
E_{mid}
E_F
E_V

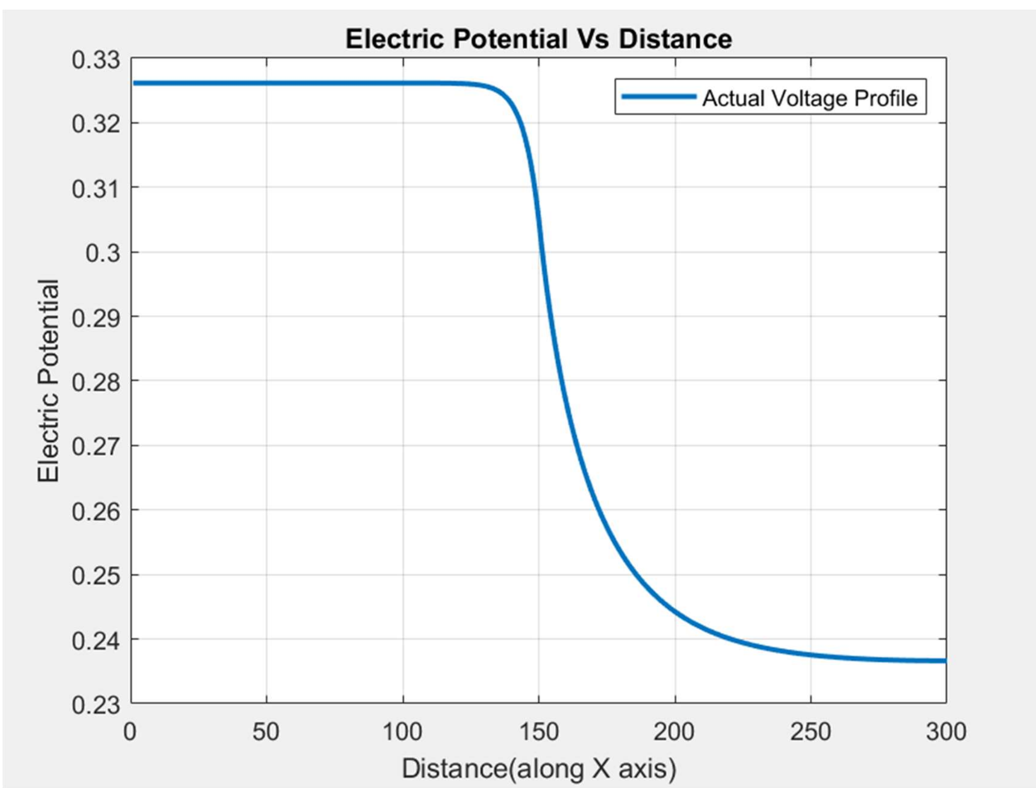
Q3)

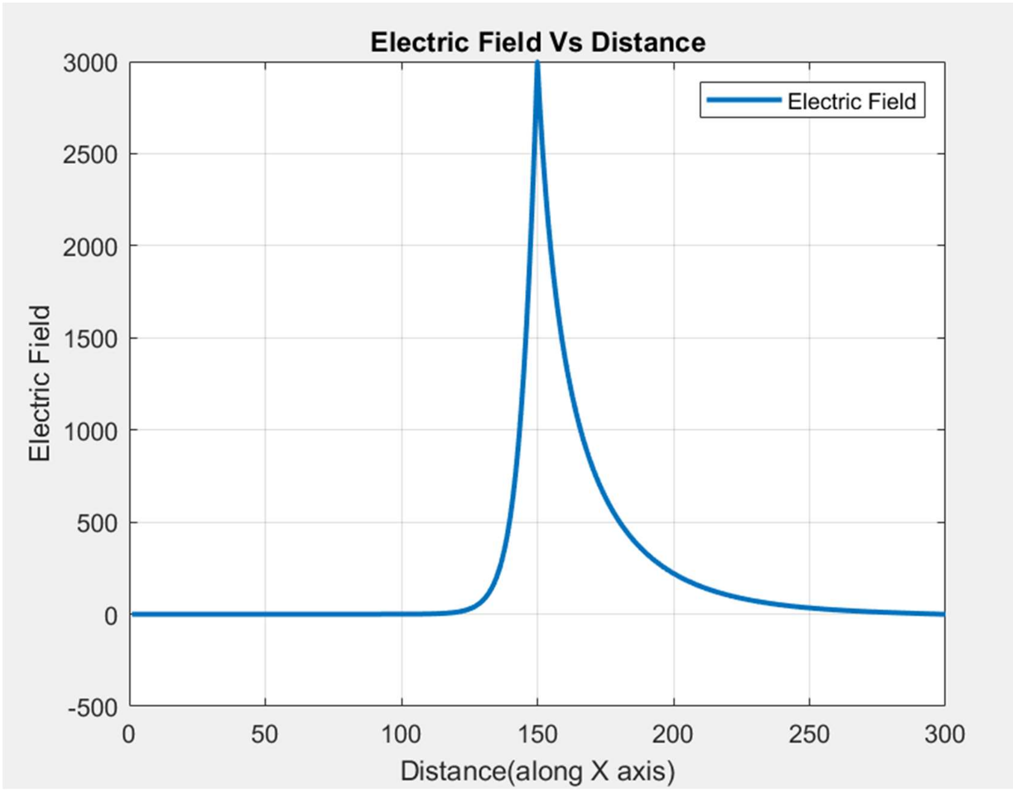
For this problem, Barrier potential=0.09V since a=3 and b=3 for me. To ensure this potential withing a 5% tolerance across the N+-N junction, we have assumed intrinsic carrier concentration to be 1.34e10cm-3 and doping on N side to be 1.18e14. The doping on the N+ side comes out to be 3.7602e15 when we use the depletion approximation formula for barrier potential.

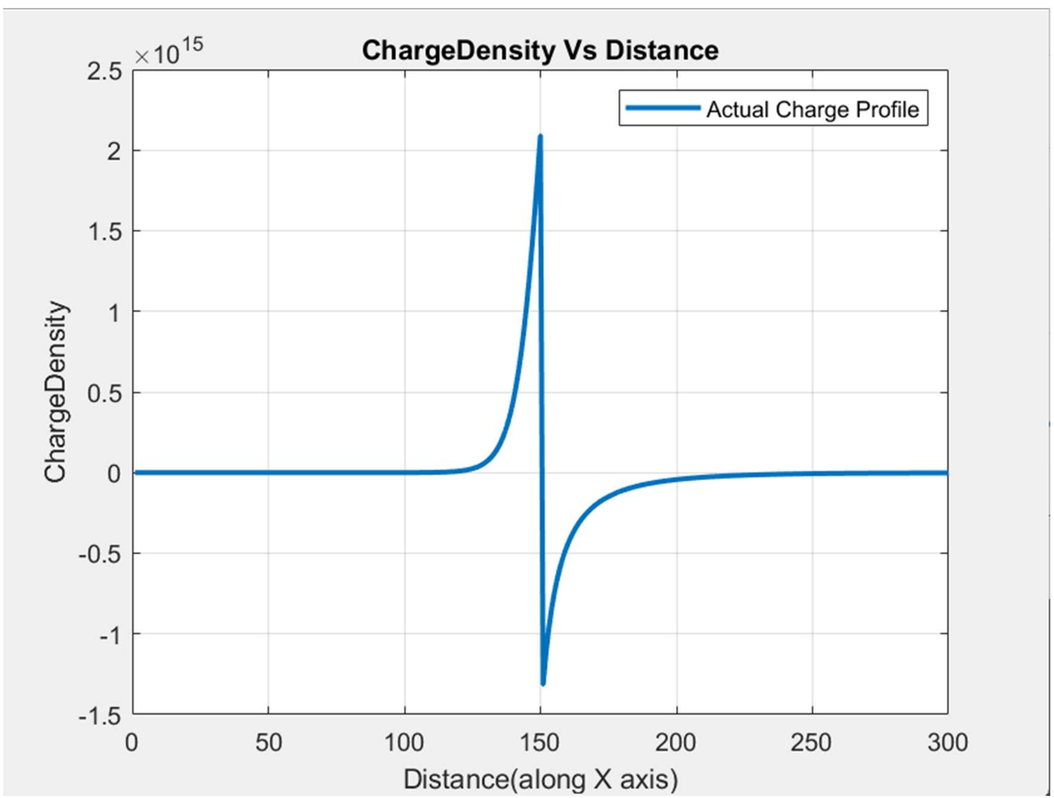
The length of N+ region is 2e-04 centimeters. The length of N region is from 2e-04 centimeters to 4e-04 centimeters.

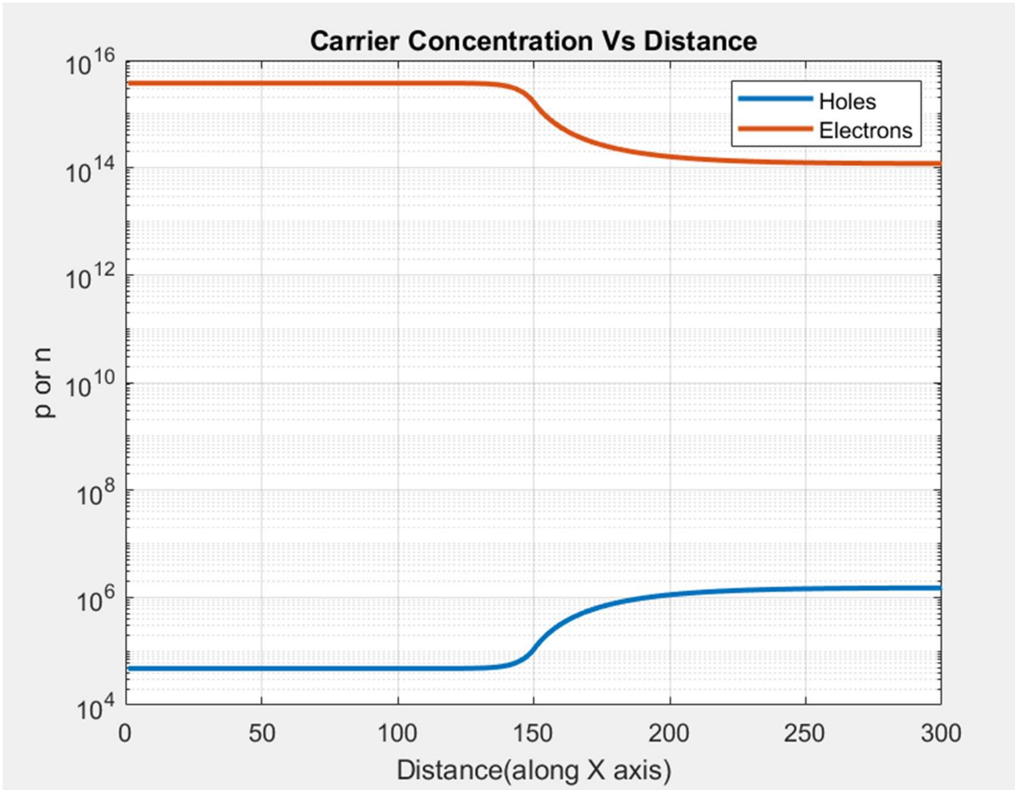
To plot all profiles from Q1, we used the same approach of solving the Poisson Equation using Newton Raphson method. However the Jacobian could not be inverted due to singularity matrix problem so LU decomposition method was used to find the inverse of Jacobian.

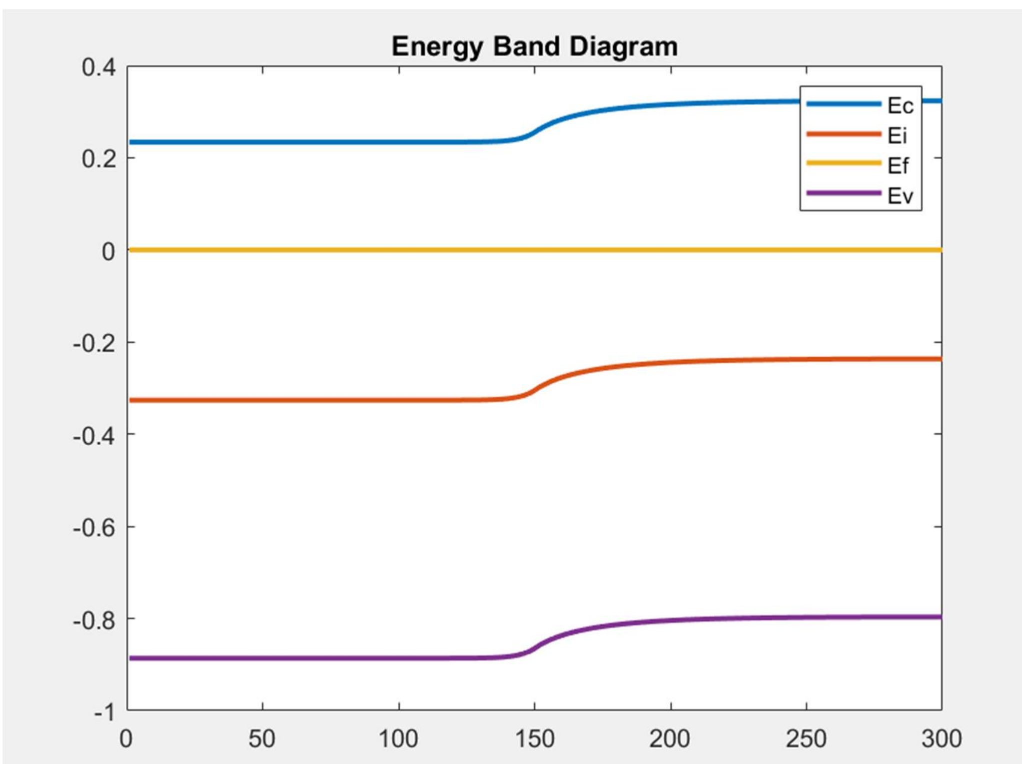
The plots obtained are as follows-




Electric Field Vs Distance
Electric Field
3000
2500
2000
1500
1000
500
0
-500
0
50
100
150
200
250
300
Distance(along X axis)
Electric Field


ChargeDensity Vs Distance
×10^15
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
ChargeDensity
0
50
100
150
200
250
300
Distance(along X axis)
Actual Charge Profile


Carrier Concentration Vs Distance
Holes
Electrons
p or n
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
0
50
100
150
200
250
300
Distance(along X axis)


Energy Band Diagram
Ec
Ei
Ef
Ev
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300