EE 735: ASSIGNMENT 2

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PROBLEM 1

SIMULATION APPROACH

(i) Abrupt Junction

Given,

Length of p-type region $= 2 \times 10^{-6}\ m$, Length of n-type region $= 2 \times 10^{-6}\ m$, N-type region doping concentration $(N_d) = 1 \times 10^{15}\ /cm^3$, Built-in potential $(V_{bi}) = 0.6\ \text{V}$, $\epsilon_{Si} = 11.8$, $\varepsilon_0 = 8.85 \times 10^{-14}\ \text{F/cm}$, $n_i = 10^{10}\ /\text{cm}^3$, $\text{q} = 1.6 \times 10^{-19}\ \text{C}$

Now, Temperature $(T) = 300 + 1.5 \times 5 = 307.5\ K$

Thus, Thermal voltage $(V_t) = 0.026 \times \frac{307.5}{300} = 0.0266\ V$

The p-type region doping concentration (N_a) is calculated using the relation $V_{bi} = V_t ln\left(\frac{N_a N_d}{n_i^2}\right)$

Thus,

P-type region doping concentration, $N_a = \frac{n_i^2}{N_d} exp\left(\frac{V_{bi}}{V_t}\right) = 5.99 \times 10^{14}\ /cm^3$

Depletion width, $W_d = \sqrt{\frac{2\epsilon V_{bi}}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)} = 1.4456 \times 10^{-4}\ cm$

Now,

Depletion width in n-type region, $W_n = \left(\frac{N_a}{N_a + N_d}\right) \times W_d = 0.5418 \times 10^{-4}\ cm$

Depletion width in p-type region, $W_p = \left(\frac{N_d}{N_a + N_d}\right) \times W_d = 0.9038 \times 10^{-4}\ cm$

The Charge profile (ρ_v) of the depletion region is obtained after the above calculations. After that,

(A) The Electric field profile is obtained by integrating the Volume charge density (ρ_v) and finally the Voltage profile is calculated by integrating Electric field intensity (E). I have implemented Trapezoidal method for numerical integration and calculation of Electric field and Voltage profile with a step size of 0.0001.

(B) I have implemented LU Decomposition method for solving the Poisson's equation and calculating the Voltage profile (V). First the continuous partial derivative is converted into finite- difference equation of voltage such that, $[A][V] = -\frac{h^2}{\epsilon}[\rho_v]$ where, h is the step size of finite-difference equation, $[A]$ is the co-efficient matrix for implementing finite-difference and $\epsilon = \epsilon_{Si}\epsilon_0$. The solution for $[V]$ is obtained by LU Decomposition method. I have taken a step size of 0.001.

(C) I have implemented Gauss-Seidel method for solving the Poisson's equation and calculating the Voltage profile (V). First the continuous partial derivative is converted into finite-difference equation of voltage such that, $[A][V] = -\frac{h^2}{\epsilon}[\rho_v]$ where, h is the step size of finite-difference equation, $[A]$ is the co-efficient matrix for implementing finite-difference and $\epsilon = \epsilon_{Si}\epsilon_0$. The solution for $[V]$ is obtained using Gauss-Seidel method. I have taken a step size of 0.01.

(ii) Linearly Graded Junction

Given,

Length of p-type region $= 2 \times 10^{-6}\ m$, Length of n-type region $= 2 \times 10^{-6}\ m$, Built-in potential $(V_{bi}) = 0.6\ \mathrm{V}$, $\epsilon_{Si} = 11.8$, $\varepsilon_0 = 8.85 \times 10^{-14}\ \mathrm{F/cm}$, $n_i = 10^{10}\ /\mathrm{cm}^3$, $\mathrm{q} = 1.6 \times 10^{-1}\ \ \mathrm{C}$.

Now, Temperature $(T) = 300 + 1.5 \times 5 = 307.5\ K$

Thus, Thermal voltage $(V_t) = 0.026 \times \frac{307.5}{300} = 0.0266\ V$

If the impurity gradient of the linearly graded junction be a.

Depletion width, W $= \left(\frac{12\epsilon \mathrm{V_{bi}}}{\mathrm{qa}}\right)^{\frac{1}{3}}$ and Built-in potential, $V_{bi} = 2V_t ln\left(\frac{aW}{2n_i}\right)$

By solving above two equations,

$$W = \sqrt{\frac{6\epsilon V_{bi}}{qn_i} e^{\frac{-V_{bi}}{2V_t}}} = 1.7421 \times 10^{-4}\ cm$$

$$a = \frac{2n_i}{W} e^{\frac{V_{bi}}{2V_t}} = 8.89 \times 10^{18}\ /cm^4$$

The Charge profile (ρ_v) of the depletion region is obtained after the above calculations. After that,

(A) The Electric field profile is obtained by integrating the Volume charge density (ρ_v) and finally the Voltage profile is calculated by integrating Electric field intensity (E). I have implemented Trapezoidal method for numerical integration and calculation of Electric field and Voltage profile with a step size of 0.0001.

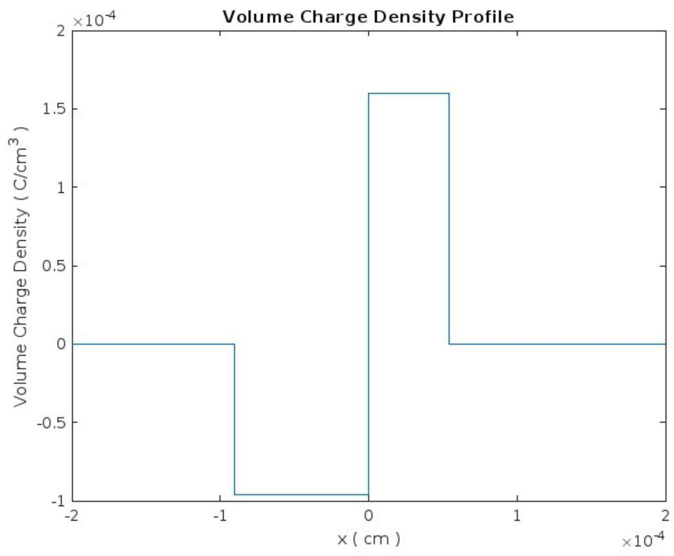
(B) I have implemented LU Decomposition method for solving the Poisson's equation and calculating the Voltage profile (V). First the continuous partial derivative is converted into finite- difference equation of voltage such that, $[A][V] = -\frac{h^2}{\epsilon}[\rho_v]$ where, h is the step size of finite-difference equation, $[A]$ is the co-efficient matrix for implementing finite-difference and $\epsilon = \epsilon_{Si}\epsilon_0$. The solution for $[V]$ is obtained by LU Decomposition method. I have taken a step size of 0.01.

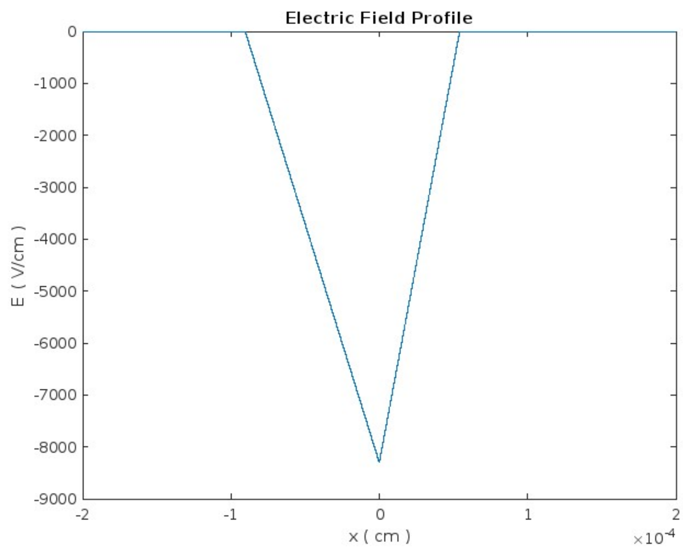
(C) I have implemented Gauss-Seidel method for solving the Poisson's equation and calculating the Voltage profile (V). First the continuous partial derivative is converted into finite-difference equation of voltage such that, $[A][V] = -\frac{h^2}{\epsilon}[\rho_v]$ where, h is the step size of finite-difference equation, $[A]$ is the co-efficient matrix for implementing finite-difference and $\epsilon = \epsilon_{Si}\epsilon_0$. The solution for $[V]$ is obtained using Gauss-Seidel method. I have taken a step size of 0.01.

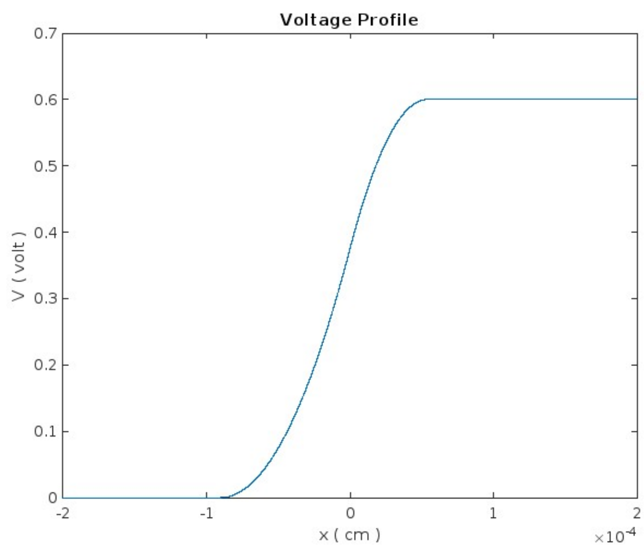
RESULT

(i) Abrupt Junction

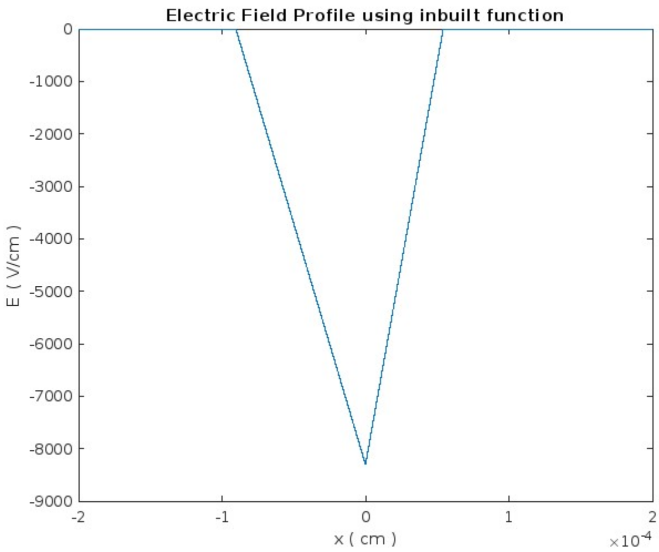
(A) The Charge profile, Electric Field Profile and Voltage Profile obtained using Trapezoidal method are given below,

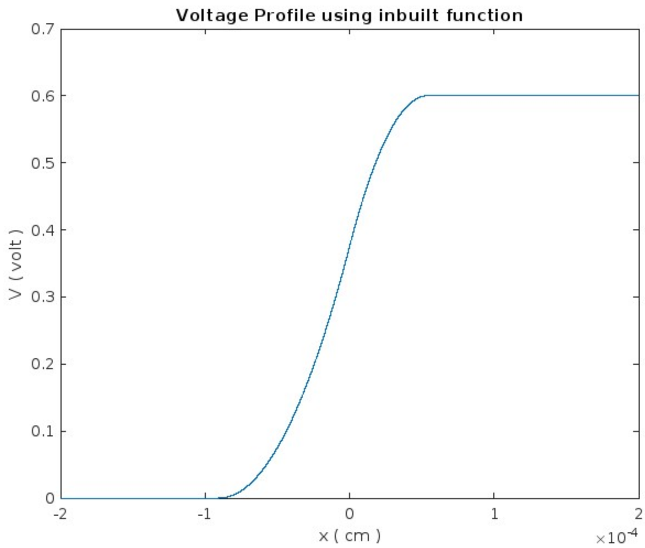

Volume Charge Density Profile
Volume Charge Density (C/cm^3)
x (cm)
$\times 10^{-4}$
2
1.5
1
0.5
0
-0.5
-1
-2
-1
0
1
2


Electric Field Profile
E (V/cm)
x (cm)
$\times 10^{-4}$
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
-2
-1
0
1
2

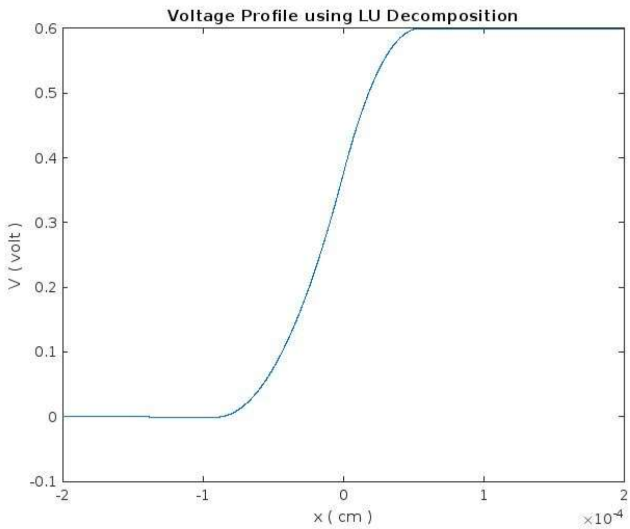

Voltage Profile
V (volt)
x (cm)
$\times 10^{-4}$
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-2
-1
0
1
2

The plots using the in-built functions are given below,

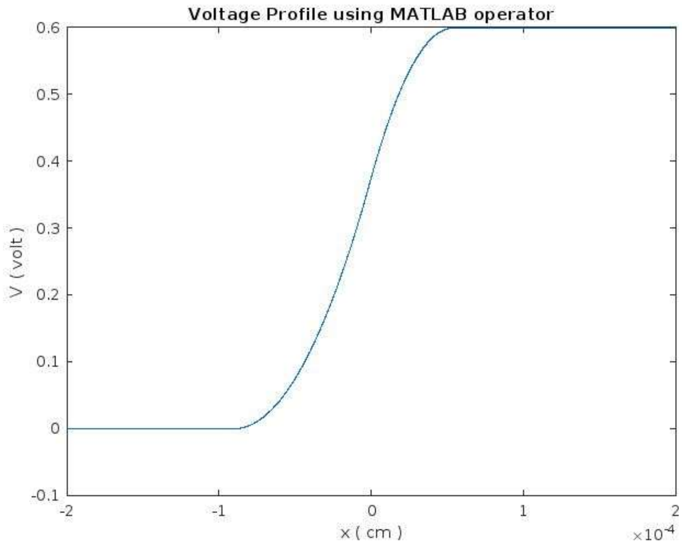




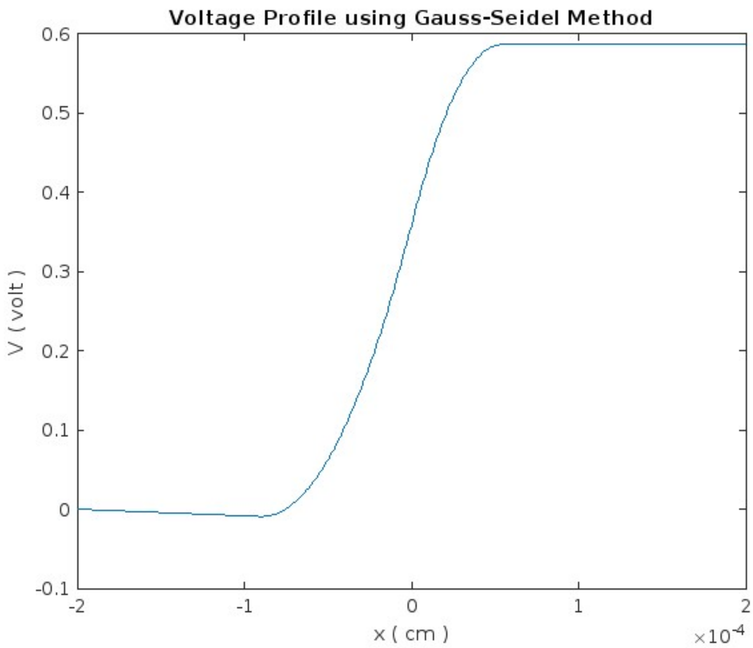
(B) The Voltage Profile obtained using LU Decomposition method is given below,



The Voltage Profile obtained using MATLAB Operator is given below,

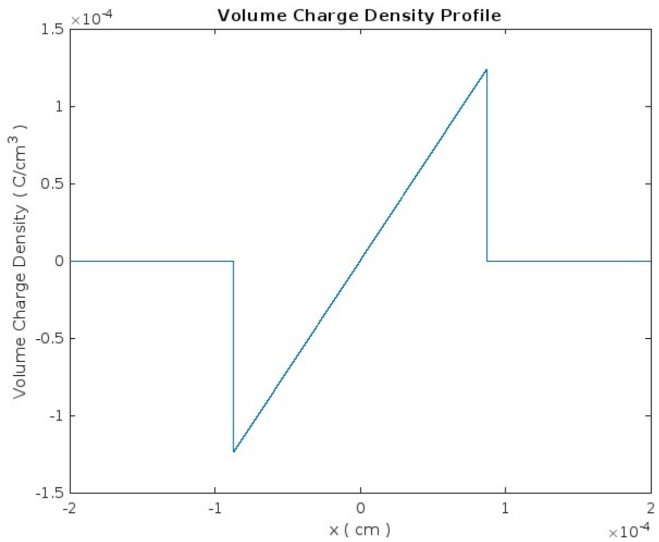


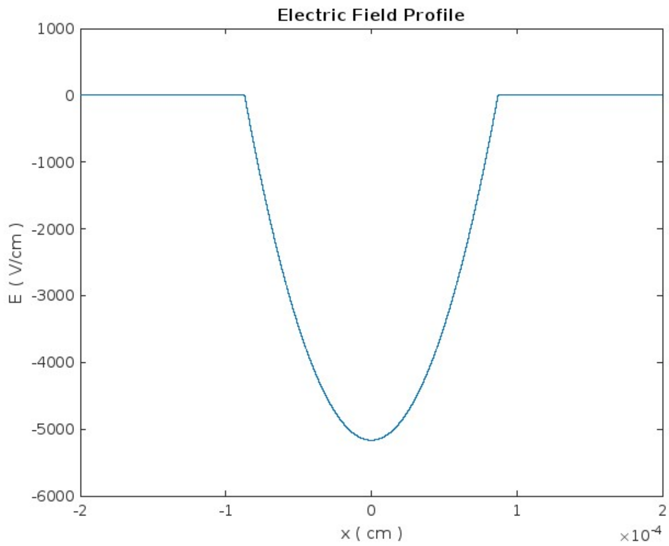
(C) The Voltage Profile obtained using Gauss-Seidel method is given below,

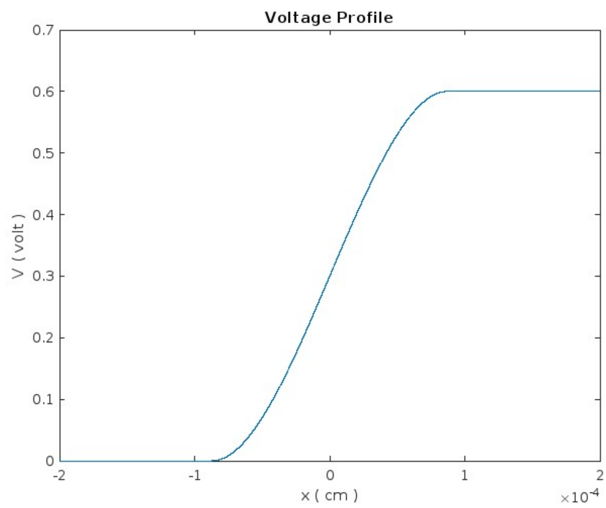


(ii) Linearly Graded Junction

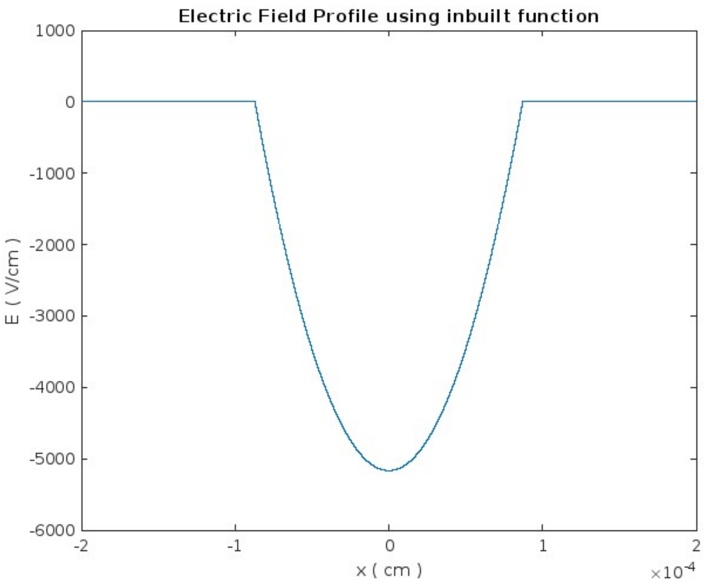
(A) The Charge profile, Electric Field Profile and Voltage Profile obtained using Trapezoidal method are given below,

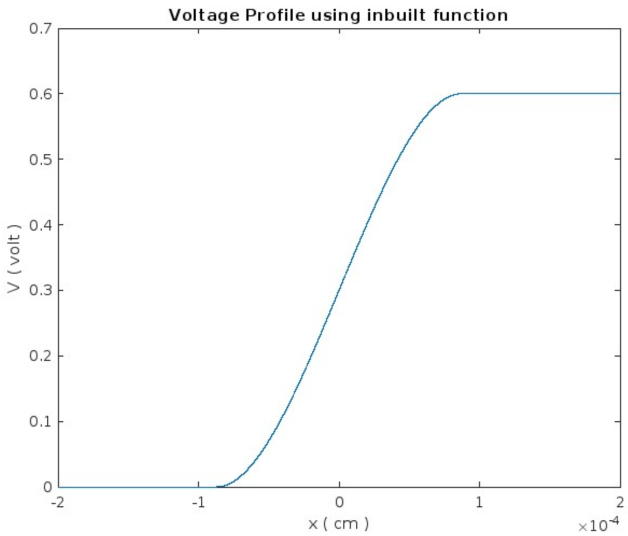




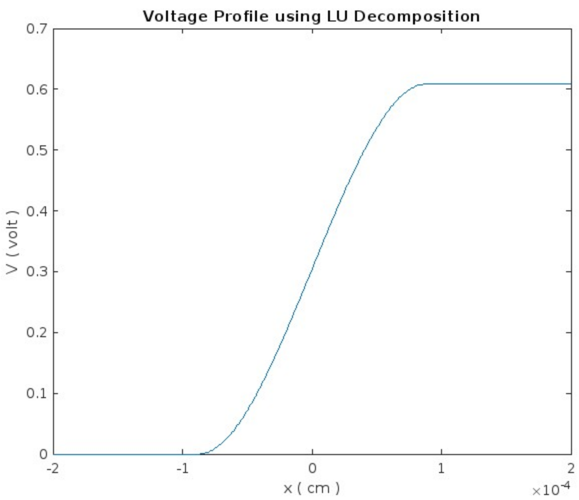


The plots using the in-built functions are given below,

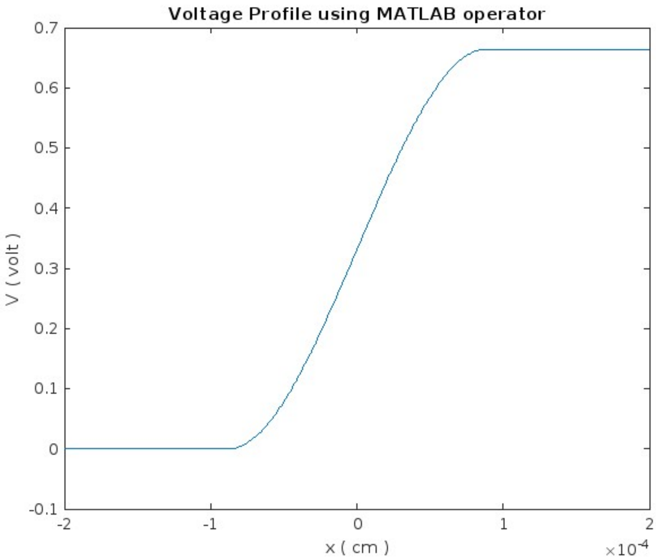




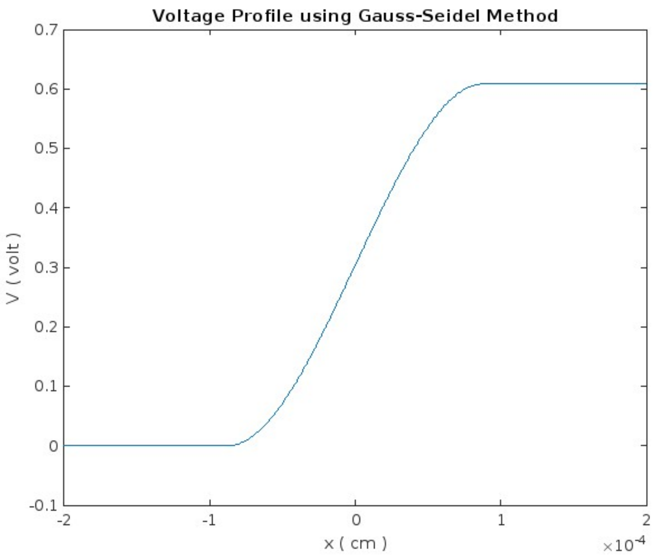
(B) The Voltage Profile obtained using LU Decomposition method is given below,



The Voltage Profile obtained using MATLAB Operator is given below,



(C) The Voltage Profile obtained using Gauss-Seidel method is given below,



CONCLUSION

(i) Abrupt Junction

(A) The built-in potential obtained using implemented Trapezoidal method and inbuilt MATLAB function is exactly equal. The value of the built in potential obtained is 0.600128 V. The MATLAB function used for comparison is *cumtrapz()*.

(B) The built-in potential obtained using LU Decomposition method and inbuilt MATLAB operator is exactly equal. The value of the built in potential obtained is 0.599660 V.

(C) The built-in potential obtained using Gauss-Seidel method is 0.586815 V

(ii) Linearly Graded Junction

(A) The built-in potential obtained using implemented Trapezoidal method and inbuilt MATLAB function is exactly equal. The value of the built in potential obtained is 0.600014 V. The MATLAB function used for comparison is *cumtrapz()*.

(B) The built-in potential obtained using LU Decomposition method is 0.608194 V and inbuilt MATLAB operator is 0.663274 V.

(C) The built-in potential obtained using Gauss-Seidel method is 0.608194 V

PROBLEM 2

SIMULATION APPROACH

Given,

$N_A = 1 \times 10^{17}\ /\mathrm{cm}^3$ and $N_D = 1 \times 10^{15}\ /\mathrm{cm}^3$

Assumptions made,

Boron is taken as acceptor type impurity with ionization energy of 0.045 eV and Phosphorus is taken as donor type impurity with ionization energy of 0.045 eV.

Effective density of states in conduction band, $N_C = 2.8\ \times 10^{19}\ /\mathrm{cm}^3$ and

Effective density of states in valence band, $N_V = 1.04\ \times 10^{19}\ /\mathrm{cm}^3$

The energy band-gap of Si is considered 1.12 eV at a temperature of 300 K.

Thermal voltage, $V_t = 0.0258\ \mathrm{V}$

The valence band is taken as reference for calculation of Fermi energy level (E_F). The calculation is done by solving Charge Neutrality Equation using Newton-Raphson Method.

RESULT & CONCLUSION

The Fermi Level is located 0.124484 eV above the valence band.

The Energy Band diagram is shown below,