EE 735: ASSIGNMENT 5

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October 1st, 2023

QUESTION 1

Consider a Si bar of length 0.1 μm and thickness 0.1 μm. Assume it is doped N-type with a density of $10^{16}\ cm^{-3}$. Simulate I-V (Voltage: 0 to 3V) for the following mobility models:

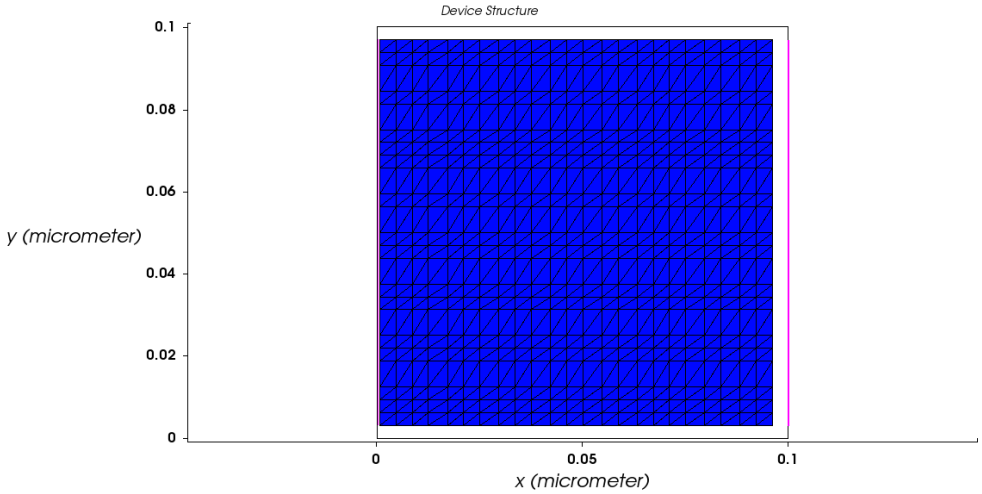
(a) Constant Mobility
(b) Doping Dependence
(c) High-field Saturation

Now do the following for each of the above three cases :

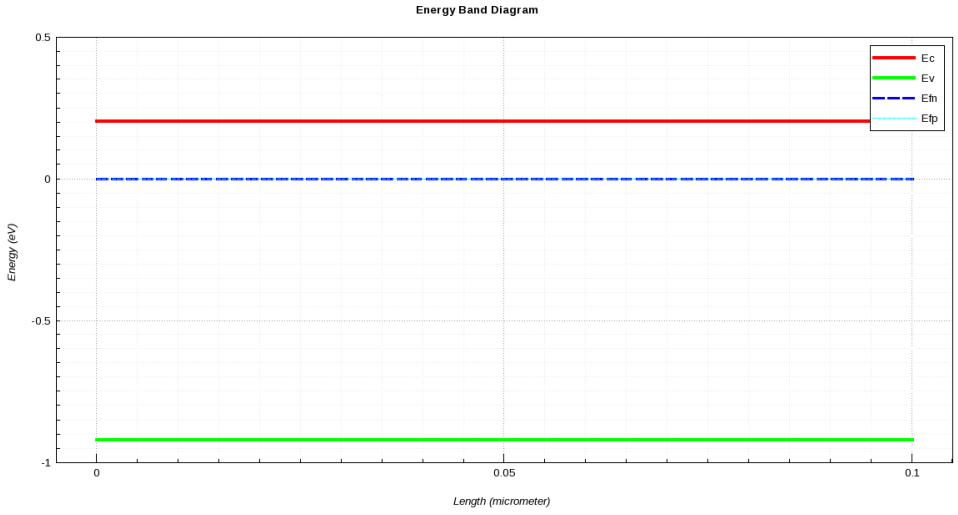
(i) Plot TCAD simulated device structure showing mesh points.
(ii) Simulated Band diagram (TCAD as well as Manual drawing) in equilibrium.
(iii) Plot I-V characteristics of the device and make an observation with appropriate comment if any to these various model's plot.

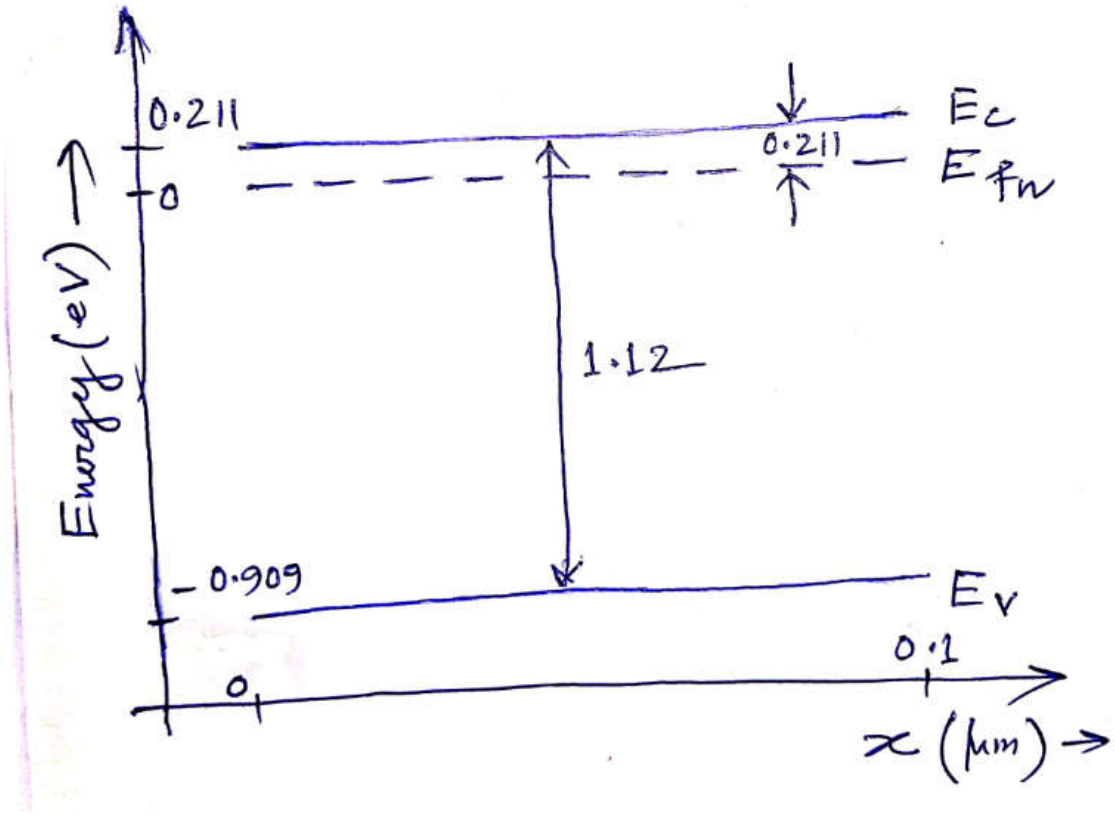
RESULT AND OBSERVATION :

The device structure with mesh points is given below,



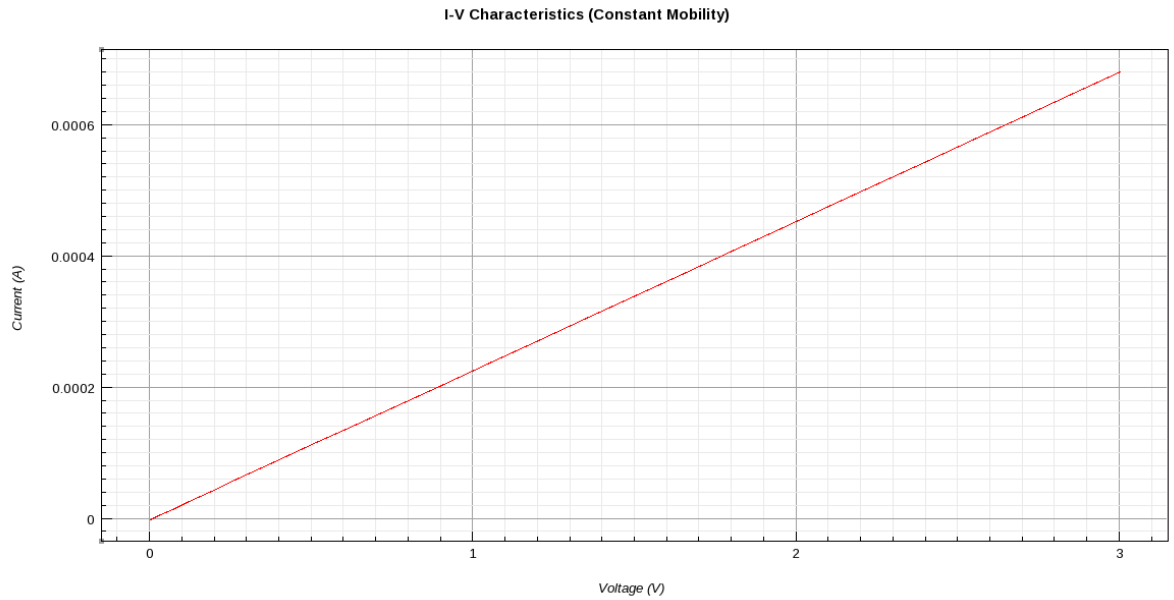
The Energy Band Diagram for the device is given below,



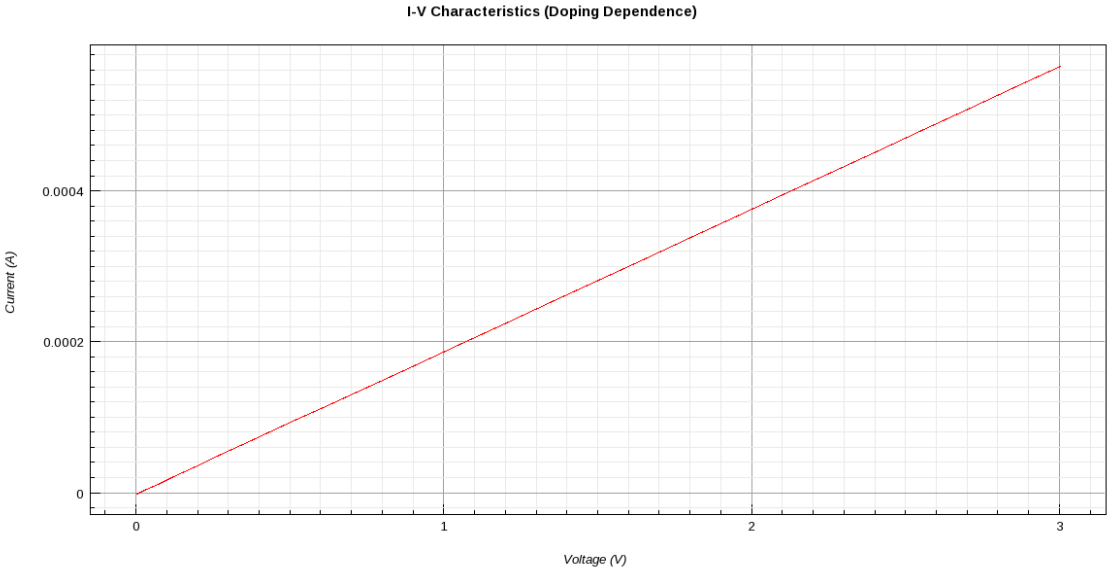


The I-V Characteristics for various models are given below,

(a) Constant Mobility :

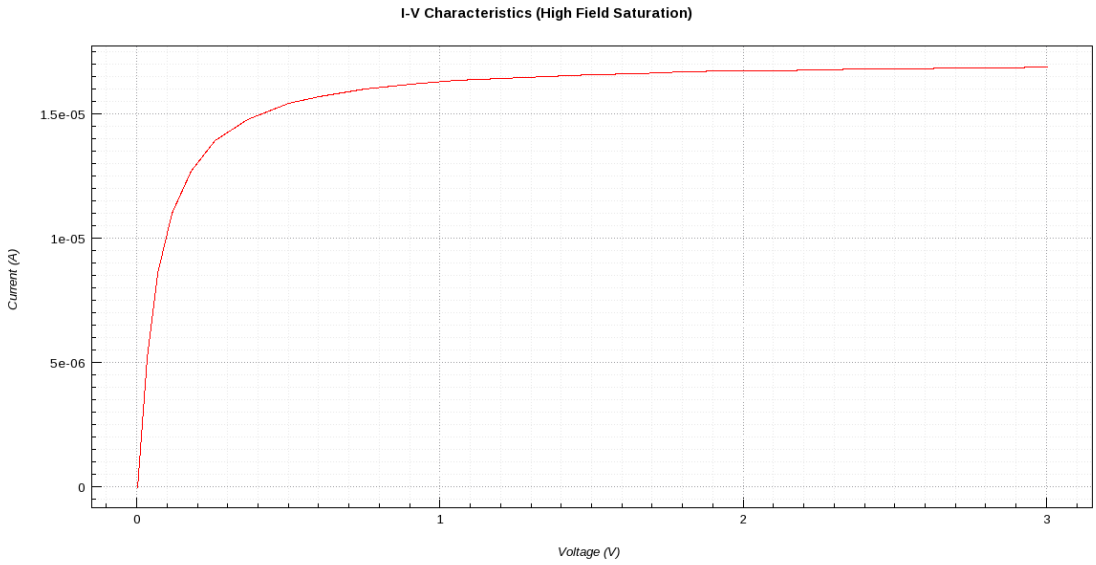


(b) Doping Dependence :



For Constant Mobility and Doping Dependence Mobility model the N-type Silicon bar acts as a simple resistor as the I-V characteristics is linear. The doping dependence model captures the effect of doping concentration as the mobility of electron decreases when doping concentration increases there by reducing the conductivity as reflected in the I-V characteristics since there is net reduction in current for Doping Dependence Mobility model compared to Constant Mobility model.

(c) High-field Saturation :



For High-field Saturation Mobility model the current saturates for higher voltage as the drift velocity of electrons saturates for higher electric field , since current is directly proportional to drift velocity it is reflected in I-V characteristics.

QUESTION 2

Let us start with simple design of a uniform resistor in TCAD and see its characteristics Consider a Si bar of length 10 μm and the width being 2 μm. Assume it is doped P-type with a density of $10 \times 10^{18}\ cm^{-3}$. Apply bias to left contact and simulate I-V (Voltage: 0 to 3 V) for the following conditions:

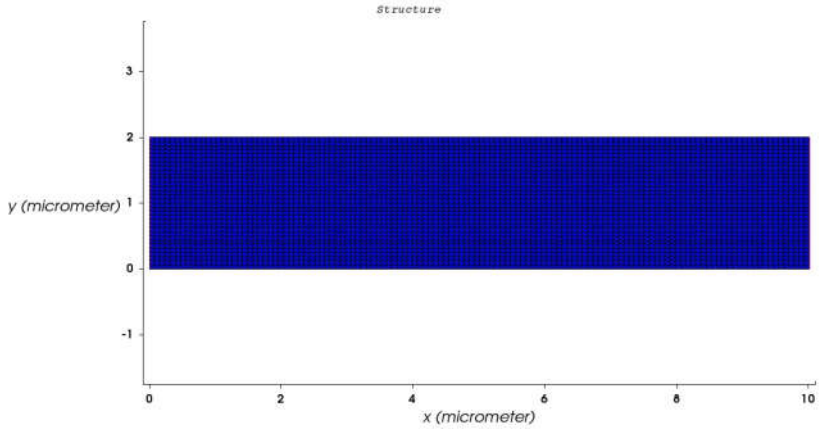
(a) both contacts are ohmic
(b) left contact is ohmic and right contact is Schottky ($\varphi_B = 0.3\ eV$)

Now do the following for each of the above three cases :

(i) Plot TCAD simulated device structure showing mesh points.
(ii) Band diagram (TCAD as well as Manual drawing) in equilibrium.
(iii) I-V characteristic of device and put a qualitative analysis for the observed plot.

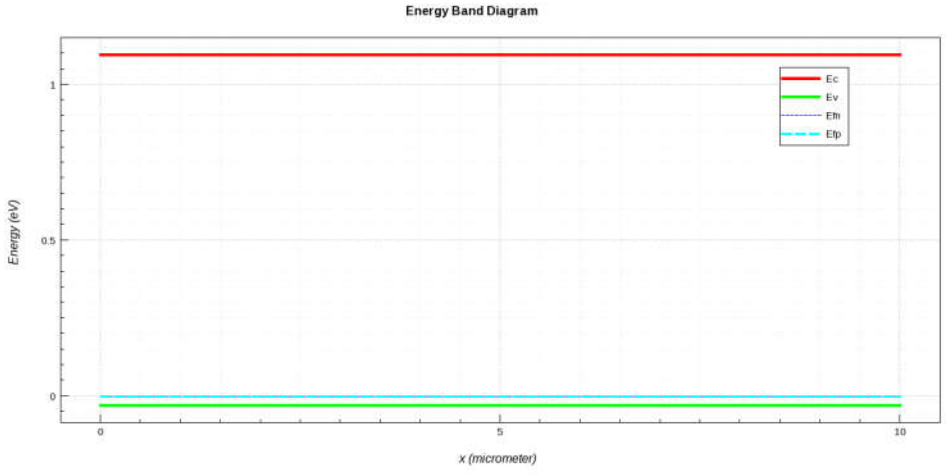
RESULT AND OBSERVATION :

The device structure with mesh points is given below,



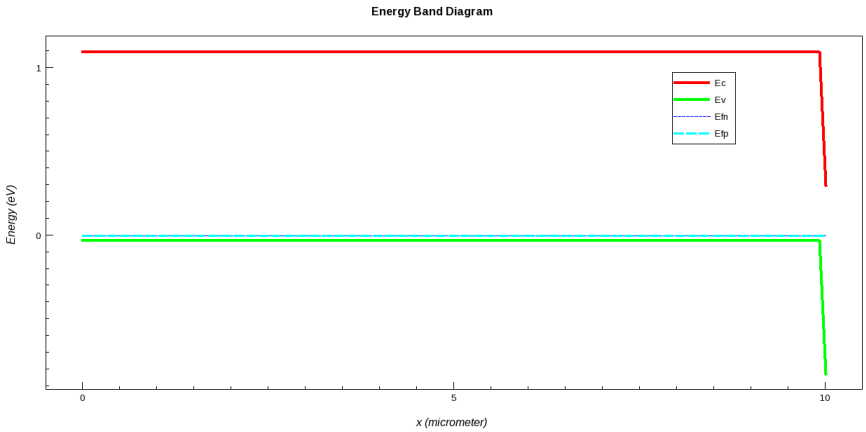
The Energy Band Diagram for the device is given below,

(a) Both contacts are Ohmic :



The doping concentration of the P-type Si bar is high. Thus, its Fermi level is very close to the valence band and it behaves as a degenerate semiconductor which is ideal for Ohmic contacts.

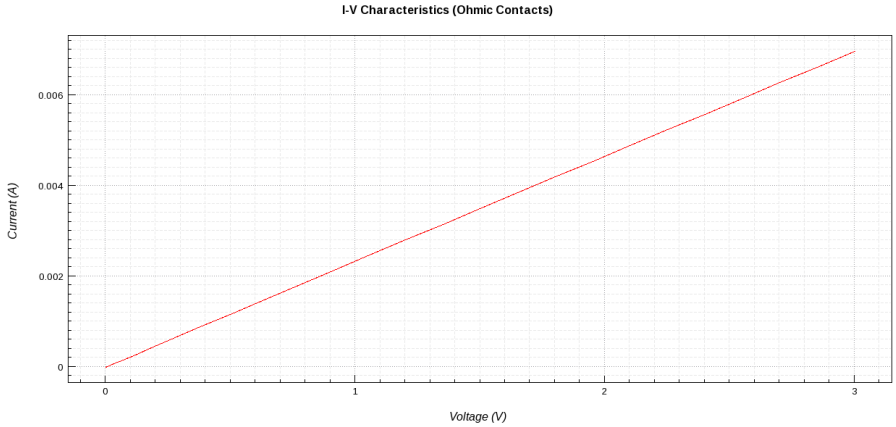
(b) Left contact is Ohmic and right contact is Schottky :



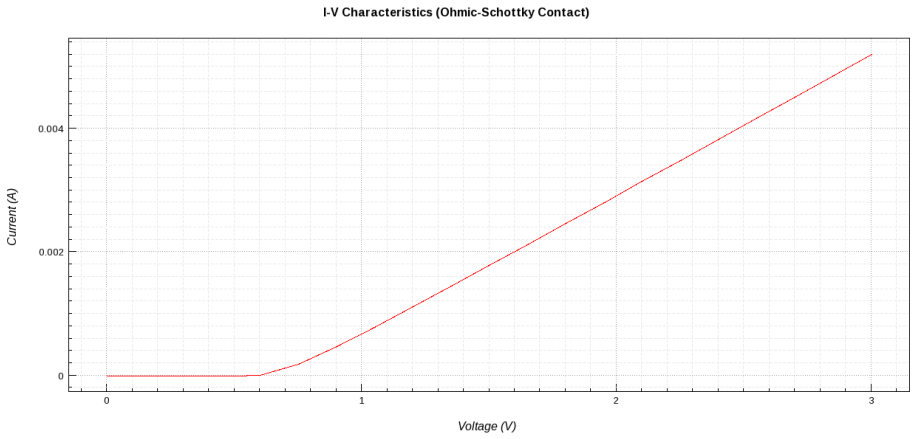
Due to work function difference between semiconductor and metal, depletion region is formed close to the metal-semiconductor contact and the energy band bends near the right sided contact.

The I-V Characteristics for various models are given below,

(a) Both contacts are Ohmic :



(b) Left contact is Ohmic and right contact is Schottky :

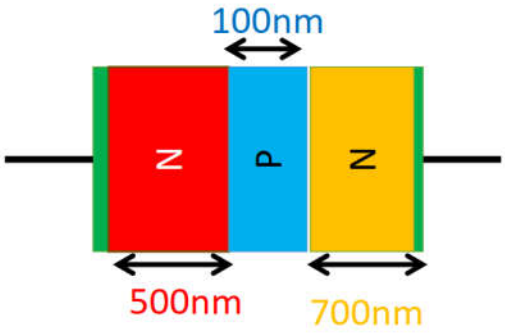


The uniform resistor made of P-type Si bar is modelled using High-field Saturation mobility model. The I-V characteristics is linear for given voltage range thereby acting as a uniform resistor as designed.
The Schottky contact has a barrier potential of 0.3 eV which restricts the current for value of voltages less than 0.6 V. For voltage greater than 0.6 V the I-V characteristics is linear and the P-type Si bar acts as a uniform resistor.

QUESTION 3

Consider a Si based two terminal NPN device as shown in following figure with indicated dimension and doping concentration.
Simulate the above structure in TCAD and do the following:

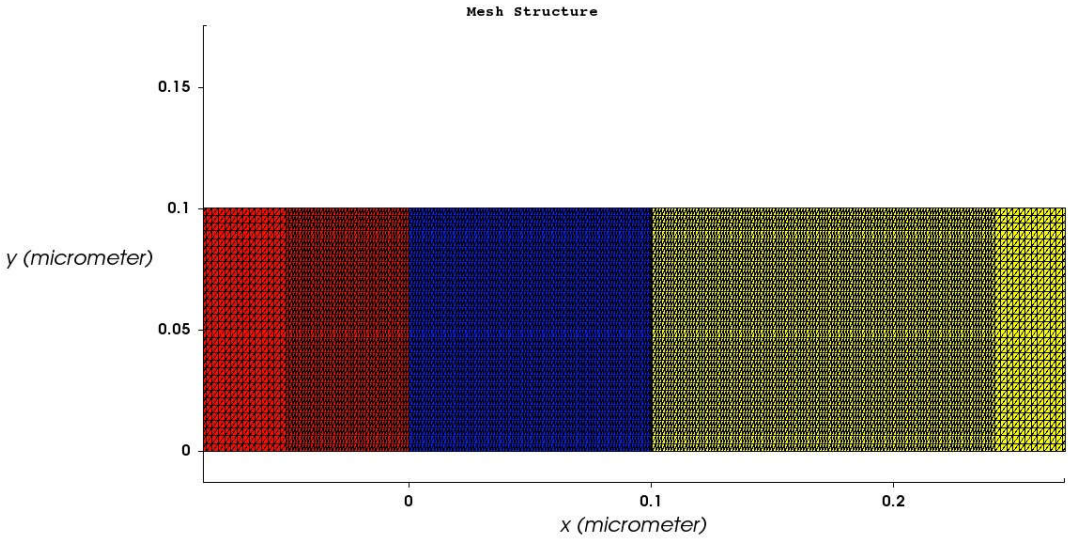
(i) Plot Device Structure showing mesh points.
(ii) Plot the Doping concentration, Donar Concentration, and acceptor concentration.
(iii) Plot the space charge density, Electric field, Electric potential and Energy Band diagram at equilibrium.
(iv) Now apply -0.5 volt at left terminal and plot the Electric field, Electric potential and Energy Band diagram.



Regions	Constant Doping density (cc)
Red colored N region	10E+18(Arsenic doped)
P-Region	1E+14 (Boron doped)
Orange colored N-Regio	3E+16 (Arsenic doped)

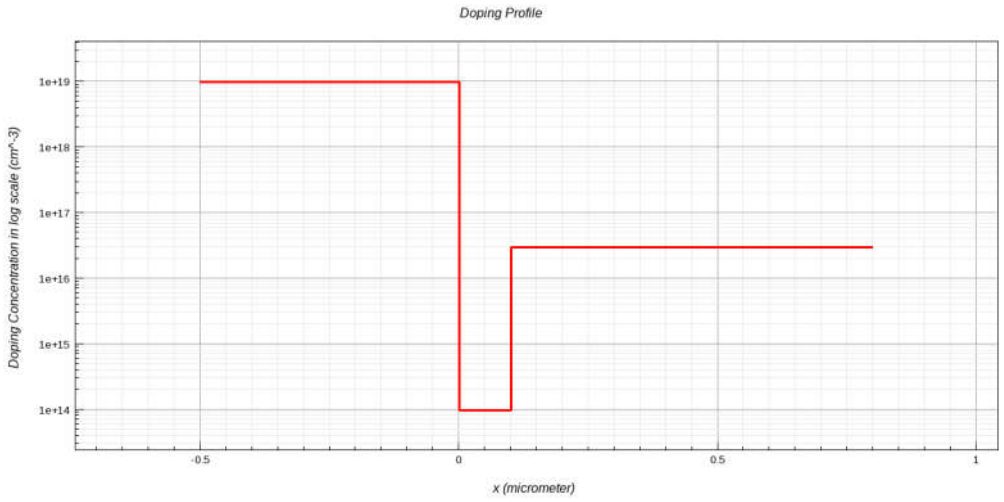
RESULT AND OBSERVATION :

The device structure with mesh points is given below,

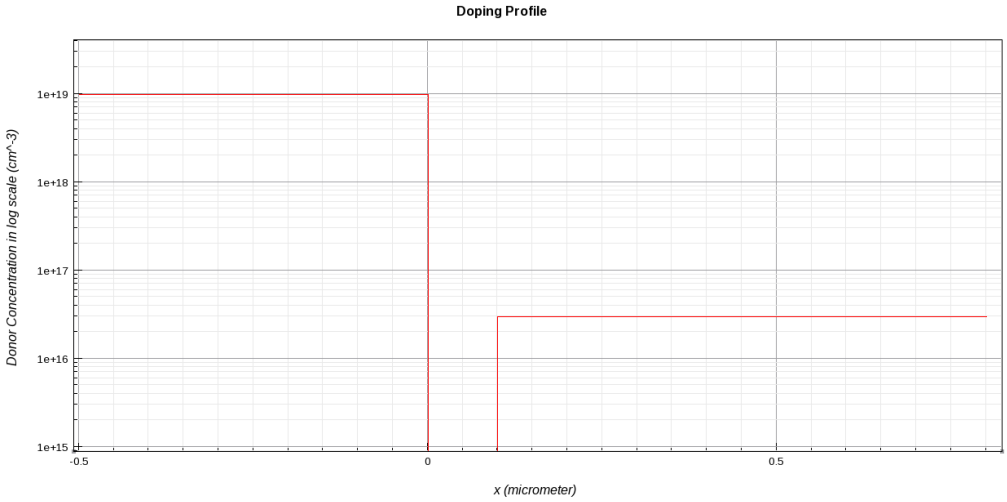


The doping concentration, donor concentration, and acceptor concentration profile are given below,

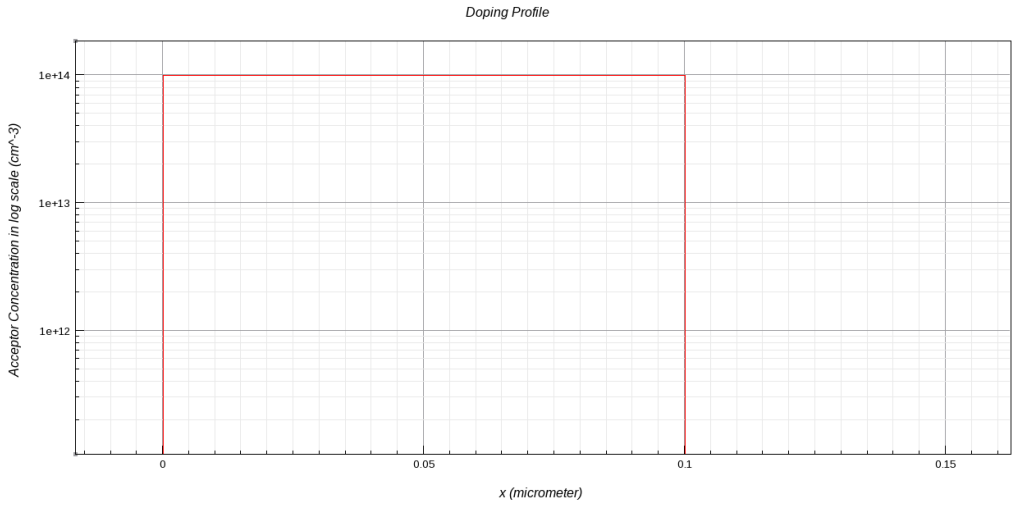
Doping Concentration :



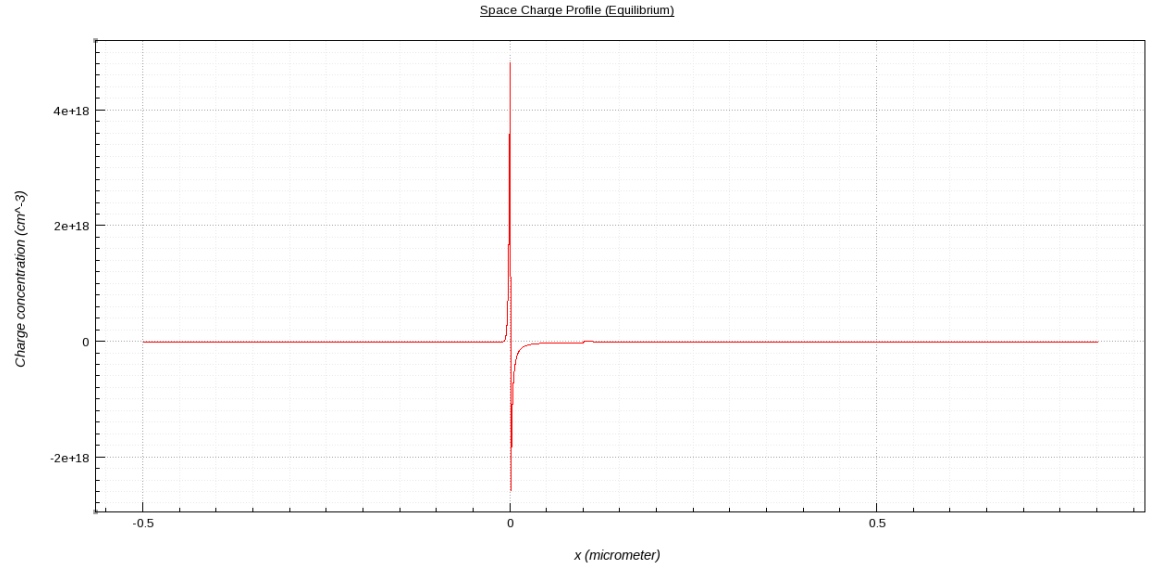
Donor Concentration :

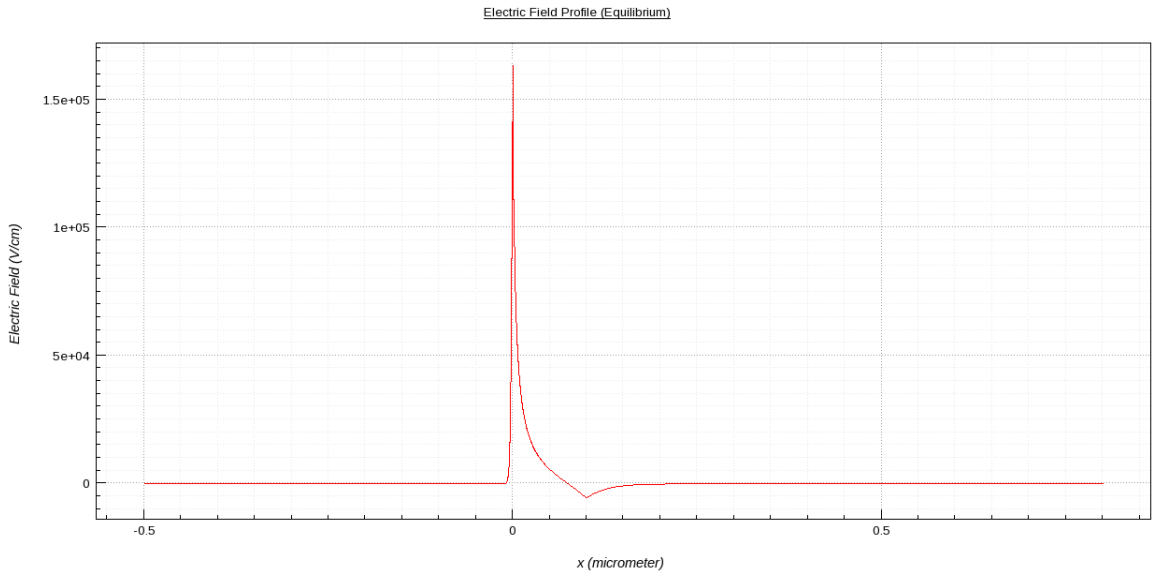


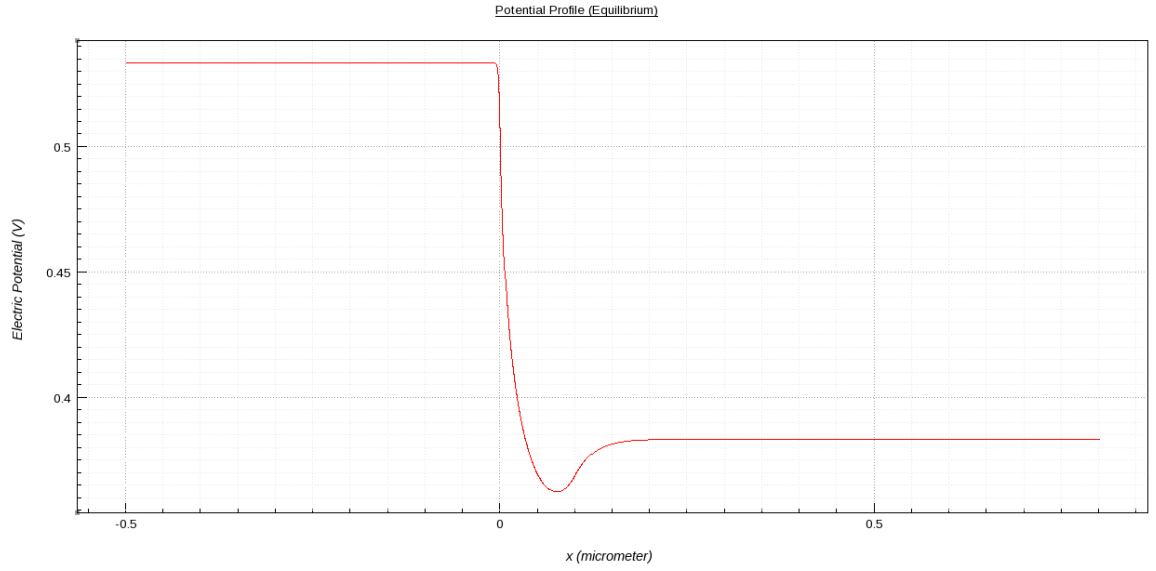
Acceptor Concentration :

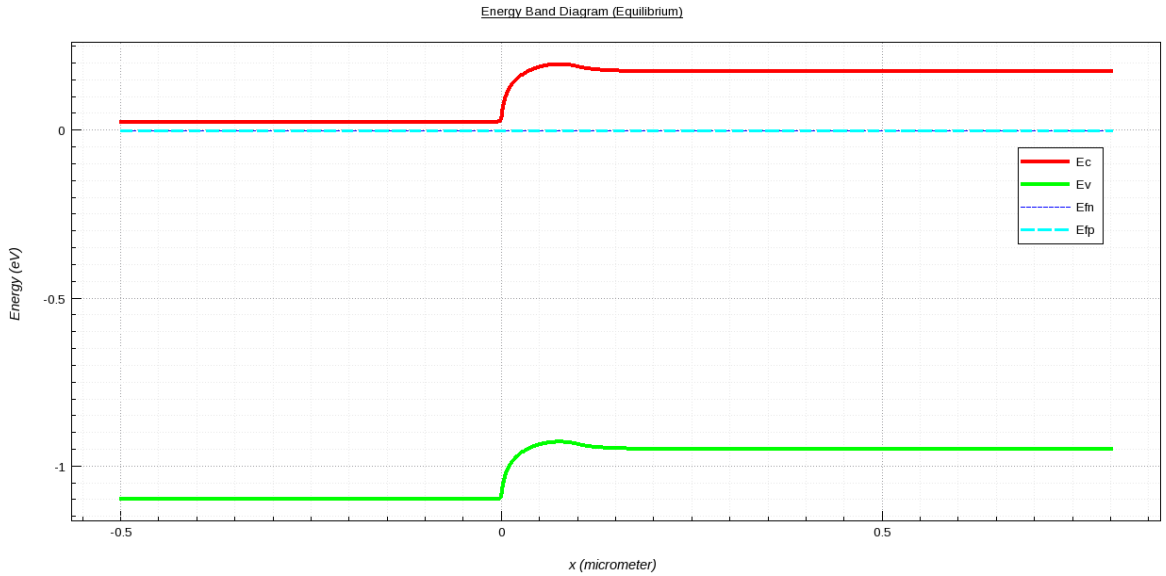


The plot of space charge density, Electric field, Electric potential and Energy Band diagram at equilibrium are given below,

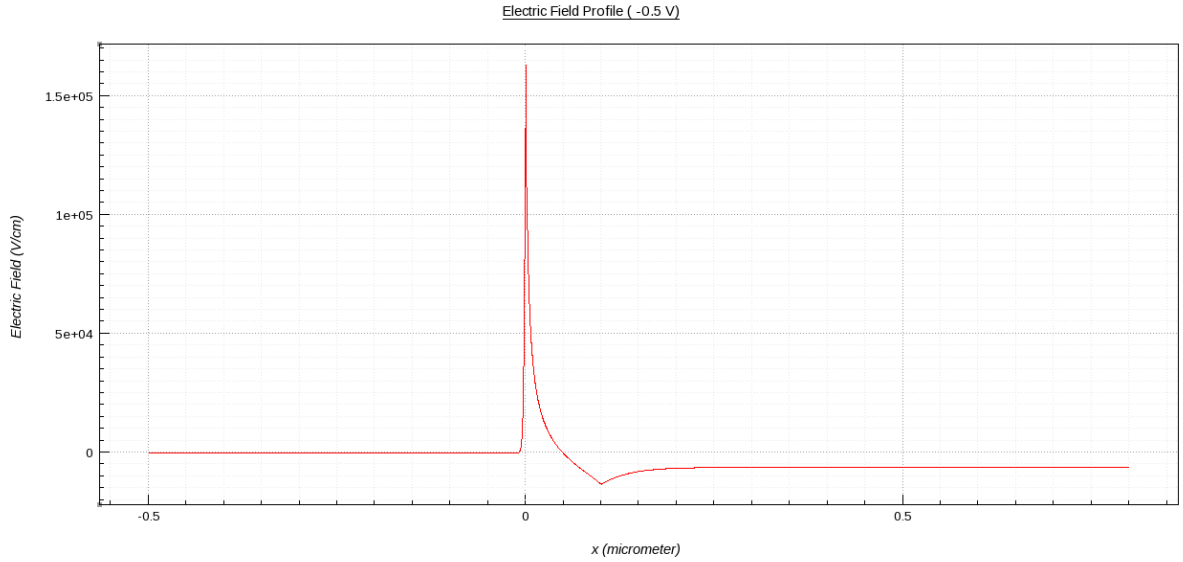


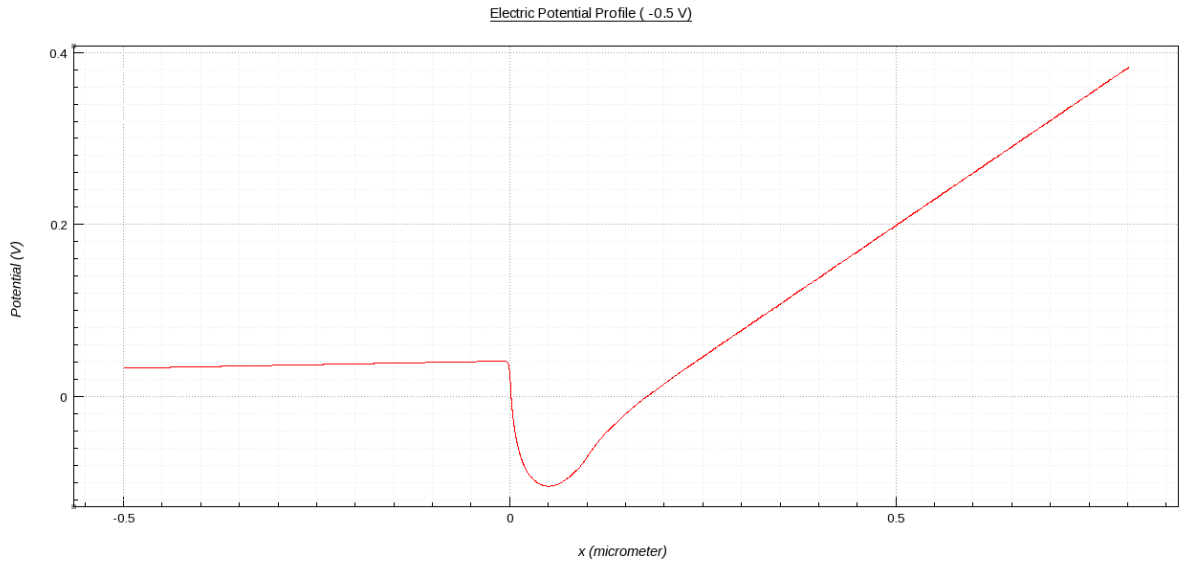


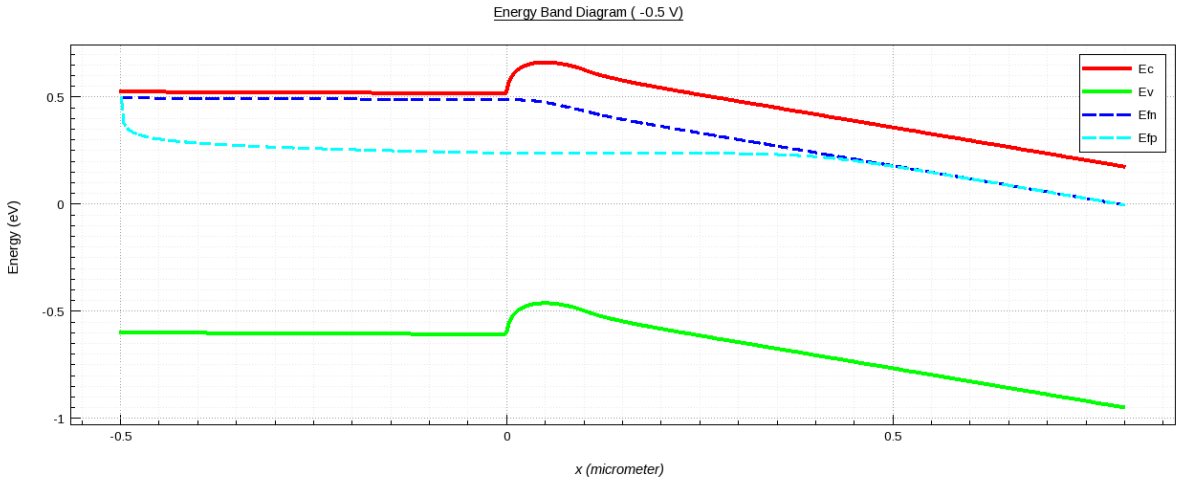




The plot of Electric field profile, Electric potential profile and Energy Band diagram at an applied voltage of – 0.5 V at the left terminal are given below,






Energy Band Diagram (-0.5 V)
Ec
Ev
Efn
Efp
Energy (eV)
0.5
0
-0.5
-1
-0.5
0
0.5
x (micrometer)