EE 735

Assignment 7

TCAD Sprocess Simulation

1. Create a p-n junction by implanting Phosphorus on a Boron substrate. Check the impact of (a) implant energy (use 10, 20 and 40 keV) and (b) implant dose (use 1E14, 5E14 and 1E15 cm^{-3} for comparison) on the peak concentration and junction depth by plotting the net-active concentration (N_D-N_A) along the device depth. Explain your observations.

Ans.:

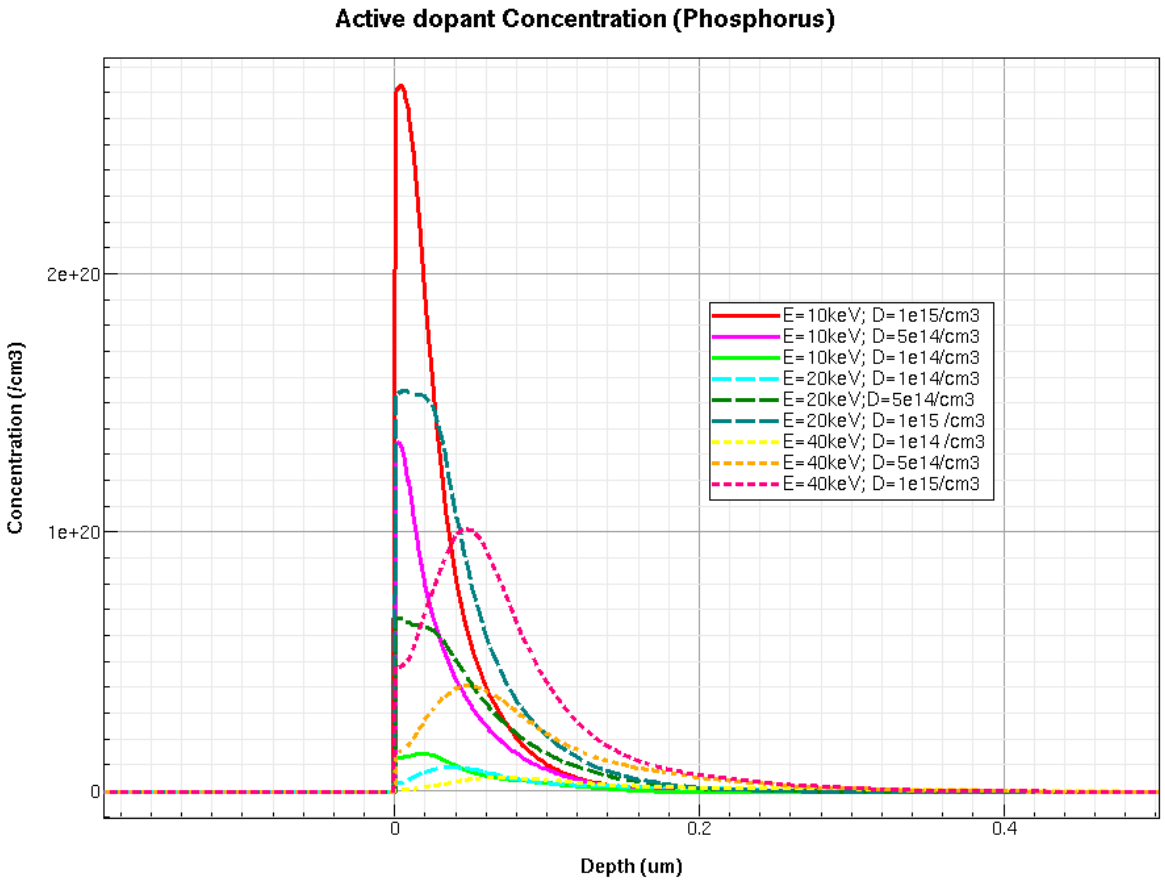

Fig.1(a). Active dopant concentration (phosphorus) for different implant energies and doses.

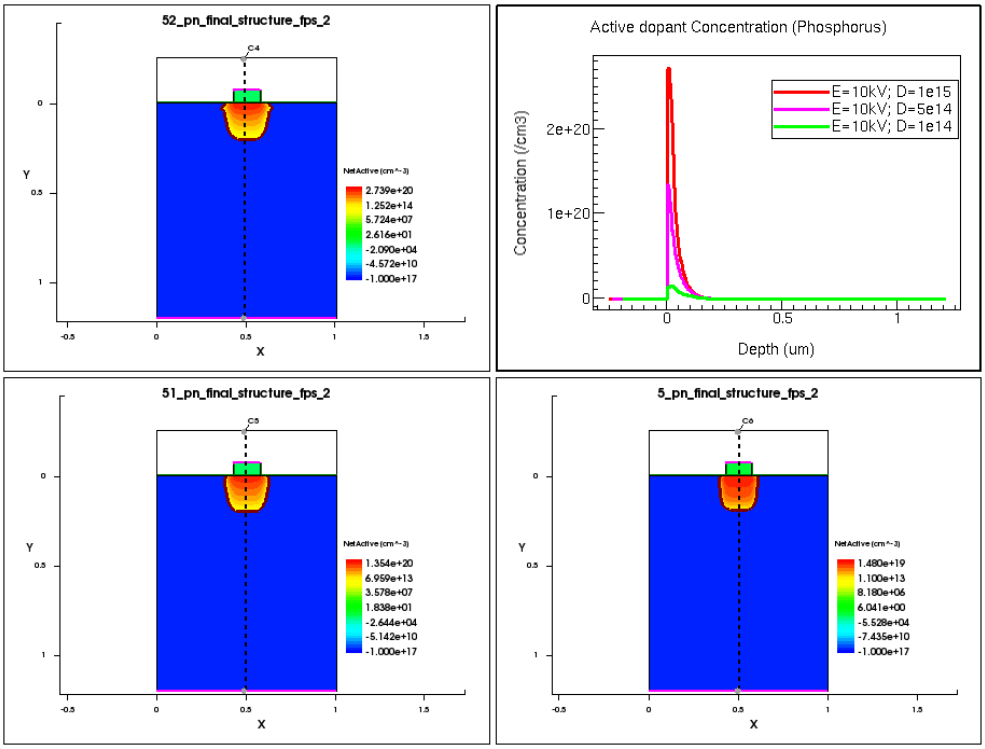

Fig.1(b). Active dopant concentration (phosphorus) and device structure for implant energy=10keV and different doses.

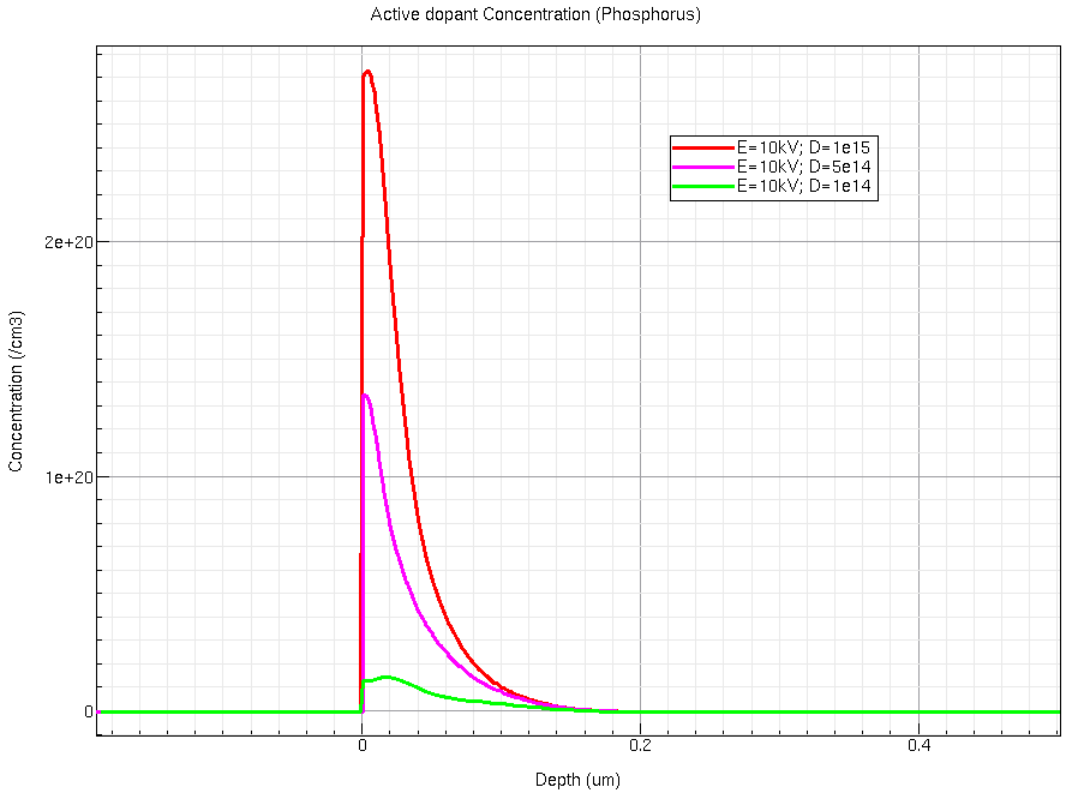

Fig.1(c). Active dopant concentration (phosphorus) for implant energy=10keV and different doses.

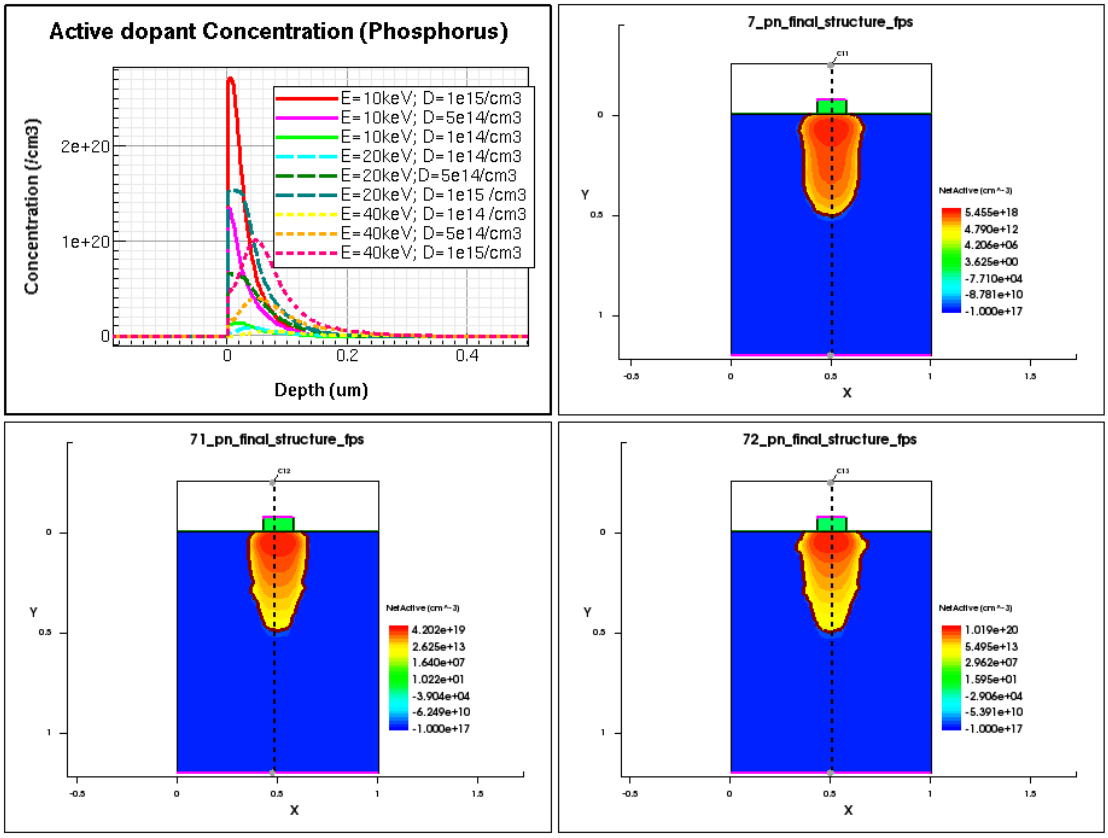

Fig.1(d). Active dopant concentration (phosphorus) and device structure for implant energy=40keV and different doses.

Implanted dose of phosphorus is introduced through a window in mask. These ions travel a distance in substrate proportional to their energy. As can be seen in above device structures the ions not only travel in vertical direction but a very small distance in lateral direction also as compared to vertical distance travelled. This lateral travel can be due to scattering events that they face in the substrate from the native atoms and also from other dopant ions. All the ions do not diffuse to equal distances. This is because some get scattered in the beginning and some after travelling some distance and some after losing their whole energy through small scattering events. Usually the scattering is high in the begging so the concentration of dopant ions decreases with increasing depth.

With increasing implant energy, the ions can travel more distance. So, the more number of ions travel larger distance without getting scattered in the beginning. Therefore, the peak concentration decreases and junction depth increases.

Junction depth also increases with increasing dose as can be seen in fig. 1(c).

2. In question 1 use **Arsenic** instead of Phosphorus and compare the results. Explain the observations.

Ans.:

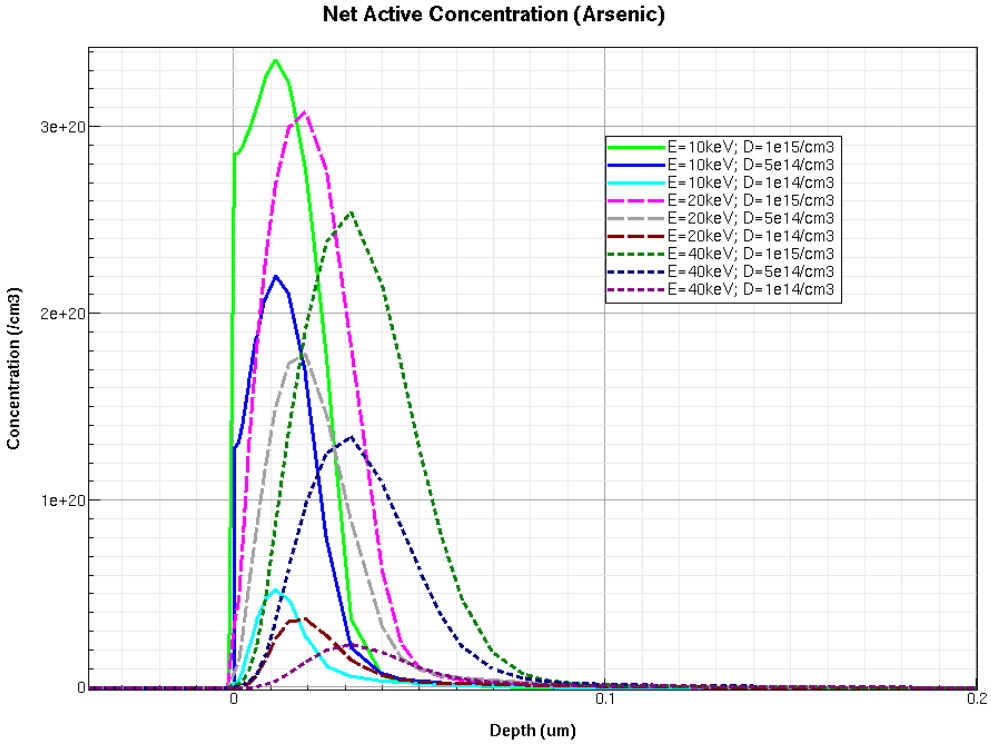

Fig.2(a). Active dopant concentration (Arsenic) for different implant energies and different doses.

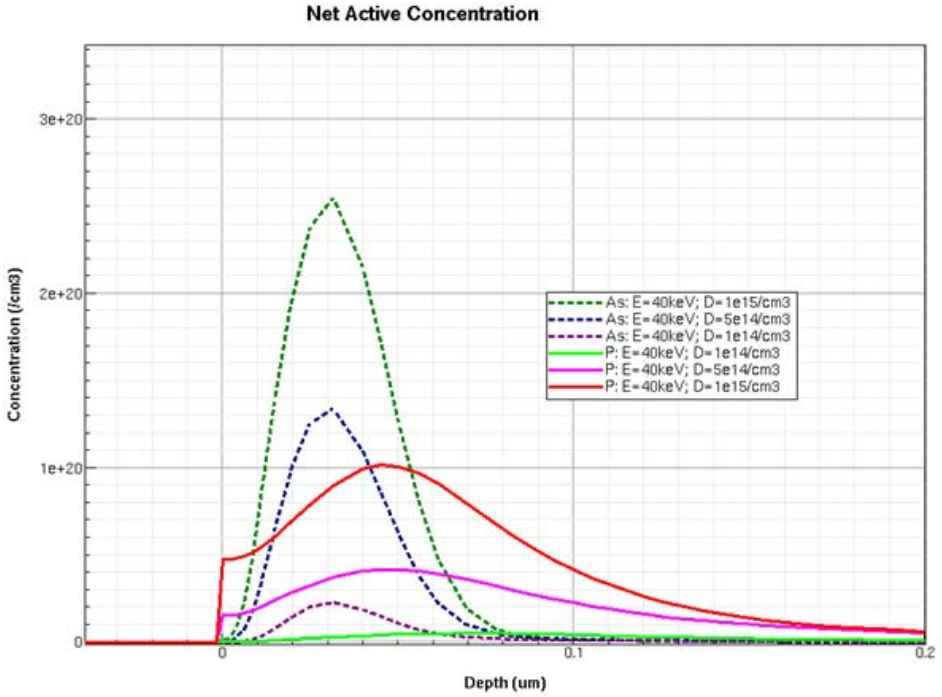

Fig.1(d). Active dopant concentration (Arsenic and Phosphorus) for implant energy=40keV and different doses.

For Arsenic also the same trend is followed as in case of phosphorus. Since, arsenic has higher atomic weight as compared to phosphorous atoms, it scatters less than phosphorous. As we know, smaller atoms with small mass get scattered easily and major part of the active concentration do not travel much distance even if the energy is high. But, heavier atoms like arsenic travel more distances before scattering near

surface. Therefore, the peak concentration is near to surface in case of Phosphorus as compared to Arsenic.

Also, the heavier atoms travel less overall distance as compared to smaller ones with same energy. Therefore, junction depth is small in case of Arsenic as dopant. Shallow junction profiles can easily be obtained with heavier atoms.

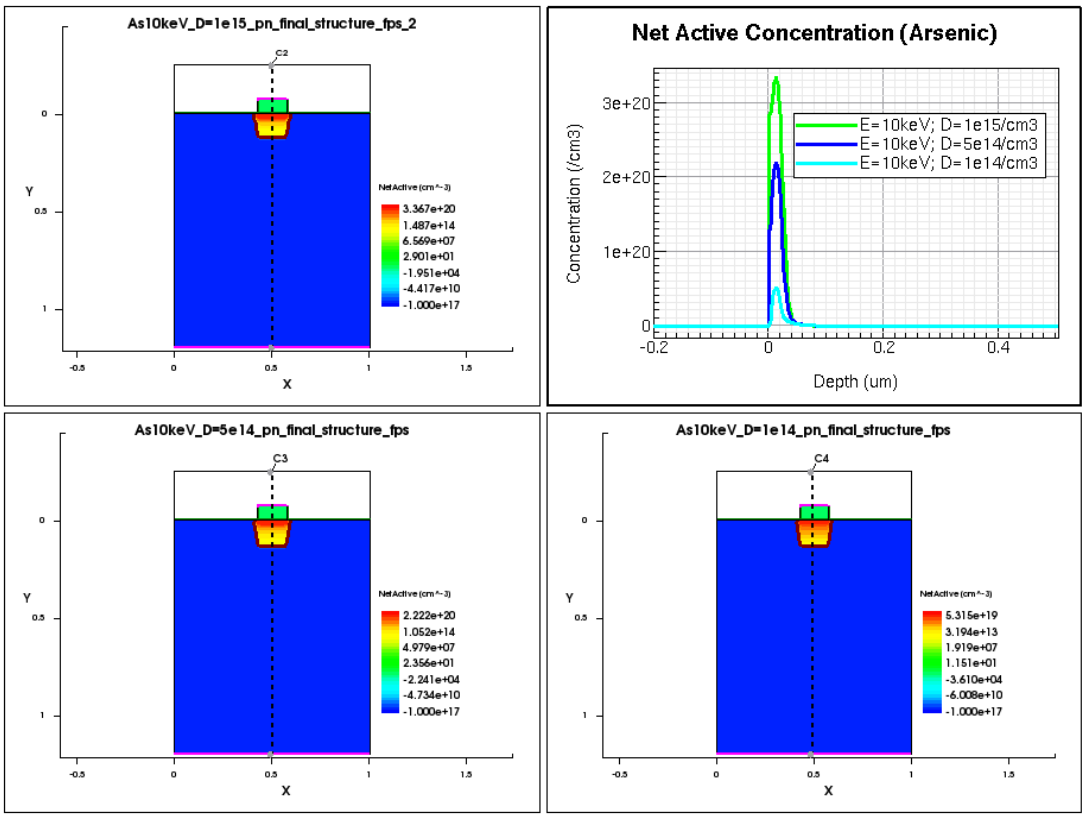

Fig.2(b). Active dopant concentration (Arsenic) and device structure for implant energy=10keV and different doses.

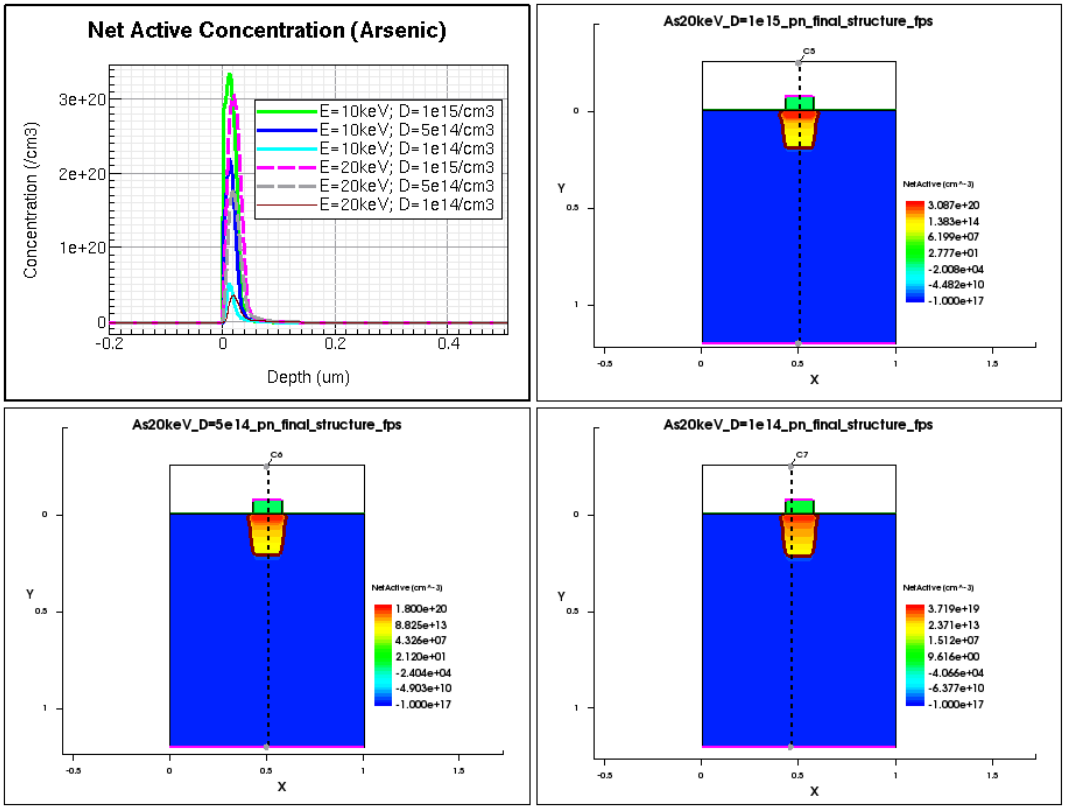

Fig.1(d). Active dopant concentration (Arsenic) and device structure for implant energy=20keV and different doses.

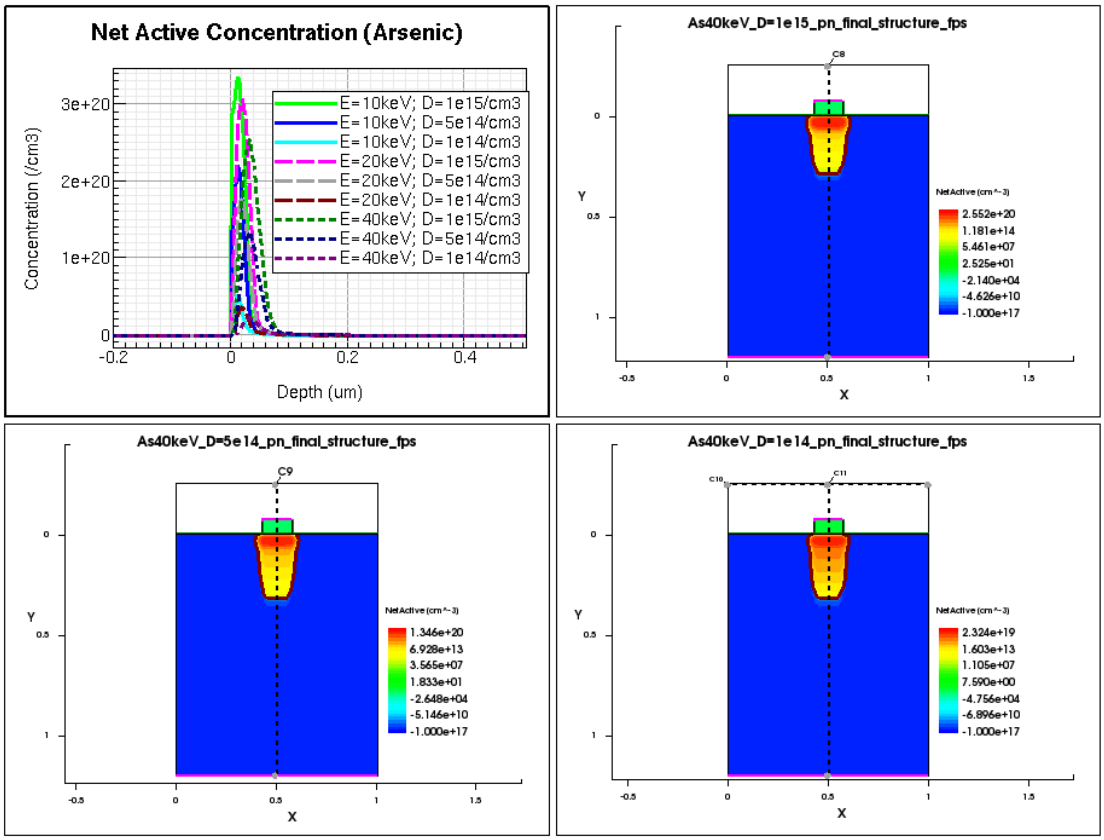

Fig.1(d). Active dopant concentration (Arsenic) and device structure for implant energy=40keV and different doses.

3. Create BJT $\mathbf{n^+p^-n}$ with collector - base junction depth ~ 300 nm and base - emitter junction depth ~200 nm. Make n+ and p region doping as uniform as possible with Phosphorus concentration, ND = 1e20 cm^{-3} and Boron concentration, NA = 1e14 cm^{-3}, by changing the parameters such as implant dose, implant energy, diffusion or annealing time and temperature etc. Assume background doping to be ND = 1e16 cm^{-3} for n^- region. Plot the net-active concentration both on linear and log scale.

Ans.

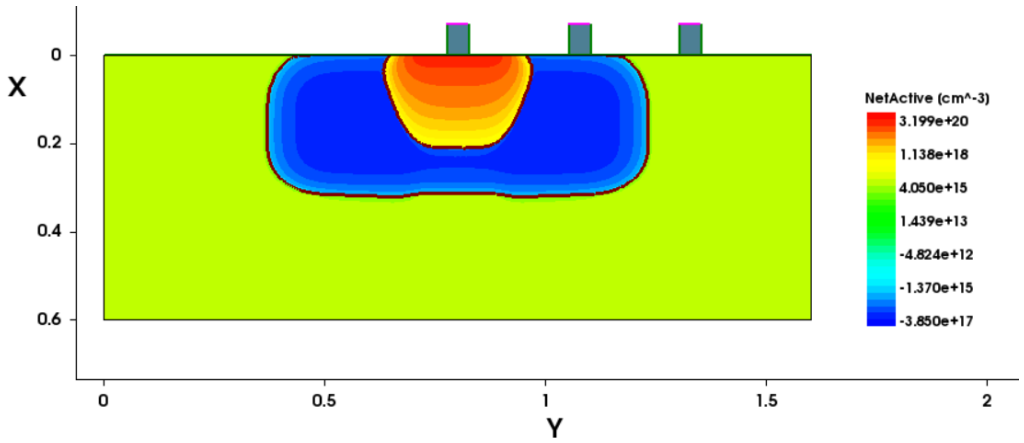

Fig.1 BJT with Emitter, Base, Collector region

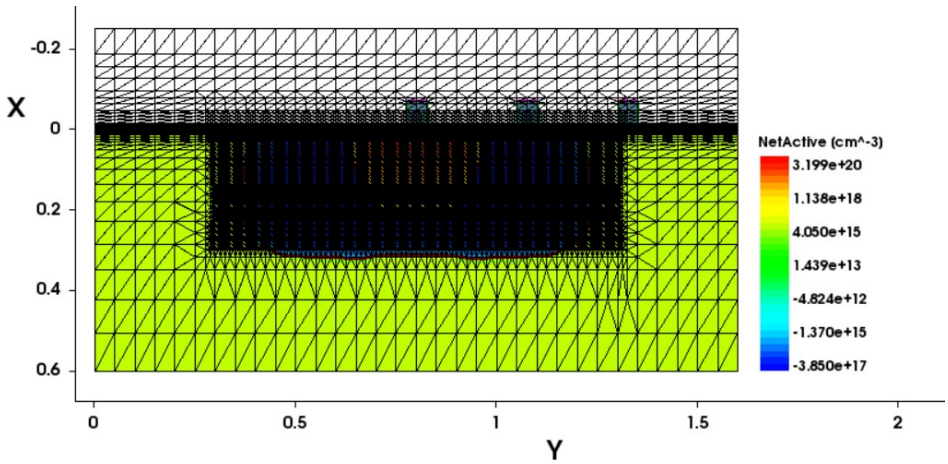

Fig.2 Device with meshing

Here the peak concentration is 3.2e20 per cm cube which is approximately 3 times asked emitter doping but I was not able to optimize the device for asked doping so I chose a little higher dose in order to increase my doping tolerance so that I could get clear doping profiles for separate n-p-n regions but junction depth is accurate here which was 200nm for emitter-base and 300nm for the base-collector junction.

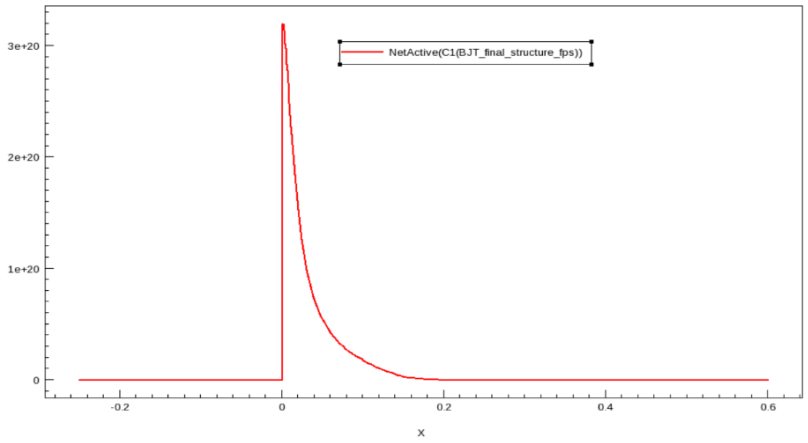

Fig.3 Net-active concentration in linear scale

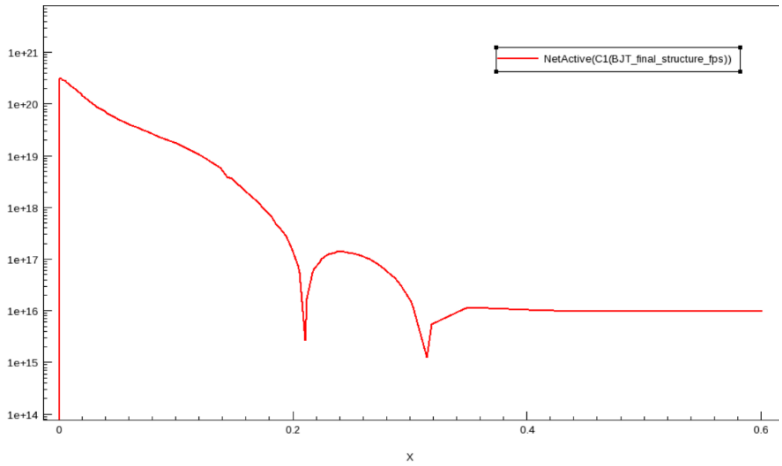

Fig.4 Net-active concentration in semi-log scale

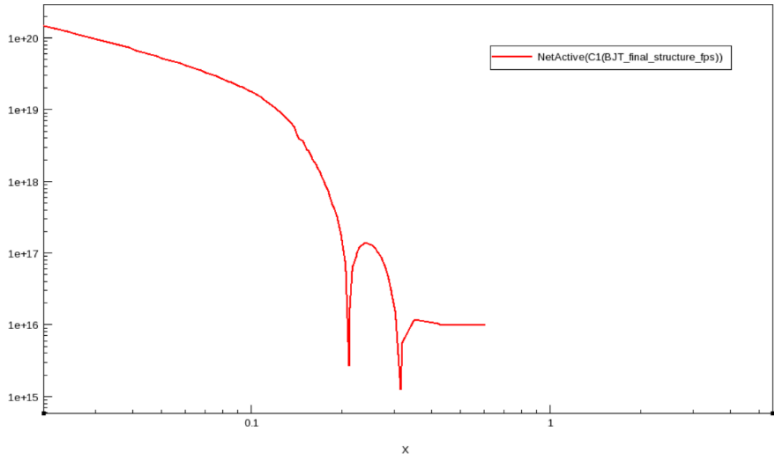

Fig.5 Net-active concentration in log-log scale

Part- B: Sdevice simulations

1. In the given $\mathbf{n^+p^-n}$ junction structure, plot the energy band diagram (E_C, E_V, E_F) along the junctions under the application of (a) in common Emitter configuration (b) common base configuration and (c) common collector configuration. Also, plot the quasi Fermi level in these cases.

Ans. E-B diag. at Equilibrium

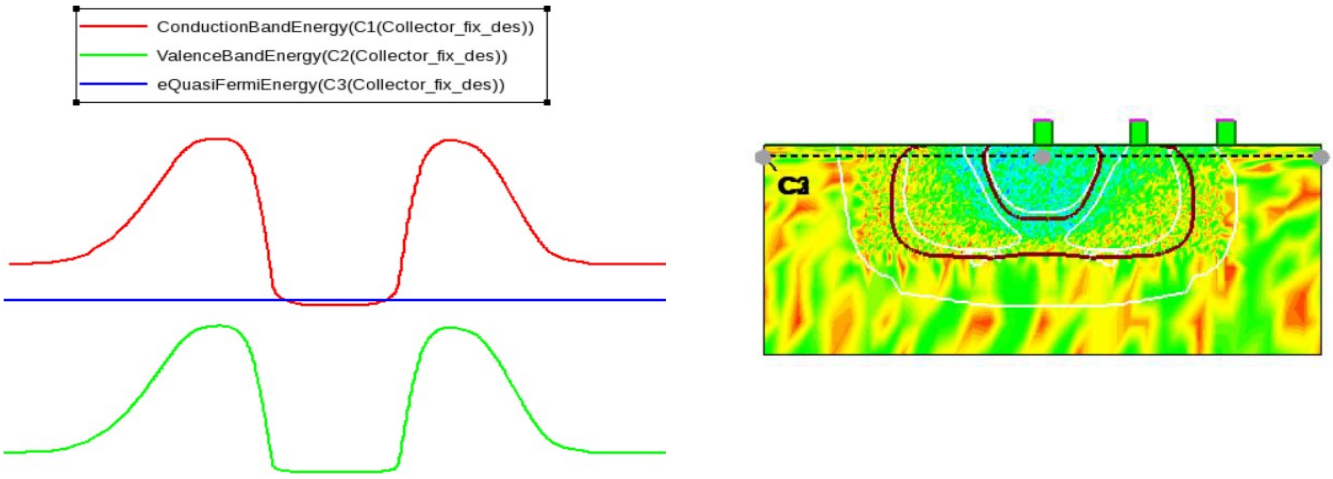

Fig.1 E-B diagram for equilibrium (X-Cut)

E-B diagram for Common Emitter –

voltages used are - Emitter voltage = 0v (Ground), Base voltage = +1.5 to +2V (Forward bias), Collector voltage = +3V to +3.5V (Reverse bias).

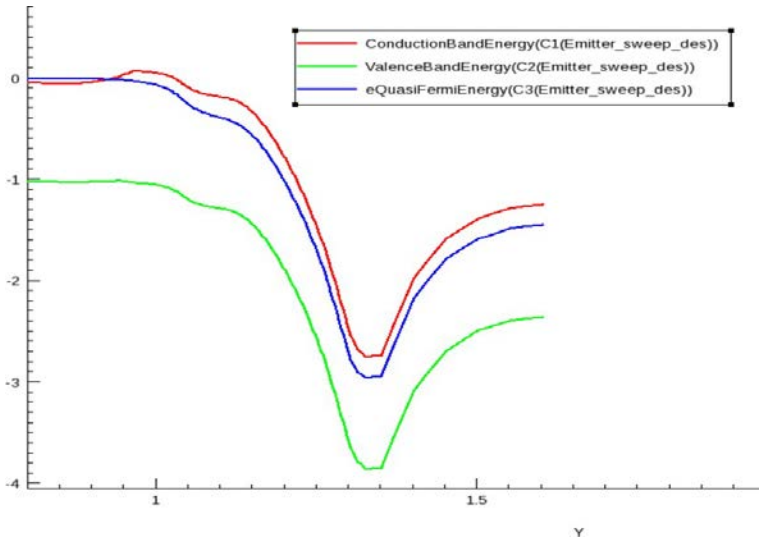

Fig.2 E-B diagram for common emitter

E-B diagram for Common Base –

voltages used are - Emitter voltage = -1.5 to -2V (Forward Bias), Base voltage = 0V (Ground), Collector voltage = +3V to +3.5V (Reverse bias).

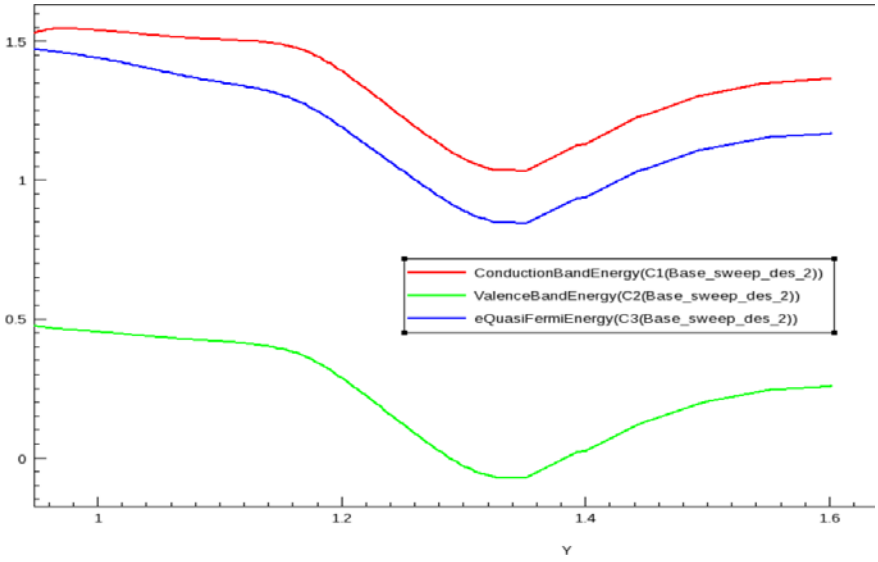

Fig.3 E-B diagram for Common Base

E-B diagram for Common Collector –

voltages used are - Emitter voltage = -1.5V (Forward Bias), Base voltage = -1V, Collector voltage = 0V (Ground).

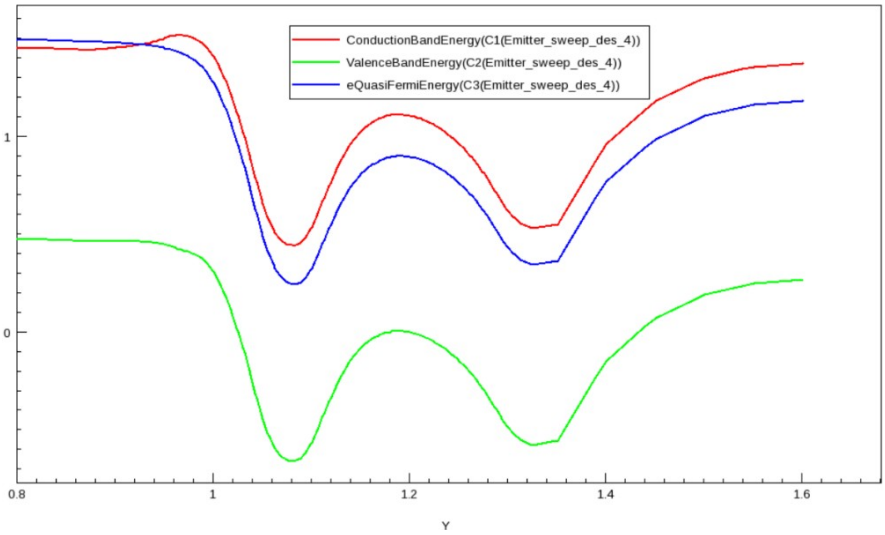

Fig.4 E-B diagram for Common Collector

2. Plot the IV curves of the BJT in common emitter as well as common base configuration.

For Common Emitter –

Input Characteristics – (I_B Vs V_{BE}) – V_{CE} = +3.5V fixed.

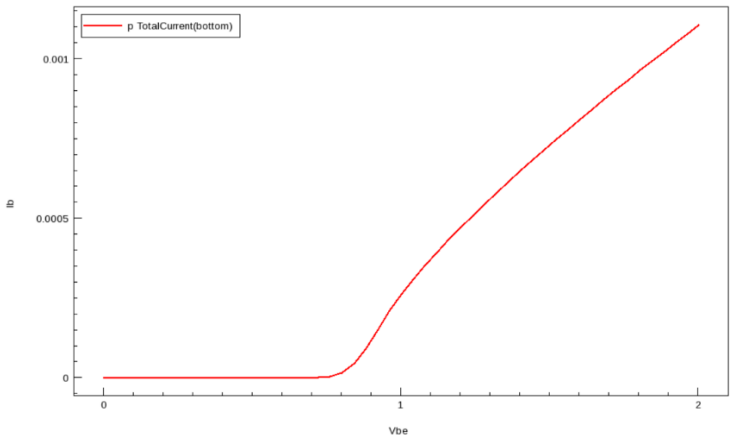

Fig.5

Output Characteristics – (I_C vs V_{CE}) – V_{BE} = 1V fixed.

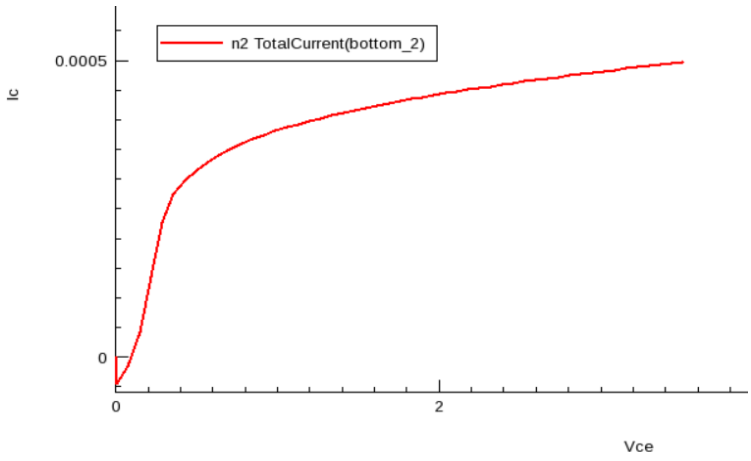

Fig.6

For Common Base –

Input Characteristics – (I_E Vs V_{EB}) – V_{CB} = +3.5V fixed.

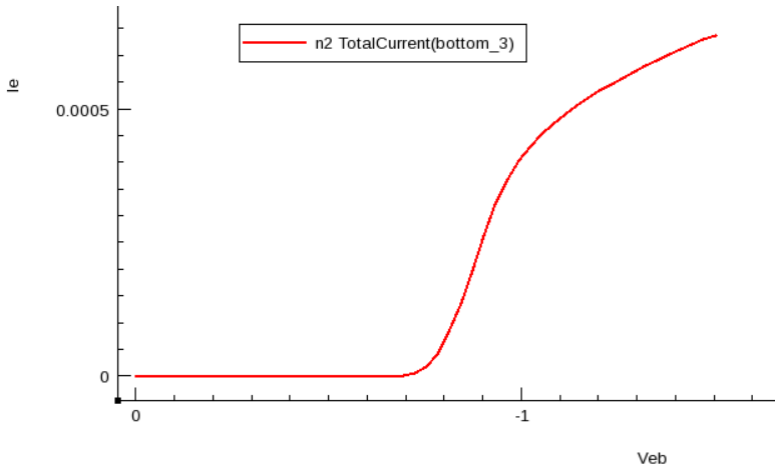

Fig.7

Output Characteristics – (I_c Vs V_{CB}) – V_{EB} = -1.5V fixed.

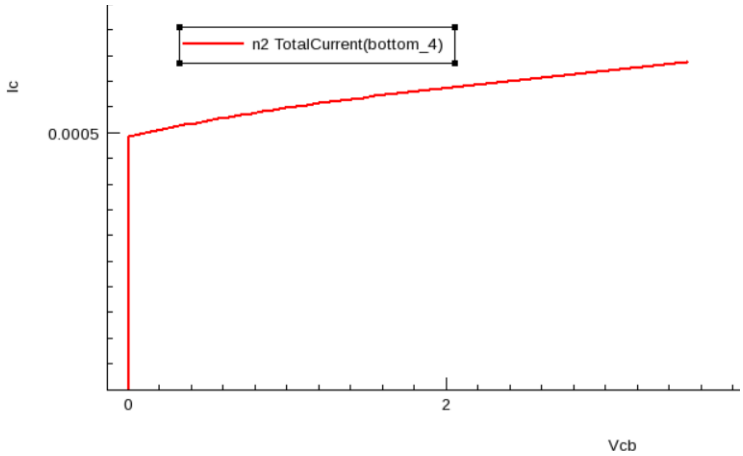

Fig.8

For Common Collector –

Input Characteristics – (I_B vs V_{BC}) – V_{EC} = -1V fixed.

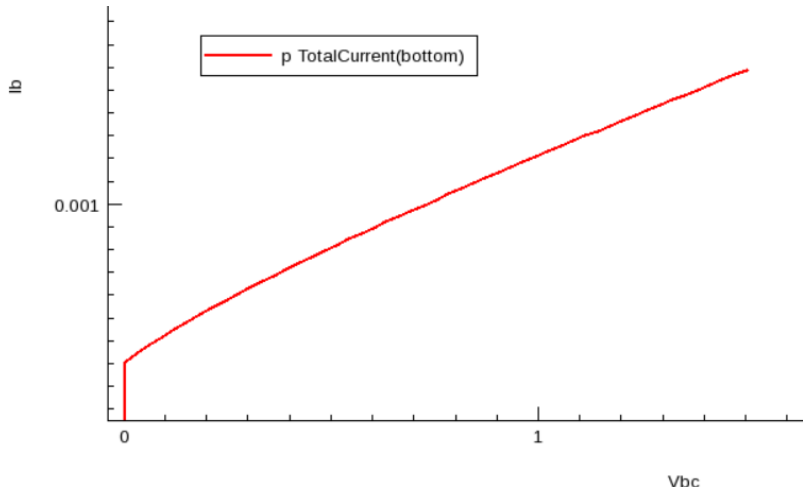

Fig.9

Output Characteristics – (I_E vs V_{EC}) – V_{BC} = +1.5V fixed.

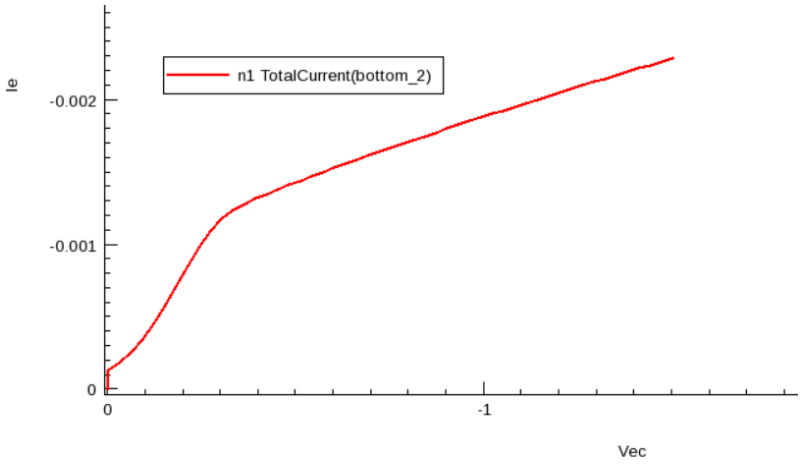

Fig.10

Observations – From the band diagram, it is clear that due to the forward biasing of the emitter-base junction the barrier height reduces while keeping the base and collector junction at reverse bias the barrier height increases as compared to the equilibrium diagram. After that, we tried to get the input and output characteristics of the 3 asked configurations a few times I used

For output characteristics, pick a combination of voltages that can roughly bias it in the desired configuration. J-V characteristics obtained are as expected of this configuration.

BJT Sprocess Command lines –

```
# 1D Grid definition in x direction
line x location= 0.0 spacing=2.0<nm> tag=SiTop
line x location=50<nm> spacing=20<nm>
line x location=100<nm> spacing=40<nm>
line x location=600<nm> spacing=100<nm> tag=SiBottom

# 1D Grid definition in y direction
line y location=0.0 spacing=50<nm> tag=Left
line y location=1600<nm> spacing=50<nm> tag=Right

# Initial simulation domain
region Silicon xlo=SiTop xhi=SiBottom ylo=Left yhi=Right
# Initial doping concentration in the region defined
init concentration=1e+16<cm-3> field=Phosphorus wafer.orient=100

# Global Mesh settings for automatic meshing in newly generated layers.
#This strategy is used when there is change in initial geometry due to
#deposit, oxidation and etching
mgoals min.normal.size =2<nm> normal.growth.ratio =1.4 accuracy=1e-5

deposit material= {Oxide} type=isotropic time=1 rate= {0.15}
grid remesh
mask name=implant_mask segments= {0<um> 0.45<um> 1.15<um> 1.6<um> }
etch material= {oxide} type=anisotropic time=1 rate= {0.17} mask=implant_mask
grid remesh
#Save the structure file after etching
struct tdr =1_bjt_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.3} max= {0.3 1.3}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh
```

```
implant Boron energy=16<keV> dose=8e12<cm-2> tilt = 0
diffuse temperature=1000<C> time=1<s>
#save the structure after implantation and diffusion
struct tdr =2_bjt_after_P_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =3_BJT_after_imp_diff_oxide_etch;

####################
deposit material = {oxide} type = isotropic time = 1 rate = {0.15}
grid remesh
mask name = implant_mask segments = {0<um> 0.70<um> 0.90<um> 1.6<um>}
etch material = {oxide} type = anisotropic time = 1 rate= {0.17} mask = implant_mask
grid remesh
#save the structure file after etching
struct tdr = 4_BJT_oxide_etch_bfr_n_implant

refinebox Silicon min= {0.0 0.3} max= {0.3 1.3}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh
implant Phosphorus energy=12<keV> dose=1e15<cm-2> tilt = 0
diffuse temp= 1000<C> time=1.15<s>
#save the structure after implantation and diffusion
struct tdr = 5_BJT_after_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr = 6_BJT_after_nplus_imp_diff_oxide_etch
```

```
deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}
grid remesh
#save structure after contact deposition
struct tdr = 7_BJT_after_metal_depos ;

mask name=contacts_mask2 segments = {0.775<um> 0.825<um> 1.05<um> 1.1<um>
1.3<um> 1.35<um>}
etch material= {Aluminum} type=anisotropic time=1 rate= {0.08} mask=contacts_mask2
grid remesh
contact name = "n1" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.775 yhi = 0.825
contact name = "p" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 1.05 yhi = 1.1
contact name = "n2" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 1.3 yhi = 1.35
# save final structure
struct tdr = BJT_final_structure
```

BJT Sdevice Command lines –

```
File {
Grid= "BJT_final_structure_fps.tdr"
Current= "bottom.plt"
Plot= "bottom.tdr"
Output= "bottom.log"
}
Electrode {
{ Name= "n1" Voltage= 0.0 }
{ Name= "p" Voltage= 0.0 }
{ Name= "n2" Voltage= 0.0 }
}
Physics {
Mobility (DopingDep)
```

```
EffectiveIntrinsicDensity(BandGapNarrowing(oldSlotboom))
Recombination (Avalanche(CarrierTempDrive)
Band2Band (E2)
SRH)
# turn them on or off to see the effect of each recombination mechanism
}

Plot {
Doping DonorConcentration AcceptorConcentration
BandGap BandGapNarrowing ElectronAffinity
ConductionBandEnergy ValenceBandEnergy
eQuasiFermiEnergy hQuasiFermiEnergy
eDensity hDensity
EffectiveIntrinsicDensity IntrinsicDensity
ElectricField/Vector
Potential
SpaceCharge
Current/Vector eCurrent /Vector hCurrent /Vector
CurrentPotential * for visualizing current lines
eMobility
hMobility
SRHRecombination AugerRecombination
TotalRecombination SurfaceRecombination
eLifeTime
hLifeTime
ComplexRefractiveIndex QuantumYield
}


Math {
Extrapolate
Iterations= 8
SubMethod= ParDiSo
Method= Blocked
```

```
}

Solve{
Coupled { Poisson }
Coupled { Poisson Electron Hole }

#NewCurrentFile="IV_sweep"
Quasistationary( InitialStep = 1e-3 MaxStep = 0.01
MinStep = 1e-3 Goal { Name = "p" Voltage =1.2})
{ Coupled { Poisson
  Electron Hole }
  plot(FilePrefix="Base
  _sweep" )
  CurrentPlot ( Time = (range = (0 1) intervals = 50))
}

Quasistationary( InitialStep = 1e-3 MaxStep = 0.01
MinStep = 1e-3  Goal { Name = "n2" Voltage =3.5}){
Coupled { Poisson Electron Hole }
   plot(FilePrefix="Emitter_sweep" )
   CurrentPlot ( Time = (range = (0 1) intervals = 50))
   }
}
```