EE 735 Assignment 7

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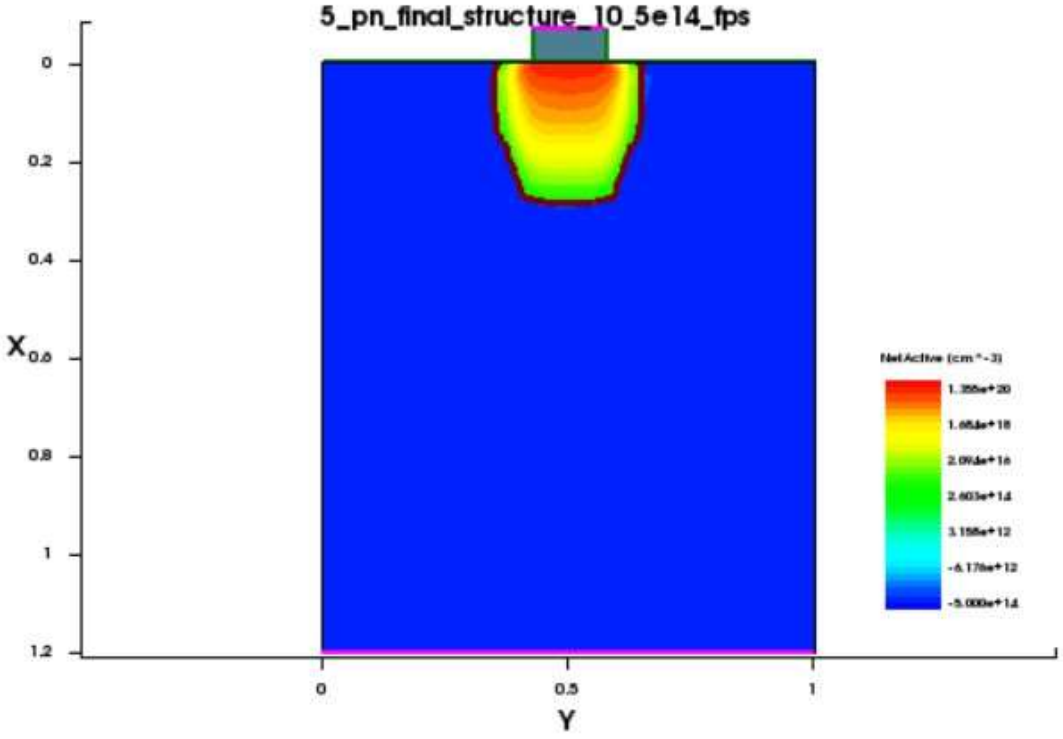
Roll- 23M1133

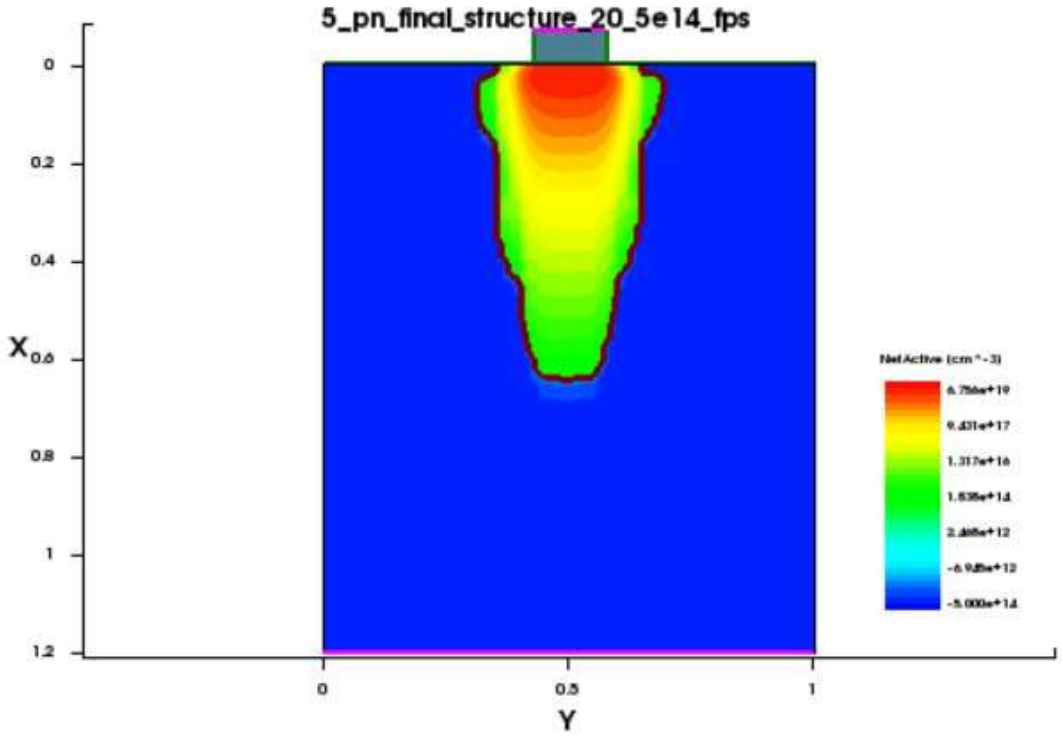
Q1) A pn junction is created by implanting Phosphorus on a Boron doped (5e14 cm-3) Si substrate using the SProcess Tool in TCAD. We increase impact energy from 10KeV to 20KeV to 40KeV while keeping the dose constant at 5e14 cm^{-3} and observe the impact of this on the peak concentration and junction depth.We received the following results when we used SVisual tool to plot the results.

Dose(kept constant): 5e14 cm^{-3}

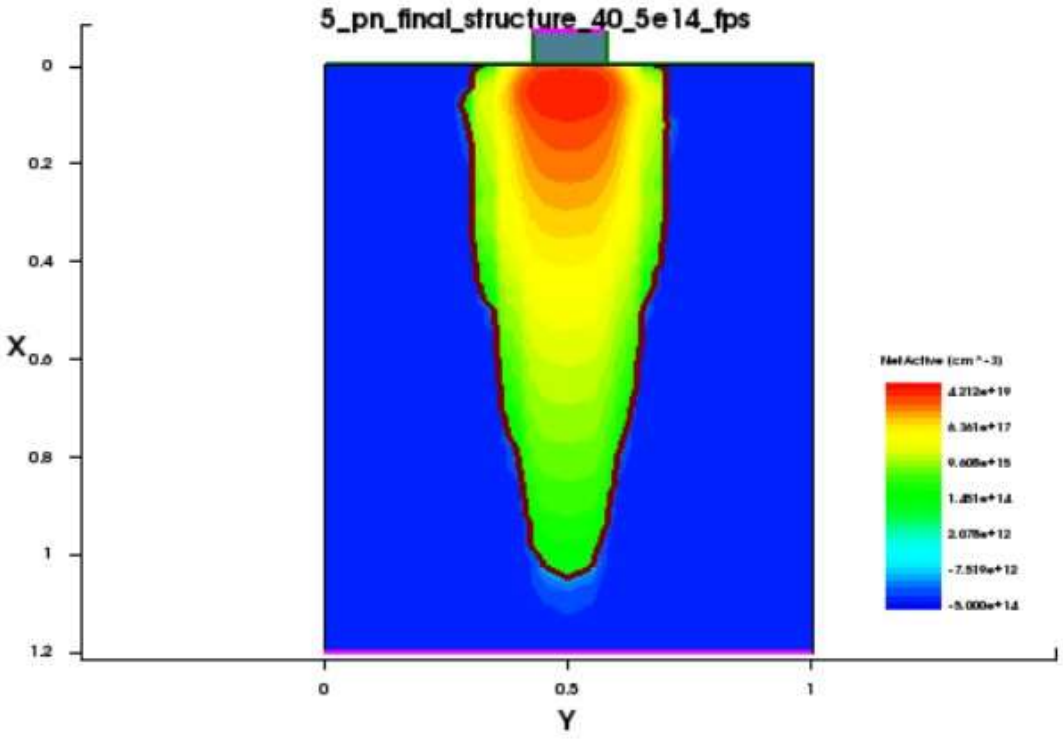
Impact energy: 10 KeV



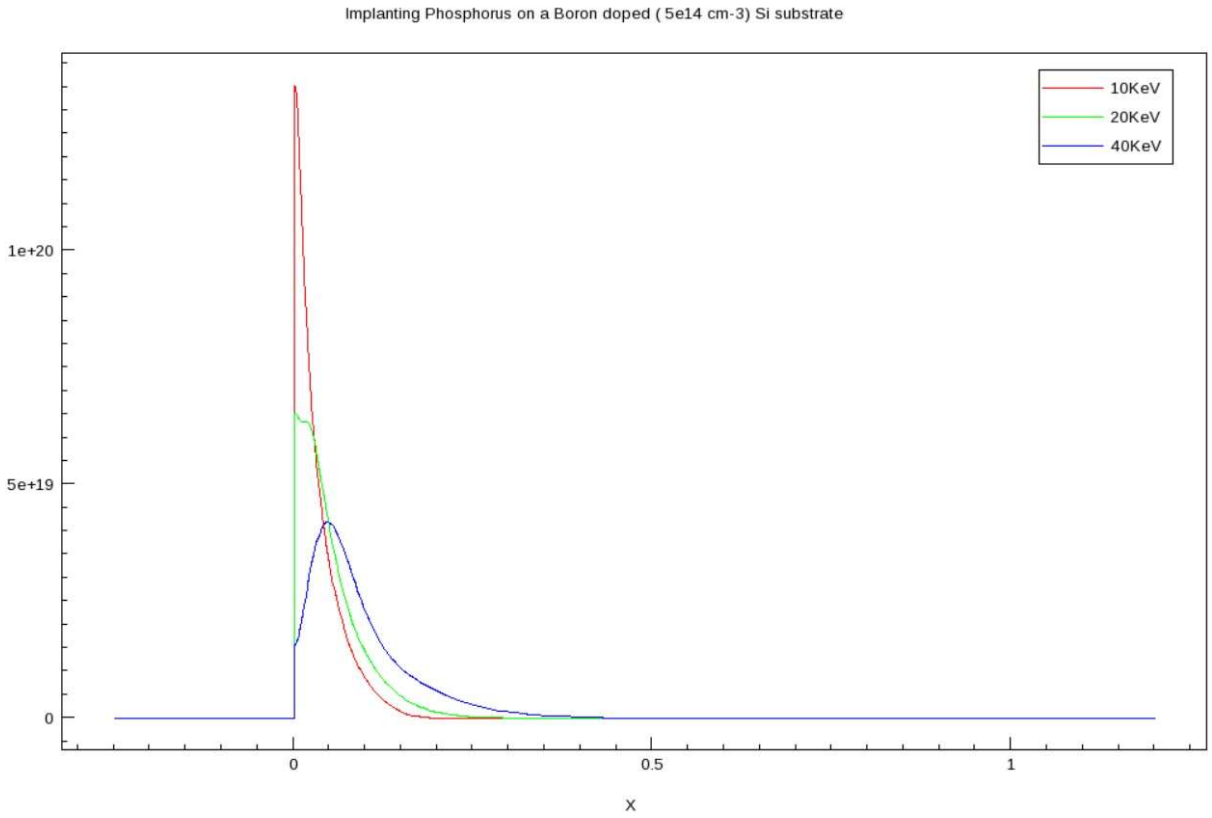
Impact energy: 20 KeV



Impact energy: 40 KeV

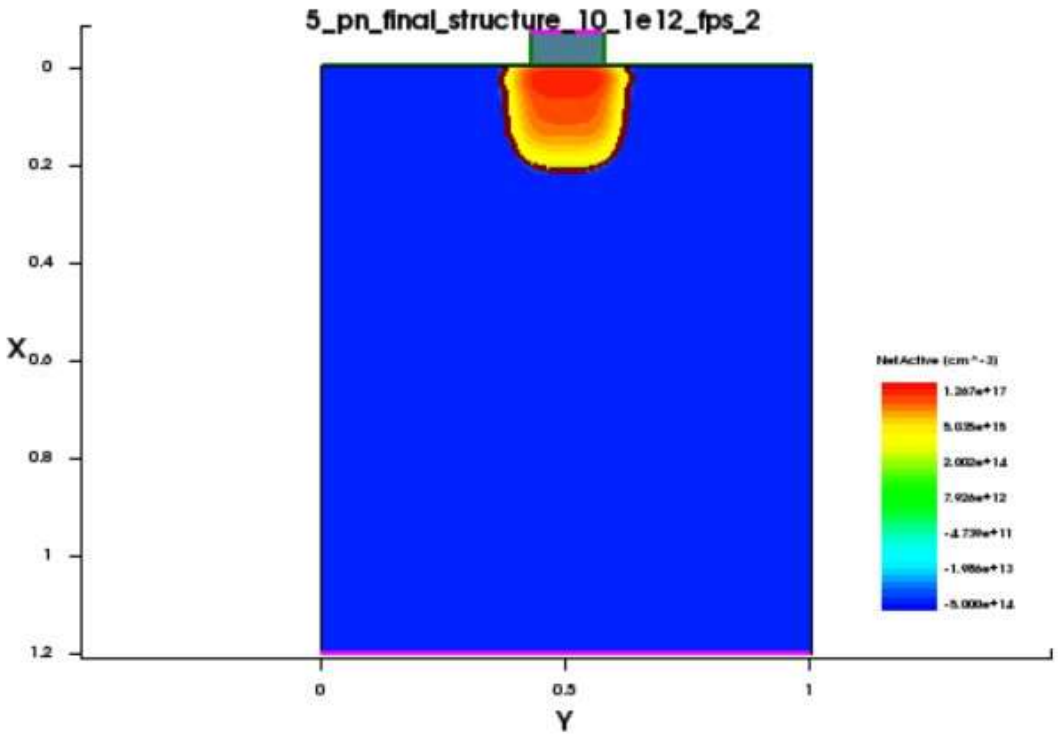


Plot of net-active concentration (N_D-N_A) along the device depth:

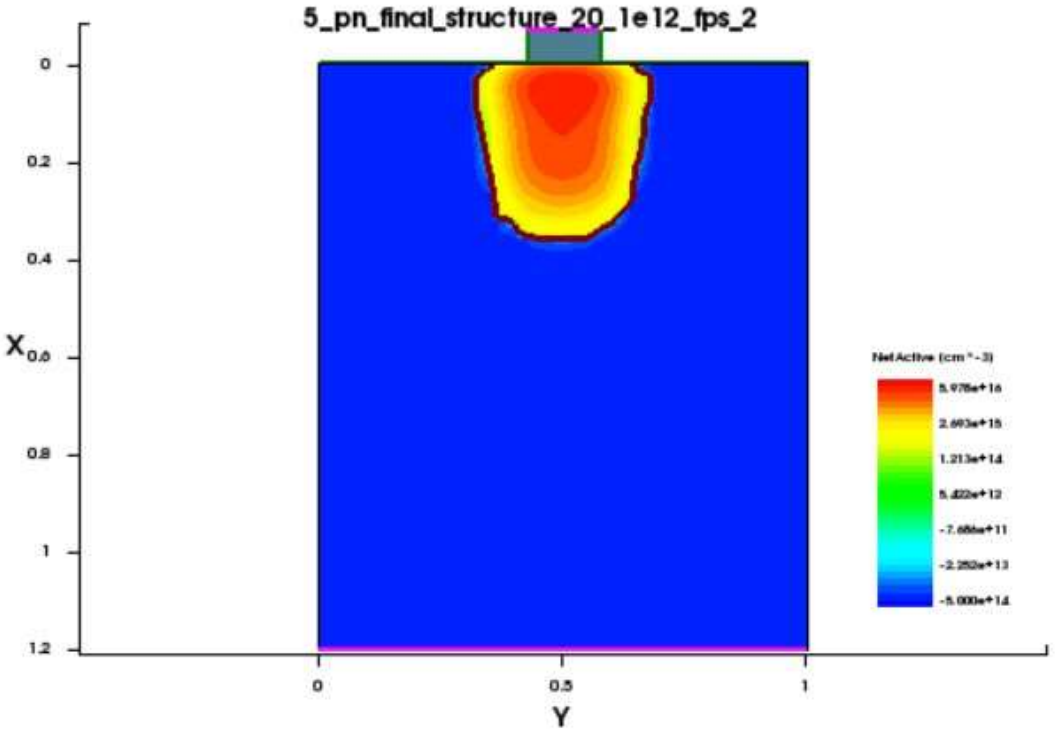


Dose(kept constant): 1e12 cm^{-3}

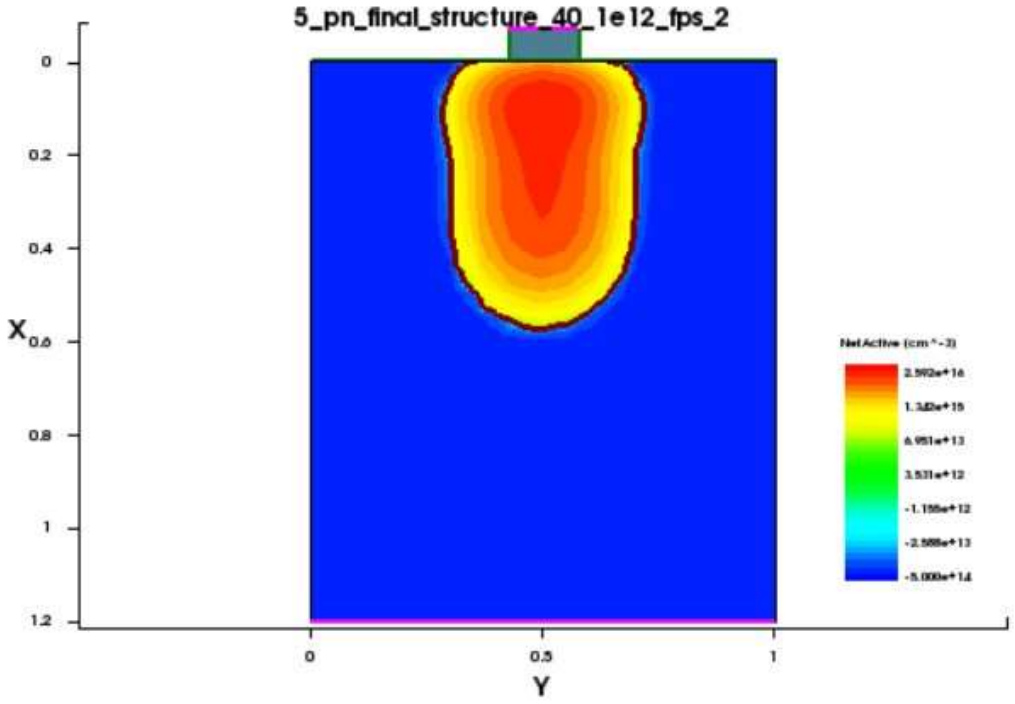
Impact energy: 10 KeV



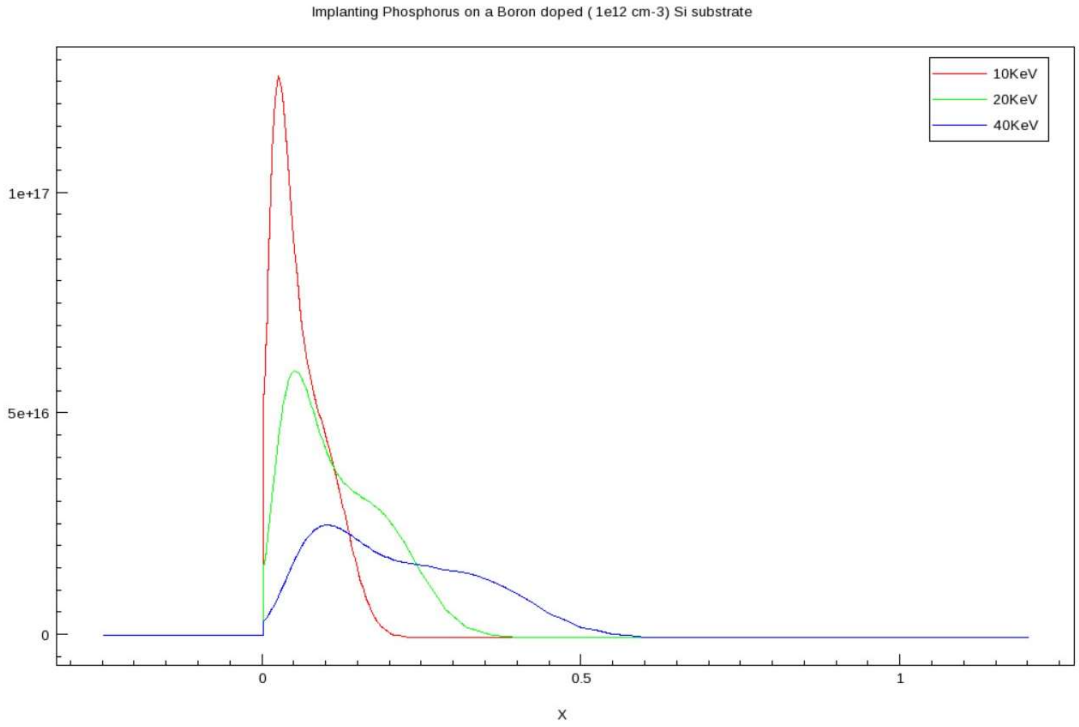
Impact energy: 20 KeV



Impact energy: 40 KeV

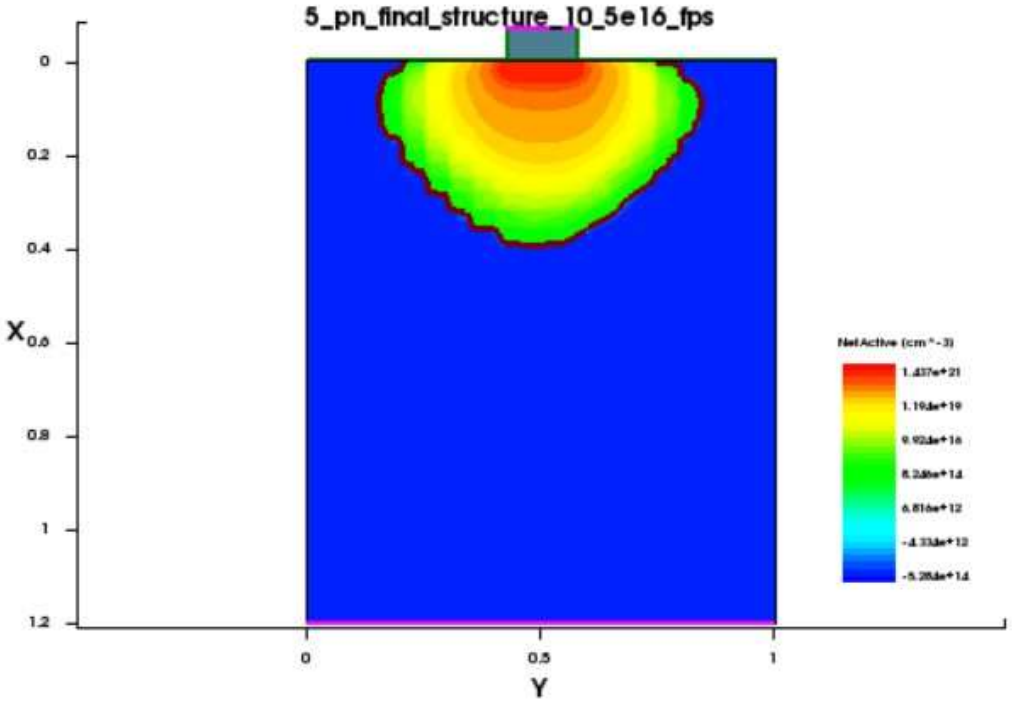


Plot of net-active concentration (N_D-N_A) along the device depth:

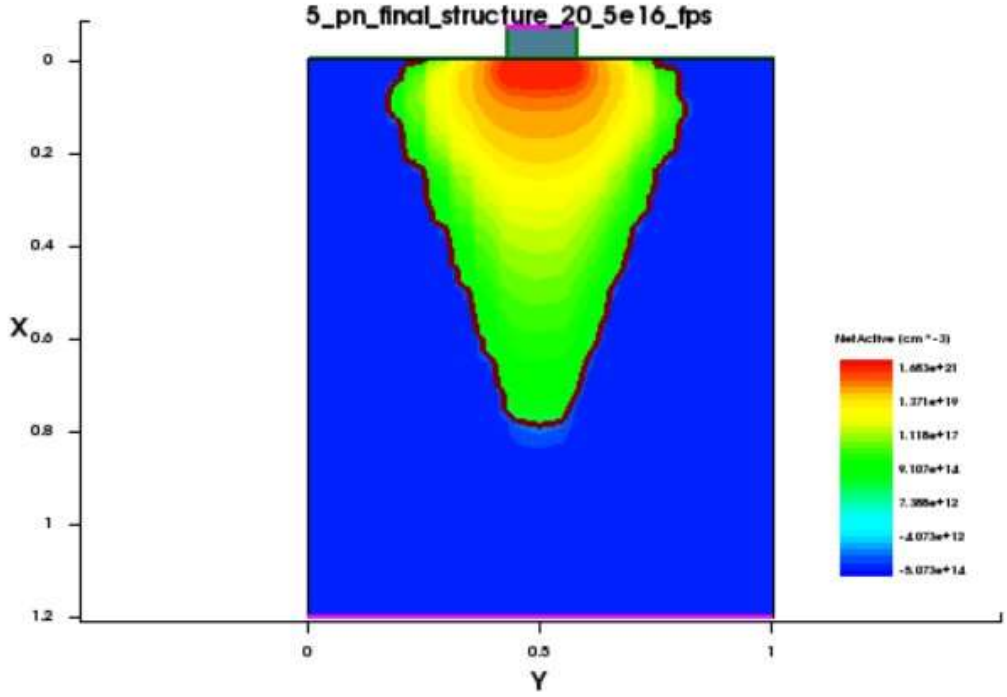


Dose(kept constant): 5e16 cm^{-3}

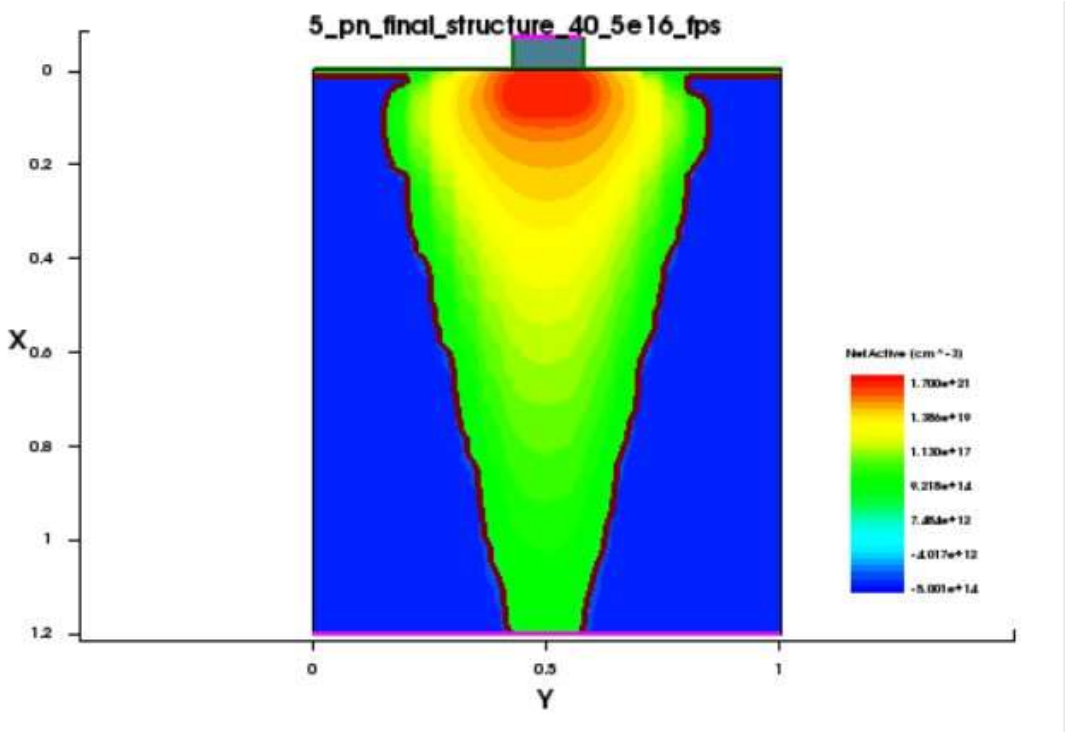
Impact energy: 10 KeV



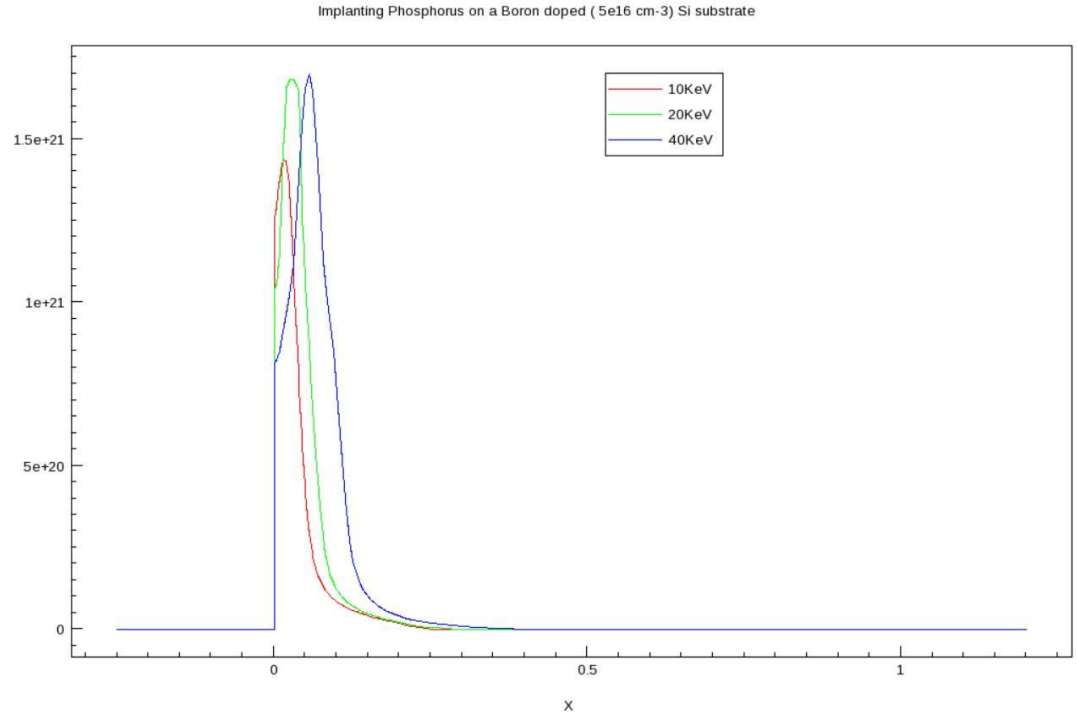
Impact energy: 20 KeV



Impact energy: 40 KeV



Plot of net-active concentration (N_D-N_A) along the device depth:



Observation:

Peak Concentration:

As we increase the implantation energy from 10 keV to 20 keV to 40 keV, the ions will have more kinetic energy, allowing them to penetrate deeper into the silicon substrate. This means that the peak concentration of the implanted Phosphorus ions will shift deeper into the substrate.

At 10 keV, the peak concentration would be relatively closer to the surface, and at 40 keV, the peak concentration will be deeper within the silicon substrate.

The peak concentration at the surface (near the Boron-doped region) will likely decrease with increasing energy due to the dose being kept constant. Thus as the curve spreads inwards, the peak comes down.

Junction Depth:

The junction depth will increase as we increase the implantation energy from 10 keV to 20 keV to 40 keV. A higher energy allows the ions to penetrate deeper into the silicon substrate before coming to rest. This results in a deeper junction.

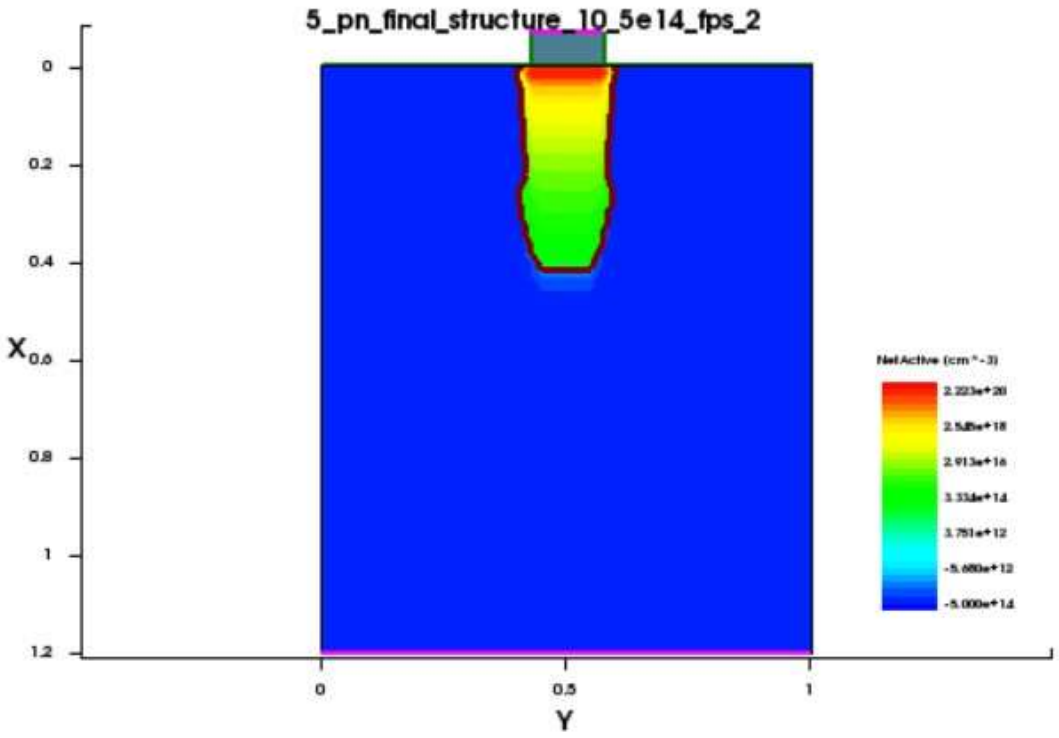
The actual junction depth will depend on the specific energy levels and the characteristics of the silicon and the implanted species. However in general,increasing the implantation energy will lead to a deeper junction.

Q2)

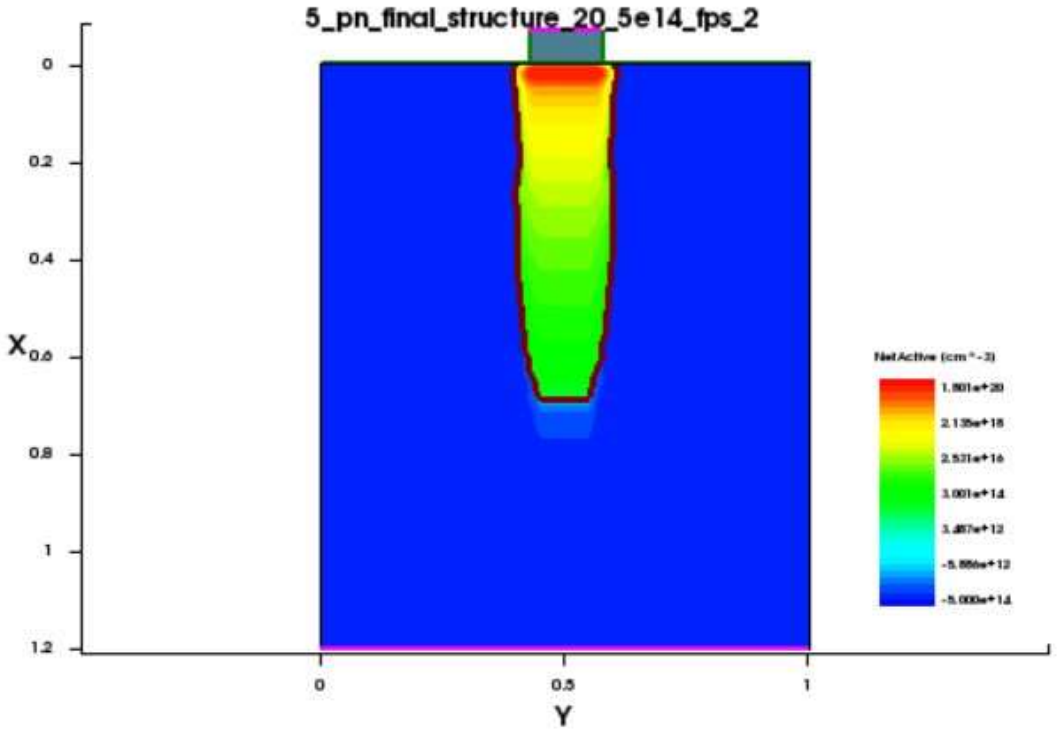
Another pn junction is created similarly by implanting Arsenic on a Boron doped (5e14 cm-3) Si substrate using the SProcess Tool in TCAD. We increase impact energy from 10KeV to 20KeV to 40KeV while keeping the dose constant at 5e14 cm^{-3} and observe the impact of this on the peak concentration and junction depth.We received the following results when we used SVisual tool to plot the results.

Dose(kept constant): 5e14 cm^{-3}

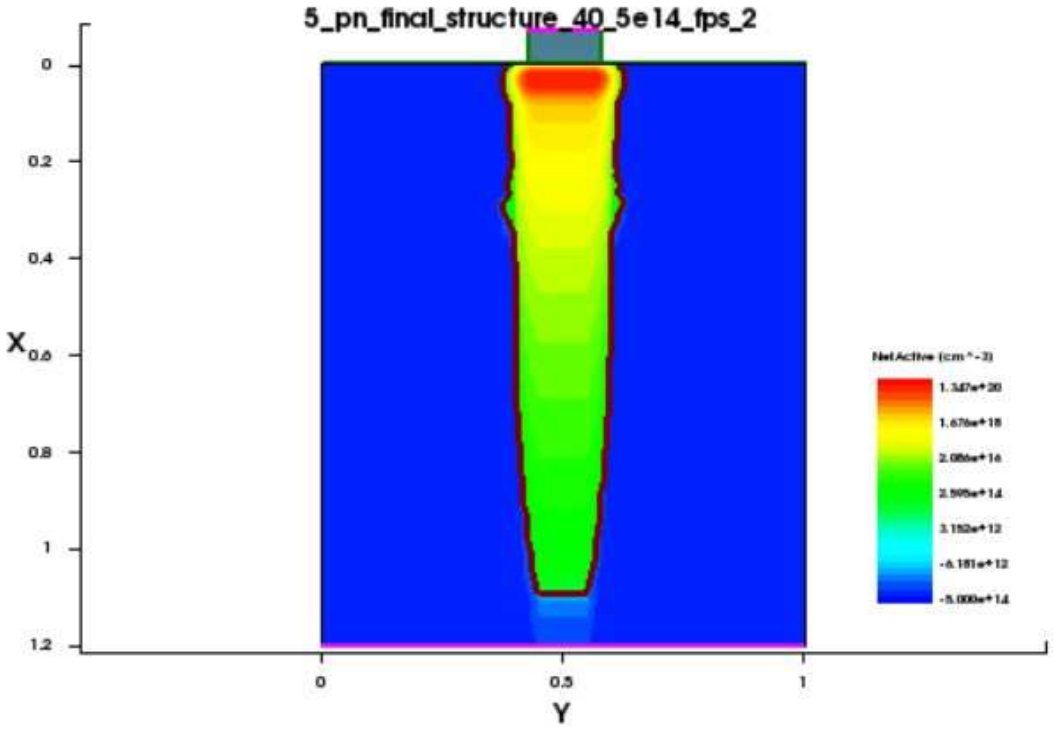
Impact energy: 10 KeV



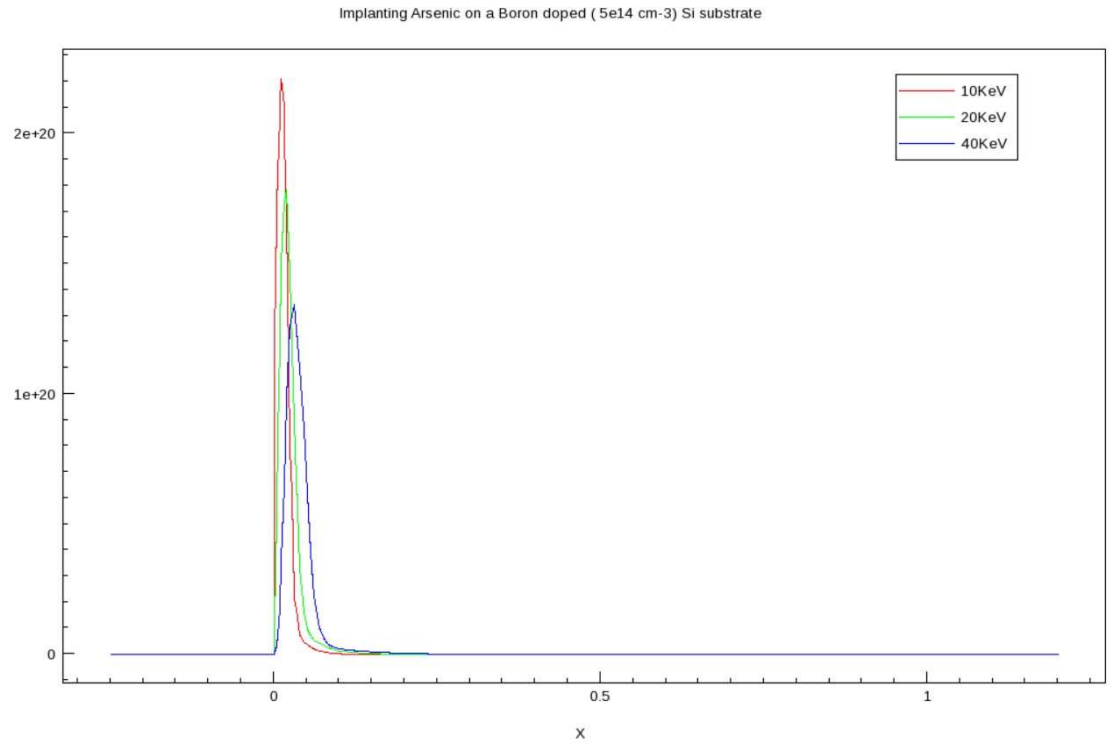
Impact energy: 20 KeV



Impact energy: 40 KeV

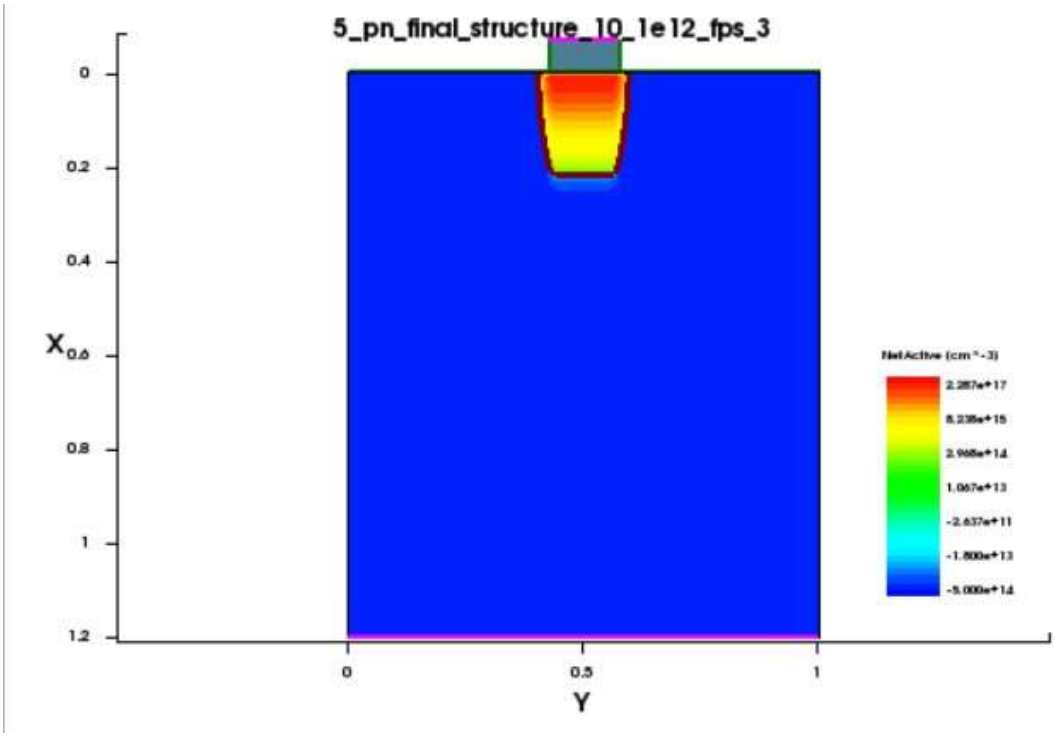


Plot of net-active concentration (N_D-N_A) along the device depth:

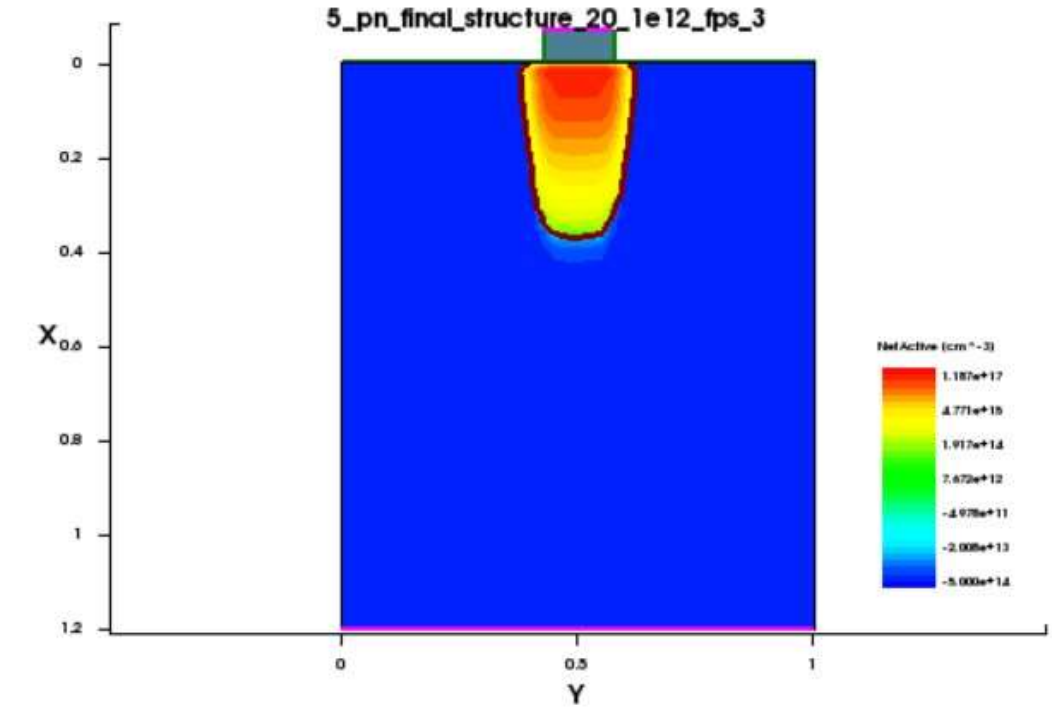


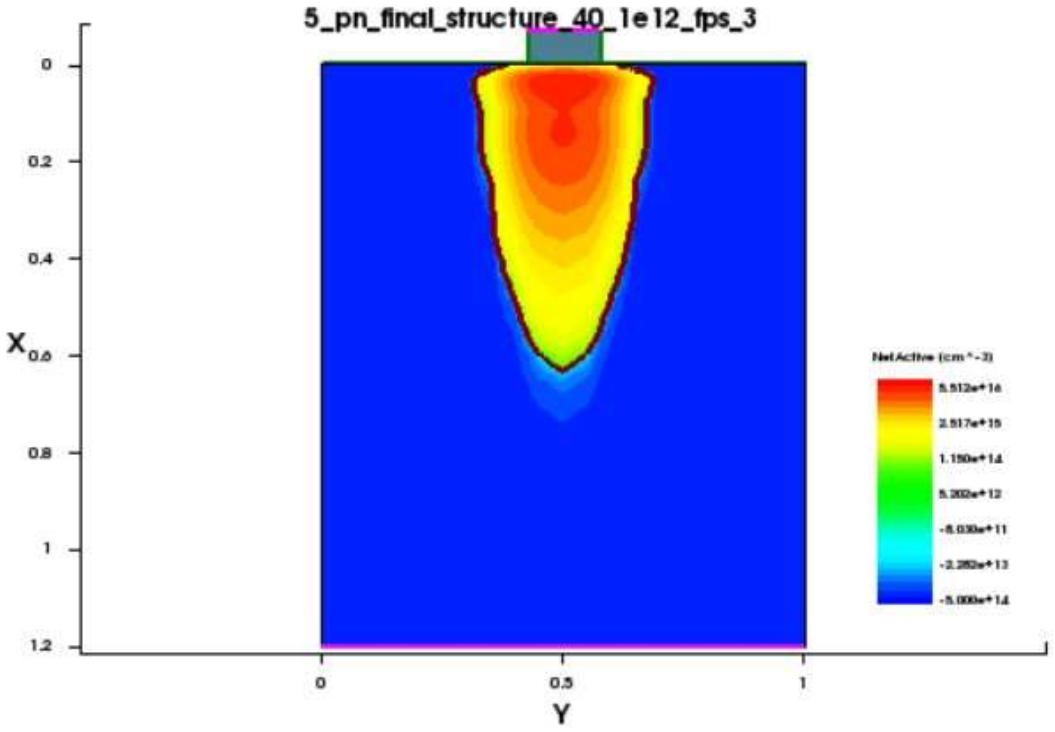
Dose(kept constant): 5e16 cm^{-3}

Impact energy: 10 KeV

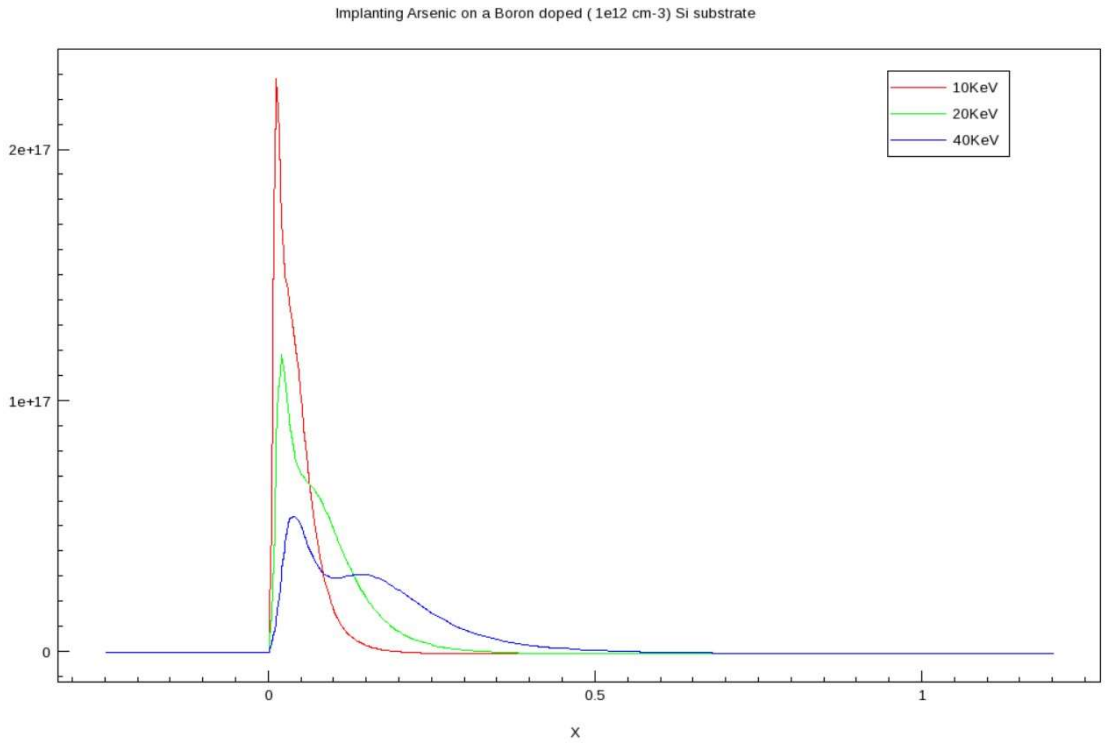


Impact energy: 20 KeV



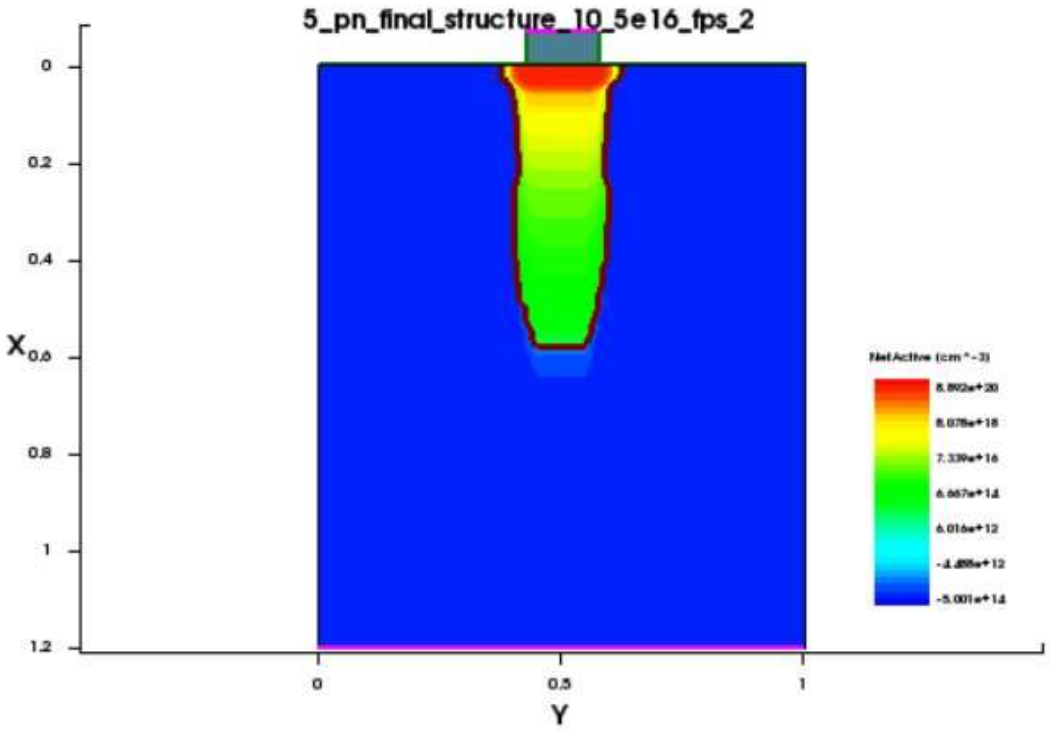


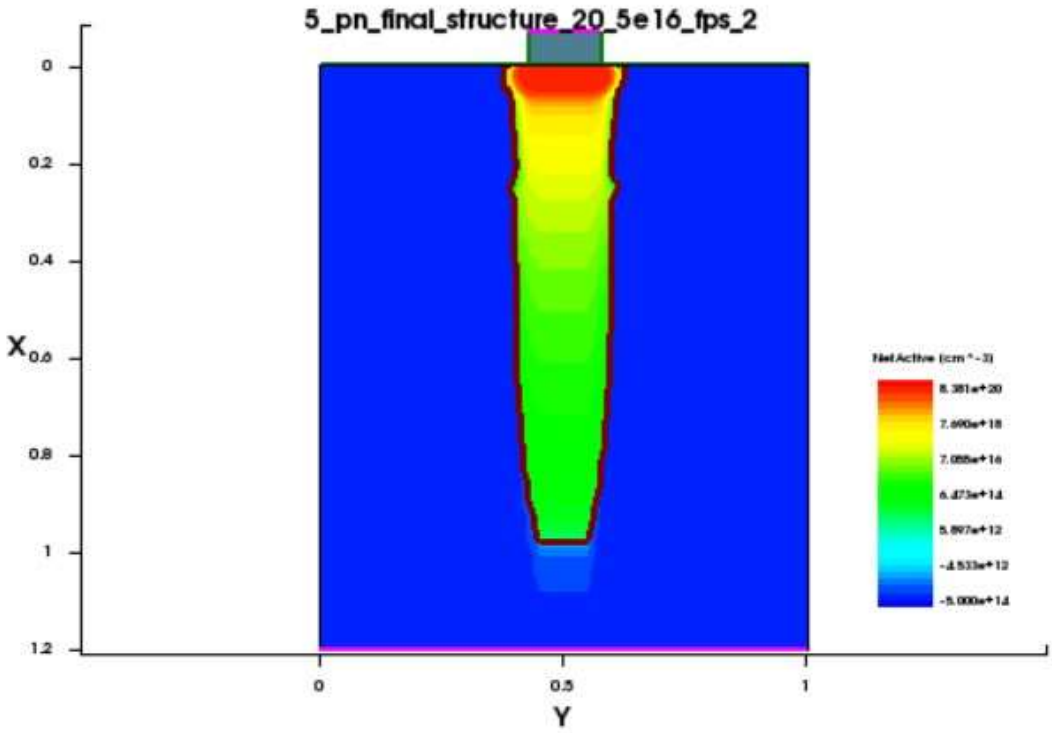
Plot of net-active concentration (N_D-N_A) along the device depth:

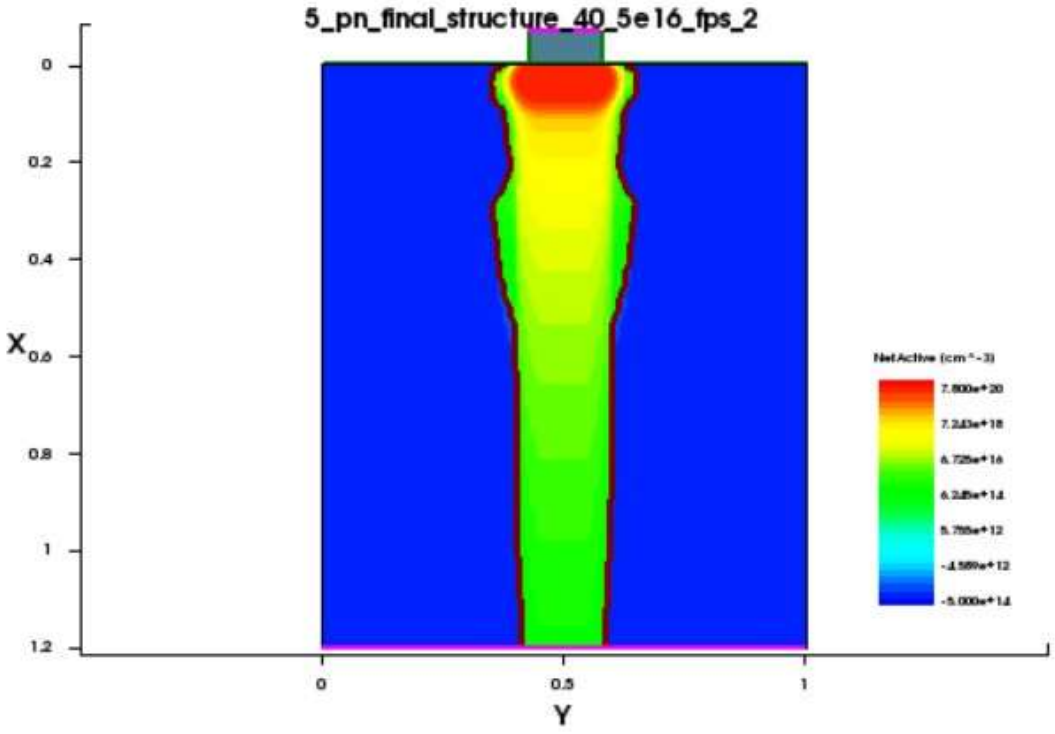


Dose(kept constant): 5e16 cm^{-3}

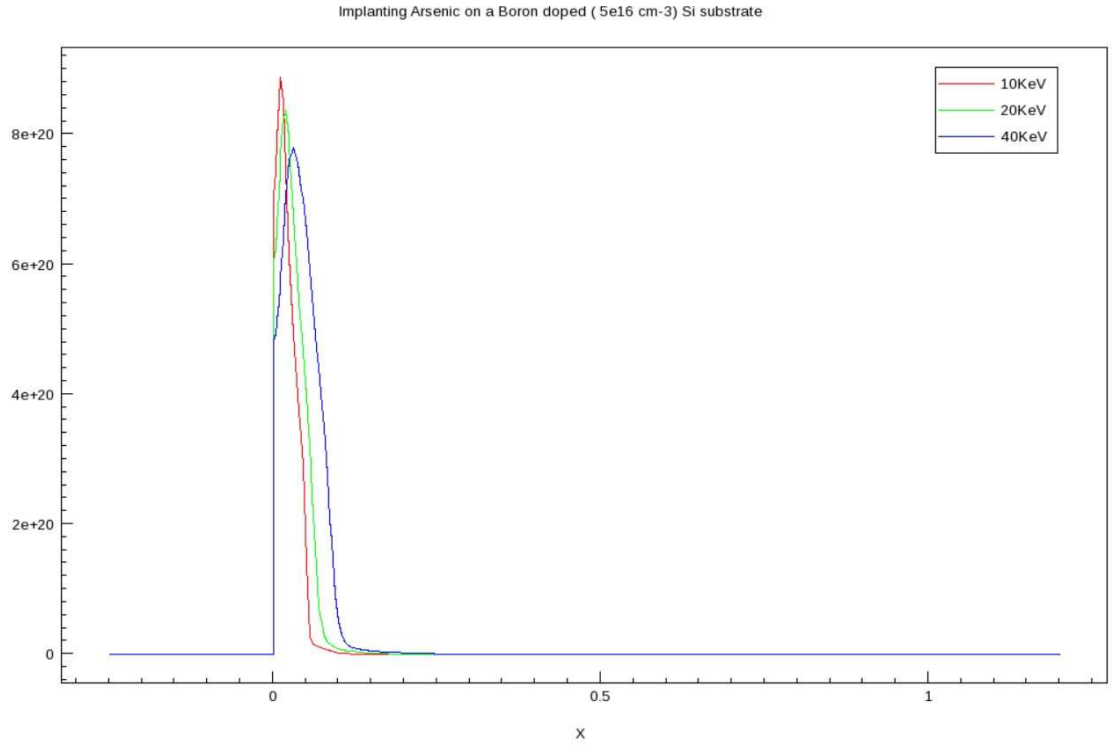
Impact energy: 10 KeV







Plot of net-active concentration (N_D-N_A) along the device depth:



Observation:

Junction Depth:

When we use heavier dopants (dopants with higher atomic mass), such as arsenic (As) we will generally get a shallower junction depth compared to lighter dopants like phosphorus (P) for the same implantation conditions. This is because heavier ions lose their energy more quickly as they penetrate the semiconductor lattice. As a result, they stop at a shallower depth.

Lighter dopants, like phosphorus tend to penetrate deeper into the semiconductor before coming to rest, leading to deeper junction depths under the same implantation conditions.

Peak Concentration:

Heavier dopants like As result in a higher peak concentration near the surface compared to lighter dopants because they stop at a shallower depth. So for the same dose comparison, the peak is higher .As a result, the majority of the dopant atoms end up at a shallower depth, and the concentration near the surface is higher.

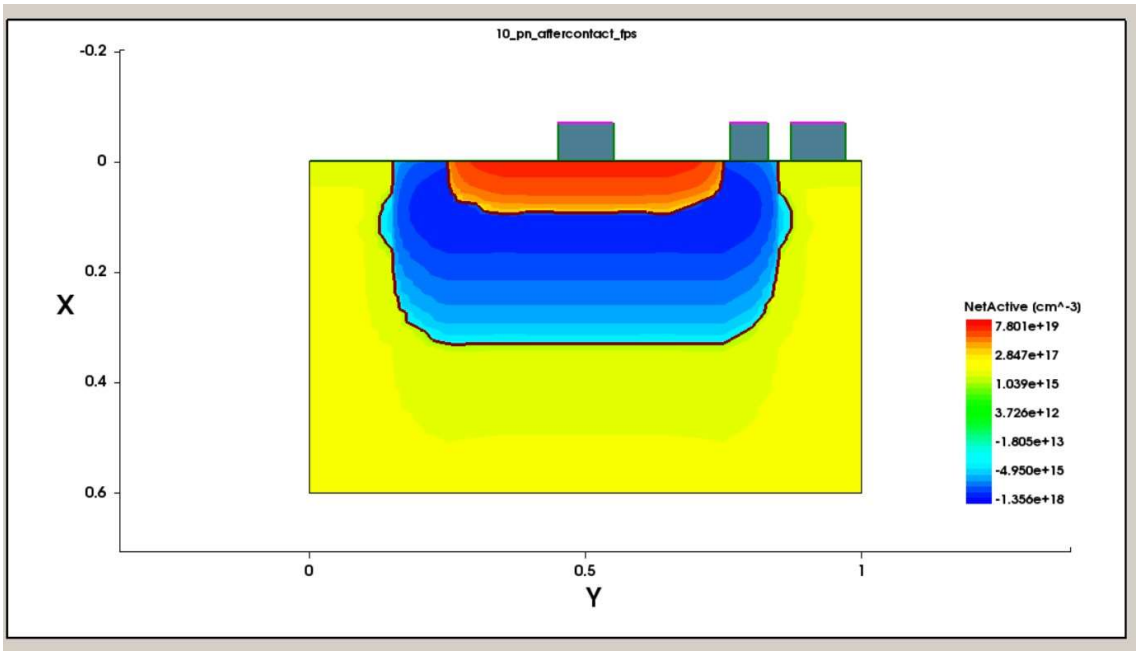
Lighter dopants like phosphorous having deeper penetration, have a lower peak concentration near the surface because they can distribute their atoms over a larger depth range. Therefore, the concentration near the surface is lower.

Q3)

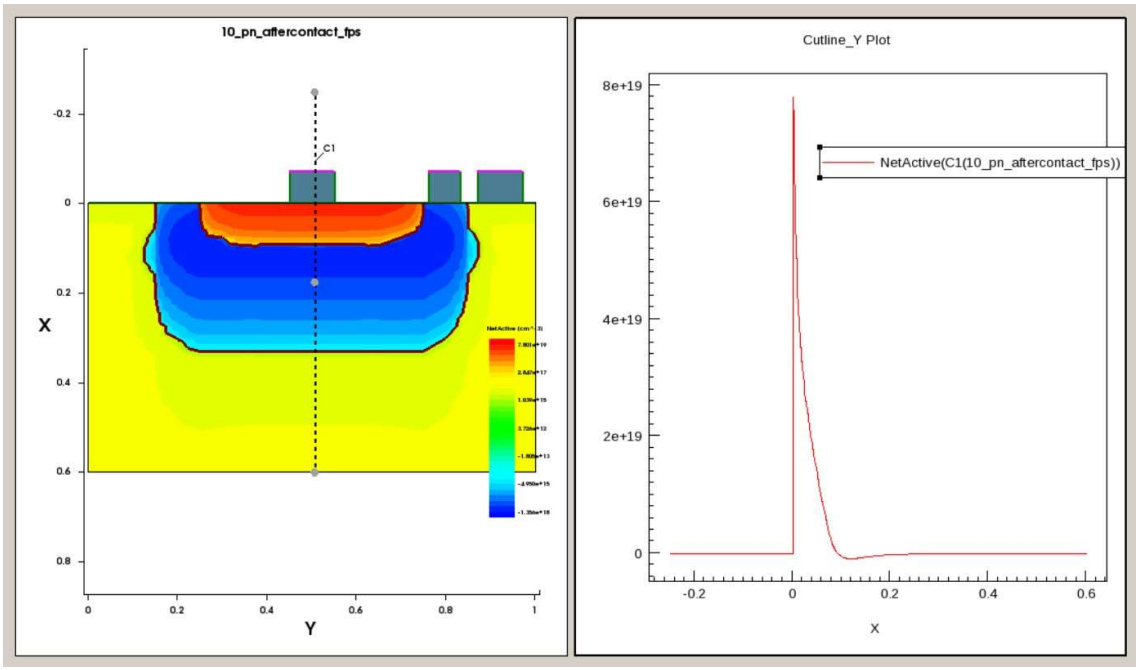
A n^+p^-n BJT was created with collector - base junction depth ~ 300 nm and base - emitter junction depth ~200 nm. The n+ and p region doping were made to be as uniform as possible with Phosphorus concentration, N_D = 1e20 cm^{-3} and Boron concentration, N_A = 1e14 cm^{-3}, by changing the parameters such as implant dose, implant energy, diffusion or annealing time and temperature. All this was done by changing the code in SProcess tool.

The device was successfully fabricated and plots for Active dopant concentration were obtained from SVisual.

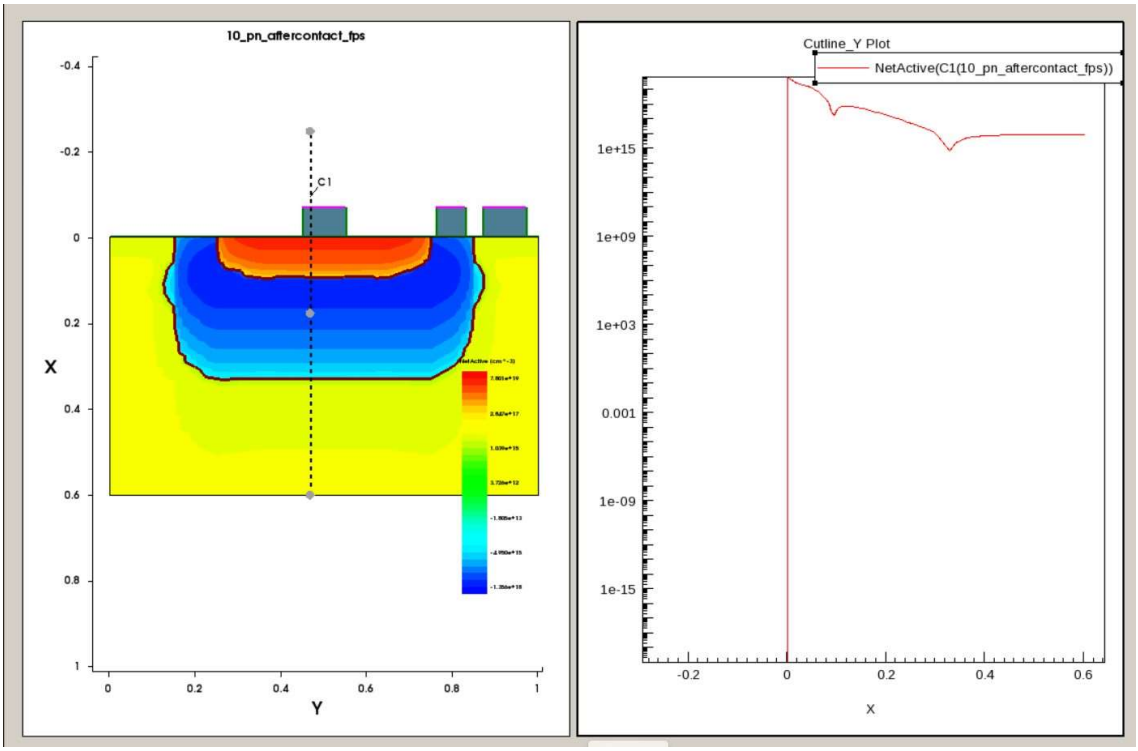
Fabricated NPN BJT :



Net active concentration(Linear Scale) :

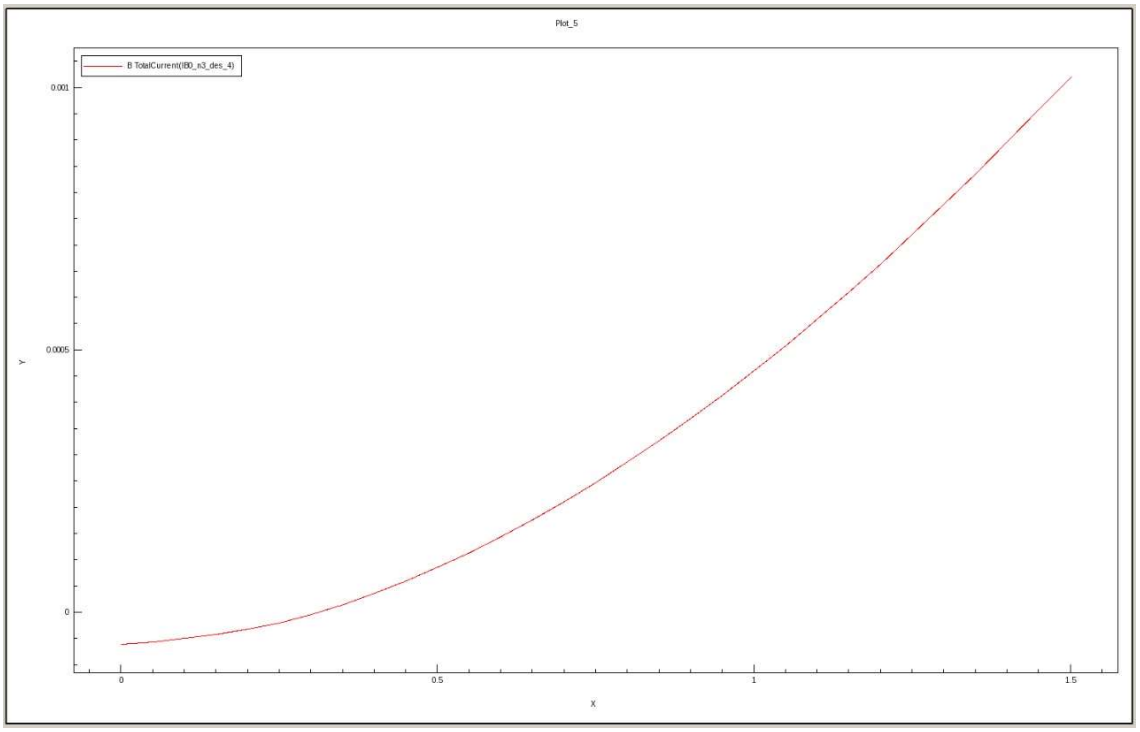


Net active concentration(Logarithmic Scale) :

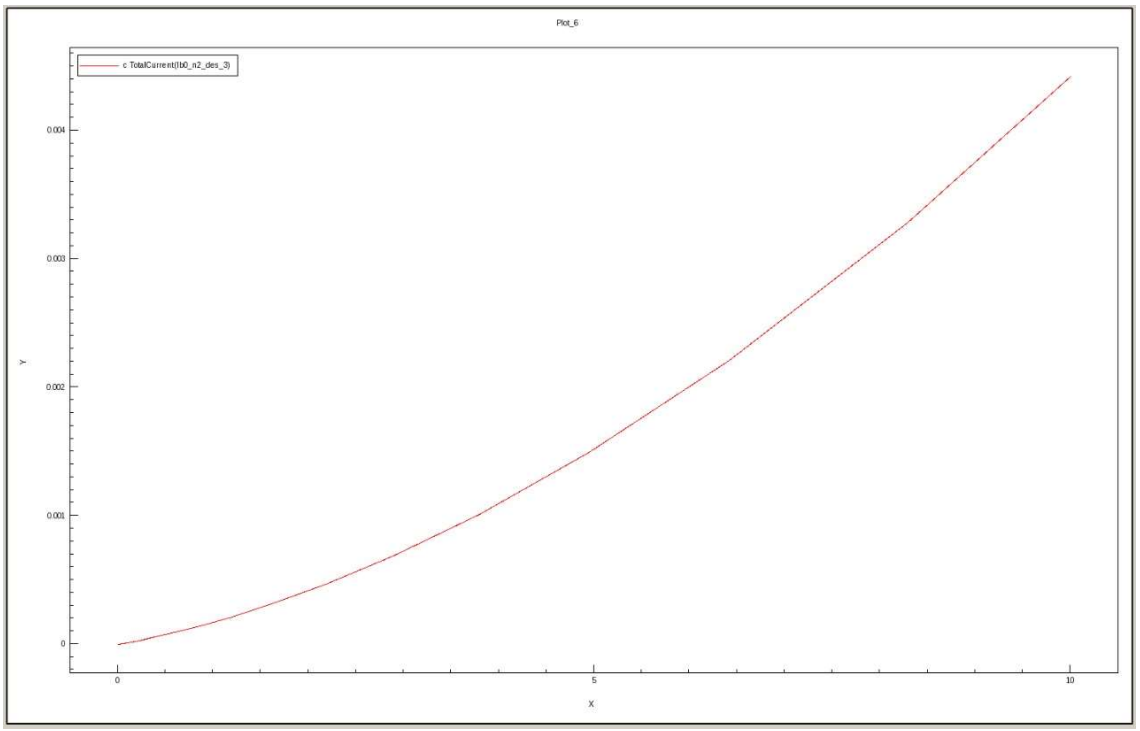


The given SDevice code was run to get the I-V Charectaristics for CE and CB configurations.The following plots were obtained.

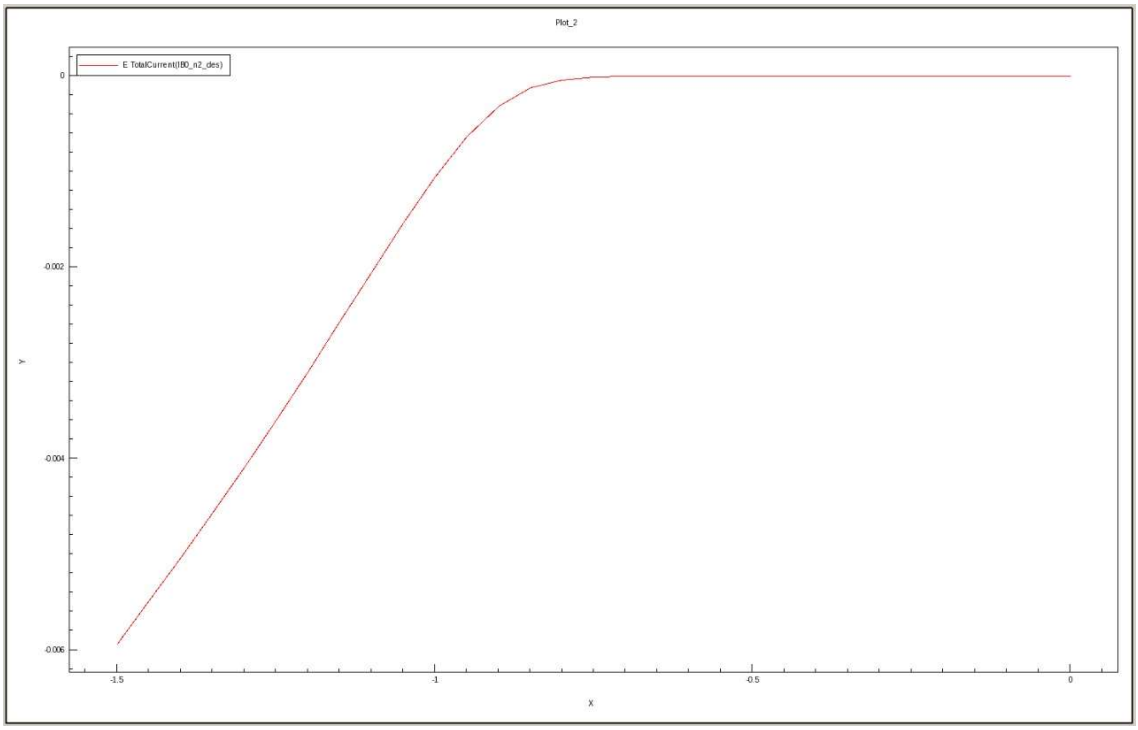
Common Emitter (Input Charectaristics):



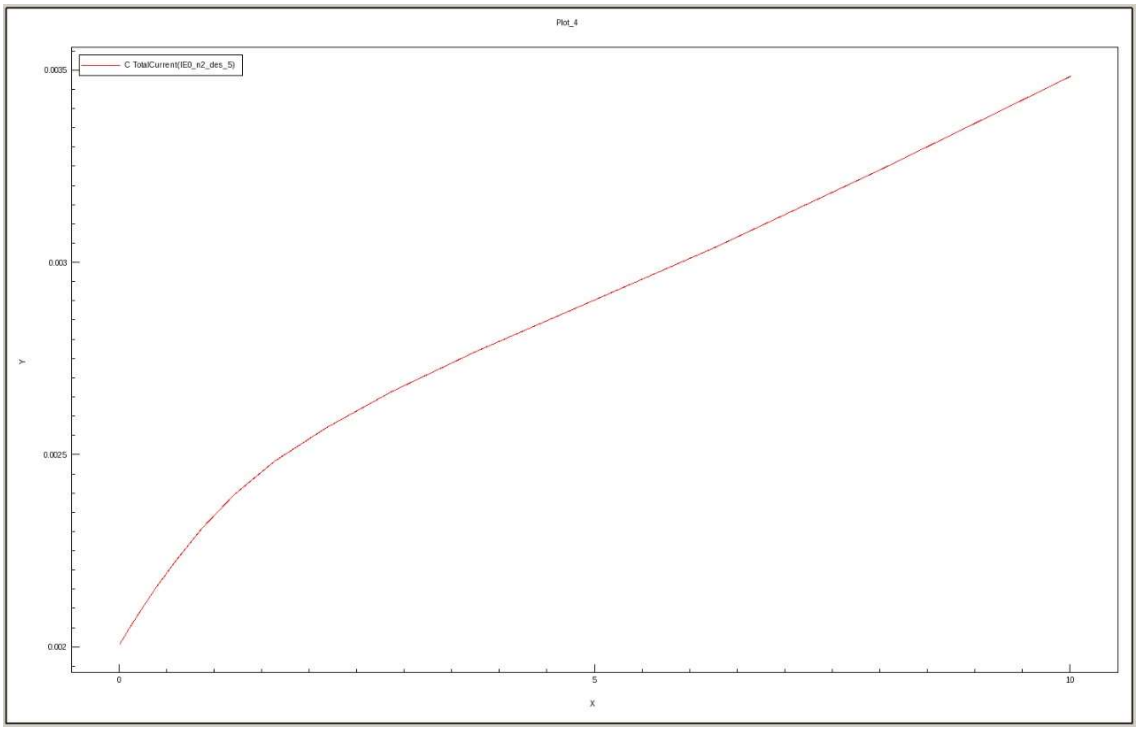
Common Emitter (Output Charectaristics):



Common Base (Input Charectaristics):



Common Base (OutputCharectaristics):



Codes:

Q1)

Sprocess:

```
# 1D Grid definition in x direction
line x location= 0.0 spacing=1.0<nm> tag=SiTop
```

```
line x location=50<nm> spacing=10<nm>
line x location=100<nm> spacing=20<nm>
line x location=500<nm> spacing=50<nm>
line x location=1200<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=1000<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=5e+14<cm-3> field=Boron 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> 0.425<um> 0.575<um>
1.0<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_pn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh
##Change implant energy and dopant dose concentration here for different cases
implant Phosphorus energy=10<keV> dose=5e14<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.2<s>
#save the structure after implantation and diffusion
struct tdr =2_pn_after_implant_diffusion

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

deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}
grid remesh
#save structure after contact deposition
struct tdr =4_pn_after_metal_depos ;
```

mask name=contacts_mask1 left=0.425<um> right=0.575<um>

etch material= {Aluminum} type=anisotropic time=1 rate= {0.08} mask=contacts_mask1

grid remesh

contact name = "n" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.425 yhi = 0.575

contact name = "p" box silicon adjacent.material = Ambient\

xlo= 1.19 xhi = 1.21 ylo = 0.0 yhi = 1

save final structure

struct tdr = 5_pn_final_structure

Q2)

SProcess:

1D Grid definition in x direction

line x location= 0.0 spacing=1.0<nm> tag=SiTop

line x location=50<nm> spacing=10<nm>

line x location=100<nm> spacing=20<nm>

line x location=500<nm> spacing=50<nm>

line x location=1200<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=1000<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=5e+14<cm-3> field=Boron 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> 0.425<um> 0.575<um> 1.0<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_pn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\

xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}

grid remesh

##Change implant energy and dopant dose concentration here for different cases. Implanted ion has been changed to Arsenic

implant Arsenic energy=10<keV> dose=5e14<cm-2> tilt = 0

```
diffuse temperature=1060<C> time=1.2<s>
#save the structure after implantation and diffusion
struct tdr =2_pn_after_implant_diffusion

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

deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}
grid remesh
#save structure after contact deposition
struct tdr =4_pn_after_metal_depos ;



mask name=contacts_mask1 left=0.425<um> right=0.575<um>
etch material= {Aluminum} type=anisotropic time=1 rate= {0.08}
mask=contacts_mask1
grid remesh

contact name = "n" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.425 yhi = 0.575
contact name = "p" box silicon adjacent.material = Ambient\
xlo= 1.19 xhi = 1.21 ylo = 0.0 yhi = 1
# save final structure
struct tdr = 5_pn_final_structure
```

Q3)

SProcess: (CE input)

```
# 1D Grid definition in x direction
line x location= 0.0 spacing=1.0<nm> tag=SiTop
line x location=50<nm> spacing=10<nm>
line x location=100<nm> spacing=20<nm>
line x location=500<nm> spacing=50<nm>
line x location=1200<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=1000<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> 0.4<um> 0.6<um> 1.0<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_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh

implant Boron energy=10<keV> dose=0.7e13<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.5<s>
#save the structure after implantation and diffusion
struct tdr =2_npn_after_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =3_npn_after_imp_diff_oxide_etch;
deposit material= {Oxide} type=isotropic time=1 rate= {0.15}
grid remesh
mask name=implant_mask segments= {0<um> 0.45<um> 0.65<um> 1.0<um> }
struct tdr =4_npn_after_imp;
```

```
etch material= {oxide} type=anisotropic time=1 rate= {0.17} mask=implant_mask
grid remesh

#Save the structure file after etching
struct tdr =5_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh


implant Phosphorus energy=15<keV> dose=0.2e15<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.2<s>
struct tdr =6_npn_after_implant_diffusion
etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =7_npn_after_imp_diff_oxide_etch;
deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}
grid remesh

mask name=contacts_mask segments= {0.45<um> 0.55<um> 0.76<um> 0.83<um> 0.87<um> 0.97<um> }
struct tdr = 8_npn_aftercontact
etch material= {Aluminum} type=anisotropic time=1 rate= {0.08} mask=contacts_mask
```

```
grid remesh
contact name = "E" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.45 yhi = 0.55
contact name = "B" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.76 yhi = 0.83
contact name = "C" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.87 yhi = 0.97
struct tdr = 9_npn_final_structure
```

SProcess: (CE output)

```
# 1D Grid definition in x direction
line x location= 0.0 spacing=1.0<nm> tag=SiTop
line x location=50<nm> spacing=10<nm>
line x location=100<nm> spacing=20<nm>
line x location=500<nm> spacing=50<nm>
line x location=1200<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=1000<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> 0.4<um> 0.6<um> 1.0<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_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh

implant Boron energy=10<keV> dose=0.7e13<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.5<s>
#save the structure after implantation and diffusion
struct tdr =2_npn_after_implant_diffusion
```

```
etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =3_npn_after_imp_diff_oxide_etch;
deposit material= {Oxide} type=isotropic time=1 rate= {0.15}
grid remesh
mask name=implant_mask segments= {0<um> 0.45<um> 0.65<um> 1.0<um> }
struct tdr =4_npn_after_imp;
etch material= {oxide} type=anisotropic time=1 rate= {0.17} mask=implant_mask
grid remesh

#Save the structure file after etching
struct tdr =5_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh



implant Phosphorus energy=15<keV> dose=0.2e15<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.2<s>
struct tdr =6_npn_after_implant_diffusion
etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =7_npn_after_imp_diff_oxide_etch;
```

deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}

grid remesh

mask name=contacts_mask segments= {0.45<um> 0.55<um> 0.76<um> 0.83<um> 0.87<um> 0.97<um> }

struct tdr = 8_npn_aftercontact

etch material= {Aluminum} type=anisotropic time=1 rate= {0.08} mask=contacts_mask

grid remesh

contact name = "E" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.45 yhi = 0.55

contact name = "B" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.76 yhi = 0.83

contact name = "C" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.87 yhi = 0.97

struct tdr = 9_npn_final_structure

SProcess: (CB input)

1D Grid definition in x direction

line x location= 0.0 spacing=1.0<nm> tag=SiTop

line x location=50<nm> spacing=10<nm>

line x location=100<nm> spacing=20<nm>

line x location=600<nm> spacing=50<nm> tag=SiBottom

1D Grid definition in y direction

line y location=0.0 spacing=50<nm> tag=Left

```
line y location=1000<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=111
# 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> 0.2<um> 0.8<um> 1.0<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_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh
```

```
implant Boron energy=18<keV> dose=1.8e13<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.5<s>
#save the structure after implantation and diffusion
struct tdr =2_npn_after_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =3_npn_after_imp_diff_oxide_etch;
deposit material= {Oxide} type=isotropic time=1 rate= {0.15}
grid remesh
mask name=implant_mask segments= {0<um> 0.3<um> 0.7<um> 1.0<um> }
struct tdr =4_npn_after_imp;
etch material= {oxide} type=anisotropic time=1 rate= {0.17} mask=implant_mask
grid remesh

#Save the structure file after etching
struct tdr =5_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh


implant Phosphorus energy=20<keV> dose=0.2e15<cm-2> tilt = 0
```

diffuse temperature=1060<C> time=2<s>

struct tdr =6_npn_after_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}

grid remesh

#save structure file after oxide etch

struct tdr =7_npn_after_imp_diff_oxide_etch;

deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}

grid remesh

mask name=contacts_mask segments= {0.45<um> 0.55<um> 0.76<um> 0.83<um> 0.87<um> 0.97<um> }

struct tdr = 8_npn_aftercontact

etch material= {Aluminum} type=anisotropic time=1 rate= {0.08} mask=contacts_mask

grid remesh

contact name = "E" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.45 yhi = 0.55

contact name = "B" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.76 yhi = 0.83

contact name = "C" box Aluminum adjacent.material = Ambient\

xlo= -0.071 xhi= -0.069 ylo = 0.87 yhi = 0.97

struct tdr = 9_npn_final_structure

SProcess: (CB output)

```
# 1D Grid definition in x direction
line x location= 0.0 spacing=1.0<nm> tag=SiTop
line x location=50<nm> spacing=10<nm>
line x location=100<nm> spacing=20<nm>

line x location=600<nm> spacing=50<nm> tag=SiBottom

# 1D Grid definition in y direction
line y location=0.0 spacing=50<nm> tag=Left
line y location=1000<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=111
# 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> 0.2<um> 0.8<um> 1.0<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_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh

implant Boron energy=18<keV> dose=1.8e13<cm-2> tilt = 0

diffuse temperature=1060<C> time=1.5<s>
#save the structure after implantation and diffusion
struct tdr =2_npn_after_implant_diffusion

etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =3_npn_after_imp_diff_oxide_etch;
deposit material= {Oxide} type=isotropic time=1 rate= {0.15}
grid remesh
mask name=implant_mask segments= {0<um> 0.3<um> 0.7<um> 1.0<um> }
struct tdr =4_npn_after_imp;
etch material= {oxide} type=anisotropic time=1 rate= {0.17} mask=implant_mask
```

```
grid remesh

#Save the structure file after etching
struct tdr =5_npn_oxide_etch_before_implant;

refinebox Silicon min= {0.0 0.4} max= {0.2 0.6}\
xrefine= {0.01 0.01 0.01} yrefine = {0.01 0.01 0.01}
grid remesh


implant Phosphorus energy=20<keV> dose=0.2e15<cm-2> tilt = 0

diffuse temperature=1060<C> time=2<s>
struct tdr =6_npn_after_implant_diffusion
etch material= {Oxide} type=isotropic time= 1 rate= {0.17}
grid remesh
#save structure file after oxide etch
struct tdr =7_npn_after_imp_diff_oxide_etch;
deposit material= {Aluminum} type=isotropic time=1 rate= {0.07}
grid remesh

mask name=contacts_mask segments= {0.45<um> 0.55<um> 0.76<um>
0.83<um> 0.87<um> 0.97<um> }
struct tdr = 8_npn_aftercontact
etch material= {Aluminum} type=anisotropic time=1 rate= {0.08}
mask=contacts_mask

grid remesh
```

```
contact name = "E" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.45 yhi = 0.55
contact name = "B" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.76 yhi = 0.83
contact name = "C" box Aluminum adjacent.material = Ambient\
xlo= -0.071 xhi= -0.069 ylo = 0.87 yhi = 0.97
struct tdr = 9_npn_final_structure



SDevice: (CE input)
Electrode {
        { Name= "E"   Voltage= 0.0 }
        { Name= "B"      Voltage= 0.0 }
        { Name= "C" Voltage= 0.0 }
}

File {
        * Input Files
        Grid= "9_npn_final_structure_fps.tdr"
        Parameter= "@parameter@"
        * Output Files
        Current= "@plot@"
        Plot= "@tdrdat@"
        Output= "@log@"
}

Physics {
```

```
        Hydrodynamic
        EffectiveIntrinsicDensity(BandGapNarrowing(Slotboom))
        Mobility (
                DopingDependence
                HighFieldSaturation
        )
        Recombination (
                Auger
                SRH(DopingDependence)
                Avalanche(Okuto)
        )
}


Solve {
* Initial Guess
        Coupled ( Iterations= 100 ) { Poisson }
        Coupled { Poisson Electron Hole }

* Initial base ramp
        Quasistationary (
                InitialStep= 1e-5 Increment= 1.5
                Minstep= 1e-8 MaxStep= 0.2
                Goal { Name= "C" Voltage= @VCE@ }
        ){ Coupled { Poisson Electron Hole } }

* Base and Collector ramp
```

```
        NewCurrentFile="IB0_"
        Quasistationary (
                InitialStep= 1.0e-3 Increment= 1.5
                Minstep= 1e-6 MaxStep= 0.04
                Goal { Name= "B"      Voltage= 1.5 }
        ){ Coupled { Poisson Electron Hole  }
                CurrentPlot ( Time= (Range= (0.0 1.0) intervals= 30))
                Plot(FilePrefix= "n@node@_snap" Time=(1.0))
        }
}


SDevice: (CE output)
Electrode {
        { Name= "E"   Voltage= 0.0 }
        { Name= "B"      Voltage= 0.0 }
        { Name= "C" Voltage= 0.0 }
}

File {
        * Input Files
        Grid= "9_npn_final_structure_fps.tdr"
        Parameter= "@parameter@"
        * Output Files
        Current= "@plot@"
        Plot= "@tdrdat@"
```

```
        Output= "@log@"
}

Physics {
        Hydrodynamic
        EffectiveIntrinsicDensity(BandGapNarrowing(Slotboom))
        Mobility (
                DopingDependence
                HighFieldSaturation
        )
        Recombination (
                Auger
                SRH(DopingDependence)
                Avalanche(Okuto)
        )
}



Solve {

  Coupled(Iterations=100){ Poisson }
  Coupled{ Poisson Electron Hole }

  Quasistationary (
    InitialStep=0.01 Increment=1.3
    MaxStep =0.2 MinStep = 1e-6
```

```
  Goal{ Name="B" Voltage=1.5 }
){ Coupled {Poisson Electron Hole } }

Set( "B" mode current )


Quasistationary (
  InitialStep=0.01 Increment=1.3
  MaxStep =0.2 MinStep = 1e-6
  Goal{ Name="B" Current=@IB@ }
){ Coupled {Poisson Electron Hole }
  Plot(FilePrefix="n@node@_IB" Time=(0.0;0.5;1) NoOverWrite )
}

NewCurrentPrefix="IB0_"
Load(FilePrefix="n@node@_IB_0002")

Quasistationary (
  InitialStep=0.01 Increment=1.3
  MaxStep =0.2 MinStep = 1e-6
  Goal{ Name="C" Voltage=10 }
){ Coupled {Poisson Electron Hole}

}
```

```
SDevice: (CB input)
Electrode {
        { Name= "E"   Voltage= 0.0 }
        { Name= "B"      Voltage= 0.0 }
        { Name= "C" Voltage= 0.0 }
}

File {
        * Input Files
        Grid= "9_npn_final_structure_fps.tdr"
        Parameter= "@parameter@"
        * Output Files
        Current= "@plot@"
        Plot= "@tdrdat@"
        Output= "@log@"
}

Physics {
        Hydrodynamic
        EffectiveIntrinsicDensity(BandGapNarrowing(Slotboom))
        Mobility (
                DopingDependence
                HighFieldSaturation
        )
        Recombination (
                Auger
                SRH(DopingDependence)
```

```
        Avalanche(Okuto)
    )
}



Solve {
* Initial Guess
    Coupled ( Iterations= 100 ) { Poisson }
    Coupled { Poisson Electron Hole }

* Initial base ramp
    Quasistationary (
        InitialStep= 1e-5 Increment= 1.5
        Minstep= 1e-8 MaxStep= 0.2
        Goal { Name= "C" Voltage= 1.5 }
    ){ Coupled { Poisson Electron Hole } }

* Base and Collector ramp

    NewCurrentFile="IB0_"
    Quasistationary (
        InitialStep= 1.0e-3 Increment= 1.5
        Minstep= 1e-6 MaxStep= 0.04
        Goal { Name= "E"      Voltage= -1.5 }
    ){ Coupled { Poisson Electron Hole  }
        CurrentPlot ( Time= (Range= (0.0 1.0) intervals= 30))
```

```
        Plot(FilePrefix= "n@node@_snap" Time=(0.7))
    }
}

SDevice: (CB output)
Electrode {
    { Name= "E"   Voltage= 0.0 }
    { Name= "B"     Voltage= 0.0 }
    { Name= "C" Voltage= 0.0 }
}

File {
    * Input Files
    Grid= "9_npn_final_structure_fps.tdr"
    Parameter= "@parameter@"
    * Output Files
    Current= "@plot@"
    Plot= "@tdrdat@"
    Output= "@log@"
}

Physics {
    Hydrodynamic
    EffectiveIntrinsicDensity(BandGapNarrowing(Slotboom))
    Mobility (
        DopingDependence
        HighFieldSaturation
```

```
        )
        Recombination (
                Auger
                SRH(DopingDependence)
                Avalanche(Okuto)
        )
}



Solve {

  Coupled(Iterations=100){ Poisson }
  Coupled{ Poisson Electron Hole }

  Quasistationary (
    InitialStep=0.01 Increment=1.3
    MaxStep =0.2 MinStep = 1e-6
    Goal{ Name="E" Voltage=-1.5 }
  ){ Coupled {Poisson Electron Hole } }

  Set( "E" mode current )


  Quasistationary (
    InitialStep=0.01 Increment=1.3
    MaxStep =0.2 MinStep = 1e-6
```

```
  Goal{ Name="E" Current=1e-3 }
 ){ Coupled {Poisson Electron Hole }
  Plot(FilePrefix="n@node@_IE" Time=(0.0;0.5;1) NoOverWrite )
 }

 NewCurrentPrefix="IE0_"
 Load(FilePrefix="n@node@_IE_0000")

 Quasistationary (
  InitialStep=0.01 Increment=1.3
  MaxStep =0.2 MinStep = 1e-6
  Goal{ Name="C" Voltage=10 }
 ){ Coupled {Poisson Electron Hole}

 }


}
```