EE 735 Assignment 6

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Q1) In this problem, to solve the given questions we had to modify the given code first for a PN junction silicon diode of length 4um and thickness 2um.The P and N sides are doped with a doping density of 10^17 cm-3.

First we define parameters of length on N side and P side “Ln” and “Lp” of PN diode with a thickness “h”.

```
{
#### Dimensions parameters (Default is um) ####

(define Ln 2)
(define Lp 2)
(define h 2)
}
```

Next we define two regions using sdegeo:create-rectangle

- The first region is for the p-region of the pn diode, made of "Silicon" material, with dimensions defined by Lp and h.
- The second region is for the n-region of the pn diode, also made of "Silicon" material, with dimensions defined by Ln and h.

```
{
#### Regions ####

(sdegeo:create-rectangle (position 0 0 0) (position (* -1 Lp) h 0) "Silicon"
"p_region")
(sdegeo:create-rectangle (position 0 0 0) (position Ln h 0) "Silicon" "n_region")
}
```

The doping is uniform on both sides of the diode. Doping profiles are defined for both p and n regions using sdedr:define-constant-profile. In this case, both regions are doped with Boron and Phosphorus, respectively, with concentrations of 1e17 cm^-3. This is ensured using the following.

```
{
(sdedr:define-constant-profile "p_doping" "BoronActiveConcentration" 1e17)
(sdedr:define-constant-profile-region "p_doping_profile" "p_doping"
"p_region")

(sdedr:define-constant-profile "n_doping" "PhosphorusActiveConcentration"
1e17)
(sdedr:define-constant-profile-region "n_doping_profile" "n_doping"
"n_region")
}
```

Contact sets are defined using sdegeo:define-contact-set for both the p and n regions. These contact sets are assigned colors and shapes. Then, 2D contacts are specified at the centers of each region using sdegeo:define-2d-contact.

```
{
#### Contacts #####


(sdegeo:define-contact-set "p_contact" 4.0 (color:rgb 1.0 0.0 0.0 ) "##")

(sdegeo:define-contact-set "n_contact" 4.0 (color:rgb 0.0 1.0 0.0 ) "||")


(sdegeo:define-2d-contact (find-edge-id (position (* -1 Lp) (/ h 2) 0))
"p_contact")

(sdegeo:define-2d-contact (find-edge-id (position Ln (/ h 2) 0)) "n_contact")

}
```

The command **sde:save-model**: saves the model with the name "pn_diode."

Parameters for the global mesh refinement are defined. A rectangular refinement window is specified using "RefWin.Global," and size constraints are set for mesh elements. The "Place.Global" command defines where the mesh refinement should take place.

```
{
#### Global course mesh ####
```

(sedr:define-refeval-window "RefWin.Global" "Rectangle" (position (* -1 Lp) h 0) (position Ln 0 0))

(sedr:define-refinement-size "RefDef.Global" (/ Lp 100) (/ h 20) (/ Lp 100) (/ h 20) 1 1)

(sedr:define-refinement-placement "Place.Global" "RefDef.Global" "RefWin.Global")

}

Similar to the global mesh section, the junction fine mesh defines parameters for fine mesh refinement specifically at the junction between the p and n regions from -Lp/5 to Ln/5 along the X axis.

{

Junction fine mesh

(sedr:define-refeval-window "RefWin.Dep" "Rectangle" (position (/ (* -1 Lp) 5) h 0) (position (/ Ln 5) 0 0))

(sedr:define-refinement-size "RefDef.Dep" (/ Lp 500) (/ h 20) (/ Lp 500) (/ h 20) 1 1)

(sedr:define-refinement-placement "Place.Dep" "RefDef.Dep" "RefWin.Dep")

}

Once the meshing dimensions and step sizes are defined, we can generate the mesh with the specified parameters and saving it as "snmesh."

{

(sde:build-mesh "snmesh" "" "pn_diode")

}

Now we can simulate the IV charectaristics in SDevice Tool by altering the necessary parts in the Physics section according to given question and see the plots.

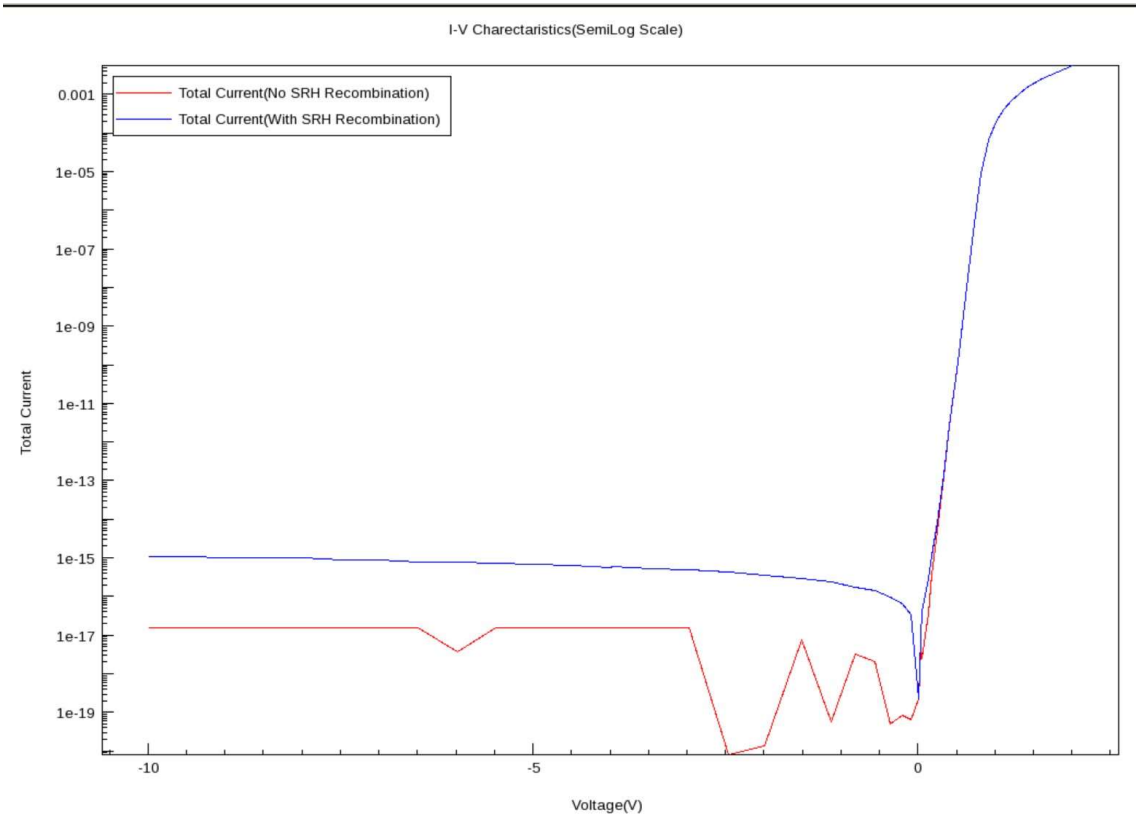
To observe the IV charectaristics for conditions with and without SRH recombination, we have to alter the physics section by commenting in and out the following line.

{

Recombination(SRH(DopingDependence)

}

The SDEVICE code is run two times for each case ie one time for forward bias from 0V to 2V and another time for reverse bias from -10V to 0V. All the plots are simultaneously plotted on Svisual and we get the following.



Observation:

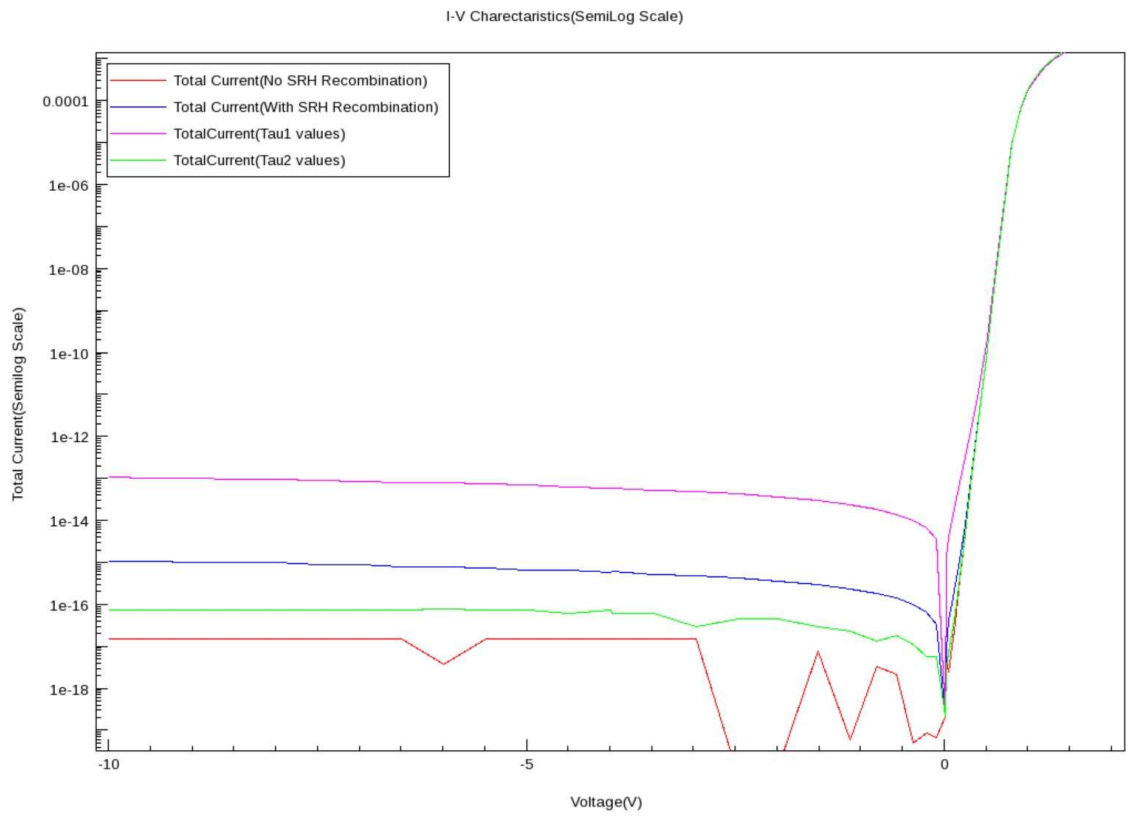
When a negative voltage is applied to the P-side relative to the N-side (reverse bias), the electric field prevents majority carriers from crossing the junction. In the presence of SRH recombination, there is a very small reverse leakage current due to recombination. This current is usually negligible. In the absence of SRH recombination, the reverse bias leakage current is theoretically zero. This is because no recombination takes place in the depletion region. The presence of SRH recombination in a PN diode introduces a non-ideal behavior, particularly

in the reverse bias condition, where a small reverse leakage current occurs due to recombination. Without SRH recombination, the diode exhibits ideal behavior, conducting current efficiently in the forward bias and essentially blocking current in reverse bias. In forward bias,this effect can only be seen at very low voltages where current with SRH model turned on is slightly more than when it was turned off. Eventually the high FB current overshadows the recombination current.

To change carrier lifetimes, we have to open parameter option above include materials in SDEVICE and then use the following code snippet obtained from manual. The first value of taumax is for electrons and the second value is for holes. They can be modified according to the question.

```
{
Scharfetter * SRH recombination lifetimes
{ * tau=taumin+(taumax-taumin) / ( 1+(N/Nref )^gamma)
* electrons holes
taumin = 0.0000e+00, 0.0000e+00 # [s]
taumax = 1.0000e-07, 1.0000e-07 # [s]
}
```

On running the code as before,we get the following plots.



Observation:

When carrier lifetimes are increased, the minority carriers have a longer average lifetime before they recombine. Longer carrier lifetimes mean that minority carriers are less likely to recombine via SRH recombination during their transit through the device. As a result, the recombination current decreases because fewer minority carriers recombine with defects and traps, and more carriers contribute to the device's useful current.

When carrier lifetimes are decreased, minority carriers have a shorter average lifetime. Shorter lifetimes lead to a higher likelihood of recombination via SRH, resulting in an increased recombination current.The overall device performance may be affected negatively, as more carriers recombine non-radiatively instead of contributing to the useful current. Therefore, the SRH recombination current is inversely related to carrier lifetimes. Increasing carrier lifetimes reduces SRH recombination, while decreasing carrier lifetimes increases SRH recombination.

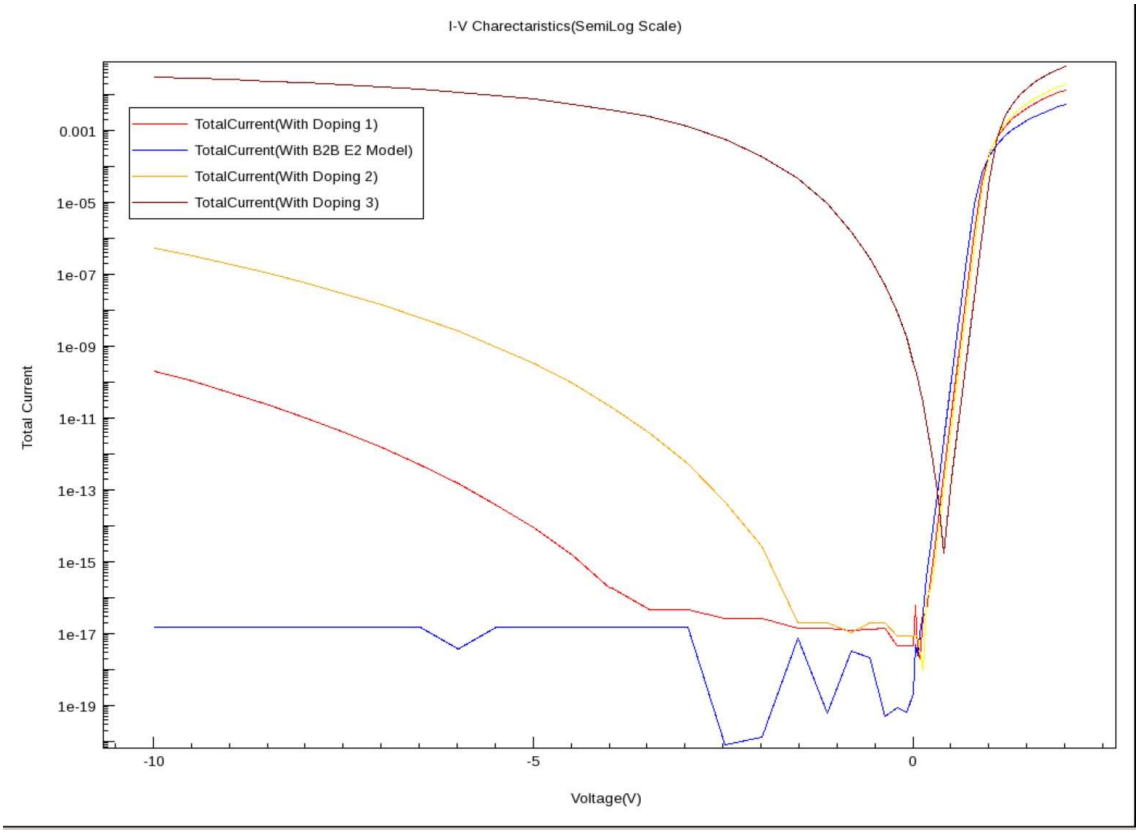
To activate the Band to Band(E2 Model), we have to again alter the physics section as given. The model can be turned on or off by commenting.

{

Recombination(Band2Band(E2))

}

The plots obtained are as below.



Observation-

The IV charectaristics with and without the B2B(E2 Model) comes as same as they overlap each other.

When the doping level is increased in both the P and N regions, the carrier concentration in these regions becomes higher. In the FB condition, the increased carrier concentration results in a higher forward bias current. This is because more charge carriers are available to participate in conduction when a positive voltage is applied to the P-side relative to the N-side.The diode conducts more current under forward bias.

Under Reverse Bias,thermally generated carriers are generated as a result of the intrinsic properties of the semiconductor material.When the doping level is

increased in a diode, it results in a higher carrier concentration in both the P and N regions.In the reverse bias condition, the electric field across the depletion region causes these thermally generated carriers to be swept towards the junction.As the doping level increases, more carriers are available, and more carriers are swept towards the junction, increasing the reverse current.

Q2)The code for SDE was written as follows.

We define several dimension parameters for the Moscap:

Lp: Length of the MOSCAP structure, set to 0.3 micrometers (um).

Lo: Length of the oxide region (SiO2), set to 0.003 um.

h: Height of the device, set to 0.5 um

```
{
#### Dimensions parameters (Default is um) ####


(define Lp 0.3)
(define Lo 0.003)
(define h 0.5)
}
```

We create two regions:

- A "p_region" made of silicon with dimensions defined by Lp and h.
- An "oxide_region" made of SiO2 with dimensions defined by Lo and h.

```
{
#### Regions ####


(sdegeo:create-rectangle (position 0 0 0) (position 0.3 0.5 0) "Silicon" "p_region")
(sdegeo:create-rectangle (position 0 0 0) (position -0.003 0.5 0) "SiO2" "oxide_region")
}
```

Doping profiles are defined for the "p_region." The "p_doping" profile is set with Boron doping at a concentration of 3e16.

{

Doping

(sdedr:define-constant-profile "p_doping" "BoronActiveConcentration" 3e16)

(sdedr:define-constant-profile-region "p_doping_profile" "p_doping" "p_region")

}

We define contact sets for the MOSCAP device. We also specifies the positions for these contacts.

"p_contact" with a red color and a pattern "##."

"o_contact" with a green color and a pattern "||."

Then parameters for global mesh refinement are defined:

A rectangular refinement window ("RefWin.Global") is set.

Mesh refinement sizes ("RefDef.Global") are specified.

Placement for the refinement is defined.

{

Global course mesh

(sdedr:define-refeval-window "RefWin.Global" "Rectangle" (position Lp h 0) (position (* -1 Lp) 0 0))

(sdedr:define-refinement-size "RefDef.Global" (/ Lp 100) (/ h 20) (/ Lp 100) (/ h 20) 1 1)

(sdedr:define-refinement-placement "Place.Global" "RefDef.Global" "RefWin.Global")

}

Similar to the global mesh section, the junction fine mesh part defines parameters for fine mesh refinement at the junction between the silicon and SiO2 regions.

{

Junction fine mesh

(sedr:define-refeval-window "RefWin.Dep" "Rectangle" (position (/ Lp 3) h 0) (position (* -1 Lo) 0 0))

(sedr:define-refinement-size "RefDef.Dep" (/ Lo 3) (/ h 50) (/ Lo 3) (/ h 50) 1 1)

(sedr:define-refinement-placement "Place.Dep" "RefDef.Dep" "RefWin.Dep")

}

The code builds the mesh using the specified parameters and saves it as "snmesh."

{

(sde:build-mesh "snmesh" "" "moscap")

}

In SDEVICE code, the contact material was changed to Aluminun in the way below.

{ Name="o_contact" Voltage= 0.0 Material="Aluminum" }

To bias the Moscap substrate contact at Vg=Vt, we find the value of Vt for each case by using the following formula.

$$V_T \equiv \Phi_{MS} + 2\Phi_F - \frac{(Q_{ox} + Q_{depl})}{C_{ox}}$$

Work function was found out from the internet for silicon with boron doping whereas the Fermi potential was calculated from the doping concentration given.

The values for Vt came as follows-

0.041V;0.016V;0.028V for the three cases respectively.

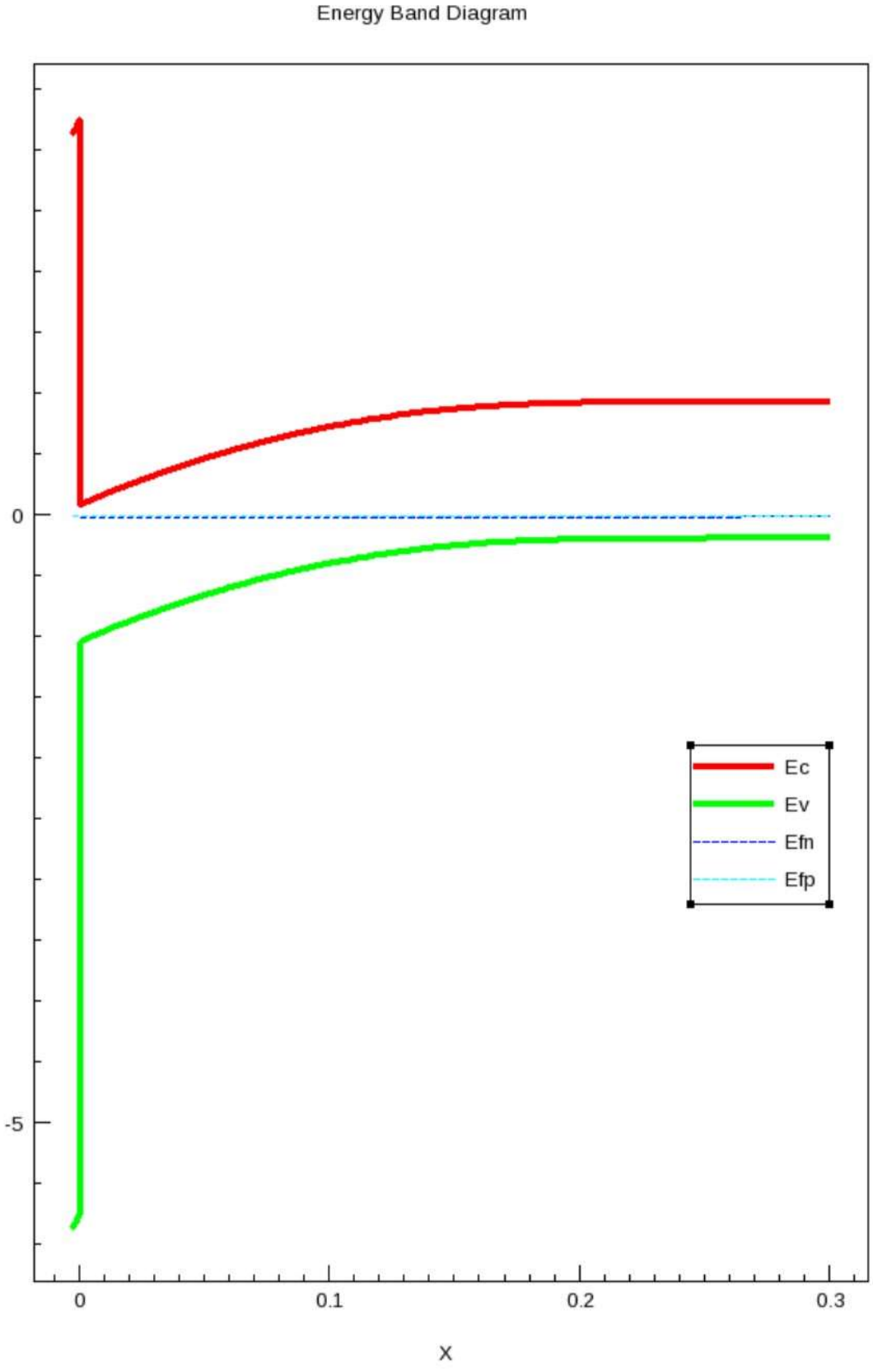
When we increase the oxide thickness, the oxide capacitance decreases hence 1/Cox increases and since this term is subtracted from Vt,the value of threshold in part b goes down as compared to a. This can be seen in the values found. A thicker oxide layer results in a higher voltage drop across the oxide.A higher

voltage drop across the oxide means that a stronger electric field is required to induce charge carriers to form a conductive channel in the semiconductor below the oxide. As a result, a higher gate-source voltage (Vgs) is needed to reach the Vth and turn the MOSFET on.

In practical terms, this means that, with increased oxide thickness, the moscap requires a larger gate-source voltage to reach the threshold voltage and allow the transistor to conduct current.

When doping density is increased, the Vth typically decreases (shifts in the negative direction). This is because the increased doping concentration reduces the surface potential in the channel region.

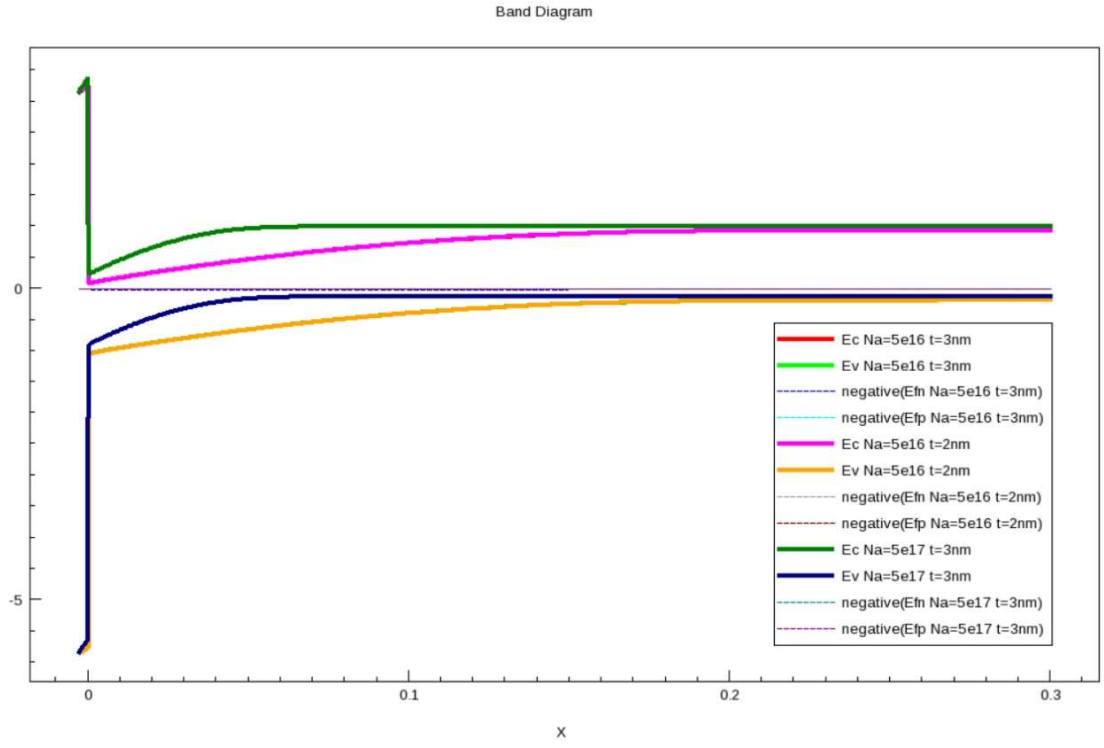
The SDEVICE code was run by biasing the substrate contact at these potentials respectively. We then used SVisual tool to plot the Energy Band Diagrams and the Carrier Densities for these cases. The plots came as following-


Energy Band Diagram
0
-5
0
0.1
0.2
0.3
X
Ec
Ev
Efn
Efp

Observation: The electron density increases towards the oxide layer and the hole density drops with the introduction of positive voltage at the gate equal to the threshold voltage(with substrate at ground). This is reflected in the EBD, and we can see that when biased as previously said, Efp moves away from Ev and toward Ec.

Reasoning: When positive voltage equal to threshold voltage is applied, electrons are drawn toward the oxide and holes are driven deep into the substrate. Because of the steady voltage drop in the substrate, which is no longer powerful enough to invert the concentration, as we proceed deeper into the oxide, the concentration of holes increases more than that of electrons.In the EBD, this can be translated. Since no current is flowing, the fermi level's slope (Efp) is 0.

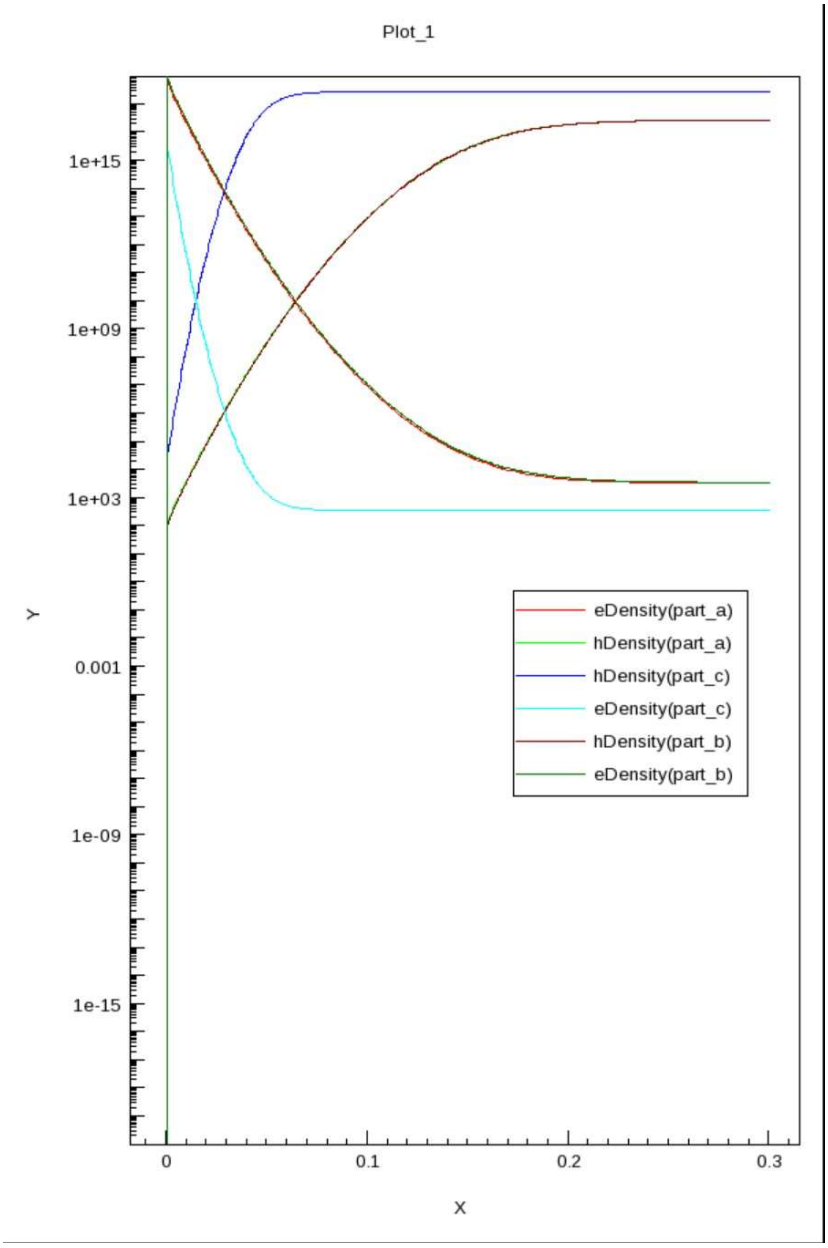
On comparing the three cases, we observe the following

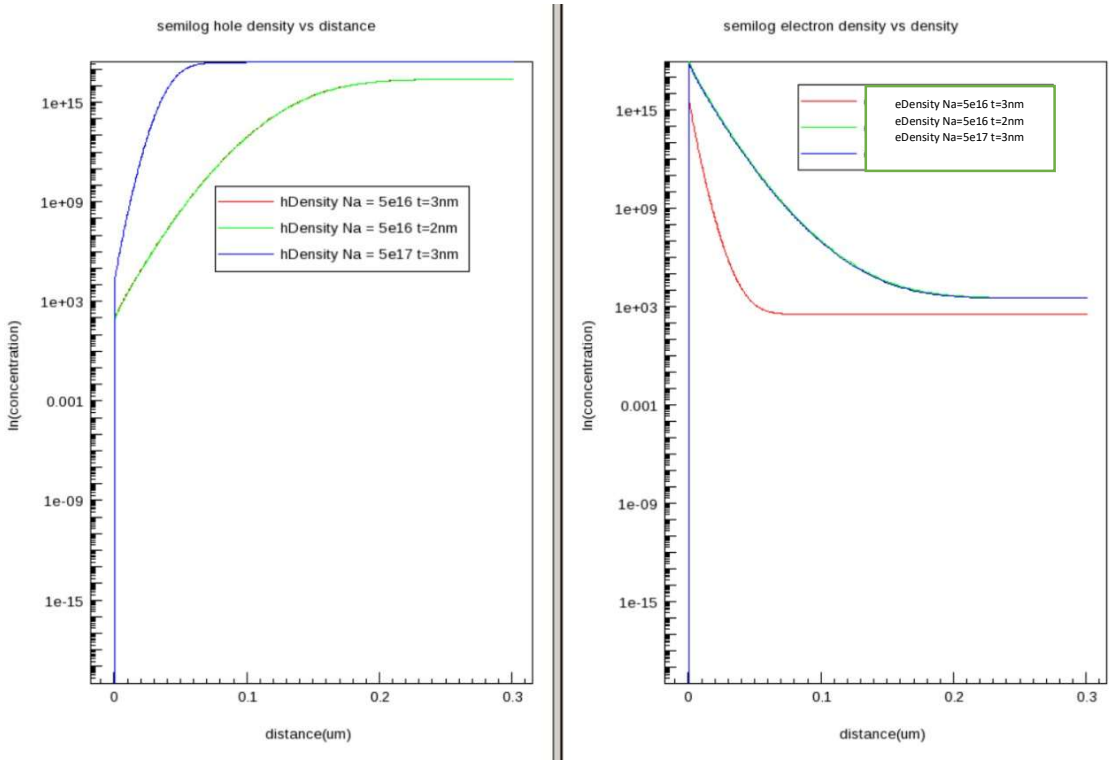


On changing the oxide thickness, we observe that the EBD does not change at all. This is due to the fact that we change the bias voltage to Vt for this new case. Also we do not change the carrier concentrations so the bending of the bands will be exactly same for both the cases. Thus the EBD for part a and b overlap each other.

For part c, we change the doping densities of the substrate and this means that the conduction band now has to bend more to reach the intrinsic level at the oxide interface since the Efp level of the substrate material comes further down.

The carrier density plots came as follows





Observation-

Efp travels away from Ec when we raise the substrate concentration (for t=3nm). Ec has to bend more to approach Efp when we bias it at Vt.When biased at Vt, the substrate's minority carrier concentration is the same. The concentration near the oxide may have increased as a result of less voltage loss there if we had biased at a voltage Vapplied and changed the thickness.The formula n=ni2/Na states that the electron concentration is less with a larger substrate concentration.