Indian Institute of Technology Tirupati

Department of Electrical Engineering

M.TECH : MVLSI

भारतीय प्रौद्योगिकी संस्थान तिरुपति

TIRUPATI

Device Simulation Laboratory (EE534P)

Instructor: Dr. Bhuktare Swapnil Sopanro

Assignment: 8

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Roll No: ee22m308

Q.1: Take an abrupt Si PN diode with equal doping on both sides, i.e. Na = Nd =1017 cm-3. Take the lengths of N & P regions to be equal to 5 µm and the width also equal to 5 µm. Plot the IV characteristics of the device for a voltage range of -5 V to 1 V in the linear as well as log scale. Plot the energy band diagrams, carrier concentrations and electron and hole components of the currents for different voltages, namely -1 V, 0 V, 0.2 V and 1 V.

JRL FILE:

```
;;

;; (journal:on
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/m3d.jrl")

;; "/home/students/MVLSI_2022/Group2/Praveen/assign1 ...

(sdegeo:define-contact-set "a" 4  (color:rgb 1 0 0 ) "##")

;; ()

(sdegeo:define-contact-set "b" 4  (color:rgb 1 0 0 ) "##")

;; ()

(sdegeo:define-2d-contact (list (car (find-edge-id (position -5 2.5 0))))
"a")


;; ()

(render:rebuild)

;; ()

(sdegeo:define-2d-contact (list (car (find-edge-id (position 5 2.5 0))))
"b")


;; ()
```

```
(render:rebuild)

;; ()

(sdedr:define-constant-profile "Constantp"
"BoronActiveConcentration" 1e17)

;; #t

(sdedr:define-constant-profile-region "Constantp" "Constantp"
"region_p")

;; #t

(sdedr:define-constant-profile "Constantn"
"PhosphorusActiveConcentration" 1e+17)

;; #t

(sdedr:define-constant-profile-region "Constantn" "Constantn"
"region_n")

;; #t

(bound? 'RefEvalWin_2)

;; #f

(sdedr:define-refeval-window "RefEvalWin_2" "Rectangle"  (position
-1 0 0) (position 1 5 0))

;; #[body 13 1]

(sdedr:define-refinement-size "Ref" 0.2 0.2 0 0.1 0.1 0 )

;; #t

(sdedr:define-refinement-placement "Ref" "Ref" (list "material"
"Silicon" ) )

;; #t

(sdedr:define-refinement-size "Ref2" 0.2 0.2 0 0.01 0.1 0 )
```

```
;; #t

(sdedr:define-refinement-placement "ref2" "Ref2" (list "window"
"RefEvalWin_2" ) )

;; #t

(sdedr:define-refinement-size "Ref2" 0.2 0.2 0 0.01 0.1 0 )

;; #t

(sdedr:define-refinement-placement "ref2" "Ref2" (list "window"
"RefEvalWin_2" ) )

;; #t

(sde:set-project-name
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/nnew")

;; ""

(sdesnmesh:iocontrols "outputFile"
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/nnew")

;; #t

(sde:set-meshing-command "snmesh")

;; #t

(sde:set-project-name
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/nnew")

;; "/home/students/MVLSI_2022/Group2/Praveen/assign1 ...

(sdesnmesh:iocontrols "outputFile"
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/nnew")

;; #t
```

```
(sde:build-mesh ""
"/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101
/nnew")

"Meshing successful"

;; #t

(system:command "svisual
/home/students/MVLSI_2022/Group2/Praveen/assign10/assign101/
nnew_msh.tdr &")

;; 0
```

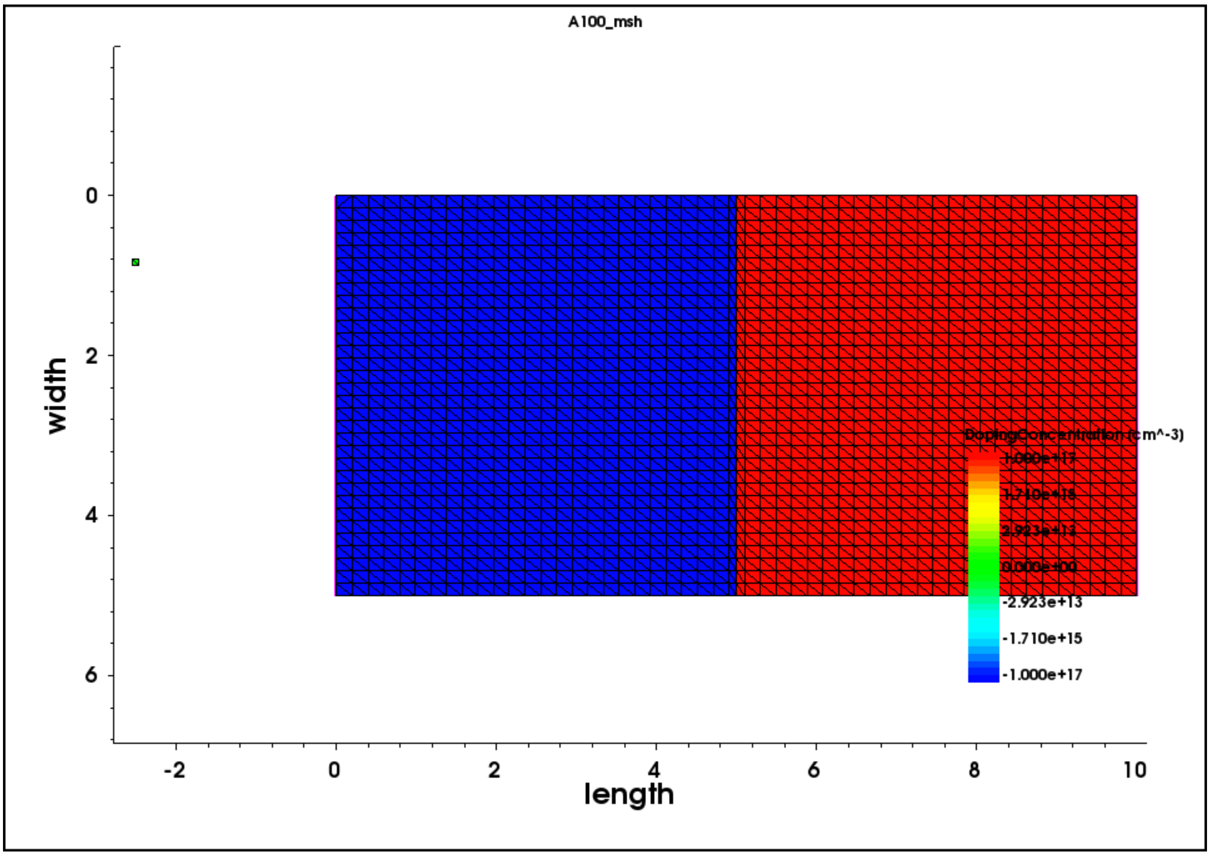
SDEVICE FILE

```
File{
   Grid      = "nnew_msh.tdr"
    Plot     = "@tdrdat@"
   Current   = "@plot@"
   Output    = "@log@"
}

Electrode{
   { Name="a"    Voltage=0.0 }
   { Name="b"    Voltage=0.0 }
}

Physics{

   Fermi
   EffectiveIntrinsicDensity( OldSlotboom )
```

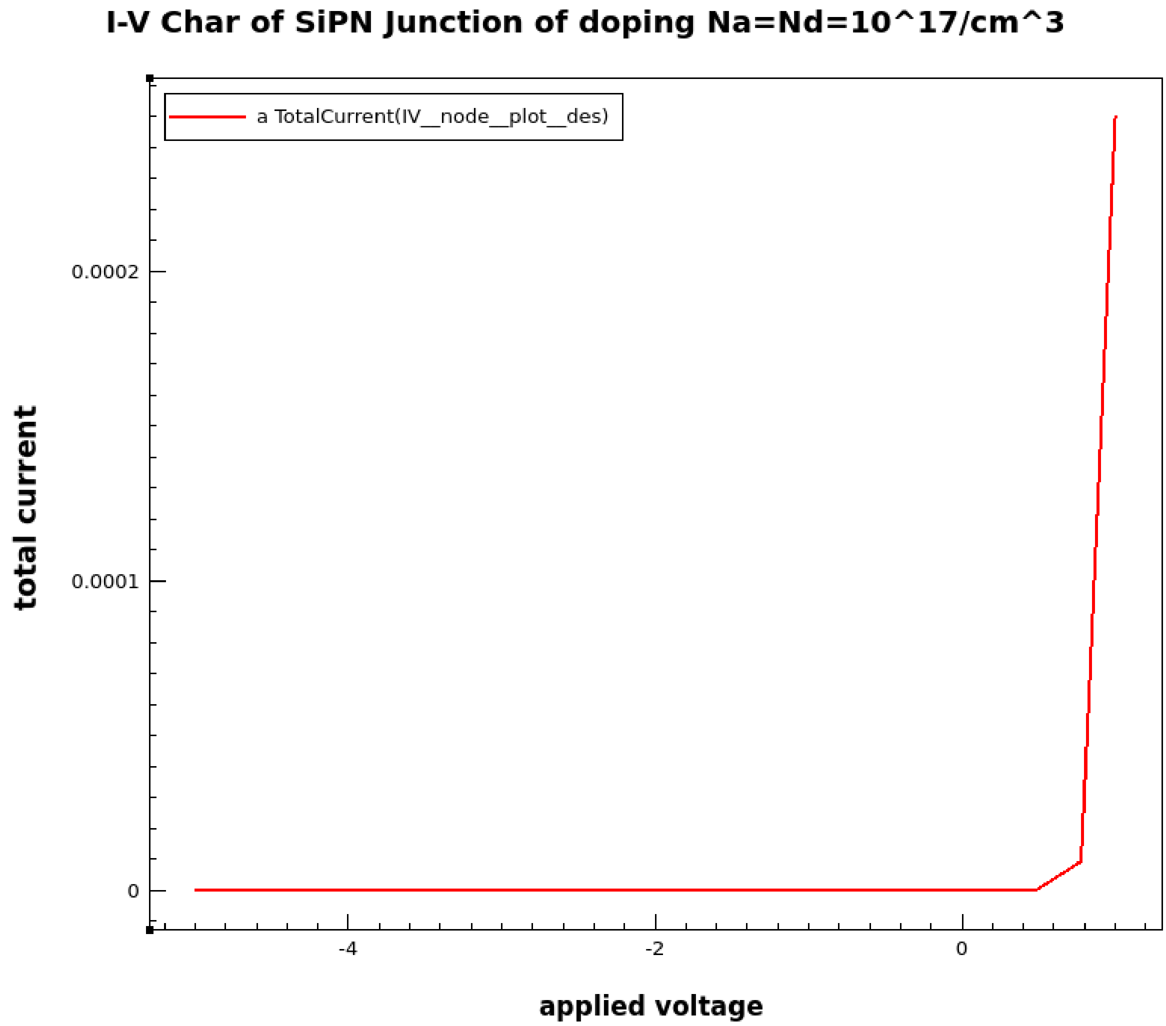
```
   Mobility(
        DopingDep )



   Recombination( SRH (DopingDependence) )

}

Plot{

   eDensity hDensity
   TotalCurrent/Vector eCurrent/Vector hCurrent/Vector
   eQuasiFermi hQuasiFermi
   eMobility hMobility

   ElectricField/Vector Potential SpaceCharge

   Doping DonorConcentration AcceptorConcentration

   BandGap
   ConductionBand ValenceBand
}

Math {
   Extrapolate
   RelErrControl
   Digits = 5
```

```
  Iterations= 20
  Notdamped= 100
  Method= Pardiso

}

Solve {



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

  NewCurrentPrefix="IV_@node@"
  Quasistationary(
    InitialStep=1e-3 MinStep=1e-4 MaxStep=0.05
    Goal{ Name="a" Voltage= -5 }
  ) { Coupled { Poisson Electron Hole } }
  Coupled(Iterations=100){ Poisson }
  Coupled{ Poisson Electron Hole }

  NewCurrentPrefix="IV_@node@"
  Quasistationary(
    InitialStep=1e-3 MinStep=1e-4 MaxStep=0.05
    Goal{ Name="a" Voltage= 1 }
  ) { Coupled { Poisson Electron Hole } }
}
```

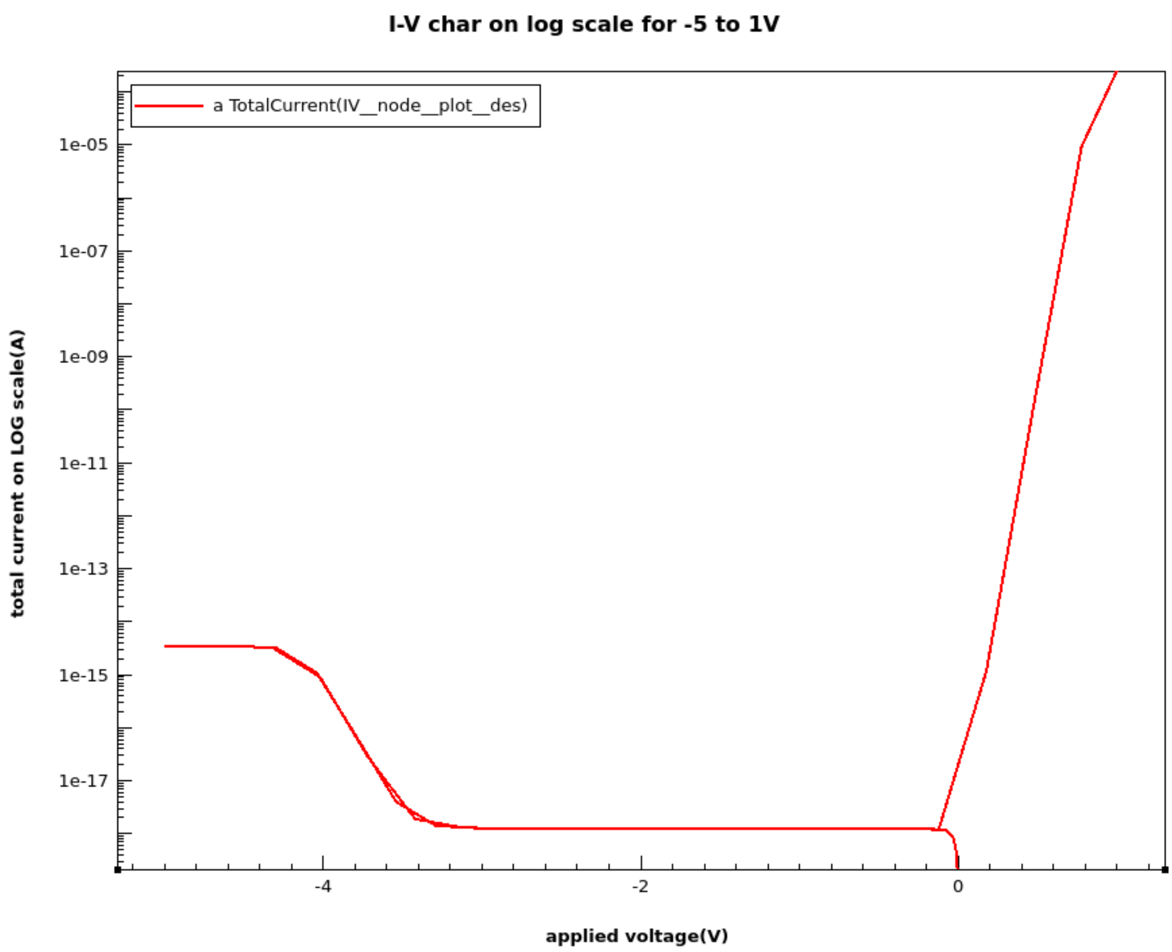
Si PN DIODE Na=Nb=10^17cm^-3:

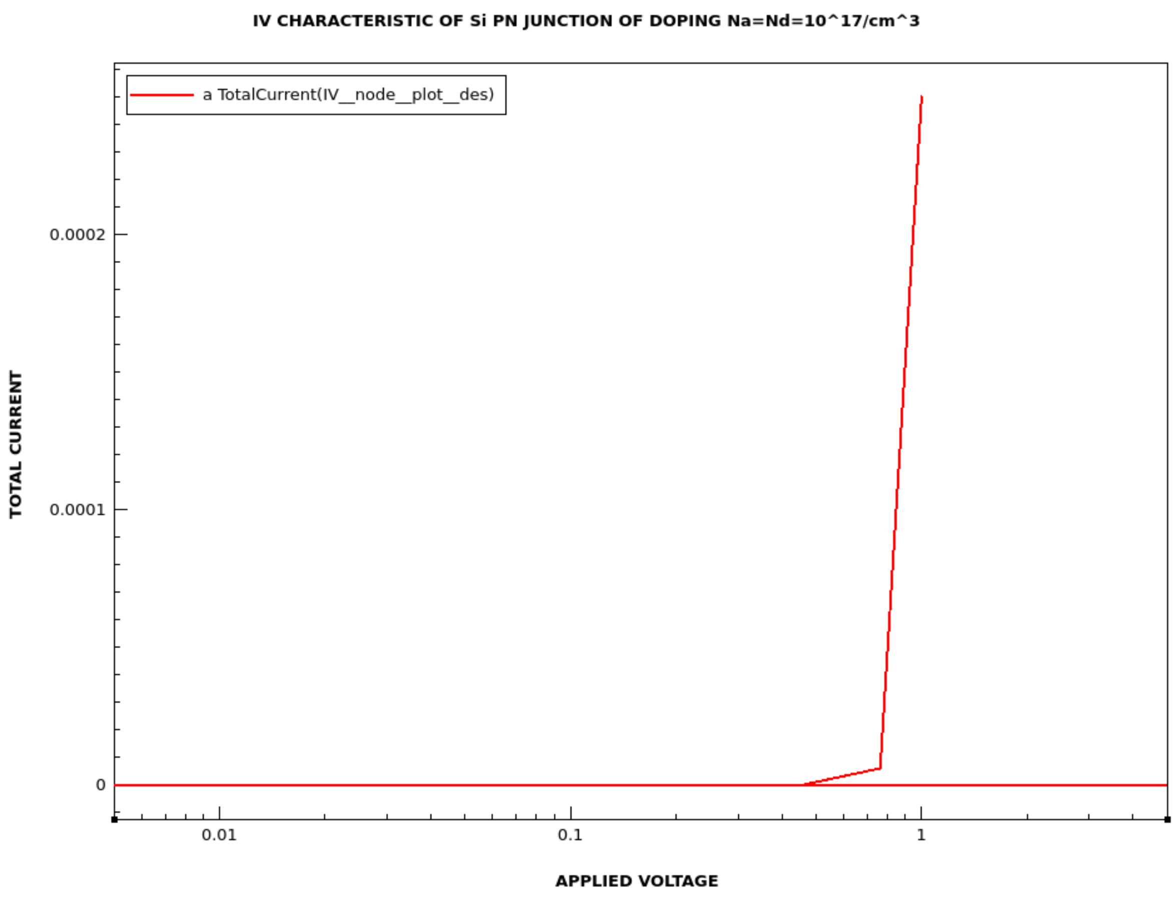


Voltage range of -5V to 1V:

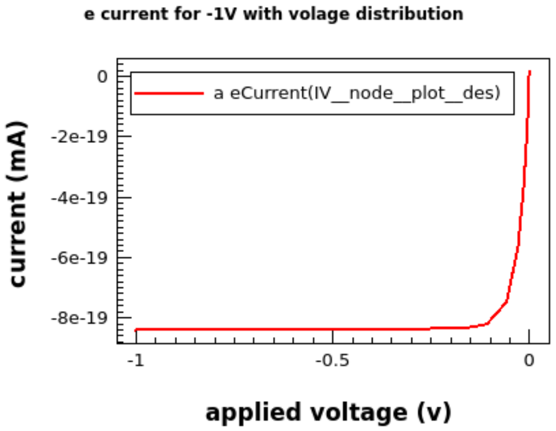

I-V Char of SiPN Junction of doping Na=Nd=10^17/cm^3
a TotalCurrent(IV__node__plot__des)
total current
0.0002
0.0001
0
-4
-2
0
applied voltage

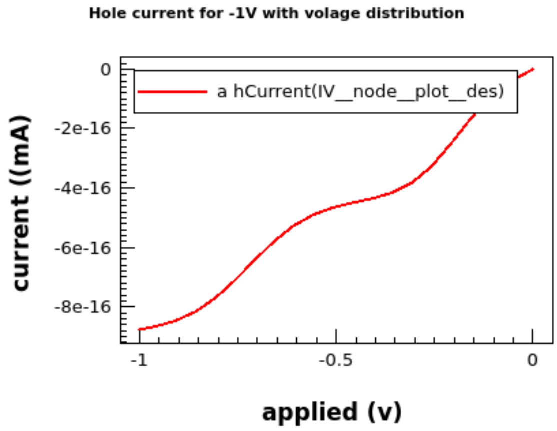
Log scale

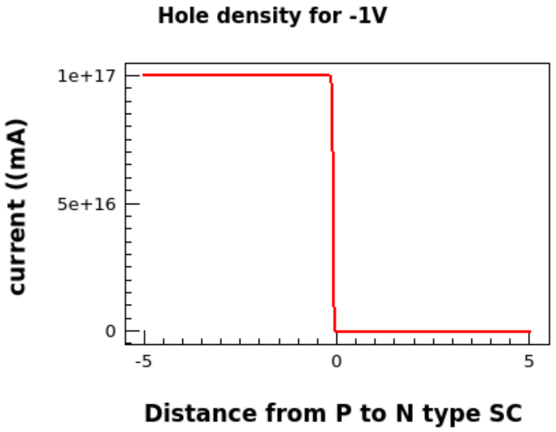

I-V char on log scale for -5 to 1V
a TotalCurrent(IV__node__plot__des)
1e-05
1e-07
1e-09
1e-11
1e-13
1e-15
1e-17
-4
-2
0
total current on LOG scale(A)
applied voltage(V)

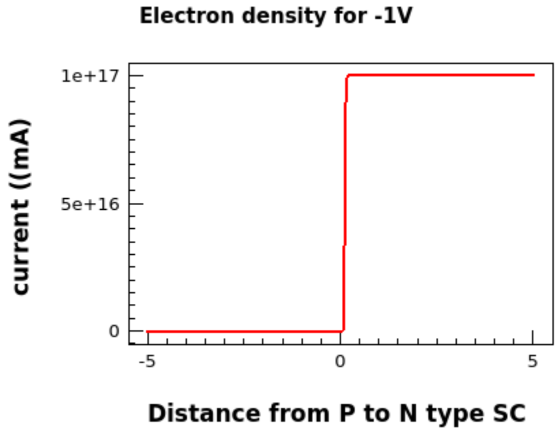

IV CHARACTERISTIC OF Si PN JUNCTION OF DOPING Na=Nd=10^17/cm^3
a TotalCurrent(IV__node__plot__des)
TOTAL CURRENT
0.0002
0.0001
0
0.01
0.1
1
APPLIED VOLTAGE

-1V :

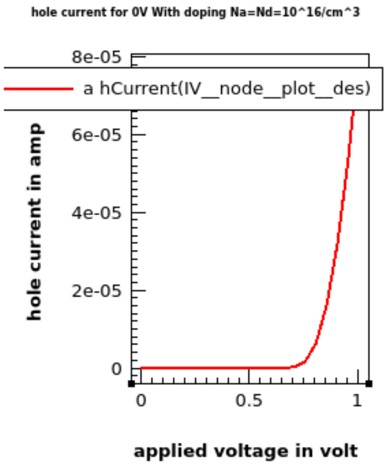

e current for -1V with volage distribution
a eCurrent(IV__node__plot__des)
current (mA)
0
-2e-19
-4e-19
-6e-19
-8e-19
-1
-0.5
0
applied voltage (v)

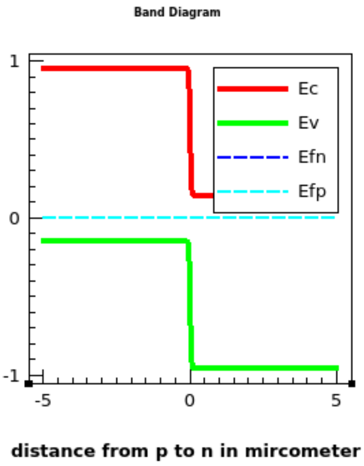

Hole current for -1V with volage distribution
a hCurrent(IV__node__plot__des)
current ((mA)
0
-2e-16
-4e-16
-6e-16
-8e-16
-1
-0.5
0
applied (v)

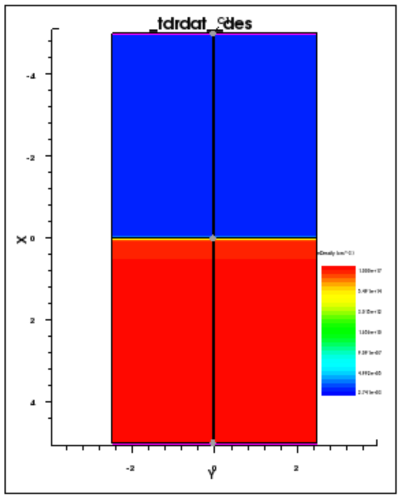

Hole density for -1V
current ((mA)
1e+17
5e+16
0
-5
0
5
Distance from P to N type SC

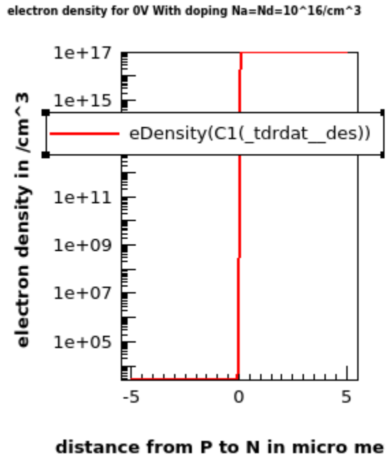

Electron density for -1V
current ((mA)
1e+17
5e+16
0
-5
0
5
Distance from P to N type SC

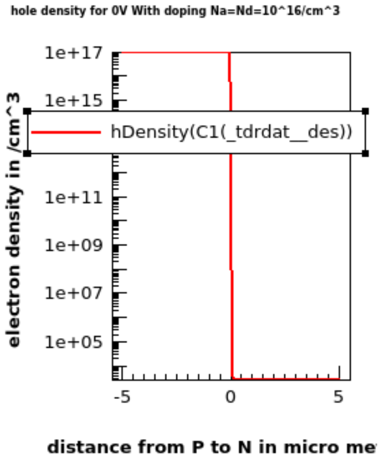
<u>0V:</u>

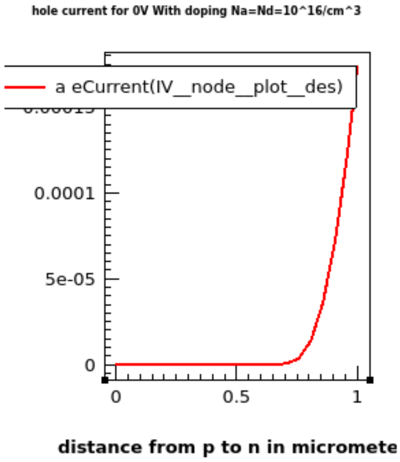

hole current for 0V With doping Na=Nd=10^16/cm^3
a hCurrent(IV__node__plot__des)
hole current in amp
8e-05
6e-05
4e-05
2e-05
0
0
0.5
1
applied voltage in volt


Band Diagram
Ec
Ev
Efn
Efp
1
0
-1
-5
0
5
distance from p to n in mircometer

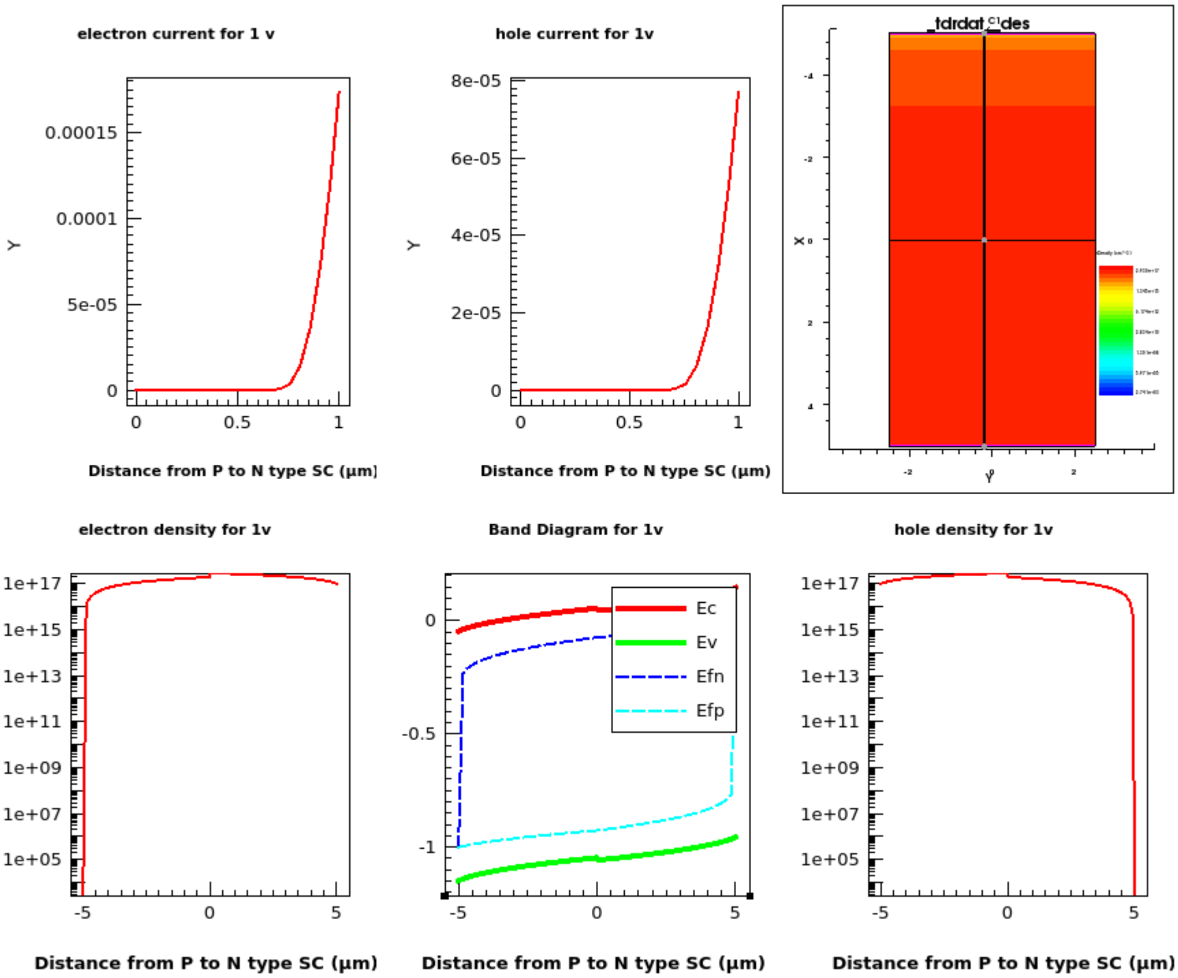

_tdrdat_des
X
Y


electron density for 0V With doping Na=Nd=10^16/cm^3
eDensity(C1(_tdrdat__des))
electron density in /cm^3
1e+17
1e+15
1e+11
1e+09
1e+07
1e+05
-5
0
5
distance from P to N in micro me

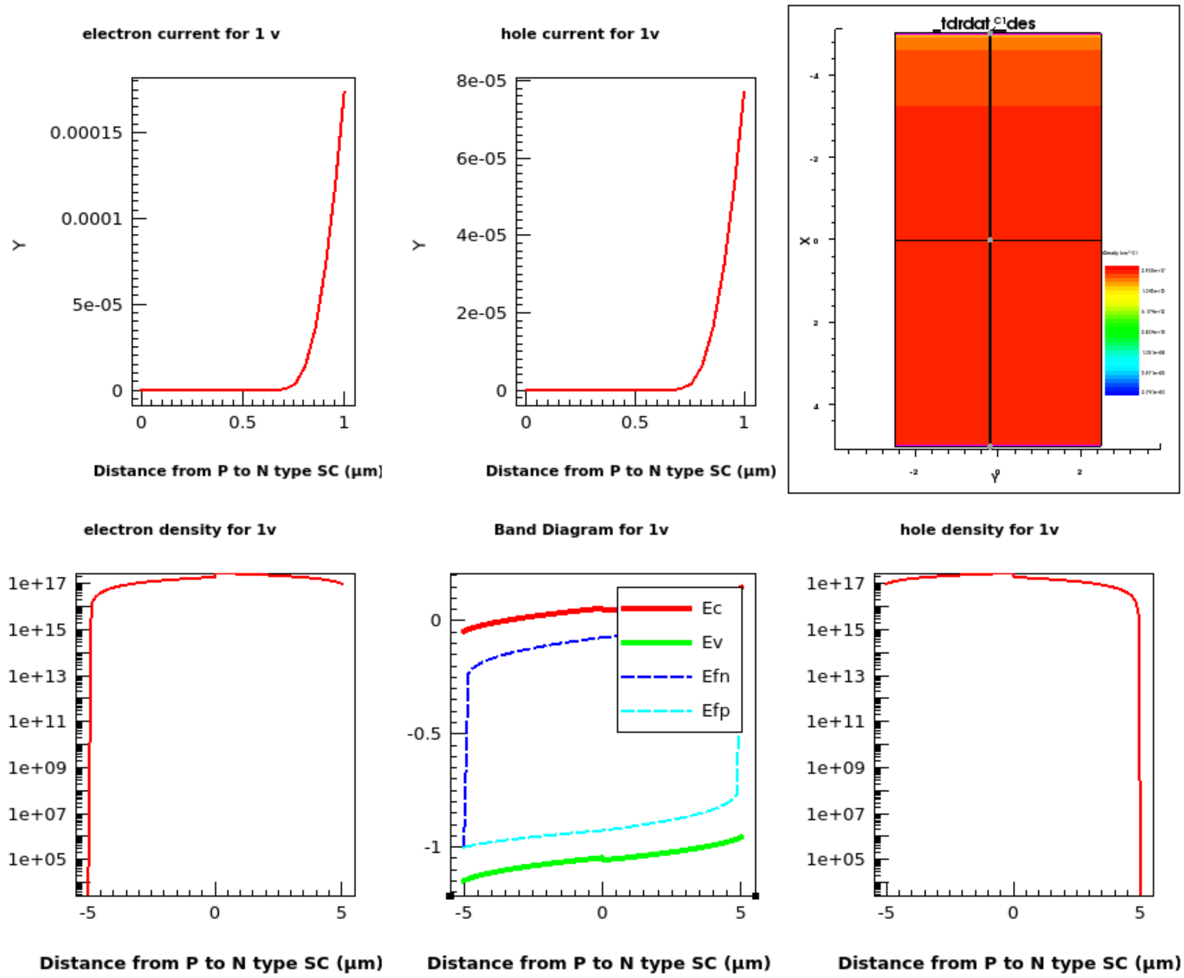

hole density for 0V With doping Na=Nd=10^16/cm^3
hDensity(C1(_tdrdat__des))
electron density in /cm^3
1e+17
1e+15
1e+11
1e+09
1e+07
1e+05
-5
0
5
distance from P to N in micro me


hole current for 0V With doping Na=Nd=10^16/cm^3
a eCurrent(IV__node__plot__des)
0.0001
5e-05
0
0
0.5
1
distance from p to n in micromete

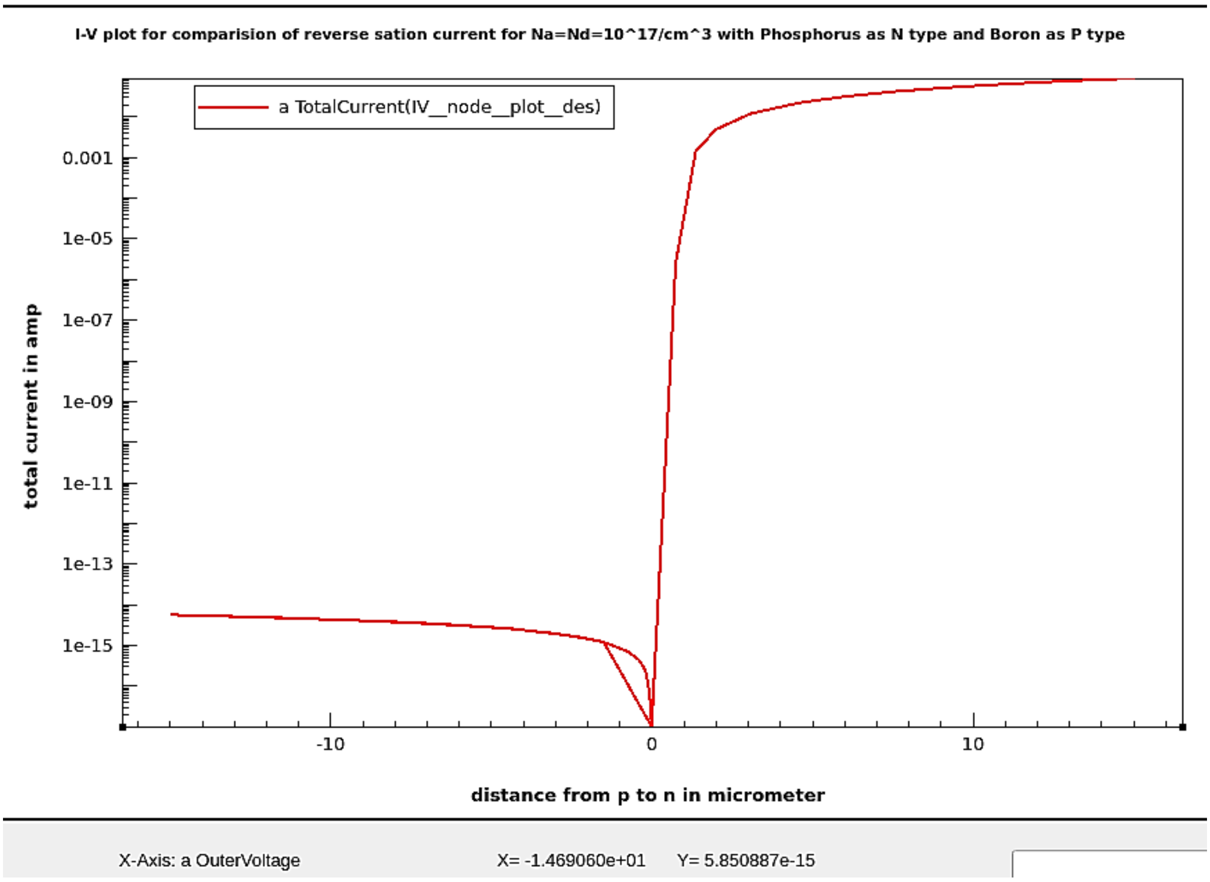
<u>**0.2V :**</u>


electron current for 1 v
hole current for 1v
_tdrdat_des
electron density for 1v
Band Diagram for 1v
hole density for 1v
Ec
Ev
Efn
Efp
Distance from P to N type SC (µm)
Distance from P to N type SC (µm)
Distance from P to N type SC (µm)
Distance from P to N type SC (µm)
Distance from P to N type SC (µm)

<u>1V:</u>



1i)Note the reverse saturation current, compare it with what you expect theoretically? Note the slope of log(I) vs V in different regions in forward bias and compare it with what you expect theoretically?


I-V plot for comparision of reverse sation current for Na=Nd=10^17/cm^3 with Phosphorus as N type and Boron as P type
a TotalCurrent(IV__node__plot__des)
0.001
1e-05
1e-07
1e-09
1e-11
1e-13
1e-15
total current in amp
-10
0
10
distance from p to n in micrometer
X-Axis: a OuterVoltage
X= -1.469060e+01
Y= 5.850887e-15

Practically :- from the above graph

at V_z -14V $I_0 = 5.85 \times 10^{-15}$ Amp for doping

$N_A = N_D = 10^{17}/cm^3$ with Phosphorus as N type & Boron as P-type SC

theoretically :-

$$I_0 = qA\left[\left(\frac{D_p}{L_p}\right)\frac{n_i^2}{N_D} + \left(\frac{D_n}{L_n}\right)\frac{n_i^2}{N_A}\right]$$

when A = total Length × width

$L_p = \sqrt{D_p \tau_p}$, $L_N = \sqrt{D_N \tau_n}$, $n_i = 1.5 \times 10^{15}$, $\mu_n = 1417$ Ge/Si

$\mu_p = 470\ cm^2/Vsec$, $n_i = 1.5 \times 10^{10}/cm^3$, $V_T = 0.02558$,

$q = 1.6 \times 10^{-19}$, $N_A = N_D = 10^{17}$

$I_0 = 3.19 \times 10^{-15} A$

Slope of log I vs applied voltage V can be given by

Region ① for pts (~~vs~~ 0.3, 4.22×10^{-12}) & (0.6, 3×10^{-8})

~~Slope = $1.36 \times 10^{-}4.20 \times 10^{-12}$~~

Slope $= 4.20 \times 10^{-12}$

Reg ② for pts (0.261, 2.56×10^{-4}) & (.651, 5.31×10^{-8})

Slope $= 1.36 \times 10^{-7}$

Reg ③ for pts (2.97, 1.14×10^{-2}) & (5.82, 3.6×10^{-2})

Slope $= 0.86 \times 10^{-2}$

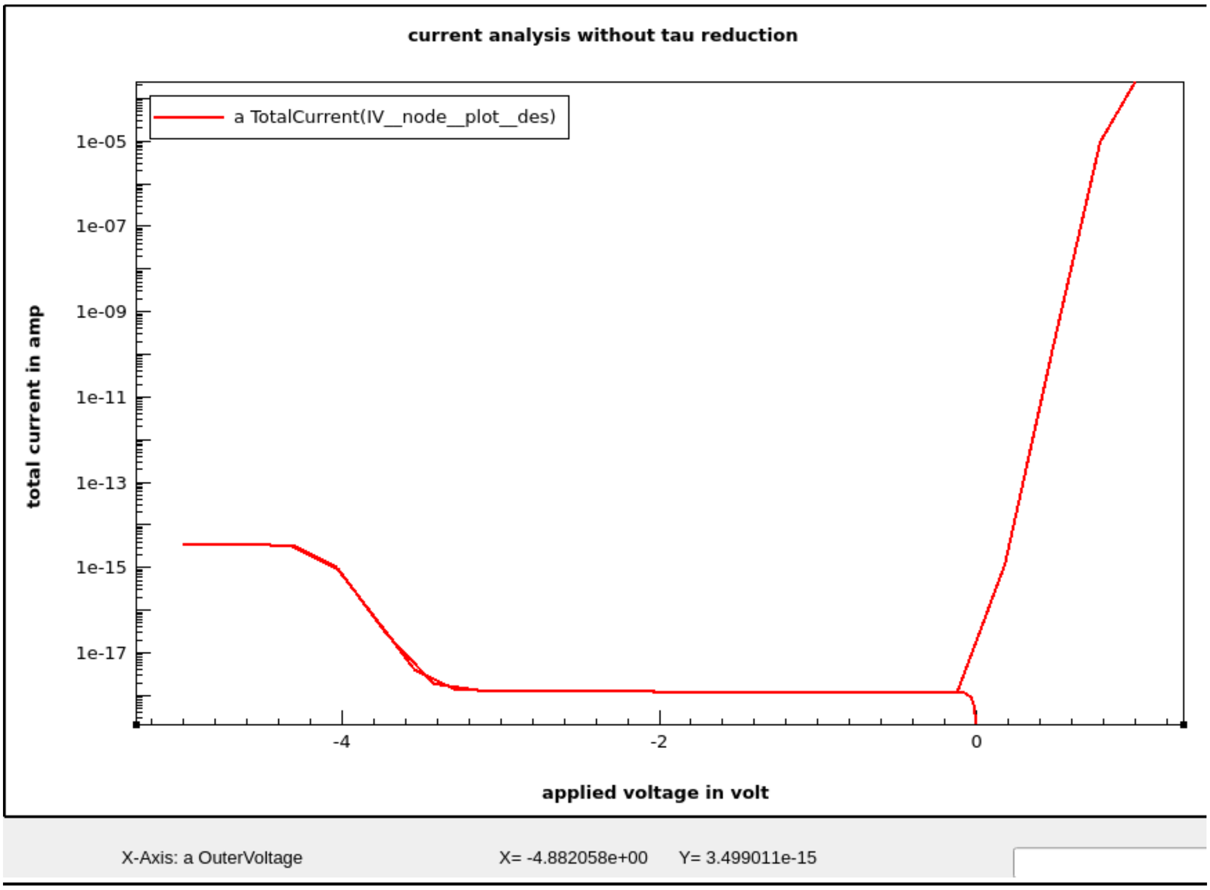
Reg ④ (18.009, 1.03×10^{-1}) & (19.39, 1.13×10^{-1})

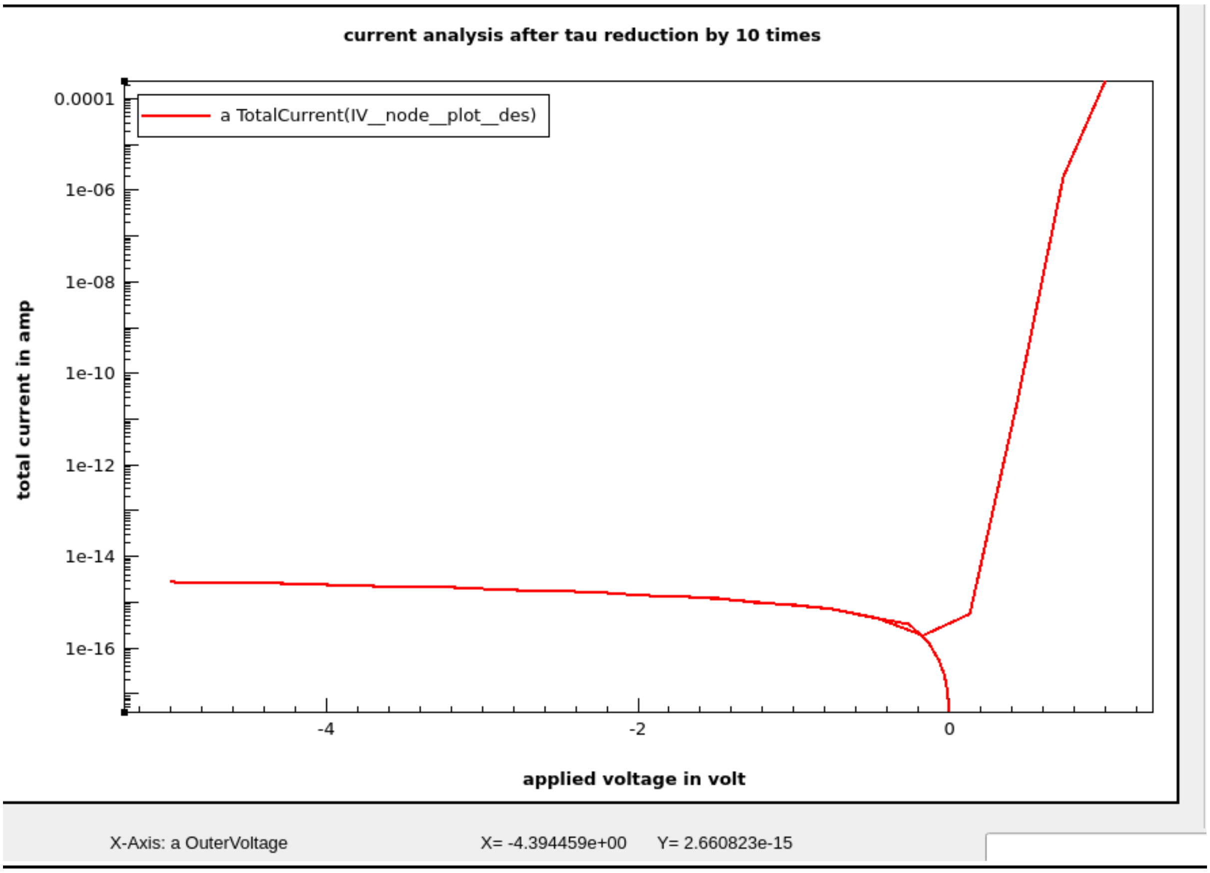
Slope $= 0.73 \times 10^{-2}$

2)(ii) Repeat part (i) for reduced values of carrier lifetime. You may reduce the

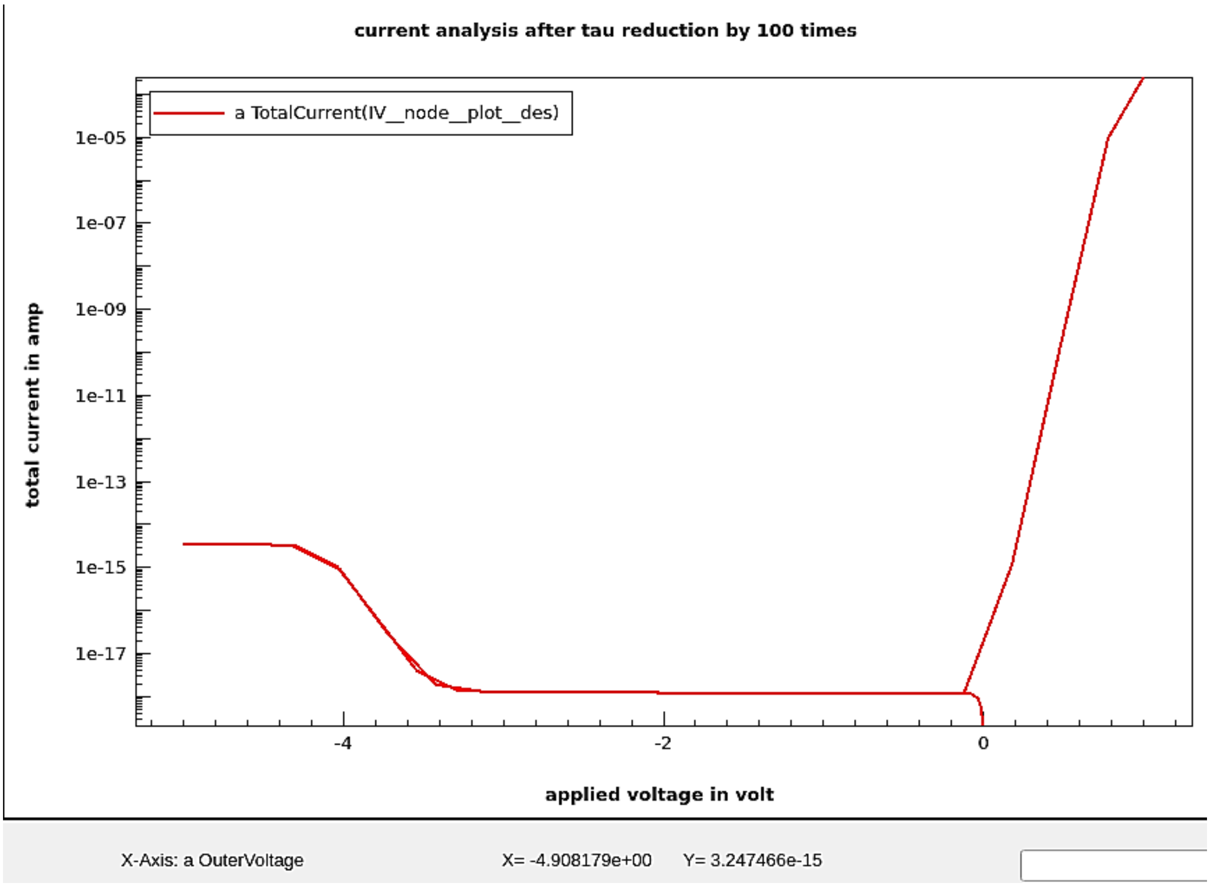
values by 10 times & 100 times. What do you observe?

Use models. par for changing the parameters.





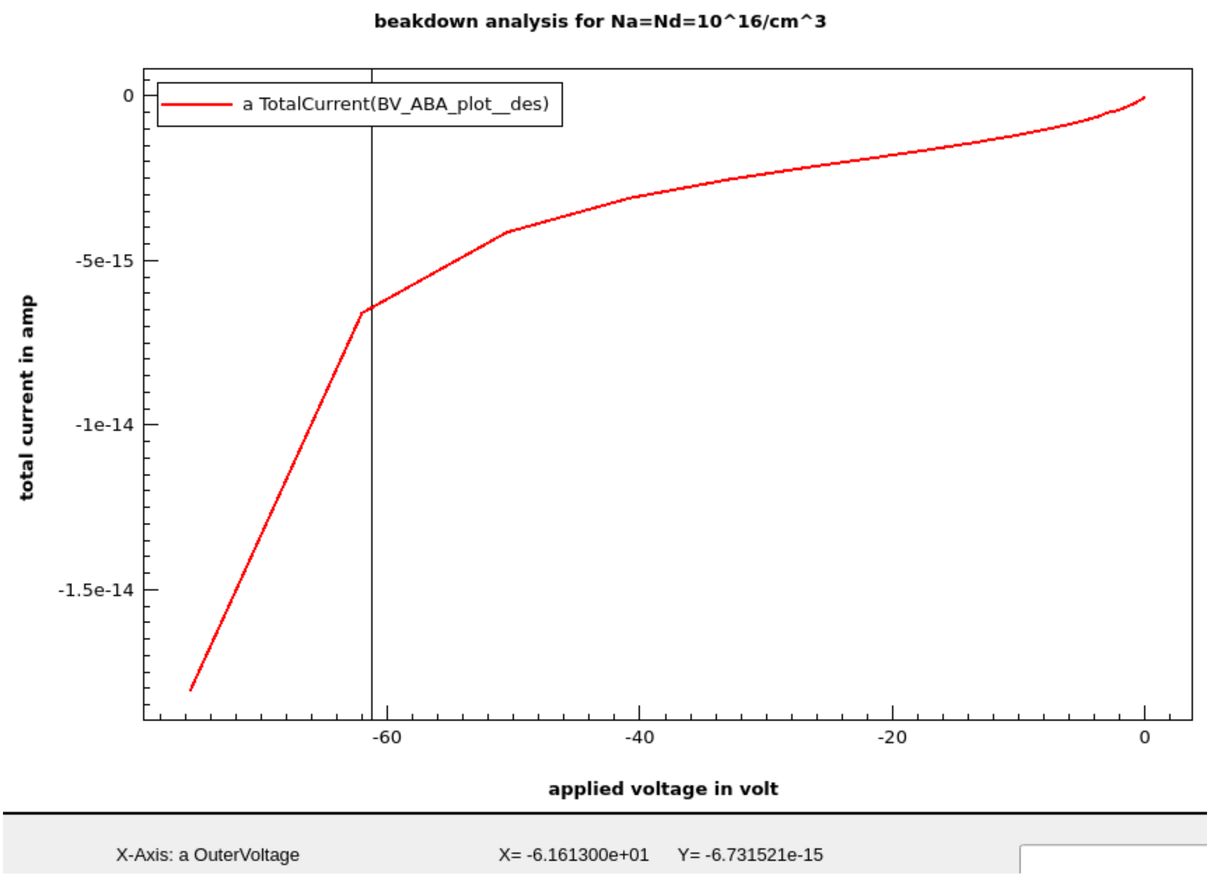
current analysis after tau reduction by 10 times
a TotalCurrent(IV__node__plot__des)
0.0001
1e-06
1e-08
1e-10
1e-12
1e-14
1e-16
-4
-2
0
total current in amp
applied voltage in volt
X-Axis: a OuterVoltage
X= -4.394459e+00
Y= 2.660823e-15



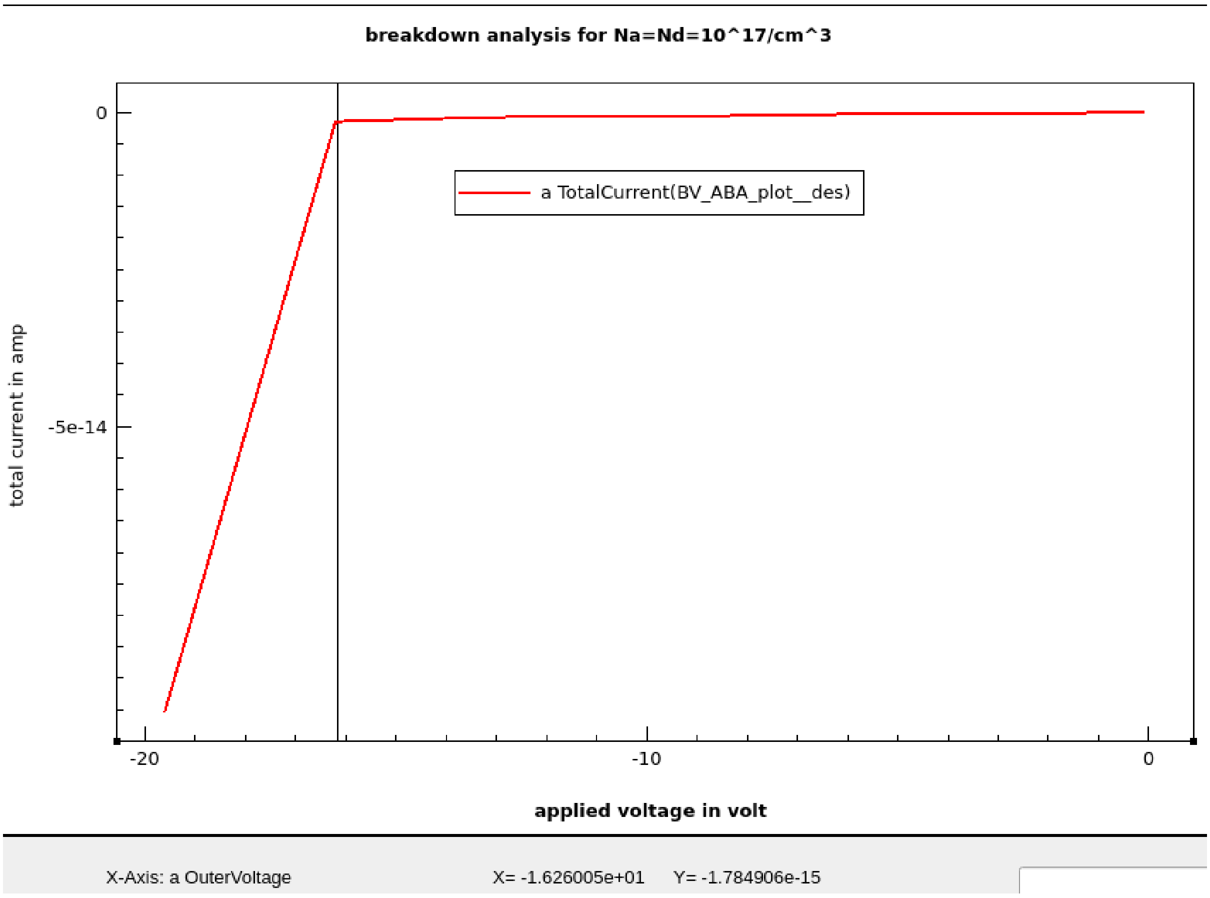
current analysis after tau reduction by 100 times
a TotalCurrent(IV__node__plot__des)
1e-05
1e-07
1e-09
1e-11
1e-13
1e-15
1e-17
-4
-2
0
total current in amp
applied voltage in volt
X-Axis: a OuterVoltage
X= -4.908179e+00
Y= 3.247466e-15

theoretically ,The reverse saturation current sholuld multiplied by a factor of 10 (in natural log scale by 2.3 , from above graphs you can observe by specified points) when tau values are reduced by a factor of 100. But practically it does not . it decreases when we reduce tau by 10 factor but for 100 times reduction it remains constant.

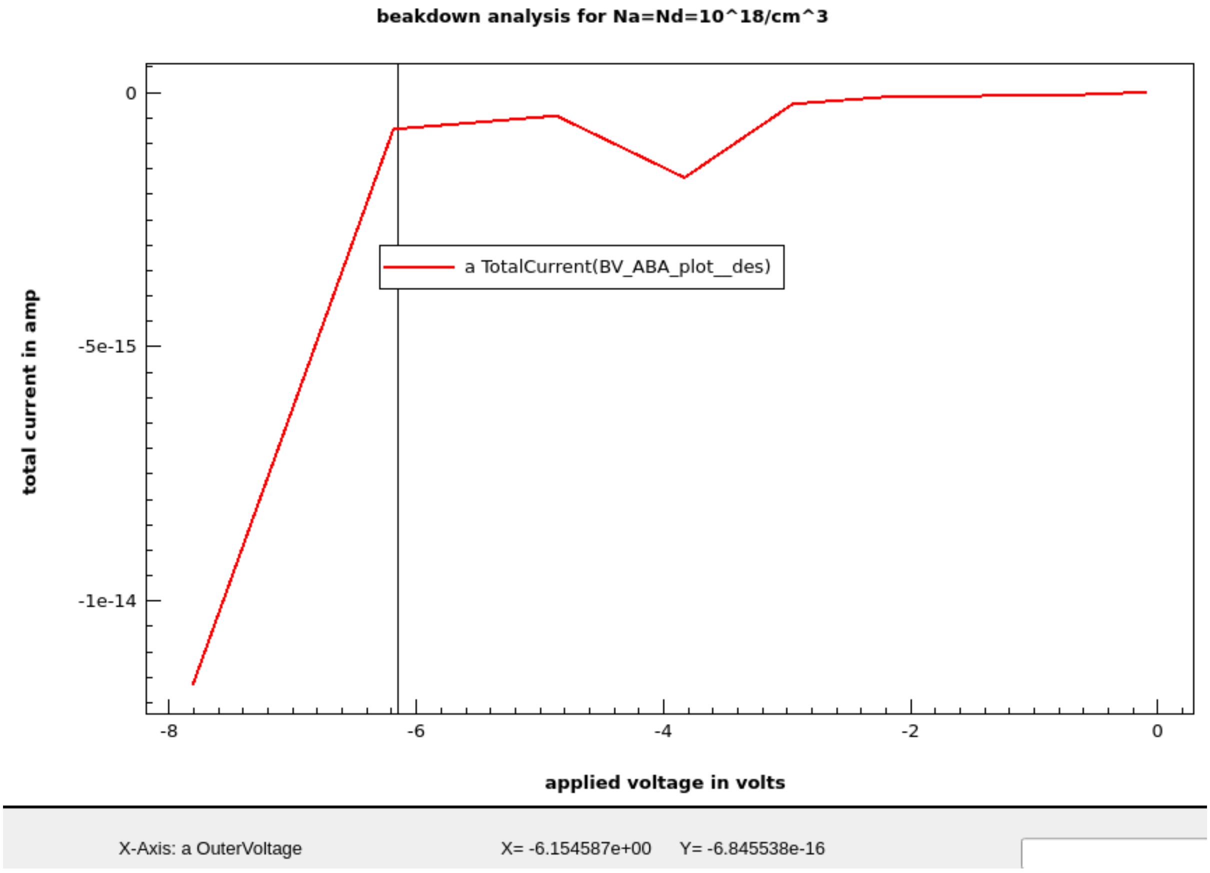
2) For the diode mentioned in Q.1, perform breakdown analysis for 3 different values of doping concentrations 10 16 cm-3, 1017 cm- and 1018 cm-3. Also check VBR vs doping, where VBR is approximate breakdown voltage. Take proper meshing in each region and Si diode.



From this VBR=-61.51Volt



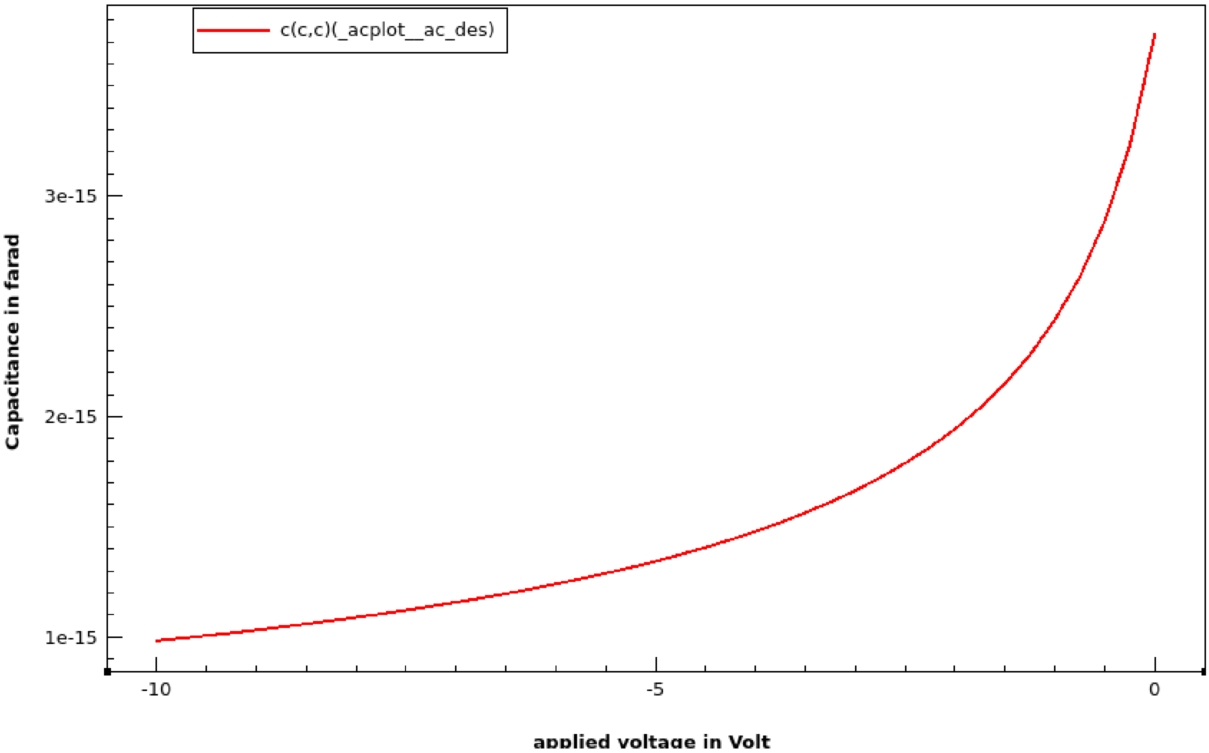
From this VBR=-16.26Volt

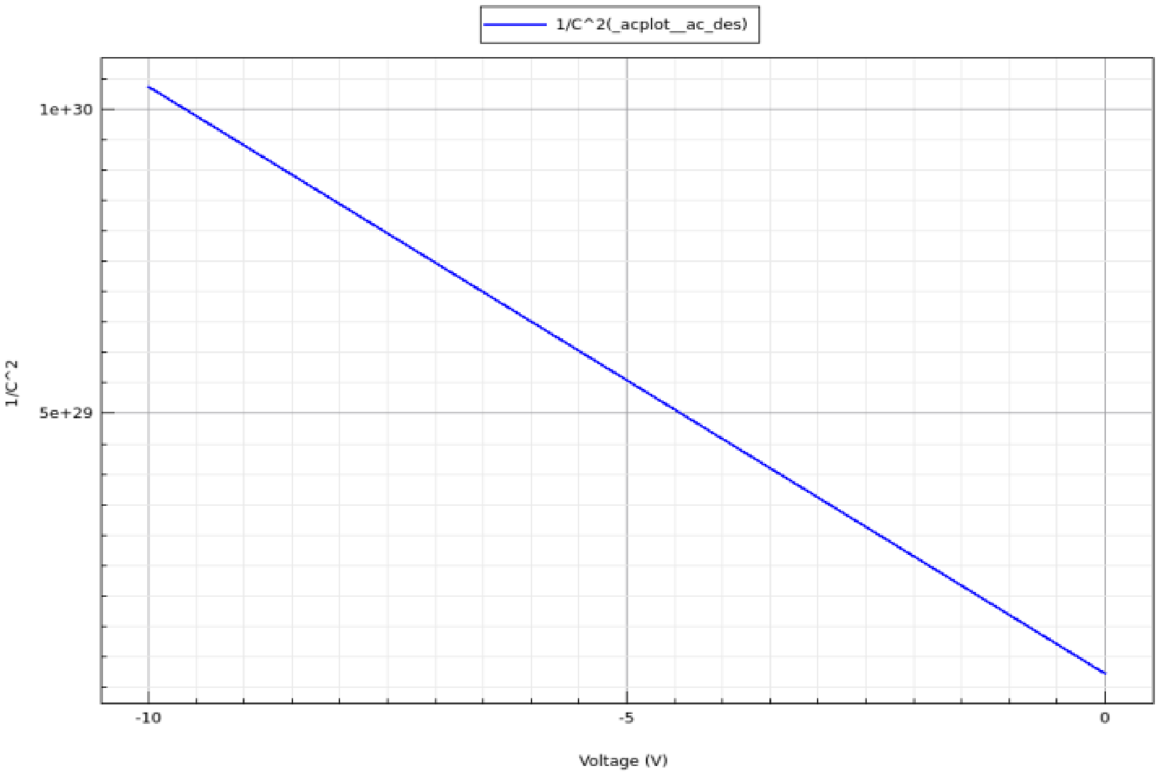


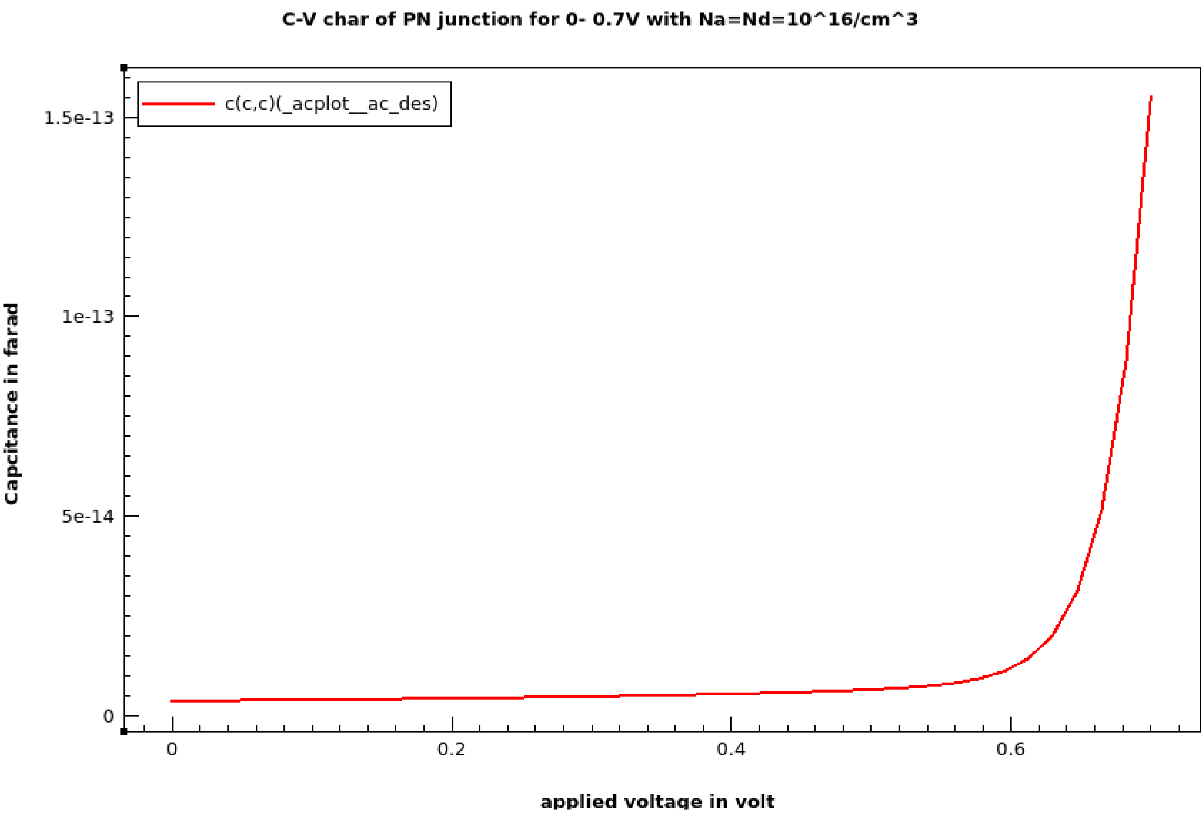
From this VBR=-6.51Volt

Q.3: For the diode mentioned in Q.1, plot the CV characteristics in reverse bias for 0 to -10 V, use a low frequency of 1 KHz. Also plot 1/C 2 vs the applied voltage and estimate doping from it. Compare it with the value used while defining the device structure. Also plot the CV characteristics in forward bias (0 to 0.7V). Note the value of the capacitance at 0.5 V from the CV plot. Compare this value with what you expect theoretically

C-V char of PN junction for Reverse bias 0 to -10V for doping Na=Nd=10^16/cm^3







- Capacitance at 0.5 V from the plot is 6.1×10-15 F

We know that

$$C = \frac{A\epsilon}{W}$$

& $W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)(V_0 - V_A)}$

By putting value in C &, then we get

$$1/C_j^2 = \frac{2}{q N_D \epsilon_r . \epsilon_0 A^2}(V_0 - V_A)$$

when $q = 1.6\times10^{-19}$, $N_D = 10^{17}/cm^3$, $\epsilon_r = 11.3$, $\epsilon_0 = 8.85\times10^{-14}$ F

A = length × width, $V_0 = V_T \ln \frac{N_A N_D}{n_i^2}$,

$n_i = 1.5\times10^{10}/cm^3$,

by simplying we get $C_j = 1.18\times10^{-15}$ F