Scilab Textbook Companion for Semiconductor Devices Basic Principle by J. Singh[1]

Created by
Rishabh Jain
B.tech
Electronics Engineering
ABES ENG. COLLEGE
College Teacher
None
Cross-Checked by
Harpreeth Singh and Bhavani Jalkrish

June 22, 2017

[1]Funded by a grant from the National Mission on Education through ICT, http://spoken-tutorial.org/NMEICT-Intro. This Textbook Companion and Scilab codes written in it can be downloaded from the "Textbook Companion Project" section at the website http://scilab.in

Book Description

Title: Semiconductor Devices Basic Principle

Author: J. Singh

Publisher: John Wiley & Sons, Singapore

Edition: 1

Year: 2000

ISBN: 9971-513-77-3

Scilab numbering policy used in this document and the relation to the above book.

Exa Example (Solved example)

Eqn Equation (Particular equation of the above book)

AP Appendix to Example(Scilab Code that is an Appednix to a particular Example of the above book)

For example, Exa 3.51 means solved example 3.51 of this book. Sec 2.3 means a scilab code whose theory is explained in Section 2.3 of the book.

Contents

List of Scilab Codes

Chapter 1

ELECTRONS IN SOLIDS

Scilab code Exa 1.1 ELECTRON DENSITY

```
1  clc
2  A1=27
3  disp("A1 = "+string(A1)+"amu") //initializing value
       of atomic mass of alluminium
4  AV = 6.023*10^23
5  disp("AV = "+string(AV)) //initializing value of
       avagadro number
6  N = 13
7  disp("N = "+string(N)) //initializing value of
       number of electrons of alluminium per atom
8  P1 = 2.7
9  disp("P1 = "+string(P1)+"gcm^-3") ////initializing
       value of density of alluminium
10 E1=AV*(N*P1/A1)
11 disp("Electrons density of alluminium,n(Al)=AV*(N*P1
       /A1))= "+string(E1)+" cm^-3")//calculation
12 A2=12
13 disp("A2 = "+string(A2)+"amu") //initializing value
       of atomic mass of carbon
14 N1 = 6
15 disp("N1 = "+string(N1)) //initializing value of
```

```
    number of electrons of carbon per atom
P2 = 3.515
disp("P2 = "+string(P2)+"gcm^-3") ////initializing
    value of density of carbon
E2=AV*(N1*P2/A2)
disp("Electrons density of carbon,n(C)=AV*(N1*P2/A2)
    )= "+string(E2)+" cm^-3")//calculation
A3=28
disp("A3 = "+string(A3)+"amu") //initializing value
    of atomic mass of silicon
N2 = 14
disp("N2 = "+string(N2)) //initializing value of
    number of electrons of silicon per atom
P3 = 2.33
disp("P3 = "+string(P3)+"gcm^-3") ////initializing
    value of density of silicon
E3=AV*(N2*P3/A3)
disp("Electrons density of silicon,n(Si)=AV*(N2*P3/
    A3))= "+string(E3)+" cm^-3")//calculation
//using Drudes approach
disp("using Drudes approach")
Zc1=3
disp("Zc1 = "+string(Zc1)) ////initializing value of
     valence electron of alluminium atom
E4=AV*(Zc1*P1/A1)
disp("Electrons density of alluminium,n(Al)=AV*(Zc1*
    P1/A1))= "+string(E4)+" cm^-3")//calculation
Zc2=4
disp("Zc2 = "+string(Zc2)) ////initializing value of
     valence electron of carbon atom
E5=AV*(Zc2*P2/A2)
disp("Electrons density of carbon,n(C)=AV*(Zc2*P2/A2
    ))= "+string(E5)+" cm^-3")//calculation
Zc3=4
disp("Zc3 = "+string(Zc3)) ////initializing value of
     valence electron of silicon atom
E6=AV*(Zc3*P3/A3)
disp("Electrons density of silicon,n(Si)=AV*(Zc3*P3/
```

```
A3) )= "+string(E6)+" cm^-3")//calculation
```

Scilab code Exa 1.2 Number of silcon atom in cubic centimeter

```
clc
// silicon has diomond structure which is made up of
    FCC lattice
N=4
disp("N = "+string(N)) //initializing value of
   number of points per cube of volume
A = 5.43*10^-8
disp("A = "+string(A)+"cm^-1") //initializing value
   of lattice constant of silicon
D = 2
disp("D = "+string(D)+"atoms") //initializing value
   of number of silicon atoms per lattice point
E1 = N*D/A^3
disp("number density of silicon ,N(Si) = N*D/A^3)= "+
   string(E1)+" atomscm^-3")//calculation
//for gallium in GaAs there is 1 Ga atom and 1 As
   atom as per lattice point , it also has fcc
   structure
A1 = 5.65*10^-8
disp("A1 = "+string(A1)+"cm^-1") //initializing
   value of lattice constant of gallium
D1 = 1
disp("D1 = "+string(D1)+"atoms") //initializing
   value of number of gallium atoms per lattice
   point
E2 = N*D1/A1^3
disp("number density of gallium atoms ,N(Ga) = N*D1/
   A1^3)= "+string(E2)+" atomscm^-3")//calculation
```

Scilab code Exa 1.3 NUMBER OF ATOMS

```
clc
// silicon has diomond structure which is made up of
    FCC lattice
N=4
disp("N = "+string(N)) //initializing value of
   number of points per cube of volume
A = 5.43*10^-8
disp("A = "+string(A)+"cm^-3") //initializing value
   of lattice constant of silicon
D = 2
disp("D = "+string(D)+"atoms") //initializing value
   of number of silicon atoms per lattice point
E1 = N*D/A^3
disp("number density of silicon ,Nsi = N*D/A^3)= "+
   string(E1)+" atomscm^-3")//calculation
//for gallium in GaAs there is 1 Ga atom and 1 As
   atom as per lattice point , it also has fcc
   structure
A1 = 5.65*10^-8
disp("A1 = "+string(A1)+"cm^-3") //initializing
   value of lattice constant of gallium
D1 = 1
disp("D1 = "+string(D1)+"atoms") //initializing
   value of number of gallium atoms per lattice
   point
E2 = N*D1/A1^3
disp("number density of gallium atoms ,NGa = N*D1/A1
   ^3)= "+string(E2)+" atomscm^-3")//calculation
// using above answer in following part
S1=10*10^-12
disp("S1 = "+string(S1)+" cm^3") //initializing
   value of dimensions of silicon transistor
N1 = (E1*S1)
disp("number Si atom in silicon transistor ,N(Si) = (
   E1*S1))= "+string(N1)+" atoms")//calculation
S2 = 200*10*5*10^(-12)
```

```
24 disp("S2 = "+string(S2)+" cm^3") //initializing
     value of dimensions of GaAs semiconductor laser
25 N2 = (E2*S2)
26 disp("number of Ga atom in GaAs semiconductor ,N(Ga)
     = (E2*S2))= "+string(N2)+" atoms")//calculation
```

Scilab code Exa 1.4 SURFACE DENSITY

```
1 clc
2 // In the (001) surface the top atoms are either Ga
     or As
3 //A square of area a^2 has 4 atoms on the edges of
     square shared by 4 other square and 1 atom in
     centre
4 N=2
5 disp("N = "+string(N)) //initializing value of total
     number of atoms per square
6 a = 5.65*10^-8
7 disp("a = "+string(a)+"cm^-1") //initializing value
     of lattice constant of gallium
8 SD = N/(a^2)
9 disp("surface density of Ga,N(Ga) = N/(a^2))= "+
     string(SD)+"cm^-2")//calculation
```

Scilab code Exa 1.5 HEIGHT OF MONOLAYER

```
1 clc
2 a = 5.65*10^-8
3 disp("a = "+string(a)+"cm^-1") //initializing value
     of lattice constant of gallium
4 A = a/2
5 disp("monolayer distance in the (001) direction ,(A(
     ml) = a/2)= "+string(A)+" cm^-1")//calculation
```

Scilab code Exa 1.6 WAVELENGTH

```
clc
h=6.6*10^-34
disp("h = "+string(h)+"Js") // plancks constant
c = 3*10^8
disp("c = "+string(c)+"m/s") // velocity of light
E1 = 1.6*10^-19
disp("E1 = "+string(E1)+"J") //initializing value of energy of photon
L1 = h*c/E1
disp("wavelengh of photon,(L(ph) = hc/E1)= "+string(L1)+" m")//calculation
E2 = 1.6*10^-19
disp("E2 = "+string(E2)+"J") //initializing value of energy of electron
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value of mass of electron
L2 = h/sqrt(2*mo*E2)
disp("wavelengh of electron,(L(e) = h/sqrt(2*mo*E2)) = "+string(L2)+" m")//calculation
m=1/1824
disp("mo/m1 = "+string(m)) //initializing value of ratio of mass of electron to mass of neutron
L3 = L2*sqrt(m)
disp("wavelengh of neutron,L(n) = L2*sqrt(mo/m1)= "+string(L3)+" m")//calculation
```

Scilab code Exa 1.7 DENSITY

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of reduced plancks constant or dirac constant or h-bar
m = 9.1*10^-31
disp("m = "+string(m)+"kg") //initializing value of mass of electron
E = 0.1
disp("E = "+string(E)+" eV") //initializing value of energy of electron
N = [sqrt(2)*(m)^(3/2)]/[(%pi)^2*(h)^3]
disp("density of states in 3D is ,(N(E) = [sqrt(2)*(m)^(3/2)]/%pi^2*h^3)= "+string(N)+"E^1/2 J^-1m^-3")//calculation
//Expressing E in eV and the density of states in commonly used units of eV^-1cm^-3
N1 = 6.8*10^21*sqrt(E)
disp("density of states in 3D is ,(N(E)= 6.8*10^21*sqrt(E))= "+string(N1)+"eV^-1cm^-3")//calculation
```

Scilab code Exa 1.8 DENSITY OF STATES

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of reduced plancks constant or dirac constant or h-bar
m = 9.1*10^-31
disp("m = "+string(m)+"kg") //initializing value of mass of electron
E = 2.0
disp("E = "+string(E)+" eV") //initializing value of energy of electron
N = [sqrt(2)*(m)^(3/2)]/[(%pi)^2*(h)^3]
```

```
9 disp("density of states in 3D is ,(N(E) = [sqrt(2)*(
    m)^(3/2)]/%pi^2*h^3)= "+string(N)+"E^1/2 J^-1m^-3
    ")//calculation
10 //Expressing E in eV and the density of states in
    commonly used units of eV^-1cm^-3
11 N1 = 6.8*10^21*sqrt(E-2.0)
12 disp("density of states in 3D is ,(N(E)= 6.8*10^21*
    sqrt(E-2.0))= "+string(N1)+"eV^-1cm^-3")//
    calculation
```

Scilab code Exa 1.9 FERMI LEVEL ENERGY

```
1 clc
2 h=1.05*10^-34
3 disp("h = "+string(h)+"Js") //initializing value of
    reduced plancks constant or dirac constant or h-
    bar
4 m = 9.1*10^-31
5 disp("m = "+string(m)+"kg") //initializing value of
    mass of electron
6 n = 10^28
7 disp("n = "+string(n)+"m^-3") //initializing value
    of mass of electron
8 E = (3*(%pi)^(2)*n)^(2/3)*(h^2/(2*m))
9 disp("The fermi energy at 0K is ,(E[F] = (3*(%pi)
    ^(2)*n)^(2/3)*(h^2/(2*m))= "+string(E)+"J")//
    calculation
10 Ef= E/(1.6*10^(-19))
11 disp("The fermi energy at 0K in eV is ,(E[F] = E
    /1.6*10^-19)= "+string(Ef)+"eV")//calculation
12 // Answer givenin the textbook is wrong
```

Scilab code Exa 1.10 BOLTZMANN STATISTICS AND JOYCE DIXON APPROXIMATION

```
clc
disp("for temperature T1=77K")
kBT1=0.0067
disp("kBT1 = "+string(kBT1)+"eV") //initializing
    value of multiplication of boltzmann constant and
     temperature T1
n1 = 10^19
disp("n1 = "+string(n1)+"cm^-3") //initializing
    value of density of electron
Nc1 = 3.34*10^18
disp("Nc1 = "+string(Nc1)+"cm^-3") //initializing
    value of effective density of electron
Ef1= kBT1*((log(n1/Nc1)))
disp("The fermi level at 77K (using boltzmann static
    ) is ,Ef1(B)= kBT1*((log(n1/Nc1)))= "+string(Ef1)
    +"eV")//calculation
Ef2= kBT1*((log(n1/Nc1))+(1/sqrt(8))*(n1/Nc1))
disp("The fermi level at 77K (using Joyce-Dixon
    static) is ,Ef1(J)= kBT1*((log(n1/Nc1))+(1/sqrt
    (8))*(n1/Nc1))= "+string(Ef2)+"eV")//calculation
disp("for temperature T2=300K")
kBT2=0.026
disp("kBT2 = "+string(kBT2)+"eV") //initializing
    value of multiplication of boltzmann constant and
     temperature T2
Nc2 = 2.56*10^19
disp("Nc2 = "+string(Nc2)+"cm^-3") //initializing
    value of effective density of electron
Ef3= kBT2*((log(n1/Nc2)))
disp("The fermi level at 300K (using boltzmann
    static) is ,Ef2(B)= kBT2*((log(n1/Nc2)))= "+
    string(Ef3)+"eV")//calculation
Ef4= kBT2*((log(n1/Nc2))+(1/sqrt(8))*(n1/Nc2))
disp("The fermi level at 300K (using Joyce-Dixon
    static) is ,Ef2(J)= kBT2*((log(n1/Nc2))+(1/sqrt
```

```
(8))*(n1/Nc2))= "+string(Ef4)+"eV") //calculation
```

Chapter 2

Electron in semiconductors

Scilab code Exa 2.1 K value

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of
    reduced plancks constant or dirac constant or h-
    bar
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value
    of mass of electron
E = 0.1*1.6*10^(-19)
disp("E= "+string(E)+"J")//initializing value of
    Energy of electron in conduction band
m=0.067*mo
disp("m = "+string(m)+"kg") //initializing value of
    appropriate mass in the conduction band for GaAs
k = sqrt(2*m*E)/h
disp("The k-value for an electron in the conduction
    band of GaAs is ,(k = sqrt(2*m*E)/h)= "+string(k)
    +"m^-1")//calculation
ko = 1.625*10^9
disp("The k-value for an electron in the free space
    is ,ko = "+string(ko)+"m^-1")// initializing k
```

```
    value of electron in the free space
14 disp("the two value are quite difference since the k
     value represent effective momentum")
```

Scilab code Exa 2.2 Density of states masses

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
     of mass of electron
4  ml = 0.98*mo
5  disp("ml* = "+string(ml)+"kg") //initializing value
     of longitudinal mass
6  mt = 0.19*mo
7  disp("mt*= "+string(mt)+"kg")//initializing value of
      transverse mass
8  mhh =0.49*mo
9  disp("mhh* = "+string(mhh)+"kg") //initializing
     value of heavy hole mass
10 mlh = 0.16*mo
11 disp("mlh*= "+string(mlh)+"kg")//initializing value
     of light hole mass
12 mdos = (((6)^(2/3))*((ml)*((mt)^2))^(1/3))
13 disp("The conduction band density of states mass is
     ,(mdos* = (((6)^(2/3))*((ml*)*((mt*)^2))^(1/3)))=
      "+string(mdos)+"kg")//calculation
14 mdos1 = (((mhh)^(3/2)+(mlh)^(3/2))^(2/3))
15 disp("The Valence band density of states mass is ,(
     mdos1* = (((mhh)^(3/2)+(mlh)^(3/2))^(2/3))= "+
     string(mdos1)+"kg")//calculation
```

Scilab code Exa 2.3 ENERGY OF ELECTRON AND OF HOLE

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of reduced plancks constant or dirac constant or h-bar
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value of mass of electron
mhh =0.5*mo
disp("m* = "+string(mhh)+"kg") //initializing value of heavy hole mass
k = 0.1*10^10
disp("k = "+string(k)+"m^-1") //initializing value of k-value in the heavy hole band of semiconductor
Ev = 0
disp("Ev= "+string(Ev)+"J")//initializing value of Energy of electron in valence band
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
//(we have assumed the valence band energy Ev=0eV as it is not provided in the book)
Ee= Ev-(((h^2)*(k^2))/(2*mhh))
disp("The electron energy in the valence band is ,( Ee= Ev-(((h^2)*(k^2))/(2*mhh))= "+string(Ee)+"J") //calculation
Ee1= Ee/e
disp("The electron energy in the valence band is ,Ee = Ee/e="+string(Ee1)+"eV")//calculation
Eh= Ev+((((h^2)*(k^2))/(2*mhh))/e)
disp("The hole energy in the valence band is ,(Eh= Ev+((((h^2)*(k^2))/(2*mhh))/e)= "+string(Eh)+"eV" )//calculation
```

Scilab code Exa 2.4 Momentum of electrons and free electrons

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of reduced plancks constant or dirac constant or h-bar
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value of mass of electron
m = 0.067*mo
disp("m = "+string(m)+"kg") //initializing value of heavy hole mass
E = 0.5*1.6*10^-19
disp("E = "+string(E)+"J") //initializing value of electron energy measured from the bandedge
//  Effective momentum of electron in the conduction band of GaAs
hk = sqrt(2*m*E)
disp("The effetive momentum of an electron in the conduction band of GaAs is ,hk = sqrt(2*m*E)= "+string(hk)+"m^-1")//calculation
k = hk/h
disp("the corresponding wavevector is ,k = hk/h = "+string(k)+"m^-1") //calculation
//Effective momentum of free electron in the space with same energy
p = sqrt(2*mo*E)
disp("The effetive momentum of an electron in the space is ,p = sqrt(2*mo*E)= "+string(p)+"kgms^-1")//calculation
```

Scilab code Exa 2.5 Energy of electron

```
clc
```

```
2  h=1.05*10^-34
3  disp("h = "+string(h)+"Js") //initializing value of
       reduced plancks constant or dirac constant or h-
       bar
4  mo = 9.1*10^-31
5  disp("mo = "+string(mo)+"kg") //initializing value
       of mass of electron
6  ml = 0.98*mo
7  disp("ml* = "+string(ml)+"kg") //initializing value
       of longitudinal mass
8  mt = 0.19*mo
9  disp("mt*= "+string(mt)+"kg")//initializing value of
        transverse mass
10 a = 5.43*10^-10
11 disp("a = "+string(a)+"J") //initializing value of
       latice constant
12 kx = ((2*%pi*0.95)/a)
13 disp("kx = "+string(kx)+"m^-1") //initializing value
        of given k-value in x direction
14 ky = ((2*%pi*0.1)/a)
15 disp("ky = "+string(ky)+"m^-1") //initializing value
        of given k-value in y direction
16 kz = ((2*%pi*0.0)/a)
17 disp("kz = "+string(kz)+"m^-1") //initializing value
        of given k-value in z direction
18 kxo = ((2*%pi*0.85)/a)
19 disp("kxo = "+string(kxo)+"m^-1") //initializing
       value of k-value for Si occupies the (100) valley
        in x direction
20 kyo = ((2*%pi*0.0)/a)
21 disp("kyo = "+string(kyo)+"m^-1") //initializing
       value of k-value for Si occupies the (100) valley
        in y direction
22 kzo = ((2*%pi*0.0)/a)
23 disp("kzo = "+string(kzo)+"m^-1") //initializing
       value of k-value for Si occupies the (100) valley
        in z direction
24 kl = kx-kxo
```

```
25 disp("the change in k vector in x direction is,kl =
     kx-kxo = "+string(kl)+"m^-1") //calculation
26 kt = ky-kyo
27 disp("the change in k vector in y direction is,kt =
     ky-kyo = "+string(kt)+"m^-1") //calculation
28 E= (((h^2)*(kl^2))/(2*ml))+(((h^2)*(kt^2))/(2*mt))
29 disp("The electron energy measured from the
     conduction bandege is ,E= (((h^2)*(kl^2))/(2*ml))
     +(((h^2)*(kt^2))/(2*mt))= "+string(E)+"J")//
     calculation
```

Scilab code Exa 2.9 effective density of states

```
1  clc
2  h=1.05*10^-34
3  disp("h = "+string(h)+"Js") //initializing value of
     reduced plancks constant or dirac constant or h-
     bar
4  mo = 9.1*10^-31
5  disp("mo = "+string(mo)+"kg") //initializing value
     of mass of electron
6  me = 0.067*mo
7  disp("me* = "+string(me)+"kg") //initializing value
     of effective mass of GaAs
8  kbT = 4.16*10^-21
9  disp("kbT = "+string(kbT)+"J/K") //initializing
     value of kbT at 300K
10 Nc=2*(((me*kbT)/(2*%pi*(h^2)))^(3/2))
11 disp("for GaAs conduction band case effective
     density of states is ,Nc = 2*(((me*kbT)/(2*%pi*(h
     ^2)))^(3/2)) = "+string(Nc)+"m^-3")//calculation
12 ml = 0.98*mo
13 disp("ml* = "+string(ml)+"kg") //initializing value
     of longitudinal mass
14 mt = 0.19*mo
```

```
15 disp("mt*= "+string(mt)+"kg")//initializing value of
     transverse mass
16 mdos = (((6)^(2/3))*((ml)*((mt)^2))^(1/3))
17 disp("The conduction band density of states mass is
   (mdos* = (((6)^(2/3))*((ml*)*((mt*)^2))^(1/3)))=
   "+string(mdos)+"kg")//calculation
18 Nc1 = 2*((mdos*kbT)/(2*(%pi)*(h^2)))^(3/2)
19 disp("for silicon conduction band case effective
   density of states is ,Nc = 2*((mdos*kbT)/(2*(%pi)
   *(h^2)))^(3/2) = "+string(Nc1)+"m^-3")//
   calculation
20 // Note : due to different precisions taken by me
   and the author ... my answer differ
21 disp("          for silicon                ")
22 mhh =0.5*mo
23 disp("mhh* = "+string(mhh)+"kg") //initializing
   value of heavy hole mass for silicon
24 mlh = 0.15*mo
25 disp("mlh*= "+string(mlh)+"kg")//initializing value
   of light hole mass for silicon
26 Nv1 =((kbT/(2*(%pi)*(h^2)))^(3/2))*2*(mhh^(3/2)+mlh
   ^(3/2))
27 disp("for silicon valence band case effective
   density of states is ,Nv = 2*(mhh^(3/2)+mlh^(3/2)
   )*(kbT/(2*(%pi)*(h^2)))^(3/2)= "+string(Nv1)+"m
   ^-3")//calculation
28 disp("for GaAs ")
29 mhh1 =0.45*mo
30 disp("mhh* = "+string(mhh1)+"kg") //initializing
   value of heavy hole mass
31 mlh1 = 0.08*mo
32 disp("mlh*= "+string(mlh1)+"kg")//initializing value
     of light hole mass
33 Nv = 2*(mhh1^(3/2)+mlh1^(3/2))*((kbT/(2*(%pi)*(h^2))
   )^(3/2))
34 disp("for GaAs valence band case effective density
   of states is ,Nv = 2*(mhh1^(3/2)+mlh1^(3/2))*(kbT
   /(2*(%pi)*(h^2)))^(3/2)= "+string(Nv)+"m^-3")//
```

```
    calculation
35 // Answer given in the book for valence band case is
       wrong
```

Scilab code Exa 2.10 Position of intrinsic Fermi level

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
       of mass of electron
4  me = 0.067*mo
5  disp("me* = "+string(me)+"kg") //initializing value
       of effective mass of GaAs
6  kbT = 0.026
7  disp("kbT = "+string(kbT)+"eV/K") //initializing
       value of kbT at 300K
8  ml = 0.98*mo
9  disp("ml* = "+string(ml)+"kg") //initializing value
       of longitudinal mass
10 mt = 0.19*mo
11 disp("mt*= "+string(mt)+"kg")//initializing value of
       transverse mass
12 mh = 0.55*mo
13 disp("mh*= "+string(mh)+"kg")//initializing value of
       density of state mass for the valence band
14 //let
15 Eg = 0.0
16 disp("Eg = "+string(Eg)+"J") //initializing value of
       valence bandedge energy
17 mdos = (((6)^(2/3))*((ml)*((mt)^2))^(1/3))
18 disp("The desity of states of effective mass of the
       combined six valleys of silicon is (mdos* = (((6)
       ^(2/3))*((ml*)*((mt*)^2))^(1/3)))= "+string(mdos)
       +"kg")//calculation
19 Efi = (Eg/2)+((3/4)*kbT*log(mh/mdos))
```

```
20 disp("The intrinsic fermi level is given by Efi = (
   Eg/2)+((3/4)*kbT*log(mh/me))= "+string(Efi)+"eV")
   //calculation
21 // -ve sign show that fermi level is below the
   centre of mid-bandgap
22 // In this question the answer is provided in the
   book is in terms of Eg and i have assumed value
   of Eg = 0 V
```

Scilab code Exa 2.11 Intrinsic carrier concentration

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
   of mass of electron
4  me = 0.027*mo
5  disp("me* = "+string(me)+"kg") //initializing value
   of effective mass of GaAs
6  kbT = 0.026
7  disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
8  mh = 0.4*mo
9  disp("ml* = "+string(mh)+"kg") //initializing value
   of longitudinal mass
10 h=1.05*10^-34
11 disp("h= "+string(h))//initializing value of plank
   constant.
12 Eg = 0.35
13 disp("Eg = "+string(Eg)+"J") //initializing value of
    valence bandedge energy
14 ni =2*(((kbT*1.6*10^-19)/(2*(%pi)*h^2))^(3/2))*((me*
   mh)^(3/4))*(exp(-Eg/(2*kbT)))
15 disp("ni =2*(kbT/(2*(%pi)*h^2))^(3/2)*((me*mh)^(3/4)
   )*(exp(-Eg/(2*kbT)))= "+string(ni)+"m^-3")//
   calculation
```

```
16 kbT = 0.05175
17 disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 600K
18 ni =2*(((kbT*1.6*10^-19)/(2*(%pi)*h^2))^(3/2))*((me*
   mh)^(3/4))*(exp(-Eg/(2*kbT)))
19 disp("ni =2*(kbT/(2*(%pi)*h^2))^(3/2)*((me*mh)^(3/4)
   )*(exp(-Eg/(2*kbT)))= "+string(ni)+"m^-3")//
   calculation
20 //Note: In the textbook wrong answer is given for
   intrinsic carrier concentration at 600K
```

Scilab code Exa 2.12 Donor and acceptor energy level

```
1 clc
2 mo = 9.1*10^-31
3 disp("mo = "+string(mo)+"kg") //initializing value
   of mass of electron
4 m_star=0.067*mo
5 disp("m_star=0.067*mo = "+string(m_star)+"kg") //
   initializing value of appropriate mass in the
   conduction band for GaAs
6 apsilen = 13.2*8.85*10^-14
7 disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity for
   GaAs
8 apsilen_not = 8.85*10^-14
9 disp("apsilen_not = "+string(apsilen_not)+"F/cm") //
   initializing value of permitivity
10 ml = 0.98*mo
11 disp("ml* = "+string(ml)+"kg") //initializing value
   of longitudinal mass
12 mt = 0.2*mo
13 disp("mt*= "+string(mt)+"kg")//initializing value of
    transverse mass
14 m_sigma_star = (3)/((1/ml)+(2/mt))
```

```
15 disp("The conductivity mass for silicon is ,
      m_sigma_star = (3*mo)/((1/ml)+(2/mt))= "+string(
      m_sigma_star)+"Kg")//calculation
16 disp("The shallow level energies are given by,Ed =
      Ec-(13.6(eV)*((m_star/mo)/(apsilen/apsilen_not)
      ^2))")
17 //Let Ec = 0 V and taking positive answer,
18 Ed_GaAs = (13.6*((m_star/mo)/(apsilen/apsilen_not)
      ^2))
19 disp("The donor level energy in GaAs is ,Ed_GaAs =
      Ed = (13.6*((m_star/mo)/(apsilen/apsilen_not)^2))
      = "+string(Ed_GaAs)+"eV")//calculation
20 m_dot_GaAs=0.45*mo
21 disp("m_dot_GaAs=0.45*mo = "+string(m_dot_GaAs)+"kg"
      ) //initializing value of heavy hole mass for
      GaAs
22 Ea_GaAs = (13.6*((m_dot_GaAs/mo)/(apsilen/
      apsilen_not)^2))
23 disp("The acceptor level energy in GaAs is ,Ea_GaAs
      = (13.6*((m_dot_GaAs/mo)/(apsilen/apsilen_not)^2)
      )= "+string(Ea_GaAs)+"eV")//calculation
24 apsilen = 11.9*8.85*10^-14
25 disp("apsilen = "+string(apsilen)+"F/cm") //
      initializing value of relative permitivity for
      GaAs
26 m_dot_Si=0.5*mo
27 disp("m_dot_Si=0.45*mo = "+string(m_dot_Si)+"kg") //
      initializing value of heavy hole mass for GaAs
28 Ea_Si = (13.6*((m_dot_Si/mo)/(apsilen/apsilen_not)
      ^2))
29 disp("The acceptor level energy in Si is ,Ea_Si =
      (13.6*((m_dot_Si/mo)/(apsilen/apsilen_not)^2))= "
      +string(Ea_Si)+"eV")//calculation
30 Ed_Si = (13.6*((m_sigma_star/mo)/(apsilen/
      apsilen_not)^2))
31 disp("The donor level energy in Si is ,Ed_Si =
      (13.6*((m_sigma_star/mo)/(apsilen/apsilen_not)^2)
      )= "+string(Ed_Si)+"eV")//calculation
```

```
32 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 2.13 Position of fermi level

```
1  clc
2  n = 10^17
3  disp("n = "+string(n)+"cm^-3") //initializing value
   of free density of electron of GaAs
4  kBT=0.026
5  disp("kBT = "+string(kBT)+"eV") //initializing value
    of multiplication of boltzmann constant and
   temperature
6  Nc = 4.45*10^17
7  disp("Nc = "+string(Nc)+"cm^-3") //initializing
   value of effective density of electron
8  //(we have assumed the valence band energy Ev=0eV as
    it is not provided in the book)
9  E1= kBT*((log(n/Nc)))
10 disp("Ef(B)= kBT*((log(n/Nc)))= "+string(E1)+"eV")//
   calculation
11 E2= kBT*((log(n/Nc))+(1/sqrt(8))*(n/Nc))
12 disp("E(J)= kBT*((log(n/Nc))+(1/sqrt(8))*(n/Nc))= "+
   string(E2)+"eV")//calculation
13 //for Boltzmann approximation the carrier
   concentration and fermi level are related as : Ef
    = Ec+E1
14 //for joyce dixon approximation the carrier
   concentration and fermi level are related as : Ef
    = Ec+E2
15 e=E1-E2
16 disp("The error produced by using boltzmann approx.
   is  e=E1-E2= "+string(e)+"eV")//calculation
```

Scilab code Exa 2.14 Electron carrier concentration using Boltzmann approximation and Joyce dixon

```
1
2 clc
3 disp("In the Boltzmann approximation, the carrier
    density is simply")
4 disp("n = Nc = 2.78*10^19 cm^-3")
5 N=2.78*10^19
6 disp("N = "+string(N)+"cm^-3") //initializing value
    of carrier density
7 //In joyce dixon approximation the carrier density
    is obtained from the solution of the equation
8 disp("Ef = 0 = kBT *(log(n/Nc)+(n/(sqrt8*Nc)))")
9 //solving by trial and error , we get
10 //n/Nc= 0.76
11 n=0.76*N
12 disp("electron carrier concentration is n=0.76*Nc= "
    +string(n)+" cm^-3")//calculation
```

Scilab code Exa 2.16 fraction of ionised

```
1 clc
2 Nc = 2.8*10^19
3 disp("Nc = "+string(Nc)+"cm^-3") //initializing
    value of effective density of electron
4 Nd = 10^16
5 disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of donor atom
6 Ec_minus_Ed = 45*10^-3
7 disp("Ec_minus_Ed = "+string(Ec_minus_Ed)+"eV") //
    initializing value of donor binding energy
```

```
kBT=0.026
disp("kBT = "+string(kBT)+"eV") //initializing value
    of multiplication of boltzmann constant and
    temperature
//let fraction of ionised donor are represented as
    Fd = (nd/(n+nd))
Fd= (1/(((Nc/(2*Nd))*exp(-(Ec_minus_Ed/kBT)))+1))
    *100
disp("fraction of ionised donor is Fd= 1/(((Nc/(2*Nd
    ))*exp(-(Ec_minus_Ed/kBT)))+1)= "+string(Fd)+"%")
    //calculation
Nd = 10^18
disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of donor atom
Fd= (1/(((Nc/(2*Nd))*exp(-(Ec_minus_Ed/kBT)))+1))
    *100
disp("fraction of ionised donor is Fd= 1/(((Nc/(2*Nd
    ))*exp(-(Ec_minus_Ed/kBT)))+1)= "+string(Fd)+"%")
    //calculation
// Note : due to different precisions taken by me
    and the author ... my answer differ
```

Scilab code Exa 2.17 Free electron density

```
clc
Nc_Si = 2.78*10^19
disp("Nc_Si = "+string(Nc_Si)+"cm^-3") //
    initializing value of effective density of
    electron for silicon
Nc_GaAs = 4.45*10^17
disp("Nc_GaAs = "+string(Nc_GaAs)+"cm^-3") //
    initializing value of effective density of
    electron for GaAs
disp("for joyce dixon approximation the carrier
    concentration and fermi level are related as : Ef
```

```
    -Ec = kBT*(log(n/Nc)+(n/(sqrt8*Nc))")
disp("using Ef-Ec = 3* kBT")
disp("solving above equation by hit and trial method
    for n/Nc,we get n/Nc = 4.4")
n_by_Nc = 4.4
n_Si = n_by_Nc*Nc_Si
disp("carrier density for silicon is n= n_by_Nc*
   Nc_Si= "+string(n_Si)+"cm^-3")//calculation
n_GaAs = n_by_Nc*Nc_GaAs
disp("carrier density for GaAs is n= n_by_Nc*Nc_GaAs
   = "+string(n_GaAs)+"cm^-3")//calculation
```

Chapter 3

CARRIER DYNAMICS IN SEMICONDUCTOR

Scilab code Exa 3.1 Relaxation time

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
      of mass of electron
4  me = 0.067*mo
5  disp("me* = "+string(me)+"kg") //initializing value
      of effective mass of GaAs
6  u1=8500*10^(-4)
7  disp("u1 = "+string(u1)+"m^2(Vs)^-1") //initializing
       value of mobility of pure GaAs
8  e = 1.6*10^-19
9  disp("e= "+string(e)+"C")//initializing value of
      charge of electron
10 u2=5000*10^(-4)
11 disp("u2 = "+string(u2)+"m^2(Vs)^-1") //initializing
       value of mobility of impure GaAs
12 Tsc1 = (me*u1)/e
13 disp("The relaxation time of pure GaAs is Tsc1 = (me
      *u1)/e= "+string(Tsc1)+"s")//calculation
```

```
14 Tsc2 = (me*u2)/e
15 disp("The relaxation time of impure GaAs is Tsc2 = (
     me*u2)/e= "+string(Tsc2)+"s")//calculation
16 //using Mathieson rule
17 Tsc = ((1/Tsc2)-(1/Tsc1))^-1
18 disp("The impurity related time is Tsc(imp) = ((1/
     Tsc2)-(1/Tsc1))^-1 = "+string(Tsc)+"s")//
     calculation
```

Scilab code Exa 3.2 Scattering time

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
     of mass of electron
4  ml = 0.98*mo
5  disp("ml* = "+string(ml)+"kg") //initializing value
     of longitudinal mass
6  mt = 0.19*mo
7  disp("mt*= "+string(mt)+"kg")//initializing value of
      transverse mass
8  u=1500*10^(-4)
9  disp("u = "+string(u)+"m^2(Vs)^-1") //initializing
     value of mobility of pure silicon
10 e = 1.6*10^-19
11 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
12 Msig = 3*((2/mt)+(1/ml))^(-1)
13 disp("The conductivity mass is ,(Msig* = 3*((2/mt)
     +(1/ml))^(-1)))= "+string(Msig)+"kg")//
     calculation
14 Tsc = u*Msig/e
15 disp("The scattering time is ,Tsc = u*Msig/e= "+
     string(Tsc)+"s")//calculation
```

Scilab code Exa 3.3 conductivity

```
clc
un1=1000
disp("un1 = "+string(un1)+"cm^2(Vs)^-1") //
    initializing value of mobility of electron of
    silicon
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
un2 = 8000
disp("un2 = "+string(un2)+"cm^2(Vs)^-1") //
    initializing value of mobility of electron of
    GaAs
up1 = 350
disp("up1 = "+string(up1)+"cm^2(Vs)^-1") //
    initializing value of mobility of holes of
    silicon
up2 = 400
disp("up2 = "+string(up2)+"cm^2(Vs)^-1") //
    initializing value of mobility of holes of GaAs
ndoped = (50/100)*10^17
disp("ndoped = "+string(ndoped)+"cm^-3") //
    initializing value of electron density of doped
    semiconductor(50% of Nd=10^17 cm^-3)
ni = 1.5*10^10
disp("ni = "+string(ni)+"cm^-3") //initializing
    value of electron density of ionisation electron
    for silicon
pdoped = (ni)^2/ndoped
disp("The hole density of doped semiconductor is
    pdoped = (ni)^2/ndoped = "+string(pdoped)+"cm^-3"
    )//calculation
//pdoped can be neglected
```

```
19 Sdoped = ndoped*e*un1
20 disp("The conductivity of doped silicon is (sigma
     doped) Sdoped = ndoped*e*un = "+string(Sdoped)+"
     ohmcm^-1")//calculation
21 p1 = 1.5*10^10
22 disp("p1 = "+string(p1)+"cm^-3") //initializing
     value of hole density for undoped silicon
23 Sundoped = ni*e*un1+p1*e*up1
24 disp("The conductivity of undoped silicon is (sigma
     undoped)Sundoped = ni*e*un+p*e*up = "+string(
     Sundoped)+"ohmcm^-1")//calculation
25 Sdoped1 = ndoped*e*un2
26 disp("The conductivity of doped GaAs is (sigma doped
     ) Sdoped = ndoped*e*un = "+string(Sdoped1)+"ohmcm
     ^-1")//calculation
27 p2 = 1.84*10^6
28 disp("p2 = "+string(p2)+"cm^-3") //initializing
     value of hole density for undoped GaAs
29 ni1 = 1.84*10^6
30 disp("ni = "+string(ni1)+"cm^-3") //initializing
     value of electron density of ionisation electron
     for GaAs
31 Sundoped = ni1*e*un2+p2*e*up1
32 disp("The conductivity of undoped silicon is (sigma
     undoped) Sundoped = ni*e*un1+p1*e*up1 = "+string(
     Sundoped)+"ohmcm^-1")//calculation
```

Scilab code Exa 3.4 Maximum and minimum conductivity

```
1 clc
2 un1=1000
3 disp("un1 = "+string(un1)+"cm^2(Vs)^-1") //
     initializing value of mobility of electron of
     silicon
4 e = 1.6*10^-19
```

```
5  disp("e= "+string(e)+"C")//initializing value of
     charge of electron
6  un2 = 400
7  disp("un2 = "+string(un2)+"cm^2(Vs)^-1") //
     initializing value of mobility of electron of
     GaAs
8  up1 = 350
9  disp("up1 = "+string(up1)+"cm^2(Vs)^-1") //
     initializing value of mobility of holes of
     silicon
10 up2 = 8000
11 disp("up2 = "+string(up2)+"cm^2(Vs)^-1") //
     initializing value of mobility of holes of GaAs
12 ni = 1.5*10^10
13 disp("ni = "+string(ni)+"cm^-3") //initializing
     value of electron density of ionisation electron
14 nmax = 2.78*10^19
15 disp("nmax = "+string(nmax)+"cm^-3") //initializing
     value of maximum electron density for silicon
16 nmax1 = 7.72*10^18
17 disp("nmax1 = "+string(nmax1)+"cm^-3") //
     initializing value of maximum electron density
     for GaAs
18 Smax = nmax*e*un1
19 disp("The maximum conductivity for silicon is (sigma
     max) Smax = nmax*e*un = "+string(Smax)+"ohmcm^-1
     ")//calculation
20 Smax1 = nmax1*e*un2
21 disp("The maximum conductivity of GaAs is (sigma max
     ) Smax = nmax*e*un = "+string(Smax1)+"ohmcm^-1")
     //calculation
22 Smin = ni*e*((un1*sqrt(up1/un1))+(up1*sqrt(un1/up1))
     )
23 disp("The minimum conductivity of silicon is (sigma
     min)Smin = ni*e*((un1*sqrt(up1/un1))+(up1*sqrt(
     un1/up1))) = "+string(Smin)+"ohmcm^-1")//
     calculation
24 ni1 = 1.84*10^6
```

```
25 disp("ni = "+string(ni1)+"cm^-3") //initializing
     value of electron density of ionisation electron
     for GaAs
26 Smin1 = ni1*e*((un2*sqrt(up2/un2))+(up2*sqrt(un2/up2
     )))
27 disp("The minimum conductivity of GaAs is (sigma min
     )Smin1 = ni*e*((un2*sqrt(up2/un2))+(up2*sqrt(un2/
     up2))) = "+string(Smin1)+"ohmcm^-1")//calculation
```

Scilab code Exa 3.5 RELAXATION TIME

```
1  clc
2  mo = 9.1*10^-31
3  disp("mo = "+string(mo)+"kg") //initializing value
     of mass of electron
4  me = 0.26*mo
5  disp("me* = "+string(me)+"kg") //initializing value
     of conductivity mass of silicon
6  v1=1.4*10^(6)
7  disp("v1 = "+string(v1)+"cm(s)^-1") //initializing
     value of velocity of silicon electron at 300K
8  e = 1.6*10^-19
9  disp("e= "+string(e)+"C")//initializing value of
     charge of electron
10 v2=1.0*10^(7)
11 disp("v2 = "+string(v2)+"cm^(s)^-1") //initializing
     value of velocity of silicon electron at 300K
12 F1= 1000
13 disp("F1 = "+string(F1)+"V(cm)^-1") //initializing
     value of electric field
14 F2= 100000
15 disp("F2 = "+string(F2)+"V(cm)^-1") //initializing
     value of electric field
16 u1 = v1/(F1*10^4)
17 disp("The mobility for electrons in silicon (1 kV/cm
```

```
    ) is u1 = v1/(F1*10^4) = "+string(u1)+"m^2/V.s")
    //calculation
u2 = v2/(F2*10^4)
disp("The mobility for electrons in silicon (100 kV/
    cm) is u2 = v2/(F2*10^4) = "+string(u2)+"m^2/V.s"
    )//calculation
Tsc1 = (me*u1)/e
disp("The relaxation time of electrons in silicon at
     1kV/cm is Tsc1 = (me*u1)/e= "+string(Tsc1)+"s")
    //calculatio
Tsc2 = (me*u2)/e
disp("The relaxation time of electrons in silicon at
     100kV/cm is Tsc2 = (me*u2)/e= "+string(Tsc2)+"s"
    )//calculation
```

Scilab code Exa 3.6 transit time

```
clc
v2=1.0*10^(7)
disp("v2 = "+string(v2)+"cm^(s)^-1") //initializing
    value of saturation velocity of GaAs device
F= 5000
disp("F = "+string(F)+"V(cm)^-1") //initializing
    value of average electric field in GaAs device
L= 2*10^(-4)
disp("L = "+string(L)+"cm") //initializing value of
    length of GaAs device
u = 8000
disp("u = "+string(u)+"cm^2/Vs") //initializing
    value of low field mobility
v1 = u*F
disp("The average velocity of electrons is v = u*F =
     "+string(v1)+"cm/s")//calculation
Ttr1 = L/v1
disp("The transit time of electrons through the
```

```
    device is Ttr1 = L/v1= "+string(Ttr1)+"s")//
    calculation
14 Ttr2 = L/v2
15 disp("The transit time of electrons using saturation
     velocity through the device is Ttr2 = L/v2= "+
    string(Ttr2)+"s")//calculation
```

Scilab code Exa 3.7 Tunneling probability

```
1  clc
2  h=1.05*10^-34
3  disp("h = "+string(h)+"Js") //initializing value of
     reduced plancks constant or dirac constant or h-
     bar
4  mo = 9.1*10^-31
5  disp("mo = "+string(mo)+"kg") //initializing value
     of mass of electron
6  me1 = 0.065*9.1*10^-31
7  disp("me*(GaAs) = "+string(me1)+"kg") //initializing
      value of electron mass of GaAs
8  me2 = 0.02*9.1*10^-31
9  disp("me*(InAs) = "+string(me2)+"kg") //initializing
      value of electron mass of InAs
10 e = 1.6*10^-19
11 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
12 Eg1 = 1.5*1.6*10^-19
13 disp("Eg(GaAs) = "+string(Eg1)+"J") //initializing
     value of valence bandedge energy of GaAs
14 Eg2 = 0.4052*1.6*10^-19
15 disp("Eg(InAs) = "+string(Eg2)+"J") //initializing
     value of valence bandedge energy of InAs
16 F= 2*10^7
17 disp("F = "+string(F)+"V(cm)^-1") //initializing
     value of applied electric field
```

```
18 T1 = exp(-(4*sqrt(2*me1)*(Eg1)^(3/2))/(3*e*h*F))
19 disp("The tunneling probability in GaAs is T1 = exp
   (-(4*sqrt(2*me1)*(Eg1)^(3/2))/(3*e*h*F)) = "+
   string(T1)+"")//calculation
20 T2 = exp(-(4*sqrt(2*me2)*(Eg2)^(3/2))/(3*e*h*F))
21 disp("The tunneling probability in InAs is T2 = exp
   (-(4*sqrt(2*me2)*(Eg2)^(3/2))/(3*e*h*F)) = "+
   string(T2)+"")//calculation
22 //NOTE: The tunneling probability in GaAs is
   approximately given zero in the textbook
```

Scilab code Exa 3.8 Diffusion current density

```
1 clc
2 e = 1.6*10^-19
3 disp("e= "+string(e)+"C")//initializing value of
   charge of electron
4 L =10^-4
5 disp("L= "+string(L)+"cm")//initializing value of
   length
6 Dn =220
7 disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
    of electron diffusion coefficient
8 //n(x) = 10^16*exp(-(x/L)) cm^-3
9 //Derivative of n(x) for x =0 is  10^16/L
10 dn_by_dx =10^16/L
11 disp("dn_by_dx= "+string(dn_by_dx)+"cm^-4")//
   initializing value of derivative of n(x) for x=0
12 Jn_diff = e*Dn*dn_by_dx
13 disp("The diffusion current density is Jn_diff = e*
   Dn*dn_by_dx = "+string(Jn_diff)+"A/cm^2")//
   calculation
14 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 3.9 diffusion coefficient

```
clc
v1=1.4*10^(4)
disp("v1 = "+string(v1)+"m(s)^-1") //initializing
    value of velocity of electrons in silion at 1kV/
    cm
v2=7*10^(4)
disp("v2 = "+string(v2)+"m(s)^-1") //initializing
    value of velocity of electrons in silion at 10kV/
    cm
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
     of kbT at 300K
F1= 10^5
disp("F1 = "+string(F1)+"V(m)^-1") //initializing
    value of applied electric field
F2= 10^6
disp("F2 = "+string(F2)+"V(m)^-1") //initializing
    value of applied electric field
D1 = (v1*kbT*1.6*10^-19)/(e*F1)
disp("The diffusion coefficient is ,D(1kV/cm) = (v*
    kbT*1.6*10^-19)/(e*F) = "+string(D1)+"m^2/s")//
    calculation
D2 = (v2*kbT*1.6*10^-19)/(e*F2)
disp("The diffusion coefficient is ,D(10kV/cm) = (v*
    kbT*1.6*10^-19)/(e*F) = "+string(D2)+"m^2/s")//
    calculation
```

Scilab code Exa 3.10 position of electron and hole quasi fermi level

```
clc
Nc=2.8*10^(19)
disp("Nc = "+string(Nc)+"cm^-3")
Nv=1.04*10^(19)
disp("Nv = "+string(Nv)+"cm^-3")
//NOTE: Ec-Ev = forbidden band gap energy = Eg
Eg = 1.1
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
n= 10^17
disp("n = "+string(n)+"cm^-3")
p= 10^17
disp("p = "+string(p)+"cm^-3")
Efn_minus_Efp = Eg+(kbT*(log(p/Nv)+log(n/Nc)))
disp("The difference in the quasi fermi level is ,
   Efn_minus_Efp = Eg+(kbT*(log(p/Nv)+log(n/Nc))) =
   "+string(Efn_minus_Efp)+"eV")//calculation
n= 10^15
disp("n = "+string(n)+"cm^-3")
p= 10^15
disp("p = "+string(p)+"cm^-3")
Efn_minus_Efp = Eg+(kbT*(log(p/Nv)+log(n/Nc)))
disp("The difference in the quasi fermi level is ,
   Efn_minus_Efp = Eg+(kbT*(log(p/Nv)+log(n/Nc))) =
   "+string(Efn_minus_Efp)+"eV")//calculation
```

Scilab code Exa 3.11 Minimum thickness of sample

```
clc
```

```
alpha1=(-10^(4))
disp("Alpha1 = "+string(alpha1)+"cm^-1") //
    initializing value of absorption coefficient near
     the bandedges of GaAs
alpha2=(-10^(3))
disp("alpha2 = "+string(alpha2)+"cm^-1") //
    initializing value of absorption coefficient near
     the bandedges of Si
Iabs_by_Iinc = 0.9
disp("Iabs/Iinc= "+string(Iabs_by_Iinc)+"C")//
    initializing value of amount of light absorbed
L1 = (1/alpha1)*log(1-(Iabs_by_Iinc))
disp("The thickness of a sample GaAs is ,L = (1/
    alpha1)*log(1-Iabs/Iinc) = "+string(L1)+"cm")//
    calculation
L2 = (1/alpha2)*log(1-(Iabs_by_Iinc))
disp("The thickness of a sample Si is ,L = (1/alpha2
    )*log(1-Iabs/Iinc) = "+string(L2)+"cm")//
    calculation
```

Scilab code Exa 3.12 Carrier generation rate

```
clc
alpha=(3*10^(3))
disp("alpha = "+string(alpha)+"cm^-1") //
    initializing value of absorption coefficient near
     the bandedges of GaAs
p=(10^(3))
disp("(power density)p = "+string(p)+"W cm^-2") //
    initializing value of power density that
    impringes on GaAs
Tr = 1.5*1.6*10^-19
disp("Tr= "+string(Tr)+"J")//initializing value of
    photon energy
d = 10^-3
```

```
disp("d= "+string(d)+"")//initializing value of
    photon energy
Rg1 = (alpha*p)/Tr
disp("The carrier generation rate at the surface is
    ,Rg(0) = (alpha*p)/Tr = "+string(Rg1)+"cm^-3s^-1"
    )//calculation
Rg2 = (alpha*p*exp(-3))/Tr
disp("The carrier generation rate at the depth of 10
    um is ,Rg(10) = (alpha*p*exp(-3))/Tr = "+string(
    Rg2)+"cm^-3s^-1")//calculation
```

Scilab code Exa 3.13 Electron trapping time

```
clc
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value
    of mass of electron
m = 0.27*mo
disp("m* = "+string(m)+"kg") //initializing value of
    effective mass of silicon
kb = (1.38*10^-23)
disp("kb = "+string(kb)+"J/K") //initializing value
    of boltzman constant
T1 = 300
disp("T1 = "+string(T1)+"K") //initializing value of
    temperature
T2 = 77
disp("T2 = "+string(T2)+"K") //initializing value of
    temperature
vth1=(sqrt((3*kb*T1)/(m)))*100
disp("The thermal velocity of the electron at 300K
    is ,vth(300K)=sqrt((3*kb*T)/(m*)) = "+string(vth1
    )+"cms^-1")//calculation
vth2=(sqrt((3*kb*T2)/(m)))*100
disp("The thermal velocity of the electron at 77K is
```

```
    ,vth(77K)=sqrt((3*kb*T)/(m*)) = "+string(vth2)+"
    cms^-1")//calculation
16 sigma=10^(-14)
17 disp("sigma = "+string(sigma)+"cm^2") //initializing
     value of cross-section
18 Nt = 10^15
19 disp("Nt= "+string(Nt)+"cm^-3")//initializing value
    of impurity density
20 Tnr1 = 1/(sigma*Nt*vth1)
21 disp("The electron trapping time is ,Tnr1 = 1/(sigma
    *Nt*vth1) = "+string(Tnr1)+"s")//calculation
22 Tnr2 = 1/(sigma*Nt*vth2)
23 disp("The electron trapping time is ,Tnr2 = 1/(sigma
    *Nt*vth2) = "+string(Tnr2)+"s")//calculation
24 //NOTE: in the Textbook the author has taken the
    approximated value for Vth thermal velocity\
25 // NOTE: these approximated values of velocity
    affects the value of electron trapping time
```

Scilab code Exa 3.14 diffusion length

```
1 clc
2 KbT = 1.38*(10^-23)*300
3 disp("kbT = "+string(KbT)+"V") //initializing value
    of kbT at 300K
4 mu=.4
5 disp("mu = "+string(mu)+"m^2(Vs)^-1") //initializing
     value of mobility of p-type GaAs
6 e = 1.6*10^-19
7 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
8 Dn = (mu*KbT)/e
9 disp("The diffusion constant using einstein relation
     is Dn = (mu*KbT)/e= "+string(Dn)+"m^2/s")//
    calculation
```

```
10 T = 0.6*10^-9
11 disp("T= "+string(T)+"s")//initializing value of
      recombination time
12 Ln = sqrt(Dn*T)
13 disp("The diffusion length of p type GaAs is Ln =
      sqrt(Dn*T)= "+string(Ln)+"m")//calculation
```

Scilab code Exa 3.16 fraction of donor and diffusion length

```
1 clc
2 e = 1.6*10^-19
3 disp("e= "+string(e)+"C")//initializing value of
      charge of electron
4 kBT = 0.026
5 disp("kbT = "+string(kbT)+"V") //initializing value
      of kbT at 300K
6 sigma=10
7 disp("sigma = "+string(sigma)+"ohmcm^-1") //
      initializing value of conductivity
8 mu_n=1100
9 disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
      initializing value of mobility of electrons
10 mu_p=400
11 disp("mu_p = "+string(mu_p)+"cm^2(Vs)^-1") //
      initializing value of mobility of holes
12 Nd = 10^17
13 disp("Nd= "+string(Nd)+"cm^-3")//initializing value
      of doping
14 n = sigma/(e*mu_n)
15 disp("The carrier concentration in n type material
      is n = sigma/(e*mu_n)= "+string(n)+"cm^-3")//
      calculation
16 // the answer in textbook is given in %
17 //The excess drops by 50% once light is off using
      this fact in below equation
```

```
18 T = -1/log(.5)
19 disp("The recombination time is T = -1/log(.5)= "+
     string(T)+"micro-sec")//calculation
20 Dp = mu_p*kbT
21 disp("The diffusion constant is Dp = mu_p*kbT = "+
     string(Dp)+"cm^2/s")//calculation
22 Lp = sqrt(Dp*T*10^-6)
23 disp("The diffusion length is Lp = sqrt(Dp*T*10^-6)
     = "+string(Lp)+"m")//calculation
```

Chapter 5

Junction in Semiconductors P N diodes

Scilab code Exa 5.1 Contact potential and depletion width

```
1  clc
2  Nd = 10^16
3  disp("Nd= "+string(Nd)+"cm^-3")//initialising value
     of donor atoms in centimeter
4  Na= 10^18
5  disp("Na= "+string(Na)+"cm^-3")//initialising value
     of accepter atoms in centimeter
6  Nc= 2.8*10^19
7  disp("Nc= "+string(Nc)+"cm^-3")//initialising value
     of conduction band effective density
8  Nv= 10^19
9  disp("Nv= "+string(Nv)+"cm^-3")//initialising value
     of valence band effective density
10 kbT = 0.026
11 disp("kbT = "+string(kbT)+"eV") //initializing value
      of kbT at 300K
12 Eg = 1.1
13 disp("Eg = "+string(Eg)+"eV") //initializing value
     of forbidden energy gap
```

```
14 //NOTE: nn=Nd and pp=Na
15 eVbi = Eg+(kbT*log(Na/Nv))+((kbT*log(Nd/Nc)))
16 disp("built in voltage is ,eVbi = Eg-(kbT*log(Na/Nv)
   )-((kbT*log(Nd/Nc))) = "+string(eVbi)+" eV")//
   calculation
17 apsilen = 11.9*8.85*10^-12
18 disp("apsilen = "+string(apsilen)+"F/m") //
   initializing value of relative permitivity
19 e = 1.6*10^-19
20 disp("e= "+string(e)+"C")//initializing value of
   charge of electron
21 Vbi=eVbi/e
22 Nd = 10^22
23 disp("Nd= "+string(Nd)+"m^-3")//initialising value
   of donor atoms in metrers
24 Na= 10^24
25 disp("Na= "+string(Na)+"m^-3")//initialising value
   of accepter atomsin meters
26 Wp_Vbi = sqrt(((2*apsilen*eVbi)/(e))*(Nd/(Na*(Na+Nd)
   )))
27 disp("depletion width at p side is ,Wp_Vbi = sqrt
   ((2*apsilen*Vbi)/(e)*(Nd/(Na*(Na+Nd)))) = "+
   string(Wp_Vbi)+" m")//calculation
28 Wn_Vo = 100*sqrt(((2*apsilen*eVbi)/(e))*(Nd/(Na*(Na+
   Nd))))
29 disp("depletion width at n side is ,Wn_Vo = 100*sqrt
   ((2*apsilen*Vbi)/(e)*(Nd/(Na*(Na+Nd)))) = "+
   string(Wn_Vo)+" m")//calculation
```

Scilab code Exa 5.2 depletion width

```
1 clc
2 Nd = 10^16
3 disp("Nd= "+string(Nd)+"cm^-3")//initialising value
   of donor atoms in centimeter
```

```
4  Na= 10^18
5  disp("Na= "+string(Na)+"cm^-3")//initialising value
       of accepter atoms in centimeter
6  ni = 1.5*10^10
7  disp("ni= "+string(ni)+"cm^-3")//initializing value
       of intrinsic carrier concentration
8  //NOTE: nn=Nd and pp=Na
9  R= 10*10^-6
10 disp("R= "+string(R)+"m") //initializing value of
       radius of pn diode
11 A = %pi*(R^2)
12 pn = ni^2/Nd
13 disp("concentration of electron in p type is ,pn =
       ni^2/Nd = "+string(pn)+" cm^-3")//calculation
14 kbT = 0.026
15 disp("kbT = "+string(kbT)+"eV") //initializing value
        of kbT at 300K
16 eVbi = (kbT*log(Na/pn))
17 disp("built in voltage is ,eVbi = (kbT*log(Na/pn)) =
       "+string(eVbi)+" V")//calculation
18 apsilen = 11.9*8.84*10^-12
19 disp("apsilen = "+string(apsilen)+"F/m") //
       initializing value of relative permitivity
20 e = 1.6*10^-19
21 disp("e= "+string(e)+"C")//initializing value of
       charge of electron
22
23 //NOTE: for reverse bias Vr = 0 V,
24 Wp_4 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
       *10^6)*((Nd*10^6)+(Na*10^6)))))
25 disp("depletion width at p side is ,Wp_4 = sqrt((2*
       apsilen*Vbi)/(e)*(Nd/(Na*(Na+Nd)))) = "+string(
       Wp_4)+"m")//calculation
26 Wn_4 = Wp_4*100
27 disp("depletion width at n side is ,Wn_4 = 100*Wp_4
       = "+string(Wn_4)+"m")//calculation
28
29 //for calculation purpose and for differentiating
```

```
    part (I), equating
Vbi_4 = eVbi

disp("")// for spacing
Vbi_2 = Vbi_4 + 2
//NOTE: for reverse bias Vr = 2 V,
disp("Vbi_2 = "+string(Vbi_2)+"V")
Wp_2 = Wp_4*sqrt(Vbi_2/Vbi_4)
disp("depletion width at p side is ,Wp_2 = Wp_4*sqrt
    (Vbi_2/Vbi_4) = "+string(Wp_2)+"m")//calculation
Wn_2 = Wp_2*100
disp("depletion width at n side is ,Wn_2 = 100*Wp_2
    = "+string(Wn_2)+"m")//calculation

disp("")// for spacing
Vbi_3 = Vbi_4 + 5
//NOTE: for reverse bias Vr = 5 V,
disp("Vbi_3 = "+string(Vbi_3)+"V")
Wp_3 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_3/Vbi_4)
disp("depletion width at p side is ,Wp_3 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_3/
    Vbi_4) = "+string(Wp_3)+"m")//calculation
Wn_3 = Wp_3*100
disp("depletion width at n side is ,Wn_3 = 100*Wp_3
    = "+string(Wn_3)+"m")//calculation

disp("")// for spacing
Vbi_4 = Vbi_4 + 10
//NOTE: for reverse bias Vr = 10 V,
disp("Vbi_4 = "+string(Vbi_4)+"V")
Wp_4 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_4/Vbi_4)
disp("depletion width at p side is ,Wp_4 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_4/
    Vbi_4) = "+string(Wp_4)+"m")//calculation
Wn_4 = Wp_4*100
disp("depletion width at n side is ,Wn_4 = 100*Wp_4
```

```
    = "+string(Wn_4)+"m")//calculation
58
59
60 disp("")// for spacing
61 Vbi_5 = Vbi_4 - 0.5
62 //NOTE: for forward bias Vf = 0.5 V,
63 disp("Vbi_5 = "+string(Vbi_5)+"V")
64 Wp_5 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_5/Vbi_4)
65 disp("depletion width at p side is ,Wp_5 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_5/
    Vbi_4) = "+string(Wp_5)+"m")//calculation
66 Wn_5 = Wp_5*100
67 disp("depletion width at n side is ,Wn_5 = 100*Wp_5
    = "+string(Wn_5)+"m")//calculation
68
69 //CALCULATION FOR PEAK FIELD :
70
71 disp("F = - e*Nd*(10^6)*Wn/apsilen")// formula for
    peak field
72
73 F = - e*Nd*(10^6)*Wn_4/apsilen
74 disp("peak fielf for Vr = 0V, F = - e*Nd*(10^6)*
    Wn_4/apsilen = "+string(F)+"V/m")
75
76 F = - e*Nd*(10^6)*Wn_2/apsilen
77 disp("peak fielf for Vr = 2V, F = - e*Nd*(10^6)*
    Wn_2/apsilen = "+string(F)+"V/m")
78
79 F = - e*Nd*(10^6)*Wn_3/apsilen
80 disp("peak fielf for Vr = 5V, F = - e*Nd*(10^6)*
    Wn_3/apsilen = "+string(F)+"V/m")
81
82 F = - e*Nd*(10^6)*Wn_4/apsilen
83 disp("peak fielf for Vr = 10V, F = - e*Nd*(10^6)*
    Wn_4/apsilen = "+string(F)+"V/m")
84
85 F = - e*Nd*(10^6)*Wn_5/apsilen
```

```
86 disp("peak fielf for Vf = 0.5V, F = - e*Nd*(10^6)*
   Wn_5/apsilen = "+string(F)+"V/m")
87
88 //calculation for
89 Q = e*(Nd*10^6)*Wn_4*A//charge in depletion region
   for Vr = 0V
90 disp("Q = "+string(e*(Nd*10^6)*Wn_4*A)+"C")
91
92 Q = e*(Nd*10^6)*Wn_2*A//charge in depletion region
   for Vr = 2V
93 disp("Q = "+string(e*(Nd*10^6)*Wn_2*A)+"C")
94
95 Q = e*(Nd*10^6)*Wn_3*A//charge in depletion region
   for Vr = 5V
96 disp("Q = "+string(e*(Nd*10^6)*Wn_3*A)+"C")
97
98 Q = e*(Nd*10^6)*Wn_4*A//charge in depletion region
   for Vr = 10V
99 disp("Q = "+string(e*(Nd*10^6)*Wn_4*A)+"C")
100
101 Q = e*(Nd*10^6)*Wn_5*A//charge in depletion region
   for Vf = 0.5V
102 disp("Q = "+string(e*(Nd*10^6)*Wn_5*A)+"C")
103
104
105 //due to approximation taken by author in the
   textbook .... the values of Vbi_2, Vbi_3, Vbi_4
   and the values of depletion width(Wp_4, Wp_2,Wp_3
   , Wp_4, Wn_4, Wn_2, Wn_3, Wn_4) differ from the
   above solution
```

Scilab code Exa 5.3 Average field in depletion region

```
1
2 clc
```

```
Nd = 10^16
disp("Nd= "+string(Nd)+"cm^-3")//initialising value of donor atoms in centimeter
Na= 10^18
disp("Na= "+string(Na)+"cm^-3")//initialising value of accepter atoms in centimeter
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value of intrinsic carrier concentration
//NOTE: nn=Nd and pp=Na
R= 10*10^-6
disp("R= "+string(R)+"m") //initializing value of radius of pn diode
A = %pi*(R^2)
pn = ni^2/Nd
disp("concentration of electron in p type is ,pn = ni^2/Nd = "+string(pn)+" cm^-3")//calculation
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value of kbT at 300K
eVbi = (kbT*log(Na/pn))
disp("built in voltage is ,eVbi = (kbT*log(Na/pn)) = "+string(eVbi)+" V")//calculation
apsilen = 11.9*8.84*10^-12
disp("apsilen = "+string(apsilen)+"F/m") //initializing value of relative permitivity
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron

//NOTE: for reverse bias Vr = 0 V,
Wp_4 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na*10^6)*((Nd*10^6)+(Na*10^6)))))
disp("depletion width at p side is ,Wp_4 = sqrt((2*apsilen*Vbi)/(e)*(Nd/(Na*(Na+Nd)))) = "+string(Wp_4)+"m")//calculation
Wn_4 = Wp_4*100
disp("depletion width at n side is ,Wn_4 = 100*Wp_4
```

```
    = "+string(Wn_4)+"m")//calculation
29
30 //for calculation purpose and for differentiating
    part (I), equating
31 Vbi_4 = eVbi
32
33 disp("")// for spacing
34 Vbi_2 = Vbi_4 + 2
35 //NOTE: for reverse bias Vr = 2 V,
36 disp("Vbi_2 = "+string(Vbi_2)+"V")
37 Wp_2 = Wp_4*sqrt(Vbi_2/Vbi_4)
38 disp("depletion width at p side is ,Wp_2 = Wp_4*sqrt
    (Vbi_2/Vbi_4) = "+string(Wp_2)+"m")//calculation
39 Wn_2 = Wp_2*100
40 disp("depletion width at n side is ,Wn_2 = 100*Wp_2
    = "+string(Wn_2)+"m")//calculation
41
42 disp("")// for spacing
43 Vbi_3 = Vbi_4 + 5
44 //NOTE: for reverse bias Vr = 5 V,
45 disp("Vbi_3 = "+string(Vbi_3)+"V")
46 Wp_3 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_3/Vbi_4)
47 disp("depletion width at p side is ,Wp_3 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_3/
    Vbi_4) = "+string(Wp_3)+"m")//calculation
48 Wn_3 = Wp_3*100
49 disp("depletion width at n side is ,Wn_3 = 100*Wp_3
    = "+string(Wn_3)+"m")//calculation
50
51 disp("")// for spacing
52 Vbi_4 = Vbi_4 + 10
53 //NOTE: for reverse bias Vr = 10 V,
54 disp("Vbi_4 = "+string(Vbi_4)+"V")
55 Wp_4 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_4/Vbi_4)
56 disp("depletion width at p side is ,Wp_4 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_4/
```

```
    Vbi_4) = "+string(Wp_4)+"m")//calculation
57 Wn_4 = Wp_4*100
58 disp("depletion width at n side is ,Wn_4 = 100*Wp_4
    = "+string(Wn_4)+"m")//calculation
59
60
61 disp("")// for spacing
62 Vbi_5 = Vbi_4 - 0.5
63 //NOTE: for forward bias Vf = 0.5 V,
64 disp("Vbi_5 = "+string(Vbi_5)+"V")
65 Wp_5 = sqrt(((2*apsilen*eVbi)/(e))*((Nd*10^6)/((Na
    *10^6)*((Nd*10^6)+(Na*10^6)))))*sqrt(Vbi_5/Vbi_4)
66 disp("depletion width at p side is ,Wp_5 = sqrt((2*
    apsilen*eVbi)/(e)*(Nd/(Na*(Na+Nd))))*sqrt(Vbi_5/
    Vbi_4) = "+string(Wp_5)+"m")//calculation
67 Wn_5 = Wp_5*100
68 disp("depletion width at n side is ,Wn_5 = 100*Wp_5
    = "+string(Wn_5)+"m")//calculation
69
70 //CALCULATION FOR PEAK FIELD :
71
72 disp("Fm = - e*Nd*(10^6)*Wn/apsilen")// Fmormula
    Fmor peak Fmield
73
74 Fm = - e*Nd*(10^6)*Wn_4/apsilen
75 disp("peak Field For Vr = 0V, Fm = - e*Nd*(10^6)*
    Wn_4/apsilen = "+string(Fm)+"V/m")
76 disp("average field , Fm/2 = "+string(Fm/2)+"V/m")
77
78 Fm = - e*Nd*(10^6)*Wn_2/apsilen
79 disp("peak Field for Vr = 2V, Fm = - e*Nd*(10^6)*
    Wn_2/apsilen = "+string(Fm)+"V/m")
80 disp("average field , Fm/2 = "+string(Fm/2)+"V/m")
81
82 Fm = - e*Nd*(10^6)*Wn_3/apsilen
83 disp("peak Field For Vr = 5V, Fm = - e*Nd*(10^6)*
    Wn_3/apsilen = "+string(Fm)+"V/m")
84 disp("average field , Fm/2 = "+string(Fm/2)+"V/m")
```

```
85
86 Fm =  - e*Nd*(10^6)*Wn_4/apsilen
87 disp("peak Field For Vr = 10V, Fm =  - e*Nd*(10^6)*
     Wn_4/apsilen = "+string(Fm)+"V/m")
88 disp("average field , Fm/2 = "+string(Fm/2)+"V/m")
89 disp("By the appendix B given in the book, the
     velocity of electron: v = 1*10^7 cm/s")
```

Scilab code Exa 5.4 Diode current

```
1  clc
2  A= 10^-7
3  disp("A= "+string(A)+"m^2") //initializing value of
     diode area
4  Na=10^18*10^6
5  disp("Na = "+string(Na)+"m^-3") //initializing value
     of acceptor atoms
6  Nd=10^16*10^6
7  disp("Nd = "+string(Nd)+"m^-3") //initializing value
     of donor atoms
8  Dp1 = 7.8*10^-4
9  disp("Dp1= "+string(Dp1)+"m^2/s")//initializing
     value of hole diffusion coefficient of n - side
10 Dn2 = 7.3*10^-4
11 disp("Dn2= "+string(Dn2)+"m^2/s")//initializing
     value of electron diffusion coefficient of p-side
12 Tn = 10^-6
13 disp("Tn= "+string(Tn)+"s")//inializing value of
     electron minority carrier lifetime
14 Tp = 10^-6
15 disp("Tp= "+string(Tp)+"s")//inializing value of
     hole minority carrier lifetime
16 e = 1.6*10^-19
17 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
```

```
18 kbT = 0.026
19 disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 300K
20 ni = 1.5*10^16
21 disp("ni= "+string(ni)+"m^-3")//initializing value
       of intrinsic carrier concentration
22 //NOTE: nn=Nd and pp=Na
23 Lp = sqrt(Dp1*Tp)
24 disp("The hole diffusion length is ,Lp = sqrt(Dp1*Tp
       )= "+string(Lp)+"m")//calculation
25 Ln = sqrt(Dn2*Tn)
26 disp("The electron diffusion length is ,Ln = sqrt(
       Dn2*Tn)= "+string(Ln)+"m")//calculation
27 // NOTE: pn= (ni^2/nn) and np=(ni^2/pp)
28 // assume that the doants are fully ionised
29 Io = A*e*((((Dn2)/(Ln))*(ni^2/Na))+(((Dp1)/(Lp))*(ni
       ^2/Nd)))
30 disp("The prefactor current is ,Io = A*e*(((Dn/Ln)*
       ni^2)+((Dp/Lp)*ni^2))= "+string(Io)+"A")//
       calculation
```

Scilab code Exa 5.5 current density

```
1 clc
2 Na=10^17
3 disp("Na = "+string(Na)+"cm^-3") //initializing
       value of acceptor atoms
4 Nd=10^17
5 disp("Nd = "+string(Nd)+"cm^-3") //initializing
       value of donor atoms
6 Dp1 = 12.5
7 disp("Dp1= "+string(Dp1)+"cm^2/s")//initializing
       value of hole diffusion coefficient for silicon
8 Dn1 = 35
9 disp("Dn1= "+string(Dn1)+"cm^2/s")//initializing
```

```
    value of electron diffusion coefficient for
    silicon
Dp2 = 10
disp("Dp2= "+string(Dp2)+"cm^2/s")//initializing
    value of hole diffusion coefficient for GaAs
Dn2 = 220
disp("Dn2= "+string(Dn2)+"cm^2/s")//initializing
    value of electron diffusion coefficient for GaAs
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of
    electron minority carrier lifetime
Tp = 10^-8
disp("Tp= "+string(Tp)+"s")//inializing value of
    hole minority carrier lifetime
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
     of kbT at 300K
pn1 = 2.25*10^3
disp("pn1= "+string(pn1)+"cm^-3")//initializing
    value of holes concentration in n type for
    silicon
np1 = 2.25*10^3
disp("np1= "+string(np1)+"cm^-3")//initializing
    value of electron concentration in p type for
    silicon
pn2 = 3.38*10^-5
disp("pn2= "+string(pn2)+"cm^-3")//initializing
    value of holes concentration in n type for GaAs
np2 = 3.38*10^-5
disp("np2= "+string(np2)+"cm^-3")//initializing
    value of electron concentration in p type for
    GaAs
//Note : since value of holes and electrons in n-
    type and p type are not given for silicon and
    germanium thus we have assume it as above
```

```
31 //NOTE: nn=Nd and pp=Na
32 Lp1 = sqrt(Dp1*Tp)
33 disp("The hole diffusion length for silicon is ,Lp =
       sqrt(Dp1*Tp)= "+string(Lp1)+"cm")//calculation
34 Ln1 = sqrt(Dn1*Tn)
35 disp("The electron diffusion length for silicon is ,
      Ln = sqrt(Dn2*Tn)= "+string(Ln1)+"cm")//
      calculation
36 Lp2 = sqrt(Dp2*Tp)
37 disp("The hole diffusion length for silicon is ,Lp =
       sqrt(Dp2*Tp)= "+string(Lp2)+"cm")//calculation
38 Ln2 = sqrt(Dn2*Tn)
39 disp("The electron diffusion length for silicon is ,
      Ln = sqrt(Dn2*Tn)= "+string(Ln2)+"cm")//
      calculation
40 // NOTE: pn= (ni^2/nn) and np=(ni^2/pp)
41 // assume that the doants are fully ionised
42 Jo1 = e*((((Dn1)/(Ln1))*np1)+(((Dp1)/(Lp1))*pn1))
43 disp("The prefactor current density for silicon is ,
      Jo1 = e*((((Dn1)/(Ln1))*np1)+(((Dp1)/(Lp1))*pn1))
      = "+string(Jo1)+"A/cm^2")//calculation
44 Jo2 = e*((((Dn2)/(Ln2))*np2)+(((Dp2)/(Lp2))*pn2))
45 disp("The prefactor current density for GaAs is ,Jo2
       = e*((((Dn2)/(Ln2))*np2)+(((Dp2)/(Lp2))*pn2))= "
      +string(Jo2)+"A/cm^2")//calculation
```

Scilab code Exa 5.6 diode injection efficiency

```
1 clc
2 Na=5*10^16
3 disp("Na = "+string(Na)+"cm^-3") //initializing
     value of acceptor atoms
4 Nd=5*10^17
5 disp("Nd = "+string(Nd)+"cm^-3") //initializing
     value of donor atoms
```

```
Dp = 15
disp("Dp= "+string(Dp)+"cm^2/s")//initializing value of hole diffusion coefficient
Dn = 30
disp("Dn= "+string(Dn)+"cm^2/s")//initializing value of electron diffusion coefficient
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of electron minority carrier lifetime
Tp = 10^-7
disp("Tp= "+string(Tp)+"s")//inializing value of hole minority carrier lifetime
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value of kbT at 300K
ni = 1.84*10^6
disp("ni= "+string(ni)+"cm^-3")//initializing value of intrinsic carrier concentration
np=ni^2/Na
disp("The electron conc in p type is ,np=ni^2/Na= "+string(np)+"cm^-3")//calculation
pn=ni^2/Nd
disp("The holes conc in n type is ,pn=ni^2/Nd= "+string(pn)+"cm^-3")//calculation
Lp = sqrt(Dp*Tp)
disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp) = "+string(Lp)+"cm")//calculation
Ln = sqrt(Dn*Tn)
disp("The electron diffusion length is ,Ln = sqrt(Dn*Tn)= "+string(Ln)+"cm")//calculation
Gamma_inj = ((e*Dn*np)/(Ln))/(((e*Dn*np)/(Ln))+((e*Dp*pn)/(Lp)))
disp("The efficiency of diode is ,Gamma_inj = ((e*Dn*np)/(Ln))/(((e*Dn*np)/(Ln))+((e*Dp*pn)/(Lp)))= "+string(Gamma_inj))//calculation
```

Scilab code Exa 5.7 Photon generation rate and optical power

```
clc
A= 0.1*10^-2
disp("A= "+string(A)+"cm^2") //initializing value of
    diode area
Vf= 1
disp("Vf= "+string(Vf)+"V") //initializing value of
   forward bias voltage
E= 1.43
disp("E= "+string(E)+"eV") //initializing value of
   energy of 1 photon
Na=5*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of acceptor atoms
Nd=5*10^17
disp("Nd = "+string(Nd)+"cm^-3") //initializing
   value of donor atoms
Dp = 15
disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
    of hole diffusion coefficient
Dn = 30
disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
    of electron diffusion coefficient
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of
   electron minority carrier lifetime
Tp = 10^-7
disp("Tp= "+string(Tp)+"s")//inializing value of
   hole minority carrier lifetime
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
kbT = 0.026
```

```
23 disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
24 ni = 1.84*10^6
25 disp("ni= "+string(ni)+"cm^-3")//initializing value
   of intrinsic carrier concentration
26 np=ni^2/Na
27 disp("The electron conc in p type is ,np=ni^2/Na= "+
   string(np)+"cm^-3")//calculation
28 pn=ni^2/Nd
29 disp("The holes conc in n type is ,pn=ni^2/Nd= "+
   string(pn)+"cm^-3")//calculation
30 Ln = sqrt(Dn*Tn)
31 disp("The electron diffusion length is ,Ln = sqrt(Dn
   *Tn)= "+string(Ln)+"cm")//calculation
32 In = ((e*A*Dn*np)/Ln)*(exp(Vf/kbT)-1)
33 disp("The electron current is ,In = ((e*A*Dn*np)/Ln)
   *(exp(Vf/kbT)-1)= "+string(In)+"A")//calculation
34 In_by_e = In/e
35 disp("The electron generation rate is ,In_by_e = In/
   e= "+string(In_by_e)+"s^-1")//calculation
36 power = In*E
37 disp("The optical power of photon is ,power = In*E=
   "+string(power)+"W")//calculation
```

Scilab code Exa 5.8 photocurrent

```
1 clc
2 apsilen = 11.9*8.85*10^-14
3 disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity
4 GL= 10^22
5 disp("GL= "+string(GL)+"cm^-3/s") //initializing
   value of rate of optical signal
6 A= 10^-4
7 disp("A= "+string(A)+"cm^2") //initializing value of
```

```
      diode area
Vr= 15
disp("Vr= "+string(Vr)+"V") //initializing value of
   reverse bias voltage
Na=2*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of acceptor atoms
Nd=10^16
disp("Nd = "+string(Nd)+"cm^-3") //initializing
   value of donor atoms
Dp = 12
disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
    of hole diffusion coefficient
Dn = 20
disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
    of electron diffusion coefficient
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of
   electron minority carrier lifetime
Tp = 10^-8
disp("Tp= "+string(Tp)+"s")//inializing value of
   hole minority carrier lifetime
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value
   of intrinsic carrier concentration
Ln = sqrt(Dn*Tn)
disp("The electron diffusion length is ,Ln = sqrt(Dn
   *Tn)= "+string(Ln)+"cm")//calculation
Lp = sqrt(Dp*Tp)
disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
   = "+string(Lp)+"cm")//calculation
Vbi = kbT*log((Na*Nd)/ni^2)
```

```
33 disp("The built in voltage is ,Vbi = kbT*log((Na*Nd)
   /ni^2)= "+string(Vbi)+"V")//calculation
34 W = sqrt(((2*apsilen)/e)*((Na+Nd)/(Na*Nd))*(Vbi+Vr))
35 disp("The depletion width is ,W = sqrt(((2*apsilen)/
   e)*((Na+Nd)/(Na*Nd))*(Vbi+Vr))= "+string(W)+"cm")
   //calculation
36 IL = e*A*GL*(W+Ln+Lp)
37 disp("The photo current is IL = e*A*GL*(W+Ln+Lp)= "+
   string(IL)+"A")//calculation
```

Scilab code Exa 5.9 prefactor in short diode

```
1  clc
2  e = 1.6*10^-19
3  disp("e= "+string(e)+"C")//initializing value of
   charge of electron
4  A= 10^-7
5  disp("A= "+string(A)+"m^2") //initializing value of
   diode area
6  Na=10^18*10^6
7  disp("Na = "+string(Na)+"m^-3") //initializing value
    of acceptor atoms
8  Nd=10^16*10^6
9  disp("Nd = "+string(Nd)+"m^-3") //initializing value
    of donor atoms
10 Dp = 7.8*10^-4
11 disp("Dp= "+string(Dp)+"m^2/s")//initializing value
   of hole diffusion coefficient of n - side
12 Dn = 7.3*10^-4
13 disp("Dn= "+string(Dn)+"m^2/s")//initializing value
   of electron diffusion coefficient of p-side
14 ni = 1.5*10^16
15 disp("ni= "+string(ni)+"m^-3")//initializing value
   of intrinsic carrier concentration
16 Wln = 5*10^-6
```

```
17 disp("The short diode width is ,Wln "+string(Wln)+"m
   ")
18 Wlp = Wln
19 //NOTE: nn=Nd and pp=Na
20 pn = ni^2/Nd
21 disp("concentration of electron in p type is ,pn =
   ni^2/Nd = "+string(pn)+" cm^-3")//calculation
22 np = ni^2/Na
23 disp("concentration of electron in n type is ,np =
   ni^2/Na = "+string(np)+" cm^-3")//calculation
24 // from example 5.4 and 5.2 we get the value of
   diffusion length and zero bias depletion widths
25 Lp = 27.9*10^-6
26 disp("The electron diffusion length is ,Lp "+string(
   Lp)+"m")
27 Ln = 27*10^-6
28 disp("The electron diffusion length is ,Ln "+string(
   Ln)+"m")
29 Wp = 3.262D-09
30 disp("The zero bias depletion widths is ,Wp "+string
   (Wp)+"m")
31 Wn = 0.0000003
32 disp("The zero bias depletion widths is ,Wn "+string
   (Wn)+"m")
33 // for short diode the prefactor current is given as
34 Io = e*A*(((Dp*pn)/(Wln-Wn))+((Dn*np)/abs(Wlp-Wp)))
35 disp("The prefactor current is ,Io = e*A*(((Dp*pn)/(
   Wln-Wn))+((Dn*np)/abs(Wlp-Wp)))= "+string(Io)+"A"
   )//calculation
36 // The prefactor current of short diode is
   approximately increase by a factor of 5.6 from
   that of long diode
37 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 5.10 Generation recombination time

```
clc
e = 1.6*10^-19;
kbT = 0.026;
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
A= 10^-7
disp("A= "+string(A)+"m^2") //initializing value of
    diode area
ni = 1.5*10^16
disp("ni= "+string(ni)+"m^-3")//initializing value
    of intrinsic carrier concentration
T = 10^-6
disp("T= "+string(T)+"s")//inializing value of
    carrier lifetime
// from example 5.2 we get the value of zero bias
    depletion widths
W = 0.32*10^-6
disp("The zero bias depletion widths is ,W "+string(
    W)+"m")
Io_GR = (e*A*W*ni)/(2*T)
disp("The prefactor of the  is ,generation
    recombination currentIo_GR = (e*A*W*ni)/(2*T)= "+
    string(Io_GR)+"A")//calculation
//let V = .2 V
V = .2
I_GR = Io_GR*(exp(V/(2*kbT))-1)
disp("The diode current is ,I_GR = Io_GR*(exp(V/(2*
    kbT))-1)= "+string(I_GR)+"A")//calculation
//let V = 0.6 V
V = 0.6
I_GR = Io_GR*(exp(V/(2*kbT))-1)
disp("The diode current is ,I_GR = Io_GR*(exp(V/(2*
    kbT))-1)= "+string(I_GR)+"A")//calculation
// The generation-recombination prefactor is much
    larger than prefactor due to diffusion term
//In forward bias the diffusion current is initially
```

much smaller than the generation recombination term but at high forward bias diffusion current will start to dominate

---

Scilab code Exa 5.11 Diode current and ideality factor

```
clc
A= 10^-8
disp("A= "+string(A)+"m^2") //initializing value of diode area
Na=10^23
disp("Na = "+string(Na)+"m^-3") //initializing value of acceptor atoms
Nd=10^23
disp("Nd = "+string(Nd)+"m^-3") //initializing value of donor atoms
Dp = 10*10^-4
disp("Dp= "+string(Dp)+"m^2/s")//initializing value of hole diffusion coefficient
Dn = 30*10^-4
disp("Dn= "+string(Dn)+"m^2/s")//initializing value of electron diffusion coefficient
Tn = 10^-7
disp("Tn= "+string(Tn)+"s")//inializing value of electron minority carrier lifetime
Tp = 10^-7
disp("Tp= "+string(Tp)+"s")//inializing value of hole minority carrier lifetime
tau = 10^-8
disp("tau= "+string(tau)+"s")//inializing value of carrier lifetime in depletion region
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
kbT = 0.026
```

```
21 disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
22 ni = 1.5*10^16
23 disp("ni= "+string(ni)+"m^-3")//initializing value
   of intrinsic carrier concentration
24 apsilen = 11.9*8.85*10^-12
25 disp("apsilen = "+string(apsilen)+"F/m") //
   initializing value of relative permitivity
26 //NOTE: nn=Nd and pp=Na
27 Lp = sqrt(Dp*Tp)
28 disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
   = "+string(Lp)+"m")//calculation
29 Ln = sqrt(Dn*Tn)
30 disp("The electron diffusion length is ,Ln = sqrt(Dn
   *Tn)= "+string(Ln)+"m")//calculation
31 // NOTE: pn= (ni^2/nn) and np=(ni^2/pp)
32 np=ni^2/Na
33 disp("The electron conc in p type is ,np=ni^2/Na= "+
   string(np)+"m^-3")//calculation
34 pn=ni^2/Nd
35 disp("The holes conc in n type is ,pn=ni^2/Nd= "+
   string(pn)+"m^-3")//calculation
36 Vbi = kbT*log((Na*Nd)/ni^2)
37 disp("The built in voltage is ,Vbi = kbT*log((Na*Nd)
   /ni^2)= "+string(Vbi)+"V")//calculation
38 Io = e*((((Dn)*np)/(Ln))+((Dp*pn)/(Lp)))
39 disp("The prefactor in the ideal diode is ,Io = e
   *(((Dn*np)/(Ln))+((Dp*pn)/(Lp)))= "+string(Io)+"A
   ")//calculation
40 //let Vf = 0.5 V
41 Vf = 0.5
42 disp("Vf= "+string(Vf)+"V") //initializing value of
   forward bias voltage
43 W = sqrt((2*apsilen/e)*((Na+Nd)/Nd/Na)*(Vbi-Vf))
44 disp("The depletion width is ,W = sqrt(((2*apsilen)/
   e)*((Na*Nd)/(Na+Nd))*(Vbi-Vf))= "+string(W)+"m")
   //calculation
45 Io_GR  = e*A*W*ni/(2*tau)
```

```
46 disp("prefactor for recombination generation current
   , Io_GR = "+string(Io_GR)+"A")
47 I = (Io*exp(Vf/kbT))+(Io_GR*exp(Vf/(2*kbT)))
48 I_V1 = I
49 disp("Current, I = (Io*exp(Vf/kbT))+(Io_GR*exp(Vf/
   kbT)) = "+string(I)+"A")
50
51 //let V = 0.6 V
52 Vf = 0.6
53 disp("Vf= "+string(Vf)+"V") //initializing value of
   forward bias voltage
54 W = sqrt((2*apsilen/e)*((Na+Nd)/Nd/Na)*(Vbi-Vf))
55 disp("The depletion width is ,W = sqrt(((2*apsilen)/
   e)*((Na*Nd)/(Na+Nd))*(Vbi-Vf))= "+string(W)+"m")
   //calculation
56 Io_GR  = e*A*W*ni/2/tau
57 disp("prefactor for recombination generation current
   , Io_GR = "+string(Io_GR)+"A")
58 I = (Io*exp(Vf/kbT))+(Io_GR*exp(Vf/(2*kbT)))
59 I_V2 = I
60 disp("Current, I = (Io*exp(Vf/kbT))+(Io_GR*exp(Vf/
   kbT)) = "+string(I)+"A")
61 V1 = 0.5
62 V2 = 0.6
63 n = e*(V2-V1)/kbT/log(I_V2/I_V1)
64 disp("Ideallity factor ,n = e*(V2-V1)/kbT/log(I_V2/
   I_V1) = "+string(n))
65 //note: in the text book the value of
66 //-+"prefactor of ideal diode equation, Io"
67 //calculated by author is wrong thus it efect the
   overall calculation of the solution
```

Scilab code Exa 5.12 Breakdown voltage

```
1 clc
```

```
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity
Na=10^19
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of acceptor atoms
Nd=10^16
disp("Nd = "+string(Nd)+"cm^-3") //initializing
   value of donor atoms
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
Fcrit1 = 4*10^5
disp("Fcrit1= "+string(Fcrit1)+"V/cm")//initializing
    value of critical field of silicon
Fcrit2 = 10^7
disp("Fcrit2= "+string(Fcrit2)+"V/cm")//initializing
    value of critical field of diamond
VBD_Si = (apsilen*Fcrit1^2)/(2*e*Nd)
disp("The breakdown field for silicon is ,VBD_Si = (
   apsilen*Fcrit1^2)/(2*e*Nd) = "+string(VBD_Si)+" V
   ")//calculation
VBD_C = (apsilen*Fcrit2^2)/(2*e*Nd)
disp("The breakdown field for diomond is ,VBD_C = (
   apsilen*Fcrit2^2)/(2*e*Nd) = "+string(VBD_C)+" V"
   )//calculation
// Note : In the textbook answer of breakdown
   voltage of silicon is wrong due to which
   breakdown voltage of diomand also differ
```

Scilab code Exa 5.13 thickness and width of n region

```
clc
disp("Let the intercept of the 1/c^2 Vs V plot is
   represented by Icv, which is the built in voltage
```

```
    ")
Icv = .68
disp("Icv = "+string(Icv)+"V") //initializing value
    of intercept of the 1/c^2 Vs V plot and the built
     in voltage
Vbi = Icv
disp("the built in voltage is Vbi = "+string(Vbi)+"V
    ")
disp("Let the slope of the intercept of the 1/c^2 Vs
     V plot is represented by dIcv")
dIcv=2.1*10^23
disp("dIcv = "+string(dIcv)+"F^-2 V^-1") //
    initializing value of slope of the intercept of
    the 1/c^2 Vs V plot
C = 7*10^-13
disp("C= "+string(C)+"F")//initializing value of
    capacitance
//NOTE: The above mentioned values are taken from
    the figure given in the question in textbook
apsilen = 11.9*8.85*10^-12
disp("apsilen = "+string(apsilen)+"F/m") //
    initializing value of relative permitivity
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
     of kbT at 300K
A = 10^-7
disp("A= "+string(A)+"m^2")//initializing value of
    diode area
ni = sqrt(2.25*10^20)
disp("ni = "+string(ni)+"cm^-3") //initializing
    value of  electron density of ionisation electron
     for silicon
Neff = 2/(A^2*e*apsilen*dIcv)
disp("The thickness of n region is ,Neff = 2/(A^2*e*
    apsilen*dIcv) = "+string(Neff)+" m^-3")//
```

```
    calculation
25 Neff = Neff/10^6
26 disp("The thickness of n region is ,Neff ="+string(
    Neff)+" cm^-3")//calculation
27 NaNd = exp(Vbi/kbT)*ni^2
28 disp("NaNd = exp(Vbi/kbT)*ni^2 = "+string(NaNd)+" cm
    ^-6")//calculation
29 // solving for Na and Nd by creating a quadratic
    equation using the equations mentioned in the
    book
30 p1 = poly([Neff*NaNd, -NaNd, Neff], 'X', 'c')
31 //Neff*NaNd - NaNd*X + Neff*X^2
32 disp (p1)
33 R= roots(p1)
34 Na= R(1)
35 Nd= R(2)
36 format ('e',10)
37 disp("Na = "+string(Na)+"cm^-3")
38 disp("Nd = "+string(Nd)+"cm^-3")
39 W = (apsilen*A)/C
40 disp("The thickness of n region is ,W = (apsilen*A)/
    C = "+string(W)+" m")//calculation
```

Scilab code Exa 5.14 admittance of diode

```
1 clc
2 e = 1.6*10^-19
3 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
4 I= 1*10^-3
5 disp("I= "+string(I)+"A") //initializing value of
    forward current
6 kbT = 0.026
7 disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
```

```
8  Tp = 10^-6
9  disp("Tp= "+string(Tp)+"s")//inializing value of
       minority carrier lifetime
10 Gs = (I)/(kbT)
11 disp("The diode conductance is Gs = (e*I)/(kbT)= "+
       string(Gs)+"A/V")//calculation
12 Cdiff = (I*Tp)/(2*kbT)
13 disp("The diffusion capacitance is Cdiff = (e*I*Tp)
       /(2*kbT)= "+string(Cdiff)+" F")//calculation
14 // The diffusion capacitance is much larger than
       junction capacitance hence neglecting junction
       capacitance
15 Y = Gs+(%i*2*%pi*10^6*Cdiff)
16 disp("The admittance of the diode is Y = Gs+%i(2*%pi
       *10^6*Cdiff)= "+string(Y)+" A/V")//calculation
17 // Note : due to different precisions taken by me
       and the author ... my answer differ
```

Scilab code Exa 5.15 Total diode recovery time

```
1  clc
2  Vr= 10
3  disp("Vr= "+string(Vr)+"V") //initializing value of
       reverse bias
4  R= 10*10^3
5  disp("R= "+string(R)+"ohm") //initializing value of
       resistance
6  //The junction capacitance is 20pF at zero bias and
       10 pF at full reverse bias so
7  Cavg= ((20+10)/2)
8  disp("Cavg= "+string(Cavg)+"pF") //initializing
       value of average capacitance during switching
9  Tp = 10^-7
10 disp("Tp= "+string(Tp)+"s")//inializing value of
       minority carrier lifetime
```

```
Ir = (Vr)/(R)
disp("The instant reverse current is Ir = (Vr)/(R)= "+string(Ir)+" A")//calculation
Tsd = Tp*log(2)
disp("The storage delay time is Tsd = Tp*log(2)= "+string(Tsd)+" s")//calculation
Tt = 2.3*R*Cavg*10^-12
disp("The time Tt = 2.3*R*Cavg*10^-12= "+string(Tt)+" s")//calculation
T = Tsd+Tt
disp("The total diode recovery time is T = Tsd+Tt = "+string(T)+" s")//calculation
// Note : due to different precisions taken by me and the author ... my answer differ
```

Chapter 6

semiconductor junctions with Metals and insulators

Scilab code Exa 6.1 Mobility of electrons in alluminium

```
clc
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
n = 10^22
disp("n = "+string(n)+"cm^-3") //initializing value
    of electron density in current flow
rho = 2.7*10^(-6)
disp("rho = "+string(rho)+" ohm-cm") //initializing
    value of resistiviy of aluminium at room
    temperature
disp("using following terms   J = Current density ;
    s(sigma) = 1/rho = conductivity ; F = Electric
    field ")
disp("Using relations  J = s*F = n*e*v = n*e*u*F ;
    we get")
mu_ = 1/(n*e*rho)
disp("The mobility of electrons in aluminium is ,mu_
    = 1/(n*e*r) = "+string(mu_)+" cm^2(Vs)^-1")//
```

```
    calculation
12 //The answer given in the book is 240.4 cm^2/Vs
    which is wrong
```

Scilab code Exa 6.2 doping density

```
1  clc
2  e = 1.6*10^-19
3  disp("e= "+string(e)+"C")//initializing value of
    charge of electron
4  apsilen = 11.9*8.85*10^-12
5  disp("apsilen = "+string(apsilen)+"F/m") //
    initializing value of relative permitivity
6  A= 7.85*10^-9
7  disp("A= "+string(A)+"m^2") //initializing value of
    area
8  S= 3*10^24
9  disp("d(1/c2)/dV = S= "+string(S)+"F^-2V^-1") //
    initializing value of area of slope of the (1/c2)
     vs V relation
10 Nd = (2/(S*e*apsilen*(A^2)))
11 disp("The doping density in silicon is ,Nd = (2/(S*e
    *Es*(A^2)))= "+string(Nd)+"m^-3")//calculation
```

Scilab code Exa 6.3 diode current

```
1  clc
2  Nd = 10^16
3  disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of diode doping
4  Nc = 2.8*10^19
5  disp("Nc = "+string(Nd)+"cm^-3") //initializing
    value of channel doping
```

```
kBT=0.026
disp("kBT = "+string(kBT)+"eV") //initializing value of multiplication of boltzmann constant and 300K temperature
Vf=0.3
disp("Vf = "+string(Vf)+"V") //initializing value of forward bias
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
A= 10^-3
disp("A= "+string(A)+"cm^2") //initializing value of area
disp("          for W-n type Si schottky barrier          ")
T = 300
disp("T= "+string(T)+"K")//initializing value of temperature
phi_b = 0.67
disp("schottky barrier heights(in volts) = phi_b= "+string(phi_b)+"eV")//initializing value of schottky barrier heights(in volts)
R = 110
disp("R* = "+string(R)+"Acm^-2K^-1") //initializing value of effective richardson constant
Is = A*R*(T^2)*(exp(-(phi_b)/(kBT)))
disp("The reverse saturation current is ,Is = A*R*(T^2)*(exp(-(phi_b/kbT))) = "+string(Is)+"A")//calculation
disp("using relation I= Is*(exp((e*V)/(nkBT))-1) and neglecting 1")
I = Is*(exp((Vf)/(kBT)))
disp("The diode current is ,I = Is*(exp((Vf)/(kBT))) = "+string(I)+"A")//calculation
disp("          for Si p+ -n junction diode          ")
Na = 10^19
disp("Na = "+string(Na)+"cm^-3") //initializing
```

```
    value of p+ doping
29 Db = 10.5
30 disp("Db= "+string(Db)+"cm^2/s")//initializing value
    of diffusion coefficient in the base
31 Tb = 10^-6
32 disp("Tb= "+string(Tb)+"s")//inializing value of
    electron lifetime
33 Lb = sqrt(Db*Tb)
34 disp("The electron carrier diffusion length is,Lb =
    sqrt(Db*Tb)= "+string(Lb)+"cm")//calculatio
35 pn = 2.2*10^4
36 disp("pn = "+string(pn)+"cm^-3") //initializing
    value of hole electron density
37 Io = A*e*pn*(Db/Lb)
38 disp("The saturation current current is Io = A*e*pn
    *(Db/Lb) = "+string(Io)+"A")//calculation
39 I1 = Io*(exp((Vf)/(kBT)))
40 disp("The diode current for HBT is ,I = I0*(exp((Vf)
    /(kBT))) = "+string(I1)+"A")//calculation
41 disp("Since diode current for HBT is almost 6 orders
    of magnitude smaller than the value in the
    Schottky diode ")
42 disp("hence for the p-n diode to have the same
    current that the schottky dode has at .3 V , the
    voltage required is .71V")
```

Scilab code Exa 6.4 saturation current density

```
1 clc
2 kBT=0.026
3 disp("kBT = "+string(kBT)+"eV") //initializing value
    of multiplication of boltzmann constant and 300K
    temperature
4 mo = 9.1*10^-31
5 disp("mo = "+string(mo)+"kg") //initializing value
```

```
    of mass of electron
m=0.08*mo
disp("m = "+string(m)+"kg") //initializing value of
    mass of electron in InAlAs
T = 300
disp("T= "+string(T)+"K")//initializing value of
    temperature
phi_b1 = 0.7
disp("schottky barrier heights(in volts) = phi_b1= "
    +string(phi_b1)+"eV")//initializing value of
    schottky barrier heights(in volts)
phi_b2 = 0.6
disp("schottky barrier heights(in volts) = phi_b2= "
    +string(phi_b2)+"eV")//initializing value of
    schottky barrier heights(in volts)
R = 120*(m/mo)
disp("The effective richardson constant is ,R* =
    120*(m/mo) = "+string(R)+" A cm^-2 k^-2")//
    calculation
Js1 = R*(T^2)*(exp(-(phi_b1)/(kBT)))
disp("The saturation current density is ,Js(phi_b
    =0.7) = R*(T^2)*(exp(-(phi_b)/(kBT))) = "+string(
    Js1)+"A/cm^2")//calculation
Js2 = R*(T^2)*(exp(-(phi_b2)/(kBT)))
disp("The saturation current density is ,Js(phi_b
    =0.6) = R*(T^2)*(exp(-(phi_b)/(kBT))) = "+string(
    Js2)+"A/cm^2")//calculation
```

Scilab code Exa 6.5 capacitance

```
clc
apsilen = 11.9*8.85*10^-12
disp("apsilen = "+string(apsilen)+"F/m") //
    initializing value of relative permitivity
Nd = 10^16
```

```
disp("Nd = "+string(Nd)+"cm^-3") //initializing value of diode doping
Nc = 2.8*10^19
disp("Nc = "+string(Nd)+"cm^-3") //initializing value of channel doping
kBT = 0.026
disp("kBT = "+string(kBT)+"eV") //initializing value of multiplication of boltzmann constant and 300K temperature
I=10*10^-3
disp("I = "+string(I)+"A") //initializing value of forward bias current
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
A= 10^-3
disp("A= "+string(A)+"cm^2") //initializing value of area
disp("          for W-n type Si schottky barrier ")
T = 300
disp("T= "+string(T)+"K")//initializing value of temperature
phi_b = 0.67
disp("schottky barrier heights(in volts) =phi_b= "+string(phi_b)+"eV")//initializing value of schottky barrier heights(in volts)
R = 110
disp("R* = "+string(R)+"Acm^-2K^-1") //initializing value of effective richardson constant
Is = A*R*(T^2)*(exp(-(phi_b)/(kBT)))
disp("The reverse saturation current is ,Is = A*R*(T^2)*(exp(-(Qb/kbT))) = "+string(Is)+"A")//calculation
V = kBT*(log(I/Is))
disp("The applied bias for schottky diode corresponding to 10mA forward current is ,V = kBT*(log(I/Is))= "+string(V)+"V")//calculation
```

```
27 E = kBT*log(Nc/Nd)
28 disp("The fermi level positionin the neutral
      semiconductor(Efs) with respect to the conduction
       band is ,Ec-Efs= E = kBT*log(Nc/Nd)= "+string(E)+
      " eV")//calculation
29 Vbi= phi_b-(E)
30 disp("The built in voltage is ,Vbi= phi_b-((1/e)*E)=
       "+string(Vbi)+"V")//calculation
31 Cd = A*sqrt((e*Nd*apsilen)/(2*(Vbi-V)))
32 disp("The diode capacitance is ,Cd = A*sqrt((e*Nd*
      apsilen)/(2*(Vbi-V))) = "+string(Cd)+"F")//
      calculation
33 R = kBT/I
34 disp("The resistance is ,R = kBT/I = "+string(R)+"
      ohm")//calculation
35 RC = R*Cd
36 disp("The RC time constant is ,RC(schottky) = R*Cd =
       "+string(RC)+"s")//calculation
37 disp("          for Si p+ -n junction diode          "
      )
38 Tb = 10^-6
39 disp("Tb= "+string(Tb)+"s")//inializing value of
      electron lifetime
40 disp("In the p-n diode the junction capacitance and
      the small signal resistance will be same as those
       in the schottky diode")
41 Cdiff = ((I*Tb)/(kBT))
42 disp("The diffusion capacitance is ,Cdiff = (I*Tb)/(
      kBT) = "+string(Cdiff)+"F")//calculation
43 RC1 = R*Cdiff
44 disp("The RC time constant is ,RC(p-n) = R*Cdiff = "
      +string(RC1)+"s")//calculation
45 disp("From the above RC time constant value it can
      be concluded that p-n diode is almost 1000 times
      slower")
46 // Note: due to approximation, the value of diode
      capicitance and diffusion capacitance are differ
      from that of the textbook
```

Scilab code Exa 6.6 Tunneling probability

```
clc
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)+"F/m") //
   initializing value of relative permitivity
phi_b = 0.66
disp("schottky barrier heights(in volts) = phi_b= "+
   string(phi_b)+"eV")//initializing value of
   schottky barrier heights(in volts)
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value
   of mass of electron
m=0.34*mo
disp("m* = "+string(m)+"kg") //initializing value of
    density of state mass
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
h = 1.05*10^-34
disp("h= "+string(h)+"C")//initializing value of
   h_cut
n1 = 10^18
disp("n= "+string(n1)+"cm^-3") //initializing value
   of silicon doping
n2 = 10^20
disp("n= "+string(n2)+"cm^-3") //initializing value
   of silicon doping
disp("Assume that the built in potential Vbi is same
    as barrier potential becouse of highly doped
   semiconductor")
W1 = (sqrt((2*apsilen*phi_b)/(e*n1)))/10^-8
disp("The depletion width is ,W(n=10^18) = sqrt((2*
   apsilen*Vbi)/(e*n)) = "+string(W1)+" Angstrom")//
```

```
    calculation
W2 = (sqrt((2*apsilen*phi_b)/(e*n2)))/10^-8
disp("The depletion width is ,W(n=10^20) = sqrt((2*
    apsilen*Vbi)/(e*n)) = "+string(W2)+" Angstrom")//
    calculation
F1 = phi_b/(W1*10^-8)
disp("The average field in depletion region for(n
    =10^18), F1 = phi_b/(W1/10^-8)=   "+string(F1)+"V
    /cm")
F2 = phi_b/(W2*10^-8)
disp("The average field in depletion region for(n
    =10^18), F2 = phi_b/(W2/10^-8)=   "+string(F2)+"V
    /cm")
F1 = F1/10^-2
F2 = F2/10^-2
T = exp(-(4*(2*m)^.5*(e*phi_b)^(3/2))/(3*e*F1*h))
disp("The tunneling current for(n=10^18),T = exp
    (-(4*(2*m)^.5*(e*phi_b)^(3/2))/(3*e*F1*h))="+
    string(T)+"V/cm")
T1 = exp(-(4*(2*m)^.5*(e*phi_b)^(3/2))/(3*e*F2*h))
disp("The tunneling current for(n=10^20), T1 = exp
    (-(4*(2*m)^.5*(e*phi_b)^(3/2))/(3*e*F2*h))="+
    string(T1)+"V/cm")

// in the textbook author has used approximate value
    for depletion width and hence it affect the
    value of all other answer
// NOTE: In the textbook author has used approximate
    answer for tunneling current
```

Scilab code Exa 6.7 length of resistor

```
clc
n = 10^18
disp("n= "+string(n)+"cm^-3") //initializing value
```

```
    of doping
4 W = 25*10^-4
5 disp("W= "+string(W)+"cm") //initializing value of
    width of the resistor
6 R = 100*10^3
7 disp("R = "+string(R)+"ohm") //initializing value of
     resistance
8 e = 1.6*10^-19
9 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
10 D= 5000*10^-8
11 disp("D= "+string(D)+"cm") //initializing value of
    thickness of film
12 mu_=100
13 disp("mu_= "+string(mu_)+"cm^2(Vs)^-1") //
    initializing value of mobility
14 Ro = 1/(n*e*mu_*D)
15 disp("The sheet resistance of the film is ,Ro = 1/(n
    *e*mu_*D) = "+string(Ro)+" ohm/square")//
    calculation
16 L = (R*W)/Ro
17 disp("The length of the desired resistor is ,L = (R*
   W)/Ro = "+string(L)+" cm")//calculation
```

Chapter 7

Bipolar junction transistor

Scilab code Exa 7.2 saturation voltage

```
clc
alpha_F=.99
disp("alpha_F = "+string(alpha_F)) //initializing
   value of forward bias current transfer ratio
alpha_R=.25
disp("alpha_R = "+string(alpha_R)) //initializing
   value of Reverse bias current transfer ratio
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
// for part a
Ic1 = 1
disp("Ic1= "+string(Ic1)+"mA")//initializing value
   of collector current
Ib1 = .02
disp("Ib1= "+string(Ib1)+"mA")//initializing value
   of base current
VCE= kbT*log((((Ic1*(1-alpha_R))+Ib1)*alpha_F)/(((
   alpha_F*Ib1)-((Ic1*(1-alpha_F))))*alpha_R))
disp("The saturation voltage is ,VCE= kbT*log((((Ic1
   *(1-alpha_R))+Ib1)*alpha_F)/(((alpha_F*Ib1)-((Ic1
```

```
    *(1-alpha_F))))*alpha_R))= "+string(VCE)+" V")//
    calculation
15  //for part b
16 Ic2 = 5
17 disp("Ic2 = "+string(Ic2)+"mA")//initializing value
    of collector current
18 Ib2 = .075
19 disp("Ib2 = "+string(Ib2)+"A")//initializing value
    of base current
20 VCE1= kbT*log((((Ic2*(1-alpha_R))+Ib2)*alpha_F)/(((
    alpha_F*Ib2)-((Ic2*(1-alpha_F))))*alpha_R))
21 disp("The saturation voltage is ,VCE1= kbT*log((((
    Ic2*(1-alpha_R))+Ib2)*alpha_F)/(((alpha_F*Ib2)-((
    Ic2*(1-alpha_F))))*alpha_R))= "+string(VCE1)+" V"
    )//calculation
```

Scilab code Exa 7.3 emitter doping

```
1 clc
2 nbo = 2.25*10^3
3 disp("nbo= "+string(nbo)+"cm^-3")//inializing value
    of majority carrier densities for the base in npn
     transistor
4 peo = 112.5
5 disp("peo= "+string(peo)+"cm^-3")//inializing value
    of majority carrier densities for the emitter in
    npn transistor
6 pco = 2.25*10^4
7 disp("pco= "+string(pco)+"cm^-3")//inializing value
    of majority carrier densities for the collector
    in npn transistor
8 // using law of mass action for a homogeneous
    semiconductor, we have relation peo*neo=nbo*pbo=
    ni^2
9 ni_power_2 = nbo/peo
```

```
10 disp("square of electron density of ionisation
     electron for npn silicon transistor is ni^2 = nbo
     /peo="+string(ni_power_2)+"cm^-3") //calculation
11 pbo = 10^16
12 disp("pbo= "+string(pbo)+"cm^-3")//initializing
     value of p type base doping
13 V = (1-((peo)/(10*nbo)))
14 disp("The emitter efficiency (gamma)is ,V = (1-((peo)
     /(10*nbo)))= "+string(V))//calculation
15 neo = ni_power_2*pbo
16 disp("The required emitter doping is ,neo =
     ni_power_2*pbo = "+string(neo)+"cm^-3")//
     calculation
```

Scilab code Exa 7.4 electron diffusion length and base width

```
1  clc
2  B= 0.997
3  disp("B= "+string(B)) //initializing value of base
     transport factor
4  Db = 10
5  disp("Db= "+string(Db)+"cm^2/s")//initializing value
      of diffusion coefficient in the base
6  Tb = 10^-6
7  disp("Tb= "+string(Tb)+"s")//inializing value of
     electron lifetime
8  Lb = sqrt(Db*Tb)
9  disp("The electron carrier diffusion length is ,Lb =
     sqrt(Db*Tb)= "+string(Lb)+"cm")//calculation
10 // assume the neutral basewidth Wbn is equal to
     actual basewidth Wb
11 Wbn = sqrt((1-B)*(2*(Lb^2)))
12 disp("The base width is ,Wb = sqrt((1-B)*(2*(Lb^2)))=
      "+string(Wbn)+"cm")//calculation
13 // Note : due to different precisions taken by me
```

```
and the author ... my answer differ
```

Scilab code Exa 7.5 current gain and transconductance

```
clc
// using values from the result of Example 7.1
VEB = 0.6
disp("VEB= "+string(VEB)+"V")//initializing value of
    Emitter-base bias voltage
Ic = .2268*10^-3
disp("Ic= "+string(Ic)+"A")//initializing value of
   collector current
Ib = 4.92*10^-6
disp("Ib= "+string(Ib)+"A")//initializing value of
   base current at the biasing
kbT = 0.026
disp("kbT = "+string(kbT)+"eV/K") //initializing
   value of kbT at 300K
Beta = Ic/Ib
disp("The current gain Beta = Ic/Ib= "+string(Beta))
   //calculation
gm = Ic/kbT
disp("The transconductance is ,gm = Ic/kbT = "+string
   (gm)+"S")//calculation
```

Scilab code Exa 7.6 current gain

```
clc
De = 20
disp("De= "+string(De)+"cm^2/s")//initializing value
    of diffusion coefficient
Db=De
Nde = 5*10^17
```

```
disp("Nde= "+string(Nde)+"cm^-3")//inializing value
   of emitter doping
Nab = 10^17
disp("Nab= "+string(Nab)+"cm^-3")//inializing value
   of base doping
Wb = 10^-4
disp("Wb= "+string(Wb)+"cm")//initializing value of
   base width
ni = 1.5*10^10
disp("ni = "+string(ni)+"cm^-3") //initializing
   value of  electron density of ionisation electron
    for silicon
// for case (a) value of Te=10^-6s
Te1 = 10^-6
disp("Te= "+string(Te1)+"s")//inializing value of
   minority carrier lifetime for the electrons and
   holes
Le1 = sqrt(De*Te1)
disp("The  diffusion length is,Le1 = sqrt(De*Te)= "+
   string(Le1)+"cm")//calculation
Lb1=Le1
disp("The  diffusion length is,Lb1= "+string(Lb1)+"
   cm")//calculation
peo1 = (ni)^2/Nde
disp("The  majority carrier densities for the
   emitter in npn transistor is,peo = (ni)^2/Nde= "+
   string(peo1)+"cm^-3")//calculation
nbo1 = (ni)^2/Nab
disp("The  majority carrier densities for the base
   in npn transistor is,nbo = (ni)^2/Nab= "+string(
   nbo1)+"cm^-3")//calculation
alpha_1 = (1-((peo1*De*Wb)/(nbo1*Db*Le1)))*(1-((Wb
   ^2)/(2*Le1^2)))
disp("The  current gain is,alpha_ = (1-((peo*De*Wb)
   /(nbo*Db*Le1)))*(1-((Wb^2)/(2*Le^2)))= "+string(
   alpha_1))//calculation
Beta1 = (alpha_1)/(1-alpha_1)
disp("The current gain Beta1 = (alpha_1)/(1-alpha_1)
```

```
    = "+string(Beta1))//calculation
28
29 //for case (b) value of Te=10^-8s
30 Te2 = 10^-8
31 disp("Te= "+string(Te2)+"s")//inializing value of
    minority carrier lifetime for the electrons and
    holes
32 Le2 = sqrt(De*Te2)
33 disp("The diffusion length is,Le = sqrt(De*Te)= "+
    string(Le2)+"cm")//calculation
34 peo2 = (ni)^2/Nde
35 disp("The majority carrier densities for the
    emitter in npn transistor is,peo = (ni)^2/Nde= "+
    string(peo2)+"cm^-3")//calculation
36 nbo2 = (ni)^2/Nab
37 disp("The majority carrier densities for the base
    in npn transistor is,nbo = (ni)^2/Nab= "+string(
    nbo2)+"cm^-3")//calculation
38 alpha_2 = (1-((peo2*De*Wb)/(nbo2*Db*Le2)))*(1-((Wb
    ^2)/(2*Le2^2)))
39 disp("The current gain alpha_ = (1-((peo*De*Wb)/(
    nbo*Db*Le2)))*(1-((Wb^2)/(2*Le^2)))= "+string(
    alpha_2))//calculation
40 Beta2 = (alpha_2)/(1-alpha_2)
41 disp("The current gain Beta2 = (alpha_2)/(1-alpha_2)
    = "+string(Beta2))//calculation
```

Scilab code Exa 7.7 emitter efficiency

```
1 clc
2 nbo = 2.25*10^3
3 disp("nbo= "+string(nbo)+"cm^-3")//inializing value
    of majority carrier densities for the base in npn
    transistor
4 peo = 112.5
```

```
5  disp("peo= "+string(peo)+"cm^-3")//inializing value
     of majority carrier densities for the emitter in
     npn transistor
6  Db = 30
7  disp("Db= "+string(Db)+"cm^2/s")//initializing value
     of diffusion coefficient in the base
8  De = 10
9  disp("De= "+string(De)+"cm^2/s")//initializing value
     of diffusion coefficient in the emitter
10 Nde = 10^18
11 disp("Nde= "+string(Nde)+"cm^-3")//inializing value
     of emitter doping
12 Nab = 10^16
13 disp("Nab= "+string(Nab)+"cm^-3")//inializing value
     of base doping
14 Lb = 10*10^-4
15 disp("Lb= "+string(Lb)+"cm")//inializing value of
     minority carrier diffusion length
16 Le = 4*10^-4
17 disp("Le= "+string(Le)+"cm")//inializing value of
     emitter diffusion length
18 kbT = 0.026
19 disp("kbT = "+string(kbT)+"eV/K") //initializing
     value of kbT at 300K
20 Wb = 0.5*10^-4
21 disp("Wb= "+string(Wb)+"cm")//initializing value of
     base width
22 We1 = 10*10^-4
23 disp("We= "+string(We1)+"cm")//initializing value of
     emitter width
24 We2 = 10^-4
25 disp("We2= "+string(We2)+"cm")//initializing value
     of emitter width
26 e = 1.6*10^-19
27 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
28 disp("for emitter thickness = 10*10^-4 cm")
29 gamma_1 = (((Db*nbo*coth(Wb/Lb))/(Lb))/(((Db*nbo*
```

```
    coth(Wb/Lb))/Lb)+((De*peo*coth(We1/Le))/Le)))
30 disp("The emitter efficiency gamma_1 = (((Db*nbo*Lb*
    coth(Wb/Lb))/(Lb))/(((Db*nbo*coth(Wb/Lb))/Lb)+((
    De*peo*coth(We/Le))/Le)))= "+string(gamma_1))//
    calculation
31 disp("for emitter thickness = 10^-4 cm")
32 gamma_2 = (((Db*nbo*coth(Wb/Lb))/(Lb))/(((Db*nbo*
    coth(Wb/Lb))/Lb)+((De*peo*coth(We2/Le))/Le)))
33 disp("The emitter efficiency (gamma)is ,gamma_2 = (((
    Db*nbo*Lb*coth(Wb/Lb))/(Lb))/(((Db*nbo*coth(Wb/Lb
    ))/Lb)+((De*peo*coth(We/Le))/Le)))= "+string(
    gamma_2))//calculation
34 //NOTE: In the textbook author has used approximate
    value for the calculation of gamma thus the above
     solution is differ from that of the gamma
```

Scilab code Exa 7.8 early voltage

```
1 clc
2 Ndc = 5*10^15
3 disp("Ndc= "+string(Ndc)+"cm^-3")//inializing value
    of collector doping
4 Nab = 5*10^16
5 disp("Nab= "+string(Nab)+"cm^-3")//inializing value
    of base doping
6 ni = sqrt(2.25*10^20)
7 disp("ni = "+string(ni)+"cm^-3") //initializing
    value of electron density of ionisation electron
     for silicon
8 kbT = 0.026
9 disp("kbT = "+string(kbT)+"eV/K") //initializing
    value of thermal voltage at 300K
10 e = 1.6*10^-19
11 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
```

```
12 Vbi= (kbT)*((log((Nab*Ndc)/(ni^2))))
13 disp("The built in voltage is ,Vbi= (kbT)*((log((Na*
     Nd)/Ni^2)))= "+string(Vbi)+"V")//calculation
14 disp("                for an applied bias of 1 V
                    ")
15 VCB1 = 1
16 disp("VCB = "+string(VCB1)+" V")//initializing value
     of Collector-base bias voltage
17 apsilent_s = 11.9*8.85*10^-14
18 disp("apsilent_s = "+string(apsilent_s)+"F/cm") //
     initializing value of relative permitivity
19 Wb = 10^-4
20 disp("Wb= "+string(Wb)+"cm")//initializing value of
     base width
21 dWb1 = sqrt((2*apsilent_s*(Vbi+VCB1)*Ndc)/(e*Nab*(
     Nab+Ndc)))
22 disp("The extent of depletion into the base side is,
     dWb = sqrt((2*apsilent_s*(Vbi+Vcb1)*Ndc)/(e*Nab*(
     Nab+Ndc))) = "+string(dWb1)+"cm")//calculation
23 Wbn1 = Wb-dWb1
24 disp("The neutral base width is,Wbn = Wb-dWb1= "+
     string(Wbn1)+"cm")//calculation
25 nbo = ((ni)^2)/Nab
26 disp("The required base doping is,nbo = (ni^2)/Nab =
     "+string(nbo)+"cm^-3")//calculation
27 Db = 20
28 disp("Db= "+string(Db)+"cm^2/s")//initializing value
     of diffusion coefficient in the base
29 VBE = 0.7
30 disp("VBE= "+string(VBE)+"V")//initializing value of
     base-Emitter bias voltage
31 Jc1 = ((e*Db*nbo)/Wbn1)*(exp(VBE/kbT))
32 disp("The collector current density is,Jc = ((e*Db*
     nbo)/Wbn)*(exp((e*VBE)/kbT))= "+string(Jc1)+"A/cm
     ^2")//calculation
33 disp("                for an applied bias of 5 V
                  ")
34 VCB2 = 5
```

```
35 disp("VCB = "+string(VCB2)+" V")//initializing value
     of Collector-base bias voltage
36 VCE1= VCB1+VBE
37 disp("The collector emitter voltage is ,VCE= VCB+VBE
   = "+string(VCE1)+" V")//calculation
38 VCE2= VCB2+VBE
39 disp("The collector emitter voltage is ,VCE= VCB+VBE
   = "+string(VCE2)+" V")//calculation
40 dWb2 = sqrt((2*apsilent_s*(Vbi+VCB2)*Ndc)/(e*Nab*(
   Nab+Ndc)))
41 disp("The extent of depletion into the base side is,
   dWb = sqrt((2*apsilent_s*(Vbi+Vcb1)*Ndc)/(e*Nab*(
   Nab+Ndc))) = "+string(dWb2)+"cm")//calculation
42 Wbn2 = Wb-dWb2
43 disp("The neutral base width is ,Wbn = Wb-dWb1= "+
   string(Wbn2)+"cm")//calculation
44 Jc2 = ((e*Db*nbo)/Wbn2)*(exp(VBE/kbT))
45 disp("The collector current density is ,Jc = ((e*Db*
   nbo)/Wbn)*(exp((e*VBE)/kbT))= "+string(Jc2)+" A/
   cm^2")//calculation
46 VA = (Jc1/((Jc2-Jc1)/(VCE2-VCE1)))-(VCE1)
47 disp("The Early voltage is ,VA = (Jc1/((Jc2-Jc1)/(
   VCE2-VCE1)))-(VCE1)= "+string(VA)+"V")//
   calculation
48 // Note : due to different precisions taken by me
   and the author ... my answer differ by "0.2"
   value.
```

Scilab code Exa 7.9 punchthrough voltage

```
1 clc
2 Ndc = 10^16
3 disp("Ndc= "+string(Ndc)+"cm^-3")//inializing value
   of collector doping
4 Nab = 5*10^16
```

```
5  disp("Nab= "+string(Nab)+"cm^-3")//inializing value
       of base doping
6  e = 1.6*10^-19
7  disp("e= "+string(e)+"C")//initializing value of
       charge of electron
8  apsilen = 11.9*8.85*10^-14
9  disp("apsilen = "+string(apsilen)+"F/cm") //
       initializing value of relative permitivity
10 Wb = .2*10^-4
11 disp("Wb= "+string(Wb)+"cm")//initializing value of
       base width
12 Vpt= ((e*(Wb^2)*Nab*(Ndc+Nab))/(2*apsilen*Ndc))
13 disp("The punchthrough voltage is ,Vpt= (e*(Wb^2)*
       Nab*(Ndc+Nab))/(2*apsilen*Ndc)= "+string(Vpt)+"V"
       )//calculation
14 Twb = 1.2*10^-4
15 disp("Twb= "+string(Twb)+"cm")//initializing value
       of total depletion width
16 F = Vpt/Twb
17 disp("The average field at punchthrough voltage is ,
       F = Vpt/Twb= "+string(F)+"V/cm")//calculation
18
19 // Note : due to different precisions taken by me
       and the author ... my answer differ by "0.16"
       value.
```

Scilab code Exa 7.10 base width

```
1  clc
2  apsilent_s = 11.9*8.85*10^-14
3  disp("apsilent_s = "+string(apsilent_s)+"F/cm") //
       initializing value of relative permitivity
4  Ndc = 5*10^16
5  disp("Ndc= "+string(Ndc)+"cm^-3")//inializing value
       of collector doping
```

```
Nde = 10^18
disp("Nde= "+string(Nde)+"cm^-3")//inializing value
   of emitter doping
Nab = 10^17
disp("Nab= "+string(Nab)+"cm^-3")//inializing value
   of base doping
ni = sqrt(2.25*10^20)
disp("ni = "+string(ni)+"cm^-3") //initializing
   value of  electron density of ionisation electron
    for silicon
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
Db = 30
disp("Db= "+string(Db)+"cm^2/s")//initializing value
    of diffusion coefficient in the base
De = 10
disp("De= "+string(De)+"cm^2/s")//initializing value
    of diffusion coefficient
Lb = 15*10^-4
disp("Lb= "+string(Lb)+"cm")//inializing value of
   minority carrier base diffusion length
Le = 5*10^-4
disp("Le= "+string(Le)+"cm")//inializing value of
   minority carrier emitter diffusion length
Beta= 100
disp("Beta= "+string(Beta)) //initializing value of
   current gain (Beta)
nbo = 2.25*10^3
disp("nbo= "+string(nbo)+"cm^-3")//inializing value
   of majority carrier densities for the base in npn
    transistor
peo = 112.5
disp("peo= "+string(peo)+"cm^-3")//inializing value
   of majority carrier densities for the emitter in
```

```
    npn transistor
30 VCB1 = 5
31 disp("VCB = "+string(VCB1)+" V")//initializing value
     of Collector-base bias voltage
32 //"using relation   B = (IC/IB) = ((Db*nbo*Le)/(De*
    peo*Wbn))"
33 Wbn = ((Db*nbo*Le)/(De*peo*100))
34 disp("neutral base width is ,Wbn = ((Db*nbo*Le)/(De*
    peo*100))= "+string(Wbn)+"cm")//calculation
35 Vbi= (kbT)*((log((Nab*Ndc)/(ni^2))))
36 disp("The built in voltage is ,Vbi= (kbT)*((log((Na*
    Nd)/Ni^2)))= "+string(Vbi)+"V")//calculation
37 dWb1 = sqrt((2*apsilent_s*(Vbi+VCB1)*Ndc)/(e*Nab*(
    Nab+Ndc)))
38 disp("The extent of depletion into the base side is,
    dWb = sqrt((2*apsilent_s*(Vbi+Vcb1)*Ndc)/(e*Nab*(
    Nab+Ndc))) = "+string(dWb1)+"cm")//calculation
39 Wb = Wbn+dWb1
40 disp("The  base width is ,Wb = Wbn+dWb1= "+string(Wb)
    +"cm")//calculation
41 // NOTE: the value calculated for Wbn is wrong in
    the book and all the succesive answer also
    depeandant on that are also wrong
42 //("Two disadvange are")
43 //("The output conductance will suffer and the
    collector current will have a stronger dependence
     on VCB")
44 //("The device may suffer punchthrough at a lower
    bias")
45 //("Two advantages")
46 //("The current gain will be higher")
47 //("The device speed will be faster")
```

Scilab code Exa 7.11 Output conductance

```
clc
Ndc = 10^16
disp("Ndc= "+string(Ndc)+"cm^-3")//inializing value of collector doping
Nab = 10^17
disp("Nab= "+string(Nab)+"cm^-3")//inializing value of base doping
Nde = 10^18
disp("Nde= "+string(Nde)+"cm^-3")//inializing value of emitter doping
ni = 1.5*10^10
disp("ni = "+string(ni)+"cm^-3") //initializing value of square of electron density of ionisation electron for silicon
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value of kbT at 300K
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
Db = 30
disp("Db= "+string(Db)+"cm^2/s")//initializing value of diffusion coefficient in the base
De = 10
disp("De= "+string(De)+"cm^2/s")//initializing value of diffusion coefficient
Lb = 10*10^-4
disp("Lb= "+string(Lb)+"cm")//inializing value of minority carrier base diffusion length
Le = 10*10^-4
disp("Le= "+string(Le)+"cm")//inializing value of minority carrier emitter diffusion length
Wb = 10^-4
disp("Wb= "+string(Wb)+"cm")//initializing value of base width
We = 10^-4
disp("We= "+string(We)+"cm")//initializing value of emitter width
```

```
26 Vbi= (kbT)*((log((Nab*Ndc)/ni^2)))
27 disp("The built in voltage is ,Vbi= (kbT)*((log((Na*
     Nd)/Ni^2)))= "+string(Vbi)+"V")//calculation
28 disp("                for an applied reverse bias of 5
     V                  ")
29 VCB1 = 5
30 disp("VCB = "+string(VCB1)+" V")//initializing value
     of Collector-base bias voltage
31 apsilen = 11.9*8.85*10^-14
32 disp("apsilen = "+string(apsilen)+"F/cm") //
     initializing value of relative permitivity
33 nbo = 2.25*10^3
34 disp("nbo= "+string(nbo)+"cm^-3")//inializing value
     of majority carrier densities for the base in npn
     transistor
35 peo = 112.5
36 disp("peo= "+string(peo)+"cm^-3")//inializing value
     of majority carrier densities for the emitter in
     npn transistor
37 dWb1 = sqrt((2*apsilen*(Vbi+VCB1)*Ndc)/(e*Nab*(Nab+
     Ndc)))
38 disp("The extent of depletion into the base side is,
     dWb = sqrt((2*apsilen*(Vbi+Vcb)*Ndc)/(e*Nab*(Nab+
     Ndc))) = "+string(dWb1)+"cm")//calculation
39 Wbn1 = Wb-dWb1
40 disp("The neutral base width is ,Wbn = Wb-dWb1= "+
     string(Wbn1)+"cm")//calculation
41 gamma_e_1 = (1-((peo*De*Wbn1)/(Db*nbo*We)))
42 disp("The emitter efficiency gamma_e_1 = (1-((peo*De
     *Wbn)/(Db*nbo*We)))= "+string(gamma_e_1))//
     calculation
43 B1 = 1-((Wbn1^2)/(2*(Lb)^2))
44 disp("The base transport factor is ,B = 1-((Wbn^2)
     /(2*(Lb)^2)) = "+string(B1))//calculation
45 alpha1 = gamma_e_1*B1
46 disp("The  current gain alpha1 = gamma_e_1*B1= "+
     string(alpha1))//calculation
47 Beta3 = (alpha1)/(1-alpha1)
```

```
48 disp("The current gain Beta3 = (alpha1)/(1-alpha1) =
    "+string(Beta3))//calculation
49 VBE = 1
50 disp("VBE= "+string(VBE)+"V")//initializing value of
    Emitter-base bias voltage
51 A= 4*10^-6
52 disp("A= "+string(A)+"cm^2") //initializing value of
    area of silicon npn transistor device
53 disp("using collector relation IC = (((e*A*Db*nbo)/(
   Wbn))*(exp((e*VBE)/(KbT))-1))-(((e*A*Db*nbo*Wbn)
   /(2*(Lb)^2))*(exp((e*VBE)/(KbT))-1)) and
   neglecting 2nd part")
54 IC = (((e*A*Db*nbo)/(Wbn1))*(exp((VBE)/(kbT))-1))
55 disp("The collector current is,IC = (((e*A*Db*nbo)/(
   Wbn))*(exp((e*VBE)/(KbT))-1)) = "+string(IC)+"A")
   //calculation
56 //Note: in text book the author hasused precision
   value for gamma and alpha thats why there is
   difference in the value of beta.
57 disp("                for an applied reverse bias of 6
    V                 ")
58 VCB2 = 6
59 disp("VCB = "+string(VCB2)+" V")//initializing value
    of Collector-base bias voltage
60 dWb2 = sqrt((2*apsilen*(Vbi+VCB2)*Ndc)/(e*Nab*(Nab+
   Ndc)))
61 disp("The extent of depletion into the base side is,
   dWb2 = sqrt((2*apsilen*(Vbi+VCB2)*Ndc)/(e*Nab*(
   Nab+Ndc))) = "+string(dWb2)+"cm")//calculation
62 Wbn2 = Wb-dWb2
63 disp("The neutral base width is,Wbn2 = Wb-dWb2= "+
   string(Wbn2)+"cm")//calculation
64 IC2 = (((e*A*Db*nbo)/(Wbn2))*(exp((VBE)/(kbT))-1))
65 disp("The collector current is,IC = (((e*A*Db*nbo)/(
   Wbn2))*(exp((VBE)/(kbT))-1)) = "+string(IC2)+"A")
   //calculation
66 go = (IC2-IC)/(VCB2-VCB1)
67 disp("The output conductance is,go = (IC2-IC)/(VCB2-
```

```
VCB1) = "+string(go)+"ohm^-1")//calculation
```

Scilab code Exa 7.12 Cutoff frequency

```
clc
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
Wb = 0.4*10^-4
disp("Wb= "+string(Wb)+"cm")//initializing value of
   base width
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
IE = 1.5*10^-3
disp("IE= "+string(IE)+"A")//initializing value of
   Emitter current current
Db = 60
disp("Db= "+string(Db)+"cm^2/s")//initializing value
    of diffusion coefficient in the base
Wdc = 2*10^-4
disp("Wdc= "+string(Wdc)+"cm")//initializing value
   of width ofc ollector depletion region
Cje = 2*10^-12
disp("Cje= "+string(Cje)+"F")//initializing value of
    emitter base junction
rC = 30
disp("rC= "+string(rC)+"ohm")//initializing value of
    collector resistance
TcC = .4*10^-12
disp("TcC= "+string(TcC)+"F")//initializing value of
    Total collector capicitance represented in book
   as(Cu+Cs)
//NOTE: Total collector capicitance represented in
   book as(Cu+Cs)
```

```
21 vs = 10^7
22 disp("vs= "+string(vs)+"cm/s")//initializing value
   of velocity
23 disp("the emitter resistance of a forward biased
   diode is re = (dIE/dVBE) = ((kbT)/(e*IE))")
24 re = kbT/IE
25 disp("The emitter resistance is,re = kbT/IE= "+
   string(re)+"ohm")//calculation
26 Te = re*Cje
27 disp("The emitter transit time is,Te = re*Cje = "+
   string(Te)+"s")//calculation
28 Tt = (Wb^2)/(2*Db)
29 disp("The base transit time is,Tt = (Wb^2)/(2*Db)= "
   +string(Tt)+"s")//calculation
30 Td = (Wdc)/vs
31 disp("The collector transit time is,Tt = (Wdc)/vs= "
   +string(Td)+"s")//calculation
32 Tc = rC*TcC
33 disp("The collector charging time is,Tc = rC*TcC = "
   +string(Tc)+"s")//calculation
34 Tec = Te+Tt+Td+Tc
35 disp("The total time is,Tec = Te+Tt+Td+Tc = "+string
   (Tec)+"s")//calculation
36 fT = 1/(2*%pi*Tec)
37 disp("The cutoff frequency is,fT = 1/(2*%pi*Tec) = "
   +string(fT)+" Hz")//calculation
38 disp("if the emitter current is doubled the time is
   reduced by half and cutoff frequency becomes 2.54
    GHz")
39 disp("if the base width is reduced by half , the
   base transit time becomes 3.3 ps and cutoff
   frequency becomes 2.08 GHz")
```

Scilab code Exa 7.13 hole concentration

```
clc
T = 300
disp("T = "+string(T)+"K") //initializing value of
   temperature
Nd1 = 10^18
disp("Nd1= "+string(Nd1)+"cm^-3")//inializing value
   of emitter doping
Nd2 = 10^20
disp("Nd2= "+string(Nd2)+"cm^-3")//inializing value
   of emitter doping
dEg1 = (22.5*sqrt((Nd1*300)/((10^18)*T)))/10^3
disp("The bandgap narrowing is,dEg = 22.5*sqrt((Nd1
   *300)/((10^18)*T)) = "+string(dEg1)+"ev")//
   calculation
dEg2= (22.5*sqrt((Nd2*300)/((10^18)*T)))/10^3
disp("The bandgap narrowing is,dEg = 22.5*sqrt((Nd2
   *300)/((10^18)*T)) = "+string(dEg2)+"ev")//
   calculation
kbT = .026
disp("kbT = "+string(kbT)+"eV/K") //initializing
   value of kbT at 300K
neo1 = 10^18
disp("neo= "+string(neo1)+"cm^-3")//inializing value
    of majority carrier densities for the emitter
neo2 = 10^20
disp("neo= "+string(neo2)+"cm^-3")//inializing value
    of majority carrier densities for the emitter
ni = sqrt(2.25*10^20)
disp("ni = "+string(ni)+"cm^-3") //initializing
   value of  electron density of ionisation electron
    for silicon
peo1 = (ni^2*exp(dEg1/kbT))/neo1
disp("The hole density in emitter is,peo = (ni^2*exp
   (dEg1/kbT))/neo1 = "+string(peo1)+"cm^-3")//
   calculation
// note:-there is error in the unit of peo in the
   book
peo2 = (ni^2*exp(dEg2/kbT))/neo2
```

```
24 disp("The hole density in emitter is,peo2 = (ni^2*
   exp(dEg2/kbT))/neo2 = "+string(peo2)+"cm^-3")//
   calculation
25 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 7.14 emitter efficiency

```
1  clc
2  ni = 2.2*10^6
3  disp("ni = "+string(ni)+"cm^-3") //initializing
   value of electron density of ionisation electron
   for GaAs
4  Nde = 5*10^17
5  disp("Nde= "+string(Nde)+"cm^-3")//inializing value
   of emitter doping
6  Nab = 10^17
7  disp("Nab= "+string(Nab)+"cm^-3")//inializing value
   of base doping
8  kbT = 0.026
9  disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
10 Wb = 0.5*10^-4
11 disp("Wb= "+string(Wb)+"cm")//initializing value of
   base width
12 Db = 100
13 disp("Db= "+string(Db)+"cm^2/s")//initializing value
    of diffusion coefficient in the base
14 De = 15
15 disp("De= "+string(De)+"cm^2/s")//initializing value
    of diffusion coefficient in the emitter
16 Le = 1.5*10^-4
17 disp("Le= "+string(Le)+"cm")//inializing value of
   minority carrier emitter diffusion length
18 dEg = .36
```

```
19 disp("dEg= "+string(dEg)+"eV")//inializing value of
     Bandgap discontinuity
20 disp("          For GaAs            ")
21 peo1 = ni^2/Nde
22 disp("The  minority carrier densities for the
     emitter in npn GaAs BJT is ,peo(GaAs) = ni1/Nde= "
     +string(peo1)+"cm^-3")//calculation
23 nbo1 = ni^2/Nab
24 disp("The  minority carrier densities for the base
     in npn GaAs BJT is ,nbo = ni1/Nab= "+string(nbo1)+
     "cm^-3")//calculation
25 Ve1 = (1-((peo1*De*Wb)/(Db*nbo1*Le)))
26 disp("The emitter efficiency (gamma)is ,Ve = (1-((peo
     *De*Wb)/(Db*nbo1*Le))) = "+string(Ve1))//
     calculation
27 disp("          For HBT             ")
28 peo2 = (peo1)*(exp(-(dEg/kbT)))
29 disp("The  minority carrier densities for the
     emitter in HBT is ,peo(HBT) = (peo1)*(exp(-(dEg/
     kbT)))= "+string(peo2)+"cm^-3")//calculation
30 disp("in this case the emitter efficiency is
     essentially unity")
```

Chapter 8

Field effect Transistors JFET and MESFET

Scilab code Exa 8.1 Built in voltage and pinch off

```
clc
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value of intrinsic carrier concentration
Na = 10^18
disp("Na = "+string(Na)+"cm^-3") //initializing value of p+ doping
Nd = 10^17
disp("Nd = "+string(Nd)+"cm^-3") //initializing value of n channel doping
kBT=0.026
disp("kBT = "+string(kBT)+"eV") //initializing value of multiplication of boltzmann constant and 300K temperature
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
Vbi= (kBT)*((log((Na*Nd)/ni^2)))
disp("The built in voltage of a p+n diode is ,Vbi= (
```

```
    kBT)*((log((Na*Nd)/Ni^2)))= "+string(Vbi)+"V")//
    calculation
14 h=.25*10^-4
15 disp("h = "+string(h)+"cm") //initializing value of
    width of the channel
16 apsilen = 11.9*8.85*10^-14
17 disp("apsilen = "+string(apsilen)+"F/cm") //
    initializing value of relative permitivity
18 Vp= (e*(h^2)*Nd)/(2*apsilen)
19 disp("The total volage drop required to pinch the
    channel is ,Vp= (e*(h^2)*Nd)/(2*apsilen)= "+
    string(Vp)+"V")//calculation
20 VG= Vbi-Vp
21 disp("The pinch off at gate bias is ,VG= Vbi-Vp= "+
    string(VG)+"V")//calculation
22 // Note : due to different precisions taken by me
    and the author ... my answer differ
```

Scilab code Exa 8.2 gate current density

```
1 clc
2 phi_b=0.8
3 disp("phi_b = "+string(phi_b)+"V") //initializing
    value of barrierpotential
4 T=300
5 disp("T = "+string(T)+"K") //initializing value of
    temperature
6 kBT=0.026
7 disp("kBT = "+string(kBT)+"eV") //initializing value
     of multiplication of boltzmann constant and 300K
     temperature
8 R_star=8
9 disp("R_star = "+string(R_star)+"Acm^-2K^-2") //
    initializing value of effective richardson
    constant
```

```
10 Dp=20
11 disp("Dp = "+string(Dp)+"cm^2/s") //initializing
      value of diffusion coefficient
12 pn = 3.38*10^-5
13 disp("pn = "+string(pn)+"cm^-3") //initializing
      value of hole electron density
14 e = 1.6*10^-19
15 disp("e= "+string(e)+"C")//initializing value of
      charge of electron
16 Lp=1*10^-4
17 disp("Lp = "+string(Lp)+"cm") //initializing value
      of length
18 // for Schottky case Js = R_star*T^2*(exp(-(phi_b)/(
      kBT)))
19 Js = R_star*T^2*(exp(-(phi_b)/(kBT)))
20 disp("The gate current density is ,Js = R_star*T^2*(
      exp(-(phi_b)/(kBT))) = "+string(Js)+"A/cm^2")//
      calculation
21 // from p-n diode theory Jo = (e*Dp*pn)/(Lp)
22 Jo = (e*Dp*pn)/(Lp)
23 disp("The gate current density is ,Jo = (e*Dp*pn)/(
      Lp) = "+string(Jo)+"A/cm^2")//calculation
```

Scilab code Exa 8.3 Threshold voltage

```
1 clc
2 ni = 1.5*10^10
3 disp("ni= "+string(ni)+"cm^-3")//initializing value
      of intrinsic carrier concentration
4 Nc = 4.45*10^17
5 disp("Nc = "+string(Nc)+"cm^-3") //initializing
      value of effective density of of states for GaAS
6 Nd = 10^17
7 disp("Nd = "+string(Nd)+"cm^-3") //initializing
      value of n channel doping
```

```
8  kBT=0.026
9  disp("kBT = "+string(kBT)+"eV") //initializing value
       of multiplication of boltzmann constant and 300K
       temperature
10 e = 1.6*10^-19
11 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
12 h=0.25*10^-4
13 disp("h = "+string(h)+"cm") //initializing value of
     width of the channel
14 apsilen = 13.2*8.85*10^-14
15 disp("apsilen = "+string(apsilen)+"F/cm") //
     initializing value of relative permitivity
16 Vh = 0.8
17 disp("Vh = "+string(Vh)+"V") //initializing value of
       barrier height of gold schottky barrier
18 Vp= (e*(h^2)*Nd)/(2*apsilen)
19 disp("The total volage drop required to pinch the
     channel is ,Vp= (e*(h^2)*Nd)/(2*apsilen)= "+
     string(Vp)+"V")//calculation
20 Ecf= -(kBT)*(log(Nd/Nc))
21 disp("The difference between the conduction band and
       fermi level is ,Ecf= (kBT)*(log(Nd/Nc)))= "+
     string(Ecf)+"V")//calculation
22 Vbi= Vh-Ecf
23 disp("The built in potential is ,Vbi= Vh-Ecf= "+
     string(Vbi)+"V")//calculation
24 VGS= Vbi-Vp
25 disp("The pinch off at gate bias is ,VT=VGS= Vbi-Vp=
       "+string(VGS)+"V")//calculation
```

Scilab code Exa 8.4 maximum channel thickness

```
1  clc
2  Nd = 10^17
```

```
3 disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of n channel doping
4 e = 1.6*10^-19
5 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
6 apsilen = 13.1*8.85*10^-14
7 disp("apsilen = "+string(apsilen)) //initializing
    value of relative permitivity
8 Vbi = 0.76
9 disp("Vbi = "+string(Vbi)+"V") //initializing value
    of built in potential
10 h= sqrt((2*apsilen*Vbi)/(e*Nd))
11 disp("The thickness at which the value of Vp is same
     at Vbi is ,h= sqrt((2*apsilen*Vbi)/(e*Nd))= "+
    string(h)+"cm")//calculation
```

Scilab code Exa 8.5 gate bias

```
1 clc
2 Nc = 4.45*10^17
3 disp("Nc = "+string(Nc)+"cm^-3") //initializing
    value of effective density of of states for GaAS
4 Nd = 10^17
5 disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of n channel doping
6 kBT=0.026
7 disp("kBT = "+string(kBT)+"eV") //initializing value
     of multiplication of boltzmann constant and 300K
     temperature
8 e = 1.6*10^-19
9 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
10 h=0.06*10^-4
11 disp("h = "+string(h)+"cm") //initializing value of
    width of the channel
```

```
12 apsilen = 13.2*8.85*10^-14
13 disp("apsilen = "+string(apsilen)) //initializing
      value of relative permitivity
14 Vh = 0.8
15 disp("Vh = "+string(Vh)+"V") //initializing value of
       barrier height of gold schottky barrier
16 Vp= (e*(h^2)*Nd)/(2*apsilen)
17 disp("The total volage drop required to pinch the
      channel is ,Vp= (e*(h^2)*Nd)/(2*apsilen)= "+
      string(Vp)+"V")//calculation
18 Ecf= -(kBT)*(log(Nd/Nc))
19 disp("The difference between the conduction band and
       fermi level is ,Ecf= (kBT)*(log(Nd/Nc)))= "+
      string(Ecf)+"V")//calculation
20 Vbi= Vh-Ecf
21 disp("The built in potential is ,Vbi= Vh-Ecf= "+
      string(Vbi)+"V")//calculation
22 VG= Vbi-Vp
23 disp("The pinch off at gate bias is ,VG= Vbi-Vp= "+
      string(VG)+"V")//calculation
```

Scilab code Exa 8.6 Transconductance of the device

```
1 clc
2 mu_n=6000
3 disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
      initializing value of channel mobility
4 phi_b=0.8
5 disp("phi_b = "+string(phi_b)+"V") //initializing
      value of Schottky barrier height
6 kBT=0.026
7 disp("kBT = "+string(kBT)+"eV") //initializing value
       of multiplication of boltzmann constant and 300K
       temperature
8 e = 1.6*10^-19
```

```
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
h=0.25*10^-4
disp("h = "+string(h)+"cm") //initializing value of
    channel depth
Nd = 5*10^16
disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of channel doping
Nc = 4.45*10^17
disp("Nc = "+string(Nc)+"cm^-3") //initializing
    value of effective density of of states for GaAS
L = 2*10^-4
disp("L = "+string(L)+"cm") //initializing value of
    channel length
Z = 25*10^-4
disp("Z = "+string(Z)+"cm") //initializing value of
    gate width
apsilen = 13.2*8.85*10^-14
disp("apsilen = "+string(apsilen)) //initializing
    value of relative permitivity
VGS1 = 0
disp("VGS1 = "+string(VGS1)+"V") //initializing
    value of gate bias voltage 1
VGS2 = -1
disp("VGS2 = "+string(VGS2)+"V") //initializing
    value of gate bias voltage 2
Vbi = (phi_b-(kBT*(log(Nc/Nd))))
disp("The built-in voltage is ,Vbi = (phi_b-(kBT*(
    log(Nc/Nd))))= "+string(Vbi)+"V")//calculation
Vp= (e*(h^2)*Nd)/(2*apsilen)
disp("The internal pinch off potential is ,Vp= (e*(h
    ^2)*Nd)/(2*apsilen)= "+string(Vp)+"V")//
    calculation
go=(e*mu_n*Nd*Z*h)/(L)
disp("The value of go of the channel is ,go=(e*mu_n*
    Nd*Z*h)/(L)= "+string(go)+"ohm^-1")//calculation
ID_sat = go*((Vp/3)-Vbi+((2*(Vbi^1.5))/(3*(Vp^.5))))
disp("The value of saturation voltage is ,ID_sat =
```

```
    go*((Vp/3)-Vbi+((2*(Vbi^3/2))/(3*(Vp^.5)))= "+
    string(ID_sat)+"V")//calculation
34  ID1 = go*((Vp/3)-Vbi+VGS2+((2*((Vbi+abs(VGS2))^1.5))
    /(3*(Vp^.5))))
35  disp("The value of saturation current at VGS1 is ,ID
    (sat) = go*((Vp/3)-(Vbi)+VGS+((2*(Vbi-VGS)^(3/2))
    /(3*(Vp)^(1/2))))= "+string(ID1)+"A")//
    calculation
36  gm_sat= go*(1-((Vbi/Vp)^.5))
37  disp("The value of saturation conductance at VGS1 is
     ,gm_sat= go*(1-((Vbi/Vp)^.5))= "+string(gm_sat)+
    "S")//calculation
38  gm_sat= go*(1-((((Vbi+abs(VGS2))/Vp)^.5)))
39  disp("The value of saturation conductance at VGS2 is
     ,gm_sat= go*(1-((Vbi+VGS2)/Vp)^.5)= "+string(
    gm_sat)+"S")//calculation
40  // Note : due to different precisions taken by me
    and the author ... my answer differ
```

Scilab code Exa 8.7 Output current and output resistance

```
1  clc
2  Nd = 5*10^16;
3  e = 1.6*10^-19;
4  disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of channel doping
5  L = 2*10^-4
6  disp("L = "+string(L)+"cm") //initializing value of
    channel length
7  apsilen = 13.2*8.85*10^-14
8  disp("apsilen = "+string(apsilen)) //initializing
    value of relative permitivity
9  VDS1 = 1.0
10 disp("VDS1 = "+string(VDS1)+"V") //initializing
    value of drain bias voltage 1
```

```
11 VDS2 = 1.5
12 disp("VDS2 = "+string(VDS2)+"V") //initializing
      value of drain bias voltage 2
13 VGS1 = 0
14 disp("VGS1 = "+string(VGS1)+"V") //initializing
      value of gate bias voltage 1
15 ID=4.03
16 disp("ID(sat) = "+string(ID)+"mA") //initializing
      value of saturated current
17 dL1 = sqrt((2*apsilen*VDS1)/(e*Nd))
18 disp("The change in channel length is ,dL (VDS(sat)
      +1 V) = sqrt((2*apsilen*VDS1)/(e*Nd))= "+string(
      dL1)+"cm")//calculation
19 dL2 = sqrt((2*apsilen*VDS2)/(e*Nd))
20 disp("The change in channel length is ,dL (VDS(sat)
      +1.5 V) = sqrt((2*apsilen*VDS2)/(e*Nd))= "+string
      (dL2)+"cm")//calculation
21 ID1 = ID*(1+(dL1/(2*L)))
22 disp("The current at the bias is ,ID1(VDS(sat)+1 V)
      = ID*(1+(dL1/(2*L)))= "+string(ID1)+"mA")//
      calculation
23 ID2 = ID*(1+(dL2/(2*L)))
24 disp("The current at the bias is ,ID2(VDS(sat)+1.5 V
      ) = ID*(1+(dL2/(2*L)))= "+string(ID2)+"mA")//
      calculation
25 rDS = (VDS2-VDS1)/((ID2-ID1)*10^-3)
26 disp("The output resistance of source drain channel
      is ,rDS = (VDS2-VDS1)/(ID2-ID1)= "+string(rDS)+"
      ohm")//calculation
27 // Note : due to different precisions taken by me
      and the author ... my answer differ
```

Scilab code Exa 8.8 maximum cutoff frequency

```
1 clc
```

```
mu_n=1000
disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
    initializing value of channel mobility
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
h=0.5*10^-4
disp("h = "+string(h)+"cm") //initializing value of
    channel depth
Nd = 10^16
disp("Nd = "+string(Nd)+"cm^-3") //initializing
    value of channel doping
L = 2*10^-4
disp("L = "+string(L)+"cm") //initializing value of
    channel length
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)) //initializing
    value of relative permitivity
Vs = 10^7
disp("Vs = "+string(Vs)+"cm/s") //initializing value
     of saturated velocity
fT = (e*mu_n*Nd*(h^2))/(2*%pi*apsilen*(L^2))
disp("The maximum cutoff frequency of the device in
    the constant mobility model is ,fT = (e*mu_n*Nd*(
    h^2))/(2*%pi*apsilen*(L^2))= "+string(fT)+"Hz")//
    calculation
fT = Vs/(2*%pi*L)
disp("The maximum cutoff frequency of the device in
    the saturation velocity model is fT = Vs/(2*%pi*L
    )= "+string(fT)+"Hz")//calculation
```

Scilab code Exa 8.9 transit time

```
clc
VDS = .5
```

```
3 disp("VDS = "+string(VDS)+"V") //initializing value
    of drain bias voltage
4 h=1*10^-4
5 disp("h = "+string(h)+"cm") //initializing value of
    MOSFET depth
6 ID=4.03
7 disp("ID(sat) = "+string(ID)+"mA") //initializing
    value of saturated current
8 F = VDS/h
9 disp("The electric field in channel is ,F = VDS/h =
    "+string(h)+"V/cm")//calculation
10 Vsi = 5*10^6
11 disp("Vsi = "+string(Vsi)+"cm/s") //initializing
    value of velocity of electrons at this field in
    Si
12 VGaAs = 10^7
13 disp("VGaAs = "+string(VGaAs)+"cm/s") //initializing
    value of velocity of electrons at this field in
    GaAs
14 Ttr1 = h/Vsi
15 disp("The transit time of electrons in silicon is ,
    Ttr(si) = h/Vsi = "+string(Ttr1)+"s")//
    calculation
16 Ttr2 = h/VGaAs
17 disp("The transit time of electrons in GaAs is ,Ttr(
    GaAs) = h/VGaAs= "+string(Ttr2)+"s")//calculation
18 fT1 = 1/(2*%pi*Ttr1)
19 disp("The corresponding frequency of silicon is ,fT(
    Si) = 1/(2*%pi*Ttr(si))= "+string(fT1)+"Hz")//
    calculation
20 fT2 = 1/(2*%pi*Ttr2)
21 disp("The corresponding frequency of GaAs is ,fT(
    GaAs) = 1/(2*%pi*Ttr(GaAs))= "+string(fT2)+"Hz")
    //calculation
```

Scilab code Exa 8.10 maximum frequency

```
clc
VB = 100
disp("VB = "+string(VB)+"V") //initializing value of
    sorce-drain voltage
FSi=3*10^5
disp("FSi = "+string(FSi)+"V/cm") //initializing
   value of breakdown field of Si
FGaAs=4*10^5
disp("FGaAs = "+string(FGaAs)+"V/cm") //initializing
    value of breakdown field of GaAs
FSiC=3*10^6
disp("FSiC = "+string(FSiC)+"V/cm") //initializing
   value of breakdown field of SiC
Vsi = 10^7
disp("Vsi = "+string(Vsi)+"cm/s") //initializing
   value of saturation velocity of Si
VGaAs = 10^7
disp("VGaAs = "+string(VGaAs)+"cm/s") //initializing
    value of  saturation velocity of GaAs
VSiC = 2*10^7
disp("VSiC = "+string(VSiC)+"cm/s") //initializing
   value of saturation velocity of SiC
LBSi = VB/FSi
disp("The minimum channel length at which Si
   material will breakdown is ,LBSi = VB/FSi = "+
   string(LBSi)+"cm")//calculation
LBGaAs = VB/FGaAs
disp("The minimum channel length at which GaAs
   material will breakdown is ,LBGaAs = VB/FGaAs = "
   +string(LBGaAs)+"cm")//calculation
LBSiC = VB/FSiC
disp("The minimum channel length at which SiC
   material will breakdown is ,LBSiC = VB/FSiC = "+
   string(LBSiC)+"cm")//calculation
fT1 = Vsi/(2*%pi*LBSi)
disp("The corresponding cutoff frequency of silicon
```

```
    is ,fT(Si) = Vsi/(2*%pi*LBSi)= "+string(fT1)+"Hz"
    )//calculation
24 fT2 = VGaAs/(2*%pi*LBGaAs)
25 disp("The corresponding frequency of GaAs is ,fT(
    GaAs) = VGaAs/(2*%pi*LBGaAs)= "+string(fT2)+"Hz")
    //calculation
26 fT3 = VSiC/(2*%pi*LBSiC)
27 disp("The corresponding cutoff frequency of SiC is ,
    fT(SiC) = VsiC/(2*%pi*LBSiC)= "+string(fT3)+"Hz")
    //calculation
```

Chapter 9

field effect transistors MOSFET

Scilab code Exa 9.1 maximum depletion width

```
1  clc
2  kbT = 0.026
3  disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 300K
4  apsilen = 11.9*8.85*10^-14
5  disp("apsilen = "+string(apsilen)+"F/cm") //
       initializing value of relative permitivity
6  e = 1.6*10^-19
7  disp("e= "+string(e)+"C")//initializing value of
       charge of electron
8  Na=10^16
9  disp("Na = "+string(Na)+"cm^-3") //initializing
       value of doped carrier concentration
10 ni = 1.5*10^10
11 disp("ni= "+string(ni)+"cm^-3")//initializing value
       of intrinsic carrier concentration
12 phi_F= (-kbT*log(Na/ni))
13 disp("The potential phi_F= (-kbT*log(Na/ni))= "+
       string(phi_F)+"V")//calculation
14 W = sqrt((4*apsilen*(-phi_F))/(e*Na))*10^4
15 disp("The space charge width is ,W = sqrt((4*apsilen
```

```
*phi_F)/e*Na)= "+string(W)+" micro_meter")//
calculation
```

Scilab code Exa 9.2 potential

```
clc
kbT = 0.026
disp("kbT = "+string(kbT)+"V/K") //initializing
    value of kbT at 300K
Eg = 1.11
disp("Eg = "+string(Eg)+"eV") //initializing value
    of forbidden energy gap
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
Na=10^14
disp("Na = "+string(Na)+"cm^-3") //initializing
    value of doped carrier concentration
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value
    of intrinsic carrier concentration
phi_m = 4.1
disp("phi_m = "+string(phi_m)+"eV") //initializing
    value of work function of Al
Es = 4.15
disp("Es = "+string(Es)+"eV") //initializing value
    of electron affinity of silicon
EF= ((Eg/2)+kbT*log(Na/ni))
disp("The position of fermi level below conduction
    band is ,EF= (EFi+kbT*log(Na/ni))= "+string(EF)+"
    eV")//calculation
Vfb = phi_m-(Es+EF)
disp("The potential is ,Vfb = Qm-(Es+EF)= "+string(
    Vfb)+"eV")//calculation
```

Scilab code Exa 9.3 Threshold voltage

```
clc
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
Na=3*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of doped carrier concentration
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value
   of intrinsic carrier concentration
Vfb = -1.13
disp("Vfb= "+string(Vfb)+"eV")//initializing value
   of flat band voltage
Eox = 3.9*8.85*10^-14
disp("Eox= "+string(Eox))//initializing value of
   relative permitivity of oxide
dox = 500*10^-8
disp("dox= "+string(dox)+"cm")//initializing value
   of thickness of oxide
Nt = 10^11
disp("Nt= "+string(Nt)+"cm^-3")//initializing value
   trap density in oxide region
phi_F= (-kbT*log(Na/ni))
disp("The potential phi_F= (-kbT*log(Na/ni))= "+
   string(phi_F)+" V")//calculation
Qs = sqrt((4*apsilen*(-phi_F))*(e*Na))
```

```
23 disp("The maximum depletion width is ,Qs = sqrt((4*
   apsilen*(-phi_F))*(e*Na))= "+string(Qs)+" C cm^-2
   ")//calculation
24 Vs = -(2*phi_F)
25 disp("The surface potential is ,Vs = -(2*phi_F)= "+
   string(Vs)+" V")//calculation
26 VT = Vfb+Vs+((Qs*dox)/Eox)
27 disp("In the absence of any oxide charge, the
   threshold voltage is ,VT = Vfb+Vs+((Qs*dox)/Eox)
   = "+string(VT)+" V")//calculation
28 dVT = -((e*Nt*dox)/Eox)
29 disp("when oxide has trap charges, the shift in
   threshold voltage is ,dVT = -((e*Nt*dox)/Eox) = "
   +string(dVT)+" V")//calculation
30 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 9.4 channel conductivity and threshold voltage

```
1 clc
2 mu_n=600
3 disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
   initializing value of mobility of electron
4 mu_p = 200
5 disp("mu_p = "+string(mu_p)+"cm^2(Vs)^-1") //
   initializing value of mobility of holes
6 kbT = 0.026
7 disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
8 apsilen = 11.9*8.85*10^-14
9 disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity
10 e = 1.6*10^-19
11 disp("e= "+string(e)+"C")//initializing value of
   charge of electron
```

```
Na=5*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing value of doped carrier concentration
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value of intrinsic carrier concentration
Vfb = -0.5
disp("Vfb= "+string(Vfb)+"eV")//initializing value of flat band voltage
Eox = 1.583*8.85*10^-14
disp("Eox= "+string(Eox))//initializing value of relative permitivity of oxide
dox = 200*10^-8
disp("dox= "+string(dox)+"cm")//initializing value of thickness of oxide
sigma_1= Na*e*mu_p
disp("The channel conductivity under flat band sigma_1= Na*e*mu_p= "+string(sigma_1)+" ohm^-1cm^-1")//calculation
sigma_2= Na*e*mu_n
disp("The channel conductivity at inversion sigma_1= Na*e*mu_n= "+string(sigma_2)+" ohm^-1cm^-1")//calculation
phi_F= (-kbT*log(Na/ni))
disp("The potential phi_F= (-kbT*log(Na/ni))= "+string(phi_F)+" V")//calculation
Qs = sqrt((4*apsilen*(-phi_F))*(e*Na))
disp("The maximum depletion width is ,Qs = sqrt((4*apsilen*(-phi_F))*(e*Na))= "+string(Qs)+" C cm^-2")//calculation
Vs = -(2*phi_F)
disp("The surface potential is ,Vs = -(2*phi_F)= "+string(Vs)+" V")//calculation
VT = Vfb+Vs+((Qs*dox)/Eox)
disp("In the absence of any oxide charge, the threshold voltage is ,VT = Vfb+Vs+((Qs*dox)/Eox) = "+string(VT)+" V")//calculation
// Note : due to different precisions taken by me
```

and the author ... my answer differ

Scilab code Exa 9.6 Capacitance

```
clc
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)+"F/cm") //
   initializing value of relative permitivity
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
Na=10^16
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of doped carrier concentration
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value
   of intrinsic carrier concentration
apsilen_ox = 3.9*8.85*10^-14
disp("apsilen_ox= "+string(apsilen_ox))//
   initializing value of relative permitivity of
   oxide
dox = 500*10^-8
disp("dox= "+string(dox)+"cm")//initializing value
   of thickness of oxide
Cox= apsilen_ox/dox
disp("The oxide capacitance Cox= apsilen_ox/dox= "+
   string(Cox)+"F/cm^2")//calculation
phi_F= (-kbT*log(Na/ni))
disp("The potential phi_F= (-kbT*log(Na/ni))= "+
   string(phi_F)+" V")//calculation
Wmax = sqrt((4*apsilen*(-phi_F))/(e*Na))
disp("The maximum depletion width is ,Wmax = sqrt
```

```
    ((4*apsilen*(-phi_F))/(e*Na))= "+string(Wmax)+"
    cm")//calculation
22  Cmin = (apsilen_ox/(dox+((apsilen_ox*Wmax)/apsilen))
    )
23  disp("The minimum capicitance is ,Cmin = (apsilen_ox
    /(dox+((apsilen_ox*Wmax)/apsilen)))= "+string(
    Cmin)+" F/cm^2")//calculation
24  Cfb = (apsilen_ox/((dox)+((apsilen_ox/apsilen)*(sqrt
    ((kbT*apsilen)/(e*Na))))))
25  disp("The capicitance under flat band conditions is
    ,Cfb = (apsilen_ox/((dox)+((apsilen_ox/apsilen)*(
    sqrt((kbT*apsilen)/(e*Na)))))) = "+string(Cfb)+"
    F/cm^2")//calculation
```

Scilab code Exa 9.7 saturation current

```
1  clc
2  mu_n=600
3  disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
     initializing value of channel mobility
4  kbT = 0.026
5  disp("kbT = "+string(kbT)+"eV") //initializing value
      of kbT at 300K
6  apsilen = 11.9*8.85*10^-14
7  disp("apsilen = "+string(apsilen)+"F/cm") //
     initializing value of relative permitivity
8  e = 1.6*10^-19
9  disp("e= "+string(e)+"C")//initializing value of
     charge of electron
10 Na=10^16
11 disp("Na = "+string(Na)+"cm^-3") //initializing
     value of doped carrier concentration
12 ni = 1.5*10^10
13 disp("ni= "+string(ni)+"cm^-3")//initializing value
     of intrinsic carrier concentration
```

```
apsilen_ox = 3.9*8.85*10^-14
disp("apsilen_ox= "+string(apsilen_ox))//
   initializing value of relative permitivity of
   oxide
dox = 500*10^-8
disp("dox= "+string(dox)+"cm")//initializing value
   of thickness of oxide
phi_ms = -1.13
disp("phi_ms = "+string(phi_ms)+"V") //initializing
   value of work function of metal semiconductor
Qss = 10^11
disp("Qss = "+string(Qss)+"cm^-2") //initializing
   value of oxide charge
VGS = 5
disp("VGS= "+string(VGS)+"V")//initializing value of
    gate voltage
Z=25*10^-6
disp("Z= "+string(Z)+"m")//initializing value of
   channel width
L=1.5*10^-6
disp("L= "+string(L)+"m")//initializing value of
   channel length
phi_F= (-kbT*log(Na/ni))
disp("The potential phi_F= (-kbT*log(Na/ni))= "+
   string(phi_F)+" V")//calculation
Cox = apsilen_ox/dox
disp("The oxide capicitance per unit area is ,Cox =
   apsilen_ox/dox= "+string(Cox)+" F/cm^-2")//
   calculation
Vfb = phi_ms-((Qss*e)/Cox)
disp("The flat band potential is Vfb = phi_ms-(Qss/
   Cox)= "+string(Vfb)+"V")//calculation
Vs = -(2*phi_F)
disp("The surface potential is ,Vs = -(2*phi_F)= "+
   string(Vs)+" V")//calculation
VT = Vfb+Vs+(sqrt(4*e*apsilen*Na*(-phi_F))/Cox)
disp("In the absence of any oxide charge, the
   threshold voltage is ,VT = Vfb+Vs+(sqrt(4*e*
```

```
    apsilen*Na*(-phi_F))/Cox) = "+string(VT)+" V")//
    calculation
38 ID = (Z*mu_n*Cox*(VGS-VT)^2)/(2*L)
39 disp("The saturation current is ,ID = (Z*mu_n*Cox*(
    VGS-VT)^2)/(2*L)= "+string(ID)+" A")//calculation
40
41 //NOTE: The value of Vfb in the text book is wrong
    for the above solution and thus the value of VT
    and saturation current is also wrong
```

Scilab code Exa 9.8 Drain current

```
1  clc
2  kbT = 0.026
3  disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 300K
4  Z = 10*10^-4
5  disp("Z = "+string(Z)+"cm") //initializing value of
    channel width
6  L = 1*10^-4
7  disp("L = "+string(L)+"cm") //initializing value of
    channel length
8  mu_n=700
9  disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
    initializing value of channel mobility
10 apsilen = 11.9*8.85*10^-14
11 disp("apsilen = "+string(apsilen)+"F/cm") //
    initializing value of relative permitivity
12 e = 1.6*10^-19
13 disp("e= "+string(e)+"C")//initializing value of
    charge of electron
14 Na=4*10^14
15 disp("Na = "+string(Na)+"cm^-3") //initializing
    value of doped carrier concentration
16 ni = 1.5*10^10
```

```
17 disp("ni= "+string(ni)+"cm^-3")//initializing value
   of intrinsic carrier concentration
18 apsilen_ox = 3.9*8.85*10^-14
19 disp("apsilen_ox= "+string(apsilen_ox))//
   initializing value of relative permitivity of
   oxide
20 dox = 200*10^-8
21 disp("dox= "+string(dox)+"cm")//initializing value
   of thickness of oxide
22 VGS = 5;
23 phi_F= (-kbT*log(Na/ni));
24 disp("VGS= "+string(VGS)+"V")//initializing value of
    gate voltage
25 Qs = sqrt(4*apsilen*(-phi_F)*e*Na)
26 disp("The maximum depletion width is ,Qs = sqrt(4*
   apsilen*(-phi_F)*e*Na)= "+string(Qs)+" cm^-2")//
   calculation
27 disp("The potential phi_F= (-kbT*log(Na/ni))= "+
   string(phi_F)+" V")//calculation
28 Cox = apsilen_ox/dox
29 disp("The oxide capicitance per unit area is ,Cox =
   apsilen_ox/dox= "+string(Cox)+" cm^-1")//
   calculation
30 Vs = -(2*phi_F)
31 disp("The surface potential is ,Vs = -(2*QF)= "+
   string(Vs)+" V")//calculation
32 VT = Vs+((Qs/Cox))
33 disp(" The threshold voltage is ,VT = Vs+((Qs/Cox))
   = "+string(VT)+" V")//calculation
34 VDS = VGS-VT
35 disp("The saturation voltage is ,VDS = VGS-VT= "+
   string(VDS)+" V")//calculation
36 ID = (Z*mu_n*Cox*(VDS)^2)/(2*L)
37 disp("The saturation current is ,ID = (Z*mu_n*Cox*(
   VDS)^2)/(2*L)= "+string(ID)+" A")//calculation
38 // Note : due to different precisions taken by me
   and the author ... my answer differ
```

Scilab code Exa 9.9 mobility of electrons

```
clc
VDS = .1
disp("VDS = "+string(VDS)+"V") //initializing value
   of saturation voltage
Z = 10*10^-4
disp("Z = "+string(Z)+"cm") //initializing value of
   channel width
L = 2*10^-4
disp("L = "+string(L)+"cm") //initializing value of
   channel length
Cox=10^-7
disp("Cox = "+string(Cox)+" F cm^2") //initializing
   value of oxide capacitance
ID1= 50
disp("ID1 = "+string(ID1)+"uA") //initializing value
    of saturation current 1
ID2= 80
disp("ID2 = "+string(ID2)+"uA") //initializing value
    of saturation current 2
VGS1 = 1.5
disp("VGS1= "+string(VGS1)+"V")//initializing value
   of gate voltage 1
VGS2 = 2.5
disp("VGS2= "+string(VGS2)+"V")//initializing value
   of gate voltage 2
mu_n = (((ID2-ID1)*10^(-6)*L)/(VDS*Z*Cox*(VGS2-VGS1)
   ))
disp("The mobility of electron in silicon is ,mu_n =
    (((ID2-ID1)*L)/(VDS*Z*Cox*(VGS2-VGS1)))= "+
   string(mu_n)+" cm^2/Vs")//calculation
```

Scilab code Exa 9.10 shift in threshold voltage

```
clc
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value of kbT at 300K
apsilen = 11.9*8.85*10^-14
disp("apsilen = "+string(apsilen)+"F/cm") //initializing value of relative permitivity
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
Na=2*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing value of doped carrier concentration
ni = 1.5*10^10
disp("ni= "+string(ni)+"cm^-3")//initializing value of intrinsic carrier concentration
VSB = 1
disp("VSB= "+string(VSB)+"V")//initializing value of sorce body voltage
apsilen_ox = 3.9*8.85*10^-14
disp("apsilen_ox= "+string(apsilen_ox))//initializing value of relative permitivity of oxide
dox = 500*10^-8
disp("dox= "+string(dox)+"cm")//initializing value of thickness of oxide
Cox = apsilen_ox/dox
disp("The oxide capicitance per unit area is ,Cox = apsilen_ox/dox= "+string(Cox)+" F*cm^-2")//calculation
phi_F= (-kbT*log(Na/ni))
disp("The potential phi_F= (-kbT*log(Na/ni))= "+
```

```
    string(phi_F)+" V")//calculation
22 dVT = ((sqrt(2*e*apsilen*Na)/Cox)*((sqrt((-2*phi_F)+
    VSB)-sqrt(-2*phi_F))))
23 disp(" The shift in threshold voltage is ,dVT = ((
    sqrt(2*e*apsilen*Na)/Cox)*((sqrt((-2*phi_F)+VSB)-
    sqrt(-2*phi_F)))) = "+string(dVT)+" V")//
    calculation
```

Scilab code Exa 9.11 threshold voltage and dopant density

```
1  clc
2  kbT = 0.026
3  disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 300K
4  apsilen = 11.9*8.85*10^-14
5  disp("apsilen = "+string(apsilen)+"F/cm") //
    initializing value of relative permitivity
6  e = 1.6*10^-19
7  disp("e= "+string(e)+"C")//initializing value of
    charge of electron
8  D = 10^-5
9  disp("D= "+string(D)+"cm")//initializing value of
    thickness
10 Na=10^14
11 disp("Na = "+string(Na)+"cm^-3") //initializing
    value of doped carrier concentration
12 dVT=.5
13 disp("dVT = "+string(dVT)+"V") //initializing value
    of change in threshold voltage
14 ni = 1.5*10^10
15 disp("ni= "+string(ni)+"cm^-3")//initializing value
    of intrinsic carrier concentration
16 apsilen_ox = 3.9*8.85*10^-14
17 disp("apsilen_ox= "+string(apsilen_ox))//
    initializing value of relative permitivity of
```

```
    oxide
18 phi_F= (-kbT*log(Na/ni))
19 disp("The potential phi_F= (-kbT*log(Na/ni))= "+
    string(phi_F)+" V")//calculation
20 dox = 5*10^-6
21 disp("dox= "+string(dox)+"cm")//initializing value
    of thickness of oxide
22 Cox = apsilen_ox/dox
23 disp("The oxide capicitance per unit area is ,Cox =
    apsilen_ox/dox= "+string(Cox)+" cm^-1")//
    calculation
24 phi_ms = -0.83
25 disp("phi_ms = "+string(phi_ms)+"V")
26 VT = (phi_ms)-(2*phi_F)+((sqrt(4*e*apsilen*Na*(-
    phi_F)))/Cox)
27 disp("the threshold voltage is ,VT = (phi_ms)-(2*
    phi_F)+((sqrt(4*e*apsilen*Na*(-phi_F)))/Cox) = "+
    string(VT)+" V")//calculation
28 Na = (dVT*Cox)/(e*D)
29 disp("the dopant density is ,Na = (dVT*Cox)/(e*D) =
    "+string(Na)+" cm^-3")//calculation
30 // Note : due to different precisions taken by me
    and the author ... my answer differ
```

Chapter 10

MOSFET TECHNOLOGY DRIVER

Scilab code Exa 10.1 Critical voltage and noise margin

```
clc
K_dash = 25*10^-6
disp("K_dash = "+string(K_dash)+"A/V^2")
VT = 1
disp("VT = "+string(VT)+"V")
Z_by_L = 2
disp("Z_by_L = "+string(Z_by_L)+"V")
VDD = 5
disp("VOH = VDD = "+string(VDD)+"V") //initialising
    value of drain voltage
VOH = 5
RL = 100*10^3
disp("RL = "+string(RL)+"ohm") //initialising value
    of load resistance
k=K_dash*Z_by_L
disp("k = "+string(k))
VOL = VDD/(1+(k*RL*(VDD-VT)))
disp("The voltage in outout load is ,VOL = VDD/(1+(k
    *RL*(VDD-VT))) = "+string(VOL)+" V")//calculation
```

```
17 VIL = (1/(k*RL))+VT
18 disp("The low input value is ,VIL = (1/(k*RL))+VT =
     "+string(VIL)+" V")//calculation
19 //VIH_VT = VIH-VT
20 //Using the relation between Vout and Vin, we have
21 //(k/2)*((3/4)*(VIH_VT)^2)+((VIH_VT)/(2*RL))-(VDD/RL
     )
22 //solving using physically correct solution
23 VIH_VT = (-0.2+2.45)/1.5
24 VIH = VIH_VT + VT
25 disp("The high input value is ,VIH = VIH_VT + VT = "
     +string(VIH)+" V")//calculation
26 //Equting the Current in the load and the transistor
     yields
27 //(k/2)*(VM-VT)^2 = ((VDD-VM)/RL)
28 //solving using physically correct solution
29 VM = 2.08
30 NML = VIL-VOL
31 disp("The low noise margin of the device is ,NML =
     VIL-VOL = "+string(NML)+" V")//calculation
32 NMH = VOH-VIH
33 disp("The high noise margin of the device is ,NMH =
     VOH-VIH = "+string(NMH)+" V")//calculation
```

Scilab code Exa 10.2 Device parameter

```
1 clc
2 K_dash = 25*10^-6
3 disp("K_dash = "+string(K_dash)+"A/V^2")
4 VT = 1
5 disp("VT = "+string(VT)+"V")
6 VDD = 5
7 disp("VDD = "+string(VDD)+"V") //initialising value
     of drain voltage
8 VOL= 0.24
```

```
9  disp("VOL = "+string(VOL)+"V") //initialising value
     of output load voltage
10 RL = 10^5
11 disp("RL = "+string(RL)+"ohm") //initialising value
     of load resistance
12 VGS = 4.7
13 disp("VGS = "+string(VGS)+"V") //initialising value
     of gate and source voltage
14 KL = (2*((VDD-VOL)/RL))/(VGS-VT)^2
15 disp("The parameter of load transistor is ,KL =
     (2*((VDD-VOL)/RL))/(VGS-VT)^2 = "+string(KL)+" A/
     V^2")//calculation
16 Z_by_L = KL/K_dash
17 disp("Z_by_L = KL/K_dash= "+string(Z_by_L))//
     calculation
18 //NOTE: let
19 L = 10*10^-6
20 disp("L = "+string(L)+"m") //initialising value of
     length of transistor
21 Z = Z_by_L*L
22 disp("the width of transistor is Z = Z_by_L*L= "+
     string(Z)+"m")//calculation
23 //NOTE: let
24 Z_by_L = 2
25 L1 = 3*10^-6
26 disp("L1 = "+string(L1)+"m") //initialising value of
     length of transistor
27 Z1 = Z_by_L*L1
28 disp("the width of transistor is Z1 = Z_by_L*L1= "+
     string(Z1)+"m")//calculation
29 // Note : due to different precisions taken by me
     and the author ... my answer differ and author
     also takes the approximate values
```

Scilab code Exa 10.3 Output high of the inverter

```
1
2  clc
3  VTO = 1.5
4  disp("VTO = "+string(VTO)+"V")
5  Two_Phi_F = .7
6  disp("Two_Phi_F = "+string(Two_Phi_F)+"V")
7  Gamma = .4
8  disp("Gamma = "+string(Gamma)+"V^.5")
9  VDD = 5
10 disp("VDD = "+string(VDD)+"V") //initialising value
       of drain voltage
11
12 //VOH = VDD-(VTO+(Gamma*(sqrt(VOH+Two_Phi_F)-sqrt(
       Two_Phi_F))))
13 //By putting all the values in the equation, we get
14 disp("Voh-3.16 = 0.4*sqrt(Voh+1.4)")
15 //squaring both sides and result in quad equation
16 disp("VOH^2-6.72VOH+9.42")
17 p1 = poly([9.42, -6.72, 1], 'VOH', 'c')
18 a = roots(p1)
19 VOH = a(1)
20 disp("The output high is VOH = "+string(VOH)+"V")
```

Scilab code Exa 10.4 Cutoff frequency

```
1  clc
2  mu_n=700
3  disp("mu_n = "+string(mu_n)+"cm^2(Vs)^-1") //
       initializing value of channel mobility
4  VT = 1.5
5  disp("VT = "+string(VT)+"V") //initializing value of
       threshold velocity
6  VG=3
7  disp("VG = "+string(VG)+"V") //initializing value of
       gate bias
```

```
vs = 10^7
disp("vs = "+string(vs)+"cm/s") //initializing value
    of saturated velocity
L = 10^-4
disp("L = "+string(L)+"cm") //initializing value of
   channel length
fT1 = (mu_n*(VG-VT))/(2*%pi*(L^2))
disp("The cutoff frequency of the device in the
   constant mobility model is ,fT1 = (mu_n*(VG-VT))
   /(2*%pi*(L^2))= "+string(fT1)+"Hz")//calculation
fT2 = vs/(2*%pi*L)
disp("The cutoff frequency of the device in the
   saturation velocity model is fT2 = vs/(2*%pi*L)=
   "+string(fT2)+"Hz")//calculation
```

Chapter 11

MOSFET TECHNOLOGY DRIVER

Scilab code Exa 11.1 Absorption coefficient

```
1 clc
2 hw=1.7
3 disp("hw = "+string(hw)+"eV") //initializing value
    of energy of incident optical beam (h-bar omega)
4 Eg = 1.43
5 disp("Eg= "+string(Eg)+"eV")//initializing value of
    Energy of band gap
6 alpha= 4.21*10^4*((hw-Eg)/(hw))
7 disp("The absorption coefficient(alpha) for GaAs is
    ,alpha= 4.21*10^4*((hw-Eg)/(hw))= "+string(alpha)
    +"cm^-1")//calculation
```

Scilab code Exa 11.2 Length of material

```
1 clc
2 hw=1.43
```

```
3 disp("hw = "+string(hw)+"eV") //initializing value
    of energy of incident optical beam (h-bar omega)
4 alpha = 2.5*10^4
5 disp("alpha= "+string(alpha)+"cm^-1")//initializing
    value of absorption coefficient(alpha) for GaAs
6 amt = .9
7 disp("amt= "+string(amt))//initializing value of
    amount of light to be absorbed
8 L= -(1/alpha)*log(1-amt)
9 disp("The length of the material is ,L= -(1/alpha)*
    ln(1-amt)= "+string(L)+"cm")//calculation
```

Scilab code Exa 11.3 excess carrier density

```
1 clc
2 Pop = 10
3 disp("Pop= "+string(Pop))//initializing value of
    amount of optical intensity
4 hw=1.65
5 disp("hw = "+string(hw)+"eV") //initializing value
    of energy of incident optical beam (h-bar omega)
6 alpha = 7*10^3
7 disp("alpha= "+string(alpha)+"cm^-1")//initializing
    value of absorption coefficient(alpha) for GaAs
8 T = 10^-9
9 disp("T= "+string(T)+"s")//inializing value of e-h
    recombination time
10 GL = (alpha*Pop)/(hw*1.6*10^-19)
11 disp("The rate of e-h pair production is ,GL = (a*
    Pop)/(hw)= "+string(GL)+"cm^-3s^-1")//calculation
12 dn = (GL*T)
13 disp("The excess carrier density is ,dn = (GL*T)= "+
    string(dn)+"cm^-3")//calculation
```

Scilab code Exa 11.4 Photocurrent

```
clc
A= 10^4*10^-8
disp("A= "+string(A)+"cm^2") //initializing value of
    diode area
Na=2*10^16
disp("Na = "+string(Na)+"cm^-3") //initializing
   value of p side doping
Nd=10^16
disp("Nd = "+string(Nd)+"cm^-3") //initializing
   value of n side doping
Dn = 20
disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
    of electron diffusion coefficient
Dp = 12
disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
    of hole diffusion coefficient
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of
   electron minority carrier lifetime
Tp = 10^-8
disp("Tp= "+string(Tp)+"s")//inializing value of
   hole minority carrier lifetime
GL = 10^22
disp("GL= "+string(GL)+"cm^-3s^-1")//inializing
   value of rate of e-h pair production
kbT = 0.026
disp("kbT = "+string(kbT)+"V/K") //initializing
   value of kbT at 300K
Es = 11.9*8.85*10^-14
disp("Es = "+string(Es)) //initializing value of
   relative permitivity
e = 1.6*10^-19
```

```
23 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
24 VR = 2
25 disp("VR= "+string(VR)+"V")//initializing value of
     Reverse bias voltage
26 ni = 1.5*10^10
27 disp("ni = "+string(ni)+"cm^-3") //initializing
     value of intrinsic carrier concentration
28 Ln = sqrt(Dn*Tn)
29 disp("The electron diffusion length is ,Ln = sqrt(Dn
     *Tn)= "+string(Ln)+"cm")//calculation
30 Lp = sqrt(Dp*Tp)
31 disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
     = "+string(Lp)+"cm")//calculation
32 Vbi = kbT*log((Na*Nd)/(ni)^2)
33 disp("The built in voltage is ,Vbi = kbT*log((Na*Nd)
     /(ni)^2)= "+string(Vbi)+"V")//calculation
34 W = sqrt((2*Es*(Na+Nd)*(Vbi+VR))/(e*Na*Nd))
35 disp("The depletion width is ,W = sqrt((2*Es*(Na+Nd)
     *(Vbi+VR))/(e*Na*Nd))= "+string(W)+"cm")//
     calculation
36 IL= (e*A*GL*(W+Ln+Lp))
37 disp("The photocurrent is ,IL= (e*A*GL*(W+Ln+Lp)= "+
     string(IL)+"A")//calculation
```

Scilab code Exa 11.5 Open circuit voltage

```
1 clc
2 A= 1
3 disp("A= "+string(A)+"cm^2") //initializing value of
     diode area
4 Na=5*10^17
5 disp("Na = "+string(Na)+"cm^-3") //initializing
     value of p side doping
6 Nd=10^16
```

```
7  disp("Nd = "+string(Nd)+"cm^-3") //initializing
     value of n side doping
8  Dn = 20
9  disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
     of electron diffusion coefficient
10 Dp = 10
11 disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
     of hole diffusion coefficient
12 Tn = 3*10^-7
13 disp("Tn= "+string(Tn)+"s")//inializing value of
     electron minority carrier lifetime
14 Tp = 10^-7
15 disp("Tp= "+string(Tp)+"s")//inializing value of
     hole minority carrier lifetime
16 kbT = 0.026
17 disp("kbT = "+string(kbT)+"eV/K") //initializing
     value of kbT at 300K
18 IL = 25*10^-3
19 disp("IL= "+string(IL)+"A")//initializing value of
     photocurrent
20 e = 1.6*10^-19
21 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
22 ni = 1.5*10^10
23 disp("ni = "+string(ni)+"cm^-3") //initializing
     value of electron density of ionisation electron
     for silicon
24 Ln = sqrt(Dn*Tn)
25 disp("The electron diffusion length is ,Ln = sqrt(Dn
     *Tn)= "+string(Ln)+"cm")//calculation
26 Lp = sqrt(Dp*Tp)
27 disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
     = "+string(Lp)+"cm")//calculation
28 Io = A*e*(ni)^2*((Dn/(Ln*Na))+(Dp/(Lp*Nd)))
29 disp("The saturation current is ,Io = A*e*(ni)^2*((
     Dn/(Ln*Na))+(Dp/(Lp*Nd)))= "+string(Io)+"A")//
     calculation
30 Voc= (kbT)*log(1+(IL/Io))
```

```
31 disp("The open circuit voltage is ,Voc= (kbT)*log
   (1+(IL/Io))= "+string(Voc)+"V")//calculation
```

Scilab code Exa 11.6 number of solar cell required to generate desire power

```
1  clc
2  A= 1
3  disp("A= "+string(A)+"cm^2") //initializing value of
       diode area
4  Na=5*10^17
5  disp("Na = "+string(Na)+"cm^-3") //initializing
     value of p side doping
6  Nd=10^16
7  disp("Nd = "+string(Nd)+"cm^-3") //initializing
     value of n side doping
8  Dn = 20
9  disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
       of electron diffusion coefficient
10 Dp = 10
11 disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
       of hole diffusion coefficient
12 Tn = 3*10^-7
13 disp("Tn= "+string(Tn)+"s")//inializing value of
     electron minority carrier lifetime
14 Tp = 10^-7
15 disp("Tp= "+string(Tp)+"s")//inializing value of
     hole minority carrier lifetime
16 kbT = 0.026
17 disp("kbT = "+string(kbT)+"V/K") //initializing
     value of kbT at 300K
18 IL = 25*10^-3
19 disp("IL= "+string(IL)+"A")//initializing value of
     photocurrent or short circuit current of solar
     cell
20 e = 1.6*10^-19
```

```
21 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
22 ni = 1.5*10^10
23 disp("ni = "+string(ni)+"cm^-3") //initializing
     value of electron density of ionisation electron
     for silicon
24 Io = 3.66*10^-11
25 disp("Io= "+string(Io)+"A")//initializing value of
     diode saturation current
26 Voc= (kbT)*log(1+(IL/Io))
27 disp("The open circuit voltage is ,Voc= (kbT)*log
     (1+(IL/Io))= "+string(Voc)+"V")//calculation
28 P = 0.8*IL*Voc
29 disp("The power per solar cell is ,P = 0.8*IL*Voc =
     "+string(P)+"W")//calculation
30 // Note: Answer given in the book is incorrect it is
      10.6 mW not 1.06 mW
31 N_series = 10/(0.9*Voc)
32 disp("The number of solar cell needed to produce
     output power 10V is ,N_series = 10/(0.9*Voc) = "+
     string(N_series))//calculation
33 N_parallel = 10/(0.9*IL*10)
34 disp("The number of solar cell needed to produce
     output power 10W is ,N_parallel = 10/(0.9*IL*10)
     = "+string(N_parallel))//calculation
35 // Note : due to different precisions taken by me
     and the author ... my answer differ
```

Scilab code Exa 11.7 photocurrent dendity

```
1 clc
2 Pop = 1
3 disp("Pop= "+string(Pop)+"W/cm^2")//initializing
     value of amount of optical power
4 hw=1.43
```

```
disp("hw = "+string(hw)+"eV") //initializing value
    of energy of incident optical beam (h-bar omega)
a = 700
disp("a= "+string(a)+"cm^-1")//initializing value of
    absorption coefficient(alpha)
W = 10^-3
disp("W= "+string(W)+"m")//inializing value of
    intrinsic region width
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
    charge of electron
Phi_o = (Pop)/(hw*1.6*10^-19)
disp("The photon flux incident on the detector Phi_o
    = (Pop)/(hw*1.6*10^-19)= "+string(Phi_o)+"cm^-2s
    ^-1")//calculation
JL=e*Phi_o*(1-exp(-(a*W)))
disp("The photocurrent density is ,JL=e*Phi_o*(1-exp
    (-(a*W))= "+string(JL)+"A/cm^2")//calculation
```

Scilab code Exa 11.8 e h recombination time

```
clc
h=1.05*10^-34
disp("h = "+string(h)+"Js") //initializing value of
    reduced plancks constant or dirac constant or h-
    bar
mo = 9.1*10^-31
disp("mo = "+string(mo)+"kg") //initializing value
    of mass of electron
me = 0.067*9.1*10^-31
disp("me* = "+string(me)+"kg") //initializing value
    of electron mass of InAs
kbT = 0.026
disp("kbT = "+string(kbT)+"eV") //initializing value
    of kbT at 300K
```

```
10 mh = 0.45*9.1*10^-31
11 disp("mh*= "+string(mh)+"kg")//initializing value of
       hole density of state mass
12 To = .6*10^-9
13 disp("To = "+string(To)+"s") //initializing value of
       minimum recombination time
14 p = 10^21
15 disp("p = "+string(p)+"m^-3") //initializing value
      of excess electron or hole density injected
16 T = (p/(2*To))*((2*(%pi)*h^2)/(kbT*1.6*10^-19*(me+mh
      )))^(3/2)
17 disp("T = (p/(2*To))*((2*(%pi)*h^2)/(kbT
      *1.6*10^-19*(me+mh)))^(3/2) = "+string(T)+"s^-1")
      //calculation
18 Tr = 1/T
19 disp("The e-h recombination time is Tr = 1/T = "+
      string(Tr)+"s")//calculation
```

Scilab code Exa 11.9 internal quantum efficiency

```
1  clc
2  h=1.05*10^-34
3  disp("h = "+string(h)+"Js") //initializing value of
      reduced plancks constant or dirac constant or h-
      bar
4  mo = 9.1*10^-31
5  disp("mo = "+string(mo)+"kg") //initializing value
      of mass of electron
6  me = 0.067*9.1*10^-31
7  disp("me* = "+string(me)+"kg") //initializing value
      of electron mass of InAs
8  kbT = 0.026
9  disp("kbT = "+string(kbT)+"eV") //initializing value
       of kbT at 300K
10 mh = 0.45*9.1*10^-31
```

```
11 disp("mh*= "+string(mh)+"kg")//initializing value of
       hole density of state mass
12 To = .6*10^-9
13 disp("To = "+string(To)+"s") //initializing value of
       minimum recombination time
14 tnr = 10^-7
15 disp("tnr = "+string(tnr)+"s") //initializing value
      of nonradiative recombination time
16 p = 10^21
17 disp("p = "+string(p)+"m^-3") //initializing value
      of excess electron or hole density injected
18 mr = 1/((1/me)+(1/mh))
19 disp("The reduced mass for the e-h system is mr* =
      1/((1/me)+(1/mh)) = "+string(mr)+"kg")//
      calculation
20 disp("            For low p-doping such as 10^16, the
       recombination time is given as below")
21 T1 = (p/(2*To))*((2*(%pi)*h^2)/(kbT*1.6*10^-19*(me+
      mh)))^(3/2)
22 disp("T = (p/(2*To))*((2*(%pi)*h^2)/(kbT
      *1.6*10^-19*(me+mh)))^(3/2) = "+string(T1)+"s^-1"
      )//calculation
23 Tr1 = 1/T1
24 disp("The e-h recombination time is Tr1 = 1/T1 = "+
      string(Tr1)+"s")//calculation
25 nQr1 = 1/(1+(Tr1/tnr))
26 disp("The internal quantum efficiency  is nQr1 =
      1/(1+(Tr1/tnr)) = "+string(nQr1))//calculation
27 disp("          For high p-doping such as 5*10^17,
      the recombination time is given as below")
28 T2 = (1/To)*((mr/mh)^(3/2))
29 disp("T2 = (1/To)*((mr/mh)^(3/2)) = "+string(T2)+"s
      ^-1")//calculation
30 Tr2 = 1/T2
31 disp("The e-h recombination time is Tr2 = 1/T2 = "+
      string(Tr2)+"s")//calculation
32 nQr2 = 1/(1+(Tr2/tnr))
33 disp("The internal quantum efficiency  is nQr2 =
```

```
    1/(1+(Tr2/tnr)) = "+string(nQr2))//calculation
34 // Note : due to different precisions taken by me
    and the author ... my answer differ
```

Scilab code Exa 11.10 injection efficiency

```
1  clc
2  Na=5*10^16
3  disp("Na = "+string(Na)+"cm^-3") //initializing
     value of p side doping
4  Nd=5*10^17
5  disp("Nd = "+string(Nd)+"cm^-3") //initializing
     value of n side doping
6  Dn = 30
7  disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
      of electron diffusion coefficient
8  Dp = 15
9  disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
      of hole diffusion coefficient
10 Tn = 10^-8
11 disp("Tn= "+string(Tn)+"s")//inializing value of
     electron minority carrier lifetime
12 Tp = 10^-7
13 disp("Tp= "+string(Tp)+"s")//inializing value of
     hole minority carrier lifetime
14 e = 1.6*10^-19
15 disp("e= "+string(e)+"C")//initializing value of
     charge of electron
16 ni = 1.84*10^6
17 disp("ni = "+string(ni)+"cm^-3") //initializing
     value of intrinsic carrier concentration in GaAs
18 kbT = 0.026
19 disp("kbT = "+string(kbT)+"V/K") //initializing
     value of kbT at 300K
20 V = 1
```

```
21 disp("V = "+string(V)+"V") //initializing value of
     forward bias potential
22 nQr=.5
23 disp("nQr = "+string(nQr)) //initializing value of
     radiative recombination efficiency
24 np = ni^2/Na
25 disp(" np = ni^2/Na= "+string(np)+"cm^-3")//
     calculation
26 pn = ni^2/Nd
27 disp(" pn = ni^2/Nd= "+string(pn)+"cm^-3")//
     calculation
28 Ln = sqrt(Dn*Tn)
29 disp("The electron diffusion length is ,Ln = sqrt(Dn
     *Tn)= "+string(Ln)+"cm")//calculation
30 Lp = sqrt(Dp*Tp)
31 disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
     = "+string(Lp)+"cm")//calculation
32 Yinj = ((e*Dn*np)/Ln)/(((e*Dn*np)/Ln)+((e*Dp*pn)/Lp)
     )
33 disp("The injection efficiency is ,Yinj = ((e*Dn*np)
     /Ln)/(((e*Dn*np)/Ln)+((e*Dp*pn)/Lp))= "+string(
     Yinj))//calculation
```

Scilab code Exa 11.11 photon flux and Optical power

```
1 clc
2 A= 10^-2
3 disp("A= "+string(A)+"cm^2") //initializing value of
     diode area
4 Na=5*10^16
5 disp("Na = "+string(Na)+"cm^-3") //initializing
     value of p side doping
6 Nd=5*10^17
7 disp("Nd = "+string(Nd)+"cm^-3") //initializing
     value of n side doping
```

```
Dn = 30
disp("Dn= "+string(Dn)+"cm^2/s")//initializing value
    of electron diffusion coefficient
Dp = 15
disp("Dp= "+string(Dp)+"cm^2/s")//initializing value
    of hole diffusion coefficient
Tn = 10^-8
disp("Tn= "+string(Tn)+"s")//inializing value of
   electron minority carrier lifetime
Tp = 10^-7
disp("Tp= "+string(Tp)+"s")//inializing value of
   hole minority carrier lifetime
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of
   charge of electron
ni = 1.84*10^6
disp("ni = "+string(ni)+"cm^-3") //initializing
   value of intrinsic carrier concentration in GaAs
kbT = 0.026
disp("kbT = "+string(kbT)+"V/K") //initializing
   value of kbT at 300K
V = 1
disp("V = "+string(V)+"V") //initializing value of
   forward bias potential
nQr=.5
disp("nQr = "+string(nQr)) //initializing value of
   radiative recombination efficiency
Eph = 1.41
disp("Eph= "+string(Eph)+"eV")//initializing value
   of Energy of each photon
np = ni^2/Na
disp(" np = ni^2/Na= "+string(np)+"cm^-3")//
   calculation
pn = ni^2/Nd
disp(" pn = ni^2/Nd= "+string(pn)+"cm^-3")//
   calculation
Ln = sqrt(Dn*Tn)
disp("The electron diffusion length is ,Ln = sqrt(Dn
```

```
    *Tn)= "+string(Ln)+"cm")//calculation
34 Lp = sqrt(Dp*Tp)
35 disp("The hole diffusion length is ,Lp = sqrt(Dp*Tp)
    = "+string(Lp)+"cm")//calculation
36 In = ((A*e*Dn*np)/Ln)*(exp(V/kbT)-1)
37 disp("The injected current is ,In = ((A*e*Dn*np)/Ln)
    *(exp(V/kbT)-1)= "+string(In)+"A")//calculation
38 Iph = (In*nQr)/e
39 disp("The photon generated per second is ,Iph = (In*
    nQr)/e= "+string(Iph)+"s^-1")//calculation
40 P = Iph*e*Eph
41 disp("The optical power is ,P = Iph*e*Eph= "+string(
    P)+"W")//calculation
```

Scilab code Exa 11.12 Cavity length

```
1 clc
2 R =.33
3 disp("R = "+string(R)) //initializing value of
    reflection coefficient
4 alpha_R = 20
5 disp("alpha_R = "+string(alpha_R)+"cm^-1") //
    initializing value of absorption loss coefficient
6 L= (-1/alpha_R)*log(R)
7 disp("The length of the cavity is ,L= (-1/alpha_R)*
    log(R)= "+string(L)+"cm")//calculation
```

Scilab code Exa 11.14 threshold carrier density

```
1 clc
2 n = 1.1*10^18
3 disp("n = "+string(n)+"cm^-3") //initializing value
    of number of electron or hole
```

```
nth=1.32*10^18
disp("nth = "+string(nth)+"cm^-3") //initializing value of theshold density
e = 1.6*10^-19
disp("e= "+string(e)+"C")//initializing value of charge of electron
d = 2*10^-4
disp("d= "+string(d)+"cm")//initializing value of active layer thickness
Tr = 2.4*10^-9
disp("Tr= "+string(Tr)+"J")//initializing value of radiatve recombination time
Jth = (e*nth*d)/Tr
disp("The current density is Jth = (e*nth*d)/Tr= "+string(Jth)+"A/cm^2")//calculation
```