Scilab Textbook Companion for Solid State Electronic Devices by D. K. Bhattacharya and R. Sharma[1]

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Book Description

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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

Electron Dynamics

Scilab code Exa 1.1 Electron mass change

```
clc;
clear;
V=20000 //potential in Volts
e=1.602*10^-19 //electronic charge in C
m=9.1*10^-31 //mass of electron in kg
c=3*10^8 //speed of light in m/s

//Calculation
u=sqrt((2*V*e)/m) //speed u after acceleration
   through a potential V in m/s
mu=1/sqrt(1-(u/c)^2) //mass of electron moving with
   velocity mu in kg
delm=mu-1 //change in mass

mprintf("The percentage change in mass of the
   electron is %1.1f %%",delm*100)
```

Scilab code Exa 1.2 Electron Kinetic Energy

```
clc;
clear;
l=3*10^-3 //distance between two plate in meters
V=400 //potential difference in Volts
e=1.602*10^-19 //electronic charge in Joules
m=9.1*10^-31 //mass of electron in kg

//Calculation
uB=sqrt((2*V*e)/m) //in m/s
KEJ=e*V //in  Joules
KEeV=int(e*V/(1.6*10^-19)) //in eV
tAB=(2*l/uB) //in ns

mprintf("i)")
mprintf("Velocity with which the electrons strikes
    the plate =")
format("e",10)
disp(uB)
mprintf("ii)")
mprintf("Kinetic energy acquired by electron in
    joules =")
disp(KEJ)
mprintf("Kinetic energy acquired by electron in eV =
    ")
disp(KEeV)
mprintf("iii)")
mprintf("transit time in ns = ")//The answers vary
    due to round off error
disp(tAB)
```

Scilab code Exa 1.3 Radius of circular path of electron

```
clc;
clear;
B=0.02 //flux Density in Wb/m^2
u=5*10^7 //speed of electron in m/s
e=1.6*10^-19 //electronic charge Joules
m=9.1*10^-31 //mass of electron in kg

//Calculation
r=(m*u)/(e*B) //in m

format("e",9)
disp(r,"radius of the circular path followed by
   electron is =")
```

Scilab code Exa 1.4 Deflection Sensitivity

```
clc;
clear;
L=3*10^-2 //length of plates in m
d=4*10^-3 //spacing betweenn plates in m
l=30*10^-2 //distance in m
V1=2500 //potential in V

//Calculation
Se=(L*l)/(2*d*V1)/10^-4

mprintf("Deflection Sensitivity = %1.1f*10^-4 m/V",
   Se)
```

Scilab code Exa 1.5 acceleration of electron

```
clc;
clear;
Ey=3*10^4 //electric field in y−axis in N/C
Ex=0      //electric field in x−axis in N/C
q=1.6*10^-19 //electric charge in C
me=9.1*10^-31 //in kg

//Calculation
//F=q*E
Fy=-q*Ey //Force in y direction
ay=Fy/me

format("e",8)
disp(ay,"Acceleration of the electron is =")
//The negative sign tells us that the direction of
   this acceleration is downward
```

Scilab code Exa 1.6 Velocity of electron

```
clc;
clear;
V=2000 //potential in V
e=1.602*10^-19 //electronic charge in eV
m=9.1*10^-31 //mass of electron in kg

//Calculation
u=sqrt((2*V*e)/m)

mprintf("velocity with which electron beam will
   travel= %.2e m/s",u)
```

Scilab code Exa 1.7 Electron time

```
clc;
clear;
l=5 //length to be covered in cm
up=26.5*10^8 //in cm/s

//Calculation
t=(2*l/up)

mprintf("Time taken= %1.1e s",t)
//The answers vary due to round off error
```

Chapter 2

Growth and Crystal Properties of Semiconductors

Scilab code Exa 2.1 Fraction of bcc unit cell

```
clc;
clear;
disp("Each corner sphere of the bcc unit cell is
   shared with eigth neighbouring  cells.Thus each
   cell contains one eigth of a sphere at all the
   eigth corners.Each unit cell also contains one
   central sphere")
S=2 //Sphere per unit cell

//Calculation
f=S*%pi*sqrt(3)/16 //maximum fraction of a unit cell

mprintf("bcc unit cell volume filled with hard
   sphere= %i %%",round(f*100))
```

Scilab code Exa 2.2 Miller Indices

```
clc;
clear;
// r = p*a + q*b + s*c
p=1
q=2
s=3

//Calculation
LCM=lcm({p,q,s}) //LCM for computing miller indices
rx=1/p*LCM //reciprocals
ry=1/q*LCM
rz=1/s*LCM

mprintf("The plane depicted in the figure is denoted
    by (%i,%i,%i)",rx,ry,rz)
```

Scilab code Exa 2.3 Densities of Si and GaAs

```
clear;
clc;
//Atomic weigths
Si=28.1
Ga=69.7
As=74.9
Na=6.02*10^23 // Avagadro Number in mol^-1
//(a)Si
a=5.43*10^-8 //in cm
n=8 //no. of atoms/cell

//(b)GaAs
a1=5.65*10^-8 //in cm
```

```

//Calculation
N=8/a^3 //Atomic Concentration in atoms/cc
N1=4/a1^3 //Atomic Concentration in atoms/cc
Density=(N*Si)/(Na)
Density1=(N1*(Ga+As))/(Na)

mprintf("Density of Si= %1.2f g/cm^3\n",Density)
mprintf("Density of GaAs= %1.2f g/cm^3",Density1)
```

Scilab code Exa 2.4 surface density of atoms

```
clear;
clc;
a=5*10^-10 //lattice constatnt in m

//Calculation
n111=1/(a^2*sqrt(3))

mprintf("n(111)= %.1e atoms/m^2",n111)
//2.3e+18 is 2.3*10^18
```

Scilab code Exa 2.5 Element requirement

```
clear;
clc;
Cs=5*10^16 //impurity concentration in solid in
    atoms/cm^3
ks=0.35 //segregation coefficient
```

```
d=2.33 //density of Si in g/cm^3
Na=6.02*10^23 // Avagadro Number in mol^-1
Si=31 //weight of Si
loadSi=4000 //initial load in gm

//Calculation
Cl=Cs/ks //impurity concentration in liquid
V=loadSi/d //volume of the melt in cm^3
Nummber_of_atoms=Cl*V //in atoms
Wt=(Cl*V*Si)/(Na)

mprintf("(a)Cl= %1.2e cm^-3\n",Cl)
mprintf("(b)Wt of P= %.3e g",Wt) //The answers vary due to round off error
```

Scilab code Exa 2.7 Miller Indices

```
clear;
clc;
// r = p*a + q*b + s*c
x=3 //intercept on x axis
y=4 //intercept on y axis
z=5 //intercept on z zxis

//Calculation
LCM=lcm({x,y,z}) //LCM for computing miller indices
rx=1/x*LCM //reciprocal
ry=1/y*LCM
rz=1/z*LCM

mprintf("Miller indices of plane are (%i,%i,%i)",rx,ry,rz)
```

Scilab code Exa 2.9 Densities of atoms

```
clear;
clc;
a=8 //number of atoms shared by 8 cells
b=6 //number of atoms shared by 2 cells
c=4 //number of atoms shared by a single cell
L=5.43*10^-8 //Lattice constant in cm

//Calculation
N=(a/8)+(b/2)+c //no. of atoms in each cell
Volume=L^3
Density=8/Volume

mprintf("(a)no. of atoms in each cell= %i\n",N)
mprintf("(b)Density of atoms in silicon= %.0e atoms cm^-3",round(Density))
//The answer provided in the textbook is wrong
```

Scilab code Exa 2.10 packing density for silicon

```
clear;
clc;
Na=6.02*10^23 // Avagadro Number in mol^-1
AtWt=28.09 //in g/mole
Density=5*10^22 //in atoms/cm^-3

//Calculation
```

```
DensityPerUnitVolume=(Density*AtWt)/(Na)

mprintf("Density per unit volume= %1.2f g cm^-3",
    DensityPerUnitVolume)
```

Chapter 3

Energy Bands and Charge Carriers in Semiconductors

Scilab code Exa 3.1 Electron and Kinetic Energy

```
clear;
clc;
v=5*10^5 //velocity of electron in cm/s
m=9.11*10^-31 //mass of electron in kg
const=1.6*10^-19 //in eV

//Calculation
delv=0.02 //change in speed in cm/s
delE=(m*v*delv)/const

mprintf("Increase in kinetic energy of electron= %1
    .1e eV",delE)
```

Scilab code Exa 3.2 Donor Binding energy

```
clear;
clc;
epsilon_r=13.2
m0=9.11*10^-31 //in kg
q=1.6*10^-19 //in eV
epsilon_0=8.85*10^-12 //in F/m
h=6.63*10^-34 //planck's constant in J/s

//Calculation
mn=0.067*m0 //in kg
E=((mn*q^4)/(8*(epsilon_0*epsilon_r)^2*h^2))
E1=E/q

mprintf("Energy required to excite the donor
    electron (J)= %.2e J\n",E)
mprintf("Energy required to excite the donor
    electron (eV)= %.4f eV",E1)
```

Scilab code Exa 3.3 density of states

```
clear;
clc;
ml=0.98//*m0
mt=0.19//*m0
//rest mass m0 = 9.1*10^-31 kg

//Calculation
mn=6^(2/3)*(ml*mt^2)^(1/3)

mprintf("Density of states effective mass of
    electrons in silicon= %1.1f m0",mn)
```

Scilab code Exa 3.4 Hole concentration

```
clear;
clc;
n0=10^16 //doping atoms of P in atoms/cm^3
ni=1.5*10^10 //in cm^-3
Const=0.0259 //constant value for kT in eV

//Calculation
p0=(ni^2)/n0 //in cm^-3
x=(n0/ni)
delE=Const*log(x) //difference between energy bands
    Ef-Ei

mprintf("Ef-Ei= %.3f eV",delE)
```

Scilab code Exa 3.5 conductivity effective mass of electron

```
clear;
clc;
ml=0.98//*m0
mt=0.19//*m0
//rest mass m0 = 9.1*10^-31 kg

//Calculation
mnc=0.33*(1/ml+2/mt)

mprintf("1/mnc*= %1.2f m0",1/mnc)
```

Scilab code Exa 3.6 resistivity

```
clear;
clc;
Nd=10^14 //in cm^-3
myu_n=3900 //in cm^2/V
e=1.6*10^-19 //in J

//Calculation
p=1/(Nd*e*myu_n)

mprintf("Resistivity of the sample p= %.2f ohm-cm",p
    )
```

Scilab code Exa 3.7 resistivity

```
clear;
clc;
n0=5*10^16 //doping level of Si with As in cm^-3
myu_n=800 //in cm^2/Vs
Ix=2*10^-3 //in A
Bz=5*10^-5 //in A
d=2*10^-2 //in cm
e=1.6*10^-19 //in J

//Calculation
p=1/(e*myu_n*n0)
```

```
RH=-1/(e*n0)
VH=(Ix*Bz*RH)/(d)

mprintf("Resistivity= %0.3f ohm-cm\n",p)
mprintf("Hall coefficient= %i cm^3/c\n",RH)
mprintf("Hall Voltage= %.2e V",VH)
```

Scilab code Exa 3.9 conductivity and density

```
clear;
clc;

Boron_impurity=10^18 //in cm^-3
Phosphorus_impurity=10^16 //in cm^-3

//Calculation
Density=Boron_impurity-(8*Phosphorus_impurity)

mprintf("Density of majority carriers(holes)= %1.1e
   cm^-3",Density)
```

Scilab code Exa 3.10 Drift velocity

```
clear;
clc;
J=14.14*10^-14 //current density in A/cm^2
v1=3*10^7 //hole group drift velocities in cm/s
v2=5*10^8 //in cm/s
v3=6*10^8 //in cm/s
```

```
q=1.6*10^-19 //in C
n=1000 //number of holes

//Calculation
x=((J/(n*q))-v1-v2-v3)

mprintf("Drift velocity of remaining hole group= %.1
   e cm s^-1",x)
```

Scilab code Exa 3.11 `GaAs semiconductor`

```
clc;
clear;
E=1.43 //in eV
h=4.14*10^-15 //plancks constant in e*V*s
c=3*10^8 //in m/s

//Calculation
//a)
v=E/h

//b)
lamda=c/v

mprintf("a)minimum frequency= %.3e Hz\n",v)
mprintf("b)wavelength= %.1e m",lamda) //The answers
   vary due to round off error
```

Scilab code Exa 3.12 `Semiconductor design`

```
clc;
clear;
R=10*10^3 //Resistance in ohm
V=5 //Voltage in V
J=50 //current density in A/cm^2
E=100 //in V/cm
q=1.6*10^10 //in eV
myu_p=410 //in cm^2/V*s
Nd=5*10^15 //in cm^-3

//Calculation
I=V/R //ohms law in mA
A=I/J //Area in cm^2
L=V/E
rho=(R*A)/L
sigma=1/rho //in ohm^-1 cm^-1
Na=(sigma/(myu_p*q))+Nd

mprintf("a)Limiting electric field= %i V/cm\n",E)
mprintf("b)Length of resistor= %.1e cm\n",L)
mprintf("c)Area of cross-section= %.1g cm^2\n",A)
mprintf("d)Acceptor doping concentration= %.2g cm^-3
   ",Na) //The answer provided in the textbook is
   wrong
```

Scilab code Exa 3.13 Doping

```
clc;
clear;
E_fi=0.35 //in eV
ni=1.5*10^10 //in cm^-3
q=1.6*10^-19 //in eV
myu_n=1400 //in cm^2/Vs
```

```
myu_p=500 //in cm^2/Vs
Const=0.0259 //constant value for kT in eV

//Calculation
//a)
n0=ni*exp((E_fi)/Const)

//c)
//doped substrate
sigma=q*(myu_n*n0) //in ohm^-1 cm^-1
rho=1/sigma

//undoped substrate
sigma1=q*(ni*(myu_n+myu_p))
rho1=1/sigma1

mprintf("a)Doping value= %1.3e cm^-3\n",n0)
mprintf("c)resistivity of the doped pieces of silicon= %.4f ohm-cm\n",rho)
mprintf("c)resistivity of the undoped pieces of silicon= %.1e ohm-cm",rho1) //The answers vary due to round off error
```

Scilab code Exa 3.14 Doping

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
Ex=0.6 //position of energy level in eV
Const=0.0259 //constant value for kT in eV

//Calculation
n0=ni*exp(Ex/Const)
```

```
mprintf("concentration of doping= %.3e cm^-3",n0) //
    The answers vary due to round off error
```

Chapter 4

Excess Carrier in Semiconductors

Scilab code Exa 4.1 excess electron concentration

```
clc;
clear;
del_n0=10^16 //concentration of electrons in cm^-3
tau_n0=5 //excess carrier lifetime in micro-s
t=1 //time in micro-s

//Calculation
del_nt=del_n0*exp(-t/tau_n0)

mprintf("excess electron concentration= %.3g cm^-3",
   del_nt)
```

Scilab code Exa 4.2 Recombination rate

```
clc;
clear;
del_n0=10^16 //concentration of electrons in cm^-3
tau_n0=5 //excess carrier lifetime in s
tau_n01=5*10^-6 //excess carrier lifetime in micro-s
t=5 //in micro-s

//Calculation
del_nt=del_n0*exp(-t/tau_n0) //in cm^-3
Rn1=del_nt/tau_n01

mprintf("Recombination rate= %.1e cm^-3 s^-1",Rn1)
```

Scilab code Exa 4.3 Recombination rate

```
clc;
clear;
Nd=10^15 //dopant concentration in cm^-3
Na=0 //in cm^-3
tau_p0=10*10^-7 //in s
tau_n0=10*10^-7 //in s
ni=1.5*10^10 //in cm^-3
deln=10^14 //in cm^-3
delp=10^14 //in cm^-3
nt=1.5*10^15 //in cm^-3
pt=1.5*10^15 //in cm^-3

//Calculation
n0=Nd //in cm^-3
p0=ni^2/Nd //in cm^-3
n=n0+deln //in cm^-3
p=p0+delp //in cm^-3
R=((n*p)-ni^2)/(tau_n0*(n+p))
```

```

mprintf("Recombination rate= %1.2e cm^-3 s^-1",R)
```

Scilab code Exa 4.4 Fermi level

```
clc;
clear;
n0=5*10^15 //carrier concentration in cm^-3
ni=10^10 //in cm^-3
p0=2*10^4 //in cm^-3
deln=5*10^13 //excess carriers in semiconductor in cm^-3
delp=5*10^13 //in cm^-3
Const=0.026 //constant value for kT/e in V

//Calculation
delE1=Const*log(n0/ni)
delE2=Const*log((n0+deln)/ni)
delE3=Const*log((p0+delp)/ni)

mprintf("1)\nposition of the Fermi level at thermal equilibrium= %0.4f eV\n",delE1)
mprintf("2)\nquasi-Fermi level for electrons in non-equilibrium= %0.4f eV\n",delE2)
mprintf("3)\nquasi-Fermi level for holes in non-equilibrium= %0.4f eV",delE3)
```

Scilab code Exa 4.6 Haynes Shockley

```
clc;
clear;
l=1.8 //distance between plates in cm
E=3/2 //in V
t=0.6*10^-3 //time taken by the pulse in s
del_t=236*10^-6 //pulse width in s

//Calculation
vd=l/t //in cm/s
myu_p=vd/E
Dp=(del_t*l)^2/(16*t^3)

mprintf("1)\nHole mobility= %i cm^2/Vs\n",myu_p)
mprintf("2)\nDiffusion coefficient= %2.2f cm^2/s",Dp
    )
```

Scilab code Exa 4.7 Doping

```
clc;
clear;
delp=4*10^14 //excess EHP in cm^-3
deln=4*10^14 //excess EHP in cm^-3
n0=10^15 //donor atoms in cm^-3
p0=0 //in cm^-3
t=0.5*10^-6 //hole-lifetime in s
myu_n=1200 //mobility of electron in cm^2/V*s
myu_p=400 //mobility of hole in cm^2/V*s
q=1.6*10^-19 //electron charge in eV
ni=1.5*10^10 //in cm^-3
Const=0.0259 //constant value for kT in eV

//Calculation
//a)
```

```
gop=delp/t

//b)
rho_0=(q*n0*myu_n)^-1 //Before illumination
n=n0+deln //in cm^-3
p=p0+delp //in cm^-3
rho=1/(q*((myu_n*n)+(myu_p*p)))//conductivity
rho1=q*myu_p*delp //in mho/cm
Pcond=(rho*rho1)*100

//c)
delE_e=Const*log(n/ni)
delE_h=Const*log(p/ni)

mprintf("a)\n")
mprintf("photo generation rate= %g EHPs/cm^3s\n",gop
    )
mprintf("b)\n")
mprintf("resistivity before illumination= %1.2f ohm-
    cm\n",rho_0)
mprintf("resistvity after illumination= %1.3f ohm-cm
    \n",rho)
mprintf("percent of conductivity= %1.2f percent\n",
    Pcond) //The answers vary due to round off error
mprintf("c)\n")
mprintf("quasi Fermi level due to electron=Efi+%0.3f
    eV\n",delE_e)
mprintf("quasi Fermi level due to holes=Efi-%0.3f eV
    \n",delE_h)
```

Scilab code Exa 4.8 Doping

```
clc;
```

```
clear;
n0=10^16 //donor atoms in cm^-3
q=1.6*10^-19 //electron charge in J
ni=1.5*10^10 //in cm^-3
Nd=10^16 //Donors added to silicon to make it n-type) in cm^-3
GT=2.25*10^10 //Thermal generation rate of carriers under equilibrium cm^-3/s
gop=10^21 //in cm^-3/s
tau_n=10^-6 //in s
tau_t=2.5*10^-3 //transit time in s
V=1 //in V

//Calculation
//a)
alpha_r=GT/ni^2
tau_p=(alpha_r*n0)^-1

//b)
delp=gop*tau_n

//c)
delI=(q*V*gop*tau_n)/tau_t

mprintf("a)\n")
mprintf("lifetime of both type of carriers= %g s\n",tau_p)
mprintf("b)\n")
mprintf("excess carrier concentration= %g cm^-3\n",delp)
mprintf("c)\n")
mprintf("Induced change in current= %.3f A",delI)
```

Scilab code Exa 4.9 Electron and Energy

```
clc;
clear;
E1000=8.48*10^5 //Current density for 1000 V in A/cm^2
delE=0.1 //in eV
q=1.6*10^-19 //electron charge in eV
ni=1.5*10^10 //in cm^-3
Nd=10^16 //Donors added to silicon to make it n-type) in cm^-3
gop=10^19 //in cm^-3/s
tau=10^-5 //in s
Const=0.0259 //constant value for kT in eV

//Calculation
//a)
E10000=E1000

//b)
n0=ni*exp(delE/Const)

//c)
deln=gop*tau //in cm^-3
n=n0 //in cm^-3
p=deln //in cm^-3s
delE_np=Const*log((n*p)/ni^2)

mprintf("a)\n")
mprintf("Current density for 1000V potential= %1.2e A/cm^2\n",E10000)
mprintf("b)\n")
mprintf("Doping concentration= %1.1e cm^-3\n",n0) //The answer provided in the textbook is wrong"
mprintf("c)\n")
mprintf("Energy gap= %0.4f eV",delE_np) //The answer provided in the textbook is wrong"
```

Chapter 5

p n Junction

Scilab code Exa 5.1 Diffusion Temperature

```
clc;
clear;
rho=10 //resistivity in ohm-cm
myu_n=1300 //electron mobility in cm^2/V*s
e=1.6*10^-19 //in eV
Cs=5*10^18 //constant surface concentartion in cm^-3
t=1 //in hour
x=1 //depth in micro-m

//Calculation
sigma=1/rho //in (ohm-cm)^-1
n=sigma/(myu_n*e) //in cm^-3
n_Cs=n/Cs
erfc1_y=n_Cs //error function
y=2.75 //reference page 181 from fig 5.1.1. value obtained by plotting erfc1_y (Complementary error function) as a function of y
rootD=x/(2*y*sqrt(t))
T=1100 //reference page 168 from fig 5.10(b)

mprintf("rootD = %.2f micro-m/h^-2\n",rootD)
```

```
mprintf("Temperature at diffusion should be carried out= %i Celsius\n",T)
mprintf("The temperature value was choosen by determing the value of T against root(D) in the figure of Diffusivity of acceptor impurities in silicon versus T")
```

Scilab code Exa 5.2 `Built in potential`

```
clc;
clear;
Na=5*10^18 //doping densities in cm^-3
Nd=5*10^15 //in cm^-3
ni=1.5*10^10 //in cm^-3
Const=0.026//constant for kT/e in V

//Calculation
Vbi=Const*log((Na*Nd)/ni^2)

mprintf("built-in potential= %0.3f V",Vbi) //The answers vary due to round off error
```

Scilab code Exa 5.3 `Total space charge width`

```
clc;
clear;
Na=5*10^18 //doping densities in cm^-3
Nd=5*10^15 //in cm^-3
ni=1.5*10^10 //in cm^-3
```

```
epsilon_s=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Vbi=0.838 //built-in potential in V
e=1.6*10^-19 //in J

//Calculation
W=((2*epsilon_s*epsilon_0*Vbi*(Na+Nd))/(e*Na*Nd))^0.5

mprintf("Total space-charge width= %0.2e m",W)
```

Scilab code Exa 5.4 space charge region

```
clc;
clear;
Na=5*10^18 //doping densities in cm^-3
Nd=5*10^15 //in cm^-3
ni=1.5*10^10 //in cm^-3
VR=4 //voltage in V
epsilon_s=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Vbi=0.838 //built-in potential in V
e=1.6*10^-19 //in J

//Calculation
W=((2*epsilon_s*epsilon_0*(Vbi+VR)*(Na+Nd))/(e*Na*Nd))^0.5

mprintf("Total space-charge width= %1.2e cm",W)
```

Scilab code Exa 5.5 Junction capacitance

```
clc;
clear;
Na=5*10^18 //doping densities in cm^-3
Nd=5*10^15 //in cm^-3
ni=1.5*10^10 //in cm^-3
VR=3 //voltage in V
epsilon_s=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Vbi=0.838 //built-in potential in V
e=1.6*10^-19 //in J
A=5*10^-4 //Area in cm^2

//Calculation
Cdep=((e*epsilon_s*epsilon_0*Na*Nd)/(2*(Vbi+VR)*(Na+
   Nd)))^0.5 //junction capacitance
Cdep1=Cdep*A

mprintf("Junction Capacitance= %.0g F/cm^2\n",Cdep)
mprintf("Depletion Capacitance= %.0g F",Cdep1)
```

Scilab code Exa 5.7 Reverse breakdown voltage

```
clc;
clear;
Na=10^17 //in cm^-3
epsilon_0=8.85*10^-14 //in F/cm
```

```
Emax=5*10^5 //peak electric field in V/cm
e=1.6*10^-19 //in J
epsilon_si=88.76*10^-14 //in F/cm

//Calculation
E=(Emax*Emax*epsilon_si)/(e*Na)

mprintf("Breakdown voltage= %2.2f V",E) //The
    answers vary due to round off error
```

Scilab code Exa 5.8 p n junction

```
clc;
clear;
Na=10^19 //doping densities in cm^-3
Nd=10^15 //in cm^-3
epsilon_s=88.76*10^-14 //in F/cm
e=1.6*10^-19 //in J
Vbi=300 //breakdown voltage in V

//Calculation
xn=((2*epsilon_s*Na*Vbi)/(e*Nd*(Na+Nd)))^0.5

mprintf("a)\n")
mprintf(" As %.4e cm is less than the given length
    of the n-region i.e 22 micro-m, device will only
    have avalanche breakdown",xn)
```

Scilab code Exa 5.9 p n junction

```
clc;
clear;
Na=10^15 //doping densities in cm^-3
Nd=10^17 //in cm^-3
V=0.5 //in V
e=1.6*10^-19 //in J
nn0=10^17 //in cm^-3
ni=1.5*10^10 //in cm^-3
Si_bandgap=1.1 //bandgap of silicon in eV
Const=0.0259 //constant value for kT/e in J

//Calculation
//a)
pn0=ni^2/nn0 //in cm^-3
pn=pn0*exp((V)/Const)

//b)

Vbi=0.6949 //breakdown voltage in V
Vp=Vbi-V //potential already present in V
Vz=Si_bandgap-Vp //Zener breakdown voltage in V

mprintf("a)\n")
mprintf("Total concentration of holes= %.2e cm^-3\n"
    ,pn)
mprintf("b)\n")
mprintf("Additional voltage required= %.4f V",Vz)
```

Scilab code Exa 5.10 Donor Concentration

```
clc;
clear;
Cj=12*10^-12 //Capacitance in F/cm^2
```

```
A=10^-4 //junction Area in A/cm^2
Vr=20 //in V
e=1.6*10^-19 //in J
epsilon_r=11.8 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm

//Calculation
Nd=((2*Cj)/A)^2*(Vr/(2*epsilon_r*epsilon_0*e))

mprintf("Donor Concentration= %1.3e cm^-3",Nd)
```

Scilab code Exa 5.11 Depletion

```
clc;
clear;
Na=4.22*10^14 //doping densities in cm^-3
Nd=4.22*10^16 //in cm^3
e=1.6*10^-19 //in eV
Vbi=0.65 //breakdown voltage in V
ni=1.5*10^10 //in cm^-3
epsilon_si=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
V=10 //applied voltage in V
Const=0.0259 //value for kT/e in V

//Calculation
Nd=sqrt((exp(Vbi/Const)*ni^2)/100)
Na=100*Nd
W=(((2*epsilon_0*epsilon_si*(Vbi+V))*(Na+Nd))/(e*Na*
    Nd))^0.5
Cj=(epsilon_0*epsilon_si)/W

mprintf("Depletion capacitance per unit area= %1.3e
```

```
F/cm^2\n",Cj) //The answers vary due to round off error
mprintf("Width of depletion region= %1.2e cm",W) //The answers vary due to round off error
```

Chapter 6

p n Junction Current

Scilab code Exa 6.1 p n junction

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
Nd=5*10^16 //doping density in cm^-3
V=0.55 //in V
Const=0.026 //constant for kT/e in V

//Calculation
Pn0=ni^2/Nd //in cm^-3
Pn=Pn0*exp(V/Const)

mprintf("minority carrier concentration= %1.2e cm^-3
   ",Pn)
```

Scilab code Exa 6.2 Reverse saturation current

```
clc;
```

```
clear;
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in J
Na=10^16 //doping density in cm^-3
Nd=5*10^16 //in cm^-3
Dn=25 //in cm^2/s
Dp=10 //in cm^2/s
tau_p0=4*10^-7 //in s
tau_n0=2*10^-7 //in s

//Calculation
Js=e*ni^2*((1/Na)*sqrt(Dn/tau_n0)+(1/Nd)*sqrt(Dp/
    tau_p0))

mprintf("Reverse saturation current density= %1.2e A
    /cm^2",Js) //The answers vary due to round off
    error
```

Scilab code Exa 6.3 p n junction

```
clc;
clear;
sigma_p=1000 //conductivity of p-junction in ohm^-1*
    m^-1
sigma_n=20 //conductivity of n-junction in ohm^-1*m
    ^-1
myu_p=0.05 //in m^2/V*s
myu_n=0.13 //in m^2/V*s
K=8.61*10^-5 //Boltzmann constant in eV/K
T=300 //in K
V=0.4 //forward bias voltage in V
e=1.602*10^-19 //in J
ni=1.5*10^16 //in m^-3
```

```
tau_n=10^-6 //minority carrier lifetime in s
tau_p=5*10^-6 //in s
Const=0.026 //constant for kT/e in V
hole_current=0.603*10^-6 //in A
electron_current=0.016*10^-6 //in A

//Calculation
pp0=sigma_p/(e*myu_p) //majority carrier densities in m^-3
nn0=sigma_n/(e*myu_n) //in m^-3
np0=ni^2/pp0 //minority carrier densities in m^-3
pn0=ni^2/nn0 //in m^-3
Dn=myu_n*K*T //in m^2/s
Dp=myu_p*K*T //in m^2/s
Ln=sqrt(Dn*tau_n) //in m
Lp=sqrt(Dp*tau_p) //in m
Js=(((e*np0*Ln)/tau_n)+((e*pn0*Lp)/tau_p))
Ratio=(hole_current)/(electron_current)
J=Js*(exp(V/Const)-1)

mprintf("1)\nReverse bias stauration current density = %0.3e A/m^2\n",Js) //The answers vary due to round off error
mprintf("2)\nRatio of hole to electron current= %2.2f \n",Ratio)
mprintf("3)\nTotal current density= %2.2f A/m^2",J) //The answers vary due to round off error
```

Scilab code Exa 6.4 `Diffusion capacitance`

```
clc;
clear;
Ip0=0.5*10^-3 //in A
```

```
tau_p0=5*10^-7 //in s
Const=0.026 //constant for kT/e in V

//Calculation
Cd0=(1/(2*Const))*tau_p0*Ip0

mprintf("Diffusion Capacitance= %.1e F",Cd0)
//The answers vary due to round off error
```

Scilab code Exa 6.5 Reverse bias generation current

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
epsilon_si=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
e=1.6*10^-19 //in J
Na=10^16 //in cm^-3
Nd=5*10^16 //in cm^-3
tau_p0=4*10^-7 //in s
tau_n0=2*10^-7 //in s

//Calculation
W=(((2*epsilon_si*epsilon_0)*(Na+Nd)*4)/(e*Na*Nd))
    ^0.5 //in micro-m
tau_m=(tau_p0+tau_n0)/2 //in s
Jgen=(e*ni*W)/(2*tau_m)

mprintf("reverse-bias generation current density= %1
    .2e A/cm^2",Jgen) //The answers vary due to round
     off error
```

Scilab code Exa 6.6 Diode design

```
clc;
clear;
Jn=20 //in A/cm^2
Jp=5 //in A/cm^2
Va=0.65 //in V
Dn=25 //in cm^2/s
Dp=10 ///in cm^2/s
tau_n0=5*10^-7 //in s
tau_p0=5*10^-7 //in s
epsilon_r=11.8 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
e=1.6*10^-19 //in eV
ni=1.5*10^10 //in cm^-3
Const=0.0259 //constant for kT/e in V

//Calculation
Lp=sqrt(Dp*tau_p0) //in cm
pn0=(Jp*Lp)/(e*Dp*(exp(Va/Const)-1)) //law of mass action in cm^-3
Nd=(ni^2/pn0)
Ln=sqrt(Dn*tau_n0) //in cm
np0=(Jn*Ln)/(e*Dn*(exp((Va/Const))-1)) //in cm^-3
Na=ni^2/np0

mprintf("Nd= %1.2e cm^-3\n",Nd) //The answers vary due to round off error
mprintf("Na= %1.2e cm^-3",Na)
```

Scilab code Exa 6.7 p n junction

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
Nd=1*10^16 //n-type doping in cm^-3
V=0.6 //forward bias current in V
e=1.6*10^-19 //in eV
Const=0.0259 //constant for kT/e in V

//Calculation
Pn0=ni^2/Nd //in cm^-3
Pn=Pn0*exp(V/Const)


mprintf("Minority carrier hole concentration= %1.2e
   cm^-3",Pn)
```

Scilab code Exa 6.8 Forward bias current

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
Nd=5*10^16 //n-type doping in cm^-3
V=0.5 //forward bias current in V
e=1.6*10^-19 //in eV
tau_p=1*10^-6 //in s
Dp=10 //in cm^2/s
```

```
A=10^-3 //cross-sectional area in cm^2
Const=0.0259 //constant for kT/e in V

//Calculation
pn=ni^2/Nd //in cm^-3
Lp=sqrt(Dp*tau_p) //in cm
I=e*A*(Dp/Lp)*pn*(exp(V/Const))

mprintf("Current= %.1e micro-Ampere",I)
```

Scilab code Exa 6.9 Electric field value

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in eV
Na=10^16 //doping density in cm^-3
Nd=10^16 //in cm^-3
tau_p0=5*10^-7 //in s
tau_n0=5*10^-7 //in s
Dn=25 //in cm^2/s
Dp=10 //in cm^2/s
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
myu_n=1350 //in cm^2/V*s
myu_p=450 //in cm^2/V*s
V=0.65 //in V
Const=0.0259 //constant for kT/e in V

//Calculation
pn0=ni^2/Nd //in cm^-3
np0=ni^2/Na //in cm^-3
Lp=sqrt(Dp*tau_p0) //in cm
```

```
Ln=sqrt(Dn*tau_n0) //in cm
Js=(((e*Dp*pn0)/Lp)+((e*Dn*pn0)/Lp)) //in A/cm^2
J=Js*(exp(V/Const)-1) //Total current density in A/
    cm^2
sigma=e*myu_n*Nd //in mho/cm
E=J/sigma

mprintf("Electric field value= %1.2f V/cm",E) //The
    answer provided in the textbook is wrong
```

Chapter 7

Metal Semiconductor Junction and Hetero junctions

Scilab code Exa 7.1 Schottkey barrier

```
clc;
clear;
Nd=5*10^16 //Doping level of n-type silicon in cm^-3
Nc=2.8*10^19 //in cm^-3
e=1.6*10^-19 //in J
phi_B0=1.09 //in eV
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Const=0.026 //constant for kT/e in V

//Calculation
phi_n=Const*log(Nc/Nd) //in eV
Vbi=(phi_B0-phi_n) //in eV
xn=((2*epsilon_r*epsilon_0*Vbi)/(e*Nd))^0.5
Emax=(e*Nd*xn)/(epsilon_r*epsilon_0)

mprintf("a) Ideal Schottky barrier height= %0.3f eV\
   n",phi_n)
mprintf("b) Built-in potential barrier= %0.3f V\n",
```

```
Vbi)
mprintf("c) Space charge width at zero bias= %1.3e cm\n",xn)//The answers vary due to round off error
mprintf("d) maximum electric field= %2.2e V cm^-1",Emax) //The answers vary due to round off error
```

Scilab code Exa 7.2 Barrier height

```
clc;
clear;
Nd=2.01*10^7 //Doping level of n-type silicon in cm^-3
Nc=2.8*10^19 //in cm^-3
e=1.6*10^-19 //in J
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
slope=6*10^13
Vbi=0.45 //in V
Const=0.026 //constant for kT/e in V

//Calculation
Nd=2/(e*epsilon_r*epsilon_0*slope) //in cm^-3
phi_n=Const*log(Nc/Nd) //in V
phi_Bn=Vbi+phi_n

mprintf("Actual barrier height= %0.3f V",phi_Bn)
```

Scilab code Exa 7.3 Schottkey barrier

```
clc;
clear;
E=10^4 //Electric field in V/cm
e=1.6*10^-19 //in J
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm

//Calculation
del_phi=sqrt((e*E)/(4*%pi*epsilon_r*epsilon_0))
xm=sqrt(e/(16*%pi*epsilon_r*epsilon_0*E))

mprintf("Schottkybarrier-lowering for Si-metal
    contact= %0.3f V\n",del_phi)
mprintf("maximum barrier height= %1.2e cm",xm)
```

Scilab code Exa 7.4 Reverse saturation current

```
clc;
clear;
A=114 //effective Richardson constant A/K^2*cm^2
e=1.6*10^-19 //in J
T=300 //in K
phi_Bn=0.82 //in eV
const=0.026 //value for kT/e in V

//Calculation
J0=A*T^2*exp(-(phi_Bn/const))

mprintf("Reverse saturation current density= %1.2e A
    /cm^2",J0)
```

Scilab code Exa 7.5 Energy Band

```
clc;
clear;
xGe=4.13  //in eV
xGaAs=4.07 //in eV
Eg_Ge=0.7 //in eV
Eg_GaAs=1.45 //in eV

//Calculation
delE_c=xGe-xGaAs
delE_v=(Eg_GaAs-Eg_Ge)-delE_c

mprintf("Conduction band= %1.2f eV\n",delE_c)
mprintf("Valence band= %1.2f eV",delE_v)
```

Scilab code Exa 7.6 Schottkey diode

```
clc;
clear;
Nd=3*10^15 //Doping level of n-type silicon in cm^-3
Nc=2.8*10^19 //in cm^-3
e=1.6*10^-19 //in J
phi_m=4.5 //work function for chromium in eV
epsilon_si=11.7 //in F/cm
epsilon_0=8.854*10^-14 //in F/cm
xsi=4.01 //electron affinity for Si in eV
Vbi=5 //reverse bias voltage in V
```

```
VR=0 //in V

//Calculation
phi_B=phi_m-xsi //in eV
xn=((2*epsilon_si*epsilon_0*(Vbi+VR))/(e*Nd))^0.5 //
    in cm
Emax=(e*Nd*xn)/(epsilon_si*epsilon_0)
CJ=((e*epsilon_si*epsilon_0*Nd)/(2*(Vbi+VR)))^0.5

mprintf("a)\n")
mprintf("ideal schottky barrier height= %1.2f ev\n",
    phi_B)
mprintf("b)\n")
mprintf("peak electric field= %1.2e V/cm\n",Emax)
mprintf("c)\n")
mprintf("depletion layer capacitance per unit area=
    %1.2e F/cm^2",CJ) //The answer provided in the
    textbook is wrong
```

Scilab code Exa 7.9 Energy Band

```
clc;
clear;
phi_m=4.3 //work function in eV
xsi=4 //electron affinity in eV
p0=10^17 //in cm^-3
Na=10^17 //in cm^-3
ni=1.5*10^10 //in cm^-3
delE_fc=0.957 //in eV
Const=0.0259 //constant value for kT in eV

//Calculation
delE_if=Const*log(p0/ni)
```

```

//a) Before contact
phi_s=xsi+delE_fc

//b) After contact
phi_B=phi_m-xsi
eV0=phi_s-phi_m

mprintf("Energy state difference= %.3f eV\n",delE_if)
mprintf(" a)phi_s= %.3f eV\n",phi_s)
mprintf(" b)Forward Bias (phi_B)= %.1f eV\n",phi_B)
mprintf("   eV0= %.3f eV",eV0) //The answer provided in the textbook is wrong
```

Scilab code Exa 7.10 `Work function of Semiconductor`

```
clc;
clear;
ni=1.5*10^10 //in cm^-3
delE_iF=0.0259 //in eV
delE_cF=0.29 //in eV
phi_G=4.8 //in eV
impurity_conc=9.9*10^14 //in cm^-3
affinity=0.55 //in eV
Const=0.0259 //constant value for kT in eV
x=4.05 //electron affinity for silicon in eV

//Calculation
//a)
n0=ni*exp(delE_iF/Const) //in cm^-3
phi_s=x+delE_cF

```

```
//b)
Ptype_conc=impurity_conc-n0 //net concentration of p
    -type on B side in cm^-3
delE_iF_Bside=Const*log(Ptype_conc/ni) //in eV
phi_s_Bside=x+delE_iF_Bside+affinity

//d)
ni1=8*10^12 //increased ni in cm^-3
delE_iF1=Const*log(n0/ni1) //in eV
phi_s1=x+(affinity-delE_iF1)

mprintf("electron doping concentration = %.1e cm^-3\
    n",n0) //The answer provided in the textbook is
    wrong
mprintf("workfuntion of the semiconductor = %.2f eV\
    n",phi_s)
mprintf("workfuntion of the semiconductor on B side
    = %.2f eV\n",phi_s_Bside) //The answer provided
    in the textbook is wrong
mprintf("workfuntion of the semiconductor at 400K =
    %.2f eV ",phi_s1) //The answer provided in the
    textbook is wrong
```

Chapter 8

Bipolar Junction Transistors

Scilab code Exa 8.1 Common base current gain

```
clc;
clear;
iC=21 //collector current in mA
iE=21.4 //Emitter current in mA

//Calculation
alpha=iC/iE

mprintf("common-base current gain= %1.2f",alpha)
```

Scilab code Exa 8.2 minority carrier concentration

```
clc;
clear;
ni=1.5*10^10 //in cm^3
Na=5*10^16 //in cm^3
Nd=5*10^18 //in cm^3
```

```
VBE=0.6 //in V
WB=3*10^-4 //in cm
Const=0.026 //constant for kT/e in V

//Calculation
//a)
np0=ni^2/Na //in cm^-3
deln_x=(np0/WB)*(((exp(VBE/Const)-1)*(2/3*WB))-WB/3)

//b)
deln_x1=(np0/WB)*(exp(VBE/Const)-1)*WB

mprintf("Excess minority carrier concentration at x=
   WB/3 = %1.2e cm^-3\n",deln_x) //The answers vary
   due to round off error
mprintf("Excess minority carrier concentration at x
   =0 = %1.2e cm^-3\n",deln_x1) //The answers vary
   due to round off error
```

Scilab code Exa 8.3 collector emitter voltage

```
clc;
clear;
alpha_F=0.98
alpha_R=0.18
IC=2 //current in mA
IB=0.06 //current in mA
Const=0.026 //constant for kT/e in V

//Calculation
VCE=Const*log((((IC*(1-alpha_R))+IB)/((alpha_F*IB)
   -((1-alpha_F)*IC)))*(alpha_F/alpha_R))

```

```
mprintf("Collector-emitter voltage at saturation= %1
    .2f V",VCE)
```

Scilab code Exa 8.4 common emiiter amplifier

```
clc;
clear;
RL=3 //load resistor in ohm
hie=1*10^3 //in ohm
hre=2*10^-4 //in mho
hfe=25 //in mho
hoe=15*10^-6 //in mho

//Calculation
gm=hfe/hie
Ave=-gm*RL*10^3

mprintf("Transconductannce= %0.3f mho\n",gm)
mprintf("Voltage gain= %0.2i",Ave)
```

Scilab code Exa 8.5 npn transistor

```
clc;
clear;
IE=1.5*10^-3 //in mA
Cje=1.2*10^-12 //in F
Dn=25 //in cm^2/s
WB=0.4*10^-4 //in cm
Wdc=2.5*10^-4 //in cm
```

```
vs=10^7 //in cm/s
Rc=25 //in ohm
CBC=0.15*10^-12 //in F
CS=0.12*10^-12 //in F
Const=0.026 //constant for kT/e in V

//Calculation
Re=Const*(1/IE) //in ohm
tau_e=Re*Cje //emitter-base junction charging in s
tau_b=WB^2/(2*Dn) //transit time in the base in s
tau_d=Wdc/vs //collector depletion region transit
    time in s
tau_c=Rc*(CBC+CS) //collector capacitance charging
    time in s
tau_D=tau_e+tau_b+tau_d+tau_c
fT=1/(2*%pi*(tau_D))

mprintf("Total emitter-to-collector delay time= %0.2
    e s\n",tau_D)
mprintf("cut-of frequency of transistor= %0.2e Hz",
    fT)
```

Scilab code Exa 8.7 npn transistor

```
clc;
clear;
Wb=0.5*10^-6 //width of base region in m
Dp=15*10^-4 // in m^2/s

//Calculation
tau_n=Wb^2/(2*Dp) //in s
tau_B=tau_n //in s
fT=1/(2*%pi*tau_B)
```

```
mprintf("a) upper frequency limit= %1.2e Hz",fT)
```

Chapter 9

Field effect Transistor

Scilab code Exa 9.1 JFET

```
clc;
clear;
Nd=5*10^16 //in cm^-3
Na=10^19 //in cm^-3
d=1.2*10^-4 //in cm
e=1.6*10^-19// in J
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
L=18*10^-4 //in cm
W=80*10^-4 //in micro-W
myu_n=1350 //in cm^2/V*s
ni=1.5*10^10 //in cm^3
VGS=0 //in V
Const=0.026 //constant for kT/e in V

//Calculation
Vp=(e*Nd*d^2)/(2*epsilon_r*epsilon_0) //Pitch-off
    voltage in V
Ip=(W*myu_n*e^2*Nd^2*d^3)/(epsilon_r*epsilon_0*L) //
    Pitch-off current in A
Vbi=Const*log((Na*Nd)/ni^2) //in V
```

```
ID=Ip*(1/3-((VGS+Vbi)/Vp)+(2/3)*((VGS+Vbi)/Vp)^3/2)

mprintf("a) Pitch-off voltage= %1.1f V\n",Vp)
mprintf("b) Pitch-off current= %.3e A\n",Ip)
mprintf("c) Drain current at pinch-off= %.2e A",ID) //The answers vary dueto round off error
```

Scilab code Exa 9.2 MESFET

```
clc;
clear;
e=1.6*10^-19 //in eV
epsilon_r=13.1 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Nc=4.7*10^17 //in cm^-3
Nd=3*10^15 //in cm^-3
phi_Bn=0.9 //barrier height in V
VT=0.3 //threshold voltage in V
Const=0.026 //constant for kT/e in V

//Calculation
phi_n=Const*log(Nc/Nd) //in V
Vbi=phi_Bn-phi_n //built-in voltage in V
Vp=Vbi-VT //pinch-off voltage in V
d=sqrt((2*epsilon_r*epsilon_0*Vp)/(e*Nd))

mprintf("Channel thickness= %0.2e m",d)
//The answer provided in the textbook is wrong
```

Scilab code Exa 9.3 Space charge width

```
clc;
clear;
e=1.6*10^-19 //in J
epsilon_r=11.7 //in F/cm
epsilon_0=8.85*10^-14 //in F/cm
Na=5*10^16 //in cm^-3
ni=1.5*10^10 //in cm^-3
Const=0.026 //constant for kT/e in V

//Calculation
phi_pF=Const*log(Na/ni) //in V
WdT=((4*epsilon_r*epsilon_0*phi_pF)/(e*Na))^0.5

mprintf("Maximum space-charge width= %0.2e meter",
    WdT)
//The answer provided in the textbook is wrong
```

Scilab code Exa 9.4 Work function difference

```
clc;
clear;
phi_m=3.20 //in V
Na=10^15 //in cm^-3
ni=1.5*10^10 //in cm^-3
x=3.25
Eg=1.11 //in eV
e=1.6*10^-19 //in J
Const=0.026 //constant for kT/e in V

//Calculation
phi_pF=Const*log(Na/ni) //in V
```

```
phi_ms=(phi_m-(x+(Eg/2)+phi_pF))

mprintf("work−function difference= %0.3f V",phi_ms)
```

Scilab code Exa 9.5 MOSFET

```
clc;
clear;
ID_sat=5*10^-3 //in mA
L=1.3*10^-4 //in micro−m
myu_n=660 //in cm^2/V*s
Cox=7*10^-8 //in F/cm^2
VGS=5 //in V
VT=0.66 //in V

//Calculaation
Z=(ID_sat*2*L)/(myu_n*Cox*(VGS-VT)^2)

mprintf("Channel width= %.2e cm",Z)
```

Scilab code Exa 9.6 MOSFET

```
clc;
clear;
epsilon_0=8.854*10^-14 //in F/cm
epsilon_r=11.8 //in F/cm
epsilon_i=3.9 //in F/cm
d=100*10^-8 //gate oxide thickness in cm
phi_ms=-1.5 //in V
```

```
Qi=5*10^10*1.6*10^-19 //fixed oxide charge in C/cm^2
Na=10^18 //in cm^-3
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in J
VB=2.5 //in V
const=0.0259 //value for kT/e in V

//Calculation
Ci=(epsilon_0*epsilon_i)/d //in F/cm^2
VFB=phi_ms-(Qi/Ci) //in V
phi_F=const*log(Na/ni) //in V
W=sqrt((2*epsilon_0*epsilon_r*(2*phi_F))/(e*Na)) //in cm
Qd=-e*Na*W //in C
VT=VFB+(2*phi_F)-(Qd/Ci) //in V
Wm=sqrt((2*epsilon_0*epsilon_r*((2*phi_F)+VB))/(e*Na)) //in cm
Qd1=-e*Na*Wm //in C
VT1=VFB+(2*phi_F)-(Qd1/Ci) //in V

mprintf("Voltage of n-channel Si(1)= %1.2f V\n",VT)
mprintf("Voltage of n-channel Si(2)= %1.3f V",VT1)
//The answers vary due to round off error
```

Scilab code Exa 9.7 MOS

```
clc;
clear;
epsilon_0=8.854*10^-14 //in F/cm
epsilon_r=11.8 //in F/cm
epsilon_i=3.9 //in F/cm
d=80*10^-8 //gate oxide thickness in cm
phi_ms=-0.15 //work-function difference in V
```

```
Qi=10^11*1.6*10^-19 //fixed oxide charge in C/cm^2
Nd=5*10^17 //in cm^-3
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in J
const=0.0259 //value for kT/e in V

//Calculation
phi_F=const*log(Nd/ni) //in V
Wm=2*sqrt((epsilon_0*epsilon_r*abs(phi_F))/(e*Nd)) //in cm
Qd=e*Nd*Wm //depletion charges in C
Ci=(epsilon_0*epsilon_i)/d //in F/cm^2
VT=phi_ms-(Qi/Ci)-(Qd/Ci)-(2*phi_F)

mprintf("Voltage of n-channel= %1.2f V",VT)
```

Chapter 10

Opto electronic Devices

Scilab code Exa 10.1 Thickness of Si

```
clc;
clear;
alpha=10^2 //absorption coefficient in cm^-1
absorption=0.2 //80% absorption represented in
   decimal format

//Calculation
d=(1/alpha)*log(1/absorption)

mprintf("Thickness of silicon= %.3f cm",d)
```

Scilab code Exa 10.2 open circuit voltage

```
clc;
clear;
Na=3*10^18 //in cm^-3
Nd=2*10^16 //in cm^-3
```

```
Dn=25 //in cm^2/s
Dp=10 //in cm^2/s
tau_n0=4*10^-7 //in s
tau_p0=10^-7 //in s
JL=20*10^-3 //photocurrent density in mA/cm^2
T=300 //in K
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in Joules
Const=0.026 //constant for KT/e in V

//Calculation
Ln=sqrt(Dn*tau_n0) //in mmicro-m
Lp=sqrt(Dp*tau_p0) //in micro-m
JS=e*ni^2*((Dn/(Ln*Na))+(Dp/(Lp*Nd))) //reverse
   saturation current density in A/cm^2
Voc=Const*log(1+(JL/JS))

mprintf("open-circuit voltage Voc= %0.3f V",Voc)
```

Scilab code Exa 10.3 Gain of photoconductor

```
clc;
clear;
L=80*10^-4 //length in m
myu_n=1350 //in cm^2/V
myu_p=480 //in cm^2/V
V=12 //applied voltage in V
tau_n=3.95*10^-9 //transit time in sec
tau_p=2*10^-6 //carrier lifetime in sec

//Calculation
tn=L^2/(myu_n*V) //transit time in sec
Gph=(tau_p/tau_n)*(1+(myu_p/myu_n))
```

```

mprintf("Gain of the photoconductor= %3.1f",Gph)
```

Scilab code Exa 10.4 Photocurrent density

```
clc;
clear;
Na=5*10^16 //in cm^3
Nd=5*10^16 //in cm^3
Dn=25 //in cm^2/s
Dp=10 //in cm^2/s
tau_n0=6*10^-7 //in s
tau_p0=2*10^-7 //in s
VR=6 //in V
GL=5*10^20 //in cm^-3/s
ni=1.5*10^10 //in cm^-3
e=1.6*10^-19 //in Joules
epsilon_s=11.7*8.85*10^-14 //in F/cm
Const=0.026 //constant for KT/e in V

//Calculation
Ln=sqrt(Dn*tau_n0) //in mico-m
Lp=sqrt(Dp*tau_p0) //in micro-m
Vbi=Const*log((Na*Nd)/ni^2) //in V
W=(((2*epsilon_s)/e)*((Na+Nd)/(Na*Nd))*(Vbi+VR))^0.5
    //in micro-m
JL=e*GL*(W+Ln+Lp) //photocurrent density

mprintf("steady-state photocurrent density= %0.2f A/
  cm^2",JL)
```

Scilab code Exa 10.5 Critical angle

```
clc;
clear;
n1=1
n2=3.66

//Calculation
theta_c=asind(n1/n2)

mprintf("Critical angle for GaAs-air interface= %2.1
   f degrees",theta_c)
```

Scilab code Exa 10.6 Doping

```
clc;
clear;
Nd=10^15 //donor atoms in cm^-3
ni=1.45*10^10 //in cm^-3
k=8.62*10^-5 //in eV/K
T=300 //in K
Const=0.025 //coonstant for kT in eV

//Calculation
//a)
n=10^15 //in cm^-3
p=ni^2/Nd //in cm^-3
delE=Const*log(n/ni) //in eV
```

```

//b)
n0=10^15 //in cm^-3
p0=10^12 //in cm^-3
delE_fni=Const*log(n0/ni) //in eV
delE_ifp=Const*log(p0/ni) //in eV

//c)
n1=10^18 //in cm^-3
p1=10^18 //in cm^-3
delE_fni1=Const*log(n1/ni) //in eV
delE_ifp1=Const*log(p1/ni) //in eV

mprintf("a)\nelectron concentration= %.1g cm^-3\n",n)
mprintf("hole concentration= %.2g cm^-3\n",p)
mprintf("Fermi level w.r.t intrinsic fermi level= %0.3f eV\n",delE)
mprintf("b)\nelectron concentration= %.1g cm^-3\n",n0)
mprintf("hole concentration= %.1g cm^-3\n",p0)
mprintf("Quasi fermi level for n-type carrier= %0.3f eV\n",delE_fni)
mprintf("Quasi fermi level for p-type carrier= %0.2f eV\n",delE_ifp)
mprintf("c)\nelectron concentration= %.1g cm^-3\n",n1)
mprintf("hole concentration= %.1g cm^-3\n",p1)
mprintf("Quasi fermi level for n-type carrier= %0.2f eV\n",delE_fni1)
mprintf("Quasi fermi level for p-type carrier= %0.2f eV\n",delE_ifp1)
//The answers vary due to round off error
```

Scilab code Exa 10.7 Wavelengths

```
clc;
clear;
h=4.135*10^-15 //plancks constant in eVs
c=3*10^8 //in m/s
EgGe=0.67 //in eV
EgSi=1.124 //in eV
EgGaAs=1.42 //in eV
EgSiO2=9 //in eV

//Calculation
lamda1=(h*c)/EgGe/10^-6 //in micro-m
lamda2=(h*c)/EgSi/10^-6 //in micro-m
lamda3=(h*c)/EgGaAs/10^-6 //in micro-m
lamda4=(h*c)/EgSiO2/10^-6 //in micro-m

mprintf("Wavelength of radiation for germanium= %1.2
   f micro-m\n",lamda1)
mprintf("Wavelength of radiation for silicon= %1.2f
   micro-m\n",lamda2)
mprintf("Wavelength of radiation for gallium-
   arsenide= %1.2f micro-m\n",lamda3)
mprintf("Wavelength of radiation for SiO2= %1.2f
   micro-m\n",lamda4)
```

Scilab code Exa 10.8 solar cells

```
clc;
clear;
Na=10^18 //in cm^-3
Nd=10^17 //in cm^-3
myu_p=471 //in cm^2/Vs
```

```
myu_n=1417 //in cm^2/Vs
tau_p=10^-8 //in s
tau_n=10^-6 //in s
JL=40 //in mA/cm^2
A=10^-5 //in cm^2
R1=1000 //in ohm
e=1.6*10^-19 //in J
ni=1.45*10^10 //in cm^-3
Vt=0.02586 //constant for kT/e at 300K in V
V=0.1 //in V
n=10 //number of solar cells

//Calculation
//a)
Dp=Vt*myu_p //in cm^2/s
Dn=Vt*myu_n //in cm^2/s
Ln=sqrt(Dn*tau_n) //in cm
Lp=sqrt(Dp*tau_p) //in cm
Js=e*ni^2*((Dp/(Nd*Lp))+(Dn/(Na*Ln))) //in A/cm^2
Is=Js*10^-5 //in A
IF=Is*(exp(V/Vt)-1) //in A

//b)
IL=40*10^-8 //in A
I=IL-IF //in
X=((10^-3)/(I))*n

mprintf("a)Current= %.2e A\n",IF) //The answers vary
    due to round off error
mprintf("b)Total number of solar cells= %i",X)
```

Scilab code Exa 10.9 `Wavelengths`

```
clc;
clear;
Eg=1.43 //Energy band gap in eV
h=4.14*10^-15 //planck's constant in eV/s
c=3*10^8 //in m/s

//Calculation
lamda=(h*c)/Eg

format("v",8)
disp(lamda,"Wavelength (m)= ") //The answers vary
   due to round off error
```

Scilab code Exa 10.10 `Power efficiency`

```
clc;
clear;
PC=190 //optical Power generated in mW
I=25*10^-3 //in mA
V=1.5 //in V

//Calculation
P=V/I //Electrical Power
n=PC/P

format("v",5)
disp(n/10,"Power conversion efficiency (%)= ")
//The answer provided in the textbook is wrong
```

Chapter 11

Power Devices

Scilab code Exa 11.1 common emiter circuit

```
clear;
clc;
RL=8 //in ohm
VCC=30 //in V

//Calculation
IC_max=VCC/RL
VCE_max=VCC
IC=VCC/(2*RL)
VCE=VCC-(IC*RL)
PT=VCE*IC

mprintf("maximum collector current= %1.2f A\n",
    IC_max)
mprintf("Maximum collector-emiiter voltage= %i V\n",
    VCE_max)
mprintf("Maximum Power rating= %2.2f W",PT)
```

Scilab code Exa 11.2 `MOSFET`

```
clear;
clc;
VDD=25 //voltage axis intersection point in V
ID=4 //current in A

//Calculation
RD=VDD/ID
ID=VDD/(2*RD)
VDS=VDD-(ID*RD)
PT=VDS*ID

mprintf("Drain Resistance= %1.2f ohm\n",RD)
mprintf("Drain current at maximum power ditribution
   point= %i A\n",ID)
mprintf("drain-to-source voltage at maximum power
   dissipation point= %2.1f V\n",VDS)
mprintf("Maximum power dissipation= %i W",PT)
```

Scilab code Exa 11.3 `common emitter current gain`

```
clear;
clc;
beta1=20 //bjt gain
beta2=20 //bjt gain

//Calculation
```

```
beta0=beta1+beta2+(beta1*beta2)

mprintf("net common-emitter current gain= %g",beta0)
```

Scilab code Exa 11.4 Power BJT

```
clear;
clc;
TJ_max=150 //in C
Tamb=27 //in C
Rth_dp=1.7 //Thermal resistance in C/W
Rth_pa=40 //in C/W
Rth_ps=1 //in C/W
Rth_sa=4 //in C/W

//Calculation
PD1_max=(TJ_max-Tamb)/(Rth_dp+Rth_pa)
PD2_max=(TJ_max-Tamb)/(Rth_dp+Rth_sa+Rth_ps)

mprintf("Case(a):No heat sink used :-Maximum power
    distribution= %1.2f W\n",PD1_max)
mprintf("Case(b):Heaat sink used :- Maximum power
    distribution= %2.2f W",PD2_max)
```

Scilab code Exa 11.5 BJT

```
clear;
clc;
B=10 //current gain
```

```
IB=0.6 //in A
VBE=1 //in V
RC=10 //in ohm
VCC=100 //in Vs

//Calculation
IC=B*IB //in A
VCE=VCC-(IC*RC) //in V
VCB=VCE-VBE //in V
PT=(VCE*IC)+(VBE*IB)

mprintf("Total power dissipation= %.1f W",PT)
disp("The BJT is working outside the SOA")
```

Scilab code Exa 11.6 BJT

```
clear;
clc;
Beff=250 //effective gain
B1=25 //current gain of transistor
B2=8.65 //effective gain of Darlington-pair
iB=50*10^-3 //in A

//Calculation
iC2=iB*(Beff-B1)
iE2=(1+(1/B2))*iC2

mprintf("Emitter current= %2.2f A",iE2)
```

Scilab code Exa 11.7 UJT

```
clear;
clc;
VBB=24 //in V
r1=3 //in k-ohm
r2=5 //in k-ohm

//Calculation
n=r1/(r1+r2)
VP=(n*VBB)+0.7

mprintf("peak-point voltage= %1.1f V",VP)
```

Scilab code Exa 11.8 Power BJT

```
clear;
clc;
Rth_sink=4 //resistance in C/W
Rth_case=1.5 //in C/W
T2=200 //Temperature in C
T1=27 //Room temperature in C
P=20 //power in W

//Calculation
Rth=(T2-T1)/P
Tdev=T2
Tamb=T1
Rth_dp=Rth
Rth_ps=Rth_case //case-sink resistance
Rth_sa=Rth_sink //sink-ambient resistance
PD=(Tdev-Tamb)/(Rth_dp+Rth_ps+Rth_sa)

```

```
mprintf("Actual power dissipation= %2.2f W",PD) //
   The answers vary due to round off error
```

Scilab code Exa 11.9 GaAs BJT

```
clear;
clc;
Tj=400 //junction temperature in Celsius
TA=50 //ambient temperature in Celsius
P=90 //power supplied in Watts
Rth_dp=1.5 //in C/W
convection_coeff=100 //heat convection cofficient in
    W/degree-C*m^2

//Calculation
Rth_sa=((Tj-TA)/P)-Rth_dp
A=1/(Rth_sa*convection_coeff)

format("v",5)
disp(Rth_sa,"Maximum thermal temperature of heat
   sink (C/W)= ") //The answers vary due to round
   off error
format("e",8)
disp(A,"Surface Area (m^2)= ")
```

Chapter 12

Integrated circuits and micro electromechanical Systems

Scilab code Exa 12.1 Resistance

```
clear;
clc;
l=100 //length of resistor in micro-m
w=10 //width of resistor in micro-m
R=0.9 //sheet resistance in k-ohm/n
End_points=0.65*2 //Total contribution of two end
   points

//Calculation
Total_squares=l/w
T=Total_squares+End_points //Total effective sqaures
Reff=T*R

format("v",8)
disp(Reff,"Effective Resistance (k-ohm)= ")
```

Scilab code Exa 12.2 Capacitance

```
clc;
clear;
epsilon_0=8.85*10^-14 //in F/cm
epsilon_i=3.9 //in F/cm
tox=0.5*10^-4 //in cm

//Calculation
C=(epsilon_0*epsilon_i)/tox

format("e",9)
disp(C,"Capacitance per unit area (F/cm^2)= ")
//The answer provided in the textbook is wrong
```

Scilab code Exa 12.3 Resistance

```
clear;
clc;
Length=4 //in micro-m
Width=1 //in micro-m
R=1000 //in ohm
xj=1*10^-4 //junction depth in cm

//Calculation
N=Length/Width
R0=R/N
rho=R0*xj
```

```
mprintf("Sheet resistance= %i ohm\n",R0)
mprintf("average resistivity= %0.3f ohm-cm",rho)
```

Chapter 13

Microwave Devices

Scilab code Exa 13.1 GaAs diode

```
clear;
clc;
l=10*10^-6 //length in m
f=10*10^9 //frequency in Hz
n=2*10^14 // n type doping concentration in cm^-3
e=1.6*10^-19 //in J
E=3200 //electric field in V/cm

//Calculation
vd=l*f //converting from m^2 to cm^2
J=e*n*vd
myu=-vd/E

format("v",7)
disp(vd,"Drift velocity (cms^-1)= ")
format("v",9)
disp(J,"current density (A/cm^2)= ")
disp(myu,"negative electron mobility (cm^2/Vs)= ")
   //The answer provided in the textbook is wrong
```

Scilab code Exa 13.2 Drift time and frequency

```
clear;
clc;
drift_length=2*10^-4 //in cm
drift_velocity=2*10^7 //in cm/s

//Calculation
d=drift_length/drift_velocity
f=(drift_velocity*10^-2)/(2*drift_length*10^-2)

format("v",8)
disp(d,"Drift time (s)= ")
disp(f,"Operating frequency (Hz)= ")
```

Scilab code Exa 13.3 Avalanche zone velocity

```
clear;
clc;
J=20*10^3 //in kA/cm^2
e=1.6*10^-19 //in C
Nd=2*10^15 //in cm^-3

//Calculation
vz=J/(e*Nd)

format("e",9)
disp(vz,"avalanche-zone velocity is (cm/s)= ")
```

Scilab code Exa 13.4 Breakdown voltage

```
clear;
clc;
e=1.6*10^-19 //in eV
Nd=2.8*10^21 // donor doping concentration in m^-3
L=6*10^-6 //length in m
epsilon_s=8.854*10^-12*11.8 // in F/m

//Calculation
Vbd=(e*Nd*L^2)/epsilon_s
Ebd=Vbd/L

format("v",7)
disp(Vbd,"Breakdown voltage is (V)= ")//The answers
    vary due to round off error
format("e",9)
disp(Ebd,"Breakdown electric field is (V/m)= ")
```

Chapter 14

Rectifiers and Power Supplies

Scilab code Exa 14.1 `Half wave rectifier`

```
clear;
clc;
Vm=100 //voltage in V
Rf=1*10^3 //resistance in series in ohm
Rl=4*10^3 //load resistance in ohm

//Calculation
Im=Vm/(Rf+Rl)
Idc=Im/%pi
Irms=Im/2

format("e",8)
disp(Im,"(a)Maximum current Im is (A)= ")
format("e",9)
disp(Idc,"(b)dc component of current Idc is (A)=")
disp(Irms,"(c)rms value of current Irms (A)= ")
```

Scilab code Exa 14.2 Full wave rectifier

```
clear;
clc;
Vm=200 //voltage in V
Rf=500 //resistance in series in ohm
Rl=1000 //load resistance in ohm

//Calculation
Im=Vm/(Rf+Rl)
Idc=(2*Im)/%pi
Irms=Im/sqrt(2)
Y=sqrt((Irms/Idc)^2-1)

mprintf("(a)Maximum current Im= %0.3f A\n",Im)
mprintf("(b)dc component of current Idc= %1.4f A\n",Idc)
mprintf("(c)rms value of current Irms= %1.3f A\n",Irms)
mprintf("(d)Ripple Factor Y= %1.3f",Y) //The answers vary due to round off error
```

Scilab code Exa 14.3 Pi filter circuit

```
clear;
clc;
RL=500 //load resistance in ohm
C1=100*10^-6 //capacitance in F
C2=50*10^-6 //capacitance in F
L=5 //in H
f=50 //frequency in Hz

//Calculation
```

```
Y=0.216/(RL*C1*C2*L*(2*%pi*f)^3)

format("v",8)
disp(Y,"Ripple factor Y= ") //The answers vary due
    to round off error
```

Scilab code Exa 14.4 Zener Diode Power rating

```
clear;
clc;
Iz_min=1492.5*10^-3 //Zener diode current in Ampere
Vz=25 //Zener diode voltage in Volt

//Calculation
Pmin=Vz*Iz_min

mprintf("Minimum Power Rating p= %2.1f W",Pmin)
```