Scilab Textbook Companion for
Semiconductor Physics And Devices
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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 4

1 Introduction to Quantum Mechanics 5

2 Introduction to the quantum theory of solids 9

3 The Semiconductor in Equilibrium 13

4 Carrier Transport Phenomenon 21

5 Non Equilibrium excess careers in semiconductors 26

6 The pn junction 28

7 The pn junction diode 32

8 Metal semiconductors and semiconductor heterojunctions 37

9 The Bipolar transistor 43

10 Fundamentals of the Metal Oxide semiconductor Field Effect Transistor 50

11 Metal semiconductors and semiconductor heterojunctions Additional concepts 57

12 The junction field effect transistor 62

13 Optical devices 69

14 Semiconductor Power Devices **75**

List of Scilab Codes

Exa 1.1 Photon energy 5
Exa 1.2 Broglie wavelength 5
Exa 1.3 Electron in infinite potential well 6
Exa 1.4 Penetration depth of a particle impinging on a potential barrier 7
Exa 1.5 Probability of an electron tunneling through a potential barrier 7
Exa 2.1 Change in kinetic energy 9
Exa 2.2 Lowest allowed energy bandwidth 9
Exa 2.3 Density of States 10
Exa 2.4 The Fermi Dirac Probability Function 10
Exa 2.5 The Fermi Dirac Probability Function 11
Exa 2.6 The Distribution function and the Fermi Energy . . . 11
Exa 2.7 The Distribution function and the Fermi Energy . . . 12
Exa 3.1 Equilibrium Distribution of Electrons and holes 13
Exa 3.2 Equilibrium Distribution of Electrons and holes 13
Exa 3.3 Intrinsic carrier concentration 14
Exa 3.4 Intrinsic fermi level position 14
Exa 3.5 Extrinsic Semiconductor 15
Exa 3.6 Extrinsic Semiconductor 15
Exa 3.7 Statistics of acceptors and donors 16
Exa 3.8 Statistics of acceptors and donors 16
Exa 3.9 Charge Neutrality 17
Exa 3.10 Charge Neutrality 17
Exa 3.11 Charge Neutrality 18
Exa 3.12 Charge Neutrality 18
Exa 3.13 Position of Fermi Energy level 19
Exa 3.14 Position of Fermi Energy level 19

Exa 4.1 Carrier drift 21
Exa 4.2 Carrier drift 21
Exa 4.3 Conductivity 22
Exa 4.4 Carrier diffusion 23
Exa 4.5 Graded impurity distribution 23
Exa 4.6 The Einstein relation 24
Exa 4.7 The hall effect 24
Exa 5.5 Relaxation time 26
Exa 5.6 Quasi Energy Fermi levels 27
Exa 5.10 Surface effects 27
Exa 6.1 Zero applied bias 28
Exa 6.2 Space charge width 28
Exa 6.3 Space charge width 29
Exa 6.4 Space charge width 29
Exa 6.5 Junction capacitance 30
Exa 6.6 Junction capacitance 30
Exa 7.1 pn junction current 32
Exa 7.2 pn junction current 32
Exa 7.3 pn junction current 33
Exa 7.4 pn junction current 34
Exa 7.5 Temperature effects on pn junction 34
Exa 7.6 small signal admittance 35
Exa 7.7 Generation recombination currents 35
Exa 8.1 Shottky barrier diode 37
Exa 8.2 Non ideal effects on barrier height 38
Exa 8.3 Non ideal effects on barrier height 38
Exa 8.4 Current voltage relationship 39
Exa 8.5 Comparison of the schottky barrier diode and the pn junction diode 39
Exa 8.6 Shottky barrier diode and pn junction 40
Exa 8.7 Tunnelling barrier 40
Exa 8.8 Equilibrium electrostatics 41
Exa 9.1 Gain factors 43
Exa 9.2 Gain factors 43
Exa 9.3 Gain factors 44
Exa 9.4 Gain factors 44
Exa 9.5 Non ideal effects 45
Exa 9.6 Non ideal effects 46

Exa 9.7 Non ideal effects 47
Exa 9.8 Breakdown voltage 47
Exa 9.9 Breakdown voltage 48
Exa 9.10 Ebers moll model 48
Exa 9.12 Transistor cut off frequency 49
Exa 10.1 The two terminal MOS structure 50
Exa 10.2 Work function 50
Exa 10.3 Flat band voltage 51
Exa 10.4 Flat band voltage 52
Exa 10.5 Threshold voltage 52
Exa 10.6 Threshold voltage 53
Exa 10.7 Capacitance Voltage characteristics 54
Exa 10.8 Current voltage relationship 54
Exa 10.9 Threshold voltage 55
Exa 10.10 Substrate bias effects 55
Exa 10.11 Cut off frequency 56
Exa 11.1 Mobility variation 57
Exa 11.2 Mobility variation 57
Exa 11.3 narrow channel effects 58
Exa 11.4 Breakdown voltage 59
Exa 11.5 Lightly doped drain transistor 59
Exa 11.6 Radiation and hot electron effect 60
Exa 12.1 Device characteristics 62
Exa 12.2 Device characteristics 63
Exa 12.3 Depletion mode JFET 63
Exa 12.4 Transconductance 64
Exa 12.5 The MESFET 64
Exa 12.6 The MESFET 65
Exa 12.7 The MESFET 65
Exa 12.8 The MESFET channel length modulation 66
Exa 12.9 cut off frequency 67
Exa 12.10 High electron mobility transistor 67
Exa 13.1 Optical absorption 69
Exa 13.2 Electron hole pair generation rate 69
Exa 13.3 Solar cells 70
Exa 13.4 Solar concentration 71
Exa 14.4 Heat sinks and junction temperature 71
Exa 13.5 Photo conductor 72

Exa 13.6 Photo diode 72
Exa 13.7 PIN Photodiode 73
Exa 13.8 Materials 73
Exa 13.9 Quantum efficiency 74
Exa 13.10 Quantum efficiency 74
Exa 14.1 Power transistor characteristics 75
Exa 14.2 Power MOSFET characteristics 75
Exa 14.3 Heat sinks and junction temperature 76

Chapter 1

Introduction to Quantum Mechanics

Scilab code Exa 1.1 Photon energy

```
// Chapter 1_Principles of Quantum Mechanics
//Caption_Photon Energy
//Ex_1//page 3
disp("X-Rays wavelength lambda=0.708*10^-8 cm");
lambda=0.708*(10^-10);//Wavelength
h=6.625*(10^-34);// Plank's constant
c=3*10^8  //speed of light

E=(h*c)/lambda;
printf('The photon energy corresponding to given wavelength is %fd J\n',E)
Evv=E/(1.6*(10^-19));
printf('Energy in the units of ev is %fd eV \n',Evv)
```

Scilab code Exa 1.2 Broglie wavelength

```
// Chapter 1_Principles of Quantum Mechanics
//Caption_Broglie wavelength
//Ex_2//page 5
disp("Velocity of electron is 10^7 cm/s");
h=6.625*(10^-34);// Plank's constant
m=9.11*(10^-31); //Mass of electron
v=10^5;  //Velocity of electron

p=m*v;   //Momentum
printf('Momentum is %fd \n',p)
lambda=(h/p)*10^10;  //De Broglie's wavelength in angstorm
printf('The De Broglie wavelength is %fd Angstorm\n',lambda);
```

Scilab code Exa 1.3 Electron in infinite potential well

```
// Chapter 1_Principles of Quantum Mechanics
//Caption_Electron in an infinite potential well
//Ex_3//page 14
disp("Width of electrons infinite potential well is 5 Angstorm");
h=1.054*(10^-34);// Plank's constant
m=9.11*(10^-31); //Mass of electron
v=10^5;  //Velocity of electron
a=5*(10^-10);
c=1.6*(10^-19);
n1=1;    // assume
En1=((h^2)*(n1^2)*(%pi^2)/(2*m*a^2))/c
printf('Energy in first energy level is %fd eV\n',En1)
n2=2;.....//assume
En2=((h^2)*(n2^2)*(%pi^2)/(2*m*a^2))/c
printf('Energy in first energy level is %fd eV\n',En2)
```

```
n3=3;       //assume
En3=((h^2)*(n3^2)*(%pi^2)/(2*m*a^2))/c
printf('Energy in first energy level is %fd eV\n',
    En3)
```

Scilab code Exa 1.4 Penetration depth of a particle impinging on a potential barrier

```
// Chapter 1_Principles of Quantum Mechanics
//Caption_Penetration depth of a particle impinging
    on a potential barrier
//Ex_4//page 18
v=10^5;             // Given velocity of electron
m=9.11*(10^-31);    // mass of electron
c=1.6*(10^-19)
E=((1/2)*m*(v^2))/c;
V0=2*E;     //Assume that the potential barrier at x
    =0 is twice as large as total energy of the
    incident particle
printf('Energy of the particle is %fd eV\n' ,E)
h=1.054*(10^-34)
d=((h^2)/(2*m*E*c))^(1/2)*10^10;
printf('The distance at which the wave funciton
    magnitude has decayed to e^-1 of its value at x=0
     is %2.1f Angstrom \n',d )
```

Scilab code Exa 1.5 Probability of an electron tunneling through a potential barrier

```
// Chapter 1_Principles of Quantum Mechanics
//Caption_Probability of an electron tunneling
    through a potential barrier
//Ex_5//page 21
```

```
E=2;      //energy of electron in eV
Vo=20;     //potential barrier in eV
w=3;   //width of potential barrier in angstrom
m=9*(10^-31)
h=1.054*(10^-34)
c=1.6*(10^-19)
K=((2*m)*(Vo-E)*c/(h^2))^(1/2)
printf('Factor K is %fd m^-1 \n',K)
l=(-2*K*w*(10^-10))
a=%e^l
x=E/Vo;
T=16*x*(1-x)*a;
printf('Transmission coefficient i.e. the probability of electron to tunnel through the potential barrier is %fd \n',T)
```

Chapter 2

Introduction to the quantum theory of solids

Scilab code Exa 2.1 Change in kinetic energy

```
// Chapter 2_Introduction to the quantum theory of solids
//Caption_Change in kinetic energy of electron
//Ex_1//page 37
v=10^5;
delV=0.01;
m=9.1*10^-31;
c=1.6 *(10^-19)
delE=m*v*delV/c;
printf('Change in kinetic energy for a very small change in velocity of electron is %1.10fd eV \n',delE)
```

Scilab code Exa 2.2 Lowest allowed energy bandwidth

```
// Chapter 2_Introduction to the quantum theory of solids
```

```
//Caption_Lowest allowed energy bandwidth
//Ex_2//page 46

m=9.11*(10^-31)       //mass of electron
h=1.054*(10^-34)
a=5*(10^-10)
c=1.6*(10^-19)      //electron charge
E=((%pi^2)*(h^2))/(2*m*(a)^2)
E2=E/c;
E1= 1.053      // For alpha a=2.628, energy is given in eV
delE=E2-E1
printf('The allowed energy bandwidth is %fd eV\n',delE)
```

Scilab code Exa 2.3 Density of States

```
// Chapter 2_Introduction to the quantum theory of solids
//Caption_Density of States
//Ex_3//page 63
m=9.11*(10^-31)       //mass of electron
h=6.625*(10^-34)
E=1.6*(10^-19)
N=((4*%pi*(2*m)^(1.5))/(h^3))*(E^(1.5))*(2/3)
printf('Density of states per unit volume with energies between 0 and 1 eV is %f states per unit vol \n',N)
```

Scilab code Exa 2.4 The Fermi Dirac Probability Function

```
// Chapter 2_Introduction to the quantum theory of solids
```

```
//Caption_The Fermi Dirac Probability Function
//Ex_4//page 68
Ni=10      //given no. of particles
gi=10      //given no. of quantum states
P=factorial(gi)/(factorial(Ni)*(factorial(gi-Ni)))
       //Possible no of ways of relizing this
   distribution
printf('This distribution can be realized in %i ways
    \n',P)
```

Scilab code Exa 2.5 The Fermi Dirac Probability Function

```
// Chapter 2_Introduction to the quantum theory of
   solids
//Caption_The Fermi Dirac Probability Function
//Ex_5//page 68
Ni=9      //given no. of particles
gi=10      //given no. of quantum states
P=factorial(gi)/(factorial(Ni)*(factorial(gi-Ni)))
       //Possible no of ways of relizing this
   distribution
printf('This distribution can be realized in %i ways
    \n',P)
```

Scilab code Exa 2.6 The Distribution function and the Fermi Energy

```
// Chapter 2_Introduction to the quantum theory of
   solids
//Caption_The Distribution function and the Fermi
   Energy
//Ex_6//page 71
T=300    // Temperature in kelvin
x=3      //x=    (E-Ef)/kT
```

```
fE=100/(1+%e^x);
printf('Probability that an energy level 3kT above
   the Fermi energy is occupied by an electron is %1
   .2fd%%\n',fE)
```

Scilab code Exa 2.7 The Distribution function and the Fermi Energy

```
// Chapter 2_Introduction to the quantum theory of
   solids
//Caption_The Distribution function and the Fermi
   Energy
//Ex_7//page 72
fE=0.01
Ef=6.25    //Fermi energy in eV
a=1/(1-fE)
x=log(a-1)
k=1.38*(10^-23)
T=(-0.30)*1.6*(10^-19)/(k*x)
printf('Temperature at which there is a 1 percent
   probability that an energy state is empty is %3.1
   fd K\n',T)
```

Chapter 3

The Semiconductor in Equilibrium

Scilab code Exa 3.1 Equilibrium Distribution of Electrons and holes

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Equilibrium Distribution of Electrons and
   holes
//Ex_1//page 85
T=300       // Temperatire in kelvin
Nc=2.8*(10^19)      //Effective density of states
   function in the conduction band in per cm cube
delE=0.25      //Fermi energy is 0.25eV below the
   conduction band
k=1.389*(10^-23)      //Boltzmann constant
kT=0.0259
fF=%e^(-delE/(kT))
no=Nc*fF
printf('The thermal equilibrium electron
   concentration in siliconn is %1.2fd per cm^3',no)
```

Scilab code Exa 3.2 Equilibrium Distribution of Electrons and holes

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Equilibrium Distribution of Electrons and holes
//Ex_2//page 87
T=400;
N=1.04*(10^19)
kT=0.0259*(T/300);
Nv=N*(T/300)^(1.5)
po=Nv*(%e^(-0.27/kT))
printf('The thermal equilibrium hole concentration in silicon at T=400K ==%fd per cm^3 \n',po)
```

Scilab code Exa 3.3 Intrinsic carrier concentration

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Intrinsic carrier concentration
//Ex_3//page 90
T1=300;    //Given temperature in kelvin
T2=450;
Nc1=4.7*(10^17)   //effective density of state function in cm^-3
Nv1=7*(10^18)
Eg=1.42       //bandgap energy in eV
kT=0.0259*(T2/T1);
ni1=(Nc1*Nv1*exp((-Eg)/0.0259))^0.5
ni2=(Nc1*Nv1*(T2/T1)^3*exp(-Eg/kT))^0.5
printf('The intrinsic carrier concentration in gallium arsenide at T=300k is %fd per cm cube and at 450k is %fd //cm^3 ', ni1, ni2)
```

Scilab code Exa 3.4 Intrinsic fermi level position

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Intrinsic fermi level position
//Ex_4//page 92
T=300;    //temperature in kelvin
mnr =1.08    //relative effective mass of negative
    charge carrier
mpr=0.56     //relative effective mass of positive
    charge carrier
kT=0.0259
Efm=(3/4)*kT*log(mpr/mnr)     //The intrinsic fermi
    level with respect to the center of bandgap
EfmF=-(Efm)*1000
printf('The intrinsic feremi level in silicon is %1
    .1fd meV below the midgap energy',EfmF)
```

Scilab code Exa 3.5 Extrinsic Semiconductor

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Extrinsic Semiconductor
//Ex_5//page 101
T=300    //temperature in kelvin
Nc=2.8*(10^19);
Nv=1.04*(10^19);    //
Fe=0.25    //Fermi energy is FeeV below the
    conduction band
Eg=1.12    // Bandgap energy of silicon is Eg in eV
no=Nc*exp(-Fe/0.0259);
po=Nv*exp(-(Eg-Fe)/0.0259);
printf('Thermal equilibrium concentration of
    electrons is %1.2fd cm ^-3 and of holes is %1.2fd
     cm^-3 ',no,po)
```

Scilab code Exa 3.6 Extrinsic Semiconductor

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Extrinsic Semiconductor
//Ex_6//page 104
nf=2    //nf=(Ef-Ec)/kT
Fe=52   //Fermi energy is above the conduction band by Fe meV
T=300;
Nc=2.8*(10^19);
F(nf)=2.3 // Value of fermi dirac integral from the graph
no=(2/((%pi)^0.5))*Nc*F(nf)
printf('Electron concentration using fermi dirac integral is %fd per cm cube ',no)
```

Scilab code Exa 3.7 Statistics of acceptors and donors

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Statistics of acceptors and donors
//Ex_7//page 108
T=300;
Nd=10^16    // donor concentration per cm cube
kT=0.0259
Ecd=0.045   //Ec-Ed
Nc=2.8*(10^19);
x=1/(1+(Nc/(2*Nd))*exp(-(Ecd)/kT))
printf('Fraction of total electrons still in the donor state is %fd ',x)
```

Scilab code Exa 3.8 Statistics of acceptors and donors

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Statistics of acceptors and donors
//Ex_8//page 110
```

```
Na=10^16    //Acceptor concentration
kT=0.0259
Nv=1.04*(10^19);
Eav=0.045
x=0.1   //90%of acceptor atoms are ionized
y=(((1/x)-1)*4*Na/Nv);
//(T/300)^1.5*exp(-Eav/kT*(T/300))=y
//By trial and error
printf('Required temperature is 193 K')
```

Scilab code Exa 3.9 Charge Neutrality

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Charge Neutrality
//Ex_9//page 112
T=300    //temperature in kelvin
Nd=10^16    //donor concentration per cm cube
Na=0
ni=1.5*(10^10)   //intrinsic carrier concentration
no=((Nd-Na)/2)+(((Nd-Na)/2)^2+ni^2)^0.5
po=ni^2/no;
printf('The majority carrier electron concentration
   is %fd per cm cube while the minority carrier
   hole concentration is %fd per cm cube',no,po)
```

Scilab code Exa 3.10 Charge Neutrality

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Charge Neutrality
//Ex_10//page 114
T=300    //temperature in kelvin
Nd=5*(10^13)
Na=0
```

```
ni=2.4*(10^13)
no=((Nd-Na)/2)+(((Nd-Na)/2)^2+ni^2)^0.5
po=ni^2/no;
printf('The majority carrier electron concentration is %fd per cm cube while the minority carrier hole concentration is %fd per cm cube',no,po)
```

Scilab code Exa 3.11 Charge Neutrality

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Charge Neutrality
//Ex_11//page 115
T=300    //temperature in kelvin
Na=10^16   //donor concentration per cm cube
Nd=3*(10^15)
ni=1.5*(10^10)   //intrinsic carrier concentration
po=((Na-Nd)/2)+(((Na-Nd)/2)^2+ni^2)^0.5
no=ni^2/po;
printf('The minority carrier electron concentration is %fd per cm cube while the majority carrier hole concentration is %fd per cm cube',no,po)
```

Scilab code Exa 3.12 Charge Neutrality

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Charge Neutrality
//Ex_12//page 116
T=550   //temperature in kelvin
Nc=2.8*(10^19)
Nv=1.04*(10^19)
Eg=1.12   // band gap energy in eV
ni=(Nc*Nv*(T/300)^3*exp(-Eg/0.0259 *(300/T)))^0.5
```

```
//no=1.05*Nd  since the intrinsic carrier concentration to contribute no more than 5 percent of the total electron concentration .
Nd=(ni^2/(1.05-1))^0.5
printf('The required impurity doping concentration is %fd per cm cube',Nd)
```

Scilab code Exa 3.13 Position of Fermi Energy level

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Position of Fermi Energy level
//Ex_13//page 116
T=300    //temperature in kelvin
Na=10^16   // acceptor carrier impurity in per cm cube
Ef=0.20   //Fermi energy is Ef eV below the conduction band edge
Nc=2.8*(10^19)
Nd=Na+(Nc*exp(-Ef/0.0259))
printf('The require donor impurity concentration is %fd per cm cube',Nd)
```

Scilab code Exa 3.14 Position of Fermi Energy level

```
// Chapter 3_The Semiconductor in Equilibrium
//Caption_Position of Fermi Energy level
//Ex_14//page 121
T=300   //temperature in kelvin
kT=0.0259
ni=1.5*(10^10)  //intrinsic carrier concentration
Efa=3*kT    //Ef-Ea=3kT
Eav=0.045
```

```
Efif=Eg/2-(Eav)-(Efa)     //The position of fermi level at the maximum doping
Na=exp(Efif/kT)*ni
printf('Maximum doping is %fd per cm cube',Na)
```

Chapter 4

Carrier Transport Phenomenon

Scilab code Exa 4.1 Carrier drift

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_Carrier drift
//Ex_1//page 134
T=300    //temperature in kelvin
Na=0
e=1.6*(10^-19)
Nd=10^16    //donor concentration in per cm cube
E=10   //Applied electric field in V/cm
ni=1.8*(10^6)
n=(Nd-Na)/2+(((Nd-Na)/2)^2+ni^2)^0.5
p=ni^2/n
muN=8500   //mobility of electron in  gallium
   arsenide in cm^2/V-s
mup=400
J=e*(muN*n+mup*p)*E
printf('The drift current density for this electric
   field is %1.2fd A/cm^2',J )
```

Scilab code Exa 4.2 Carrier drift

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_Carrier drift
//Ex_2//page 143
T=300
sig=16   //CONDUCTIVITY IN (OHM-CM)^-1
Na=10^16    //acceptor doping concentration
e=1.6*(10^-19)
// sig=e*muN*(Nd-Na)
//By trial and error
printf('Doping concentration is 3.5*10^17 cm^-3 and
   mobilityis 400 cm^2/V-S')
```

Scilab code Exa 4.3 Conductivity

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_Conductivity
//Ex_2//page 144
T=300
Nd=5*(10^15)     //donor concentration
R=10    //resistance in kohm
J=50     //current density in A/cm^2
V=5    //voltage  in volts
i=V/R     //current
A=i/J     //cross sectional area
E=100
L=V/E    //length of the resistor
pho=L/(V*A)
// The conductivity of a compensated p-type
   semiconductor is
//pho=e*muP*(Na-Nd)
//where the mobilty is a function of the total
   ionized impurity concentration Na+Nd
//Using trial and error , if
 Na=1.25*(10^16)
 muP=410
```

```
 e=1.6*(10^-19)
sig=e*muP*(Na-Nd)
printf('Conductivity obtained is %1.2fd which is very close to the value we need',sig)
```

Scilab code Exa 4.4 Carrier diffusion

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_Carrier diffusion
//Ex_4//page 150
T=300
d=0.10    //distance in cm over which concentration varies
Dn=225     //diffusion coefficient
e=1.6*(10^-19)
delN=1*(10^18)-7*(10^17)
J=e*Dn*(delN/d)
printf('The diffusion current density is %1.2fd A/cm^3',J)
```

Scilab code Exa 4.5 Graded impurity distribution

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_Graded impurity distribution
//Ex_5//page 153
T=300
x=0    //given 0<x<1 micrometer
Nd=10^16-10^19*x
//Taking the derivative of donor concentration , we have d(ND)/dx=-10^19
e=1.6*(10^-19)
Ex=-(0.0259)*(-10^19)/Nd
```

```
printf('The induced electric field is %1.1fd V/cm',
   Ex)
```

Scilab code Exa 4.6 The Einstein relation

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_The Einstein relation
//Ex_6//page 155
T=300
mu=1000    //mobility of a particular carrier
kT=0.0259
e=1.6*(10^-19)
D=(kT)*mu
printf('Diffusion coefficient is %1.2fd cm^2/s ',D)
```

Scilab code Exa 4.7 The hall effect

```
// Chapter 4_Carrier Transport Phenomenon
//Caption_The Hall Effect
//Ex_7//page 158
L=10^-3    //LENGTH IN M
W=10^-2    //WIDTH IN CM
d=10^-5
Ix=10^-3   //current in Amp
Vx=12.5
e=1.6*(10^-19)
Bz=500    //magnetic field in gauss
Vh=-6.25*10^-3    //hall voltage

//A negative hall voltage for this geometry implies
   that we have an n-type semiconductor
BzT=Bz*10^-4   //magnetic field in tesla
n=-(Ix*BzT)/(e*d*Vh*10^6)
```

```
mun=(Ix*L)/(e*n*Vx*W*d)
printf('Majority carrier concentration is %1.1fd cm^-3 and mobility is %1.1fd cm^2/V-s ',n,mun)
```

Chapter 5

Non Equilibrium excess careers in semiconductors

Scilab code Exa 5.5 Relaxation time

```
// Chapter 5_Non equilibrium excess carriers in semiconductors
//Caption_Relaxation time
//Ex_5//page 190
Nd=10^16    //donor concentration
e=1.6*(10^-19)    //electronic charge
mun=1200    //mobility
sig=e*mun*Nd
epsR=11.7  //dielectric constant for silicon
epso=8.85*(10^-14)
eps=epso*epsR      //permitivity of silicon
taud=eps/sig      //dielectric relaxation time constant
tau=taud*10^12
printf('The dielectric relaxation time constant for this semiconductor is %1.2f ps',tau)
```

Scilab code Exa 5.6 Quasi Energy Fermi levels

```
// Chapter 5_Non equilibrium excess carriers in semiconductors
//Caption_Quasi Energy Fermi Levels
//Ex_6//page 194
T=300    //temperature in kelvin
no=10^15   //carrier concentration
ni=10^10   //intrinsic concentration
po=10^5
deln=10^13   //excess carrier concentration
delp=10^13
EfFi=0.0259*log(no/ni)    //fermi level for thermal equilibrium
EfnEfi=0.0259*log((no+deln)/ni)
EfiEfp=0.0259*log((po+delp)/ni)
printf('Quasi fermi level for electrons in non equilibrium is %1.4f eV and for hholes is %1.3f eV ',EfnEfi,EfiEfp)
```

Scilab code Exa 5.10 Surface effects

```
// Chapter 5_Non equilibrium excess carriers in semiconductors
//Caption_Surface effects
//Ex_10//page 206
gtaupo=10^14
Dp=10
Lp=31.6*(10^-4)
delpo=10^13
s=(Dp/Lp)*((gtaupo/delpo)-1)
printf('Surface recombination velocity is %1.2fd cm/s',s)
```

Chapter 6

The pn junction

Scilab code Exa 6.1 Zero applied bias

```
// Chapter 6_The pn junction
//Caption_Zero applied bias
//Ex_1//page 220
Na=10^18     //acceptor ion concentration
T=300    //temperature in kelvin
Nd=10^15
ni=1.5*(10^10)    //intrinsic ion concentration
Vbi=(0.0259)*log(Na*Nd/(ni^2))
printf('The built in potential barrier is %1.3f V',
   Vbi)
```

Scilab code Exa 6.2 Space charge width

```
// Chapter 6_The pn junction
//Caption_Space charge width
//Ex_2//page 224
T=300
Na=10^16      //acceptor ion concentration
```

```
Nd=10^15      //donor ion concentration
eps=11.7*8.85*(10^-14)
e=1.6*(10^-19)
Vbi=0.635      //built in potential barrier
W=(2*eps*Vbi/e*(Na+Nd)/(Na*Nd))^0.5
Emax=-e*Nd*W/eps
printf('The space charge width is %f cm and the electric field is %f V/cm',W,Emax)
```

Scilab code Exa 6.3 Space charge width

```
// Chapter 6_The pn junction
//Caption_Space charge width
//Ex_3//page 227
Na=10^16    //acceptor ion concentration
T=300    //temperature in kelvin
Nd=10^15
ni=1.5*(10^10)    //intrinsic ion concentration
Vr=5     //Reverse applied voltage
Vbi=0.635
V=Vr+Vbi
W=(2*eps*V/e*(Na+Nd)/(Na*Nd))^0.5
printf('The space charge width is %f cm ',W)
```

Scilab code Exa 6.4 Space charge width

```
// Chapter 6_The pn junction
//Caption_Space charge width
//Ex_4//page 228
T=300
Na=10^18     //acceptor ion concentration
Emax=3*10^5    //Max electric field
Vr=25    //Reverse bias voltage
```

```
eps=11.7*8.85*(10^-14)
e=1.6*(10^-19)
x=eps*(Emax^2)/(2*e*Vr);
Nd=Na*x/(Na-x)
printf('The ntype doping concentration such that the
    maximum electric field is obtained is %f /cm^3',
   Nd)
```

Scilab code Exa 6.5 Junction capacitance

```
// Chapter 6_The pn junction
//Caption_Junction capacitance
//Ex_5//page 230
Na=10^16   //acceptor ion concentration
T=300   //temperature in kelvin
Nd=10^15
ni=1.5*(10^10)   //intrinsic ion concentration
Vr=5    //Reverse applied voltage
Vbi=0.635
V=Vr+Vbi
C=(e*eps*Na*Nd/(2*(V)*(Na+Nd)))^0.5
A=10^-4   //Area of the pn junction
Ca=A*C*10^12
printf('The junction capacitance for the given
   semiconductor is %1.3f pF',Ca)
```

Scilab code Exa 6.6 Junction capacitance

```
// Chapter 6_The pn junction
//Caption_Junction capacitance
//Ex_6//page 232
T=300   //temperature in kelvin
```

```
S=1.32*10^15      //slope of the curve between Vr and (1/c)^2
ni=1.5*(10^10)
Vbi=0.855      //Built in potential barrier
eps=11.7*8.85*(10^-14)
e=1.6*(10^-19)
Nd=2/(e*eps*S)
Na=((ni^2)/Nd)*exp(Vbi/0.0259)
printf('The impurity doping concentration in p+n junction is -acceptor %f cm^-3 and donor %f cm^-3',Na,Nd)
```

Chapter 7

The pn junction diode

Scilab code Exa 7.1 pn junction current

```
// Chapter 7_The pn junction Diode
//Caption_pn Junction current
//Ex_1//page 252
T=300   //temperature in kelvin
ni=1.5*(10^10)    //intrinsic ion concentration
Nd=10^16
Vf=0.60        //forward bias voltage
pno=(ni^2)/Nd
e=1.6*10^-19
pn=pno*exp(Vf/0.0259)
printf('Minority carrier hole concentration is %f cm^-3',pn)
```

Scilab code Exa 7.2 pn junction current

```
// Chapter 7_The pn junction Diode
//Caption_pn Junction current
//Ex_2//page 258
```

```
Na=10^16     //acceptor impurity
Nd=10^16     // donor impurity
ni=1.5*10^10      //intrinsic concentration
Dn=25
Dp=10
tau_po=5*10^-7
tau_no=5*10^-7
epsr=11.7
Js=e*ni^2*((1/Na*(Dn/tau_no)^0.5)+(1/Nd)*(Dp/tau_po)
   ^0.5)*10^9
printf('Ideal reverse satureation current density is
    %f nA/cm',Js)
```

Scilab code Exa 7.3 pn junction current

```
// Chapter 7_The pn junction Diode
//Caption_pn Junction current
//Ex_3//page 258
Jn=20      //electron current density
Jp=5      //hole current density
T=300
Va=0.65
ni=1.5*10^10      //intrinsic concentration
Dn=25
Dp=10
e=1.6*10^-19
tau_po=5*10^-7
tau_no=5*10^-7
epsr=11.7
Na=1/(Jn/((e*(Dn/tau_no)^0.5)*(ni^2*(exp(Va/0.0259)
   -1))))
Nd=1/(Jp/((e*(Dp/tau_po)^0.5)*(ni^2*(exp(Va/0.0259)
   -1))))
printf('The design parameters for this semiconductor
    are Na=%f cm^-3 and Nd=%f cm^-3',Na,Nd)
```

Scilab code Exa 7.4 pn junction current

```
// Chapter 7_The pn junction Diode
//Caption_pn Junction current
//Ex_4//page 261
T=300
Va=0.65
Js=4.15*10^-11
e=1.6*10^-19
J=Js*(exp(Va/0.0259)-1)
mun=1350
Nd=10^16

E=J/(e*mun*Nd)
printf('The electric field required to produce a
    given majority carrier drift is %f V/cm',E)
```

Scilab code Exa 7.5 Temperature effects on pn junction

```
// Chapter 7_The pn junction Diode
//Caption_Temperature effects on pn Junction current
//Ex_5//page 262
T2=310
T1=300
Eg=1.12    //energy band gap
Va1=0.60    //forward bias voltage at 300k
Va2=Eg-((T2/T1)*(Eg-Va1))
delV=Va2-Va1
printf('Change in fprward bias voltage on a pn
    junction with the change in temperature is %f V',
    delV)
```

Scilab code Exa 7.6 small signal admittance

```
// Chapter 7_The pn junction Diode
//Caption_Small signal admittance
//Ex_6//page 272
T=300
tau_po=10^-7
Ipo=0.001
Idq=0.001
Cd=10^9*(1/(2*0.0259))*(Ipo*tau_po)
rd=0.0259/(Idq)       //diffusion resistance
printf('Diffusion capacitance is %1.2f nF and
   diffusion resistance is %1.2f ohm',Cd,rd)
```

Scilab code Exa 7.7 Generation recombination currents

```
// Chapter 7_The pn junction Diode
//Caption_Generation Recombination currents
//Ex_7//page 277
T=300
tau_o=5*10^-7
tau_po=5*10^-7
tau_no=5*10^-7
Na=10^16     //acceptor impurity
Nd=10^16     // donor impurity
ni=1.5*10^10      //intrinsic concentration
epsr=11.7
eps=epsr*8.85*10^-14
V=5      //V=Vbi+VR
e=1.6*10^-19
W=((2*eps/e)*((Na+Nd)/(Na*Nd))*(V))^0.5
Jgen=e*ni*10^9*W/(2*tau_o)
```

```
printf('The ideal reverse saturation current density was calculated in example 2 and it was 4.15810^-11 A/cm^2 and the generation current density calculated here is %f nA/cm^2',Jgen)
```

Chapter 8

Metal semiconductors and semiconductor heterojunctions

Scilab code Exa 8.1 Shottky barrier diode

```
// Chapter 8_Metal Semiconductor and Semiconductor
   heterojunctions
//Caption_Shottky barrier diode
//Ex_1//page 308
T=300    //temperature in kelvin
Nd=10^16    //donor impurity
phi_m=4.55    //metal work function for tungsten
xi=4.01     //electron affinity for silicon
phi_bo=phi_m-xi
phi_n=0.0259*log(2.8*10^19/Nd)
Vbi=phi_bo-phi_n
xn=(2*eps*Vbi/(e*Nd))^0.5     //space charge width
   at zero bias
Emax=e*Nd*xn/eps    //maximum electric field
printf('Theoritical barrier height is %f V, built-in
    potential barrier is %f V and maximium electric
   field is %f V/cm', phi_bo,phi_n,Emax)
```

Scilab code Exa 8.2 Non ideal effects on barrier height

```
// Chapter 8_Metal Semiconductor and Semiconductor
    heterojunctions
//Caption_Non ideal effects on the barrier height
//Ex_3//page 312
E=6.8*10^4
T=300
e=1.6*10^-19
eps=13.1*8.85*10^-14
delphi=(e*E/(4*%pi*eps))^0.5
xm=(e/(16*%pi*eps*E))^0.5*10^8
printf('Position of the maximum barrier height is %1
    .0f Angstorm',xm)
```

Scilab code Exa 8.3 Non ideal effects on barrier height

```
// Chapter 8_Metal Semiconductor and Semiconductor
    heterojunctions
//Caption_Non ideal effects on the barrier height
//Ex_3//page 312
E=6.8*10^4
T=300
e=1.6*10^-19
eps=13.1*8.85*10^-14
delphi=(e*E/(4*%pi*eps))^0.5
xm=(e/(16*%pi*eps*E))^0.5*(10^8)
printf('Position of maximum barrier height is %fA',
    xm)
```

Scilab code Exa 8.4 Current voltage relationship

```
// Chapter 8_Metal Semiconductor and Semiconductor heterojunctions
//Caption_Current voltage relationship
//Ex_4/page 318
phi_bn=0.67    //barrier height
Jst=6*10^-5    //reverse saturation current density
T=300
e=1.6*10^-19
A=Jst/(T^2)*exp(phi_bn/0.0259)
printf('The effective Richardson constant is %1.0f A/K^2-cm^2',A)
```

Scilab code Exa 8.5 Comparison of the schottky barrier diode and the pn junction diode

```
// Chapter 8_Metal Semiconductor and Semiconductor heterojunctions
//Caption_Comparison of the schottky barrier diode and the pn junction diode
//Ex_5/page 319
e_phi_bn=0.67
A=114     //effective richardson constant
T=300
Jst=A*T^2*exp(-e_phi_bn/0.0259)
//if we neglect the barrier lowering effect , we have for the schottky barrier diode
//for a pn junction
Na=10^18
Nd=10^16
Dp=10
Dn=25
tau_po=10^-7
tau_no=10^-7
```

```
Lp=(Dp*tau_po)^0.5
Ln=(Dn*tau_no)^0.5
pno=2.25*10^4
npo=2.25*10^2
//the ideal reverse saturation current density of
   the pn junction diode can be determined as
Js=e*Dn*npo/Ln+(e*Dp*pno/Lp)
J=10^9*(Js+5.7*10^-13)
printf('Reverse saturation current density for
   schottky baarier diode is %f A/cm^2 and for pn
   junction is %f nA/cm^2',Jst,J)
```

Scilab code Exa 8.6 Shottky barrier diode and pn junction

```
// Chapter 8_Metal Semiconductor and Semiconductor
   heterojunctions
//Caption_Shottky barrier diode and pn junction
//Ex_6//page 308
Jf=10   //forward biased current density
Jst=5.98*10^-5
Va=(0.0259*log(Jf/Jst))
//for pn junction diode
Js=3.66*10^-11    //reverse saturation current
   density
Va_pn=0.0259*log(Jf/Js)
printf('Forward bised voltage required for schottky
   is %1.3f V  and for pn junction is %1.3fV',Va,
   Va_pn)
```

Scilab code Exa 8.7 Tunnelling barrier

```
// Chapter 8_Metal Semiconductor and Semiconductor
   heterojunctions
```

```
//Caption_Tunnelling barrier
//Ex_7//page 325
T=300   //temperature in kelvin
Nd=7*10^18    //donor impurity
e=1.6*10^-19
phi_bn=0.67     //schottky barrier
Vbi=phi_bn    //assumption with neglection of barrier lowering effect
eps=11.7*8.85*10^-14
xn=(2*eps*Vbi/(e*Nd))^0.5
x=10^8*xn
printf('The space charge width is %1.0f Angstorm',x)
```

Scilab code Exa 8.8 Equilibrium electrostatics

```
// Chapter 8_Metal Semiconductor and Semiconductor heterojunctions
//Caption_Equilibrium electrostatics
//Ex_8//page 333
Nd=10^16    //donor impurity
Na=10^16    //acceptor impurity
ni=2.4*10^13     //intrinsic ion concentration
T=300
e=1.6*10^-19
xi_n=4.13     //electron affinity
xi_p=4.07
del_Ec=(xi_n-xi_p)    //difference between two conduction band energies
del_Eg=1.43-0.67

del_Ev=del_Eg-del_Ec    //difference between two valence band energies
pno=ni^2/Nd
Ncp=6*10^18
Ncn=7*10^18
```

```
Vbi=del_Ev+(0.0259*log(Na*Ncp/(pno*Ncn)))
printf('Difference between two conduction band energies is %1.2f eV ,difference between two valence band energies is %f eV and Vbi=%fV',del_Ec,del_Ev,Vbi)
```

Chapter 9

The Bipolar transistor

Scilab code Exa 9.1 Gain factors

```
// Chapter 9_The bipolar transistor
//Caption_Gain factors
//Ex_1//page 371
gamma=0.9967      //emitter injection efficiency
   factor
Nbe=(1/gamma)-1     //base to emitter doping
   concentration ratio
NEB=1/Nbe
printf('The emitter doping concentration must be
   much larger i.e.%1.0ftimes that of base',NEB)
```

Scilab code Exa 9.2 Gain factors

```
// Chapter 9_The bipolar transistor
//Caption_Gain factors
//Ex_2//page 372
alpha_T=0.9967
Db=10
```

```
tau_bo=10^-7
xbLb=abs(acosh(alpha_T))    //xB/Lb where LB is the
   length
Lb=(Db*tau_bo)^0.5
xb=xbLb*Lb*10^4
printf('Base width required to achieve the given
   base transport factor is %1.3f micrometer',xb)
```

Scilab code Exa 9.3 Gain factors

```
// Chapter 9_The bipolar transistor
//Caption_Gain factors
//Ex_3//page 373
delta=0.9967      //recombination favtor
T=300
Jro=10^-8
Jso=10^-11
del=1/delta-1
x=del*Jso/Jro
Vbe=-2*0.0259*log(x)
printf('Forward biased BE voltage required to
   achieve the given delta is %1.3f V',Vbe)
```

Scilab code Exa 9.4 Gain factors

```
// Chapter 9_The bipolar transistor
//Caption_Gain factors
//Ex_4//page 373
DE=10
DB=25
XB=0.70*10^-4    //width of base
XE=0.50*10^-4     //width of emitter
NE=10^18    //doping concentration in emitter
```

```
NB=10^16    //doping concentration in base
VBE=0.65
e=1.6*10^-19
tau_eo=10^-7    //minority carrier lifetime in emitter
tau_bo=5*10^-7    //minority carrier lifetime in base
Jro=5*10^-8
T=300
peo=(1.5*10^10)^2/NE
nbo=(1.5*10^10)^2/NB
Le=(DE*tau_eo)^0.5
Lb=(DB*tau_bo)^0.5
gamma_i=1/(1+((peo*DE*Lb*tanh(0.0198))/(nbo*DB*Le*tanh(0.050))))
alpha_T=1/(cosh(XB/Lb))
Jso=e*DB*nbo/(Lb*tanh(XB/Lb))
delta=1/1+(Jro*exp(-VBE/(2*0.0259)/Jso))
delta=0.99986
alpha=gamma_i*alpha_T*delta
beta_i=alpha/(1-alpha)
printf('Common emitter current gain is %1.0f',beta_i)
```

Scilab code Exa 9.5 Non ideal effects

```
// Chapter 9_The bipolar transistor
//Caption_Non ideal effects
//Ex_5//page 376
T=300
e=1.6*10^-19
NB=5*10^16      //doping concentration in base
NC=2*10^15      //doping concentration in collecor
XB=0.70*10^-4    //mettulurgical base width
ni=1.5*10^10      //intrinsic ion concentration
Vbi=0.718     //built-in potential
```

```
Vcb1=2
eps=11.7*8.85*10^-14
xdb1=(2*eps*(Vbi+Vcb1)*NC/(e*NB*(NC+NB)))^0.5
Vcb2=10
xdb2=(2*eps*(Vbi+Vcb2)*NC/(e*NB*(NC+NB)))^0.5
xb1=XB-xdb1     //neutral base width
xb2=XB-xdb2
del_xb=((xb1-xb2)/xb1)*100
printf('The neutral base width changes by %1.0f percent as the C–B voltage changes from 2 to 10 V',del_xb)
```

Scilab code Exa 9.6 Non ideal effects

```
// Chapter 9_The bipolar transistor
//Caption_Non ideal effects
//Ex_6//page 377
DB=25
VBE=0.60
T=300
e=1.6*10^-19
NB=5*10^16      //doping concentration in base
NC=2*10^15      //doping concentration in collecor
XB=0.70*10^-4    //mettulurgical base width
ni=1.5*10^10      //intrinsic ion concentration
nB0=ni^2/NB
xb1=0.648*10^-4
Jc1=e*DB*nB0*exp(VBE/0.0259)/xb1
xb2=0.597*10^-4
Jc2=e*DB*nB0*exp(VBE/0.0259)/xb2
VCE1=2.6
VCE2=10.6
del_JC_VCE=(Jc2-Jc1)/(VCE2-VCE1)
Va=3.20/del_JC_VCE-2.6
printf('The early voltage is %1.0f V',Va)
```

Scilab code Exa 9.7 Non ideal effects

```
// Chapter 9_The bipolar transistor
//Caption_Non ideal effects
//Ex_7//page 382
T=300
NE1=10^18   //emitter doping
NE2=10^19
ni=1.5*10^10      //intrinsic ion concentration
pE01=ni^2/NE1
pE02=ni^2/NE2
//This we did by neglecting bandgap narrowing , if
   we consider it , we get
pE011=pE01*exp(0.030/0.0259)
pE021=pE02*exp(0.1/0.0259)
printf('The thermal equilibrium minority carrier
   concentration increases by a factor of 1.5
   instead of decreasing by a factor of 9.This
   effect is due to bandgap narrowing')
```

Scilab code Exa 9.8 Breakdown voltage

```
// Chapter 9_The bipolar transistor
//Caption_Breakdown voltage
//Ex_8//page 387
Wb=0.5*10^-4     //metallurgical base width
NB=10^16
eps=11.7*8.85*10^-14
e=1.6*10^-19
Vpt=25     //punch through voltage
x=Vpt*2*eps/(e*Wb^2*NB)
```

```
y=x-1
NC=NB/y
xn=(2*eps*(Vpt)*NB/(e*NC*(NB+NC)))^0.5*10000
printf('The collector doping is %1.2f per cm^3 and collector widt is %1.2f micrometer',NC,xn)
```

Scilab code Exa 9.9 Breakdown voltage

```
// Chapter 9_The bipolar transistor
//Caption_Breakdown voltage
//Ex_9//page 390
bet=100   //common emitter current gain
NB=10^17    //base doping concentration
vmin=15    //minimum open base breakdown voltage
BVcbo=(bet)^(1/3)*vmin
printf('To achieve this breakdown voltage, the maximum collector doping concentration should be 7*10^15 cm^-3 from the figure')
```

Scilab code Exa 9.10 Ebers moll model

```
// Chapter 9_The bipolar transistor
//Caption_Ebers Moll model
//Ex_10//page 394
T=300
alpha_f=0.99
alpha_r=0.20
Ic=.001
Ib=50*10^-6
Vt=0.0259
x=Ic*(1-alpha_r)+Ib
y=alpha_f*Ib-((1-alpha_f)*Ic)
z=alpha_f/alpha_r
```

```
VCEsat=Vt*log(x*z/y)
printf('The collector emitter saturation voltage is %1.3f V',VCEsat)
```

Scilab code Exa 9.12 Transistor cut off frequency

```
// Chapter 9_The bipolar transistor
//Caption_Transistor cut off frequency
//Ex_12//page 403
Ie=0.001      //emitter current
Cje=10^-12
xb=0.5*10^-4
vs=10^7
Dn=25
xdc=2.4*10^-4
rc=20
Cu=0.1*10^-12      //B–C junction capacitance
Cs=0.1*10^-12     //collector to substrate capacitance
re=0.0259/Ie
tau_e=re*Cje*10^12    //emitter base junction charging time
tau_b=(xb^2)/(2*Dn) *10^12     //base transit time
tau=xdc/vs*10^12
tau_c=rc*(Cu+Cs)*10^12
tau_ec=(tau_e+tau_b+tau+tau_c)    //total emitter to collector time delay
fT=(10^3)/(2*%pi*tau_ec)
bet=100
fB=fT/bet       //beta cutoff frrequency
printf('Emitter to collector transit time is %1.1f psec and cut off frequency is %1.2f GHz',tau_ec,fT)
```

Chapter 10

Fundamentals of the Metal Oxide semiconductor Field Effect Transistor

Scilab code Exa 10.1 The two terminal MOS structure

```
// Chapter 10_Fundamentals of the Metal Oxide
   Semiconductor Field Effect Transistor
//Caption_The two terminal MOS structure
//Ex_1//page 434
Na=10^16
T=300
eps=11.7*8.85*10^-14
e=1.6*10^-19
ni=1.5*10^10     //intrinsic carrier concentration
phi_fp=0.0259*log(Na/ni)
xdT=10^4*(4*eps*phi_fp/(e*Na))^0.5
printf('The maximum space charge width is %1.2f
   micrometer',xdT)
```

Scilab code Exa 10.2 Work function

```
// Chapter 10_Fundamentals of the Metal Oxide
   Semiconductor Field Effect Transistor
//Caption_Work function
//Ex_2//page 437
phi_m=3.2    //work function for Al-Si junction
xi=3.25    //oxide electron affinity
Eg=1.11
ni=1.5*10^10     //intrinsic carrier concentration
Na=10^14
phi_fp=0.0259*log(Na/ni)
phi_ms=phi_m-(xi+Eg/(2)+phi_fp)
printf('Metal semiconductor work function difference
    is %1.2f V',phi_ms)
```

Scilab code Exa 10.3 Flat band voltage

```
// Chapter 10_Fundamentals of the Metal Oxide
   Semiconductor Field Effect Transistor
//Caption_Flat band voltage
//Ex_3//page 442
Na=10^16
tox=500*10^-8     //oxide thickness
Qss=10^11      //trapped charge per unit area
e=1.6*10^-19
eps_ox=3.9*8.85*10^-14
Cox=eps_ox/tox
QSS=Qss*e
phi_ms=-1.1
Vfb=phi_ms-(QSS/Cox)
printf('Flat band voltage for this MOS capacitor is
   %1.2f V',Vfb)
```

Scilab code Exa 10.4 Flat band voltage

```
// Chapter 10_Fundamentals of the Metal Oxide
   Semiconductor Field Effect Transistor
//Caption_Flat band voltage
//Ex_4//page 445
Na=3*10^16
eps=11.7*8.85*10^-14
eps_ox=3.9*8.85*10^-14
e=1.6*10^-19
Qss=10^11
Vtn=0.65
ni=1.5*10^10     //intrinsic carrier concentration
phi_ms=-1.13
phi_fp=0.0259*log(Na/ni)
xdt=(4*eps*phi_fp/(e*Na))^0.5
QSD=e*Na*xdt
x=Vtn-phi_ms-2*phi_fp
y=(QSD-Qss*e)/eps_ox
z=x/y*10^8
printf('The oxide thickness of this MOS system is %1
   .0f angstorm',z)
```

Scilab code Exa 10.5 Threshold voltage

```
// Chapter 10_Fundamentals of the Metal Oxide
   Semiconductor Field Effect Transistor
//Caption_Threshold voltage voltage
//Ex_5//page 446
T=300
eps=11.7*8.85*10^-14
eps_ox=3.9*8.85*10^-14
```

```
e=1.6*10^-19
ni=1.5*10^10      //intrinsic carrier concentration
Na=10^14    //acceptor impurity concentration
Qss=10^10
tox=500*10^-8      //oxide thickness
phi_ms=-0.83
phi_fp=0.0259*log(Na/ni)
xdt=(4*eps*phi_fp/(e*Na))^0.5
QSD_MAX=e*Na*xdt;
Vtn=(QSD_MAX-Qss*e)*(tox/eps_ox)+phi_ms+2*phi_fp
printf('The threshold voltage of this MOS system is %1.3f V',Vtn)
```

Scilab code Exa 10.6 Threshold voltage

```
// Chapter 10_Fundamentals of the Metal Oxide Semiconductor Field Effect Transistor
//Caption_Threshold voltage voltage
//Ex_6//page 448
tox=650*10^-8
eps=11.7*8.85*10^-14
eps_ox=3.9*8.85*10^-14
Qss=10^10
Vtp=-1
Nd=2.5*10^14
ni=1.5*10^10      //intrinsic carrier concentration
phi_tn=0.0259*log(Nd/ni)
xdt=(4*eps*phi_tn/(e*Nd))^0.5
QSD_MAX=e*Nd*xdt;
phi_ms=-0.35
Vtp2=(-QSD_MAX-Qss*e)*(tox/eps_ox)+phi_ms-2*phi_tn
q=abs(Vtp2)==Vtp
printf('Since Vtp2=Vtp, it is essentially equal to the desired result')
```

Scilab code Exa 10.7 Capacitance Voltage characteristics

```
// Chapter 10_Fundamentals of the Metal Oxide Semiconductor Field Effect Transistor
//Caption_Capacitance Voltage characteristics
//Ex_7//page 455
Na=10^16
tox=550*10^-8     //oxide thickness
eps=11.7*8.85*10^-14
eps_ox=3.9*8.85*10^-14
Cox=eps_ox/tox*10^9
ni=1.5*10^10     //intrinsic carrier concentration
phi_fp=0.0259*log(Na/ni)
xdt=(4*eps*phi_fp/(e*Na))^0.5
Cmin=eps_ox/(tox+(eps_ox/eps)*xdt)*10^9
r=Cmin/Cox
CFB=eps_ox/(tox+(eps_ox/eps)*(0.0259*eps/(e*Na))^0.5) *10^9    //flat band capacitance
r2=CFB/Cox
printf('The value of oxide capacitance, minimum capacitance and flat band capacitance are %1.2f nF, %1.2f nF and %1.2f nF respectively',Cox,Cmin,CFB)
```

Scilab code Exa 10.8 Current voltage relationship

```
// Chapter 10_Fundamentals of the Metal Oxide Semiconductor Field Effect Transistor
//Caption_Current voltage relationship
//Ex_8//page 473
L=1.25*10^-4     //channel length
mun=650    //mobility of electrons
```

```
Cox=6.9*10^-8    //oxide capacitance
Vt=0.65    //thermal voltage
Idsat=4*10^-3 //saturated current
VGS=5
W=2*L*Idsat/(mun*Cox*(VGS-Vt)^2)*10^4
printf('The width of MOSFET such that the specified current is induced is %1.1f micrometer',W)
```

Scilab code Exa 10.9 Threshold voltage

```
// Chapter 10_Fundamentals of the Metal Oxide Semiconductor Field Effect Transistor
//Caption_Current voltage relationship
//Ex_9//page 474
W=15*10^-4    //Width of MosFET
L=2*10^-4    //length of MOSFET
COX=6.9*10^-8     //oxide capacitance
VDS=0.10
ID1=35*10^-6    //DRAIN CURRENT
VGS1=1.5
ID2=75*10^-6
VGS2=2.5
mun=L*(ID2-ID1)/(W*COX*(VGS2-VGS1)*VDS)
printf('The inversion carrier mobility is %1.0f cm^2/V-s',mun)
```

Scilab code Exa 10.10 Substrate bias effects

```
// Chapter 10_Fundamentals of the Metal Oxide Semiconductor Field Effect Transistor
//Caption_Substrate bias effects
//Ex_10//page 478
T=300
```

```
Na=3*10^16
tox=500*10^-8
VSB=1
ni=1.5*10^10     //intrinsic carrier concentration
phi_fp=0.0259*log(Na/ni)
eps_ox=3.9*8.85*10^-14
Cox=eps_ox/tox
delVT=(2*e*eps*Na)^0.5*((2*phi_fp+VSB)^0.5-(2*phi_fp
    )^0.5)/Cox
printf('The change in threshold voltage is %1.2fV',
    delVT)
```

Scilab code Exa 10.11 Cut off frequency

```
// Chapter 10_Fundamentals of the Metal Oxide
    Semiconductor Field Effect Transistor
//Caption_Cut off frequency
//Ex_11//page 484
mun=400     //mobility
L=4*10^-4
VT=1
VGS=3
fT=mun*(VGS-VT)/(2*%pi*L^2)*10^-6
printf('The cut off frequency of this MOSFET  with
    constant mobility is %1.0f MHz',fT)
```

Chapter 11

Metal semiconductors and semiconductor heterojunctions Additional concepts

Scilab code Exa 11.1 Mobility variation

```
// Chapter 11_ Metal-Oxide-Semiconductor Field Effect Transistor:Additional Concepts
//Caption_Mobility variation
//Ex_1//page 509
T=300
Na=3*10^16
ni=1.5*10^10     //intrinsic carrier concentration
phi_fp=0.0259*log(Na/ni)
xdt=(4*eps*phi_fp/(e*Na))^0.5
QSD_MAX=e*Na*xdt;
Eeff=1/eps*QSD_MAX
printf('Effective electric field at threshold is %1.2f V/cm',Eeff)
```

Scilab code Exa 11.2 Mobility variation

```
// Chapter 11_ Metal-Oxide-Semiconductor Field Effect Transistor:Additional Concepts
//Caption_Mobility variation
//Ex_2//page 517
Na=3*10^16
tox=450*10^-8
eps=11.7*8.85*10^-14
e=1.6*10^-19
eps_ox=3.9*8.85*10^-14
ni=1.5*10^10     //intrinsic carrier concentration
L=1.25*10^-4
rj=0.5*10^-4
Cox=eps_ox/tox     //oxide capacitance
phi_fp=0.0259*log(Na/ni)
xdt=(4*eps*phi_fp/(e*Na))^0.5
x=e*Na*xdt/Cox
y=(1+(2*xdt/rj))^0.5-1
delVt=-x*(rj*y/L)      //voltage shift

printf('Threshold voltage shift due to short channel effects is %1.3f V',delVt)
```

Scilab code Exa 11.3 narrow channel effects

```
// Chapter 11_ Metal-Oxide-Semiconductor Field Effect Transistor:Additional Concepts
//Caption_Narrow channel effects
//Ex_3//page 520
Na=3*10^16
tox=450*10^-8     //oxide thickness
fi=%pi/2      //fitting parameter
delVt=0.2
Cox=7.67*10^-8     //oxide capacitance
```

```
xdt=0.18*10^-4
W=10^4*e*Na*(fi*xdt^2)/(Cox*delVt)
printf('The channel width that will limit the
   threshold voltage is %1.2f micrometer',W)
```

Scilab code Exa 11.4 Breakdown voltage

```
// Chapter 11_ Metal-Oxide-Semiconductor Field
   Effect Transistor:Additional Concepts
//Caption_Breakdown voltage
//Ex_4//page 527
Nd=10^19    //donor concentration
Na=10^16    //acceptor concentration
L=1.2*10^-4      //channel length
ni=1.5*10^10      //intrinsic carrier concentration
Vbi=0.0259*log(Na*Nd/ni^2)
xdo=(2*eps*Vbi/(e*Na))^0.5    //zero biased source-
   substrate pn junction width
//xd=(2*eps*(VbiVDS)/(e*Na))^0.5    //reverse biased
   drain substrate pn junction width
xd=L-xdo   //at punch through
VbiVDS=xd^2*e*Na/(2*eps)     //Vbi+VDS
VDS=VbiVDS-Vbi
printf('The punch through voltage is %1.1f V',VDS)
```

Scilab code Exa 11.5 Lightly doped drain transistor

```
// Chapter 11_ Metal-Oxide-Semiconductor Field
   Effect Transistor:Additional Concepts
//Caption_Lightly doped drain transistor
//Ex_5//page 531
tox=500*10^-8
VFBO=-1.25      //initial flat band voltage
```

```
e=1.6*10^-19
eps_ox=3.9*8.85*10^-14
ni=1.5*10^10     //intrinsic carrier concentration
VT=0.70
Na=5*10^15
phi_fpo=0.0259*log(Na/ni)
xdto=(4*eps*phi_fpo/(e*Na))^0.5
Cox=eps_ox/tox
VTO=VFBO+2*phi_fpo+(e*Na*xdto)/Cox
x=VT-VTO
Dt=Cox*x/e    //implant dose
xt=0.15*10^-4    //depth to which uniform implant extends
Nsa=Dt/xt
Ns=Nsa+Na
printf('The required implant dose to achieve the desired threshold voltage is %1.2f per cm^2',Dt)
```

Scilab code Exa 11.6 Radiation and hot electron effect

```
// Chapter 11_ Metal-Oxide-Semiconductor Field Effect Transistor:Additional Concepts
//Caption_Radition and hot electron effect
//Ex_6//page 535
tox=500*10^-8   //oxide thickness
p=0.2    //20% are trapped at oxide semiconductor surface
N=10^18    //electron hole pair
e=1.6*10^-19
eps_ox=3.9*8.85*10^-14
ni=1.5*10^10     //intrinsic carrier concentration
Nh=N*tox    //areal density of holes
Qss=Nh*p    //trapped surface charge density
Cox=eps_ox/tox
delVt=-Qss*e/Cox
```

```
printf('The threshold voltage shift due to radiation induced oxide charge trapping is %1.2f V',delVt)
```

Chapter 12

The junction field effect transistor

Scilab code Exa 12.1 Device characteristics

```
// Chapter 12_The junction field effect transistor
//Caption_Device characteristics
//Ex_1//page 557
T=300
Na=10^18
e=1.6*10^-19
eps=8.85*10^-14*11.7
ni=1.5*10^10
Nd=10^16       //donor concentration
a=0.75*10^-4      //metallurgical channel thichness
Vpo=e*a^2*Nd/(2*eps)      //internal pinch off voltage
Vbi=0.0259*log(Na*Nd/ni^2)      //built in potential barrier
Vp=Vbi-Vpo     //pinch off voltage
printf('The pinch off voltage of this n-channel JFET is %1.2fV',Vp)
```

Scilab code Exa 12.2 Device characteristics

```
// Chapter 12_The junction field effect transistor
//Caption_Device characteristics
//Ex_2//page 558
T=300
Nd=10^18
Na=2*10^16
e=1.6*10^-19
eps=8.85*10^-14*11.7
ni=1.5*10^10
Vp=2.25      //pinchoff voltage
Vbi=0.0259*log(Na*Nd/ni^2)
Vpo=Vp+Vbi
a=(2*eps*Vpo/(e*Na))^0.5*10^4
printf('Metallurgical channel thickness is %1.3f
   micrometer',a)
```

Scilab code Exa 12.3 Depletion mode JFET

```
// Chapter 12_The junction field effect transistor
//Caption_Depletion mode JFET
//Ex_3//page 558
T=300
Na=10^18
e=1.6*10^-19
eps=8.85*10^-14*11.7
Vbi=0.814
Vpo=4.35
ni=1.5*10^10
Nd=10^16
a=0.75*10^-4     //metallurgical channel thickness
```

```
L=10*10^-4    //channel length
W=30*10^-4     //channel width
mun=1000
Ipi=10^3*mun*(e*Nd)^2*W*a^3/(6*eps*L)
IDmax=Ipi*(1-3*(Vbi/Vpo)*(1-(2/3)*(Vbi/Vpo)^0.5))
printf('The maximum current is %1.3f mA while pinch
   off current is %1.3fmA',IDmax,Ipi)
```

Scilab code Exa 12.4 Transconductance

```
// Chapter 12_The junction field effect transistor
//Caption_Transconductance
//Ex_4//page 566
Ipi=0.522*10^-3
Vbi=0.814    //built in potential barrier
Vpo=4.35     //pinch off
VGS=0
gms_max=10^3*3*Ipi*(1-(Vbi/Vpo)^0.5)/Vpo
printf('The maximum transconductance is %1.3f mA/V',
   gms_max)
```

Scilab code Exa 12.5 The MESFET

```
// Chapter 12_The junction field effect transistor
//Caption_The MESFET
//Ex_5//page 567
Nc=4.7*10^17
e=1.6*10^-19
eps=8.85*10^-14*13.1
T=300
phi_bn=0.89     //barrier height
Nd=2*10^15
Vt=0.25
```

```
phi_n=0.0259*log(Nc/Nd)
Vbi=phi_bn-phi_n    //built in potential barrier
Vpo=Vbi-Vt
a=10^4*(Vpo*2*eps/(e*Nd))^0.5
printf('The channel thickness of GaAs is %1.3f micrometer',a)
```

Scilab code Exa 12.6 The MESFET

```
// Chapter 12_The junction field effect transistor
//Caption_The MESFET
//Ex_6//page 568
e=1.6*10^-19
eps=8.85*10^-14*13.1
T=300
ni=1.8*10^6
Na=10^18
Nd=3*10^15
a=0.70*10^-4
Vbi=0.0259*log(Na*Nd/ni^2)
Vpo=e*a^2*Nd/(2*eps)      //internal pinch off voltage
Vt=Vbi-Vpo    //threshold voltage
h=0.6*10^-4
VGS=Vbi-(e*h^2*Nd/(2*eps))
printf('The forward bias voltage required in an n channel GaAs enhancement mode pn jfet to open up a channel is %1.2f V',VGS)
```

Scilab code Exa 12.7 The MESFET

```
// Chapter 12_The junction field effect transistor
//Caption_The MESFET
```

```
//Ex_7//page 570
e=1.6*10^-19
eps=8.85*10^-14*13.1
T=300
ni=1.8*10^6
L=1.2*10^-4
mun=8000
a=0.70*10^-4
Idi=75*10^-6
VGS=0.5
Vt=0.24
kn=Idi/(VGS-Vt)^2    //conduction parameter
W=10^4*kn*2*a*L/(mun*eps)
printf('The required channel width is %1.2f
   micrometer',W)
```

Scilab code Exa 12.8 The MESFET channel length modulation

```
// Chapter 12_The junction field effect transistor
//Caption_The MESFET–Channel length modulation
//Ex_8//page 573
Nd=3*10^15
eps=8.85*10^-14*11.7
L=10
ID1=4
VDSsat=0  //assume
VDS1=VDSsat+2
VDS2=VDSsat+2.5

delL2=10^4*(2*eps*(VDS2-VDSsat)/(e*Nd))^0.5   //
   change in length
delL1=10^4*(2*eps*(VDS1-VDSsat)/(e*Nd))^0.5   //
   change in length
//drain currents are
ID22=ID1*(L/(L-0.5*delL2))
```

```
ID11=ID1*(L/(L-0.5*delL1))
rds=(VDS2-VDS1)/(ID22-ID11)
printf('The small signal output resistance at the drain terminal due to channel length modulation effects is %1.1f kohm',rds)
```

Scilab code Exa 12.9 cut off frequency

```
// Chapter 12_The junction field effect transistor
//Caption_Cutoff frequency
//Ex_9//page 579
e=1.6*10^-19
mun=1000
L=5*10^-4
eps=8.85*10^-14*11.7
a=0.60*10^-4
Nd=10^16
fT=(e*mun*Nd*a^2)/(2*%pi*eps*L^2)*10^-9
printf('The cutoff frequency of silicon JFET with given parameters is %1.2f GHz',fT)
```

Scilab code Exa 12.10 High electron mobility transistor

```
// Chapter 12_The junction field effect transistor
//Caption_High electron mobility transistor
//Ex_10//page 585
Nd=10^18
d=20*10^-8
dd=500*10^-8    //thickness
phi_B=0.85
q=1.6*10^-19
VG=0
epsn=12.2  //relative dielectric constant
```

```
Vp2=q*Nd*dd^2/(2*epsn*8.85*10^-14)    //a parameter
x=0.22     //x=del Ec/q
Voff=phi_B-x-Vp2      //threshold voltage
ns=(VG-Voff)*epsn*8.85*10^-14/(q*(dd+d+80*10^-8))
printf('The two dimensional electron concentration is %1.2f cm^-2',ns)
```

Chapter 13

Optical devices

Scilab code Exa 13.1 Optical absorption

```
// Chapter 13_Optical Devices
//Caption_Optical absorption
//Ex_1//page 598
lambdai1=1*10^-4      //incident wavelength
lambdai2=0.5*10^-4
alpha1=100   //absorption coefficient
d1=1*log(1/0.1)/alpha1      //If 90percent of the
   incident flux is to be absorbed in a distance d ,
    then the flux emerging at x=d will be 10% of the
    incident flux
alpha2=10000
d2=1*log(1/0.1)/alpha2*10^4
printf('As the incident photon energy increases , the
    absorption coefficient increases rapidly since
   d1=%1.4f cm and d2=%1.2f micrometer',d1,d2)
```

Scilab code Exa 13.2 Electron hole pair generation rate

```
// Chapter 13_Optical Devices
//Caption_Electron hole pair generation rate
//Ex_2//page 600
T=300
Ivx=0.05    //photon intensity
lambda=0.75  //wavelength
alpha=0.7*10^4        //absorption coefficient
h=1.24
v=1/lambda // v is the frequency
E=h*v   //energy in eV,
g=alpha*Ivx/(1.6*10^-19*h*v)     //generation rate of electron hole pair
tau=10^-7     //lifetime of minority carrier
deln=g*tau    //excess carrier concentration
printf('The generation rate of electron hole pair is %1.2f cm^-3 s^-1',g)
```

Scilab code Exa 13.3 Solar cells

```
// Chapter 13_Optical Devices
//Caption_Solar cells
//Ex_3//page 602
Na=5*10^18
Nd=10^16
Dn=25
e=1.6*10^-19
ni=1.5*10^10
Dp=10
tau_no=5*10^-7
tau_po=10^-7
JL=15*10^-3    //photocurrent density
Ln=(Dn*tau_no)^0.5
Lp=(Dp*tau_po)^0.5
Js=e*(ni^2)*((Dn/(Ln*Na))+(Dp/(Lp*Nd)))
Voc=0.0259*log(1+JL/Js)
```

```
printf('Open circuit voltage of SI pn juncton solar cell is %1.3f V',Voc)
```

Scilab code Exa 13.4 Solar concentration

```
// Chapter 13_Optical Devices
//Caption_Solar concentration
//Ex_4//page 605
JL==150*10^-3     //PHOTOCURRENT DENSITY
Js=3.6*10^-11    //reverse saturation current density
Voc=0.0259*log(1+JL/Js)
printf('Open circuit voltage when solar concentration is used is %1.3f V',Voc)
```

Scilab code Exa 14.4 Heat sinks and junction temperature

```
// Chapter 14_Semiconductor Power Devices
//Caption_Heat sinks and junction temperature
//Ex_4//page-663
P=20    //Rated power
Tj_max=175     //Junction temperature
TOC=25
Tamb=25    //ambient temperature
Theta_case_snk=1
Theta_snk_amb=5
Theta_dev_case=(Tj_max-TOC)/P
PD_MAX=(Tj_max-Tamb)/(Theta_dev_case+Theta_case_snk+Theta_snk_amb)
printf('Maximum power dissipated is %1.1f W',PD_MAX)
```

Scilab code Exa 13.5 Photo conductor

```
// Chapter 13_Optical Devices
//Caption_Photo conductor
//Ex_5//page 611
mup=480
mun=1350
L=100*10^-4  //length of photoconductor
A=10^-7    //cross sectional area
tau_p=10^-6    //minority carrier lifetime
V=10    //applied voltage
tn=L^2/(mun*V)
//photoconductor gain is
G=(tau_p/tn)*(1+(mup/mun))
printf('The photoconductor gain is %1.2f',G)
```

Scilab code Exa 13.6 Photo diode

```
// Chapter 13_Optical Devices
//Caption_Photodiode
//Ex_6//page 616
Na=10^16
eps=8.85*10^-14;
Nd=10^16
Dn=25
Dp=10
tau_no=5*10^-7
e=1.6*10^-19
ni=1.5*10^10
tau_po=10^-7
VR=5     //reverse bias voltage
GL=10^21    //generation rate of excess carriers
Ln=(Dn*tau_no)^0.5
Lp=(Dp*tau_po)^0.5
Vbi=0.0259*log(Na*Nd/ni^2)
```

```
W=((2*eps/e)*((Na+Nd)/(Na*Nd))*(Vbi+VR))^0.5
JL=e*(W+Ln+Lp)*GL
printf('The steady state photocurrent density is %1
    .2f A/cm^2',JL)
```

Scilab code Exa 13.7 PIN Photodiode

```
// Chapter 13_Optical Devices
//Caption_PIN Photodiode
//Ex_7//page 618
W=20*10^-4   //intrinsic region width
phio=10^17    //photon flux
alpha=10^3    //absorption coefficient
GL1=alpha*phio   //generation rate of electron hole
    pair at the front region
GL2=GL1*exp(-alpha*W)
JL=1000*e*phio*(1-exp(-alpha*W))     //photocurrent
    density
printf('The photocurrent density in PIN photodiode
    is %1.1f mA/cm^2   ',JL)
```

Scilab code Exa 13.8 Materials

```
// Chapter 13_Optical Devices
//Caption_Materials
//Ex_8//page 625
Eg=1.42
lambda=1.24/Eg    //output wavelength of photon
lam=0.653    //desired wavelength
E=1.24/lam     //bandgap energy
printf('The band gap energy corresponding to visible
     given wavelength is %1.2f eV and it would
    correspond to a mole fraction of x=4',E)
```

Scilab code Exa 13.9 Quantum efficiency

```
// Chapter 13_Optical Devices
//Caption_Quantum efficiency
//Ex_9//page 628
n2=3.666     //index of refraction in GaAs
n1=1     //index of refraction in air
T=((n2-n1)/(n2+n1))^2     //reflection coeffucient
printf('The reflection coefficient at semiconductor-
    air interface ius %1.2f',T)
```

Scilab code Exa 13.10 Quantum efficiency

```
// Chapter 13_Optical Devices
//Caption_Quantum efficiency
//Ex_10//page 629
n2=3.66    //index of refraction in GaAs
n1=1     //index of refraction in air
theta=asind(n1/n2)
printf('The critical angle at semiconductor-air
   interface is %1.1f degree',theta)
```

Chapter 14

Semiconductor Power Devices

Scilab code Exa 14.1 Power transistor characteristics

```
// Chapter 14_Semiconductor Power Devices
//Caption_Power transistor characteristics
//Ex_1//page-651
RL=10
Vcc=35
Ic_max=Vcc/RL
Ic=Vcc/(2*RL)
VCE=Vcc-Ic*RL      //Collector emitter voltage at
   maximum power point
PT=VCE*Ic    //Maximum transistor power dissipation
printf('The maximum power dissipation in transistor
   occurs at centre of the load line. The maximum
   power dissipation is therefore %1.1f W',PT)
```

Scilab code Exa 14.2 Power MOSFET characteristics

```
// Chapter 14_Semiconductor Power Devices
//Caption_Power MOSFET characteristics
```

```
//Ex_2//page-658
VDD=24
PT=30   //Maximum rated power
ID1max=5    //Maximum rated current
ID2max=4
RD1=VDD/ID1max      //Drain resistance
RD2=VDD/ID2max
ID1=VDD/(2*RD1)     //Current at the maximum power point
ID2=VDD/(2*RD2)
VDS1=VDD-ID1*RD1      //Drain to source voltage
VDS2=VDD-ID2*RD2
P1=VDS1*ID1   //Maximum power that may be dissipated in transistor
P2=VDS2*ID2
printf('The maximum dissipated power in first case is %1.0f W which corresponds to the maximum rated power while in second case is %1.0f W which is less than the maximum rated power',P1,P2)
```

Scilab code Exa 14.3 Heat sinks and junction temperature

```
// Chapter 14_Semiconductor Power Devices
//Caption_Heat sinks and junction temperature
//Ex_3//page-662
Theta_dev_case=1.75
Theta_case_snk=1
Theta_snk_amb=5
Theta_case_amb=50
Tamb=30  //Ambient temperature
Tdev=150   //maximum junction or device temperature
PD_max=(Tdev-Tamb)/(Theta_dev_case+Theta_case_amb)   //when no heat sink is used
PD_MAX2=(Tdev-Tamb)/(Theta_dev_case+Theta_case_snk+Theta_snk_amb)
```

```
printf('Maximum power dissipated when no sink was used is %1.2f W while with the sink is %1.2f W which is more than the previous case.Thus use of heat sink allows more power to be dissipted in the device.',PD_max,PD_MAX2)
```