Scilab Textbook Companion for Semiconductor Device Physics And Design by U. K. Mishra And J. Singh[1]

Created by
Priyanka Jain
B.Tech. + M.Tech. Dual Degree
Electrical Engineering
IIT Bombay
College Teacher
None
Cross-Checked by

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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

STRUCTURAL PROPERTIES OF SEMICONDUCTORS

Scilab code Exa 1.1 Crystal structure

```
a = 5.43*10^-8; //lattice constant for silicon in cm
N = 8/8 +6/2; // Silicon has a diamond structure
    which is made up of the fcc lattice with two
    atoms on each lattice point. The fcc unit cube
    has a volume a3. The cube has eight lattice sites
     at the cube edges. However, each of these points
     is shared with eight other cubes. In addition,
    there are six lattice points on the cube face
    centers. Each of these points is shared by two
    adjacent cubes.
disp("Silicon has a diamond structure which is made
    up of the fcc lattice with two atoms on each
    lattice point. The fcc unit cube has a volume a3.
     The cube has eight lattice sites at the cube
    edges. However, each of these points is shared
    with eight other cubes. In addition, there are
    six lattice points on the cube face centers. Each
     of these points is shared by two adjacent cubes.
    ")
```

```
disp(N, "Thus, number of lattice points per cube of
   volume a^3 = ")
disp("In silicon there are two silicon atoms per
   lattice point. The number density is, therefore,"
   )
Nsi = N*2/a^3;
disp(Nsi,"in atoms per cm cube")
l = 50*10^-4;
b = 2*10^-4;
h = 1*10^-4;
vol = l*b*h; //volume of the MOSFET
disp(vol, "volume of th MOSFET (in cm cube) = ")
nmos = Nsi*vol;
disp(nmos,"Number of Si atoms in the MOSFET = ")
```

Scilab code Exa 1.2 Surface density

```
a = 5.65*10^-8; //lattice constant in cm
disp("In the (001) surfaces, the top atoms are
   either Ga or As leading to the terminology Ga
   terminated (or Ga stabilized) and As terminated (
   or As stabilized), respectively. A square of area
    a2 has four atoms on the edges of the square and
    one atom at the center of the square. The atoms
   on the square edges are shared by a total of four
    squares. The total number of atoms per square is
   ")
N = 4/4 +1;
disp(N)
density = N/a^2; //Surface density
disp(density, "The surface density (in per cm square
   ) of Ga atoms on a Ga terminated (001) GaAs
   surface")
```

Scilab code Exa 1.2.5.1 Planar density of atoms on a surface

```
a = 5.63*10^-8; //lattice constant in cm
disp("We can form a triangle on the (111) surface of GaAs. There are three atoms on the tips of the triangle. These atoms are shared by six other similar triangles. There are also 3 atoms along the edges of the triangle which are shared by two adjacent triangles. Thus the number of atoms in the triangle are")
N = 3/6 +3/2;
disp(N)
area = 3^0.5/2*a^2; //area of triangle
density = N/area; //The density of GaAs atoms on the surface
disp(density,"The density (in per square cm) of GaAs atoms on the surface = ")
```

Chapter 2

ELECTRONIC LEVELS IN SEMICONDUCTORS

Scilab code Exa 2.1 density of states in 2D and 3D systems

```
m0 = 0.91 * 10^-30; //in kg
h = 1.05*10^-34; //in J.s
E = 1; // energy in eV
q = 1.6*10^-19;
N3 = 2^0.5*(m0*q)^1.5*E^0.5/((%pi)^2*h^3);
disp(N3*10^-6,"The density of states for a 3D system
    in per eV per cm cube")
N2 = m0*q/(%pi*h^2);
disp(N2*10^-4,"The density of states for a 2D system
    in per eV per cm square")
```

Scilab code Exa 2.2 effective density of states for the conduction and valence bands

```
kBT = 26*10^-3; //in eV
m0 = 0.91 * 10^-30; //in kg
```

```
me = 0.067*m0;
q = 1.6*10^-19;
h = 1.05457*10^-34; //in J.s
N = 2*(me*q*kBT/2/%pi/h^2)^1.5;
disp(N*10^-6, "The effective density of states (in
    per cm cube) is")
disp("In silicon, the density of states mass is to
    be used in the effective density of states, which
     is")
kdos = 6^(2/3)*(0.98*0.19*0.19)^(1/3);
disp(kdos,"m0 times");
mdos = kdos*m0;
disp(mdos,"In silicon, the density of states mass is
     to be used in the effective density of states,
    which is")
```

Scilab code Exa 2.5 Piezoelectric Effect

```
//a = 0.3*aAlN + 0.7*aGaN = 3.111
a = 3.111*10^-8; //in cm
q = 1.6*10^-19;
Exx = 0.006; //strain tensor
disp(Exx,"Exx = ")
Ezz = -0.6*0.006;
disp(Ezz,"Ezz = ")
Ppz = 0.0097; //in C/m2
disp("The pizoelectric effect induced polar charge
    then becomes Ppz = 0.0097 C/m2")
disp(Ppz/q*10^-4,"The pizoelectric effect induced
    polar charge (in electron charge per cm2)=")
Psp= 0.3*0.089 + (0.7-1)*0.029;
disp(Psp,"The piezoelectric charge the spontaneous
    polarization charge(in C/m2) is")
disp(Psp/q*10^-4,"The piezoelectric charge the
    spontaneous polarization charge(in electron
```

charge per cm2) =")
```

**Scilab code Exa 2.7.1** Fermi energy and Fermi velocity

```
n = 10^22; // electrons per cm cube
h = 1.05457*10^-34; //in J.s
m0 = 0.91 * 10^-30; //in kg
q = 1.6*10^-19;
E= 0.5*h^2*(3*%pi*%pi*n)^(2/3)/(m0*q);
disp(E*10^4,"The Fermi energy (in eV) is the highest
    occupied energy state at 0 K is")
vel = h*(3*%pi*%pi*n*10^6)^(1/3)/m0;
disp(vel, "The fermi velocity (in m/s) is")
```
```

Chapter 3

CHARGE TRANSPORT IN MATERIALS

Scilab code Exa 3.1 polar optical phonon emission rate

```
opeGaAs = 36; //optical phonon energies in GaAs in
    meV
opeGaN = 90; //optical phonon energies in GaN in meV
disp(opeGaAs,"The optical phonon energies in GaAs (
    in meV)")
disp(opeGaN,"The optical phonon energies in GaN (in
    meV)")
disp ("If the electron energies are below these
    values, there is no phonon emission.The phonon
    occupation number in GaAs at 300 K is 0.33 and in
     GaN is 0.032. Thus above threshold, the emission
     to absorption ratios are approximately 4:1 and
    32:1 respectively.")
```

Scilab code Exa 3.2 transport under an electric field

```
m0 = 0.91 * 10^-30; //in kg
m = 0.26*m0; //effective mass
E = 50*10^-3; //optical phonon energy in eV
t = 10^-13; //carrier scattering relaxation time at 300K
q = 1.6*10^-19;
kBT = 26*10^-3; //in eV
vd = (2*q*(E-1.5*kBT)/m)^0.5;
disp(vd, "Drift velocity (in m/s) = ")
ef = vd*m/t/q; //electric field in V/cm
disp(ef,"Electric field(in V/m) =")
```

Scilab code Exa 3.3 relaxation time due to ionized impurity scattering

```
u = 8500*10^-4; //in m2/V.s
Nd = 10^17;
new_u = 5000*10^-4;
m0 = 0.91 * 10^-30; //in kg
m = 0.067*m0;
q = 1.6*10^-19;
t1 = m*u/q;
disp(t1,"relaxation time(in s) = ")
t2 = m*new_u/q;
disp(t2, "If the ionized impurities are present, the time (in s) =")
t_imp = t2*t1/(t1-t2);
disp (t_imp,"The impurity-related time (in s) = ")
```

Scilab code Exa 3.4 time between scattering events using the conductivity effective mass

```
u = 1500*10^-4; // in m2/V.s
m0 = 0.91 * 10^-30; //in kg
```

```
q = 1.6*10^-19;
kt = 0.19;
kl = 0.98;
ks = 3*kt*kl/(2*kl+kt);
t = u*ks*m0/q;
disp(t,"The scattering time(in s) =")
```

Scilab code Exa 3.5 conductivity of doped versus undoped

```
Nd = 10^17;
Ni = 1.5*10^10;
Ni2 = 1.84 * 10^6;
Pi2 = 1.84 * 10^6;
Pi = 1.5*10^10;
un1 = 1000;
up1 = 350;
un2 = 8000;
up2 = 400;
Nn = 0.5*Nd;
Pn = Ni^2/Nn;
q = 1.6*10^-19;
disp(Pn,"Hole density for Si(in per cm cube) =")
s_n1 = Nn*q*un1+Pn*q*up1;
s_un1 = Ni*q*un1+Pi*q*up1;
s_n2 = Nn*q*un2+Pn*q*up2;
s_un2 = Ni2*q*un2+Pi2*q*up2;
disp(s_n1,"The conductivity of Si (in per ohm per cm
    ) = ")
disp(s_un1,"The conductivity of undoped Si (in per
    ohm per cm) = ")
disp(s_n2,"The conductivity of GaAs (in per ohm per
    cm) = ")
disp(s_un2,"The conductivity of undoped GaAs (in per
    ohm per cm) = ")
```

Scilab code Exa 3.6 maximum and minimum conductivity

```
d1 = 2.78 * 10^19; //max density for Si
d2 = 7.72 * 10^18; // max density for GaAs
Nd = 10^17;
Ni = 1.5*10^10;
Ni2 = 1.84 * 10^6;
Pi2 = 1.84 * 10^6;
Pi = 1.5*10^10;
un1 = 1000;
up1 = 350;
un2 = 8000;
up2 = 400;
Nn = 0.5*Nd;
Pn = Ni^2/Nn;
q = 1.6*10^-19;
s1 = d1*q*un1;
s2 = d2*q*up2;
//To find the minimum we take the derivative with respect to p and equate the result to zero, which gives the below expression
p = Ni*(un1/up1)^0.5;
smin1 = Ni*q*(un1*(up1/un1)^0.5 + up1*(un1/up1)^0.5);
smin2 = Ni2*q*(un2*(up2/un2)^0.5 + up2*(un2/up2)^0.5);
disp(s1,"maximum conductivity for Si = ")
disp(s2,"maximum conductivity for GaAs = ")
disp(smin1,"minimum conductivity for Si = ")
disp(smin2,"minimum conductivity for GaAs = ")
```

Scilab code Exa 3.7 High field transport velocity field relations

```
E1 = 10^3; //in V/cm
E2 = 10^5; //in V/cm
v1 = 1.4*10^6; //in cm/s
v2 = 1*10^7;//in cm/s
m0 = 0.91 * 10^-30; //in kg
m = 0.26*m0;
q = 1.6*10^-19;
u1 = v1/E1;
u2 = v2/E2;
disp(u1,"mobility (in cm square per V.s) at 1 kV/cm
    = ")
disp(u2,"mobility (in cm square per V.s) at 100 kV/
    cm = ")
t1 = m*u1*10^-4/q;
t2 = m*u2*10^-4/q;
disp(t1,"relaxation time (in s) at 1 kV/cm = ")
disp(t2,"relaxation time (in s) at 100 kV/cm = ")
```

Scilab code Exa 3.8 transit time of electron in semiconductor device

```
E = 50*10^3; //in V/cm
v = 10^7; // in cm/s
L = 10^-5; //in cm
m0 = 0.91 * 10^-30; //in kg
m = 0.067*m0;
q = 1.6*10^-19;
a = q*E/m;
t = (2*L/a)^0.5;
disp(t,"If the transport is ballistic , transit time
    (in s) = ")
t2 = L/v;
disp(t2,"If the saturation velocity is used, transit
    time (in s) = ")
```

Scilab code Exa 3.9 band to band tunneling probability

```
E = 2*10^7; //in V/m
m0 = 0.91 * 10^-30; //in kg
q = 1.6*10^-19;
h = 1.05*10^-34; //in J.s
m1 = 0.065*m0; //for GaAs
m2 = 0.02*m0; // for InAs
E1 = 1.5; //in eV
E2 = 0.4; //in eV
p1 = -4*(2*m1)^0.5*(E1*q)^1.5/(3*q*h*E);
disp(p1,"Tunneling probability is exponent to the power")
tp1 = %e^p1;
disp(tp1,"Tunneling probability = ")
p2 = -4*(2*m2)^0.5*(E2*q)^1.5/(3*q*h*E);
disp(p2,"Tunneling probability is exponent to the power")
tp2 = %e^p2;
disp(tp2,"Tunneling probability = ")
disp("In InAs the band-to-band tunneling will start becoming very important if the field is    2 105 V/cm.")
```

Scilab code Exa 3.10 diffusion coefficient using velocity field relation

```
E1 = 10^5; //in V/m
E2 = 10^6; //in V/m
v1 = 1.4*10^4; //in m/s
v2 = 7*10^4;//in m/s
kBT = 26*10^-3; //in eV
q = 1.6*10^-19;
```

```
D1 = v1*kBT/E1;
D2 = v2*kBT/E2;
disp(D1,"diffusion constant (in m square per.s) at 1
    kV/cm = ")
disp(D2,"diffusion constant (in m square per.s) at
   10 kV/cm = ")
```

Scilab code Exa 3.11 carrier generation rate for optical radiation

```
P = 10^3; //in W per cm square
E = 1.5; //in eV
ab = 3*10^3; //in per cm
t = 10^-9; //in s
q = 1.6*10^-19;
G = ab*P/E/q;
disp(G,"The carrier generation rate (in per cm cube
   per sec) at the surface of the sample = ")
d = G*t;
disp(d,"The excess carrier density (in per cm cube)
   = ")
```

Chapter 4

JUNCTIONS IN SEMICONDUCTORS PN DIODES

Scilab code Exa 4.1 pn junction in equilibrium

```
Nd = 10^16; //in per cm cube
p = 10^18; //in per cm cube
Na = 10^18; //in per cm cube
Nc = 2.8 * 10^19; //in per cm cube
Nv = 10^19; //in per cm cube
kT = 26*10^-3; //in eV
eps0 = 8.84*10^-12; //in F/m
eps = 11.9*eps0;
Eg = 1.1; //in eV
q = 1.6*10^-19;
En = kT*log(Nd/Nc);
disp(En,"The Fermi level positions in the n-region
    relative to the conduction band (in eV) = ")
Ep = -kT*log(p/Nv);
disp(Ep,"The Fermi level positions in the p-region
    relative to the valence band (in eV) = ")
Vbi = Eg + En - Ep;
```

```
disp(Vbi,"built-in potential = ")
Wp = (2*eps*Vbi*Nd/(q*Na*10^6*(Na+Nd)))^0.5;
disp(Wp,"depletion width on the p-side (in m) = ")
```

Scilab code Exa 4.2 effect of the generation recombination current in pn diode

```
kT = 26*10^-3; //in eV
t = 10^-6;
q = 1.6*10^-19;
A = 10^-3; //in square cm
ni = 1.5*10^10;
eE = 3.2*10^4;
Igr0 = q*ni*A*%pi*kT/(2*t*eE);
disp(Igr0,"prefactor of the generation-recombination current (in Ampere) =")
V1 = 0.2;
Igr1 = Igr0*(exp(0.5*V1/kT)-1);
disp(Igr1,"generation-recombination current (in A) at bias of 0.2 V =")
V2 = 0.6;
Igr2 = Igr0*(exp(0.5*V2/kT)-1);
disp(Igr2,"generation-recombination current (in A) at bias of 0.6 V =")
```

Scilab code Exa 4.3 diode current at a forward bias

```
n = 10^17;
p = 10^17;
Tn = 10^-7;
Tp = 10^-7;
Dn = 30;
Dp = 10;
```

```
A = 10^-4;
t = 10^-8;
V1 = 0.5;
V2 = 0.6;
E1 = 6.94 * 10^4;
E2 = 5.74 * 10^4;
np = 2.25*10^3;
pn = 2.25*10^3;
Ln = 17.32*10^-4;
Lp = 10*10^-4;
Vbi = 0.817;
q = 1.6*10^-19;
I0 = q*A*(Dp*pn/Lp + Dn*np/Ln);
disp(I0,"prefactor in the ideal diode equation = ")
Igr01 = q*ni*A*%pi*kT/(2*t*E1);
Igr02 = q*ni*A*%pi*kT/(2*t*E2);
disp(Igr01,"prefactor to the recombination-
    generation current at 0.5V = ")
disp(Igr02,"prefactor to the recombination-
    generation current at 0.6V")
I1 = I0*exp(V1/kT)+Igr01*exp(0.5*V1/kT);
disp(I1,"Current at 0.5 V = ")
I2 = I0*exp(V2/kT)+Igr02*exp(0.5*V2/kT);
disp(I2,"Current at 0.6 V = ")
n = (log(I2/I1)*kT/(V2-V1))^-1;
disp(n,"ideality factor of the diode in the given
    range =")
```

Scilab code Exa 4.4 breakdown voltage of diode

```
Na = 10^19;
Nd = 10^16;
E1 = 4*10^5;
E2 = 10^7;
eps0 = 8.84*10^-14; //in F/m
```

```
eps = 11.9*eps0;
q = 1.6*10^-19;
V1 = eps*E1^2/(2*Nd*q);
disp(V1,"breakdown voltage for Si = ")
V2 = eps*E2^2/(2*Nd*q);
disp(V2,"breakdown voltage for diamond = ")
```

Scilab code Exa 4.5 e h recombination time

```
p = 10^21;
t0 = 0.6*10^-9;
kT = 26*10^-3; //in eV
m0 = 0.91 * 10^-30; //in kg
m1 = 0.067*m0;
m2 = 0.45*m0;
q = 1.6*10^-19;
h = 1.05*10^-34;
tri = (0.5*p/t0)*(2*%pi*h*h/kT/q/(m1+m2))^1.5;
tr = 1/tri;
disp(tr)
```

Scilab code Exa 4.6 internal radiative efficiency for diodes

```
t0 = 0.6*10^-9;
tnr = 10^-7;
p = 10^22;
kT = 26*10^-3; //in eV
m0 = 0.91 * 10^-30; //in kg
m1 = 0.067*m0;
m2 = 0.45*m0;
tri = (0.5*p/t0)*(2*%pi*h*h/kT/q/(m1+m2))^1.5;
tr1 = 1/tri;
```

```
disp(tr1,"When the p-type doping is 10^16 cm 3 , the hole density is low and the e-h recombination time (in s) for the injected electrons = ")
tr2 = t0*((m1+m2)/m1)^1.5;
disp(tr2,"In the case where the p-doping is high, the recombination time(in s) = ")
nqr1 = (1+tr1/tnr)^-1;
disp(nqr1,"For the low-doping case, the internal quantum efficiency for the diode = ")
nqr2 = (1+tr2/tnr)^-1;
disp(nqr2,"For the more heavily doped p region, the internal quantum efficiency for the diode = ")
```

Scilab code Exa 4.7 injection efficiency of LED

```
Dn = 30;
Dp =15;
Na = 5*10^16;
Nd = 5*10^17;
q = 1.6*10^-19;
tn = 10^-8;
tp = 10^-7;
ni = 1.84*10^6;
np = ni^2/Na;
pn = ni^2/Nd;
Ln = (Dn*tn)^0.5;
Lp = (Dp*tp)^0.5;
disp(Ln,"diffusion length, Ln (in cm) = ")
disp(Lp,"diffusion length, Lp (in cm) = ")
n = (q*Dn*np/Ln)/((q*Dn*np/Ln)+(q*Dp*pn/Lp));
disp(n,"injection efficiency (assuming no recombination via traps) = ")
```

Scilab code Exa 4.8 photon flux and optical power generated by LED

```
V1 = 1;
nqr = 0.5;
A = 10^-2;
Dn = 30;
Dp =15;
Na = 5*10^16;
Nd = 5*10^17;
q = 1.6*10^-19;
tn = 10^-8;
tp = 10^-7;
ni = 1.84*10^6;
np = ni^2/Na;
pn = ni^2/Nd;
Ln = (Dn*tn)^0.5;
Lp = (Dp*tp)^0.5;
kT = 26*10^-3; //in eV
In = A*q*Dn*np/Ln*(exp(V1/kT)-1);
disp(In,"The electron current injected into the p-
    region will be responsible for the photon
    generation. This current (in A) = ")
Iph = In*nqr/q;
disp(Iph,"photons generated per second = ")
E = 1.41; //in eV
P = Iph*E*q;
disp(P,"Each photon has an energy of 1.41 eV (=
    bandgap of GaAs). The optical power (in W) = ")
```

Chapter 5

SEMICONDUCTOR JUNCTIONS

Scilab code Exa 5.2 SCHOTTKY BARRIER

```
A = 10^-3;
Na = 10^19;
Nd = 10^16;
q = 1.6*10^-19;
Tp = 10^-6;
Tn = 10^-6;
Dp = 10.5;
kT = 26*10^-3; //in eV
T = 300;
Vs = -0.67;
Vf = 0.3;
eRc = 110;
Is = A*eRc*T^2*exp(Vs/kT);
disp(Is,"Reverse saturation current (in Ampere) = ")
I = Is*exp(Vf/kT);
disp(I,"For a forward bias of 0.3 V, the current(in Ampere) = ")
Lp = (Dp*Tp)^0.5;
disp(Lp, "Lp(in cm) = ")
```

```
pn = 2.25*10^4;
I0 = A*q*Dp*pn/Lp;
disp(I0,"Saturation current (in Ampere) = ")
disp("For the p-n diode to have the same current
   that the Schottky diode has at 0.3 V, the voltage
    required is 0.71 V.")
```

Chapter 6

BIPOLAR JUNCTION TRANSISTORS

Scilab code Exa 6.1 emitter efficiency of BJT and HBT

```
Nde = 5*10^17;
Nab = 10^17;
Db = 100;
De = 15;
Wb = 0.5*10^-4;
dEg = 0.36;
Le = 1.5*10^-4;
ni = 2.2*10^6;
kT = 26*10^-3; //in eV
peo = ni^2/Nde;
nbo = ni^2/Nab;
disp(peo,"emitter minority carrier concentrations (
    in per cm cube)= ")
disp(nbo,"base minority carrier concentrations (in
    per cm cube) = ")
gammae = 1- (peo*De*Wb)/(nbo*Db*Le);
disp(gammae,"emitter efficiency = ")
peo1 = peo*exp(-dEg/kT);
disp(peo1,"In the HBT, the value of peo is greatly
```

```
    suppressed. The new value(in per cm cube) = ")
gamma1 = 1- (peo1*De*Wb)/(nbo*Db*Le);
disp(gamma1,"emitter efficiency = ")
disp("In this case the emitter efficiency is
    essentially unity")
```

Scilab code Exa 6.2 change in the base width and collector current with voltage and Early voltage

```
Wb = 10^-4;
Vcb1 = 1;
Vcb2 = 5;
q = 1.6*10^-19;
Db = 20;
Vbe = 0.7;
kT = 26*10^-3; //in eV
ni = 1.5*10^10;
Nab = 5*10^16;
Nde = 5*10^15;
eps0 = 8.84*10^-14; //in F/m
eps = 11.9*eps0;
Vbi = kT*log(Nab*Nde/ni^2)
disp(Vbi,"Built in voltage (in V) = ")
dW2 = 2*eps*(Vbi+Vcb1)*Nde/(q*Nab*(Nab+Nde));
dW = sqrt(dW2);
disp(dW,"The extent of depletion into the base side
    (in cm) = ")
Wbn = Wb - dW;
disp(Wbn,"neutral base width (in cm) = ")
dW1 = (2*eps*(Vbi+Vcb2)*Nde/(q*Nab*(Nab+Nde)))^0.5;
disp(dW1,"When the collector-base voltage increases
    to 5 V, extent of depletion into the base side (
    in cm)")
Wbn1 = Wb - dW1;
disp(Wbn1,"neutral base width (in cm) = ")
```

```
nbo = ni^2/Nab;
disp(nbo,"base minority carrier concentrations (in per cm cube) = ")
Jc1 = q*Db*nbo/Wbn*exp(Vbe/kT);
disp(Jc1,"For the base-collector bias of 1 V, collector current density (in A/square cm)")
Jc2 = q*Db*nbo/Wbn1*exp(Vbe/kT);
disp(Jc2,"For the base-collector bias of 5 V, collector current density (in A/square cm)")
slope = (Jc2-Jc1)/(Vcb2-Vcb1);
disp(slope,"The slope of the Jc vs. VCE curve = ")
Va = Jc2/slope - (Vcb2+Vbe);
disp(Va, "Early voltage (in V) = ")
```

Scilab code Exa 6.3 maximum base width for a given beta

```
kT = 26*10^-3; //in eV
ni = 1.5*10^10;
eps0 = 8.84*10^-14; //in F/m
eps = 11.9*eps0;
q = 1.6*10^-19;
Nde = 10^18;
Nab = 10^17;
Ndc = 5*10^16;
Db = 30;
Lb = 15*10^-4;
De = 10;
Le = 5*10^-4;
Vf = 1;
B = 100;
Vr = 5;
Wbn = Db*Nde*Le/(De*Nab*B);
disp(Wbn,"neutral base width (in cm) = ")
Vbi = kT*log(Nab*Ndc/ni^2);
disp(Vbi,"built in voltage (in V) = ")
```

```
//dW = (2*eps*(Vbi+Vr)*Nde/(q*Nab*(Nab+Nde)))^0.5;
dW = (2*eps*(Vbi+Vr)*Ndc/(q*Nab*(Nab+Ndc)))^0.5;
disp(dW,"the depletion width (in cm) on the base side of the EBJ for a 5 volt bias at the base collector junction")
Wb = Wbn + dW;
disp(Wb, "base width (in cm) = ")
```

Scilab code Exa 6.4 output conductance and emitter efficiency and gain

```
kT = 26*10^-3; //in eV
ni = 1.5*10^10;
Vbe = 0.7;
q = 1.6*10^-19;
Nde = 10^18;
Nab = 10^17;
Ndc = 10^16;
Db = 30;
Lb = 10*10^-4;
Wb = 10^-4;
De = 10;
Le = 10*10^-4;
We = 10^-4;
A = 4*10^-6;
Vf = 1;
Vr1 = 5;
Vr2 = 6;
Vbi = kT*log(Nab*Ndc/ni^2);
disp(Vbi,"built in voltage (in V) = ")
dW1 = (2*eps*(Vbi+Vr1)*Ndc/(q*Nab*(Nab+Ndc)))^0.5;
dW2 = (2*eps*(Vbi+Vr2)*Ndc/(q*Nab*(Nab+Ndc)))^0.5;
disp(dW1,"depletion width (in cm) on the base side of the BCJ at 5 V = ")
disp(dW2,"depletion width (in cm) on the base side of the BCJ at 6 V = ")
```

```
Wbn1 = Wb - dW1;
disp(Wbn1,"neutral base width (in cm) at 5V = ")
Wbn2 = Wb - dW2;
disp(Wbn2,"neutral base width (in cm) at 6V = ")
gammae = 1- (Nab*De*Wbn1)/(Nde*Db*We)
disp(gammae,"emitter efficiency (for a narrow
    emitter of width We) = ")
B = 1 - Wbn1^2/2/Lb^2;
disp(B,"the base transport factor = ")
alpha = B*gammae;
disp(alpha,"alpha = ")
betae = alpha/(1-alpha);
disp(betae,"current gain = ")
Nbo = ni^2/Nab;
Ic1 = q*A*Db*Nbo/Wbn1*(exp(Vf/kT)-1);
disp(Ic1,"collector current (in A) at 5V = ")
Ic2 = q*A*Db*Nbo/Wbn2*(exp(Vf/kT)-1);
disp(Ic2,"collector current (in A) at 6V = ")
g0 = Ic2-Ic1/(6-5);
disp(g0,"The output conductance = ")
```

Chapter 7

TEMPORAL RESPONSE OF DIODES AND BIPOLAR TRANSISTORS

Scilab code Exa 7.1 cutoff frequency of transistor

```
Ie = 1.5*10^-3;
Cje = 2*10^-12;
Wb = 0.4*10^-4;
Db = 60;
Wdc = 2*10^-4;
Rc = 30;
Ct = 0.4*10^-12;
vs = 5*10^6;
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
Re = kT/Ie;
disp(Re,"The emitter resistance (in ohm) = ")
Te = Re*Cje;
disp(Te, "Te (in s) = ")
Tt = Wb^2/2/Db;
disp(Tt,"base transit time (in s) = ")
Tc = 0.5*Wdc/vs;
```

```
disp(Tc,"collector transit time (in s) = ")
Tcc = Rc*Ct;
disp(Tcc,"collector charging time (in s) = ")
Tec = Te+Tt+Tc+Tcc;
disp(Tec,"total time (in s) = ")
ft = (2*%pi*Tec)^-1;
disp(ft,"cutoff frequency (in Hz) = ")
```

Chapter 8

FIELD EFFECT TRANSISTORS

Scilab code Exa 8.1 gate current density for MESFET

```
phiB = 0.8;
N = 10^17;
Dp = 20;
Lp = 10^-4;
A = 8;
kT = 26*10^-3; //in eV
T = 300;
q = 1.6*10^-19;
Js = A*T^2*exp(-phiB/kT);
disp(Js,"For the Schottky case, Js (in A/cm2) = ")
ni = 1.84*10^6;
pn = ni^2/N;
disp(pn)
J0 = q*Dp*pn/Lp;
disp(J0,"For the p+-gate we have from p-n diode
    theory, J0 (in A/cm2) = ")
```

Scilab code Exa 8.5.1 2DEG concentration for MODFET

```
phiB = 0.9;
Nd = 10^18;
dEc = 0.24;
eps0 = 8.84*10^-14; //in F/m
epsb = 12.2*eps0;
ds = 30*10^-8;
d = 350*10^-8;
VG1 = 0;
VG2 = -0.5;
q = 1.6*10^-19;
Vp2 = q*Nd*(d-ds)^2/epsb;
disp(Vp2,"The parameter Vp2 (in V) of this structure
    = ")
Voff = phiB - Vp2 - 0.24;
disp(Voff,"threshold voltage (in V)")
Ns1 = -epsb*Voff/q/d;
Ns2 = epsb*(VG2-Voff)/q/d;
disp(Ns1,"The 2DEG carrier concentration (in per
    sqaure cm) at 0 V = ")
disp(Ns2,"The 2DEG carrier concentration (in per
    sqaure cm) at -0.5 V = ")
```

Chapter 9

FIELD EFFECT TRANSISTORS MOSFET

Scilab code Exa 9.1 maximum depletion width in a MOS capacitor

```
kT = 26*10^-3; //in eV
T = 300;
q = 1.6*10^-19;
Na = 10^16;
ni = 1.5*10^10;
eps0 = 8.84*10^-14; //in F/m
eps = 11.9*eps0;
phiF = kT*log(Na/ni);
disp(phiF,"the potential  F (in V) = ")
W = (4*eps*phiF/(q*Na))^0.5;
disp(W,"The corresponding space charge width(in cm)
   = ")
```

Scilab code Exa 9.2 MOS capacitor

```
kT = 26*10^-3; //in eV
```

```
T = 300;
q = 1.6*10^-19;
Wf = 4.1;
EA1 = 0.9;
EA2 = 4.15;
Na = 10^14;
Eg = 1.11;
Efi = Eg/2;
Ef = Efi + kT*log(Na/ni);
disp(Ef,"Ef = ")
disp("below the conduction band")
Vfb = Wf - (EA2+Ef);
disp(Vfb,"V(fb) = ")
```

Scilab code Exa 9.3 MOS capacitor threshold voltage

```
Na = 3*10^16;
t = 500*10^-8;
Vfb = -1.13;
T = 300;
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
c = 10^11;
phiF = kT*log(Na/ni);
disp(phiF,"The position of the Fermi level (in V) is
    given by (measured from the intrinsic Fermi
   level)")
Qs = (4*eps*phiF*q*Na)^0.5;
disp(Qs,"Under the assumption that the charge Qs is
   simple NaW where W is the maximum depletion width
   , we get Qs (in C per cm2)= ")
```

```
Vt = Vfb+2*phiF+(Qs*t/eps1);
disp(Vt,"In the absence of any oxide charge, the
   threshold voltage (in V) = ")
dVt = c*q*(t/eps1);
disp(dVt,"In the case where the oxide has trap
   charges, the threshold voltage is shifted by  VT
    (in V)= ")
```

Scilab code Exa 9.4 MOS capacitor threshold voltage and channel conductivity

```
Na = 5*10^16;
phiMS = -0.5;
un = 600;
up = 200;
T = 300;
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
psiS = 2*phiF;
w = 200*10^-8;
sigma_fb= Na*q*up;
disp(sigma_fb,"  (fb) (in per ohm-cm) = ")
sigma_inv = Na*q*un;
disp(sigma_inv,"  (inv) (in per ohm-cm) = ")
phiF = kT*log(Na/ni);
disp(phiF,"  F (in V) = ")
Vt = phiMS + psiS + 1.637;
disp(Vt,"the threshold voltage (in V) = ")
```

Scilab code Exa 9.6 oxide capacitance and capacitance at the flat band and the minimum capacitance at threshold for MOS capacitor

```
Na = 10^16;
t = 500*10^-8;
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
Cox = eps1/t;
disp(Cox,"The oxide capacitance (in F/cm2) = ")
phiF = kT*log(Na/ni);
disp(phiF,"  F (in V) = ")
Wmax = (4*eps*phiF/(q*Na))^0.5;
disp(Wmax,"The maximum depletion width (in cm) = ")
Cmin = eps1/(t+(eps1*Wmax/eps));
disp(Cmin,"The minimum capacitance (in F/cm2) = ")
Cfb = eps1/(t+(eps1/eps*(kT*eps/q/Na)^0.5));
disp(Cfb,"The capacitance (in F/cm2) under flat band conditions = ")
disp("Note that Cfb is     80% of Cox and Cmin is 33% of Cox.")
```

Scilab code Exa 9.7 saturation current of MOSFET

```
L = 1.5*10^-4;
Z = 25*10^-4;
un = 600;
Na = 10^16;
dox = 500*10^-8;
Qss = 10^11;
phiMS = -1.13;
V = 5;
```

```
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
phiF = kT*log(Na/ni);
disp(phiF,"The Fermi level position (in V) for the
    device = ")
Cox = eps/dox;
Vfb = phiMS - 0.23;
disp(Vfb,"The flat band voltage (in V) = ")
Qs = (4*eps*phiF*q*Na)^0.5;
Vt = Vfb + 2*phiF + (Qs*dox/eps1);
disp(Vt,"The threshold voltage (in V) = ")
Id = Z*un*eps1*(V-Vt)^2/(2*L*dox);
disp(Id,"The saturation current (in A) = ")
```

Scilab code Exa 9.8 drain current for NMOS device

```
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
phiMS = 0;
Na = 4*10^14;
dox = 200*10^-8;
L = 10^-4;
Z = 10*10^-4;
Vgs = 5;
Vd = 4;
un = 700;
phiF = kT*log(Na/ni);
```

```
disp(phiF,"The Fermi level position (in V) for the device = ")
Qs = (4*eps*phiF*q*Na)^0.5;
Vt = 2*phiF + (Qs*dox/eps1);
disp(Vt,"The threshold voltage (in V) = ")
Vds = Vgs - Vt;
disp(Vds,"saturation voltage (in V) for a gate bias of 5 V = ")
Id = Z*un*eps1*(Vds)^2/(2*L*dox);
disp(Id,"The saturation current (in A) = ")
```

Scilab code Exa 9.9 threshold voltage in n channel MOSFET

```
Z = 10*10^-4;
L = 2*10^-4;
Cox = 10^-7;
Vds = 0.1;
Vgs1 = 1.5;
Id1 = 50*10^-6;
Vgs2 = 2.5;
Id2 = 80*10^-6;
slope = Id2-Id1/(Vgs2-Vgs1);
Vt = -Id2/slope + Vgs2;
disp(Vt,"the threshold voltage (in V) = ")
```

Scilab code Exa 9.10 shift in the threshold voltage arising from source body bias

```
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
```

```
eps1 = 3.9*eps0;
Na = 2*10^16;
dox = 500*10^-8;
Vsb = 1;
phiF = kT*log(Na/ni);
disp(phiF,"The Fermi level position (in V) for the
    device = ")
Cox = eps1/dox;
disp(Cox,"The oxide capacitance (in F/cm2) = ")
dVt = (2*q*eps*Na)^0.5/Cox*((2*phiF+1)^0.5 - (2*phiF
    )^0.5);
disp(dVt,"The change in the threshold voltage (in V)
     = ")
```

Scilab code Exa 9.11 n channel MOSFET characteristics

```
kT = 26*10^-3; //in eV
q = 1.6*10^-19;
ni = 1.5*10^10;
eps0 = 8.85*10^-14; //in F/m
eps = 11.9*eps0;
eps1 = 3.9*eps0;
Na = 10^14;
dox = 500*10^-8;
phiMS = -0.83;
t = 0.1*10^-4;
dVt = 0.5;
phiF = kT*log(Na/ni);
disp(phiF,"The Fermi level position (in V) for the
    device = ")
Qs = (4*eps*phiF*q*Na)^0.5;
Vt = phiMS+2*phiF + (Qs*dox/eps1);
disp(Vt,"The threshold voltage (in V) = ")
disp("In this device there is an inversion layer
    formed even at zero gate bias and the device is
```

```
   in the depletion mode. To increase the threshold
   voltage by + 0.5 V, i.e., to convert the device
   into an enhancement-mode device, we need to place
    more negative charge in the channel. If we
   assume that the excess acceptors are placed close
    to the semiconductor-oxide region (i.e., within
   the distance Wmax), the shift in threshold
   voltage is simply (Na2D is the areal density of
   the acceptors implanted)")
Na2D = dVt/dox*eps1/q;
disp(Na2D, "the areal density (in per cm2) of the
   acceptors implanted = ")
Na1 = Na2D/t;
disp(Na1,"The dopants are distributed over a
   thickness of 0.1  m , the dopant density (in per
   cm3) = ")
```