Scilab Textbook Companion for Solid State Electronic Devices by B. G. Streetman And S. K. Banerjee[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.

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Chapter 1

Crystal Properties and Growth of Semiconductors

Scilab code Exa 1.1 Maximum packing fraction

```
1 a = 5; // lattice constant
2 b = 0.5*sqrt(a^2 + a^2 +a^2); //separation between
    nearest atoms
3 r = 0.5*b; //radius of each atom
4 V = 4/3*%pi*r*r*r; //Volume of each atom
5 n = 1+8*0.125; //number of atoms per cube
6 pf = V*n/(a*a*a); //packing fraction
7 disp("1)")
8 disp(a,"lattice constant (in armstrong)=")
9 disp(r,"radius of atoms (in armstrong) =")
10 disp(pf,"maximum packing fraction =")
```

Scilab code Exa 1.2 planes and directions

```
1 disp("The plane illustrated in Fig. 1-5 has
    intercepts at 2a, 4b and lc along the three
```

```
    crystal axes. Taking the reciprocals of these
    intercepts, we get 1/4, 1/2,and 1. These three
    fractions have the same relationship to each
    other as the integers 2,1, and 4 (obtained by
    multiplying each fraction by 4).Thus the plane
    can be referred to as a (214) plane. The only
    exception is if the intercept is a fraction of
    the lattice constant a. In that case, we do not
    reduce it to the lowest set of integers.")
x = 0:0.05:2;
y = 0:0.1:4;
a=2;
b=4;
c=1;
deff('[z]=fs(x,y)','z = (1-(0.5*x)-(0.25*y))');
//z = (1-(0.5*x)-(0.25*y));
fplot3d(x,y,fs);
```

Scilab code Exa 1.3 Volume density of Silicon in lattice

```
a = 5.43*10^-8; // lattice constant
d = (1+4*0.25)/(a*a); //areal density on (100) plane
n = 2*(6*0.5+8*0.125); //number of atoms per cube
V = n/(a*a*a); //volume density
disp("3)")
disp(a,"lattice constant (in cm)=")
disp(d,"areal density on (100) plane (in per cm
    square) =")
disp(V,"volume density (in per cm cube) =")
```

Scilab code Exa 1.4 Czochralski method for Silicon crystal growth

```
n = 10^16; // desired density of P atoms
```

```
k = 0.35;
l = 5000; //initial load of Si in grams
w =31;//atomic weight of P
d = 2.33; //density of Si
i = n/k; //initial concentration of P in melt,
   assuming C(S)=kC(L)
V = l/d; //volume of Si
N = i*V; //number of P atoms
W = N*w/(6.02*10^23)
disp("4.a)")
disp(n,"desired density of P atoms (per cubic
   centimeter)=")
disp(i,"initial concentration of P in melt (in per
   cubic cm )=")
disp("4.b)")
disp(V,"Volume of Si (in cubic cm) =")
disp(N,"number of P atoms =")
disp(W,"weight of phosphorus to be added(in grams) =
   ")
```

Chapter 2

Atoms and Electrons

Scilab code Exa 2.1 expectation of momentum

```
1 //j=complex(0,1);
2 //psi = A*exp(j*k*x);
3 disp("px = h_cross*k(x)");
4 disp("If we try to evaluate these integrals directly
    , we run into the problem that both numerator and
     denominator tend to infinity, because an ideal
    plane wave is strictly not a normalizable wave
    function. The trick to use is to choose the
    limits of integration from, say, -L/2 to +L/2 in
    a region of length L.The factor L cancels out in
    the numerator and denominator. Then we can
    consider L approaches infinity. For wave
    functions that are normalizable, such a
    mathematical trickdoes not have to be used.")
```

Chapter 3

Energy Bands and Charge Carriers in Semiconductors

Scilab code Exa 3.1 free electron momentum

```
1 //j=complex(0,1);
2 //psi = U*exp(j*k*x);
3 disp("px = h_cross*k(x)");
4 disp("With infinite limits of integration, both the
    numerator and denominator are infinite. For
    problems of this type, one integrates between the
     finite limits -LI2 and +L/2 and, in the final
    result, then assumes that L approaches infinity.
    This result implies that (E, k) diagrams can be
    considered plots of electron energy vs. momentum,
     with a scaling factor h_cross.")
```

Scilab code Exa 3.2 E k Rleationship

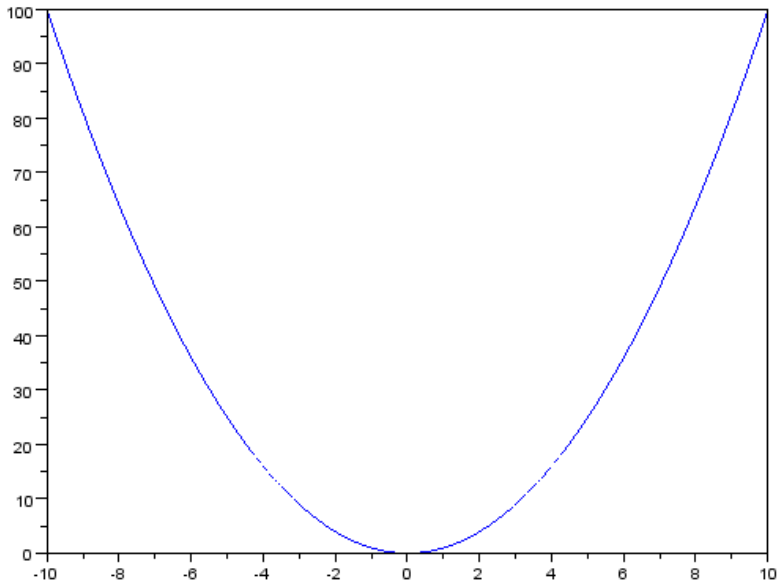

Figure 3.1: E k Rleationship

```
1 //p = m*v
2 //p = h*k; //electron momentum, where h is constant
3 //E = 0.5*p*p/m
4 //E = 0.5*h*k*k/m; //electron energy
5 k = -10:0.01:10; //limits on wave vector k
6 E = k^2; // E is proportional to square of wave
     vector
7 plot(k,E)
```

Scilab code Exa 3.3 radius of electron orbit

```
1 n = 1;
2 epsilonr = 11.8; //relative dielectric constant for
     silicon
3 epsilon = 8.85*10^-12; //dielectric constant
4 m = 9.11*10^-31; //mass of electron
5 mn = 0.26*m; //for silicon
6 h = 6.63*10^-34;
7 q = 1.6*10^-19; //electronic charge
8 r = 10^10*(epsilonr*epsilon*h*h)/(mn*q*q*%pi); //
     radius in armstrong
9 disp(r,"radius of electron orbit around donor (in
     armstrong) =")
10 disp("This is more than 4 lattice spacings a = 5.43
     armstrong.")
```

Scilab code Exa 3.4 density of states effective mass

```
1 m = 9.11*10^-31; //mass of electron
2 ml = 0.98*m;
3 ms = 0.19*m;
4 mn = 6^(2/3)*(ml*ms*ms)^(1/3); //density of states
     effective mass calculation
```

```
5 mn0 = mn/m;
6 disp(mn,"density of states effective mass (in
    kilogram)=")
7 disp(mn0,"density of states effective mass in
    proportion to mass of electron= ")
```

Scilab code Exa 3.5 equilibrium hole concentration

```
1 n0 = 10^17; //concentration of electrons
2 ni = 1.5*10^10; //intrinsic concentration
3 T = 300; //(temperature in Kelvin)
4 p0 = ni*ni/n0; // concentration of holes
5 k = 0.0259; //Boltzmann's constant multiplied with T
    = 300
6 E = k*log(n0/ni);
7 disp(p0,"concentration of holes (in per cubic
    centimeter)=")
8 disp(E,"Fermi level energy with respect to intrinsic
    level energy (in electron volt)=")
```

Scilab code Exa 3.6 conductivity effective mass

```
1 m = 9.11*10^-31; //mass of electron
2 ml = 0.98*m;
3 mt = 0.19*m;
4 mninverse = (1/3) * ((1/ml)+(2/mt));
5 mn = 1/mninverse;
6 mn0 = mn/m;
7 disp(mn0,"Conductivity effective mass in proportion
    to mass of an electron =")
```

Scilab code Exa 3.7 current and resistance in a Si bar

```
un= 700;
q = 1.6*10^-19;
n0 = 10^17;
L = 0.1;
A = 10^-6;
V = 10;
sigma = q*un*n0;
rho = 1/sigma;
R = rho*L/A;
I = V/R;
disp(sigma,"Conductivity (in per ohm-cm)=")
disp(rho,"resistivity (in ohm-cm)=")
disp(R,"resistance (in ohm)=")
disp(I,"current (in ampere)=")
```

Scilab code Exa 3.8 concentration and mobility of majority carrier

```
w = 0.01;
w1 = w*10^-3
t = 10^-3;
L = 0.5;
B = 10*10^-5;
I = 10^-3;
Vab = -2 *10^-3;
Vcd = 0.1;
q = 1.6*10^-19;
q1 = q*10^-3
n0 = I*B/(q1*-Vab);
rho = (Vcd/I)/(L/w1);
u = 1/(rho*q*n0);
disp(n0,"electron concentration (in per cubic
   centimeter)=")
disp(rho,"resisitivity (in ohm-cm)=")
```

```
16 disp(u,"mobility (in square cm per volt-sec)=")
```

Chapter 4

Excess Carriers in Semiconductors

Scilab code Exa 4.1 Excitation and band to band recombination leading to photoluminescence

```
1  t = 0.46 *10^-4;
2  hv = 2;
3  alpha = 5*10^4;
4  I0 = 10^-2;
5  It = I0*exp(-alpha*t);
6  Pabs = I0 - It;
7  f = (2-1.43)/2;
8  P = f*Pabs;
9  n = Pabs/(1.6*10^-19*hv);
10 disp(Pabs,"total energy absorbed per second (in watt
     )=")
11 disp(P,"amount of energy converted to heat per
     second (in watt)=")
12 disp(n,"number of photons per second given off form
     recombination events =")
```

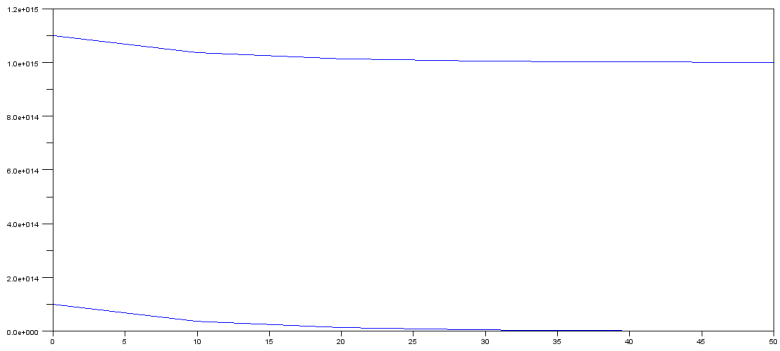

Figure 4.1: decay of excess population for a carrier recombination

Scilab code Exa 4.2 decay of excess population for a carrier recombination

```
1  p0 = 10^15;
2  ni = 10^6;
3  n0 = ni^2/p0;
4  disp(n0,"Minority electron concentration (in per
       cubic centimeter)=" )
5  dn = 10^14;
6  dp = 10^14;
7  tn = 10; //in nanoseconds
8  tp = tn;
9  t = 0:10:50;
10 del_n = dn*exp(-t/tn);
11 del_p = dp*exp(-t/tp);
12 p = p0 + del_p;
13 n = del_n; //since n0 is negligible
14 subplot(121);
15 plot(t,log(p));
16 plot(t,log(n));
17 subplot(122);
```

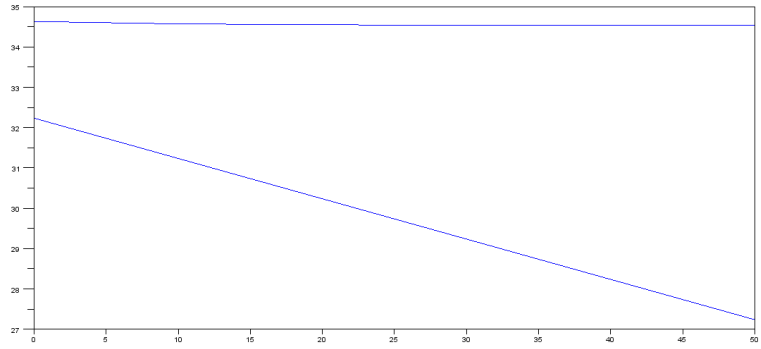

Figure 4.2: decay of excess population for a carrier recombination

```
18 plot(t,p);
19 plot(t,n);
```

Scilab code Exa 4.3 steady state carrier generation

```
1 n0 = 10^14;
2 ni = 1.5*10^10;
3 Tn = 2 *10^-6;
4 Tp = 2 *10^-6;
5 p = 2*10^13;
6 p0 = ni^2/n0;
7 disp(p0,"hole concentration (per cubic centimeter)="
    )
```

Scilab code Exa 4.4 electron quasi fermi level position and carrier concentration

```
n0 = 10^14;
dn = 2*10^13;
n = n0+dn;
kT = 0.0259;
ni = 1.5*10^10;
Ei = kT*log(n0/ni);
Fn = Ei + kT*log(n/ni);
E = Fn-Ei;
disp(n,"steady state electron concentration=")
disp(Ei,"equilibrium Fermi level (in eV)=")
disp(E,"electron quasi Fermi level position(in eV)="
   )
```

Scilab code Exa 4.5 diffusion length and hole current

```
A = 0.5;
Na = 10^17;
p0 = Na;
ni = 1.5*10^10;
dp = 5*10^16;
x = 10^-5;
up = 500;
Tp = 10^-10;
kT = 0.0259;
q0 = 1;
q = 1.6*10^-19;
Dp = kT*up/q0;
Lp = sqrt(Dp*Tp);
p = p0 + dp*exp(-x/Lp);
E = kT*log(p/ni);
E0 = 1.1/2 + E;
Ip = q*A*Dp*dp*exp(-x/Lp)/Lp;
Qp = q*A*dp*Lp;
Qp0 = Qp*10^6;
disp(E0,"steady state separation between Fp and Ec (
```

```
    in eV)=")
21 disp(Ip,"hole current (in ampere)=")
22 disp(Qp,"excess stored hole charge (in coulomb)=")
23 disp(Qp0,"excess stored hole charge (in micro-
    coulomb)=")
```

Scilab code Exa 4.6 Haynes Shockley experiment

```
1  l = 1;
2  d = 0.95;
3  E0 = 2;
4  t = 0.25*10^-3;
5  dt = 117*10^-6;
6  up = (d/t)/(E0/l);
7  Dp = dt^2*d^2/(16*t^3);
8  C = Dp/up;
9  kT = 0.0259;
10 disp(up,"hole mobility (in square cm per Volt-second
    )=")
11 disp(Dp,"diffusion coefficient (in square cm per
    second)=")
12 disp(C,"Diffisuion coefficient/Hole mobility (in
    volts) = ")
13 disp("Verified according to Einstein Relation")
```

Chapter 5

Junctions

Scilab code Exa 5.1 contact potential and fermi level position

```
Na = 10^18;
Nd = 5*10^15;
ni = 1.5*10^10;
kT = 0.0259;
E1 = kT*log(Na/ni);
E2 = kT*log(Nd/ni);
qV1 = E1+E2;
qV2 = kT*log(Na*Nd/ni^2);
disp(E1,"Fermi level position in p region (in eV)=")
disp(E2,"Fermi level position in n region (in eV)=")
disp(qV1,"Contact potential (in eV)=")
disp(qV2,"Contact potential (in eV)=")
disp("Contact potential value verified")
```

Scilab code Exa 5.2 electric field and charge density in junction

```
Na = 10^18;
Nd = 5*10^15;
```

```
ni = 1.5*10^10;
kT = 0.0259;
epsilon0 = 8.85*10^-14;
epsilon = 11.8;
q = 1.6*10^-19;
E1 = kT*log(Na/ni);
E2 = kT*log(Nd/ni);
qV1 = E1+E2;
qV2 = kT*log(Na*Nd/ni^2);
d = 10*10^-4; //in centimetre
A = %pi*d^2/4;
W = sqrt(2*epsilon*epsilon0*qV1/q *(Na^-1 + Nd^-1));
xn0 = W/(1+(Nd/Na));
xp0 = W/(1+(Na/Nd));
Q = q*A*xn0*Nd;
E0 = -q*xn0*Nd/(epsilon*epsilon0);
disp(W*10^4,"width of the transition region(in
   micron)=")
disp(xn0*10^4,"penetration of the space charge
   region into the n material (in micron)=")
disp(xp0*10^4,"penetration of the space charge
   region into the p material (in micron)=")
disp(Q,"total uncompensated charge (in coulomb)=")
disp(E0,"maximum electric field(in V per cm)=")
```

Scilab code Exa 5.4 Current in forward and reverse biased pn junction

```
A = 10^-4;
kT = 0.0259;
ni = 1.5*10^10;
q = 1.6*10^-19;
q0 = 1;
Na = 10^17;
Nd = 10^15;
Tn = 10^-7;
```

```
Tp = 10^-5;
upp = 200;
unn = 1300;
unp = 700;
upn = 450;
V1 = 0.5;
V2 = -0.5;
pn =  ni^2/Nd;
np = ni^2/Na;
Dp = kT*upn/q0;
Dn = kT*unp/q0;
Lp = sqrt(Dp*Tp);
Ln = sqrt(Dn*Tn);
I1 = q*A*((Dp*pn/Lp)+(Dn*np/Ln))*(exp(q0*V1/kT)-1);
I2 = -q*A*((Dp*pn/Lp)+(Dn*np/Ln));
disp(pn,"hole concentration (per cubic centmeter)=")
disp(np,"electron concentration (per cubic centmeter
   )=")
disp(Dp,"diffusion coefficient on n side(in square
   centimter per second)=")
disp(Dn,"diffusion coefficient on p side(in square
   centimter per second)=")
disp(I1*10^6,"current at forward bias (in
   microampere)=")
disp(I2*10^6,"current at reverse bias (in
   microampere)=")
```

Scilab code Exa 5.6 depletion capacitance

```
A = 10^-4;
kT = 0.0259;
ni = 1.5*10^10;
q = 1.6*10^-19;
Na = 10^17;
Nd = 10^15;
```

```
epsilon0 = 8.85*10^-14;
epsilon = 11.8;
E1 = kT*log(Na/ni);
E2 = kT*log(Nd/ni);
V0 = E1+E2;
V = -4;
Cj = sqrt(epsilon*epsilon0)*A*sqrt(q*Nd*Na/(2*(V0-V)
   *(Na+Nd)));
disp(V0,"V0 (in volt)=")
disp(Cj,"total depletion constant (in farad)=")
```

Scilab code Exa 5.7 Heterojunctions

```
dEtg = 1.85;
band_gap = 1.43; //for GaAs-AlGaAs system
dEg = dEtg - band_gap;
dEc = dEg*2/3;
dEv = dEg/3;
disp(dEc, "Conduction band offset(in eV) =")
disp(dEv, "Valence band offset(in eV) =")
```

Chapter 6

Field Effect Transistors

Scilab code Exa 6.1 mos transistor

```
kT = 0.0259;
ni = 1.5*10^10;
q = 1.6*10^-19;
q0 = 1;
epsilon0 = 8.85*10^-14;
epsilon = 11.8;
epsiloni = 3.9;
Na = 5*10^15;
d = 10^-6;
Qi = 4*10^10*q;
Vf = kT*log(Na/ni)/q0;
Wm = 2*sqrt(epsilon*epsilon0*Vf/(q*Na));
Vms = -0.95;
Ci = epsiloni*epsilon0/d;
Vfb = Vms -(Qi/Ci);
Qd = -q*Na*Wm;
Vt = Vfb-Qd/Ci+2*Vf;
Cd = epsilon*epsilon0/Wm;
Cmin = Ci*Cd/(Ci+Cd);
disp(Vf,"Phi(F) (in eV)=")
disp(Wm*10^4,"W(m) (in micron)=")
```

```
22 disp(Qi,"effective interface charge (in coulomb per
     square cm)=")
23 disp(Ci*10^6,"C(i) (in microfarad per square cm)=")
24 disp(Vfb,"V(fb)(in V)=")
25 disp(Qd,"Q(d)(in coulomb per square cm)=")
26 disp(Vt,"V(T) (in V)=")
27 disp(Cd*10^6,"C(d) (in microfarad per square cm)=")
28 disp(Cmin,"C(min) (in farad per square cm)=")
```

Scilab code Exa 6.2 drain current in mosfet

```
1  kT = 0.0259;
2  ni = 1.5*10^10;
3  q = 1.6*10^-19;
4  q0 = 1;
5  epsilon0 = 8.85*10^-14;
6  epsilon = 11.8;
7  epsiloni = 3.9;
8  Na = 5*10^15;
9  d = 10^-6;
10 Vt = 0.6;
11 Z = 25*10^-4;
12 L = 10^-4;
13 Vg1 = 5;
14 Vd1 = 0.1;
15 Vg2=3;
16 Vd2=5;
17 Vdsat = Vg2-Vt;
18 Vd3=7;
19 un = 200;
20 Ci = epsiloni*epsilon0/d;
21 Id1 = (Z*un*Ci/L)*((Vg1-Vt)*Vd1-0.5*Vd1^2); //linear
     region
22 Id2 = (Z*un*Ci/L)*((Vg2-Vt)*Vdsat-0.5*Vdsat^2); //
     saturation region
```

```
23 disp(Ci*10^6,"C(i) (in microfarad per square cm)=")
24 disp(Id1*10^3,"For V(G)=5V and V(D)=0.1V, we are in
     the linear region and drain current (in
     miliampere)=")
25 disp(Id2*10^3,"For V(G)=3V and V(D)=5V, we are in
     the saturation region and drain current (in
     miliampere)=")
26 disp("For VD = 7 V, ID will not increase, because we
     are in the saturation region.")
```

Scilab code Exa 6.3 ion implantation

```
1  q = 1.6*10^-19;
2  q0 = 1;
3  epsilon0 = 8.85*10^-14;
4  epsilon = 11.8;
5  epsiloni = 3.9;
6  d = 10^-6;
7  Vt1 = -1.1;
8  Vt2 = -0.5;
9  I = 10^-5;
10 A = 650;
11 Ci = epsiloni*epsilon0/d;
12 Fb = (Vt2-Vt1)*Ci/q;
13 t = Fb*q*A/I;
14 disp(Ci*10^6,"C(i) (in microfarad per square cm)=")
15 disp(Fb,"boron ion dose required (in per square cm)=
     ")
16 disp(t,"implant time (in second)=")
```

Chapter 7

Bipolar Junction Transistor

Scilab code Exa 7.1 steady state charge in transistor

```
1 tp = 10^-5;
2 ts = 10^-7;
3 ib = 10^-4;
4 ic = 10^-2;
5 Qn = ic*ts;
6 Qp = ib*tp;
7 disp(Qp,"steady state charge due to excess holes (in
    coulomb)=")
8 disp(Qn,"steady state charge due to excess electrons
    (in coulomb)=")
```

Scilab code Exa 7.4 bjt saturation current

```
1 A=10^-4;
2 q = 1.6*10^-19;
3 kT = 0.0259;
4 Wb = 10^-4;
5 ni = 1.5*10^10;
```

```
Na = 10^17;
Tn = 10^-7;
upe=200;
une=700;
Nd = 10^15;
Tp=10^-5;
unb=1300;
upb=450;
Veb = 0.3;
Vcb = -40;
pn = ni^2/Nd;
Dp = upb*kT;
Lp = sqrt(Dp*Tp);
Ies = q*A*Dp*pn/Lp*(csch(Wb/Lp)+tanh(Wb/Lp));
dpe = pn*exp(Veb/kT);
Ib = q*A*Dp*dpe/Lp*tanh(Wb/2*Lp);
Ib1 = q*A*Wb*dpe/(2*Tp);
Dn = kT*une;
Ln = sqrt(Dn*Tn);
gamma1 = (1+((Dn*Lp*Nd)/(Dp*Ln*Na))*tanh(Wb/Lp))^-1;
B = sech(Wb/Lp);
alpha = B*gamma1;
beta1 = alpha/(1-alpha);
disp(pn,"hole concentration (in per cubic centimeter
    )=")
disp(Dp,"Dp (in sqaure centimeter per second)=")
disp(Lp*10,"Lp(in micrometer) =")
disp(dpe,"dp(E)(in per cubic centimeter) =")
disp(Ies,"I(ES) (in ampere)=")
disp(Ib1,"I(B) (in ampere)=")
disp(Dn,"Dn (in sqaure centimeter per second)=")
disp(Ln*10,"Ln (in micrometer)=")
disp(gamma1,"gamma =")
disp(B,"B =")
disp(alpha,"alpha =")
disp(beta1,"beta =")
```

Chapter 8

Optoelectronic Devices

Scilab code Exa 8.2 solar cells

```
1 Isc=100;
2 Voc=0.8;
3 ff = 0.7;
4 Pmax = ff*Isc*Voc;
5 disp(Pmax,"maximum power delivered(in miliwatt)=")
```

Scilab code Exa 8.3 fibre optic communication

```
1 wavelength = 0.68;
2 Eg = 1.24/wavelength;
3 disp(Eg,"band gap (in eV)=")
4 disp("From Fig, 3-6, we get Al(0.32)Ga(0.68)As. From
      Fig. 8-11, we get GaAs(0.68)P(0.32)")
```