BECE2011L

DIGITAL ASSIGNMENT-1

1) The Fermi energy level for a particular material at T=300K is 5.5eV. The electrons in this material follow the Fermi-Dirac distribution func. (a) Find the probability of an electron occupying an energy at 5.8eV. (b) Repeat part (a) if the temp is increased to T=700K (Assume E_F is a constant). (c) Determine the temperature at which there is a 2 percent probability that a state 0.25eV below the Fermi-level will be an empty electron.

Now,

a) $$f_F = \frac{1}{1+\exp\left(\frac{E-E_F}{KT}\right)}$$

For 5.80eV at 300K,

$$KT = (8.62\times10^{-5})(300)$$

$$= 0.0259\,eV.$$

$$\therefore f_F = \frac{1}{1+\exp\left[\frac{5.8-5.5}{0.0259}\right]}$$

$$= \frac{1}{1+\exp\left[\frac{0.3}{0.0259}\right]} = \frac{1}{1+\exp\left[\frac{3}{0.259}\right]}$$

$$= \boxed{9.32\times10^{-6}}$$

Page No

Date ___/___/___

b) For 5.8eV at 700K,

$$kT = (8.62\times10^{-5})(700)$$
$$= 0.0604\,eV.$$

Now,

$$f_F = \frac{1}{1+\exp\left[\frac{0.3}{0.0604}\right]} = \frac{1}{1+\exp\left[\frac{3}{0.604}\right]}$$

$$= \boxed{6.98\times10^{-3}}$$

c) Probability = 2%

$$\Rightarrow 2 = 1 - \frac{1}{1+\exp\left[\frac{0.25}{kT}\right]}$$

$$\Rightarrow 0.02 = \exp\left[\frac{-0.25}{kT}\right]$$

$$\Rightarrow \frac{1}{0.02} = \exp\left[\frac{0.25}{kT}\right]$$

$$\Rightarrow 50 = \exp\left[\frac{0.25}{kT}\right]$$

taking log on both sides,

$$\ln(50) = \frac{0.25}{kT}$$

$$\Rightarrow kT = \frac{0.25}{\ln(50)} = 0.0639\,eV.$$

Now,

$K = 8.62 \times 10^{-6} eV/K$

Also,

ΔT is from 300K to 700K.

$$\Rightarrow (0.0254 eV)\left(\frac{T}{300K}\right) = 0.0639 eV.$$

$$\Rightarrow \boxed{T = 740K}.$$

2) Determine the probability that a quantum state energy $E = E_c + kT$ is occupied with an electron, and calculate the e^- concentration in GaAs at $T = 300K$ if the fermi energy level is 0.25eV below E_c. At temperature $T = 300K$, N_c for GaAs is 4.7×10^{17}.

$$f_F = \frac{1}{1 + \exp\left[\frac{E - E_f}{kT}\right]}$$

$$= \exp\left[-\left(\frac{E - E_f}{kT}\right)\right]$$

Now,

$E = E_c + kT$

$E_c = 0.25 eV$, $k = 8.62 \times 10^{-5} eV/K$, $T = 300K$.

Now, $kT = 0.0259 eV$.

$$f_F = \exp\left[\frac{-(0.0259 + 0.25)}{0.0259}\right]$$

$$= \boxed{2.36 \times 10^{-5}}.$$

Concentration of e^-:

$$x_o = N_c \exp\left[-\frac{(E_c - E_f)}{KT}\right]$$

But,

$E_c - E_f = 0.25eV$; $N_c = 4.7 \times 10^{17} cm^{-3}$.

$$\Rightarrow x_o = (4.7 \times 10^{17} cm^{-3}) \exp\left[\frac{-0.25}{0.0259}\right]$$

$$= 3.02 \times 10^{13} cm^{-3}.$$

$$\therefore \boxed{\text{Con}^c \text{ of } e^- = 3.02 \times 10^{13} cm^{-3}}$$

3) Determine the thermal equilibrium electron and hole concentration in GaAs at $T = 300K$ for the case when the Fermi-energy level is $0.30eV$ above the valence-band energy E_v. The value of E_g is $1.42eV$.

$$x_o = N_c \exp\left[-\frac{[E_c - E_f]}{KT}\right]$$

for holes,

$$P_o = N_v \exp\left[-\frac{(E_F - E_v)}{KT}\right]$$

Concentration of holes:

$n_v = 7 \times 10^{18} cm^{-3}$

$KT = 0.0259eV$ [at 300K].

$E_F - E_v = 0.30eV$.

$\therefore \quad P_o = 7 \times 10^{18} \times \exp\left[\frac{-0.3}{0.0259}\right]$

$\Rightarrow \quad P_o = 6.53 \times 10^{13} cm^{-3}$

Also,

$E_g = 1.42 eV$

Now,

$E_c - E_f = E_g - [E_f - E_c]$

$= 1.42 - 0.3$

$= \underline{\underline{1.12 eV}}$

$N_c = 4.7 \times 10^{17} cm^{-3}$.

$kT = 0.0259 eV$.

$E_c - E_f = 1.12 eV$.

$\therefore \quad X_o = 4.7 \times 10^{17} \exp\left[\frac{-1.12}{0.0259}\right]$

$X_o = 0.0779 cm^{-3}$.

4) Silicon atoms, at a concentration of $7 \times 10^{15} cm^{-3}$, are added to gallium arsenide. Assume that the silicon atoms act as fully ionized dopant atoms and that 5 percent of the concentration added replace gallium atoms and 95 percent replace the arsenic atoms. Let T = 300K. (a) Determine the donor and acceptor concentrations. (b) Is the material n-type or p-type? (c) Calculate the electron and hole concentrations. (d) Determine the position of the Fermi-level w.r.t E_{Fi}.

Page No.

a) For Ga atoms, Si acts as donor.

$\Rightarrow N_d = (0.05)(7 \times 10^{15})$

$= 3.5 \times 10^{14}\ cm^{-3}$.

For As atoms, Si acts as an acceptor.

$\Rightarrow N_a = (0.95)(7 \times 10^{15})$

$= 6.65 \times 10^{15}\ cm^{-3}$.

b) Now,

$\because N_a > N_d$,

$\Rightarrow$ its a p-type.

(c)

$P_o = N_a - N_d = (66.5 - 3.5) \times 10^{14}\ cm^{-3}$

$= 63 \times 10^{14}\ cm^{-3}$

$= \underline{\underline{6.3 \times 10^{15}\ cm^{-3}}}$.

~~c~~) $n_o = \dfrac{n_i^2}{P_o} = \dfrac{1.8 \times 1.8 \times 10^{12}}{6.3 \times 10^{15}}$

$= \dfrac{3.24 \times 10^{-3}}{6.3}$

$= 0.514 \times 10^{-3}$

$= \underline{\underline{5.14 \times 10^{-4}\ cm^{-3}}}$

d) $E_{Fi} - E_F = kT \ln\left[\dfrac{P_o}{n_i}\right] = 0.0259 \ln\left[\dfrac{6.3 \times 10^{15}}{1.8 \times 10^{6}}\right]$

$= \boxed{0.569\ eV}$.

5) Two semi-conductor materials have exactly the same properties except material A has a bandgap energy of 0.9eV and the material B has a bandgap energy of 1.1eV. Determine the ratio of n_i of material B to that of material A for (a) at T = 200K (b) at T = 400K.

$$\frac{n_{iB}}{n_{iA}} = \frac{\exp\left[\frac{-1.1}{kT}\right]}{\exp\left[\frac{-0.9}{kT}\right]} = \exp\left[\frac{-0.2}{kT}\right]$$

(a) For T = 200K.

$kT = 0.0172\ eV.$

$$\Rightarrow \frac{n_{iB}}{n_{iA}} = \exp\left[\frac{-0.2}{0.0172}\right] = 9.325\times10^{-6}.$$

b) For T = 400K.

$kT = 0.0345\ eV.$

$$\Rightarrow \frac{n_{iB}}{n_{iA}} = \exp\left[\frac{-0.2}{0.0345}\right] = 3.05\times10^{-3}.$$