Solution to tutorial questions – 01

ESP5403 Nanomaterial for Energy Systems

03/09/2021

1. Determine the temperature at which an energy level which is 0.3 eV below Fermi energy is 2% unoccupied by an electron.

Solution:

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The probability that a state being occupied is

$$f(E) = \frac{1}{1 + \exp\left(E - E_F \big/ kT\right)}$$

Given: The probability that an energy state *E* is empty
= 0.02

i.e. $1-f(E) = 0.01$ or $f(E) = 0.98$

$E-E_f = -0.3\ eV$
$k = 8.625\times10^{-5}$ eV/K and
T = ?

$$0.98 = \frac{1}{1 + \exp\left(-0.3 \big/ 8.25\times10^{-5}\times T\right)}$$

$$\Rightarrow T = 894\,K$$

2. The value of p_o in Si at T = 300 *K* is 10^{15} cm^{-3}. Determine the following:
   (i) The position of Fermi energy below conduction band edge, and
   (ii) Equilibrium concentration of electrons

   Note that for Si at 300 *K*, $N_V = 1.04\times10^{19}$ cm^{-3} and $N_C = 2.8\times10^{19}$ cm^{-3}.

   Assume E_g of Si is 1.12eV.

Given, $p_o = 10^{15}$ cm^{-3} and for Si, $N_v = 1.04\times10^{19}$ cm^{-3}

i. And we know $p_0 = N_v \exp\left(-\frac{E_F - E_v}{kT}\right)$

$$10^{15} = 1.04\times10^{19} \exp\left(-\frac{E_F - E_v}{0.0259}\right)$$

$$\Rightarrow E_F - E_v = 0.24\,eV$$

$$Given, E_g = 1.12\,eV$$

$$\Rightarrow E_c - E_F = 0.88\,eV$$

Using, $E_c - E_F = 0.88\,eV$ in $n_0 = N_c \exp\left(-\frac{E_c - E_F}{kT}\right)$

We get, $n_o = 4.91\times10^{4}$ cm^{-3}

3. A semiconductor has $N_C = 10^{19}$ cm^{-3}, $N_v = 5 \times 10^{18}$ cm^{-3} and $E_g = 2$ eV doped with 10^{17} cm^{-3} donors (fully ionized)
   (a) Calculate the intrinsic, electron and hole concentrations at 627^{o}C
   (b) Where is E_F located relative to E_i?
   (c) Sketch the simplified band diagram, showing the position of E_F (assume the E_i is nearly at the midgap).

1) $N_c = 19\ cm^{-3}$; $N_v = 5 \times 10^{18}\ cm^{-3}$; $E_g = 2\ eV$; $N_D = 10^{17}$;
$T = 627^0C = 900K$

a) Intrinsic carrier concentration:

$$\mathbf{n_i = (N_c\ N_v)^{1/2} \exp(-E_g/2KT)}$$

$$= (10^{19} \times 5 \times 10^{18})^{1/2} \exp(-2/2 \times 8.617 \times 10^{-5} \times 900)$$

$$= 7.07 \times 10^{18} \times \exp(-12.9199)$$

$$= 1.776 \times 10^{13} / cm^3$$

Electron concentration: $\mathbf{n \cong N_D}$ $= 10^{17}$ (since, donors are fully ionized)

Hole concentration: $p = n_i^2/N_D$

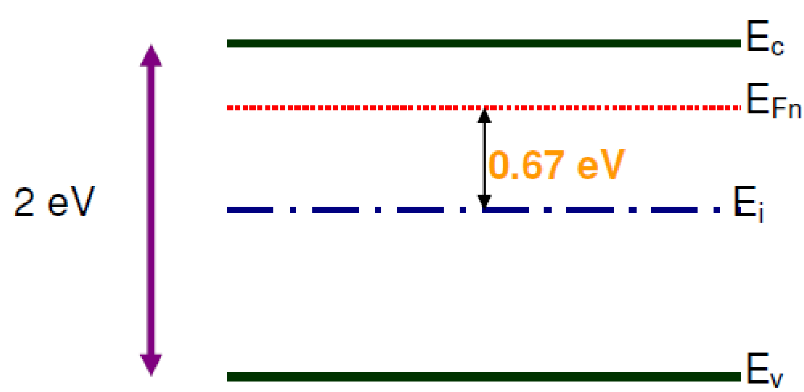
$$= (1.776 \times 10^{13})^2 / 10^{17} = 3.154 \times 10^9/cm^3$$

(b) $\mathbf{E_{Fn} - E_{Fi} = KT\ln n/n_i}$

$$= 8.617 \times 10^{-5} \times 900 \times \ln(10^{17} / 1.776 \times 10^{13})$$

$$= 0.67\ eV$$

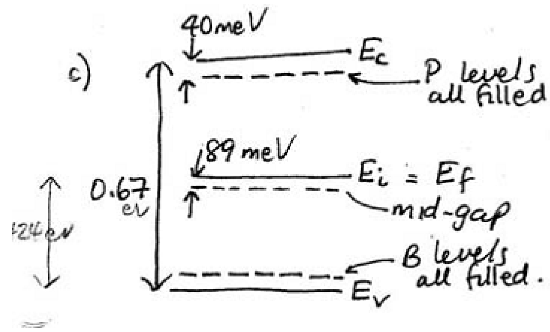
(c)



4. The Ge is now doped with Boron and with Phosphorous. Both dopants have the same concentration. Assume the Boron and Phosphorous energy levels are each 40 *meV* from

the band edge. If $m_n^*/m_p^* = 0.01$, draw the band diagram of the doped Ge as accurately as you can, showing E_g, E_f and E_i. Assume E_g of Ge is 0.67eV.

c. This is *compensated* (donors and acceptors cancel). Since $N_A = N_D$,



$E_f = E_i$, and $n = p = n_i$. Difference between E_i and midgap:

$$E_i = \text{midgap} + \frac{3}{4}kT \ln \frac{m_p^*}{m_n^*}$$

$$E_i = midgap + 89meV$$

5. Consider a GaAs semiconductor illuminated with photons of energy 1.65 eV.
   The absorption coefficient at 1.65 eV is 10^4 *cm*$^{-1}$.
   (a) Determine the thickness of the material so that 75% of the energy is absorbed.
   (b) Determine the thickness so that 75% of the energy is transmitted.

Solution:

Given: At $hv = 1.65$ *eV*, $\alpha = 10^4$ *cm*$^{-1}$.

(a) Let '***t***' be the thickness of the sample so that 75% of the energy is absorbed.
Intensity of light absorbed = 0.75 I(0) , where I(0) is the intensity of light just below the front surface.

Therefore, intensity of the light transmitted, I(t) = I(0)- 0.75 I(0)=0.25 I(0)

We have, $I(t) = I(0)e^{-\alpha t}$

$$\therefore 0.25I(0) = I(0) \times e^{-10^4 \times t}$$

$$\Rightarrow t = 1.39\,\mu m$$

(b) Let ***'t'*** be the thickness of the sample so that 75% of the energy is transmitted.

Therefore, intensity of the light transmitted, I(t) = 0.75 I(0)

We have, $I(t) = I(0)e^{-\alpha t}$

$$\therefore 0.75I(0) = I(0) \times e^{-10^4 \times t}$$

$$\Rightarrow t = 0.29\,\mu m$$

6. The optical properties of silicon measured at 300K are given below:

Wavelength (*nm*)	Absorption coefficient (cm^{-1})	Refraction coefficient R
400	1×10^4	0.49
700	1.90×10^3	0.34

Two monochromatic light sources at 400 *nm* and 700 *nm* are available to illuminate a silicon solar cell of 1 μm thick. Recommend the most suitable source for illumination. Assume that the light incidents normally on the front surface of the solar cell with an intensity of 10 W/cm^2.

Solution:

$I_S = 10\ W/cm^2$

$At\ 400\,nm \qquad R = 0.49$

$$I(0) = (10 - (0.49 \times 10)) \qquad = 5.1\,W/cm^2$$

$$I(t) = 5.1 \cdot \exp(-10^4 \times 10^{-4}) = 1.88\,W/cm^2$$

$$I(a) = 3.2\,W/cm^2$$

$At\ 700\,nm \qquad R = 0.34$

$$I(0) = 6.6\,W/cm^2$$

$$I(t) = 5.46\,W/cm^2$$

$$I(a) = 1.1\,W/cm^2$$