ISHAN AMRIT
19102227
AB

ASSIGNMENT :- 5

1) For intrinsic semi-conductor, the concentration of electrons in conduction band is equal to the concentration of holes in valence band;

$$n_0 = n_i = N_c \exp \frac{-(E_c - E_{fi})}{KT} \quad —①$$

$$p_0 = p_i = N_v \exp \frac{-(E_{fi} - E_v)}{KT} \quad —②$$

$\boxed{n_i = p_i}$ → for intrinsic semiconductor

③

→ From eq. ①, ② and ③, we get;

$$\Rightarrow n_i^2 = N_c \exp \frac{-(E_c - E_{fi})}{KT} \cdot N_v \exp \frac{-(E_{fi} - E_v)}{KT}$$

$$\Rightarrow n_i^2 = N_c N_v \exp \frac{-(E_c - E_v)}{KT}$$

Now, band gap;

$$\boxed{E_c - E_v = E_g}$$

$$\boxed{n_i^2 = N_c N_v \exp \frac{-E_g}{KT}}$$

→ The intrinsic carrier concentration is a function of bandgap, independent of fermi level.

→ The intrinsic Fermi-level position;

$n_i = p_i \longrightarrow$ for intrinsic semiconductor

$$N_c \exp \frac{-(E_c - E_{fi})}{KT} = N_v \exp \frac{-(E_{fi} - E_v)}{KT}$$

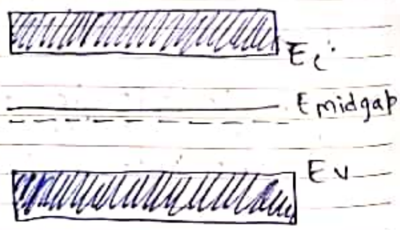
$$\Rightarrow E_{fi} = \frac{1}{2}(E_c + E_v) + \frac{1}{2} KT \ln\left(\frac{N_v}{N_c}\right)$$

$$\Rightarrow E_{fi} = \frac{1}{2}(E_c + E_v) + \frac{1}{2} KT \ln\left(\frac{m_p^*}{m_n^*}\right)^{3/2} \rightarrow ①$$

$\Rightarrow \cancel{E_{fi} = E}$

At 0 K, E_{fi}

$E_{midgap} = \frac{1}{2}(E_c + E_v)$ → eq②

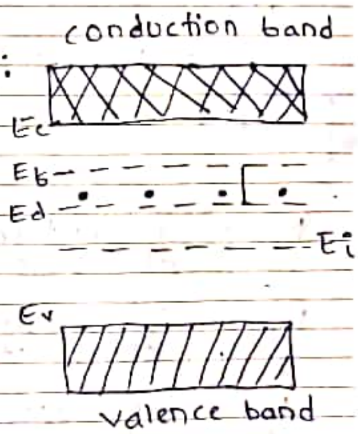


→ On putting eq② in eq.①, we get;

$$\boxed{E_{fi} = E_{midgap} + \frac{3}{4} KT \ln\left(\frac{m_p^*}{m_n^*}\right)}$$

2) n-type semiconductor:

$n = N_c e^{\frac{-(E_c - E_F)}{KT}}$ → eq①



→ $N_d^+ + p = n$

→ $N_d^+ \approx n$ or $p = n_i^2 / N_d^+$ → eq②

→ The probability of finding unionized donor atoms at energy level E_d is given as :-

$$\frac{N_d^0}{N_d} = f(E_d)$$

$$= N_d^+ = N_d[1 - f(E_d)]$$

$$\left[\because N_d^+ + N_d^0 = N_d\right]$$

N_d = concentration of donor atoms in the donor level.

N_d^+ = concentration of ionized donor atoms.

N_d^0 = concentration of un-ionized donor atoms

$$N_d^+ = N_d\left[1 - \frac{1}{1 + \exp\left(\frac{E_d - E_f}{KT}\right)}\right]$$

$$\approx N_d \exp\left(\frac{E_d - E_f}{KT}\right)$$

With the assumption, $E_f - E_d \ll KT$

→ Hence, from $N_d^+ \approx n$,

we can write ;

$$N_c e^{\frac{-(E_c - E_F)}{KT}} = N_d e^{\frac{E_d - E_F}{KT}}$$

on solving we get ;

$$\boxed{E_F = \frac{E_d + E_c}{2} + \frac{KT}{2} \ln\left[\frac{N_d}{N_c}\right]}$$

but, $N_c = 2\left[\frac{2\pi m_c^* KT}{h^2}\right]^{3/2}$

So we get,

$$E_F = \frac{E_d + E_c}{2} + \frac{KT}{2} \ln\left[\frac{N_d h^3}{2(2\pi m_c^* KT)^{3/2}}\right]$$

→ This gives position of fermi level at moderate temp. in n-type semi-conductor.

This equation is not valid at T = 0K (E_F becomes indeterminate) and T = ∞ (extrinsic semi-conductor behaves like an intrinsic semi-conductor).

$$n = N_c e^{-\frac{(E_c - E_F)}{kT}}$$

On subsituting;

$$E_F = \frac{E_d + E_c}{2} + \frac{kT}{2}\ln\left[\frac{N_d}{N_c}\right]$$

we get;

$$n = N_c \exp\left\{\frac{E_d - E_c}{2kT} + \frac{1}{2}\ln\left[\frac{N_d}{N_c}\right]\right\}$$

$$\Rightarrow \boxed{n = \sqrt{N_c N_d}\; e^{-\frac{\Delta E}{2kT}}}$$

where $\Delta E = E_c - E_d$

(b) P-type Semi-conductor

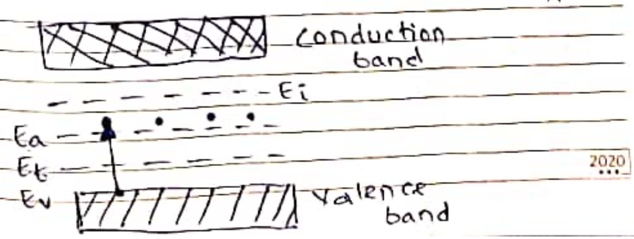
$$p = N_v e^{\frac{E_v - E_F}{kT}}$$

Also, $p = N_A^- + n$

if acceptors are ionized
$N_A^- \approx N_A$
$\Rightarrow p = N_A$

But, $np = n_i^2 \Rightarrow n = \frac{n_i^2}{p}$

$$\Rightarrow n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A}$$



→ Fermi Level ~~in an~~ in p-type semi-conductor;

* If all acceptors are ionized:-

$$p \approx N_A = N_V e^{\frac{(E_V - E_f)}{KT}}$$

$$\Rightarrow (E_V - E_f) = KT \ln \frac{N_A}{N_V}$$

$$\Rightarrow \frac{(E_V - E_f)}{KT} = \ln \frac{N_A}{N_V}$$

$$\Rightarrow \boxed{E_f = E_V - KT \ln \frac{N_A}{N_V}}$$

→ If N_A^- acceptors are ionized:-

$$p \approx N_A^- = N_A f(E_A)$$

$$= N_A \left[\frac{1}{1 + e^{\frac{(E_A - E_F)}{KT}}}\right]$$

$$= N_A e^{\frac{(E_f - E_A)}{KT}}$$

(Assuming $E_A - E_f >> KT$)

$$\Rightarrow p = N_A^- = N_A e^{\frac{E_f - E_A}{KT}}$$

$$\Rightarrow N_A e^{\left(\frac{E_f - E_A}{KT}\right)} = N_V e^{\left(\frac{E_V - E_F}{KT}\right)}$$

$$\Rightarrow \ln N_A + \frac{E_f - E_A}{KT} = \ln N_V + \frac{E_V - E_f}{KT}$$

$$\Rightarrow \ln N_A - \ln N_V = \frac{E_V - E_f}{KT} - \frac{E_f - E_A}{KT}$$

$$\Rightarrow \ln \frac{N_A}{N_V} = \frac{-2E_f}{KT} + \frac{E_V + E_A}{KT}$$

$$\Rightarrow \frac{2E_f}{KT} = \frac{E_V + E_A}{KT} - \ln \frac{N_A}{N_V}$$

$$\Rightarrow \boxed{E_f = \frac{E_A + E_V}{2} - \frac{KT}{2} \ln \frac{N_A}{N_V}}$$

Since,

$$N_V = \frac{2(2\pi m_h^* KT)^{3/2}}{h^3}$$

$$\Rightarrow E_f = \frac{E_A + E_V}{2} - \frac{KT}{2} \ln \frac{N_A h^3}{2(2\pi m_h^* KT)^{3/2}}$$

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→ This gives position of Fermi level at moderate temp. in p-type semiconductor. (not valid at T = 0K or T = ∞)

⇒ Thus free electron in the conduction band would be

$$p = N_V \exp\left(\frac{E_V - E_f}{KT}\right)$$

On substituting, ~~we get~~;

$$\Rightarrow E_f = \frac{E_A + E_V}{2} - \frac{KT}{2} \ln \frac{N_A}{N_V}$$

⇒ ~~p = N_V exp~~ we get;

$$\Rightarrow p = N_V \exp\left(\frac{E_V}{KT} - \frac{E_f}{KT}\right)$$

$$= N_V \exp\left(\frac{E_V}{KT} - \frac{E_A + E_V}{2KT} + \frac{KT}{2KT} \ln \frac{N_A}{N_V}\right)$$

M	T	W	T	F	S	S	M	T	W	T	F	S	S
	1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26	27
28	29	30	31										

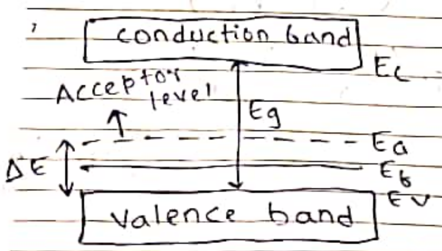
$$\Rightarrow p = N_V \exp\left(\frac{E_V - E_A}{2KT} + \frac{1}{2}\ln\frac{N_A}{N_V}\right)$$

$$\Rightarrow \cancel{p = N_V \exp\left(\frac{E_V - E_A}{2KT} + \frac{1}{}\right)}$$

$$= N_V \left(\frac{N_A}{N_V}\right)^{1/2} \exp\left(\frac{E_V - E_A}{2KT}\right)$$

$$\Rightarrow \boxed{p = (N_A N_V)^{1/2} \exp\left(\frac{\Delta E}{2KT}\right)}$$

Ionization energy of acceptors.



M	T	W	T	F	S	S	M	T	W	T	F	S	S
				1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31							

3) Hall effect

↳ When a material carrying current is subjected to a magnetic field in a direction perpendicular to the direction of current, an electric field is developed across the material in a direction perpendicular to both the direction of magnetic field and current direction. This phenomenon is called "Hall - effect".

→ When a current - carrying semi conductor is kept in a magnetic field, the charge carriers of the semi - conductor experience a force in a direction perpendicular to both the magnetic field and the current. At equilibrium, a voltage appears at the semi - conductor edges.

→ For moderate magnetic fields the Hall coefficient is :-

$$\boxed{R_H = \frac{p\mu_h^2 - n\mu_e^2}{e(p\mu_h + n\mu_e)^2}}$$

or equivalently,

$$\boxed{R_H = \frac{(p - nb^2)}{e(p+nb)^2}}$$

Where,
$$b = \frac{\mu_e}{\mu_h}$$

n = electron concentration
p = hole concentration
μ_e = electron mobility
μ_h = hole mobility
e = charge

* Applications of Hall effect :-

(1) Determination of the type of semiconductors.
→ R_H is -ve for n- type semiconductors.
→ R_H is +ve for p-type semiconductors.

(2) Calculation of carrier concentration
→ $R_H = \frac{-1}{ne}$ (n-type)
→ $R_H = \frac{1}{pe}$ (p-type)

(3) Determination of mobility
→ If the conduction is due to one type carriers,

$$\boxed{\mu_e = \sigma R_H}$$

(4) Measurement of magnetic flux density.

$$E_y = \frac{J_x B_z}{e} \frac{p u_h^2 - n u_e^2}{(n u_e + p u_h)^2}$$

→ Hall voltage is proportional to the magnetic flux density 'B' for a given current.