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PHYSICS-II

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Assignment-5

1. For intrinsic semiconductor, concentration of e^- in conduction Band is equal to concentration of holes in valence band

$$n_0 = n_i = N_c e^{-\frac{(E_c - E_{Fi})}{KT}} \quad \text{--- (i)}$$

$$p_0 = p_i = N_v e^{-\frac{(E_{Fi} - E_v)}{KT}} \quad \text{--- (ii)}$$

$(n_i = p_i)$ — (iii). for intrinsic semiconductor

From (i), (ii), (iii), we get →

$$n_i^2 = N_c e^{-\frac{(E_c - E_{Fi})}{KT}} \cdot N_v e^{-\frac{(E_{Fi} - E_v)}{KT}}$$

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

Now Band Gap Energy

$$E_c - E_v = E_g$$

$$n_i^2 = N_c N_v e^{-E_g/KT}$$

The intrinsic carriers concentration is a function of Band independent of Fermi-level.

The intrinsic fermi-level position → $n_i = p_i$

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

$$E_f = \frac{1}{2}(E_c - E_v) + \frac{1}{2} KT \ln\left(\frac{N_v}{N_c}\right)$$

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

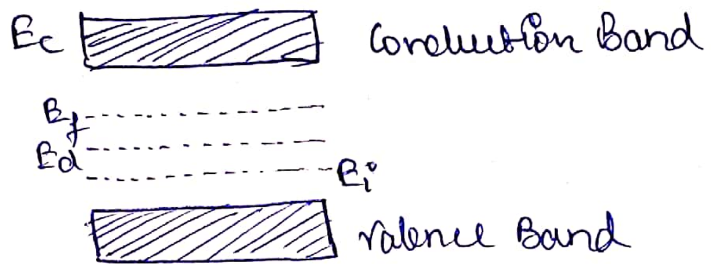
At zero Kelvin →

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

On putting eqn (iii) in (i) we get

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

2. Carrier Concentration and fermi level in n-type semiconductor-



N_d = Concentration of donor atoms in donor level
N_d^+ = Concentration of ionized donor atom.
N_d^0 = Concentration of un-ionized donor atom.

n e^-s concentration in conduction Band $= N_c e^{-\frac{(E_c - E_F)}{KT}}$

$$N_d^+ + p = n$$

$$N_d^+ \approx n \text{ or } p \approx n_i^2 / N_d T \quad \text{—— (2)}$$

The probability of finding unionized donor atom at Energy level E_d is given as -

$$\frac{N_d^0}{N_d} = F(E_d) > N_d^+ = N_d[1 - F(E_d)]$$

$$\text{as } N_d^+ + N_d^0 = N_d$$

$$N_d^+ = N_d\left[1 - \frac{1}{1 + e^{-\frac{(E_c - E_F)}{KT}}}\right] = N_d \cdot e^{\frac{(E_d - E_F)}{KT}}$$

$E_F - E_d << KT$ (assumption)

from (2) $$N_c e^{-\frac{(E_c - E_f)}{KT}} = N_d e^{\frac{(E_d - E_F)}{KT}}$$

On solving →

$$E_f = \frac{E_d + E_c}{2} + \frac{1}{2} KT \ln\left(\frac{N_d}{N_c}\right)$$

But $$N_c = 2\left[\frac{2\pi m^* KT}{h^2}\right]^{3/2}$$

so, $$E_F = \frac{E_d + E_c}{2} + \frac{1}{2} KT \ln\left[\frac{N_d h^3}{2(2\pi m^* KT)^{3/2}}\right]$$

so, $$E_F = \frac{E_d + E_c}{2} + \frac{1}{2} KT \left[\frac{N_d h^3}{2(2\pi m^* KT)^{3/2}}\right]$$

Free $\bar{e}$ concentration in conduction Band would be -

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

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

$$n = N_c e^{\left\{\frac{E_d + E_c}{2KT} + \frac{1}{2}\ln\left[\frac{N_d}{N_c}\right]\right\}}$$

$$n = \sqrt{N_c N_d}\, e^{-\frac{\Delta E}{2KT}}$$

$\Delta E = E_c - E_d$ (Ionised Energy of Donor atom)

Carrier concentration and Fermi-level in p-type semiconductor

However if acceptance sufficiently ionised. $N_A^- = N_A$

$p = N_V e^{(+E_V - E_F)/KT}$

Also. $p = N_A + n$

But $np = n_i^2$

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

From fermi level and conductivity in p-type semiconductor

If all acceptors are ionised

$$p \times N_A = N_V e^{\frac{E_V - E_F}{KT}}$$

$$E_V - E_F = KT \ln\left(\frac{N_d}{N_V}\right)$$

$$E_F = E_V - KT \ln\left(\frac{N_d}{N_V}\right)$$

If N_A^- acceptance are ionised

$$p \times N_A^- = N_A F(E_A)$$

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

By assumption →

$E_A - E_F >> KT$

$$p \cdot N_A = N_A e^{(E_F - E_A)/KT}$$

$$p = N_A^- = N_A e^{(E_F - E_A)/KT}$$

$$N_A e^{(E_F - E_A)/KT} = N_V e^{(E_V - E_F)/KT}$$

By solving →

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

Since $N_V = \frac{2(2\pi m^*_h KT)^{3/2}}{h^3} \Rightarrow E_F = \frac{E_A + E_V}{2} - \frac{KT}{2}\ln\left[\frac{N_A h^3}{(2\pi m^*_h KT)^{3/2}}\right]$

Free $\bar{e}$s concentration in conduction Band would be

$$p = N_V e^{\frac{E_V - E_F}{KT}}$$

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

(4) $$p = N_v e^{\left(\frac{E_V}{KT} - \frac{E_F}{KT}\right)} = N_v e^{\left(\frac{E_V}{KT} - \frac{E_A + E_V}{2KT} + \frac{KT}{2KT}\ln\left(\frac{N_A}{N_V}\right)\right)}$$

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

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

$$p = \sqrt{N_A N_V}\, e^{\frac{\Delta E}{2KT}}$$ ΔE = Ionised Energy at acceptor

3. Hall Effect

When a material carrying current is subjected to magnetic field in a direction perpendicular to direction of current, an E_F 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.

Application

1) Determination of type semiconductor —

Hall coefficient R_H is negative for a n type semiconductor and +ve for p-type. Thus the sign of Hall coefficient can be used to determine whether a given semiconductor is n-type / p-type.

2) Calculation of Carrier Concentration —

$$R_H = -\frac{1}{ne} \rightarrow \text{n-type} \qquad R_H = \frac{1}{pe} \rightarrow \text{p-type}$$

3) Definition of mobility —

If conductivity is due to one type of carriers ex electrons

$$\sigma = ne\nu$$
$$\nu_0 = \sigma/ne = \sigma R_H$$
$$\boxed{\nu_e = \sigma R_H}$$

4) Measurement of magnetic flux Density —

$$E_y = \frac{J_x B_z}{c}$$

Hall voltage x Magnetic flux density B for a given current I so Hall effect as the basis for design of Magnetic Flux Density Method.