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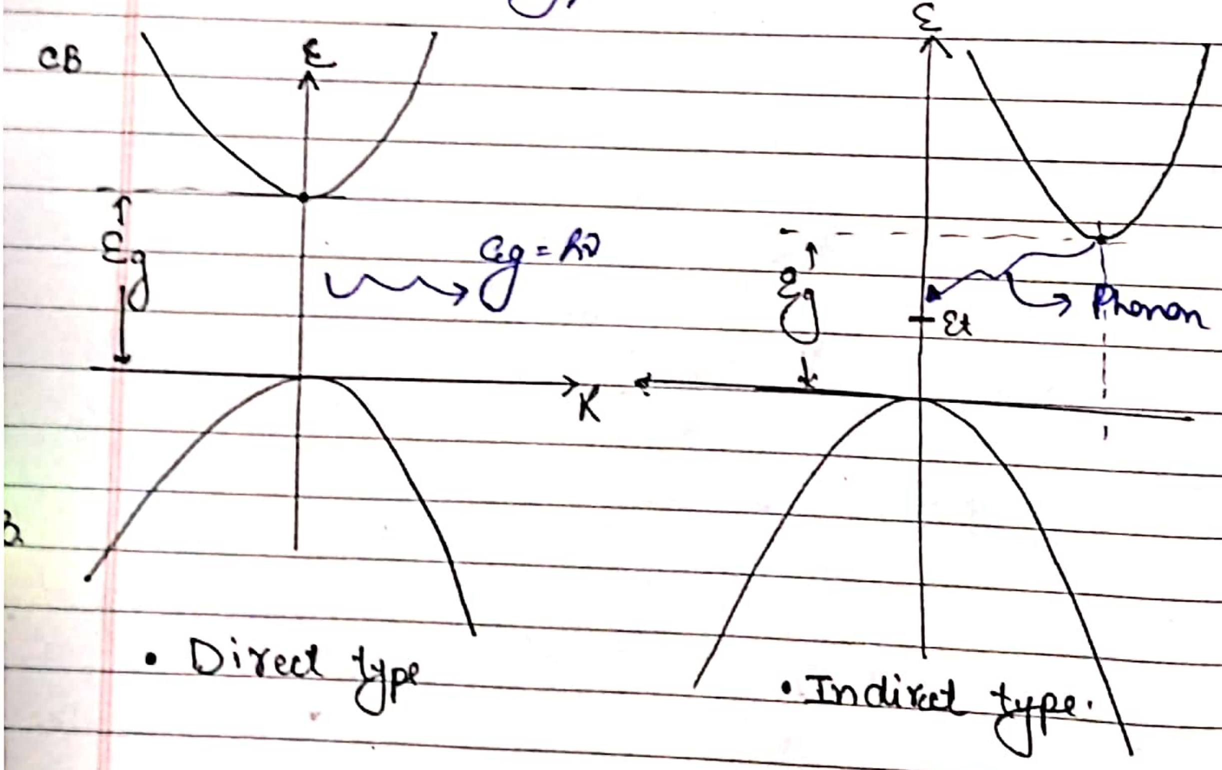
UNIT 1: (ASSIGNMENT-I)

Q1. With the help of suitable dig. diff between the direct and indirect semiconductor & hence show that a semiconductor is due to the motion of uncompensated electrons.

Ans: Direct type:

If the maximum (top) of the valence band and minimum/bottom of conduction band are at same value of 'K' or lies on same value of 'K', band gap is called as "Direct Band gap"



• Direct type • Indirect type.

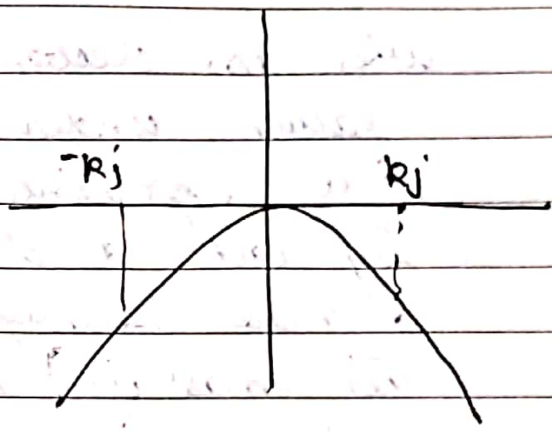
Indirect type:

If the top of VB and minima of CB are not at same value of K, they are referred as Indirect Band gap and so are the semiconductors

In Semiconductor at 0K, most of the all states of valence band has been occupied. The $\bar{e}$ are mainly randomly cancelling each other effect. For eg an electron of $k = k_j$ momentum there exist another $k = -k_j$.

But as temp is raised, electrons from VB jumps to CB after getting energy to overcome forbidden gap.

For fully filled,



$$J_1 = -q \sum_i^N v = 0$$

After J^{th} electron removed,

$$J_2 = -q \sum_{i=}^{N} v - (-q) v_j \qquad J_1 = 0$$

$$J_2 = q v_j$$

Thus, there is generation of a current due to hole or we can say due to uncompensated electron.

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Q2 What is effective mass? Show that effective mass of an electron under the influence of an external electric field moving in a crystal is

$$m^* = \left(\frac{\hbar^2}{\frac{\partial^2 E}{\partial k^2}}\right)$$

when an electron moves within a periodic crystal lattice under an external $\vec{E}$, then electron will experience the periodic potential offered by each and every crystal atom, causing its mass seemingly to be altered.
This mass is known as altered mass or effective mass.

$$\vec{F}_{net} = \vec{F}_{ext} + \vec{F}_{int}$$

internal resistance offers

$$m\vec{a} = -e\vec{E} + F_{int}$$

$$\boxed{m^*\vec{a} = -e\vec{E}}$$

Effective mass.

Energy $(E) = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ $\quad p = mv = \hbar k$

$$E = \frac{\hbar^2 k^2}{2m^*}$$

$$\frac{\partial E}{\partial k} = \frac{\hbar^2 k}{2m^*} \quad \& \quad \frac{\partial^2 E}{\partial k^2} = \frac{\hbar^2}{m^*} \quad \therefore \left(m^* = \frac{\hbar^2}{\frac{\partial^2 E}{\partial k^2}} \right)$$

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Q. Calculate the amount of energy required to excite a donor electron from a donor level to the conduction band of a doped GaAs.

[Given. $\varepsilon_r = 13.2$, $m_n^* = 0.06 m_0$ $m_0 = 9.1 \times 10^{-31}$ kg]

Amount of energy required to excite an electron in CB is equal to the binding energy of donor level.

$$E = \frac{m_n^* q^4}{2\hbar^2 k^2}$$

where;

$$k = 4\pi \varepsilon_0 \varepsilon_r$$

$$E = \frac{m_n^* . q^4}{2\hbar^2 \times (4\pi \varepsilon_0 \varepsilon_r)^2} \qquad \hbar = \frac{h}{2\pi}$$

$$= \frac{m_n^* q^4 \times 4\cancel{\pi^2}}{2 \times h^2 \times \cancel{16}\cancel{\pi^2} \varepsilon_0^2 \varepsilon_r^2}$$

$$= \frac{m_n^* q^4}{8 h^2 \varepsilon_0^2 \varepsilon_r^2}$$

$$= \frac{0.067 \times (9.1 \times 10^{-31}) \times (1.6 \times 10^{-19})^4}{8 \times (6.63 \times 10^{-34})^2 \times (8.85 \times 10^{-12} \times 13.2)^2}$$

$$= \frac{8.32 \times 10^{-7} \times 10^{-92} \times 10^{101}}{1.6 \times 10^{-19}}$$

$$= \boxed{5.204 \text{ mev}}$$

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Q4. Si is doped with 10^{17} accepter atom cm^{-3}. Calculate the value of equilibrium electon concentration (n_o) at 300K. & where the Fermi Level (E_f) will be located with respect to the intrins level (E_i) ?

$$N_a = 10^{17} \text{ atom } cm^{-3}$$

$$p_o = 10^{17} \text{ atom } cm^{-3}$$

n_i for Si at room temp $= 1.5 \times 10^{10} \, cm^{-3}$

$$n_i^2 = n_o p_o$$

$$\therefore n_o = \frac{n_i^2}{p_o} = \frac{(1.5 \times 10^{10})^2}{10^{17}} = 2.25 \times 10^3 \text{ atom } cm^{-3}$$

we know,

$$n_o = n_i e^{(E_f - E_i)/kT}$$

K = Baltzmann costal
$= 0.8625 \times 10^{-4} \, eV K^{-1}$

$$\frac{n_o}{n_i} = e^{(E_f - E_i)/kT}$$

$$\ln \frac{n_o}{n_i} = \frac{(E_f - E_i)}{kT}$$

$$\therefore E_f = E_i + KT \ln \frac{n_o}{n_i}$$

$$= E_i + 0.8625 \times 300 \times \left[\log(1.5) + \log_{10}(10^{-7})\right] \times 2.3$$

$$= E_i + 595.9 \times 10^{-4} \, [0.176 - 7]$$

$$\boxed{E_f = E_i - 0.41 \, eV}$$

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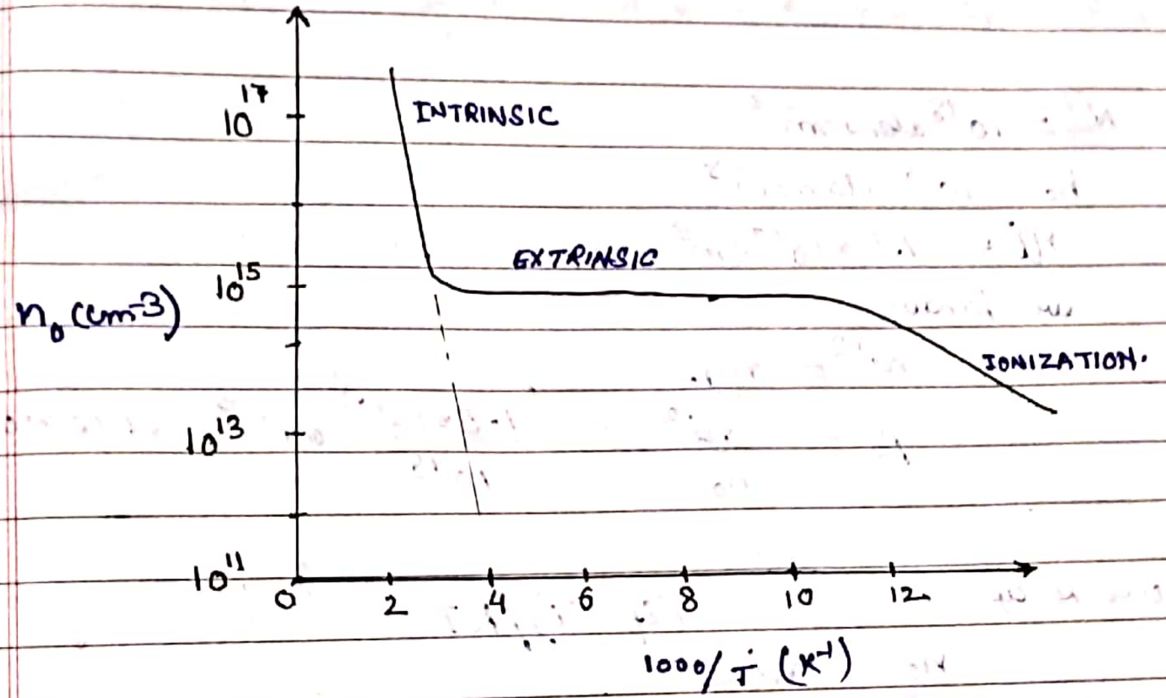
5. Discuss about the temperature dependance of electron concentration in an extrinsic semiconductor with help of suitable diag.



Carrier Conn vs Inverse Temp. for Si doped with 10^{15} donor atoms.

In the following case, Si is doped n-type with a donor concentration Nd of $10^{15} cm^{-3}$. At very low temperatures, negligible intrinsic EHP's exist and donor e⁻ are bound to respective atom. As temp is raised, these electrons are donated to the conduction band and at about 100K all the donor atom are ionized. This temp range is called ionization range. Once the donors are ionized, the conduction band e⁻ is $n_0 \simeq Nd = 10^{15} cm^{-3}$ since one e⁻/donor atom. when every available extrinsic electron has been transferred to CB, n_0 is virtually constant, until conn of intrinsic carriers n_i become comparable to the extrinsic conn Nd. Finally at higher temp n_i is ... generated from Nd & intrinsic carrier dominate.

Q7. A Si sample is doped with 10^{18} As atom cm^{-3}. Calculate eq. hole conc^n (p_0) at 300K, Also estimate the position of E_f relative to E_i.

[Given: $k = 8.62 \times 10^{-5}\, eV K^{-1}$ & n_i for Si $= 1.5 \times 10^{10}\, cm^{-3}$]

$N_d = 10^{18}$ atom cm^{-3}

$n_0 = 10^{18}$ atom cm^{-3}

$n_i = 1.5 \times 10^{10}\, cm^{3}$

we know,

$$n_i^2 = n_0 p_0$$

$$p_0 = \frac{n_i^2}{n_0} = \frac{(1.5 \times 10^{10})^2}{10^{18}}\, cm^{-3} = 2.25 \times 10^{2}$$

we know,

$$n_0 = n_i e^{(E_f - E_i)/kT}$$

$$E_f - E_i = kT \ln\left(\frac{n_0}{n_i}\right)$$

$$E_f = E_i + kT \ln\left(\frac{n_0}{n_i}\right)$$

$$= E_i + 8.62 \times 10^{-5} \times 300 \ln\left(\frac{10^{18}}{1.5 \times 10^{10}}\right)$$

$$= E_i + 8.62 \times 300 \times 2.303 \left[\log_{10}(10^8) - \log_{10}(1.5)\right]$$

$$= E_i + 8.62 \times 300 \times 2.303 \, [8 - 0.176]$$

$$= E_i + 8.62 \times 300 \times 18.02$$

$$= \cancel{E_i + 0.466 eV}$$

$$E_f = \boxed{E_i + 0.47 eV}$$

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Q8. A Ge sample is doped with 10^{18} Sb atoms cm^{-3}. where is E_f wrt E_i at 300 K. Also calculate the minority charge carrier conc^n.

[Given $n_i = 2.5 \times 10^{19}/m^{-3}$ $K_B = 1.38 \times 10^{-23}\ JK^{-1}$
$K = 8.62 \times 10^{-5}\ eV/K$

$N_d = 10^{18}$ atom cm^{-3}

$n_0 = 10^{18}$ " "

n_i for Ge $= 2.5 \times 10^{19} m^{-3} = 2.5 \times 10^{13} cm^{-3}$

we know

$$n_i^2 = n_0 p_0$$

$$p_0 = \frac{n_i^2}{n_0} = \frac{(2.5 \times 10^{13})^2}{10^{18}} = 6.25 \times 10^{8} cm^{-3}$$

$$p_0 = 6.25 \times 10^{8} \text{ atoms } cm^{-3}$$

we know that,

$$n_0 = n_i e^{(E_f - E_i)/kT}$$

$$E_f = E_i + kT \ln\left(\frac{n_0}{n_i}\right)$$

$$E_f = E_i + 8.62 \times 10^{-5} \times 300 \times \ln\left(\frac{10^{\cancel{18}\ 5}}{2.5 \times 10^{\cancel{13}}}\right)$$

$$= E_i + 8.62 \times 300 \times 2.303 \times [\log_{10}(10^5) - \log_{10}(2.5)]$$

$$= E_i + 8.62 \times 300 \times 2.303 [5 - 0.398]$$

$$= E_i + 0.274\ eV$$

$$\therefore \boxed{E_f = E_i + 0.274\ eV}$$

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Q3. Si is doped with donor ($2\times10^{17}\ cm^{-3}$) and acceptor ($6\times10^{17} cm^{-3}$) where is E_f relative to E_i at 300K. Also calculate Hall coefficient.

[Given, $n_i = 1.5\times10^{16} m^{-3}$ and $K = 8.62\times10^{-5}\ eV\,K^{-1}$

$N_d = 2\times10^{17}\ cm^{-3}$ $\quad n_i = 1.5\times10^{-6}\ cm^{-3}$

$N_a = 6\times10^{17} cm^{-3}$

$\therefore \quad p_0 = N_a - N_d = 6\times10^{17} - 2\times10^{17}$

$= 4\times10^{17}\ cm^{-3}$

we know,

$$n_0 p_0 = n_i^2$$

$\therefore$

$$n_0 = \frac{n_i^2}{p_0} = \frac{(1.5\times10^{10})^2}{4\times10^{17}} cm^{-3}$$

$\therefore \quad n_0 = 5.625\times10^{2}\ cm^{-3}$

As,

$$n_0 = n_i . e^{(E_f - E_i)/KT}$$

$$E_f = E_i + KT \ln\left(\frac{n_0}{n_i}\right)$$

$$= E_i + 8.62\times10^{-5}\times300\times2.303\times\left[\log_{10}(3.75) - \log_{10}(10^{-8})\right]$$

$$= E_i - 442\times10^{4}\times10^{-5}\ eV$$

$$E_f = E_i - 0.442\ eV$$

$$\boxed{E_f = E_i - 0.44 eV}$$

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Hall coefficient $(R_H) = \frac{1}{q p_0}$

$$= \frac{1}{1.6\times10^{-19}\times p_0} \quad \& \; p_0 = 4\times10^{23}\,m^{-3}$$

$$= \frac{1}{1.6\times10^{-19}\times 4\times10^{23}} \; C^{-1}m^{3}$$

$$\boxed{R_H = 1.56\times10^{-5}\; C^{-1}m^{3}}$$

Q10 Calculate effective densities of state N_c and N_v for GaAs at 300K. Also calculate intrinsic carrier con. and compare it with given n_i.

Given, $m_n^* = 0.067\, m_0$, $m_p^* = 0.48\, m_0$, $m_0 \rightarrow$ rest mass of e^-.
$n_i = 2\times10^{6}\,cm^{-3}$, $E_g = 1.43\,eV$.
$K = 8.62\times10^{-5}\,eVK^{-1}$.

We know,

$$N_c = 2\left(\frac{2\pi m_n^* KT}{h^2}\right)^{3/2}$$

$$N_v = 2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2}$$

$$n_i(T) = 2\left(\frac{2\pi KT}{h^2}\right)^{3/2} (m_n^* m_p^*)^{3/4} e^{-E_g/2KT}$$

$$\text{or} \quad n_i(T) = N_c \cdot N_v \cdot e^{-E_g/KT}$$

1. $$N_c = 2\left(\frac{2\pi m_n^* KT}{h^2}\right)^{3/2}$$

$$= 2\times\left(\frac{2\pi\times 0.067\times 9.1\times10^{-31}\times 1.38\times10^{-23}\times 300}{(6.63\times10^{-34})^2}\right)^{3/2}$$

$$= 2\left(\frac{1585.17\times10^{-31-23}}{43.96\times10^{-68}}\right)^{3/2}$$

$$= 2\times(36\times10^{14})^{3/2}$$

$$= 2\times 216\times10^{21}$$

$$N_c = 4.32\times10^{23}$$

2. $$N_v = 2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2}$$

$$= 2\left(\frac{2\pi\times 0.48\times 9.1\times10^{-31}\times 1.38\times10^{-23}\times 300}{(6.63\times10^{-34})^2}\right)^{3/2}$$

$$= 2\cdot\left(\frac{11356.45\times10^{-54}}{43.96\times10^{-68}}\right)^{3/2}$$

$$= 2\cdot(258.34\times10^{14})^{3/2}$$

$$= 2\times 4152.2\times10^{21}$$

$$\boxed{N_v = 8.30\times10^{24}}$$

iii) $n_i^2(T) = N_v . N_c . e^{-Eg/KT}$

$$\frac{Eg}{KT} = \frac{1.43 \times 10^2}{8.62 \times 10^{-5} \times 300} = 55.33$$

$$n_i^2(T) = 4.32 \times 10^{23} \times 8.30 \times 10^{24} \times e^{-55.33}$$

$$n_i^2(T) = 35.86 \times 10^{47} e^{-55.33}$$

$$\therefore \quad n_i(T) = (334.93 \times 10^{22})^{1/2}$$

$$n_i(T) = 18.30 \times 10^{11} m^{-3}$$

$$\boxed{n_i(T) = 1.83 \times 10^{6} cm^{-3}}$$

14. Show that the minimum conductivity of an intrinsic semi-conductor sample occurs when,

$$n_m = n_i \sqrt{\mu p / \mu n}$$

where,

$n_m \rightarrow$ electron conc^n corresponding to minimum conductivity
$n_i \rightarrow$ intrinsic conc^n
$\mu p \rightarrow$ hole mobility and μn is e^- mobility.

Conductivity of a semiconductor $(\sigma) = q(n\mu n + p\mu p)$ — ①

we know,

$$n_i^2 = np$$

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

$\therefore$

$$\sigma = q\left(n\mu_n + \frac{n_i^2 \mu_p}{n}\right) \quad \text{— (1)}$$

diff (1) wrt n

$$\frac{\partial \sigma}{\partial n} = q\left(\mu_n - \frac{n_i^2}{n^2}\mu_p\right)$$

for minimum $\frac{d\sigma}{dn} = 0$

$\therefore$

$$\mu_n = \frac{n_i^2 \mu_p}{n^2}$$

$$\therefore n = n_i^2 \frac{\mu_p}{\mu_n}$$

for min. conduct. $n = n_m$

$$n_m^2 = n_i^2 \frac{\mu_p}{\mu_n}$$

$$\boxed{n_m = n_i \sqrt{\frac{\mu_p}{\mu_n}}}$$

Hence Proved