Semi Conductor

* Derive the expression for the concentration of electrons in conduction band of semiconductor and conc^n of hole in the valence band.

→ The concentration of electrons in the conduction band is given by

$$N_e = \int_{E_c}^{\infty} D(E) f(E)\, dE \quad \text{— i)}$$

where, $D(E)$ is density of state
$f(E)$ is Fermi-dirac distribution function

$$f(E) = \frac{1}{e^{\frac{E-E_f}{k_BT}} + 1} = \frac{1}{\left(e^{\frac{E-E_f}{k_BT}} + 1\right)}$$

and

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2} E_f^{1/2}$$

$$= \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2} (E - E_c)^{1/2}$$

Now eq^n i) becomes,

$$N_e = \int_{E_c}^{\infty} \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2} \frac{(E-E_c)^{1/2}}{\left(e^{\frac{E-E_f}{k_BT}} + 1\right)}\, dE$$

$$= \frac{1}{2\pi^2}\left(\frac{\cancel{2me}\, 2me}{\hbar^2}\right)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2}\frac{1}{\left(e^{\frac{E-E_f}{k_BT}}+1\right)}\,dE \qquad \text{--- ii)}$$

$\cancel{\text{II}}$. Since $E > E_f$ so, $e^{\frac{E-E_f}{k_BT}} >> 1$

so,

$$e^{\frac{E-E_f}{k_BT}}+1 \approx \cancel{E}\, e^{\frac{E-E_f}{k_BT}}$$

Now eqn ii) becomes,

$$N_e = \frac{1}{2\pi^2}\left(\frac{2me}{\hbar^2}\right)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2}\, e^{-\frac{E-E_f}{k_BT}} \times dE$$

$$N_e = \frac{1}{2\pi^2}\left(\frac{2me}{\hbar^2}k_BT\right)^{3/2}\int_{E_c}^{\infty}\left(\frac{E-E_c}{k_BT}\right)^{1/2} e^{-\frac{(E-E_c+E_c-E_f)}{k_BT}} \times \frac{dE}{dk_BT}$$

$$n_e = \frac{1}{2\pi^2}\left(\frac{2me}{\hbar^2}k_BT\right)^{3/2}\int_{E_c}^{\infty}\left(\frac{E-E_c}{k_BT}\right)^{1/2} e^{-\frac{(E-E_c)}{k_BT}} \times e^{-\frac{(E_c-E_f)}{k_BT}} \times \frac{dE}{dk_BT}$$

$$n_e = \frac{1}{2\pi^2}\left(\frac{2me\,k_BT}{\hbar^2}\right) e^{-\frac{(E_c-E_f)}{k_BT}}\int_{E_c}^{\infty}\left(\frac{E-E_c}{k_BT}\right)^{1/2} e^{-\left(\frac{E-E_c}{k_BT}\right)} \times \frac{dE}{dk_BT}$$

let $x = \frac{E - E_c}{k_B T}$

$dx = \frac{dE}{k_B T}$

Now

$$= \quad n_e = \frac{1}{2\pi^2}\left[\frac{2 m_e k_B T}{\hbar^2}\right]^{3/2} e^{-\frac{(E_c - E_f)}{k_B T}} \int_0^{\infty} x^{1/2} \cdot e^{-x}\, dx.$$

$$= \frac{1}{2\pi^2}\left(\frac{2 m_e k_B T}{\hbar^2}\right)^{3/2} \cdot \left(\frac{\pi}{4}\right)^{1/2}$$

$\left[\because \int x^{1/2} e^{-x}\, dx = \left(\frac{\pi}{4}\right)^{1/2} + C \right.$ is a standard integration.

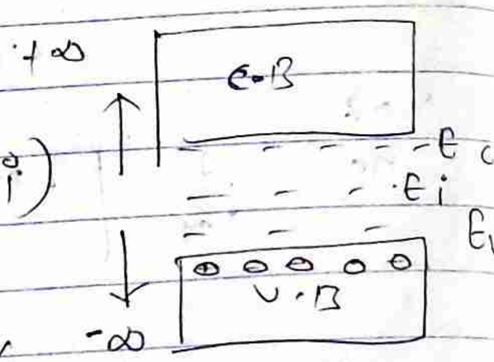
$$\therefore \quad n_e = \frac{1}{2\pi^2}\left[\frac{2 m_e k_B T}{\hbar^2}\right]^{3/2} \cdot \left(\frac{\pi}{4}\right)^{1/2} \quad \text{--- iii)}$$

This gives the concentration of electron in conduction band of pure semiconductor.

* Hole concentration in intristnic semiconductor

-) The hole concentration in intristnic semiconductor is given by

$$n_p = \int_{-\infty}^{E_v} D(E)\, f_h(E)\, dE \quad \text{— i)}$$



where,

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2} E^{1/2}.$$

where, equilibrium Femi-dirak distribution function for hole is given by

$$f_h(E) = 1 - f_e(E) = 1 - \frac{1}{\left(e^{\frac{E-E_f}{k_BT}} + 1\right)}$$

$$= \frac{\left(e^{\frac{E-E_f}{k_BT}} + 1\right) - 1}{\left(e^{\frac{E-E_f}{k_BT}} + 1\right)}$$

$$= \frac{e^{\frac{E-E_f}{k_BT}}}{\left(e^{\frac{E-E_f}{k_BT}} + 1\right)}$$

For holes $E < E_f$ in $e^{\frac{E-E_f}{k_B T}} << 1$ and $\simeq$

$$e^{\frac{E-E_f}{k_B T}} + 1 \simeq e^{\cancel{\frac{E-E_f}{k_B T}}} 1$$

$$\therefore \quad f_h(E) = e^{\frac{E-E_f}{k_B T}}$$

and

~~$f_h(E) =$~~ ~~$D(E) =$~~ ~~$2m_h$~~

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\right)^{3/2} E^{1/2}$$

Now,

~~1~~. E is replaced by $E_V - E$ for holes.

$$D(E) = \frac{1}{2\pi^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\left(E_V - E\right)^{1/2}$$

Using the femi-dirak ~~fu~~ distribution fumction and density of state for holes in the eq^n i) we have,

$$n_p = \int_{-\infty}^{E_V} \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\right)^{3/2}\left(E_V - E\right)^{1/2} \cdot e^{\frac{E-E_f}{k_B T}} \cdot dE$$

$$n_p = \int_{-\infty}^{E_V} \frac{1}{2\pi^2}\left(\frac{2m_h\, k_B T}{\hbar^2}\right)^{3/2}\left(\frac{E_V - E}{k_B T}\right)^{1/2} \cdot e^{\frac{E-E_f}{k_B T}} \frac{dE}{k_B T}$$

$$n_p = \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\times k_BT\right)^{3/2}\int_{-\infty}^{E_V}\left(\frac{E_V-E}{k_BT}\right)^{1/2} e^{\frac{E-E_V+E_V-E_f}{k_BT}} \times \frac{dE}{dk_BT}$$

$$= \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}k_BT\right)^{3/2}\int_{-\infty}^{E_V}\left(\frac{E_V-E}{k_BT}\right)^{1/2} e^{\frac{-(E_V-E)}{k_BT}} \times e^{\frac{(E_V-E_f)}{k_BT}} \times \frac{dE}{k_BT}$$

$$= \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}k_BT\right)^{3/2} \cdot e^{\frac{E_V-E_f}{k_BT}}\int_{-\infty}^{E_V}\left(\frac{E_V-E}{k_BT}\right)^{1/2} e^{-\left(\frac{E_V-E}{k_BT}\right)}\frac{dE}{dk_BT}$$

let $x = \frac{E_V-E}{k_BT}$ $\quad dx = -\frac{dE}{k_BT}$

$$n_p = \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\times k_BT\right)^{3/2} e^{\frac{E_V-E_f}{k_BT}}\int_{\infty}^{0} -x^{1/2}\cdot e^{-x}(-dx)$$

$$\text{or } n_p = \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\times k_BT\right)^{3/2}\left(\frac{\pi}{4}\right)^{1/2}\times e^{\frac{E_V-E_f}{k_BT}} \quad -\text{ⓐ}$$

$$= N_h\, e^{\frac{E_V-E_f}{k_BT}} \qquad -\text{ii)}$$

where

$$N_h = \frac{1}{2\pi^2}\left(\frac{2m_h k_B T}{\hbar^2}\right)^{3/2}\left(\frac{\pi}{4}\right)^{1/2}$$

Eqn ii) gives the hole concn in intristnic semiconducter.

Derive fermienergy for the Intristic semiconductor

→ As we know that electron concn must be equal to hole concn in the intrisnic semiconducter

$$\therefore \quad n_e = n_h \quad \text{— i)}$$

where

ne is electron concn i.e

$$n_e = N_e\, e^{\frac{E_f - E_e}{k_B T}}$$

&

$$n_h = N_h\, e^{\frac{E_V - E_f}{k_B T}}$$

Now eqn i) can be written as

$$N_e\, e^{\frac{E_f - E_e}{k_B T}} = N_h\, e^{\frac{E_v - E_f}{k_B T}}$$

$$\frac{e^{\frac{E_f - E_e}{k_B T}}}{e^{E_v - E_f/k_B T}} = \frac{N_h}{N_e}$$

or, $$e^{\frac{E_f - E_c}{k_B T} - \frac{E_v - E_f}{k_B T}} = \frac{N_h}{N_e}$$

or $$e^{\frac{2E_f - E_c - E_v}{k_B T}} = \frac{N_h}{N_e}$$

Taking log on both sides,

$$\frac{2E_f - E_c - E_v}{k_B T} = \log_e\left(\frac{N_h}{N_e}\right)$$

$$2E_f - E_c - E_v = k_B T \log_e\left(\frac{N_h}{N_e}\right)$$

or, $$2E_f = E_c + E_v + k_B T \log_e\left(\frac{N_h}{N_e}\right)$$

$$E_f = \frac{E_c + E_v}{2} + \frac{k_B T}{2} \log_e\left(\frac{N_h}{N_e}\right) \quad \text{— ii)}$$

Since, fermi energy exist in the band at T = 0K

Hence

$$E_f = \frac{E_c + E_v}{2} + 0 = \frac{E_c + E_v}{2} \quad \text{— iii)}$$

This gives the fermi energy expression in intrinsic semiconductor and shows that fermi energy lies betn midway of conduction band energy and valence band energy.

* Show that product of electron and hole concn is constant for intrinsic semiconductor.

According to law of action of mass the product of hole and electron concn is equal to square of concn of intrinsic semiconductor. Let n_i be the concn of intrinsic semiconductor. Then,

$$n_i = n_e = n_h$$

$$\therefore \quad n_e n_h = (n_i)^2 = \text{const} \quad \text{— i)}$$

Now,

$$n_e = \cancel{n_e} \; \frac{1}{2\pi^2}\left(\frac{\pi}{4}\right)^{1/2} \cdot \left(\frac{2m_e k_B T}{\hbar^2}\right)^{3/2}$$

$$n_h = \frac{1}{2\pi^2}\left(\frac{\pi}{4}\right)^{1/2}\left(\frac{2m_h k_B T}{\hbar^2}\right)^{3/2}.$$

Now eqn i) becomes,

$$n_i^2 = n_e \cdot n_h$$

$$= \frac{1}{2\pi^2}\left(\frac{\pi}{4}\right)^{1/2}\left(\frac{2m_e k_B T}{\hbar^2}\right)^{3/2} \cdot \frac{1}{2\pi}\left(\frac{\pi}{4}\right)^{1/2}\left(\frac{2m_h k_B T}{\hbar^2}\right)^{3/2}$$

$$= \left(\frac{1}{2\pi^2} \times \frac{1}{2\pi^2}\right)\left(\frac{\pi}{4}\right)\left(\frac{2 k_B T}{\hbar^2}\right)^{6/2}(m_e m_h)^{3/2}$$

$$= \frac{1}{4\pi^4} \times \frac{\pi}{4} \times \left(\frac{2 k_B T}{\hbar^2}\right)^3 (m_e m_h)^{3/2}$$

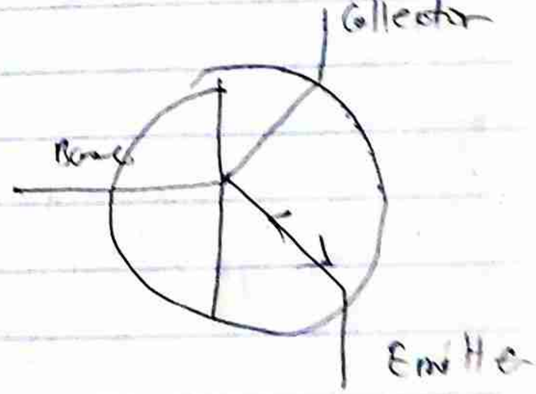
$$= \frac{1}{16\pi^3}\left(\frac{2 k_B T}{\hbar^2}\right)^3 (m_e \cdot m_h)^{3/2} = \text{constant}$$

This gives the product of hole and electron concn for intrinsic semiconductor which is constant.

It verifies the law of mass of action. for intrinsic semiconductor.

* Field Effect Transistor

→ The transistor whose operation depends on majority charge carrier and electrons are controlled by electric field connected with the electrode is known as field effect transistor



This transistor has only kind of majority charge carrier. So, it is called unipolar transistor.

The features of Field Effect Transistors (FET)

(1) They are voltage controlled device. The current through the device is controlled by an electric field associated with a voltage placed at an electrode called gate. This features give the name of field effect Transistor.

(3)

2) The current in a FET is carried out only by one type of majority charge carrier that may be electrons or holes. so, it is called unipolar transistor.

① JFET (Junction field Effect Transistor)

② MOSFET (Metal oxide semiconducter field Effect Transistor)

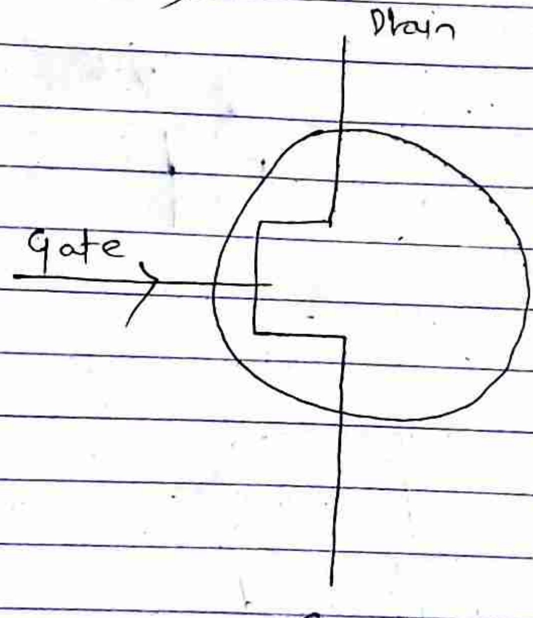


fig i) N-channel JFET

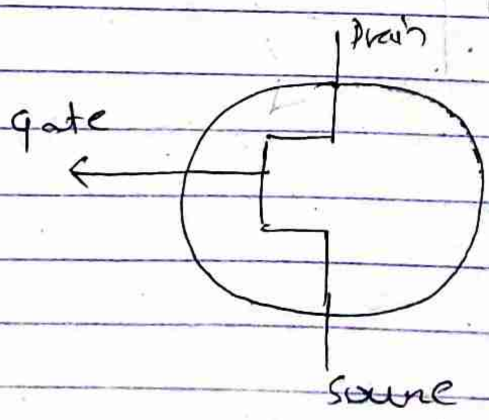
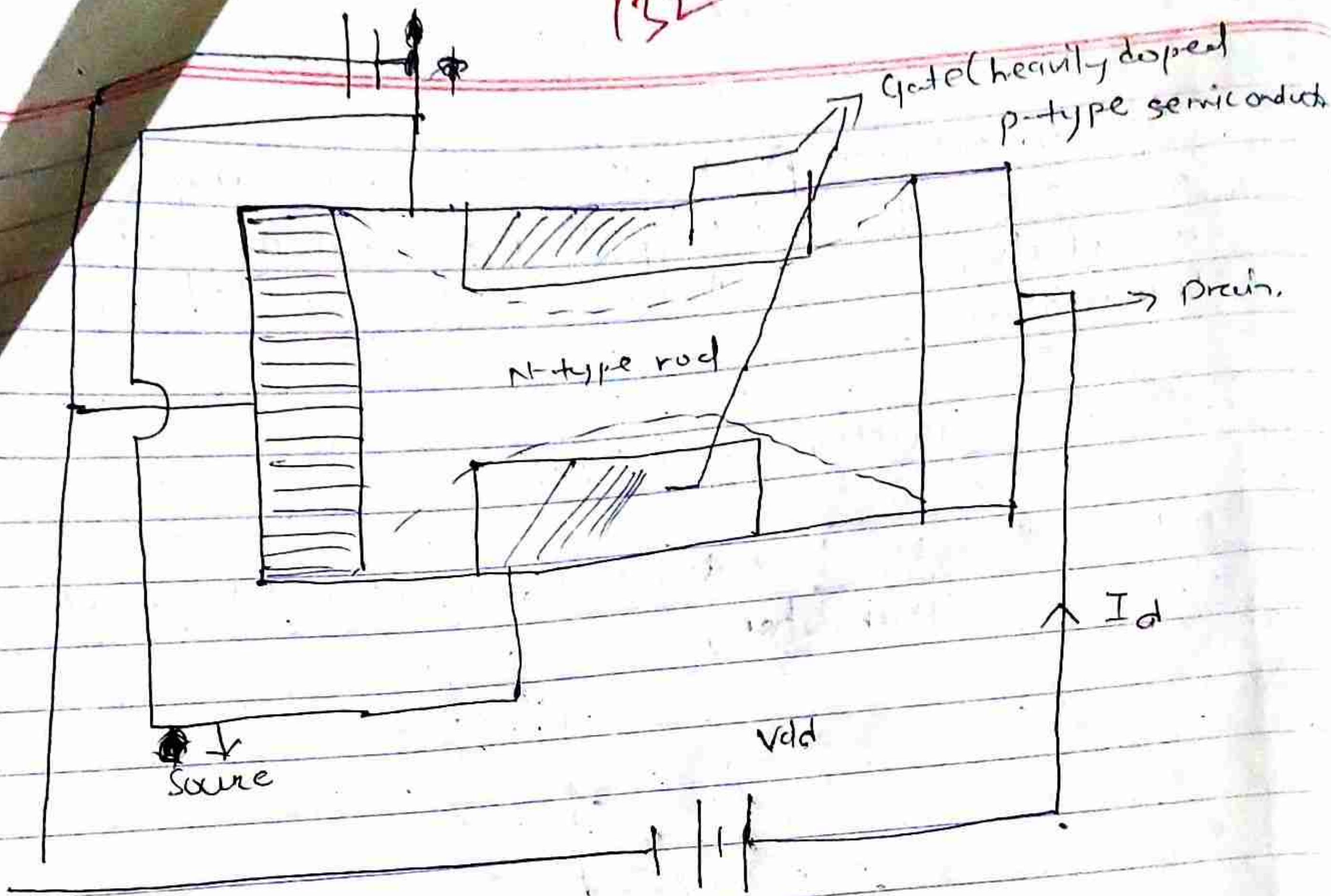
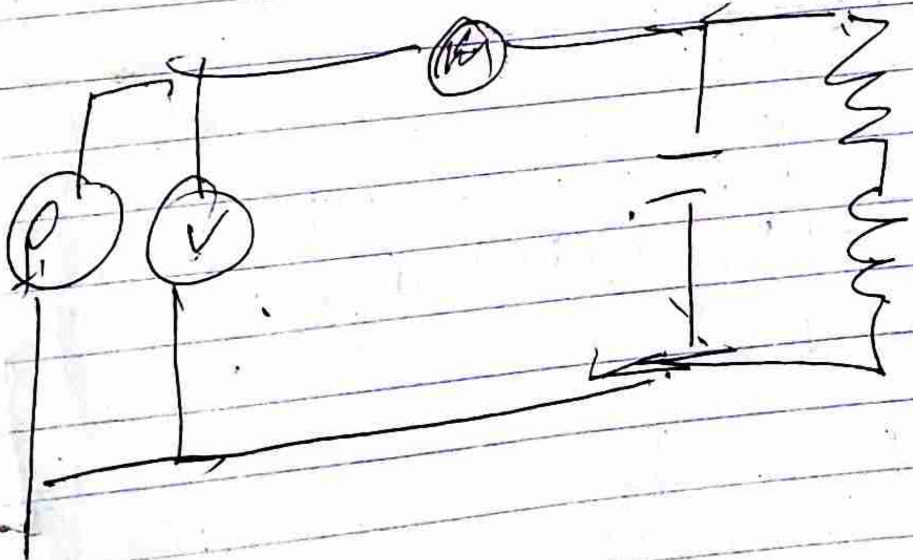


fig ii) P-channel JFET


Gate (heavily doped
p-type semiconduct
Drain.
N-type rod
I_d
Vdd
Soure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