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AN AUTONOMOUS INSTITUTION

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UNIT -III SEMICONDUCTOR PHYSICS

TOPIC – II CARRIER CONCENTRATION OF ELECTRONS AND HOLES

Density of electrons in conduction band

Density of electrons in conduction band $n_e = \int_{E_c}^{\infty} Z(E).F(E)dE$ .... (1)

From Fermi-Dirac statistics we can write

$$Z(E)dE = 2.\frac{\pi}{4}\left[\frac{8m_e^*}{h^2}\right]^{\frac{1}{2}} E^{\frac{1}{2}} dE \quad \text{.......... (2)}$$

Considering minimum energy of conduction band as E_c and the maximum energy can go upto ∞

we can write eqn (2) as

$$Z(E)dE = \frac{\pi}{2}\left[\frac{8m_e^*}{h^2}\right]^{\frac{3}{2}} (E - E_c)^{\frac{1}{2}} dE \quad \text{........... (3)}$$

We know Fermi function, $F(E) = \frac{1}{1+e^{(E-E_F)/}}$ .... (4)

Sub. Eqn (4) and (3) in eqn (1) we have Density of electrons is conduction band within the limits E_c to ∞

$$n_e = \frac{\pi}{2}\left[\frac{8m_e^*}{h^2}\right]^{\frac{3}{2}} \int_{E_c}^{\infty} \frac{(E-E_c)^{\frac{1}{2}}}{1+e^{(E-E_F)/TK_B}}.dE \quad \text{.......... (5)}$$

Since to move an electron from valence band to conduction band the energy required is greater than $4K_BT$. (i.e) $e^{(E-E_F)/TK_B} \gg 1$ & $1 + e^{(E-E_F)/TK_B} = e^{(E-E_F)/TK_B}$

Eqn. (5) becomes

$$n_e = \frac{\pi}{2}\left[\frac{8m_e^*}{h^2}\right]^{\frac{3}{2}} \int_{E_c}^{\infty} (E - E_c)^{\frac{1}{2}}. e^{(E-E_F)/TK_B} \, dE \quad \text{.......... (6)}$$

Let us assume that $E-E_c = xK_BT$ Differentiating we get $dE = K_BT.dx$, Limits: when $E=E_c$; $x=0$, when $E=\infty$; $x=\infty$ Therefore limits are 0 to ∞

By solving Eqn (6) using this limits we can get,

Density of electrons in conduction band is $n_e = 2\left[\frac{2\pi m_e^* K_B T}{h^2}\right]^{\frac{3}{2}} . e^{(E-E_F)/TK_B}$ ……….. (7)

Density of holes in valence band

We know, F(E) represents the probability of filled state.

As the maximum probability will be 1, the probability of unfilled states will be [1-F(E)]

Example, if F(E) = 0.8, then 1-F(E) = 0.2

Let the maximum energy in valence band be E_v and the minimum energy be $-\infty$. So density of holes in valence band n_h is given by

$$n_h = \int_{-\infty}^{E_V} Z(E).\,[1 - F(E)]dE \qquad \text{…………. (8)}$$

We know $Z(E)dE = \frac{\pi}{2}\left[\frac{8m_e^*}{h^2}\right]^{\frac{3}{2}} (E - E_c)^{\frac{1}{2}} dE$ …………. (9)

$$1\text{-}F(E) = e^{(E-E_F)/TK_B} \qquad \text{………… (10)}$$

Sub eqn (10) and (9) in (8), we get

$$n_h = \frac{\pi}{2}\left[\frac{8m_h^*}{h^2}\right]^{\frac{3}{2}} \int_{-\infty}^{E_V} (E - E_c)^{\frac{1}{2}} . e^{(E-E_F)/TK_B}\, dE \qquad \text{……………. (11)}$$

Let us assume that $E_v - E = xK_BT$ Differentiating we get $dE = -K_BT.dx$,

Limits: when $E=-\infty$; we have $E_v - (-\infty) = x$ Therefore $x=\infty$

When $E=E_v$; $x=0$,

Therefore limits are ∞ to 0

Using these limits we can solve eqn (11) and we can get the Density of holes.

Density of holes in valence band is

$$n_h = 2\left[\frac{2\pi m_h^* K_B T}{h^2}\right]^{\frac{3}{2}} . e^{(E_v-E_F)/TK_B} \qquad \text{……………}$$