Electrical conductivity measurement

To calculate electrical conductivity coefficient we must know electrical density current J_e and hole current density J_h. If we have the number of free electrons per unit volume n_e and drift velocity of electrons $< v_e >$, so J_e in conduction band

$$J_e = n_e e < v_e > \text{---------------}\rightarrow(1) \quad \text{------} v = q\tau E / m$$

$$J_h = n_h e < v_h > \text{---------------}\rightarrow(2)$$

n_h : number of hole in valance

As average drift velocity for electrons and hole associated with electrical field intensity by mobility equation

$$< v_e > = \mu_e E \text{------------------}\rightarrow (3) \qquad \mu_e = e\tau_e / m_e$$

$$< v_h > = \mu_h E \text{------------------}\rightarrow (4) \qquad \mu_h = e\tau_h / m_h$$

μ: The mobility is the magnitude of drift velocity of charge carrier per unit electrical field $\mu = v/E$.

Substitute 3, 4 in 1, 2 we get

$$J_e = n_e e \mu_e E \text{-----------------}\rightarrow (5)$$

$$J_h = n_h p \mu_h E \text{-----------------}\rightarrow (6)$$

As the total current density J in semiconductor is the sum of electrical and hole contribution ($J_e + J_h$) .

$$J = J_e + J_h) = (n e \mu_e + p e \mu_h) E \text{-----------}\rightarrow (7)$$

According Ohm law

$$J = \sigma E \text{---------------------}\rightarrow (8)$$

$$\sigma = (n e \mu_e + p e \mu_h) \text{-------------}\rightarrow(9)$$

Equation 9 represent electrical conductivity coefficient for semiconductor .

In intrinsic semiconductor the number of electrons equal the number of hole ($n = n_e = n_h$), so Equation 9 become

$$\sigma = n e (\mu_e + \mu_h)\text{-------------------}\rightarrow(10)$$

Concentration of electrons and holes in intrinsic

To calculate the concentration of electrons and holes (n, p) in intrinsic semiconductor we need Fermi-Derick distribution and fermi level and density state

$$f(E) = \frac{1}{1 + \exp\left(\frac{E_i - E_f}{k_\beta T}\right)} \quad ------\rightarrow (1)$$

There are two methods to calculate concentration carriers

Frist: Simple method

Suppose that the width of valance and conduction band is small comparing with energy gap width, all electrons in conduction band have same energy E_c and all electrons in valance band same E_v

$$n = n_c + n_v \text{-------------------}\rightarrow(2)$$

$$n_c = n f(E_c)\text{------------------}\rightarrow(3)$$

n_c: number of electrons in conduction band , n_v : number of electrons in valance band.

Here, *f* (*E*), is the probability that an electron state of energy, E_c is occupied. The quantity, E_F, is called *Fermi energy* and defines a characteristic energy for which it is equally likely that an electron state of precisely that energy will be either vacant or occupied, *i.e.*, the state has an occupation probability of exactly one half. Clearly, any band state must be either occupied or vacant and, moreover, the approximate symmetric behavior of electrons and holes implies that a vacant electronic state can just as well be regarded as an occupied *hole state* and vice versa. Accordingly, it follows that the occupation probability for holes, *fh*(□*E*), is trivially related to *f*(*E*)

At T=0 all energy state of F(E) until $E=E_F$ equal 1 , F(E) equal zero at $E>E_F$, so all state which have $E < E_F$ be full and all state which have $E > E_F$ be empty. At $E=E_F$ f(E)=1/2

Substitute 1in 3we get

$$n_c = \frac{n}{e^{-\frac{E_c - E_F}{K_\beta T}} + 1} ----------\rightarrow (4)$$

As same as

$$n_v = \frac{n}{e^{-\frac{E_v - E_F}{K_\beta T}} + 1} ----------\rightarrow (5)$$

We know that $n = n_c + n_v$ ------------------→(6)

So

$$n = \frac{n}{e^{-\frac{E_c - E_F}{K_\beta T}} + 1} + \frac{n}{e^{-\frac{E_v - E_F}{K_\beta T}} + 1} ----------\rightarrow (7)$$

$$1 = \frac{1}{e^{-\frac{E_c - E_F}{K_\beta T}} + 1} + \frac{1}{e^{-\frac{E_v - E_F}{K_\beta T}} + 1} ----------\rightarrow (8)$$

By simplistic equation

$$E_F = \frac{E_c + E_v}{2} ------\rightarrow (9)$$

Equation 9 explain that Fermi level energy in simple model placed at mid distance between conduction band and valance band and this position independent at temperature.

In intrinsic semiconductor the width of energy gap between (o.1 ev -10 ev)and at room temperature $K_\beta T = \frac{1}{40}\ electron - volt$

So $E_c - E_f \gg K_\beta T ------\rightarrow exp\frac{E_c - E_F}{K_\beta T} \gg 1 ------\rightarrow (10)$

So equation 4 become

$$n_c = n\, e^{-\frac{E_F - E_c}{K_\beta T}} ----------\rightarrow (11)$$

We can rewrite equation 11 by substitute eq 9 we get

$$n_c = n\, e^{-\frac{E_v - E_c}{K_\beta T}} ----------\rightarrow (12)$$

$$n_c = n\, e^{-\frac{-E_g}{2K_\beta T}} ----------\rightarrow (13)$$

$E_g = E_c - E_v$

We note that from equation 13 the number of electrons in conduction band proportional with $e^{-\frac{-E_g}{2K_\beta T}}$, so the carriers concentration increases with temperature increases and decreases with increasing energy gap E_g at constant temperature.