Atomic Structure and Semiconductor

Lecture - 40

(24/04/2021)

B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Chapter – 4
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➢ Fermi Level in an Extrinsic Semiconductor (PART – 1)

- In extrinsic or **impurity semiconductor impurity atoms**, however, **reduce the Energy gap E_g.** Donors represent **isolated energy levels** located so close to unfilled band (**0.01 eV** below the lower edge of conduction band) that **very little energy is required to lift an electron from the donor level into the unfilled band (conduction band),** where it is available for the conduction of electricity.

- **Similar case is for acceptors** representing **isolated energy levels** close to the filled band. The energy levels of the impurity atoms are **shown as isolated dots,** not as a band because these atoms are isolated from each other (i.e., there is no interaction between impurity atoms).

➢ n- Type Semiconductor

⇨ From **Figure (1)** shown in below, **Conduction Band,** there are N_d **Donor Levels per cm**^{3} **of energy** E_i. At **low temperatures, small fraction of Donors** will be **ionised** and **practically Donor Levels will be filled with electrons.**

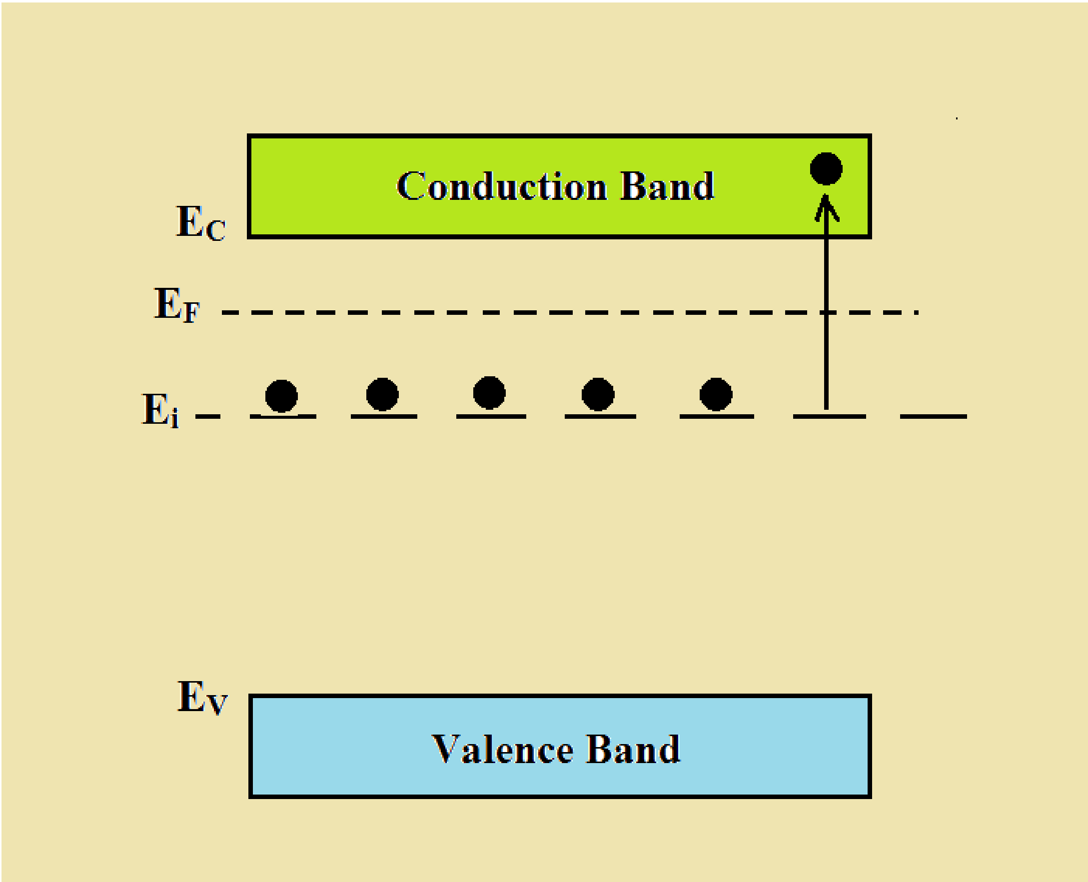

Fig. (1) Shown Indicating donor levels.

⇨ Let us **assume that** $(E_C - E_F) > 4\,K_B\,T$, **then** in that case **density of electrons in conduction band** will be given by **equation (10)** of **Lecture – 37, i.e.,**

$$n_c = 2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{K_B\,T}\right) \qquad \text{.............................. (10)}$$

$$\therefore\; n_c = 2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}} \exp\left\{\frac{(E_F - E_C)}{K_B\,T}\right\} \qquad \text{....................... (55)}$$

⇨ If we **assume** that E_F lies more than a few $K_B\,T$ **above the donor level** then the **density of empty donors** is given by,

$$N_d\,[1 - F_i(E_i)] \approx N_d \exp\left(\frac{E_i - E_F}{K_B\,T}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (56)$$

⇨ But the **density of empty donors should be the same as the density of electrons in the conduction band.** Then from **equation (55)** and **equation (56),** we get,

$$\therefore\; 2\left[\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right]^{\frac{3}{2}} \exp\left\{\frac{(E_F - E_C)}{K_B\,T}\right\} = N_d \exp\left\{\frac{(E_i - E_F)}{K_B\,T}\right\} \quad \ldots\ldots \quad (57)$$

⇨ Taking **logarithm** of the above **equation (57),** then we get,

$$\text{or,}\quad \frac{(E_F - E_C)}{K_B\,T} - \frac{(E_i - E_F)}{K_B\,T} = \log N_d - \log 2\left[\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right]^{\frac{3}{2}} \quad \ldots\ldots \quad (58)$$

$$\text{or,}\quad E_F = \frac{E_i - E_C}{2} + \frac{K_B\,T}{2}\log\left[\frac{N_d}{2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (59)$$

⇨ At **T = 0 K,**

$$\therefore\; E_F = \frac{E_i - E_C}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (60)$$

⇨ Which shows that **Fermi Level lies exactly half way between the donor levels and bottom of conduction band.** As **T increases, Fermi Level drops.** This is shown below in **Figure (2)** for the case $(E_F - E_C) = 0.2\,eV$ for three different values of N_d.

⇨ Putting the value of E_F from **equation (59)** into $exp(E_F - E_C)$, we get,

$$\text{or, } exp\left(\frac{E_F - E_C}{K_B\,T}\right) = exp\left[\frac{E_i - E_C}{2\,K_B\,T} + \frac{1}{2}\,log\left\{\frac{N_d}{2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}}\right\}\right] \quad \ldots\ldots\ (61)$$

$$\text{or, } exp\left(\frac{E_F - E_C}{K_B\,T}\right) = exp\left(\frac{E_i - E_C}{2\,K_B\,T}\right).\frac{(N_d)^{\frac{1}{2}}}{\left\{2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}\right\}^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (62)$$

⇨ The above value of $exp\left(\frac{E_F - E_C}{K_B\,T}\right)$ Which when substituted in **equation (55)** gives,

$$\because\ n_c = 2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}} \text{exp}\left(\frac{E_F - E_C}{K_B\,T}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (55)$$

$$\text{or, } n_c = 2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_i - E_C}{2\,K_B\,T}\right).\frac{(N_d)^{\frac{1}{2}}}{\left\{2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}\right\}^{\frac{1}{2}}} \quad \ldots\ (63)$$

$$\text{or, } n_c = 2\left[\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right]^{\frac{3}{2}}.\frac{(N_d)^{\frac{1}{2}}}{\left[2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}\right]^{\frac{1}{2}}}.exp\left\{\frac{(E_i - E_C)}{2\,K_B\,T}\right\} \quad \ldots\ (64)$$

$$\text{or, } n_c = (2N_d)^{\frac{1}{2}}\left[\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right]^{\frac{3}{4}} exp\left\{\frac{(E_i - E_C)}{2\,K_B\,T}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ (65)$$

$$\text{or, } n_c = (2N_d)^{\frac{1}{2}}\left[\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right]^{\frac{3}{4}} exp\left\{\frac{-\Delta E}{2\,K_B\,T}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (66)$$

⇨ Where $\Delta E = (E_C - E_i)$ **is called Ionisation Energy of donors.** We note that:-

(1) ***Density of electrons in the conduction band*** *is proportional to the* ***square root of the donor concentration.***

(2) *As the* ***temperature increases****, the* ***Fermi Level falls below the donor level*** *and* ***it approaches the centre of forbidden gap which makes the substance an intrinsic semiconductor.*** *The conductivity of intrinsic semiconductor is smaller the* ***n- type and p- type semiconductors.***

(3) ***In this case Fermi Level lies Half way between the Donor Levels and Bottom of Conduction Band.***

⇨ In below **Figure (2)** shown, a graph is plotted in log n_c and $\frac{1}{T}$ which gives a straight line with a slop $\frac{-\Delta E}{2\,K_B}$.

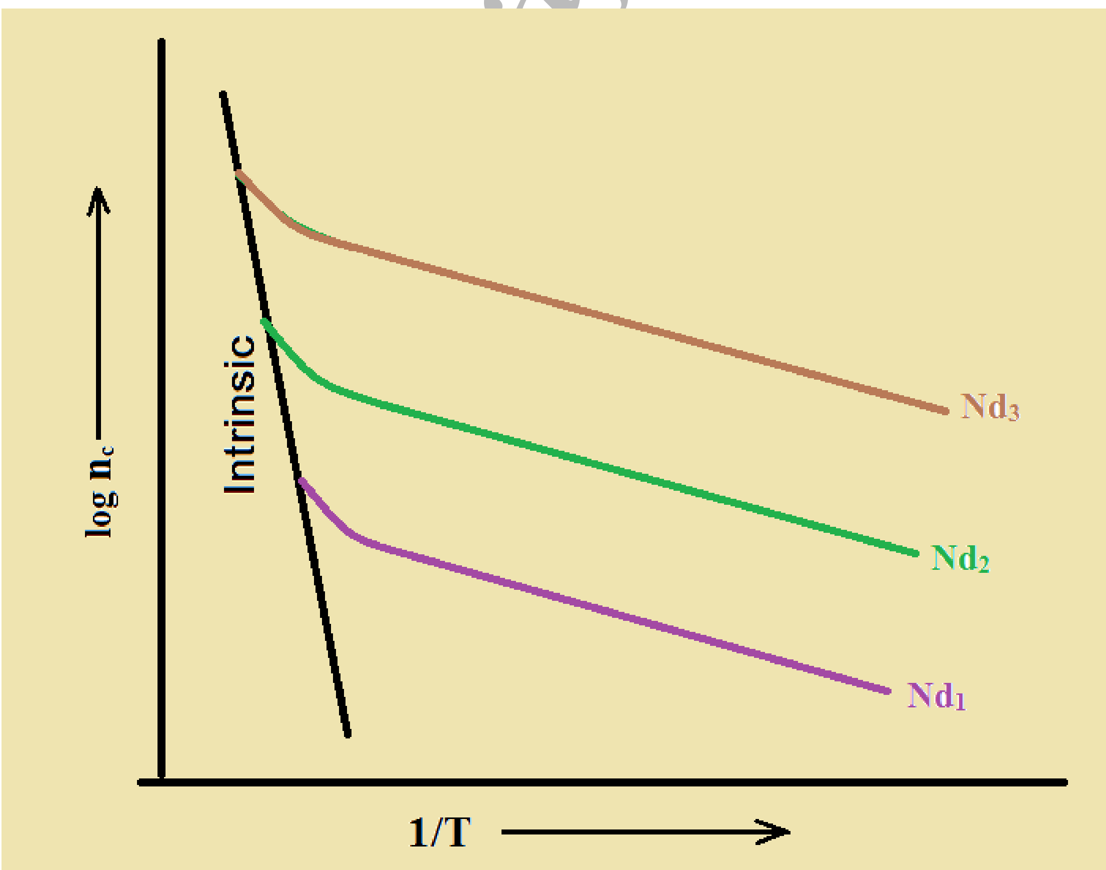

Fig. (2) Shown Variation of Conduction Electron Density with Temperature.

⇨ If **T** becomes sufficient high so as to excite electrons from valence band to reach directly to conduction band (intrinsic excitation) then this slop change to $\frac{-E_g}{2K_B}$ **as mentioned in Lecture -39.**

to be continued ....

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