Atomic Structure and Semiconductor

Lecture - 36

(13/04/2021)

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

⇨ **Fermi Level is simply a reference energy level.** It is the **energy level** at which the **probability of finding an electron** n **energy unit above it in the conduction band** is **equal** to the **probability of finding a hole (electron absence)** n **energy units below it in the valence band.** Very simply, it can be considered to be the **average energy level of the electrons,** as illustrated below in **Figure (1).**

⇨ Let at **any temperature** $T^0\ K$

⇨ **Number of electrons in the Conduction Band** be n_c

⇨ **Number of electrons in the Valence Band** be n_v

⇨ **Total number of electrons in both bands,** $n = n_c + n_v$

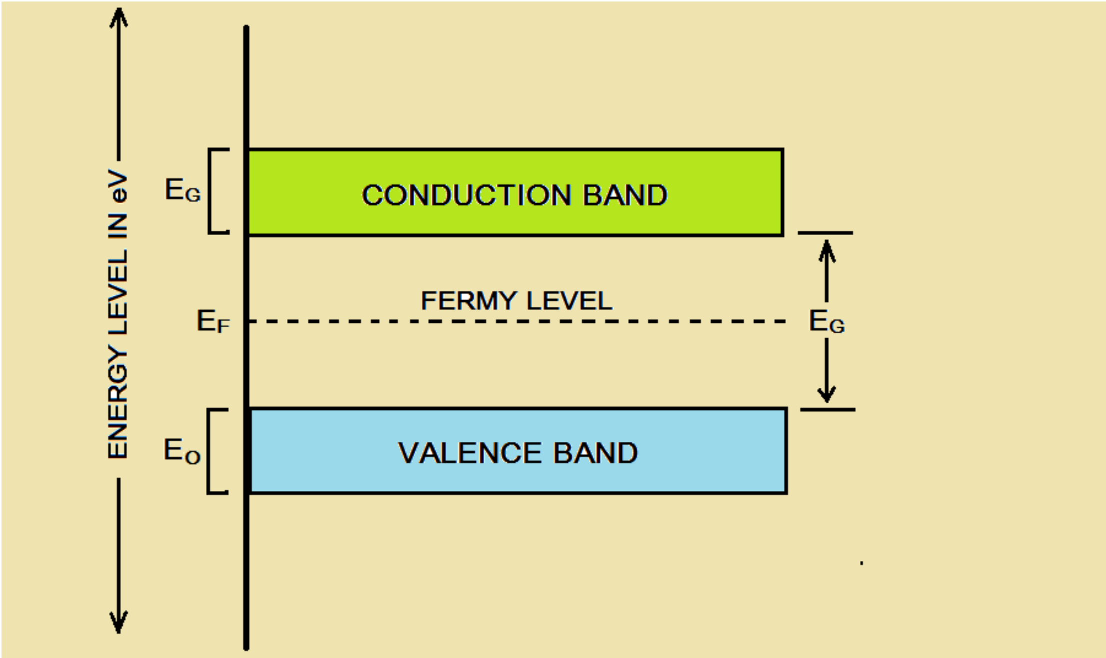

Fig. (1) Shown Fermi Level is the energy level at which the probability of finding an electron ***n*** energy unit above it in the conduction band is equal to the probability of finding a hole (electron absence) ***n*** energy units below it in the valence band.

⇨ For **simplification let us assume** that,

(1) Widths of energy bands are small in comparison of Forbidden energy gap between them,

(2) All levels in a band have the same energy, bandwidths being assumed to be small,

(3) Energies of all levels in Valence band are E_O as shown in above **Figure (1)** and,

(4) Energies of all levels in Conduction Band are E_G

⇨ Let the **zero energy reference level be taken arbitrarily at the Valence band,** as shown in below **Figure (2).**

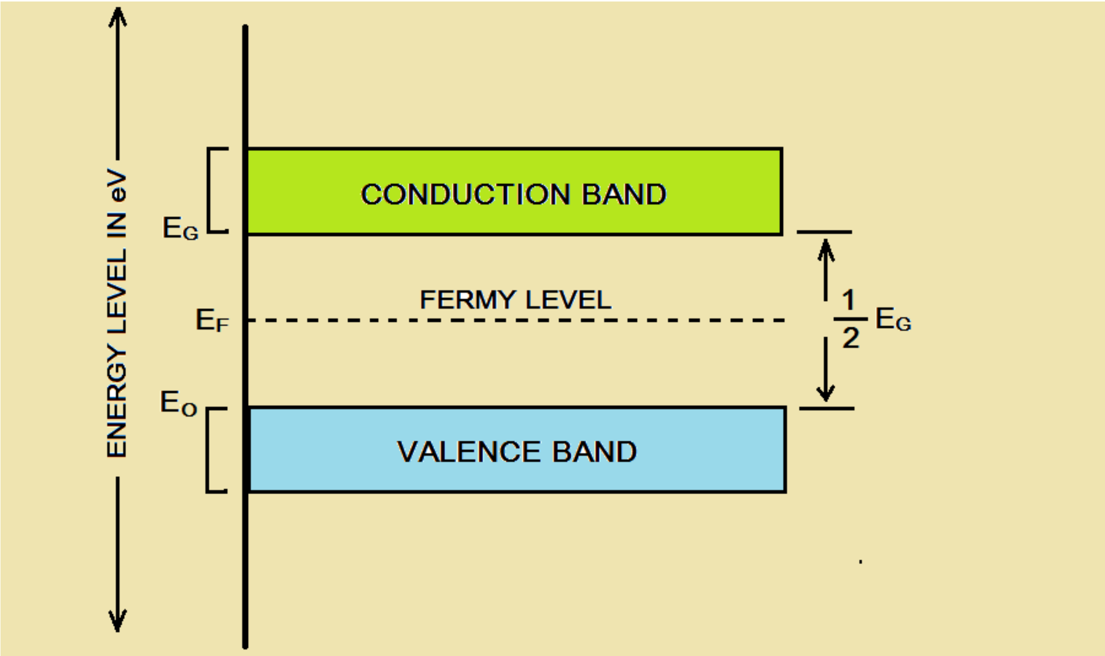

Fig. (2) Shown zero energy reference level be taken arbitrarily at the Valence band.

- ➢ Now **Number of Electrons in Conduction Band**, given as

⇨ $$n_c = n.P(E_G) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(1)}$$

⇨ Where, $P(E_G)$ represents the probability of an electron having energy E_G.

⇨ Its value may be determined from **Fermi-Dirac Probability Distribution Function** given as,

⇨ $$P(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{kT}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(2)}$$

⇨ where, $P(E)$ is the probability of finding an electron having any particular value of energy E.

⇨ So, The probability $P(E_G)$ of an **electron being found in the Conduction band** with **energy** E can be determined by substituting $E = E_G$ in **equation (2)** then we get,

⇨ $$P(E_G) = \frac{1}{1+e^{\frac{(E_G - E_F)}{kT}}} \quad \ldots\ldots\ldots \quad (3)$$

⇨ where, E_F is the Fermi Level.

⇨ Substituting the value of $P(E_G)$ from **equation (3) in equation (1),** we have,

⇨ $$\because \; n_c = n.P(E_G) \quad \ldots\ldots\ldots \quad (1)$$

⇨ $$\because \; P(E_G) = \frac{1}{1+e^{\frac{(E_G - E_F)}{kT}}} \quad \ldots\ldots\ldots \quad (3)$$

⇨ $$\text{or, } n_c = n \frac{1}{1+e^{\frac{(E_G - E_F)}{kT}}}$$

⇨ $$\therefore \; n_c = \frac{n}{1+e^{\frac{(E_G - E_F)}{kT}}} \quad \ldots\ldots\ldots \quad (4)$$

⇨ Now **Number of Electrons in Valence Band**, given as

$$n_v = n\,P(0) \quad \ldots\ldots\ldots \quad (5)$$

⇨ The probability $P(0)$ of an **electron being found in the Valence band** with **zero energy** can be determined by substituting $E = 0$ in **equation (2)** then we get,

$$\because \; P(E) = \frac{1}{1+e^{\frac{(E - E_F)}{kT}}} \quad \ldots\ldots\ldots \quad (2)$$

$$\text{or, } P(0) = \frac{1}{1+e^{\frac{(0-E_F)}{kT}}}$$

$$\text{or, } P(0) = \frac{1}{1+e^{\frac{-E_F}{kT}}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (6)$$

⇨ Substituting the value of $P(0)$ from **equation (6) in equation (5),** we have,

$$\because \; P(0) = \frac{1}{1+e^{\frac{-E_F}{kT}}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (6)$$

$$\because \; n_v = n\,P(0) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (5)$$

$$\text{or, } n_v = n\,\frac{1}{1+e^{\frac{-E_F}{kT}}}$$

$$\therefore \; n_v = \frac{n}{1+e^{\frac{-E_F}{kT}}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (7)$$

⇨ Now, **Total number of Electrons in both Bands,**

$$\therefore \; n = n_c + n_v$$

$$\text{or, } n = \frac{n}{1+e^{\frac{(E_G-E_F)}{kT}}} + \frac{n}{1+e^{\frac{-E_F}{kT}}}$$

$$\text{or, } 1 - \frac{1}{1+e^{\frac{-E_F}{kT}}} = \frac{1}{1+e^{\frac{(E_G-E_F)}{kT}}} \quad \dots\dots\dots\dots\dots\dots \quad (7a)$$

⇨ After solving the above **equation (7a)** then we get,

$$\therefore \; E_F = \frac{1}{2}E_G \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (8)$$

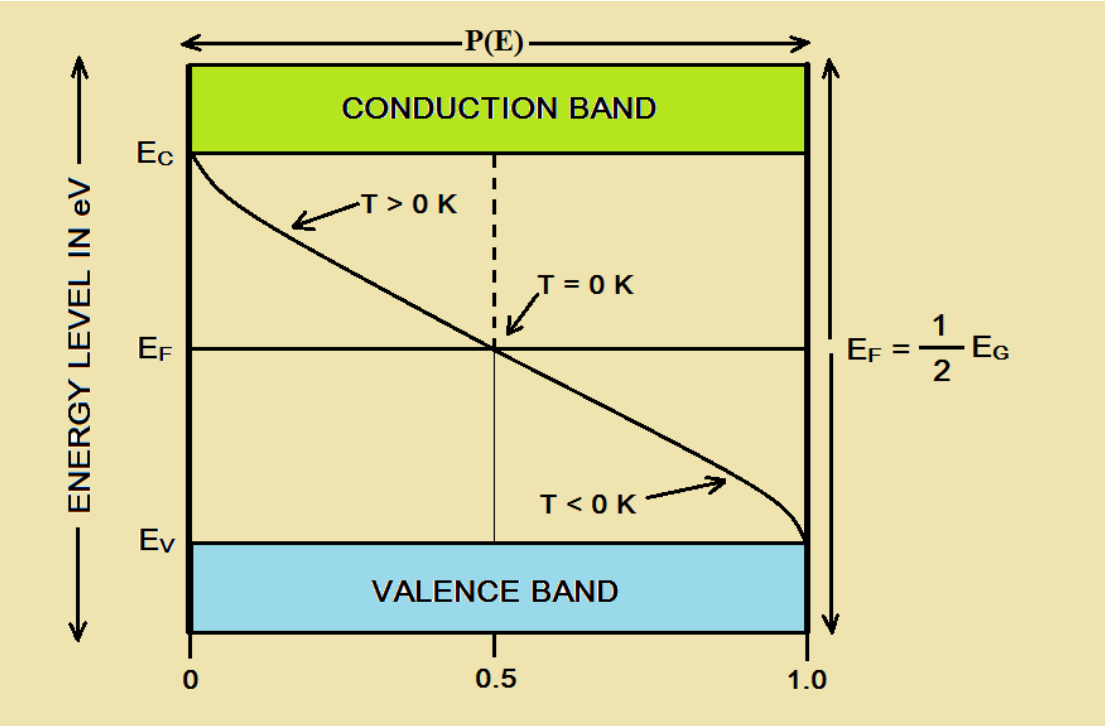

Fig. (3) Shown in an Intrinsic Semiconductor, the Fermi Level lies midway between the Conduction and Valence Bands.

⇨ i.e., from above **equation (8)** we can say that, in an **Intrinsic Semiconductor,** the **Fermi Level lies midway ($E_F = \frac{1}{2} E_G$)** between the **Conduction** and **Valence Bands.**

to be continued ....

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