Atomic Structure and Semiconductor

Lecture - 37

(15/04/2021)

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

⇨ The band model of an intrinsic semiconductor at **0 ^{O}K** is shown below in **Figure (1). Filled Valence Band and empty Conduction Band** are **separated** by an **energy gap** E_g. At **T = 0 ^{O}K**, **no conduction is possible** but as the **temperature is raised** the **electrons are thermally excited** from **Valence Band** to the **Conduction Band**. In **Conduction Band** these electrons become free so that conduction is possible. Both, **electrons in Conduction Band**, n_c, and the **Holes in Valence band** n_h will contribute to the electrical conductivity.

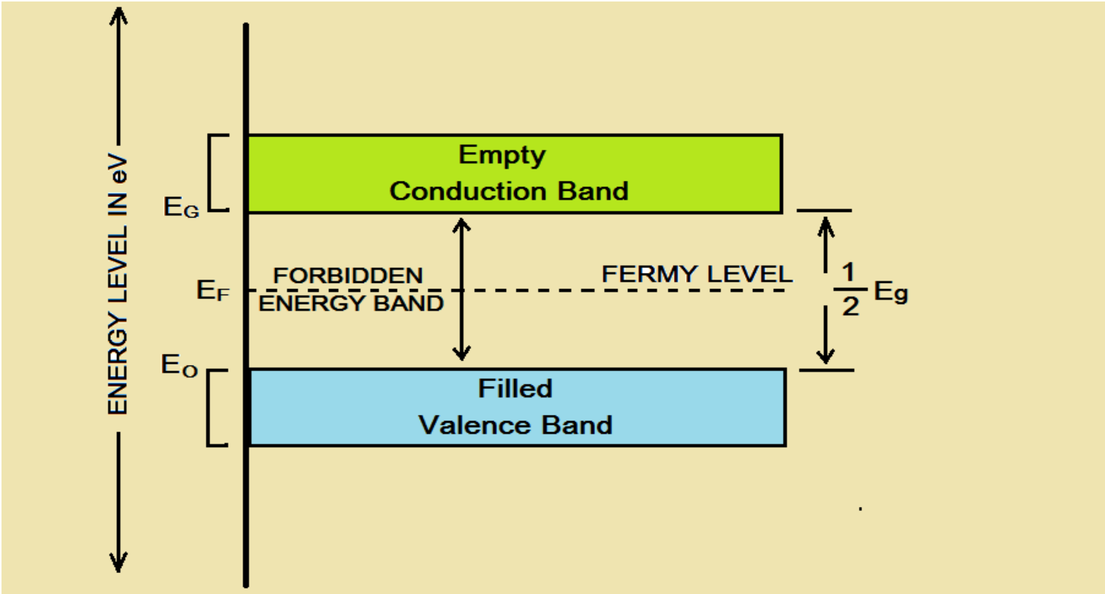

Fig. (1) Shown Band Model in an Intrinsic Semiconductor.

➢ Calculation of Electron and Hole Concentration

⇨ We shell now **calculate the number of electrons** excited into the **Conduction Band** at **Temperature** T and also the **Hole Concentration** in the **Valence Band**. It will be assumed that **Electrons** in the **Conduction Band** behave as if they are free particles with an **Effective mass** m_e^*, also the **Holes** near the top of the **Valence Band** behave as if they are free particles with **Effective mass** m_h^* .

⇨ In calculating the **Carrier Concentrations in Intrinsic Semiconductor** we shell proceed in two ways:-

(1) In the first way we assume that **widths of Conduction and Valence Bands** are small as compared with **Forbidden Gap** so that we can take that **all the conduction electrons have energy equal to** E_C, whereas **all Valence electrons have energy equal to** E_V**.** That is the **energy of Valence Band** can be presented by a **single energy** E_V and that of **Conduction Band** by E_C**.** This assumption is not accurate.

(2) As stated in above **Point (1),** it is not justified to take up a single value of energy for a complete band and we take up the widths of allowed energy band as comparable to **Forbidden Gap**. We take that the **electrons in Conduction Band** may have **energy lying between E_C to ∞** while the **electrons in Valence Band** of **energy lying from -∞ to E_V.**

- The derivation done in first way will not be accurate since in an **Intrinsic Semiconductor** neither all the **electrons in Valence Band** have **energy equal to E_V**, nor all the **Electrons in Conduction Band** possess **energy equal to E_C**. **Electrons** in **Conduction Band** may have, **energies laying from E_C to ∞** while the **Electrons** in **Valence Band** may have **energies lying from -∞ to E_V.**

(A) Density of Electrons in Conduction Band:-

- Therefore the **Density of Electrons in Conduction Band** will be given by,
- $n_c = \int_{E_c}^{\infty} Z(E)F(E)dE$ .... **(1)**

- The **upper limit of the integral** is put as **infinity** for convenience in the **integration**. The limit will certainly include **all the Electrons** in the **Conduction Band (E_C** is the energy at the bottom of the Conduction Band**)**. Further function **$F(E)$ decreases** as **we move up** in the **Conduction Band** because for **$E >> E_g$, $F(E) = 0$** and hence we can take **$E = \infty$** as the **upper limit for this band**. The **Energy Density of States** has plotted below in **Figure (2)** as a function of energy.

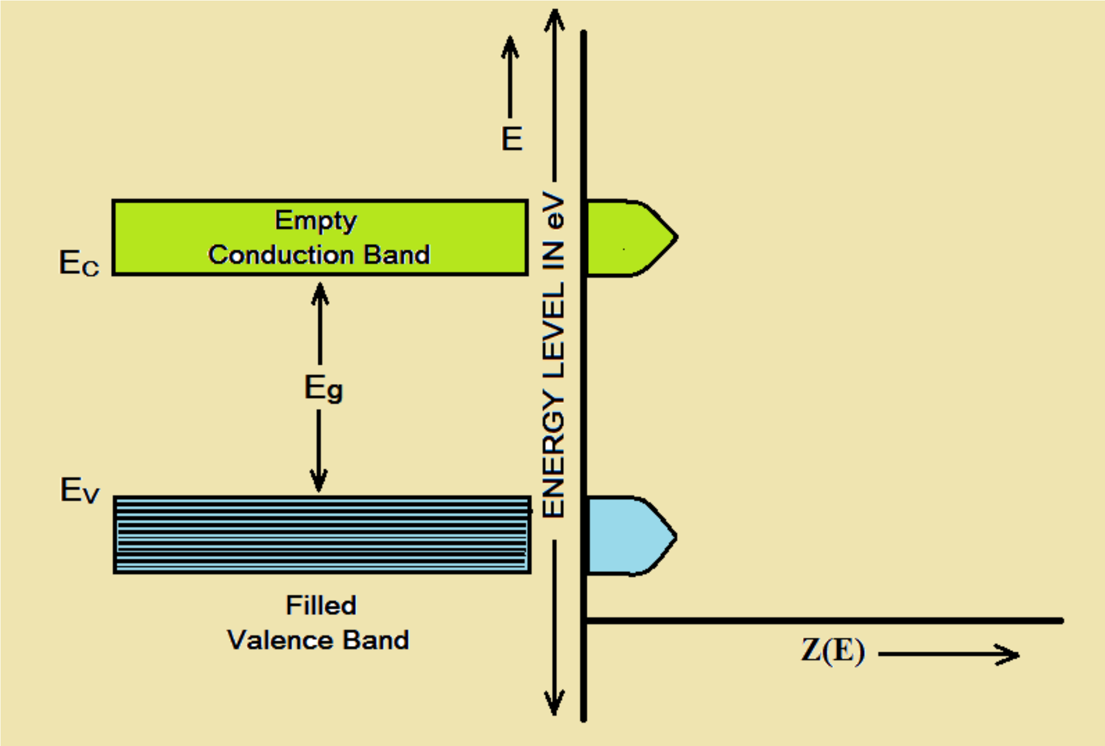

Fig. (2) Shown Density of States in an Intrinsic Semiconductor. Near lower edge of Conduction Band $\boldsymbol{Z(E) \propto (E - E_C)^{\frac{1}{2}}}$ and near top of Valence Band $\boldsymbol{Z(E) \propto (E_V - E)^{\frac{1}{2}}}$

⇨ Here the **Energy Density of States** at the bottom of the **Conduction Band** of a **semiconductor** is given by,

⇨ $$\boldsymbol{Z(E) = \frac{4\pi}{h^3}(2\,m_e^*)^{\frac{3}{2}}\,(E - E_c)^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(2)}$$

⇨ Where $\boldsymbol{m_e^*}$ is the **Effective Mass** of the **Electron** in the **band.** It is necessary to introduce the concept of **Effective Mass** to take into account the influence of the neighbouring atoms and charges on the motion of an electron in the band. Thus an electron will respond to an applied force as if it had a **Effective Mass** $\boldsymbol{m_e^*}$ (not the free electronic **mass** **m**) when it is in **Conduction Band**. In the **Valence Band**, the **Effective Mass** of the **Hole** is written as $\boldsymbol{m_h^*}$.

⇨ $$F(E) = \frac{1}{\exp\left\{\frac{(E - E_F)}{K_B\, T}\right\} + 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(3)}$$

and applying **equation (2)** and **equation (3) in equation (1)** then we get this **Density of Electrons** in **Conduction Band** as,

⇨ $$n_c = \frac{4\,\pi}{h^3}\,(2\,m_e^*)^{\frac{3}{2}} \int_{E_C}^{\infty} \frac{(E - E_C)^{\frac{1}{2}}\, dE}{\exp\left\{\frac{(E - E_F)}{K_B\, T}\right\} + 1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(4)}$$

⇨ If $(E_C - E_F) \gg 4\,K_B\,T$ then from above the **equation (4), term 1** in the **denominator** of the **integrand** can be neglected so that,

⇨ $$n_c = \frac{4\,\pi}{h^3}\,(2\,m_e^*)^{\frac{3}{2}} \int_{E_C}^{\infty} (E - E_C)^{\frac{1}{2}} \exp\left\{\frac{(E_F - E)}{K_B\, T}\right\} dE \quad \ldots\ldots \quad \textbf{(5)}$$

⇨ $$n_c = \frac{4\,\pi}{h^3}\,(2\,m_e^*)^{\frac{3}{2}} \times \exp\left(\frac{E_F - E_C}{K_B\, T}\right) \int_{E_C}^{\infty} (E - E_C)^{\frac{1}{2}} \exp\left(\frac{E_C - E}{K_B\, T}\right) dE$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(6)}$$

⇨ Now Putting $\frac{E - E_C}{K_B\, T} = x$ and giving $dE = K_B\, T dx$, in the above **equation (6),** then we get,

⇨ $$n_c = \frac{4\,\pi}{h^3}\,(2\,m_e^*)^{\frac{3}{2}} \times \exp\left(\frac{E_F - E_C}{K_B\, T}\right) \int_{0}^{\infty} x^{\frac{1}{2}}\, (K_B\, T)^{\frac{1}{2}}\, e^{-x}\, K_B\, T\, dx$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(7)}$$

⇨ $$n_c = \frac{4\,\pi}{h^3}\,(2\,m_e^*)^{\frac{3}{2}} \times (K_B\, T)^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{K_B\, T}\right) \int_{0}^{\infty} x^{\frac{1}{2}}\, e^{-x}\, dx$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(8)}$$

⇨ $n_c = \frac{4\,\pi}{h^3}\ (2\, m_e^*)^{\frac{3}{2}} \times (K_B\, T)^{\frac{3}{2}}\ \exp\left(\frac{E_F - E_C}{K_B\, T}\right) . \frac{\pi^{\frac{1}{2}}}{2}$

.... **(9)**

⇨ where, for **Integrand**, $\frac{\pi^{\frac{1}{2}}}{2}$ has been substituted, then we get,

⇨ Thus,

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

⇨ Detailed of the **Density of Hole in Valence Band (PART – 2)** are discussed in next **Lecture – 38.**

to be continued ....

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