Atomic Structure and Semiconductor

Lecture - 35

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

- Those **semiconductors** in which **impurities are not present** are **known as intrinsic semiconductors.** The **electrical conductivity** of the **semiconductor** depends upon the **total number of electrons** moved to the **conduction band** from the **valence band**. **Eg.** Silicon(Si) and Germanium(Ge).

- If the t**emperature will be maintained at Zero Kelvin (0^0 K)**, then the **valence band** will be full of **electrons.** So, at **such a low temperature range** it is impossible to cross the **energy barrier**. **It will act as an insulator at Zero Kelvin (0^0 K).** The **minimum energy required** to the **break the covalent bond** for **germanium crystal** is **0.72 eV** and **for silicon crystal** its value is **1.1 eV.**

⇨ At **room temperature thermal energy excite** some **electrons** present in **valence band**, **electrons to shift** to the **conduction band**. So, the **semiconductor will be able** to show some **electrical conductivity**.

⇨ As the **temperature increases**, the **electrons movement** from the **valence band** to the **conduction band will also increase**. The **holes** will be **left behind** in the **valence band** in place of **electrons**. This **vacancy created** by the **electron** after the breakage of the **covalent bonding** is **known as hole**.

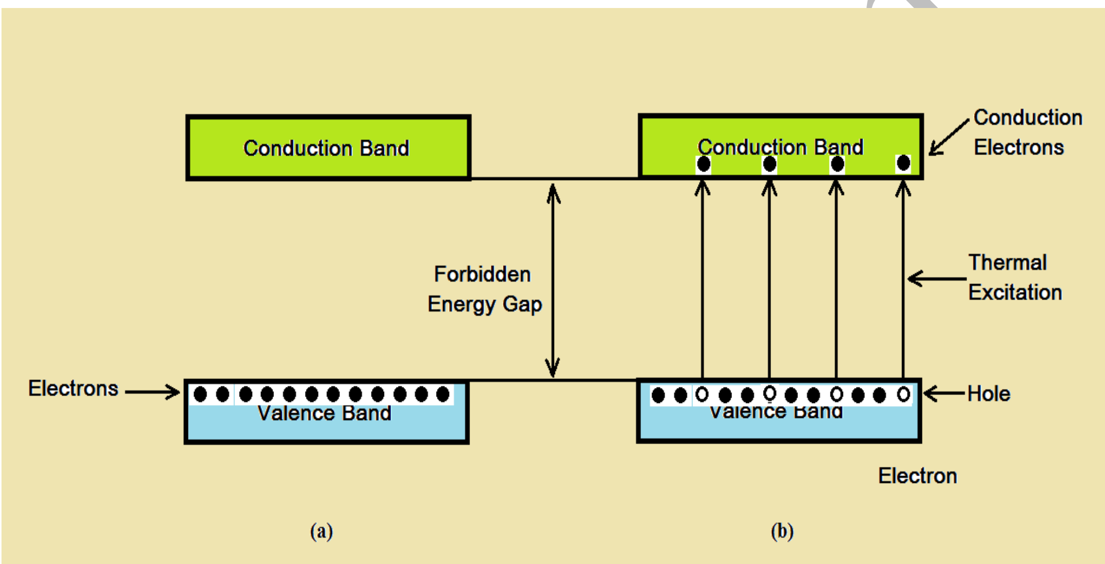

Fig. (1) Shown Energy Band diagram of Intrinsic Semiconductor at **(a) T = 0^0 K**

(b) Temperature > 0^0 K .

⇨ **Hence,** the **probability of occupation of energy levels in valence band and conduction band** is **called Fermi level.** At **absolute zero temperature (at 0^0K) intrinsic semiconductor acts as perfect insulator**. However as the temperature increases **free electrons** and **holes pairs** get **generated.**

⇨ In **intrinsic or pure semiconductor**, the **number** of **holes in valence band** is **equal** to the **number** of **electrons in the conduction band**. Hence, the **probability of occupation of energy levels** in **conduction band** and **valence band** are **equal.** Therefore, the **Fermi level for the intrinsic semiconductor lies in the middle of forbidden band/gap.**

⇨ **Fermi level** in the **middle of forbidden band** indicates **equal concentration of free electrons and holes** in **Conduction band** and **Valence band respectively.**

⇨ At temperature $T\ ^0K$, the electron concentration 'n' is equal to hole concentration 'p' in an intrinsic semiconductor i.e., $n = p$.

⇨ The **Hole-concentration in the Valence band** is given as,

⇨ $$p = n_v = N_V\, e^{\frac{-(E_F - E_V)}{K_B T}} \quad \text{...} \quad (1)$$

⇨ The **Electron-concentration in the Conduction band** is given as,

⇨ $$n = n_c = N_C\, e^{\frac{-(E_C - E_F)}{K_B T}} \quad \text{...} \quad (2)$$

where,

- K_B is the Boltzmann constant,
- T is the absolute temperature of the **intrinsic semiconductor,**
- Nc is the effective density of states in the **conduction band,**
- Nv is the effective density of states in the **valence band.**
- n_c is the number / density of electrons in **conduction band,**
- n_v is the number / density of holes in **valence band,**
- e is the electronic charge of an **electron.**

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(1) The number of electrons in the conduction band is depends on effective density of states in the conduction band and the distance of Fermi level from the conduction band.

(2) The number of holes in the valence band is depends on effective density of states in the valence band and the distance of Fermi level from the valence band.

(3) For an intrinsic semiconductor, the electron-carrier concentration is equal to the hole-carrier concentration.

⇨ It can be written as,

⇨ $p = n = n_i$ .... **(3)**

where,

- p = hole-carrier concentration
- n = electron-carrier concentration and
- n_i = intrinsic carriers concentration

⇨ $N_C \, e^{\frac{-(E_C - E_F)}{K_B T}} = N_V \, e^{\frac{-(E_F - E_V)}{K_B T}}$

⇨ $\dfrac{e^{\frac{-(E_C - E_F)}{K_B T}}}{e^{\frac{-(E_F - E_V)}{K_B T}}} = \dfrac{N_V}{N_C}$

⇨ $e^{\frac{2E_F - (E_C + E_V)}{K_B T}} = \dfrac{N_V}{N_C}$ .... **(4)**

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⇨ Taking **logarithms on both sides** of above **equation (4),** we get,

$$\Rightarrow \frac{2\,E_F - (E_C + E_V)}{K_B\,T} = log_e\left(\frac{N_V}{N_C}\right) \quad \text{.. (5)}$$

where,

$$\therefore \quad \frac{N_V}{N_C} = \frac{2\left(\frac{2\,\pi\,m_h^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}}{2\left(\frac{2\,\pi\,m_e^*\,K_B\,T}{h^2}\right)^{\frac{3}{2}}}$$

or, $$\frac{N_V}{N_C} = \left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} \quad \text{.. (6)}$$

⇨ Therefore, putting the above value $\frac{N_V}{N_C} = \left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}}$ of **equation (6)** into **equation (5)**

then we get,

$$\Rightarrow \frac{2\,E_F - (E_C + E_V)}{K_B\,T} = log_e\left(\frac{N_V}{N_C}\right) \quad \text{.. (5)}$$

$$\Rightarrow \frac{N_V}{N_C} = \left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} \quad \text{.. (6)}$$

$$\therefore \quad \frac{2\,E_F - (E_C + E_V)}{K_B\,T} = log_e\left(\frac{m_h^*}{m_e^*}\right)^{\frac{3}{2}} \quad \text{.................................... (7)}$$

or, $$E_F = \frac{(E_C + E_V)}{2} + \frac{3}{4}\,K\,T\,log_e\left(\frac{m_h^*}{m_e^*}\right) \quad \text{............................ (8)}$$

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⇨ Normally m_h^* is greater than m_e^*, then we have following,

(1) In case $m_h^* > m_e^*$ **or T > 0 K,** then

⇨ Since $log_e\left(\frac{m_h^*}{m_e^*}\right)$ is very small, so **Fermi Level** is **just above the middle** of the **Energy Band** and **slightly rises** with **increase in temperature.**

(2) In case $m_h^* = m_e^*$ **or T = 0 K**

⇨ **then above equation (8) written as,**

$$E_F = \frac{(E_C + E_V)}{2} + \frac{3}{4} K\,T\,log_e\left(\frac{m_e^*}{m_e^*}\right) \quad \text{.................................... (9)}$$

$$E_F = \frac{(E_C + E_V)}{2} + \frac{3}{4} K\,T\,log_e(1) \quad \text{....................................... (10)}$$

⇨ Since $log_e(1)$ is **zero.** This means that **Fermi Level lies exactly half way between the top of valence band an bottom of conduction band.**

⇨ But in actual case m_h^* is greater than m_e^* and Fermi Level is raised slightly as **T** increases.

⇨ Thus from above discussion, **Fermi level for intrinsic semiconductor** is given as,

$$\therefore\ E_F = \frac{E_C + E_V}{2} = \frac{E_G}{2} \quad \text{.. (11)}$$

$$\text{or, } E_F = \frac{E_G}{2} = \frac{1}{2} E_G \quad \text{... (12)}$$

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where ,

- E_F is the Fermi level
- E_C is the Energy of conduction band
- E_V is the Energy of valence band
- E_G is Forbidden Energy Gap

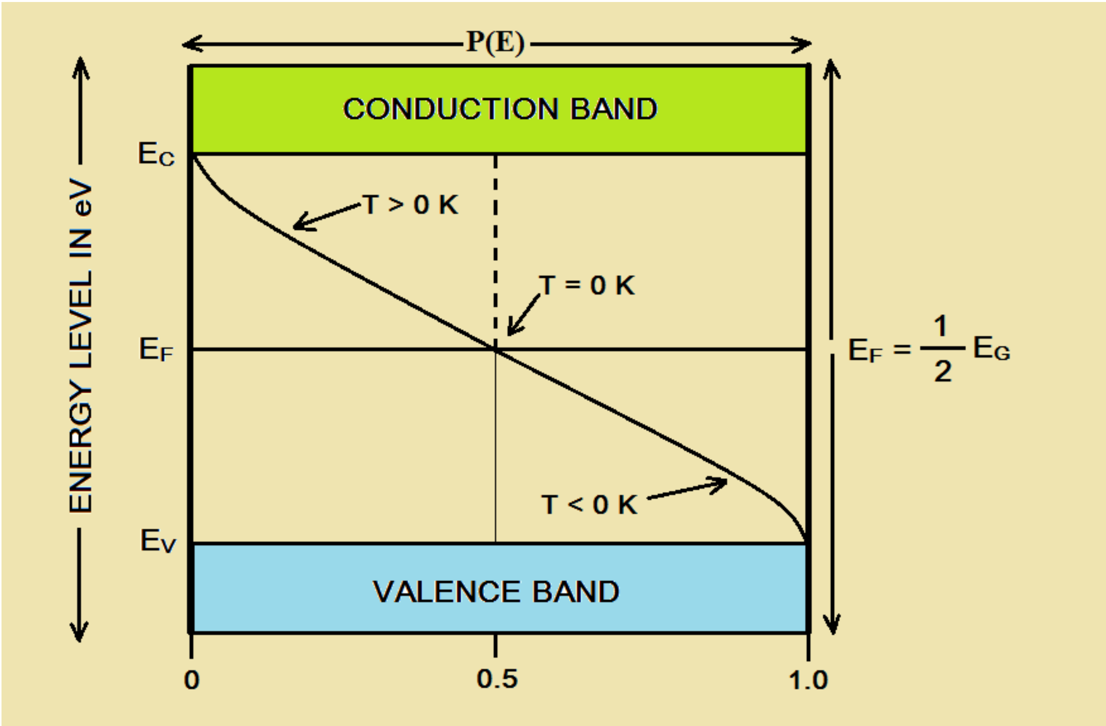

Fig. (2) Shown in an Intrinsic Semiconductor, the Fermi Level lies midway between the Conduction and Valence Bands.

Therefore, from the above discussion, we can say that, **Fermi level in an intrinsic semiconductor lies in the middle of the Forbidden Gap (E_g).**

to be continued ....

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