Junction Diode

Lecture - 7

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B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Unit – 5
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➢ Overview of P-N Junction

⇨ When a piece of P – type material is in contact (say used) with N - type material then the interface between the different regions is **called** **P-N Junction** which is **shown below in Figure (1) (a).**

⇨ A **typical width of such a junction** is **10^{-4} cm.** The **Fermi Level** in P – type material is located close to the **top of Valence Band** whereas in N - type material it lies to the **bottom of Conduction Band**.

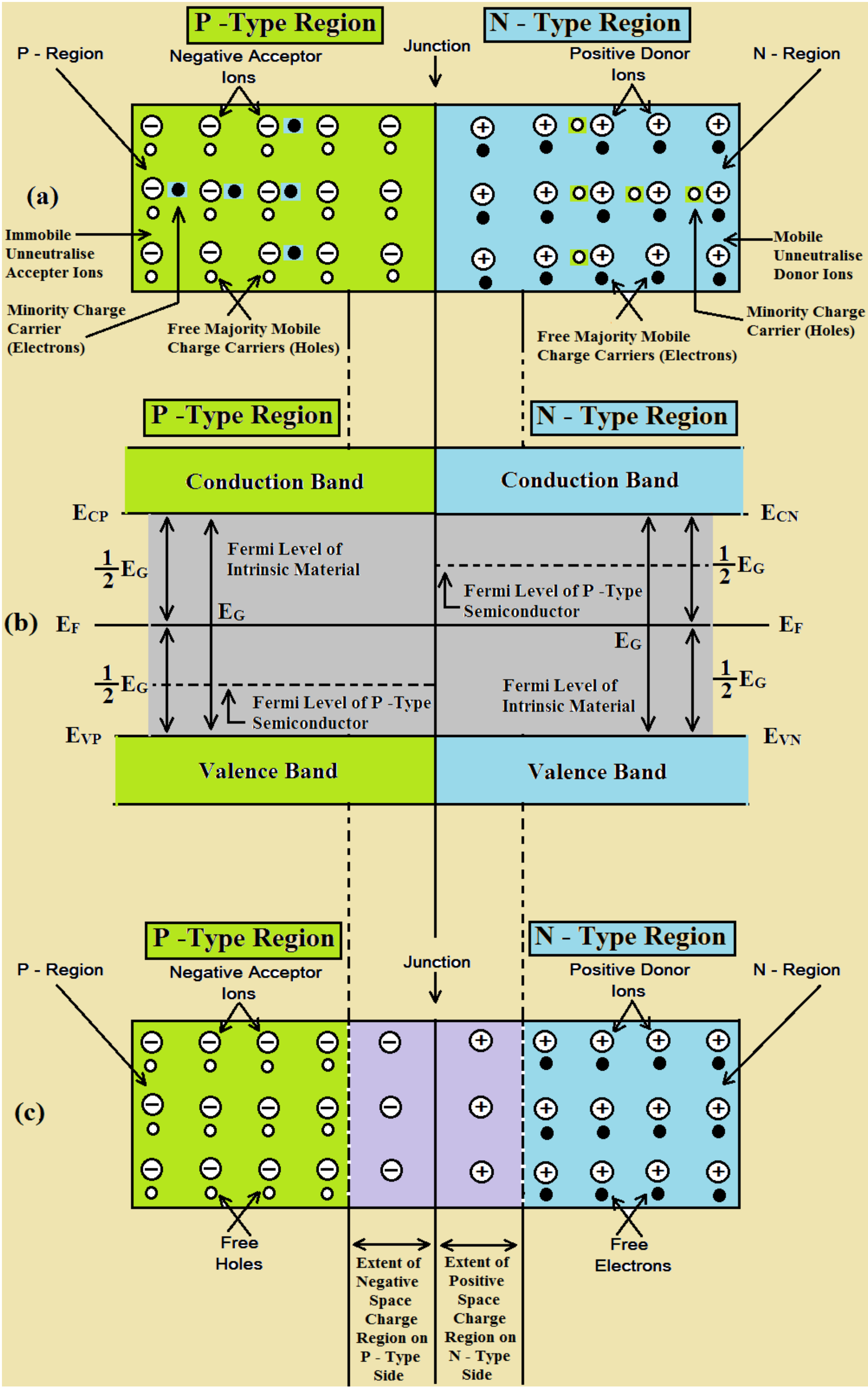

Fig. (1) (a) Shown P-N Junction.

Fig. (1) (b) Shown Non –Equilibrium Energy Band Scheme.

Fig. (1) (c) Shown Development of Space Charge.

- The above narrated situation is **shown in above Figure (1) (b).** When the contact between two types of materials is made then to **bring Fermi Level in a line**, **Electrons** in Conduction Band on N – type side (supplied by **pentavalent impurity atoms**) travel across the junction and leave the **Positively Ionised Impurity Atoms un-neutralised**. Consequently, there is a **Positively Charged region** adjacent to the junction in N – type material.

- On P – type side, the Electrons which have **traversed** the boundary and **recombine** with **Positive Holes** in the **Valence Band**. **Near** to the **junction** on P – type side, there is a **layer of un-neutralised Negatively Ionised Trivalent Impurity Atoms** which **form a Negatively Charged region** which is **shown above in Figure (1) (c).**

- These **un-neutralised Impurity Atoms** are **termed as Ions.** These **ions being bound** in the **crystal lattice are immobile** and **no charges are available for Conduction close to the junction.** As **shown in above Figure (1) (c),** this region around the junction is **called <u>Charge Depletion Region or Space Charge Region</u>.** Due to this space charge, an **internal Potential Barrier**, V_B, exist between N – region and P – region. The **Band Edges** in the **two samples shifts themselves to make the alignments Fermi Level possible** and the **Energy Band Diagram** remains no more of the shape **shown in above Figure (1) (b),** but assumes a shape **shown below in Figure (2).**

- The **Conduction Band of P –type is shifted upwards** by $e\,V_B$ over the Conduction Band of N – type where V_B is **Potential Barrier** across the junction arising due to already mentioned **Space Charge.**

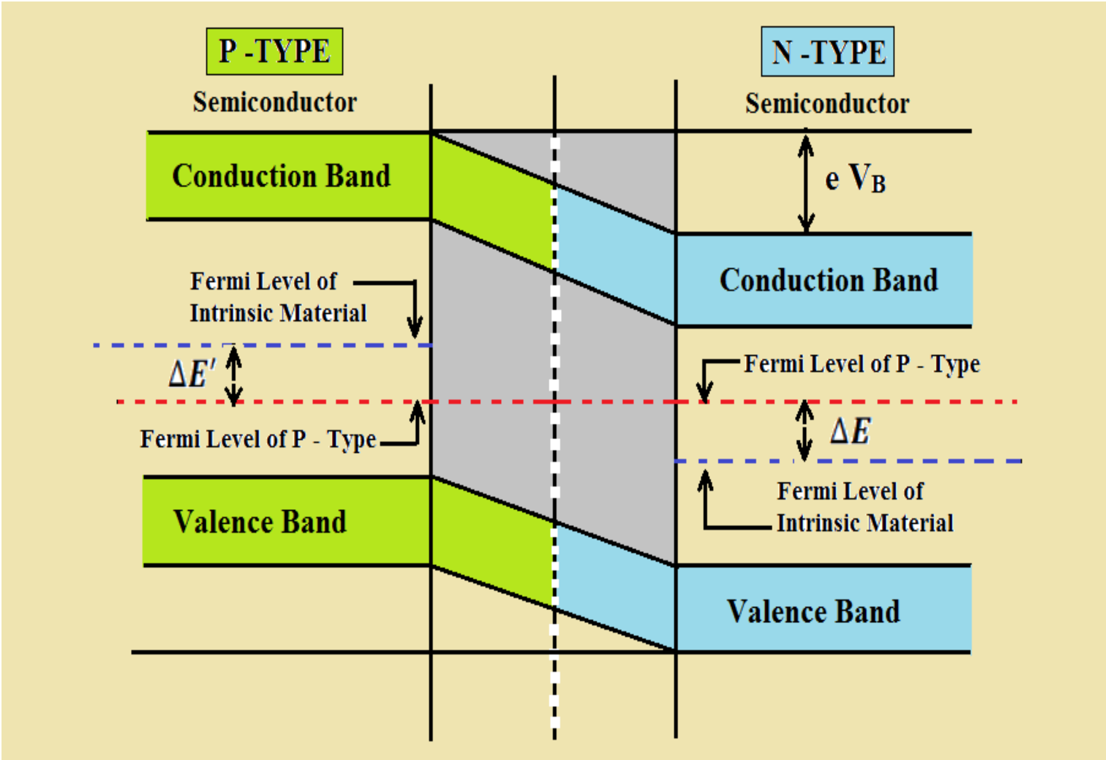

Fig. (2) Shown Shifting of the Bands of the two Semiconductor Sample

⇨ Obviously, **Minority Electrons** in the **Conduction Band of P –type crystal** is at a **Higher Energy** than the **Majority Electrons** in the **Conduction Band** of **N – type crystal.** The **Electrons crossing the junction** from **P – region side** will **not encounter** the **Potential Barrier** while the **Electrons crossing the junction from N – region side will face this barrier.**

➢ Barrier Potential in Terms of the Intrinsic Density of Either Carrier (PART – 3)

⇨ As we learn and know from the **previous Lectures**, that the **Potential Barrier** is **created due to the Alignment of Fermi Levels** of the **two sides**. From **Figure (2)** shown below, **Fermi Level on P – Type side has come down by $\Delta E'$** and has **gone up by ΔE** on N – Type side, thus,

$$\Delta E' + \Delta E = e\,V_B \quad \text{...} \quad (34)$$

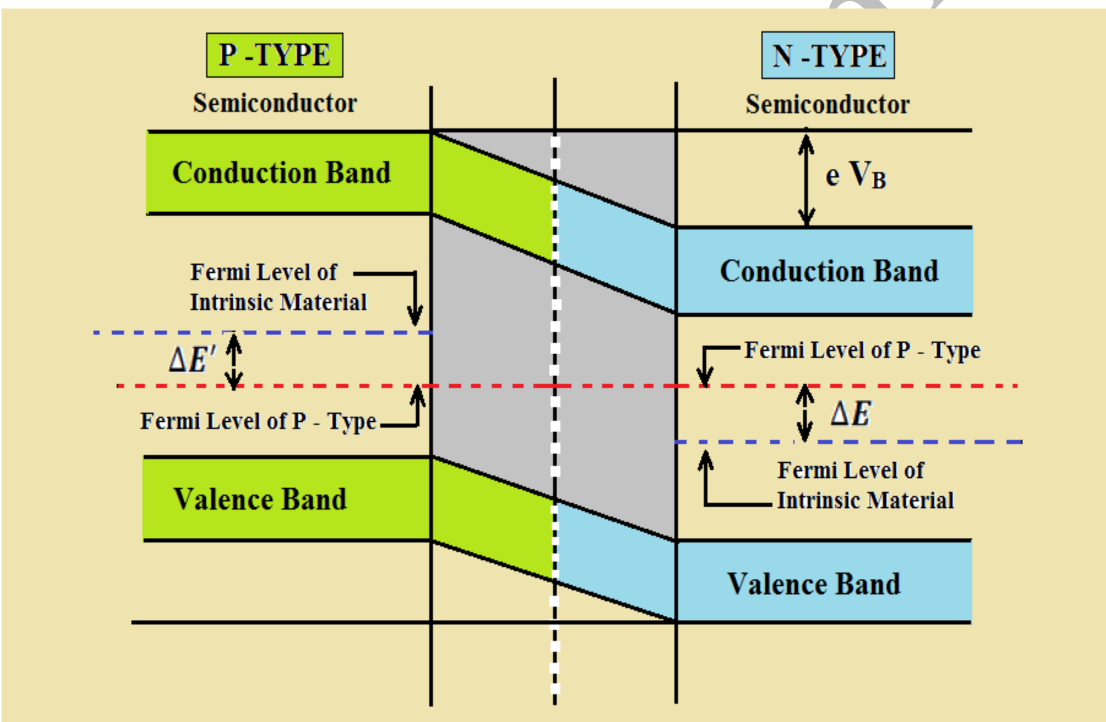

Fig. (2) Shown Shifting of the Bands of the two Semiconductor Sample

⇨ We have seen in **Equation (39)** and **Equation (45)** of **Lecture – 39 (Unit – 4, Atomic Structure and Semiconductor),** that **Electron Density** in an **Intrinsic Semiconductor** depends on the **Fermi-Level** and **addition of Donor Impurities** simply **increase** the **Fermi factor** by,

$$exp\left(\frac{\Delta E}{K_B\,T}\right) \quad \text{.. (35)}$$

⇨ where, ΔE is the **shift in Fermi-Level.**

⇨ We know that **Density of Electrons in Conduction Band in an Intrinsic Semiconductor** is given by **Equation (10)** of **Lecture – 37 (Unit – 4, Atomic Structure and Semiconductor)** which is,

⇨ $$n_c \;=\; 2\left(\frac{2\,\pi\, m_e^*\;K_B\,T}{h^2}\right)^{\frac{3}{2}} \exp\left(\frac{E_F - E_C}{K_B\,T}\right) \quad \text{...... (10) From Lecture – 37}$$

⇨ Addition of **Donor Impurities raises** the **Fermi Level**, say, by and **amount** ΔE so that new **Fermi Level** is,

$$E_F' \;=\; E_F \;+\; \Delta E \quad \text{... (36)}$$

⇨ Therefore **Density of Majority Carriers**, i.e., Electron Density on **N – side** will be,

$$(n_c\,)_{n\;side} \;=\; 2\left(\frac{2\,\pi\, m_e^*\;K_B\,T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_F' - E_F}{K_B\,T}\right) \quad \text{............ (37)}$$

$$(n_c\,)_{n\;side} \;=\; 2\left(\frac{2\,\pi\, m_e^*\;K_B\,T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_F + \Delta E - E_C}{K_B\,T}\right) \quad \text{...... (38)}$$

$$(n_c\,)_{n\;side} \;=\; n_i\; exp\left(\frac{\Delta E}{K_B\,T}\right) \quad \text{.. (39)}$$

⇨ The **Density of Minority Carriers**, i.e., **Electron Density on P – side** will be,

$$(n_c\,)_{p\;side} \;=\; \frac{n_i^2}{n_h} \quad \text{... (40)}$$

⇨ where, n_h is the **Hole Density on P – side** and given by,

$$n_h = n_i \, exp\left(\frac{\Delta E'}{K_B \, T}\right) \quad \text{...} \quad (41)$$

⇨ Therefore,

$$(n_c)_{p\,side} = n_i \, exp\left(\frac{-\Delta E'}{K_B \, T}\right) \quad \text{.......................................} \quad (42)$$

⇨ Now from above **Equation (39)** and **Equation (42),** we get,

$$\frac{(n_c)_{n\,side}}{(n_c)_{p\,side}} = \frac{n_i \, exp\left(\frac{\Delta E}{K_B \, T}\right)}{n_i \, exp\left(\frac{-\Delta E'}{K_B \, T}\right)} \quad \text{..} \quad (43)$$

$$\frac{(n_c)_{n\,side}}{(n_c)_{p\,side}} = exp\left(\frac{\Delta E + \Delta E'}{K_B \, T}\right) \quad \text{...} \quad (44)$$

$$\frac{(n_c)_{n\,side}}{(n_c)_{p\,side}} = \left(\frac{e \, V_B}{K_B \, T}\right) \quad \text{..} \quad (45)$$

$$\boxed{V_B = \frac{K_B \, T}{e} \, log\left[\frac{(n_c)_n}{(n_c)_p}\right] \quad \text{...} \quad (46)}$$

⇨ Now, we can able to calculate the **Minority Carrier Density** from the relation

$n_c \times n_h = n_i^2$**,** for a **semiconductor or crystal**.

⇨ In a crystal containing N_d **completely ionised Donor Atoms**, we can write,

$$(n'_c + N_d) \, n'_h = n_i^2 \quad \text{...} \quad (47)$$

⇨ where, n'_c and n'_h are **thermally generated Electron-Hole pairs**.

⇨ When **doping is such that** $N_d \gg n_c'$ and is **true for N – type crystal**, then,

$$N_d\, n_h' = n_i^2 \quad \text{...} \quad (48)$$

⇨ In Abovewhich n_h' should give the Hole Concentration in N – type crystal or in other words give **Minority Carrier (holes) Concentration** in N – type crystal.

⇨ Thus, we can write above **Equation (48)** as following,

$$(n_h')_n = \frac{n_i^2}{N_d} \quad \text{...} \quad (49)$$

gives **Minority Carriers (holes) Concentration in N – type crystal**

⇨ **Similarly,** in crystal containing N_a **completely ionised Acceptor Atoms**, we can write,

$$n_c'\,(N_a + n_h') = n_i^2 \quad \text{...} \quad (50)$$

⇨ When **doping is such that** $N_a \gg n_h'$ and is **true for P – type crystal** then,

$$n_c'\, N_a = n_i^2 \quad \text{...} \quad (51)$$

⇨ In above which n_c' should give the **Electron Concentration in P – type crystal** or in other words give **Minority Carrier (Electrons) Concentration** in P – type crystal.

⇨ Thus, we can write above **Equation (51)** as following,

$$(n_c')_p = \frac{n_i^2}{N_a} \quad \text{...} \quad (52)$$

gives **Minority Carriers (electrons) Concentration in P – type crystal**.

⇨ Now from above **Equation (52)** and **Equation (46)**,

$$(n_c')_p = \frac{n_i^2}{N_a} \quad \text{..} \quad (52)$$

$$V_B = \frac{K_B T}{e} \log \left[\frac{(n_c)_n}{(n_c)_p}\right] \quad \text{..} \quad (46)$$

⇨ **Then we get,**

$$V_B = \frac{K_B T}{e} \log \left[\frac{(n_c)_n N_a}{n_i^2}\right] \quad \text{..} \quad (53)$$

⇨ From above discussion, we assuming that **Minority Carriers on P- side** are **thermally generated**, i.e., taking,

$$(n_c')_p = (n_c)_p \quad \text{..} \quad (54)$$

⇨ Further **Majority Carriers in N – type** will be **largely contributed by Donor Atoms** and we can take $(n_c)_n = N_d$, then putting the value of $(n_c)_n = N_d$ in above **Equation (53)**, so that **Equation (53)** becomes,

$$\therefore\ V_B = \frac{K_B T}{e} \log \left[\frac{N_d N_a}{n_i^2}\right] \quad \text{..} \quad (55)$$

⇨ In the next **Lecture - 8,** we will discuss the detailed of the **Charge Neutrality and Compensated Semiconductors**.

to be continued ....

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