Junction Diode

Lecture - 10

(10/06/2021)

B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Unit – 5
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➢ Energy Band Structure of an Open-Circuited P-N Junction

⇨ Let us consider that a P-N Junction is formed by placing P – type and N – type materials in intimate contact on an atomic scale. Under such conditions the Fermi-Level must be constant through-out the specimen at equilibrium.

⇨ **If this were not true,** Electrons on one side of the junction would have an average energy higher than those on the other side and there would be a transfer of electrons and energy until the Fermi Level on the two sides equalize. In **Previous Lecture – 40** and **Lecture – 41** we have already learn and see that **Fermi Level** E_F is closer to the **Conduction Band edge** E_{CN} in the N – type material and closer to the **Valence Band edge** E_{VP} in the P – type material.

⇨ Obviously the **Conduction Band edge** E_{CP} in the P - type material cannot be at the same level as E_{CN}, nor can the **Valence Band edge** E_{VN} in the N – side line up with E_{Vp}. Thus on formation of a P-N Junction, **Conduction Band edge** E_{CP} in P – type material is higher than E_{CN} in N – type material and **Valence Band edge** E_{VP} in P – type material is higher than E_{VN} in N – type material. This is **illustrated below in Figure (1),** where a **shift in energy level** E_O is shown.

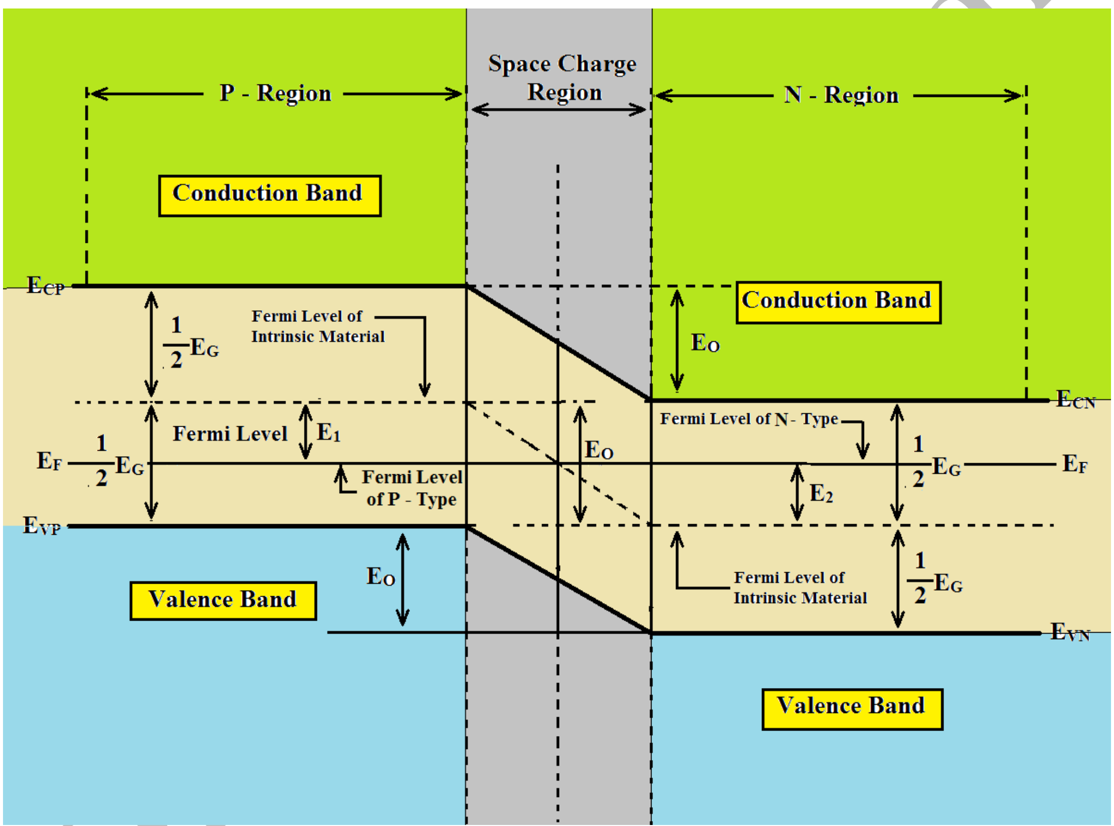

Fig. (1) Shown Energy Band Structure of an Open-Circuit P-N Junction.

⇨ The Total shift in the **Energy Level** E_O is given as,

$$E_O = E_{CP} - E_{CN} + E_{VP} - E_{VN} \quad \text{.......................................} \quad \textbf{(62)}$$

$$E_O = E_1 + E_2 \quad \text{..} \quad \textbf{(63)}$$

where, E_1 and E_2 represent the **shifts in the Fermi Level** from the Intrinsic Condition in P – type and N – type materials.

⇨ The Energy E_O represents the **Potential Energy of the Electrons at the Junction**, as **shown below in Figure (2) (e).**

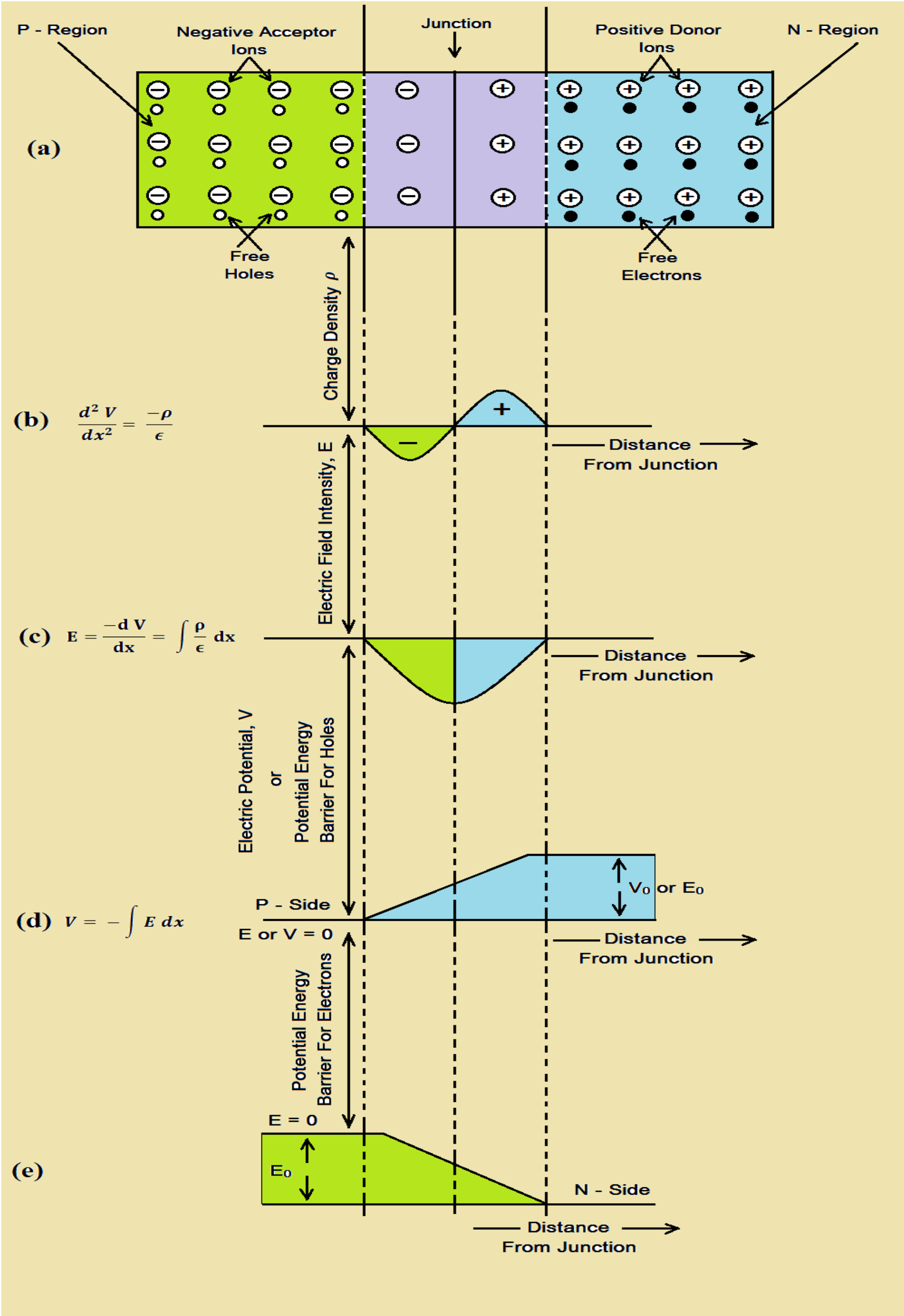

Fig. (2) Shown Energy E_O or $V_O$represents the **potential Energy of the Electrons at the Junction**.

⇨ Now, from **above** **Figure (1),** we have,

$$E_F - E_{VP} = \frac{1}{2} E_G - E_1 \quad \text{..} \quad \textbf{(64)}$$

and

$$E_{CN} - E_F = \frac{1}{2} E_G - E_2 \quad \text{..} \quad \textbf{(65)}$$

⇨ Now **adding** above **Equation (64)** and **Equation (65),** we have,

$$E_1 + E_2 = E_G - (E_{CN} - E_F) - (E_F - E_{VP}) \quad \text{...................} \quad \textbf{(66)}$$

$$E_o = E_G - (E_{CN} - E_F) - (E_F - E_{VP}) \quad \text{............................} \quad \textbf{(67)}$$

⇨ We already known from **Previous Lecture** that,

⇨ In **Intrinsic Semiconductor,** **Concentration of free Electrons n in Conduction Band** may be expressed as,

$$n = n_C \, e^{-(E_C - E_F)/kT} \quad \text{..} \quad \textbf{(68)}$$

and

⇨ In **Intrinsic Semiconductor,** **Concentration of free Holes p in Valence Band** may be expressed as,

$$p = n_V \, e^{-(E_F - E_V)/kT} \quad \text{..} \quad \textbf{(69)}$$

where,

- n_C is the number of Electrons in Conduction Band,
- n_V is the number of Electrons in the Valence Band,
- E_C is the lowest energy in the Conduction Band in eV,
- E_V is the maximum energy of Valence Band in eV.

⇨ Now, from **Law of Mass Action,** then we already have,

$$n\,p \;=\; n_i^2 \quad \text{...} \quad (70)$$

$$n_i^2 \;= n\,p$$

$$n_i^2 \;=\; n_C\, e^{-(E_C \;-\; E_F)/kT} \;.\; n_V\, e^{-(E_F \;-\; E_V)/kT} \quad \text{....................} \quad (71)$$

$$n_i^2 \;=\; n_C \;\; n_V\, e^{-(E_C \;-\; E_F)/kT} \;.\; e^{-(E_F \;-\; E_V)/kT} \quad \text{..................} \quad (72)$$

$$n_i^2 \;= n_C \;\; n_V \;\; e^{-[(E_C \;-\; E_F) + (E_F \;-\; E_V)]/kT} \quad \text{...........................} \quad (73)$$

$$n_i^2 \;= n_C \;\; n_V \;\; e^{-E_C \;-\; E_F \;+\; E_F \;-\; E_V \;/kT} \quad \text{..............................} \quad (74)$$

$$n_i^2 \;= n_C \;\; n_V \;\; e^{-(E_C \;-\; E_V)/kT} \quad \text{...} \quad (75)$$

$$n_i^2 \;= n_C \;\; n_V \;\; e^{-E_G/kT} \quad \text{...} \quad (76)$$

⇨ We already know from **Previous Lecture** that $E_C \;-\; E_V \;=\; E_G$, then we get,

$$\therefore\; n_i^2 \;= n_C \;\; n_V \;\; e^{-E_G/kT} \quad \text{..} \quad (77)$$

⇨ Again finally we can write the above **Equation (77)** as

$$\therefore\; E_G \;=\; kT\, log_e\, \frac{n_C \;\; n_V}{n_i^2} \quad \text{..} \quad (78)$$

⇨ Now again, we already know from **Previous Lecture** that,

⇨ **Exact position of the Fermi Level in an N – type of Extrinsic Semiconductor** is give by,

$$E_F \;=\; E_C - \; kT\, log_e\, \frac{n_C}{N_D} \quad \text{..} \quad (79)$$

$$E_{CN} - E_F = kT\ log_e \frac{n_C}{N_D} \quad \text{...} \quad (80)$$

⇨ Again, **Exact position of the Fermi Level in an P – type of Extrinsic Semiconductor** is give by,

$$E_F = E_V - kT\ log_e \frac{n_V}{N_A} \quad \text{...} \quad (81)$$

$$E_F - E_{VP} = kT\ log_e \frac{n_V}{N_A} \quad \text{...} \quad (82)$$

⇨ Now substituting values of E_G, $(E_{CN} - E_F)$ and $(E_F - E_{VP})$ from **Equation (78), Equation (80)** and **Equation (82)** in **Equation (67),** then we get,

$$E_o = E_G - (E_{CN} - E_F) - (E_F - E_{VP}) \quad \text{...........................} \quad (67)$$

$$E_o = kT\ log_e \frac{n_C\ n_V}{n_i^2} - kT\ log_e \frac{n_C}{N_D} - kT\ log_e \frac{n_V}{N_A} \quad \text{...} \quad (83)$$

$$E_o = kT\ log_e \left[\frac{n_C\ n_V}{n_i^2} \cdot \frac{N_D}{n_C} \cdot \frac{N_A}{n_V}\right] \quad \text{...................................} \quad (84)$$

$$\therefore\ E_o = kT\ log_e \frac{N_D\ N_A}{n_i^2} \quad \text{...} \quad (85)$$

⇨ **It is to be noted that** in above Equations all **E's** are expressed in **electron-volt** and **k** has the dimensions of **electron-volts per Kelvin**. The **contact difference** of **Potential** V_O is expressed in **volts** and is **numerically equal** to E_O.

⇨ It is obvious from above **Equation (84)** that **E_O** **depends upon** the **equilibrium concentrations** and not upon the **charge density** in **transition region**.

⇨ In the next **Lecture - 11,** we will discuss the detailed of the **Metal Semiconductor Junctions.**

to be continued ....

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