Junction Diode

Lecture - 4

(03/06/2021)

B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Unit – 5
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➢ Equilibrium Conditions

⇨ The Electron and Hole concentrations, under thermal equilibrium can be found by knowing the position of the **Fermi Energy** E_F with respect to the bottom of the **Conduction Band Energy** E_C and top of **Valence Band Energy** E_V. As discussed in pervious **Lecture No – 24,** in case of an Intrinsic Semiconductor, the **Fermi Level lies midway** between the **Conduction and Valence Bands**.

⇨ With the rise in temperature above **0 K**, the Valence Electrons gain thermal energy. A few Electrons in the Valence Band may gain sufficient energy to jump to the Conduction Band.

⇨ Under this condition an empty state or Hole is generated in the Valence Band. In an Intrinsic Semiconductor Electrons and Holes are generated in pairs by thermal energy so that the number of Electrons in the Conduction Band is equal to the number of Holes in the Valence Band.

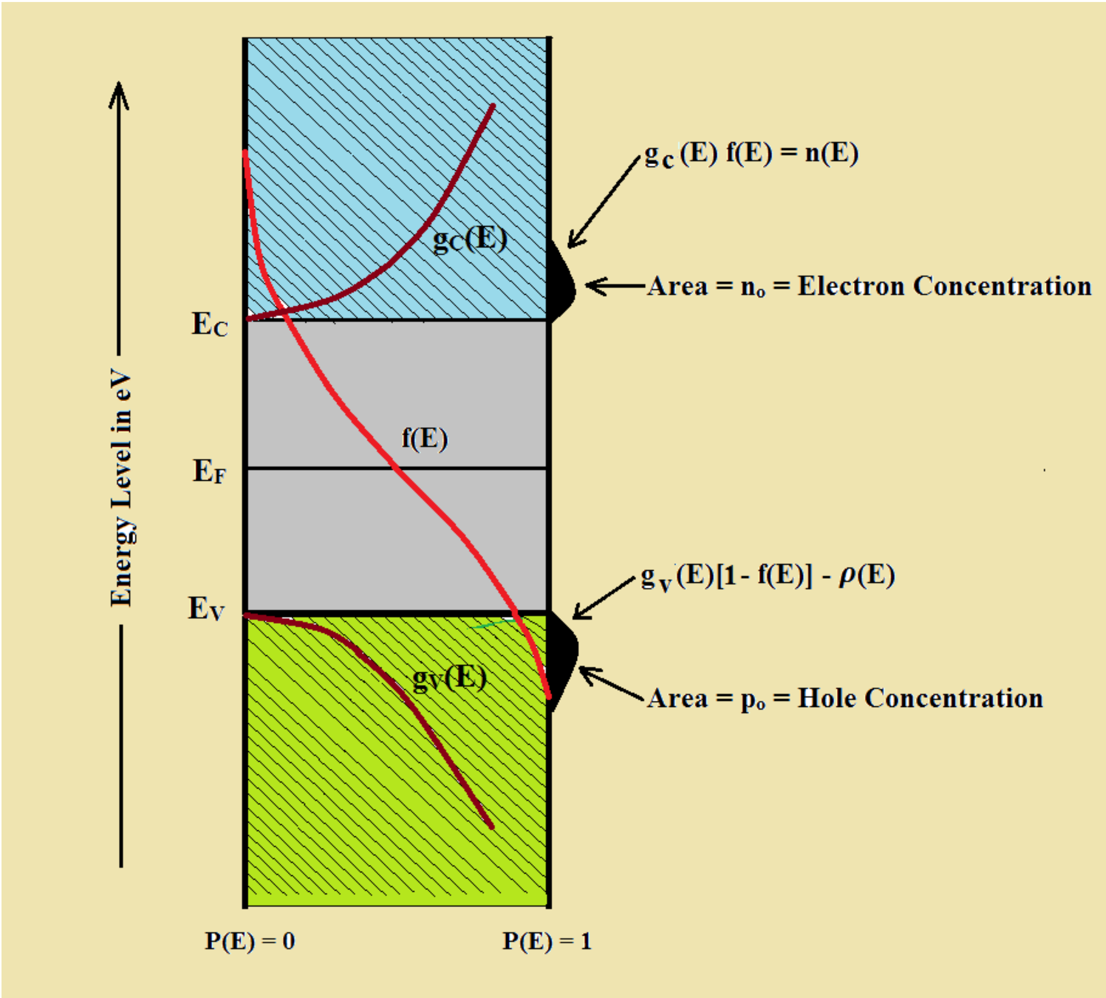

Fig. (1) Shown Density of States Functions Fermi-Dirac Probability Function, and Areas Representing Electron and Hole Concentration for $\mathbf{E_F}$ near the Midgap Energy.

⇨ **In above Figure (1) shows** a plot of the **Density of States Function in the Conduction Band** **gc(E),** and the **Density of States Function in the Valence Band** **gv(E),** and the Fermi-Dirac Probability Function for **T > 0 K** when $\mathbf{E_F}$ is approximately **halfway between** $\mathbf{E_C}$ and $\mathbf{E_V}$**.**

➢ Contact Potential

⇨ Upon joining the two regions P and N (**shown below in Figure (2)**) **holes diffuse from P - region to N – region** and **electrons diffuse from N – region to P – region**, as discussed in Previous **Lecture – 3.**

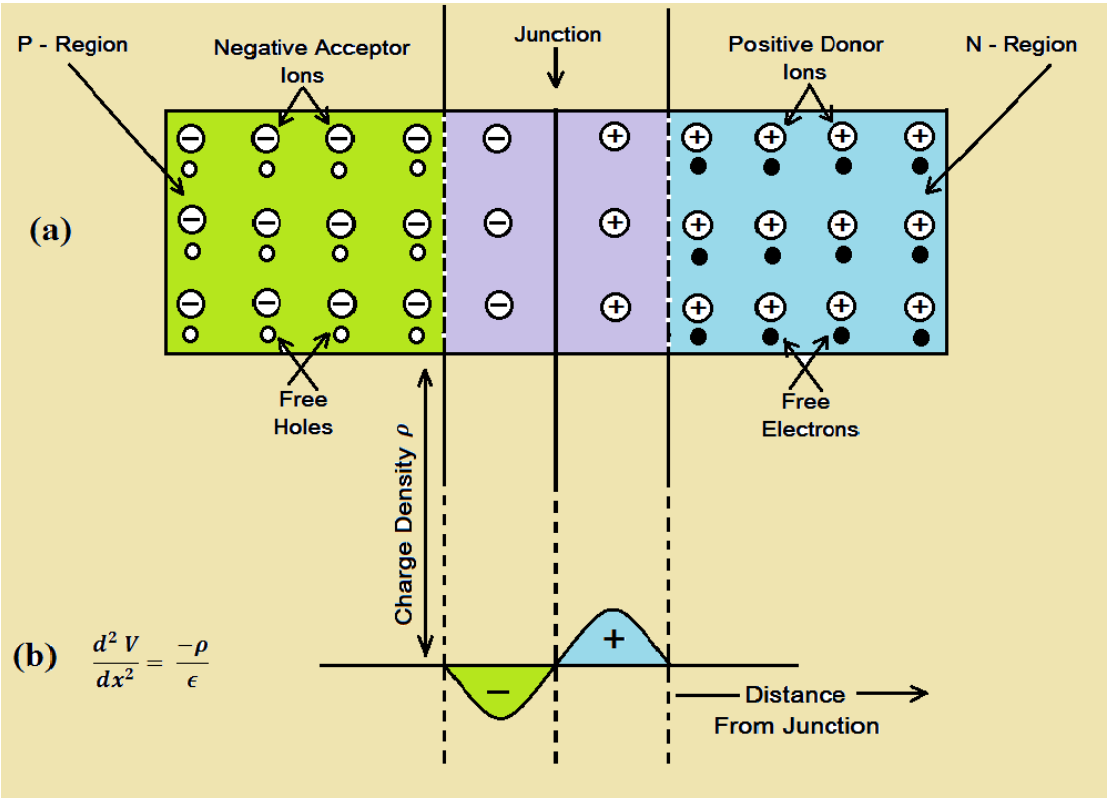

Fig. (2) Shown Joining the Two Regions P and N Holes Diffuse from P - Region to N – Region and Electrons Diffuse from N – Region to P – Region.

⇨ The resulting diffusing current cannot build up indefinitely due to creation of opposite electric field at the junction. The **Electric Field E** builds up to the point where the net current is zero at equilibrium. The **Electric Field** appears in some region **W (Width)** about the junction, **called the Transition Region,** and there is an **Equilibrium Potential Difference V_O** across **Junction width W**, **called a Contact Potential.**

⇨ The **Contact Potential** across **Junction width W** is a build-in Potential Barrier, essential to the maintenance of equilibrium at the junction. The **Valence and Conduction Energy Bands**, are higher on the **P – side** of the junction than on the **N – side** by an amount **eV_O**.

⇨ The relations between different quantities under conditions of equilibrium are:-

I_h (drift) + I_h (diffusion) = 0 .... (1)

Ie (drift) + Ie (diffusion) = 0 .... (2)

⇨ The relationship between **Hole Currents** is,

$$I_h(x) = e\left[\mu_h\, p(x)E(x) - D_h \frac{dp(x)}{dx}\right] \quad \text{.................................. (3)}$$

⇨ Which can be **simplified** as,

$$\frac{\mu_h}{D_h} E(x) = \frac{1}{p(x)} \frac{dp(x)}{dx} \quad \text{.. (4)}$$

⇨ where the **x-direction** is arbitrarily taken from **P - region** to **N - region.**

⇨ The **Electric Field** can be written in terms of the **Gradient in the Potential**,

$$E(x) = \frac{-dV(x)}{dx}$$

⇨ Putting the above value of **Electric Field** $E(x)$ into above **Equation (4),** then that **Equation (4)** becomes,

$$\frac{-e}{KT} \frac{dV(x)}{dx} = \frac{1}{p(x)} \frac{dp(x)}{dx} \quad \text{.. (5)}$$

⇨ With the use of **Einstein Relation** for $\frac{\mu_h}{D_h}$, the integration of above **Equation (5)** provides,

$$\frac{-e}{KT}\int_{V_p}^{V_n} dV \;=\; \int_{P_p}^{P_n}\frac{1}{p}\,dp \quad \dots\dots\dots \quad (6)$$

or, $$\frac{-e}{KT}(V_n - V_P) = \log p_n - \log p_p \quad \dots\dots\dots \quad (7)$$

or, $$\frac{-e}{KT}(V_n - V_P) = \log\frac{p_n}{p_p} \quad \dots\dots\dots \quad (8)$$

❖ Einstein Relation

The relationship between Diffusion Constant D and Mobility μ is called as Einstein Relation. Diffusion Constant D and Mobility μ is statistical thermodynamic phenomena. Hence they are not independent of each other. It is observed that at fixed temperature, the ratio of **Diffusion Constant D to Mobility μ** is constant and is known as **Einstein Relation. The Diffusion Constants D_h and D_e** and **Mobilities μ_h** and μ_e are related by **Einstein Relation** given as,

$$\frac{D_h}{\mu_h} = \frac{D_e}{\mu_e} = V_T \quad \dots\dots\dots \quad (9)$$

Hence, D_h = is Diffusion constant for Holes

D_e = is Diffusion constant for Electrons

μ_h = is Mobility for Holes

μ_e = is Mobility for Electrons

V_T = is volt-equivalent of temperature and is defined as,

$$V_T = \frac{k\,T}{e} = k\,T = \frac{T}{11600} \quad \text{...} \quad (10)$$

Where, **T** = is temperature in Kelvin

k = is Boltzmann constant

⇨ The **Potential Difference** $V_n - V_P$ is the **Contact Potential** **V**V_O. In terms of the **Equilibrium Hole Concentrations** on either side of the junction, the **Contact Potential** V_O **may be written as,**

$$\therefore\ V_o = \frac{KT}{e} \log \frac{p_p}{p_n} \quad \text{...} \quad (11)$$

⇨ If a **Step junction** is made up of material with a concentration of N_A **accepters/cm^3** on the P – side and a concentration of N_D **donors/cm^3** on the N – side, then above **Equation (10)** becomes,

$$\frac{p_p}{p_n} = e^{eV_o/KT} \quad \text{...} \quad (12)$$

⇨ Using **Law Mass Action** the Concentration p_n of Holes in **n – type semiconductor** is written as,

$$p_n\, n_n = n_i^2 \quad \text{...} \quad (13)$$

⇨ Using **Law Mass Action** the Concentration p_p of Holes in **p – type semiconductor** is written as,

$$p_p\, n_p = n_i^2 \quad \text{...} \quad (14)$$

⇨ Hence Using above **Equation (12)** and **Equation (13)** for the **Equilibrium condition** we get the **Law Mass Action expression as,** ,

$$p_p\, n_p \;=\; n_i^2 \;=\; p_n\, n_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (15)$$

⇨ Using **Law Mass Action and** for the **Equilibrium condition**

$p_p\, n_p \;=\; n_i^2 \;=\; p_n\, n_n$ **,** the above **Equation (12)** becomes,

$$\therefore\ \frac{p_p}{p_n} \;=\; \frac{n_n}{n_p} \;=\; e^{eV_o/KT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

⇨ **The** above relation will be vary useful in determination of **I-V Characteristics of the P-N Junction Diode.**

⇨ In the next **Lecture - 5,** we will discuss the detailed of the **Barrier Voltage of Contact Potential across the P-N Junction (PART – 1)**.

to be continued ....

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