Junction Diode

Lecture - 14

(15/06/2021)

B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Unit – 5
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➢ Zero Applied Biased P-N Junction Diode (PART – 2)

⇨ Here in this **Lecture** we will examine the properties of the **Step Junction** in Thermal Equilibrium, where no currents exist and no External Excitation is applied. We will also determine here,

(1) Built-in Potential Barrier through the Depletion Layer or Space Charge Region,

(2) Electric Field and

(3) Space Charge Width

➢ (2) Electric Field

⇨ The **separation of Positive and Negative Space charge densities results in an Electric Field in a Depletion Region**. **Figure (1) depicted below** the **Volume Charge Density** distribution in P-N Junction **assuming uniform doping and assuming an Abrupt Junction approximation**.

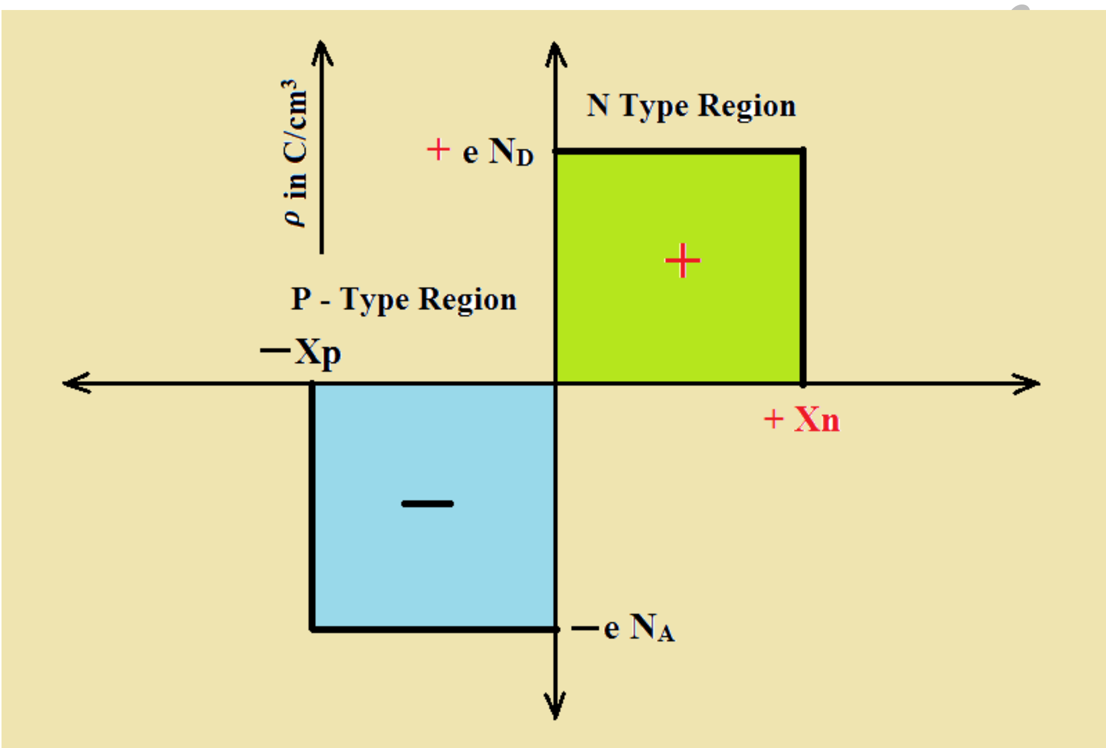

Fig. (1) Shown Space Charge Density in Uniformly Doped P-N Junction for Abrupt Junction Approximation.

Abrupt Junction

If one side of the P-N Junction is highly doped compared to the other, the diode is **known as the abrupt P-N Junction diode.** An abrupt P-N Junction (either heavily doped on one side or both sides) offers dynamical resistance for a longer range of applied potential difference.

⇨ Let us assume that the **Space Charge Region abruptly ends** in the N - Type region at $x = +x_n$ and $x = -x_p$ (x_p is a positive quantity) in the P – Type region.

⇨ The **Electric Field** is found from Poisson's equation and is,

$$\frac{d^2 \phi(x)}{d x^2} = \frac{-\rho(x)}{\epsilon} = \frac{-d E(x)}{dx} \quad \text{...} \quad \textbf{(97)}$$

where,

$\phi(x)$ = is the **Electric Potential**,

$E(x)$ = is the **Electric Field,**

$\rho(x)$ = is the **Volume Charge Density,** and

ϵ = is the **Permittivity of the semiconductor material**.

⇨ Now from above **Figure (1),** the **Charge Densities** are,

$$\rho(x) = -e N_A \qquad -x_p < x < 0 \quad \text{.............................} \quad \textbf{(98)}$$

$$\rho(x) = +e N_D \qquad 0 < x < x_n \quad \text{............................} \quad \textbf{(99)}$$

⇨ Integrating **Equation (97),** we find **Electric Field in the P – Type region**. We have,

$$E = \int \frac{\rho(x)}{\epsilon} dx \quad \text{...} \quad \textbf{(100)}$$

$$E = -\int \frac{e N_A}{\epsilon} dx \quad \text{..} \quad \textbf{(101)}$$

$$E = \frac{-e N_A}{\epsilon} x + C_1 \quad \text{...} \quad \textbf{(102)}$$

where, C_1 is a **constant of integration**

⇨ The **Electric Field is assumed** to be **zero** in the **neutral P – Type region** for $x = < -x$ as in **Thermal Equilibrium** the **currents are zero.** Since **there are no Surface Charge Densities** within the P-N Junction structure, the **Electric Field** is a **continuous function.** The **constant of integration can be found** by setting $E = 0$ at $x = -x_p$.

⇨ So C_1 come out to be $\frac{-e N_A}{\epsilon} x_p$ and **Electric Field** in the **P – Type region** is given by,

$$E = \frac{-e N_A}{\epsilon} (x + x_p) \qquad -x_p \le x \le 0 \quad \text{.................} \quad \textbf{(103)}$$

⇨ **Similarly** the **Electric Field in the N – Type region** can be found from,

$$E = \int \frac{\rho(x)}{\epsilon} dx \quad \text{..} \quad \textbf{(104)}$$

$$E = \int \frac{e N_D}{\epsilon} dx \quad \text{..} \quad \textbf{(105)}$$

$$E = \frac{e N_D}{\epsilon} x + C_2 \quad \text{..} \quad \textbf{(106)}$$

Where, C_2 is a **constant of integration.**

⇨ The **Electric Field is assumed** to be **zero** in the **neutral N – Type region** for $x = < +x$ as in **Thermal Equilibrium** the **currents are zero.** Since **there are no Surface Charge Densities** within the P-N Junction structure, the **Electric Field** is a **continuous function.**

⇨ Here, C_2 is a **constant of integration** which can be determined by setting $E = 0$ at $x = +x_n$, because the **Electric Field** is **assumed to be zero** in the **N – Type region** and is a **continuous function**.

⇨ So C_2 come out to be $\frac{-e N_D}{\epsilon}\, x_n$ and **Electric Field** in the **N – Type region** is given by,

$$E = \frac{-e N_D}{\epsilon}\,(x_n + x) \qquad 0 \leq x \leq x_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (107)$$

⇨ The **Electric Field** is also **continuous at the metallurgical junction**, or at $x = 0$.

Equating **Equation (103)** and **Equation (107)** at $x = 0$ we have,

$$E = \frac{-e N_A}{\epsilon}\,(x + x_p) \qquad -x_p \leq x \leq 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (103)$$

$$E = \frac{-e N_D}{\epsilon}\,(x_n + x) \qquad 0 \leq x \leq x_n \quad \ldots\ldots\ldots\ldots\ldots \quad (107)$$

$$N_A\, x_p = N_D\, x_n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (108)$$

⇨ Above **Equation (108)** **reveals that number of Negative Charge per unit area in the P – Type region and number of Positive Charge per unit area in the N – Type region are equal.**

⇨ **Electric Field in the Depletion Region** is **depicted in below Figure (2).** The **Electric Field acts in direction from N – Type region to P – Type region, or in the Negative X direction for this geometry.**

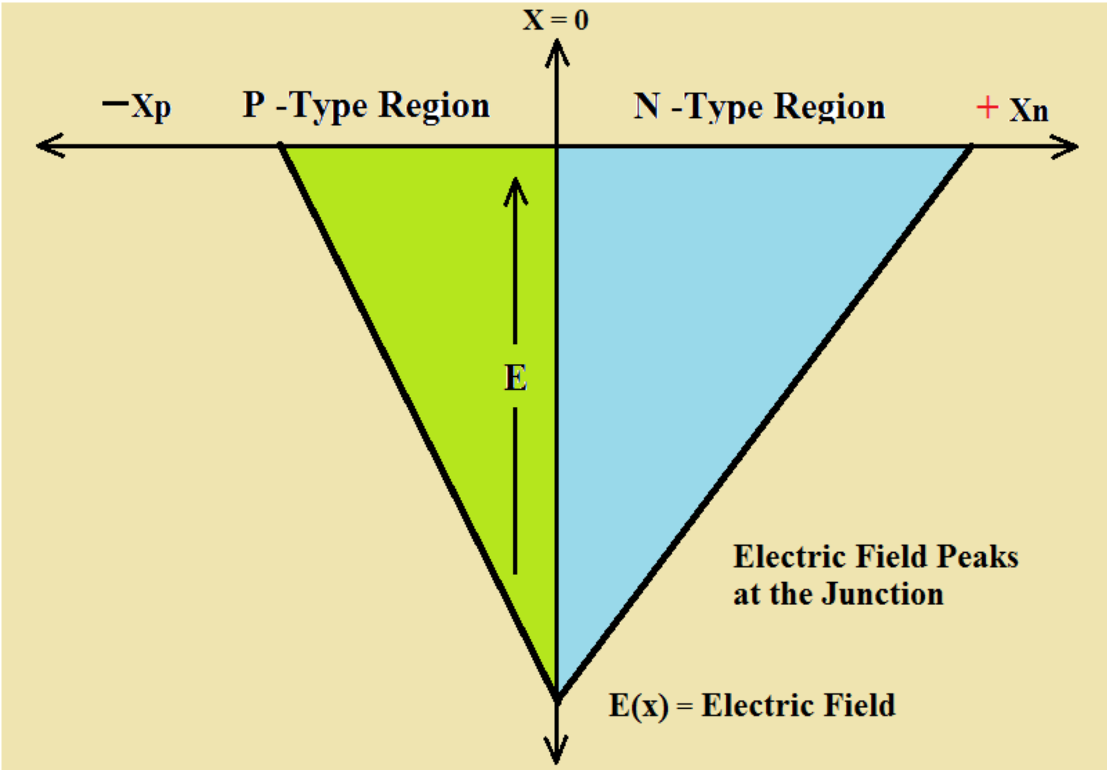

Fig. (2) Shown the Uniformly Doped P-N Junction Structure, with the Charge and the Electric Field Profile in the Depletion Region or Space Charge Region. The Electric Field Peaks at the Junction as shown.

⇨ For the **uniformly doped P-N Junction**, the **Electric Field varies linearly with the distance** through the junction and the **maximum (magnitude) Electric Field** is **at the Metallurgical Junction**. **Though no voltage is applied between the P – Type region and N – Type region but there is an Electric Field in the Depletion Region.**

⇨ **Integration of Electric Field** gives **Potential in the junction**. Then in the **P –Type region** we have,

$$\emptyset\,(x) = -\int E(x)dx \quad \text{...} \quad (109)$$

$$\emptyset\,(x) = -\int \left[\frac{-\,e\,N_A}{\epsilon}\,(x + x_p)\right] dx \quad \text{......................................} \quad (110)$$

$$\emptyset\,(x) = \int \frac{e\,N_A}{\epsilon}\,(x + x_p)\,dx \quad \text{...} \quad (111)$$

$$\emptyset\,(x) = \frac{e\,N_A}{\epsilon}\left(\frac{x^2}{2} + x_p\,x\right) + C_3 \quad \text{..} \quad (112)$$

where, C_3 is again a **constant of integration.**

⇨ **The Potential Difference through the P-N Junction is the important parameter, rather than the absolute potential.**

⇨ Let us set the **Potential** equal to **0 arbitrarily** at $x = -\,x_p$. The **Constant of Integration come out** to be,

$$\therefore\ C_3 = \frac{e\,N_A}{2\epsilon}\,x_p^2 \quad \text{...} \quad (113)$$

⇨ Again putting the value of C_3 into the above **Equation (112),** then thus the **Expression for Potential** in the **P – Type region becomes**,

$$\emptyset\,(x) = \frac{e\,N_A}{\epsilon}\left(\frac{x^2}{2} + x_p\,x\right) + C_3 \quad \text{..} \quad (112)$$

$$\therefore\ \emptyset(x) = \frac{e\,N_A}{\epsilon}\left(\frac{x^2}{2} + x_p\,x\right) + \frac{e\,N_A}{2\epsilon}\,x_p^2 \quad (-\,x_p < x < 0) \text{ ..... } \mathbf{(114)}$$

⇨ **Again Similarly,** **Integration of Electric Field** in the **N – Type region** gives **Expression for the Potential** in the **N – Type region** and we have,

$$\emptyset(x) = \int E(x)dx \text{ .... } \mathbf{(115)}$$

$$\emptyset(x) = \int\left[\frac{e\,N_D}{\epsilon}\ (x_n + x)\right] dx \text{ .... } \mathbf{(116)}$$

$$\emptyset(x) = \int\frac{e\,N_D}{\epsilon}\ (x_n + x)\,dx \text{ .... } \mathbf{(117)}$$

$$\emptyset(x) = \frac{e\,N_D}{\epsilon}\left(x_n\,x + \frac{x^2}{2}\right) + C_4 \text{ .... } \mathbf{(118)}$$

where, C_4 is a **constant of Integration.**

⇨ Now setting **Equation (114)** and **Equation (118)** equal at the **Metallurgical Junction**, or at $x = 0$ (because Potential is a continuous function), then we have,

$$\emptyset(x) = \frac{e\,N_A}{\epsilon}\left(\frac{x^2}{2} + x_p\,x\right) + \frac{e\,N_A}{2\epsilon}\,x_p^2 \quad (-\,x_p < x < 0) \text{ .... } \mathbf{(114)}$$

$$\emptyset(x) = \frac{e\,N_D}{\epsilon}\left(x_n\,x + \frac{x^2}{2}\right) + C_4 \text{ .... } \mathbf{(118)}$$

$$\therefore\ C_4 = \frac{e\,N_D}{2\epsilon}\,x_p^2 \text{ .... } \mathbf{(119)}$$

⇨ Again putting the above value of C_4 into the above **Equation (118),** then thus the **Expression for Potential** in the **N – Type region becomes**,

$$\emptyset\,(x) = \frac{e\,N_D}{\epsilon}\left(x_n\,x + \frac{x^2}{2}\right) + C_4 \quad \text{...} \quad \textbf{(118)}$$

$$\therefore\ \emptyset\,(x) = \frac{e\,N_D}{\epsilon}\left(x_n\,x + \frac{x^2}{2}\right) + \frac{e\,N_D}{2\epsilon}\,x_n^2 \qquad (0 < x < x_n) \quad \textbf{... (120)}$$

⇨ A **plot of Potential through the junction** is **depicted in below Figure (3).** It shows the **Quadratic Dependence of Potential on the distance X**.

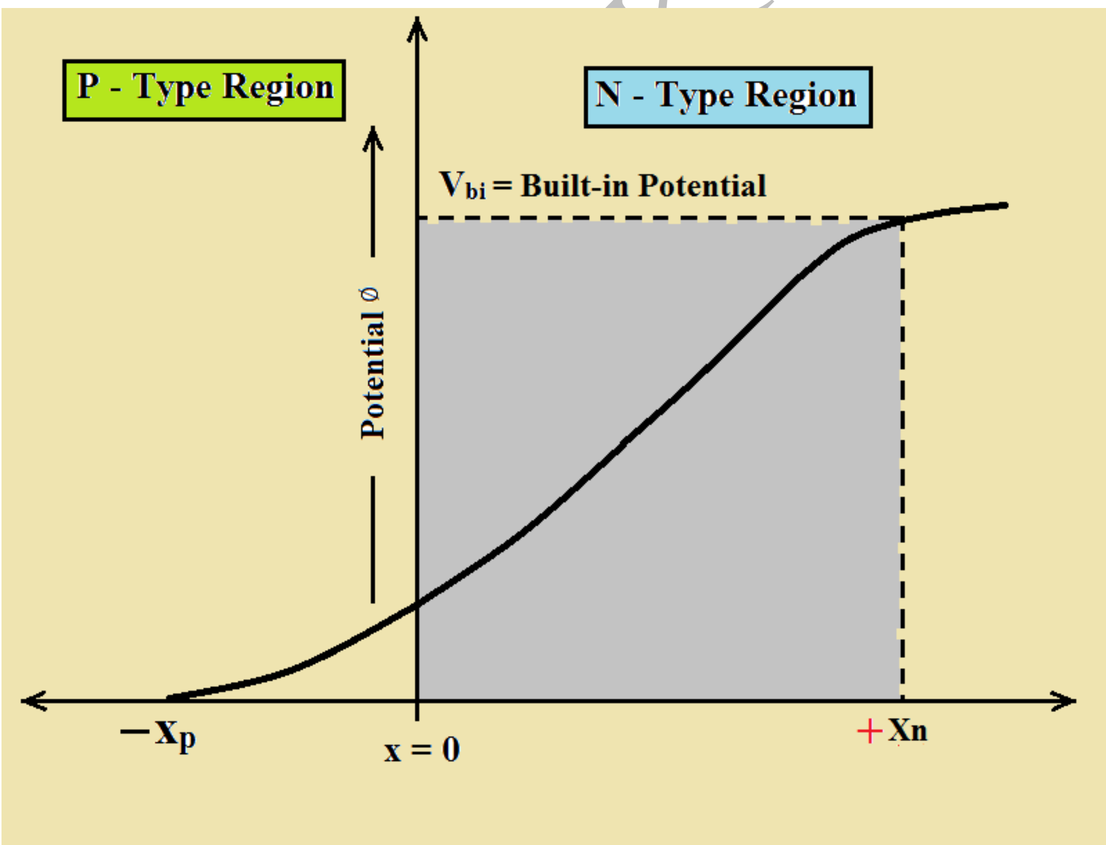

Fig. (3) Shown Electric Potential through the Space Charge Region of a Uniformly Doped P-N Junction.

⇨ The **Magnitude of the Potential** at $x = x_n$ is equal to the **Built-in Potential Barrier** V_{bi}. Then **Equation (120)** yields,

$$\therefore\ V_{bi} = \emptyset\,(x = x_n) = \frac{e}{2\epsilon}\left(N_D\, x_n^2 + N_A\, x_p^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (121)$$

⇨ The **Potential Energy of an Electron is given as** $E = -e\,\emptyset$. **It means that the Electron Potential Energy also varies as a Quadratic Function of Distance through the Space Charge Region.**

⇨ In the next **Lecture - 15,** we will discuss the detailed of the **Zero Applied Biased P-N Junction Diode (PART – 3) and (3) Width of the Space Charge Region.**

to be continued ....

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