Atomic Structure and Semiconductor

Lecture - 32

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B.Sc (Electronics)
TDC PART - I
Paper – 1 (Group – B)
Chapter – 4
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➢ Continuity Equation

- Under equilibrium condition, the concentration of carriers (holes and electrons) is constant throughout the **semiconductor crystal.** On disturbing the equilibrium concentration of carriers, the concentrations of holes and electrons vary with time and approach the equilibrium value exponentially.

- Therefore, in **general,** the carrier concentration of a semiconductor is a function of **both time t** and **distance x.** The differential equation governing this functional relationship is **called Continuity Equation.**

⇨ Consider the case of an **infinitesimal element** of volume of **Area *A*** and Length ***dx*** along ***X- axis*** as shown in below **Figure (1).** The variation of concentration along ***Y-*** and ***Z- axes*** is assumed to be **Zero.**

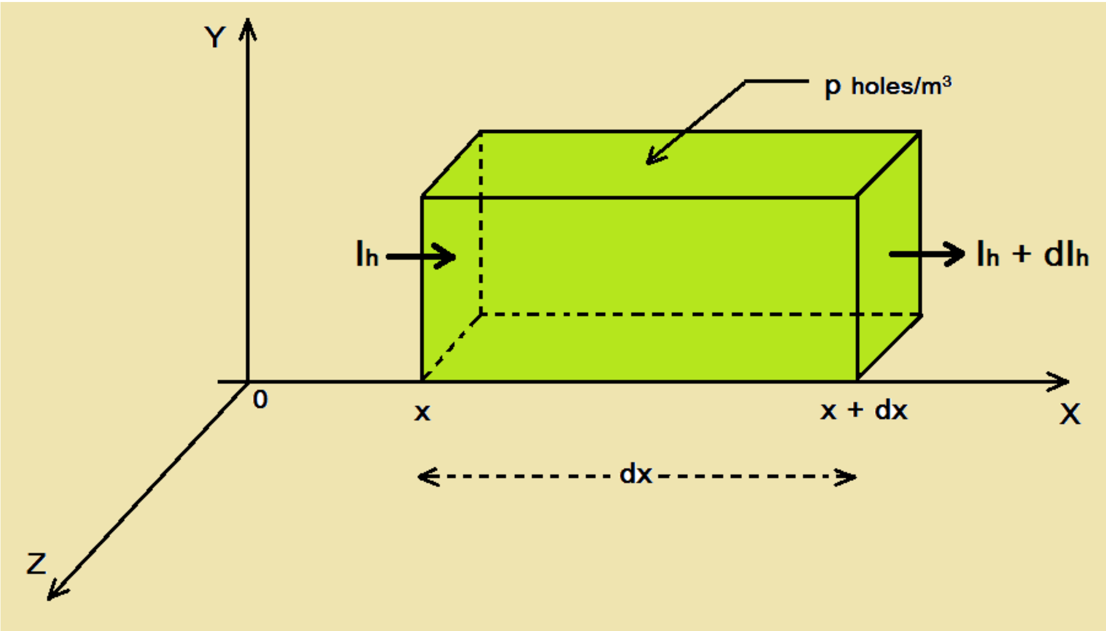

Fig. (1) Shown the case of an infinitesimal element of volume of **Area *A*** and Length ***dx*** along ***X- axis.***

⇨ Let the concentration of holes in the volume be ***p*** **holes/m**^{3}. The **current** I_h **enters the volume** and the **current** (I_h + dI_h) **leaves the volume**. Thus **more current** (i.e., dI_h **coulomb/sec.**) **leaves the volume** for positive value of dI_h. The following three factors are observed which cause the change in concentration ***p*** :-

(1) Concentration of holes **decreases** due to additional current **(**dI_h**),**

(2) Concentration of hole **increases** due to thermal generation, and

(3) Concentration of holes **decreases** due to recombination.

⇨ The **decrease** in the number of holes per second within the volume is,

$= \frac{dI_h}{e}$, ... where e is the **magnitude of charge.**

⇨ So the **decrease** in hole concentration (holes per unit volume) per second due to current I_h is given by,

$$\frac{decrease\ in\ charge}{unit\ charge\ \times\ volume} = \frac{dI_h}{e\ .\ (A\ dx)}$$

$$\frac{decrease\ in\ charge}{unit\ charge\ \times\ volume} = \frac{dJ_h}{e\ .\ dx}$$

$$\left(\because\ J_h = \frac{I_h}{A}\right)$$

⇨ The thermal generation **increases** the number of holes at a rate of g **holes** per second. The **increase** of holes per unit time per second due to **thermal generation is given by,**

$g = \frac{p_o}{\tau_h}$, ... where τ_h is **life time of holes.**

⇨ The **decrease** of holes per unit time per second due to **recombination** is given by,

Recombination rate = $\frac{p}{\tau_h}$, ... where **p** is concentration of holes.

⇨ As the charge cannot be generated or destroyed, the **increase** in hole concentration per second, **(dp/dt)** must be equal to the algebraic sum of the increase in hole concentration.

⇨ Again if τ_h is the **mean lifetime of holes**, then $\frac{p}{\tau_h}$ equals the **holes per second lost by recombination per unit volume.** If e is the electronic charge, then because of recombination, the number of coulombs per second **decreases** within the **volume** and,

⇨ **Decrease** within the volume = - $e\,A\,dx\,\frac{p}{\tau_h}$ .... **(1)**

⇨ If g is the **thermal rate of generation of electron-hole pairs per unit volume,** the number of coulombs per second **increases** within the **volume** and

⇨ **Increase** within the volume = + $e\,A\,dx\,g$ .... **(2)**

⇨ In general, the **current varies** with **distance** within the semiconductor. If the current entering the volume at x is I_h and leaving at $x + dx$ is $I_h + dI_h$, as shown in above **Figure (1),** the number of coulombs per second **decreases** within the volume and

⇨ **Decrease** within the volume = - $d\,I_h$ .... **(3)**

⇨ Because of the three effects enumerated above, the hole concentration must change with time, and the total number of coulombs per second **increases** within the **volume** and,

⇨ **Increase** within the volume = + $e\,A\,dx\frac{dp}{dt}$ .... **(4)**

⇨ Since the **charge must be conserved**, so,

$$e\,A\,dx\,\frac{dp}{dt} = -e\,A\,dx\,\frac{p}{\tau_h} + e\,A\,dx\,g - d\,I_h \quad \text{.........................} \quad (5)$$

⇨ The hole current $\boldsymbol{I_h}$ is the sum of **drift current** and **Diffusion current** so,

$$\boldsymbol{I_h \;=\; A\,E\,p\,e\,\mu_h - A\,e\,D_h\,\frac{dp}{dx}a} \quad \text{...} \quad \textbf{(6)}$$

⇨ If the semiconductor is in thermal equilibrium with its surrounding and is subjected to no applied fields, the hole density will attain a constant value $\boldsymbol{p_o}$. Under these conditions $\boldsymbol{I_h = 0}$ and $\boldsymbol{\frac{dp}{dt} = 0}$. So from the **equation (5)** we have,

$$\boldsymbol{g = \frac{p_o}{\tau_h}} \quad \text{...} \quad \textbf{(7)}$$

⇨ The above equation indicates that the **rate of thermal generation of holes** **equals the rate of holes lost due to recombination**, under **equilibrium** conditions.

⇨ Combining **equation (5), (6) and (7)** we have the equation of **conservation of charge,** **called the Continuity Equation,**

$$\boldsymbol{\frac{dp}{dt} = -\frac{p - p_o}{\tau_h} + D_h\,\frac{d^2\,p}{d\,x^2} - \mu_h\,\frac{d\,(p\,E)}{d\,x}} \quad \text{....................................} \quad \textbf{(8)}$$

⇨ The **equation (8)** is the **Continuation Equation** or **equation of conservation of charge for holes** stating the condition of **dynamic equilibrium** for the density of mobile carrier holes.

⇨ Since $\boldsymbol{p}$ is a function of both $\boldsymbol{t}$ and $\boldsymbol{x}$**,** **partial derivatives** should be used and **equation (8)** may be modified as,

$$\boldsymbol{\frac{\partial p}{\partial t} = -\frac{p - p_o}{\tau_h} + D_h\,\frac{\partial^2\,p}{\partial\,x^2} - \mu_h\,\frac{\partial\,(p\,E)}{\partial\,x}} \quad \text{....................................} \quad \textbf{(9)}$$

⇨ Here as both $\boldsymbol{p}$, $\boldsymbol{D_h}$ and $\boldsymbol{\mu_h}$ are functions of both $\boldsymbol{t}$ and $\boldsymbol{x}$, the **partial derivative** have been used. **This is known as Continuity Equation** for charge or **law of conservation of charge.**

⇨ Similarly, the **Continuity Equation for electrons** states the condition of **dynamic equilibrium** for the density of mobile carrier electrons and given by,

$$\frac{\partial n}{\partial t} = -\frac{n - n_o}{\tau_h} + D_e \frac{\partial^2 n}{\partial x^2} - \mu_e \frac{\partial (n E)}{\partial x} \quad \text{.......................................} \quad \textbf{(10)}$$

⇨ Here as both $\boldsymbol{n}$, $\boldsymbol{D_e}$ and $\boldsymbol{\mu_e}$ are functions of both $\boldsymbol{t}$ and $\boldsymbol{x}$, the partial derivative have been used. **This is known as Continuity Equation** for charge or **law of conservation of charge.**

to be continued ....

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