Atomic Structure and Semiconductor

Lecture - 33

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

⇨ As we know already from previous lecture that in an intrinsic semiconductor the number of holes is equal to the number of free electrons. Due to thermal agitation new electron-hole pairs are continuously generated while other electron-hole pairs disappear as a result of recombination i.e., free electrons falling into empty covalent bonds. On an average, a hole exists for τ_h second **known as mean lifetime of hole** and similarly an electron exists for τ_e second **known as mean lifetime of electron.**

⇨ These lifetimes vary from a few nanoseconds to several microseconds. The lifetimes of carriers (holes and electrons) form very important factors in semiconductor devices; because they indicate the time required for hole and electron concentrations to return to their equilibrium values after being influenced by any external cause such as illumination by light.

⇨ Let us consider an **N-type silicon bar** containing the thermal equilibrium concentration p_o and n_o . Assume that at any instant **t = t'** the bar illuminated as shown in below **Figure (1)** and that additional **EHPs (Electron-Hole Pairs)** are produced uniformly throughout the crystal.

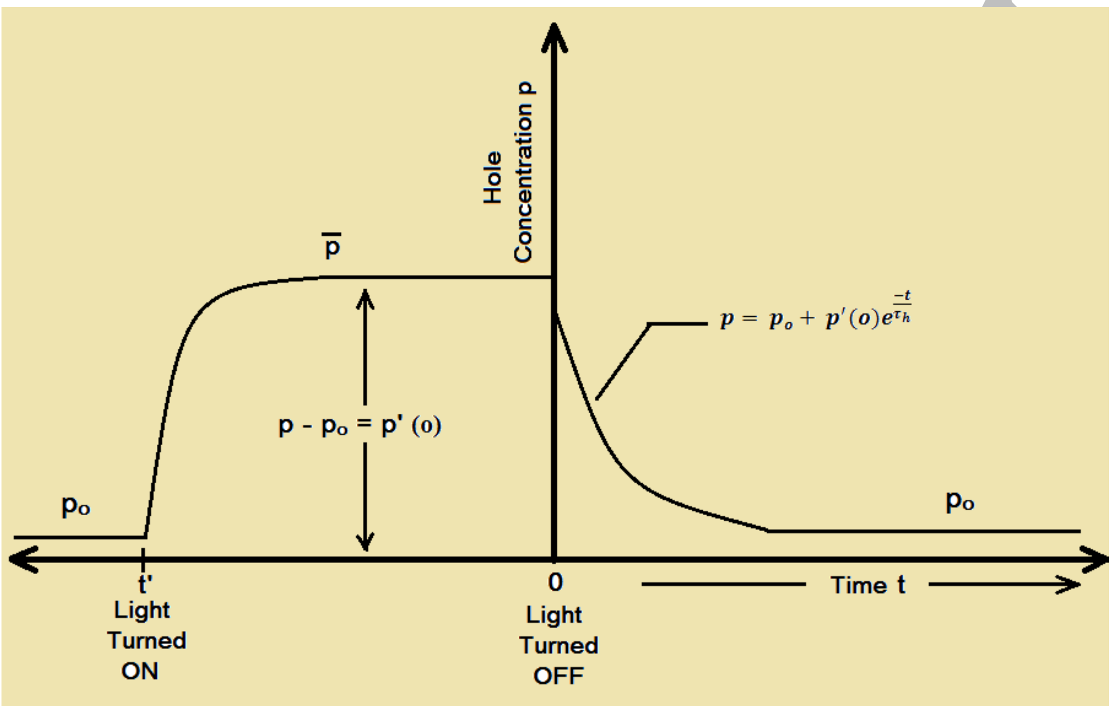

Fig .(1) Shown Hole (Majority) Concentration in an N-Type Semiconductor Bar as a Function of time Due to Generation and Recombination

⇨ An equilibrium condition is attained and the new concentrations are $\bar{p}$ and $\bar{n}$ under the influence of radiation. The photo injected, or excess, concentration is $\bar{p} - p_o$ for holes and $\bar{n} - n_o$ for electrons. As **EHPs (Electron-Hole Pairs)** are generated due to radiation, then clearly,

⇨ $\bar{p} - p_o = \bar{n} - n_o$ .... **(1)**

- Although the increases in hole concentration and electron density are equal, the percentage increase for electrons in an **N-type semiconductor** is very small while percentage increase in holes may be tremendous.

- This is because electrons are plentiful and holes are scarce in an **N-type crystal**. In short it can be said that the majority carrier concentration is hardly affected due to radiation. So our discussion will be limited to the behaviour of the minority carriers.

- When a steady-state condition is reached, at time $\mathbf{t = 0}$ as shown in above **Figure (1)**, the radiation is removed. Now it is to be shown that the excess carrier density returns to zero exponentially with time.

- From the definition of mean lifetime $\boldsymbol{\tau_h}$ and assuming that $\boldsymbol{\tau_h}$ is independent of magnitude of the hole concentration,
- $\frac{p}{\tau_h}$ = Decrease in hole concentration per second due to recombination **........... (2)**

- From the **definition** of **generation rate**,
- **g =** Increase in hole concentration per second due to thermal generation **.........(3)**

- Since charge can neither be generated nor destroyed, the increase in hole concentration per second must be equal to $\frac{dp}{dt}$. This rate must at every instant of time, equal the algebraic sum of the rates given in **equation (2)** and **equation (3)** i.e.,
- $$\frac{dp}{dt} = g - \frac{p}{\tau_h} \qquad \text{...} \quad \textbf{(4)}$$

⇨ Under steady-state conditions, the rate of increase in hole concentration $\frac{dp}{dt}$ must be equal to zero, and with no radiation falling on the sample, the hole concentration attains its thermal-equilibrium value p_o .

⇨ So $g - \frac{p_o}{\tau_h}$ and the above **equation (4)** becomes,

⇨ $$\frac{dp}{dt} = \frac{p_o - p}{\tau_h} \quad \text{...} \quad (5)$$

⇨ The excess or injected carrier density **p'** may be defined as the increase in minority concentration above the equilibrium magnitude. Since **p'** is a function of time, then,

⇨ $$p' = p - p_o = p'(t) \quad \text{..} \quad (6)$$

⇨ From **equation (5),** the differential equation controlling **p'** is,

⇨ $$\frac{dp'}{dt} = \frac{-p'}{\tau_h} \quad \text{...} \quad (7)$$

⇨ The **rate of change of excess concentration is** proportional to **this concentration-an intuitively correct result.** The minus sign indicates that the change is a decrease in the case of recombination and an increase when the concentration is recovering from a temporary depletion.

⇨ Since the radiation causes an initial **(at ≤ 0)** excess concentration $p'(0) = \bar{p} - p_o$ and then this excitation is removed, the solution of equation for $\mathbf{t \geq 0}$ is,

⇨ $$p'(t) = p'(0)\, e^{\frac{-t}{\tau_h}} = (\bar{p} - p_o)^{e^{\frac{-t}{\tau_h}}} = p - p_o \quad \text{....................} \quad (8)$$

- The excess concentration falls exponentially to zero **(p' = 0 or p =** p_o**)** with a time constant equal to the mean lifetime τ_h, as shown in above **Figure (1).**

- The most important mechanism through which recombination of holes and electrons occur is the mechanism involving recombination centres or traps which contribute electronic states in the energy gap of the semiconductor material.

- These new states are associated with imperfections in the crystal. Specifically, metallic impurities in the semiconductor are capable of introducing energy states in the forbidden gap. Recombination is affected not only by volume impurities, but also by surface imperfections in the crystal.

- Gold is extensively employed as a recombination agent in semiconductor manufacture. Thus the designer of the semiconductor device can obtain desired carrier lifetimes by introducing gold into silicon under controlled conditions.

to be continued ....

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