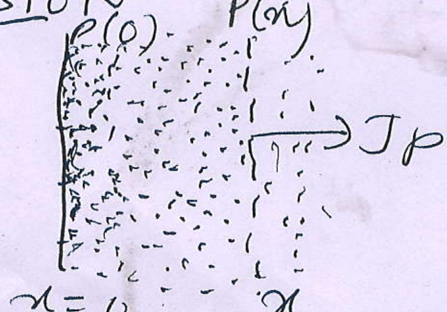
LECTURE DATE 16/9/2020 [1]

RECOMBINATION CENTRES:

Recombination means where an electron moves from conduction band into valence band. But classical mechanics requires that momentum be conserved in an encounter of 2 particles. Since momentum = 0 after recombination, the conservation law requires that the colliding electron and hole must have equal magnitudes of momentum & must be travelling in opposite direction. This requirement is very stringent and hence the probability of recombination by such a direct encounter is very small.

Therefore traps or recombination centres are used which contribute electronic states in the energy gap of the semiconductor. Such a location acts as a third body which can satisfy the conservation of momentum requirement. These new states / traps are associated with imperfections in the crystal. e.g. metallic impurities / surface impurities (Gold).

DIFFUSION:



A non-uniform concentration $p(x)$ results in a diffusion current J_p.

The concentration p of holes varies with distance x in the semiconductor and there exists a concentration gradient $\frac{dp}{dx}$ in the density of carriers. In the figure one side has more density than the other side. Holes move from higher concentration to the lower concentration. The net transport of holes across the surface ~~contributes~~ constitutes a current in the positive X direction.

The diffusion hole current density J_p

$$J_p = -q D_p \frac{dp}{dx} \quad \cdots (1)$$

where D_p is called diffusion constant for holes.

Since p decreases with x $\therefore \frac{dp}{dx}$ is -ve.

$$J_n = +q D_n \frac{dn}{dx} \quad \cdots (2)$$

EINSTEIN RELATIONSHIP:

Since both diffusion and mobility are statistical thermodynamic phenomena, D and μ are not independent.

$$\therefore \frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T$$

where V_T = volt equivalent of temp.

$$V_T = \frac{KT}{q} = \frac{T}{11{,}600}$$

K = Boltzmann's constant in joules per degrees Kelvin. At room temp. (300°K), $V_T = 0.026\,V$.

∴ Total current in semiconductor 3

$$J_p = q \mu_p p E - q D_p \frac{dp}{dx} \quad \cdots (3)$$

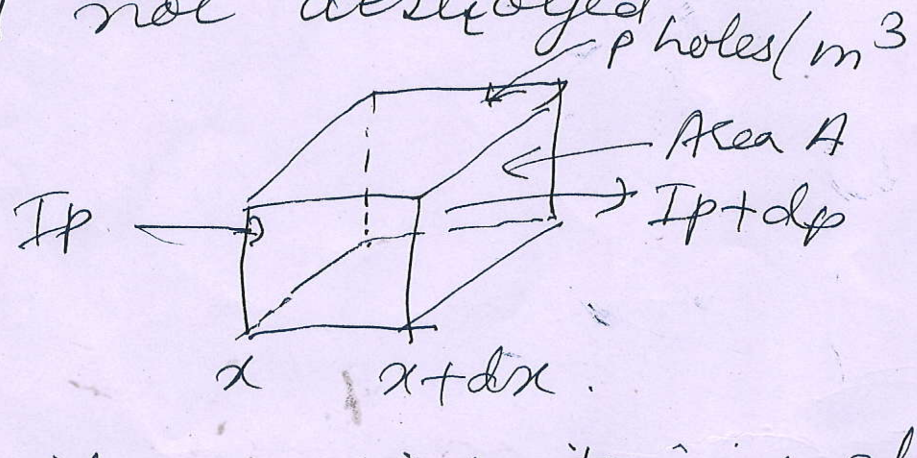
$$J_n = q \mu_n n E + q D_n \frac{dn}{dx} \quad (4)$$

The continuity Equation:

The carrier concentration in the body of a semiconductor is a function of both time and distance

A partial differential equation governs this functional relationship between carrier concentration, time and distance. Such an equation is called continuity equation.

Bases: charge can neither be created nor destroyed



Consider an infinitesimal element of volume of area A and length dx within which the average hole concentration is p. Assume that hole current I_p is a function of x.

The current entering the volume at x is I_p at time t and leaving at $x + dx$ is $I_p + dI_p$ at the same time t there must be dI_p more coulombs per second leaving the volume than entering it (for a positive value of dI_p.

Hence the decrease in number of coulombs per second within the volume ~~of~~ is dI_p.

$\frac{dI_p}{q}$ = decrease in number of holes per second within the elemental volume $A\,dx$.

Now $J_p = \frac{I_p}{A}$

$$\frac{1}{qA}\frac{dI_p}{dx} = \frac{dJ_p}{q\,dx}$$

= decrease in hole concentration (holes per unit volume) per second due to current I_p.

$g = \frac{P_0}{\tau_p}$ = increase in per second of holes per unit volume due to thermal generation

$\frac{P}{\tau_p}$ = decrease per second of holes per second due to recombination

Since charge can neither be created or destroyed, the increase in holes per unit volume per second must be equal to the algebraic sum of 3 components

$$\frac{\partial p}{\partial t} = \frac{P_0 - P}{\tau_p} - \frac{1}{q}\frac{\partial J_p}{\partial x} \quad \ldots (5)$$

(Since both p and J_p are functions of both t and x then partial derivatives are used in the equation.

$$\frac{\partial n}{\partial t} = \frac{n_0 - n}{\tau_n} + \frac{1}{q}\frac{\partial J_n}{\partial x} \quad \ldots (6)$$

(5) and (6) are continuity equations for holes & electrons resply

LECTURE 14/9/2020 ①

LAW OF MASS ACTION.

Let n = concentration of free electrons
p = concentration of free holes

Defn: Product of concentrations of electrons & holes is always constant at a fixed temp.

$$\therefore \; n \cdot p = n_i^2$$

Where n_i = ~~In~~ Intrinsic concentration

Note:

1. Law can be applied to both intrinsic & extrinsic semiconductors
2. n_i depends on temperature.
3. For extrinsic semiconductor, n_i of basic semiconductor is used.

(i) n type : $n_n p_n = n_i^2$
p type : $n_p p_p = n_i^2$

Carrier concentrations of extrinsic Semi

(i) N type semiconductor

$n_n \simeq N_D$ (D = Donor)

At any fixed temperature

$$n_n p_n = n_i^2$$

n_n = majority carrier conentration (2)
p_n = minority carrier concentration

$\therefore N_D \times p_n = n_i^2$ as $n_n = N_D$

$\therefore p_n = \frac{n_i^2}{N_D}$

(2) P type semiconductor:

$p_p \simeq N_A$ (A = Acceptor)

$\therefore n_p \times p_p = n_i^2$

$n_p \times N_A = n_i^2$

$n_p = \frac{n_i^2}{N_A}$

LAW OF ELECTRICAL NEUTRALITY

semiconductor material is considered to be doped with both types of impurities (donor & acceptor)

N_D = concentration of donor impurity
N_A = concentration of acceptor impurity

Donor atom donates one electron & becomes +vely charged ion. similarly acceptor atom accepts one electron and becomes -vely charged ion.

$\therefore$ Total positive charge concentration $= N_D + p$

Total negative charge concentration $= N_A + n$

$\therefore N_D + p = N_A + n$. This is

called law of electrical neutrality or equation of charge neutrality (3)

Semiconductor parameters vary with temperature.

(i) Intrinsic concentration (n_i) (ii) Mobility (μ)

(iii) conductivity (σ) (iv) Energy gap (E_g)

(i) Intrinsic concentration:

As temp. increases, concentration of n & p increases $\therefore$ n_i also increase

$$n_i^2 = A_0 T^3 e^{-\frac{E_{G0}}{KT}}$$

Where A_0 = constant. E_{G0} = Forbidden energy gap at absolute zero temp.

K = Boltzmann's constant

(ii) Mobility (μ)

$\mu \propto T^{-m}$ (for $100^\circ K$ to $400^\circ K$)

$\therefore$ It decreases with temperature

(iii) Conductivity (σ)

It increases with temperature

(iv) Energy gap (E_g)

E_g decreases with rise in temperature

Mathematical derivation for generation & recombination of charges.

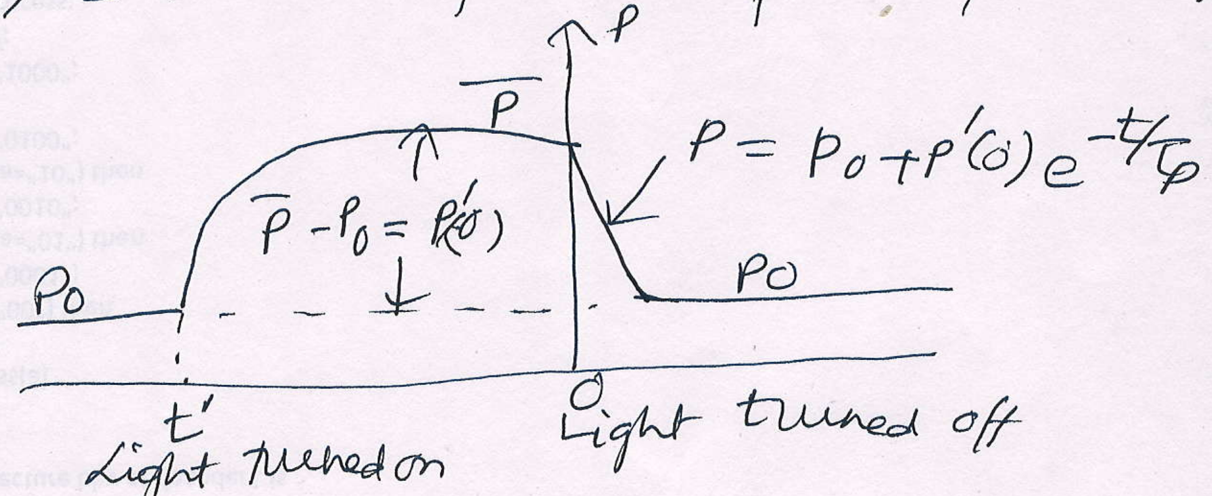
In pure semiconductor

no. of holes = no. of free electrons

Thermal agitation generates 'g' new hole electron pairs per unit volume per second.

In recombination free electrons fall into empty covalent bonds resulting in loss of a pair of mobile carriers.

$\tau_p (\tau_n)$ = mean lifetime of hole/electron



Consider specimen of n type, with n_0 & p_0 = thermal equilibrium concentration

At $t = t'$ specimen is illuminated & additional EHPs are generated

At $t = 0$, equilibrium situation is reached as light is turned off.

Now the concentrations are $\bar{P}$ & $\bar{n}$

Photoinjected / Excess concentration

$= \bar{P} - p_0$ (holes) & $= \bar{n} - n_0$ (electrons)

As radiation causes EHP to be generated

$\therefore \bar{P} - p_0 = \bar{n} - n_0$

Note: Although $p = n$ but increase in electrons in n type semiconductor is small as compared to increase in holes. (For this I will give an example $p = 10$, $n = 100$ & $\bar{P} - p_0 = 5 = \bar{n} - n_0$ $\therefore$ p has higher % increase than n)

$\therefore$ In the diagram p is considered. (5)

Now after radiation is removed, the excess carrier density returns to zero exponentially

Let us derive this exponential expression for $t > 0$.

(1) $\frac{p}{\tau_p}$ = decrease in hole concentration per second due to recombination

(2) g = increase in hole concentration per second due to recombination

Since charge can neither be created nor destroyed, there must be an increase in hole concentration per second of $\frac{dp}{dt}$

$$\therefore \frac{dp}{dt} = g - \frac{p}{\tau_p} \quad \ldots (3)$$

Under steady state condition & with no radiation falling on specimen p reaches equilibrium value p_0.

$$\therefore \frac{dp}{dt} = 0 = g - \frac{p_0}{\tau_p}$$

$$\therefore g = \frac{p_0}{\tau_p}$$

$$\therefore \frac{dp}{dt} = \frac{p_0}{\tau_p} - \frac{p}{\tau_p} \quad \ldots \cancel{(4)}$$

$$\frac{dp}{dt} = \frac{p_0 - p}{\tau_p} \quad \ldots (4)$$

Let p' = excess or injected carrier density = increase in minority carrier concentration above the equilibrium value

p' is a function of time.

$\therefore p' = p - p_0 = p'(t)$

From equation 4

$$\frac{dp'}{dt} = \frac{-p'}{\tau_p}$$

(- sign indicates decrease in case of recombination)

~~At~~ $t \leq 0$, $p'(0) = \bar{p} - p_0$

For $t \geq 0$

$$p'(t) = p'(0)\, e^{-t/\tau_p}$$

$$p - p_0 = (\bar{p} - p_0)\, e^{-t/\tau_p}$$

$$p - p_0 = p'(0)\, e^{-t/\tau_p}$$

$$\therefore \boxed{p = p_0 + p'(0)\, e^{-t/\tau_p}}$$

Conclusion: The excess carrier concentration decreases exponentially to zero with time constant equal to τ_p.