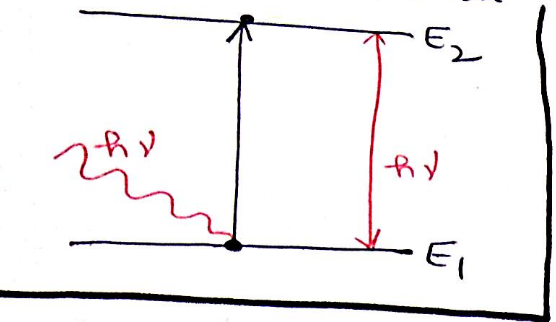
UNIT - 3

In orderto understand electrons transistion between two energy Bands we will study the transistion between two Energy levels E_1 and E_2

Electronic Transistion

① **Stimulated Absorption** → Electron of atom will absorb energy of Photon and will undergoes transistion from Energy level E_1 to E_2



⇒ Rate of stimulated absorption → No. of atoms undergoing stimulated absorption per unit time denoted by R_{sta} will depends on ① No. of atoms/electrons in Energy state E_1 say N_1

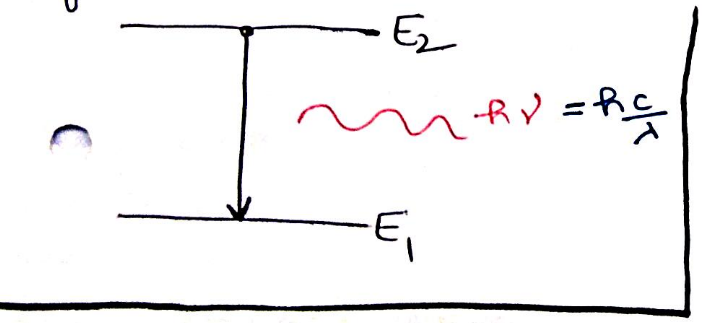
② Energy density $u(\nu)$ of incident Photon (Energy density is the Total Photon energy per unit volume per unit frequency)

$$R_{sta} \propto N_1 u(\nu)$$

$$R_{sta} = B_{12} N_1 u(\nu)$$

where B_{12} is proportionality constant and is called Einstein coefficient for stimulated absorption

② **Spontaneous Emission** → Electron present in higher state E_1 is Not stable its life time is equal to 10^{-8} sec and then falls back to lower state E_1 itself be emitting energy $h\nu$



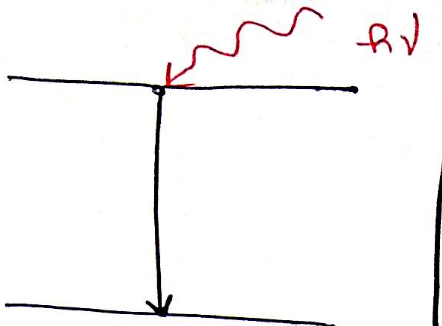
where the Rate of Spontaneous Emission R_{sp} (No. of atoms undergoing Spontaneous Emission per unit time) it will only depends on No. of atoms/electrons in state E_2 say N_2

$$R_{sp} \propto N_2$$

$$R_{sp} = A_{21} N_2$$

where A_{21} is constant of proportionality and is called Einstein coefficient of spontaneous Emission

③ **Stimulated Emission** Unlike spontaneous Emission the process of stimulated Emission requires External stimulus i.e incident Energy. Photon is required to trigger the transistion of electrons. Leading to the emission of Photon having same energy as that of incident Photon



The Rate of Stimulated Emission R_{ste} depends on ① Energy density of incident Photon $u(\nu)$

② No. of atoms/electrons in state E_2 say N_2.

$$R_{ste} \propto N_2 u(\nu)$$
$$R_{ste} = B_{21} N_2 u(\nu)$$

$B_{21} \rightarrow$ Einstein coefficient for stimulated Emission

Difference Between Spontaneous and stimulated Emission

Spontaneous	Stimulated
① It does Not require any external stimulus and occurs spontaneously	① It requires external stimulus in the form of incident Photon
② Emission of Photon is in random direction	② Emission of Photon is in same direction leading to the amplificat-on of light
③ It is Non-Monochromatic	③ It is Mono chromatic (having single frequency)
④ It is Not coherent	④ It is highly coherent

Two waves are said to be coherent if the two waves have same or contant Phase difference.

Phase difference between two waves having same frequency is the two difference in which the two waves reaches the same fixed Point

⑥ Intensity is Low	⑥ Intensity is high
⑦ Take Place in LED	⑧ Take Place in Semiconductor laser

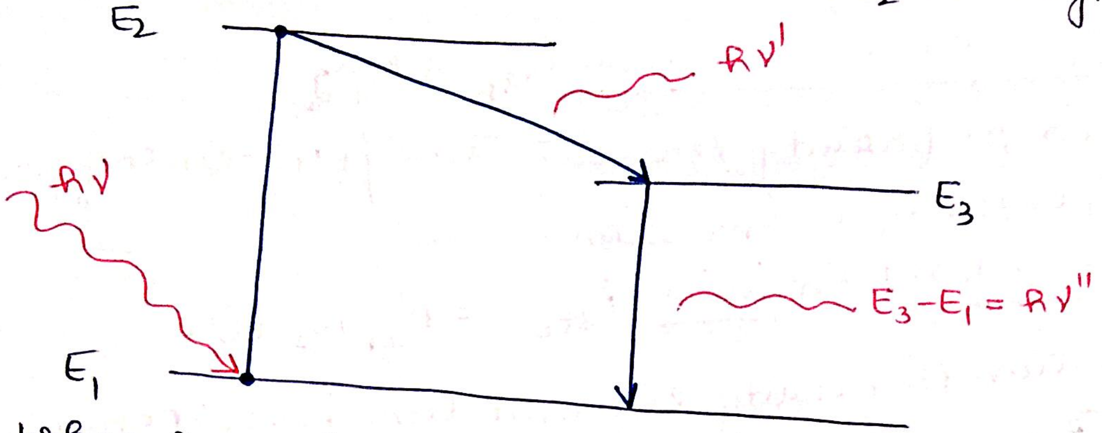
Population Inversion

Normally $N_1 > N_2$ i.e No. of electron in lower state is More than No. of electrons in higher state but if a situation is reach when N_2 becomes More than N_1 this is called Population inversion.

① Population inversion can only occurs in those substance which have special Energy state called Metastable state (This is another excited state) having life Time equal to 10^{-3} sec which is quite More than 10^{-8} Sec.

Such Material are called Active Materials

Let us consider three state E_1, E_2 and E_3 where E_1 is ground state, E_3 is Metastable state and E_2 is higher Excited state.



⇒ When Photon of Energy $h\nu$ is incident on the Material atoms in the state E_1 absorbs the energy and will Jumps to higher excited state E_2

⇒ The life Time of electron in state E_2 is 10^{-8}s hence it will Jump to state E_3 leaving some amount of Energy $h\nu'$ in the form of heat

⇒ As the life Time of electron in this state is 10^{-3} sec hence electrons reaches the state E_3 at Much faster rate than they leave it. As a result No. of electrons in the state E_3 becomes More than E_1. This condition is called Population inversion

Einstein Coefficients

As we know that N_1 = No. of atoms/electrons in state E_1

N_2 = No. of atoms in state E_2

The electron in state E_1 absorbs energy $h\nu$ and More to State E_2

Rate of induced absorption / Stimulated absorption $= B_{12} N_1 u(\nu)$

$$\frac{R_{sta}}{N_1 \; u(\nu)} = B_{12}$$

$$\frac{\text{No. of atoms undergoing stimulated absorption}}{t \quad N_1 \; u(\nu)} = B_{12}$$

B_{12} = Transition Probability per unit Time per unit Energy density. / Einstein coefficient for stimulated absorption

The atom/electron in the state E_2 May Jump by two process

1. Spontaneous Emission
2. Stimulated Emission

Rate of spontaneous Emission $R_{sp} = A_{21} N_2$

A_{21} = Transistion probability per unit time / Einstein coefficient for Spontaneous Emission.

Rate of stimulated Emission $R_{ste} = B_{21} N_2 u(\nu)$

B_{21} = Transistion probability per unit time per unit Energy density / Einstein coefficient for stimulated Emission

Rate of change in No. of atoms in state $E_2 = \frac{dN_2}{dt}$

$\frac{dN_2}{dt}$ = [Rate of induced absorption] − [Rate of spontaneous emission + stimulated Emission]

$$\frac{dN_2}{dt} = B_{12} N_1 u(\nu) - [A_{21} N_2 + B_{21} N_2 u(\nu)]$$

In Equilibrium (when $\frac{dN_2}{dt} = 0$ because $dN_2 = 0$) (Rate of absorption = Rate of Emission)

$$B_{12} N_1 u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$$

$$u(\nu)[B_{12} N_1 - B_{21} N_2] = A_{21} N_2$$

$$u(\nu) = \frac{N_2 A_{21}}{B_{12} N_1 - B_{21} N_2}$$

$$u(\nu) = \frac{N_2 A_{21}}{N_2 B_{21}\left[\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right]}$$

$$u(\nu) = \frac{A_{21}}{B_{21}\left[\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right]} \quad \text{—(1)}$$

According to Maxwell boltzmann distribution Law

$$N_1 = N_0 e^{-\frac{E_1}{kT}}$$

$$N_2 = N_0 e^{-\frac{E_2}{kT}}$$

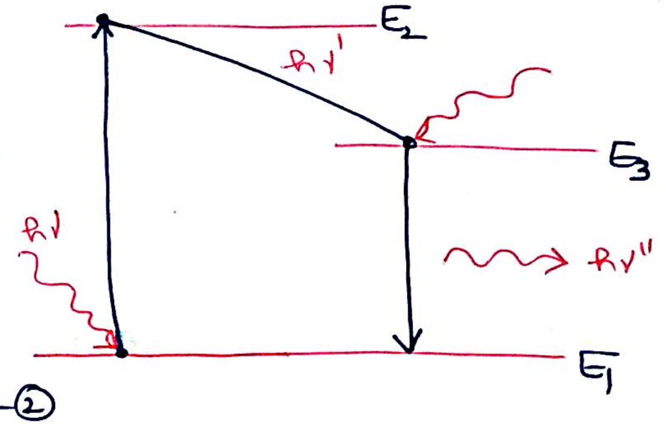
where N_0 is the Total No. of electrons in the Material

$$\frac{N_1}{N_2} = \frac{N_0 e^{-\frac{E_1}{kT}}}{N_0 e^{-\frac{E_2}{kT}}}$$

$$\frac{N_1}{N_2} = e^{\frac{1}{kT}(-E_1 - (-E_2))}$$

$$\frac{N_1}{N_2} = e^{\frac{E_2 - E_1}{kT}} \quad \text{as } E_2 - E_1 = h\nu$$

$$\frac{N_1}{N_2} = e^{h\nu/kT}$$



Put the value in Equation ①

$$\boxed{u(\nu) = \frac{A_{21}}{B_{21}\left[e^{h\nu/kT}\frac{B_{12}}{B_{21}} - 1\right]}} \quad —②$$

According to Planks radiation Law → This law gives the intensity of the radiation emitted

$$\boxed{u(\nu) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/kT} - 1}} \quad —③$$

where ν = frequency, C = constant

comparing equation ② and ③, we get

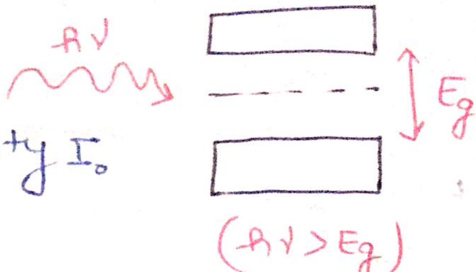
$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad \text{and} \quad \frac{B_{12}}{B_{21}} = 1$$

$$\boxed{\frac{A_{21}}{B_{21}} \propto \nu^3} \quad \text{and} \quad B_{12} = B_{21}$$

Transistion probability of stimulated absorption and stimulated emission are same

These are the relations between einstein coefficients

Optical Absorption



Let us consider semiconductor is illuminated by light source having intensity I_0.
The Energy of the light is $h\nu \geq E_g$
As light passes through semiconductor photon will be absorbed hence intensity of light will decreases with distance

$\Rightarrow$ Fraction of photons absorbed with depend on intensity of light and also as photons absorbed intensity will also dec.

$$\frac{I_2 - I_1}{x_2 - x_1} \propto I$$

$$-\frac{dI}{dx} \propto I$$

$$\frac{dI}{dx} = -\alpha I$$

(α is proportionality ~~coeffi~~ constant called absorption coefficient)

$$\frac{dI}{I} = -\alpha\, dx$$

Integrating both sides

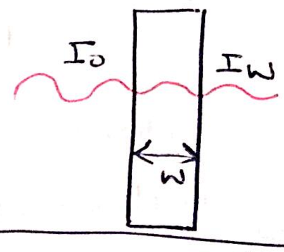
$$\int_{I_0}^{I} \frac{dI}{I} = -\alpha \int_0^x dx$$

$$\ln\left(\frac{I}{I_0}\right) = -\alpha x$$

$$\frac{I}{I_0} = e^{-\alpha x}$$

$$\boxed{I = I_0 e^{-\alpha x}} \quad -(1)$$

Let us consider W be thickness of semiconductor



$$\boxed{I_W = I_0 e^{-\alpha W}}$$

Intensity absorbed $= [-I_W + I_0] = I_0 - I_0 e^{-\alpha W} = I_0\left(1 - e^{-\alpha W}\right)$

Photon flux ϕ = No. of Photon emitted by light source per sec

$$\phi \propto I$$
$$\propto W$$
$$\propto A$$
$$\propto \frac{1}{E_g} = \frac{1}{h\nu}$$

$$\boxed{\phi = \frac{IWA}{h\nu}}$$

$$I = \frac{\phi h\nu}{WA}$$

as $I_{absorbed} = I_0(1 - e^{-\alpha W})$ — 2

$$I_{absorbed} = \frac{\phi_{absorbed}\, h\nu}{WA}$$

$$I_0 = \frac{\phi_0\, h\nu}{WA}$$

Put the value in Eq^n 2

$$\frac{\phi_{absorbed}\, h\nu}{WA} = \frac{\phi_0\, h\nu}{WA}(1 - e^{-\alpha W})$$

$\boxed{\phi_{absorbed} = \phi_0(1 - e^{-\alpha W})}$ = No. of Photons absorbed by the Semiconductor per second. — 3

Intensity of radiant energy is Power transferred per unit area of the Plane ⊥ to the direction of propagation of light

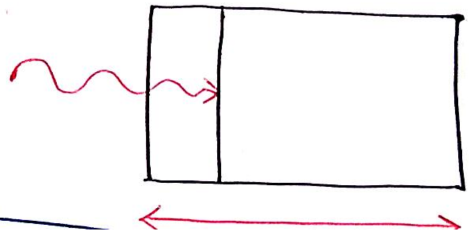
$$I = \frac{P}{WA}$$

$$\frac{\phi\, h\nu}{WA} = \frac{P}{WA}$$

$$\boxed{P = \phi\, h\nu}$$

$P_{absorbed} = \phi_{abs}\, h\nu$

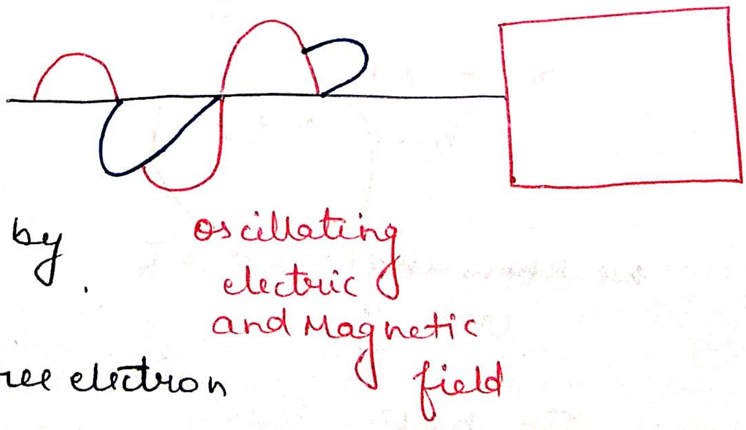
$P_{absorbed} = \phi_0\, h\nu(1 - e^{-\alpha W})$



P

Optical drude Model

This Model tells the response of any solid when it is Placed in oscillating electro Magnetic field in order words when the solid is illuminated by light source.



The equation of Motion of free electron in the presence of field

when electrons Moves under the effect of Electric and Magnetic field it will undergoes collision where τ = relaxation time between two collision

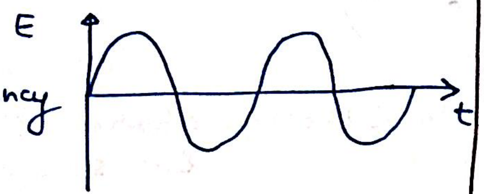
Force acting on the electron

$$F = -eE - \frac{m}{\tau}\frac{dx}{dt}$$

$$\boxed{m\frac{d^2x}{dt^2} + \frac{m}{\tau}\frac{dx}{dt} = -eE} \quad -①$$

as Electron Moving under oscillating electric and Magnetic field

$E = E_0 e^{-i\omega t}$



ω = angular frequency

t = time Period

Hence $x = x_0 e^{-i\omega t}$

$$\frac{dx}{dt} = x_0(-i\omega)e^{-i\omega t}$$

$$\boxed{\frac{dx}{dt} = -i\omega x}$$

$$\frac{d^2x}{dt^2} = (-i\omega)^2 x_0 e^{-i\omega t}$$

$$\frac{d^2x}{dt^2} = -\omega^2 x$$

Put the value in eq^n ①

$$-m\omega^2 x - \frac{i\omega x m}{\tau} = -eE$$

$$x\left(m\omega^2 + \frac{mi\omega}{\tau}\right) = eE$$

$$x = \frac{eE}{m\omega^2 + \frac{i\omega m}{\tau}}$$

$$x = \frac{eE}{m\omega\left(\omega + \frac{i}{\tau}\right)}$$

we know that $x = v\tau$

$$v = \frac{x}{\tau}$$

$$J = nev$$

$$J = ne\frac{x}{\tau} = \frac{ne}{\tau}\frac{eE}{m\omega\left(\omega + \frac{i}{\tau}\right)}$$

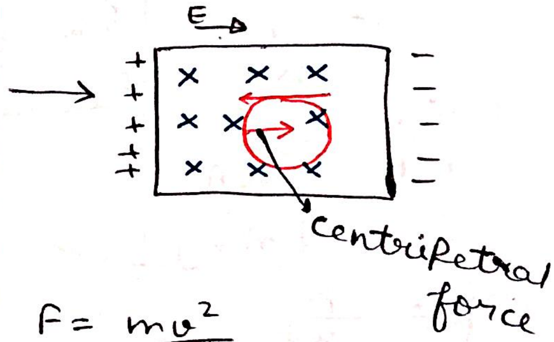
$$\frac{F_e}{q} = E$$

$$F_e = -qE$$

$$F_e = -eE$$

-ve sign shows the direction of force is opposite to the direction of electric field

when electron Moves under ⊥ electric and Magnetic field it will undergoes circular Path and centripetal force will act towards to centre



$$F = \frac{mv^2}{r}$$

$$F = \frac{mv}{r}\frac{dx}{dt}$$

$$F = \frac{m}{\tau}\frac{dx}{dt} \qquad \left[v = \frac{r}{\tau}\right]$$

$$J = \frac{I}{A} = \frac{q}{tA} = \frac{Ne}{tA}$$

$$J = \frac{nVe}{tA} \qquad \left[n = \frac{N}{V}\right]$$

$$J = \frac{nA\ell e}{tA}$$

$$\boxed{J = nev}$$

$$J = \sigma E$$

$$\sigma = \frac{J}{E} = \frac{ne^2 \cancel{E}}{\tau m v \left(\omega + \frac{i}{\tau}\right) \cancel{E}}$$

$$\sigma = \frac{ne^2}{\tau m v \left(\omega + \frac{i}{\tau}\right)}$$

$$\sigma = \frac{ne^2}{\cancel{\tau} m v \left(\frac{\omega\tau + i}{\cancel{\tau}}\right)}$$

$$\sigma = \frac{ne^2}{m v (\omega\tau + i)}$$

If $\omega >> \frac{1}{\tau}$

If angular frequency of light is much much greater than collision frequency

$$\omega\tau >> 1$$

$$\sigma = \frac{ne^2}{m v \omega\tau}$$

This is called drude formula for optical conductivity

Semiconductor laser

Principle → In a semiconductor Material when electron and hole recombine, excess of energy is released. This energy can be released either in the form of heat or in the form of light. In case of Si and Ge light is Not emitted heat will emit where as in case of GaAs, Cds energy is emitted in the form of light

Semiconductor laser is similar to LED But in led light is emitted due to spontaneous emission where as in semiconductor laser light is emitted ~~in the form~~ due to stimulated emission

When semiconductor material is illuminated by photons whose energy is equal to band gap energy of semiconductor or higher, such a photon can be absorbed by electron in the top of valence band. This excited electron then jumps to conduction band as shown in Fig. 4.14 (a). Practically the same probability exist for the photon to initiate the opposite process i.e. transfer of electron from bottom of conduction band to the valence band. When this transferred electron combines with the hole in valence band, a quantum of energy equal to difference in energy of two states is emitted. This secondary emitted photon is in phase with primary photon as shown in Fig. 4.14 (b).

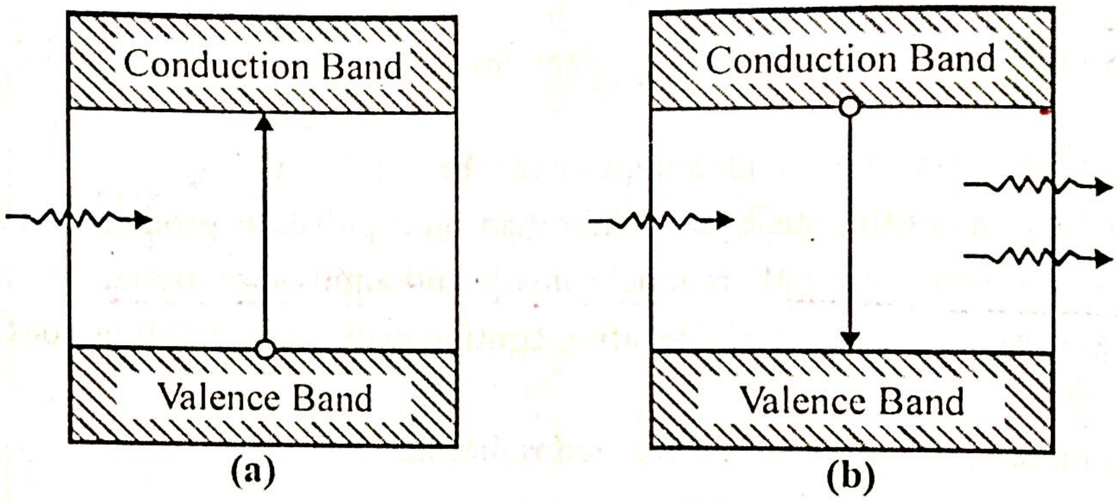


Fig. 4.14

Thermal excitation of a semiconductor moves electron from valence band to conduction band to very small extent so concentration of electron even at room temperature at bottom of conduction band is lower than that in valence band. Thus at reasonable temperature process of light absorption dominates over stimulated emission i.e. more and more electron in valence band absorbs incident photon and jumps over to conduction band. As a result of it, concentration of electrons at the bottom of conduction band becomes higher than at the top of valence band. In this state, semiconductor is said to be *inverted or degenerate semiconductor.* A semiconductor can be made degenerate in *p*-type carrier or in *n*-type carriers or in both types of carriers simultaneously.

Degenerate *n*-type and *p*-type semiconductor or laser action in extrinsic semiconductor

When a pure semiconductor is doped with impurity atoms which donates electrons is called *donor* or *n-type impurity* and those which accept electron from host material is called *acceptor* or *p-type impurity*. The energy level diagram of *n*-type and *p*-type semiconductor is as shown in Fig. 4.15 (a) and (b).

In Fig. 4.15 (a), the donor energy level is just below the bottom of conduction band at $\Delta E = 0.01$ eV. When temperature of *n*-type semiconductor is gradually increased from 0 K, the transition from donor energy level to conduction band takes whereas transition from valence band to conduction band are virtually nonexistent. Around 20 to 50 K, the donor energy level will be depleted i.e. all the donor atoms have donated their electrons in to conduction band. This makes the material as *n*-type degenerate.

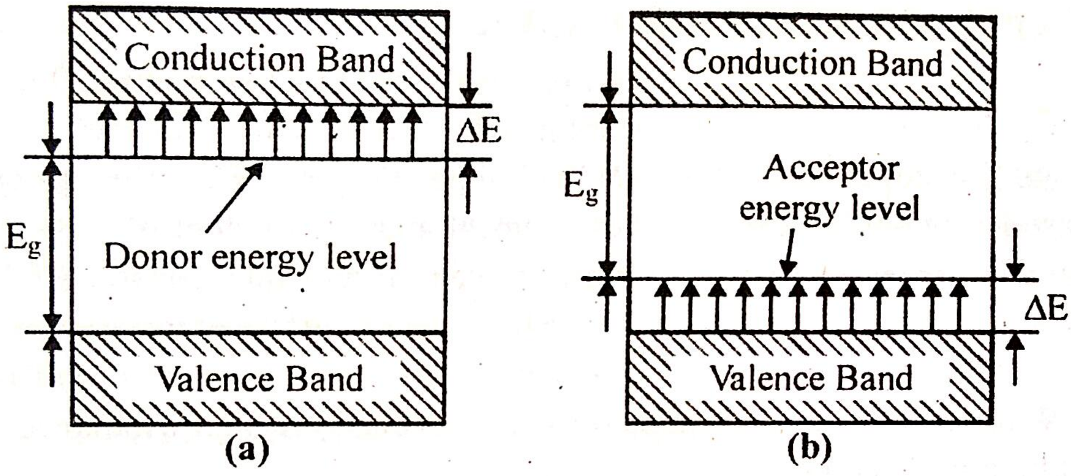


Fig. 4.15 (a) *n*-type semiconductor (b) *p*-type semiconductor

In Fig. 4.15 (b), the acceptor energy level is just above the top of valence band at $\Delta E = 0.01$ eV. When temperature is gradually increased from 0 K, the transition of electrons from valence band to acceptor energy levels takes place. Around 20 to 50 K, the acceptor energy level will be completely filled and the electrons raised to this level leaves behind holes. This makes the semiconductor *p*-type degenerate.

Laser action in PN Junction

Construction → Heavily doped P and N type semiconductor are Joined together and the PN Junction is connected to forward Biasing. Its front and back side to Polished and Parallel to each other. Front side is 90% reflecting

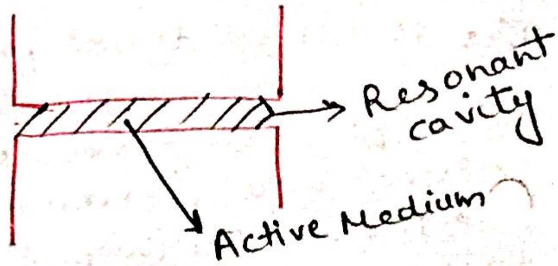
whereas back end is 100% reflecting. laser emission is through the front end. The whole system is called Resonant cavity (~~depletion layer~~). In The upper and lower faces . Metallic contacts are provided across the ends of Pn Junction for the smooth flow of current. Heavy doping is done to achieve the condition of Population inversion. Here Upper surface of N-type and lower surface of p-type act as Resonant cavity
Pn Junction used in the form of thin rectangular wafer (~~1mm x 1mm x 200 µm~~)

Working ① when pn Junction is forward biassed (called Pumping) the excess of holes in the p region and excess of holes in the n region will Moves towards the depletion layer

② Here heavy doping is done to overcome the effect of depletion layer. The size of depletion layer is around 0.1 µm

③ In the way Population inversion condition is achieved.

④ when electrons with combine will holes light will emit in the form of laser light from the depletion region (Active Medium)



Application of laser

① laser light is used in surgery

② laser light is used in isotope separation

③ laser light is used to get clear Pictures of clouds and wind Movements and hence can help in weather forecasting.

④ In Military → A large amount of energy can be concentrated in small area, so laser light is used as "death ray" type of weapon.

emiconductor *p*-type degenerate.

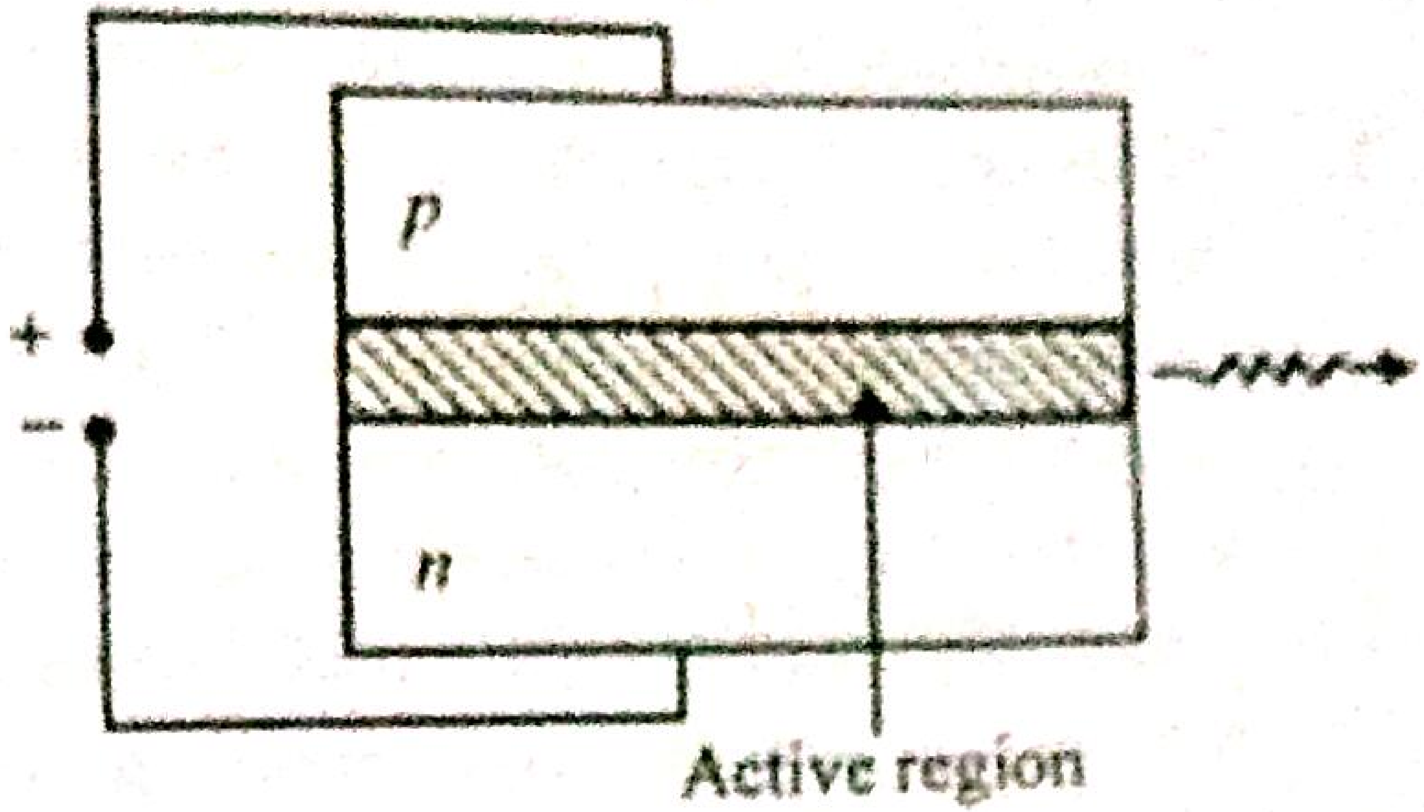


Fig. 4.16

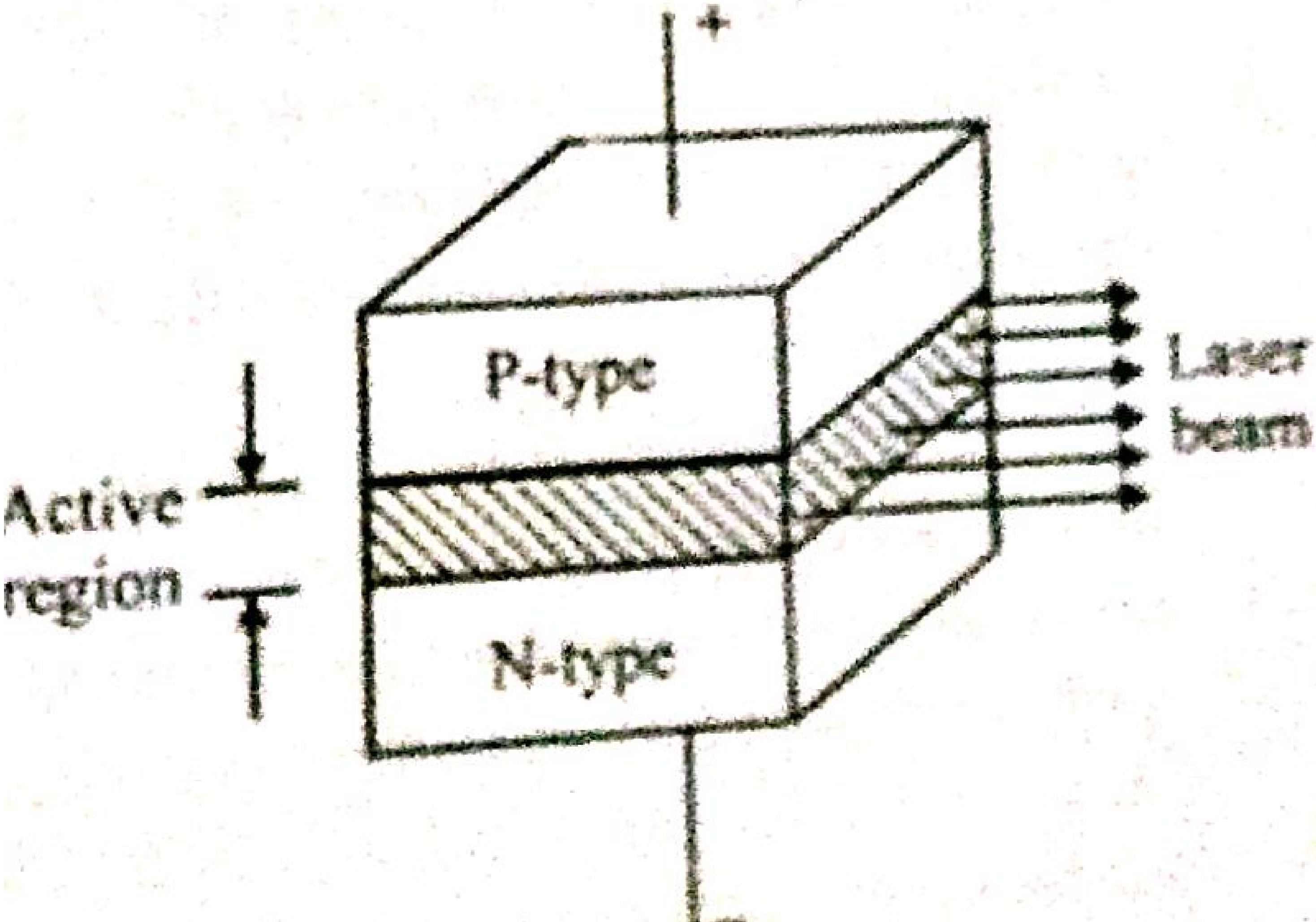


Fig. 4.17

...... This makes the semiconductor p-type degenerate.

Laser action in p-n-junction

The most common way of producing population inversion in the semiconductor is by joining a p-type and n-type material together as shown in Fig. 4.16, the resulting arrangement is known as p-n junction. When forward bias is applied to p-n junction, electrons from n-side and holes from p-side will be injected into junction area. The p-n junction will experience transition of electrons from the conduction band into valence band, the electrons and holes recombine there, and thus emits excess of energy as radiation. If material is placed within suitable optical resonator, laser action may be realised.

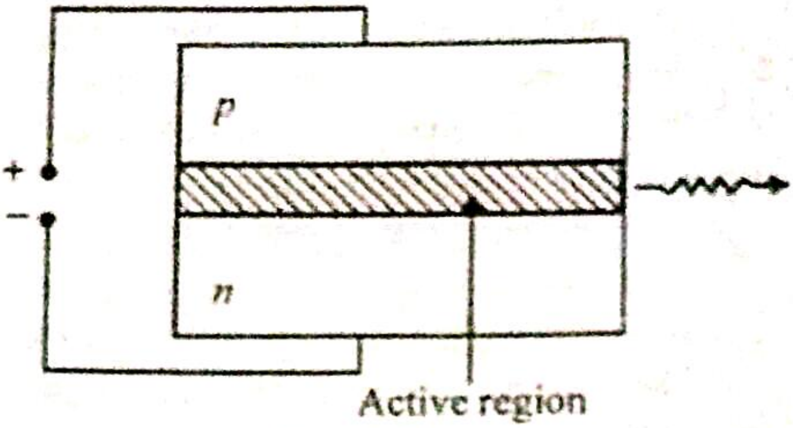


Fig. 4.16

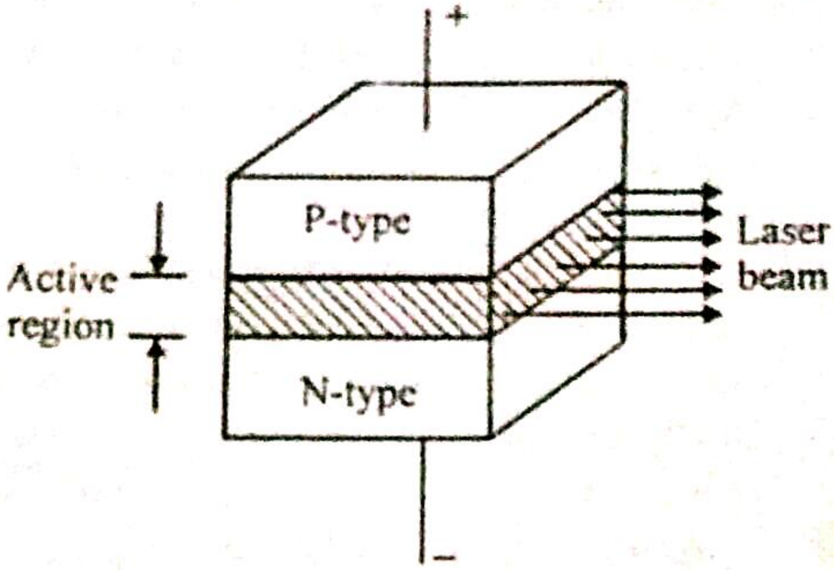
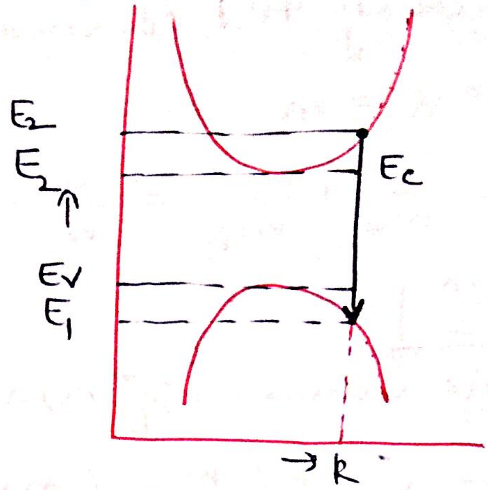


Fig. 4.17

Laser produced using p-n junction in forward biased is referred as injection laser. First semiconductor laser of this type was made in 1962 using GaAs material. The galium arsenide was made n-type by adding tellurium. While p- region was achieved by diffusing zinc. For achieving laser action, two end faces are made parallel and other two surfaces are left rough to suppress oscillation in undesired direction. The thickness of p-n-junction is 2 μm. In semiconductor diode laser no mirrors are needed for feedback because refractive index is large enough to give considerable reflection at semiconductor air interface. The laser output of GaAs oscillates at wavelength 8500Å to 9000Å near infrared region.

Energy and Momentum of e^- and hole

Let us consider the transition of electron between E_1 and E_2



Direct Band gap Semiconductor

According to the E-k diagram

$$E_1 = E_V - \frac{\hbar^2 k^2}{2m_h} \quad \text{--- (1)}$$

$$E_2 = E_c + \frac{\hbar^2 k^2}{2m_e} \quad \text{--- (2)}$$

here $k_1 = k_2 = k$ (say) Because Momentum is same

$$E_2 - E_1 = E_c + \frac{\hbar^2 k^2}{2m_e} - \left[E_V - \frac{\hbar^2 k^2}{2m_h}\right]$$

$$E_2 - E_1 = E_c - E_V + \frac{\hbar^2 k^2}{2m_e} + \frac{\hbar^2 k^2}{2m_h}$$

$$E_2 - E_1 = E_g + \frac{\hbar^2 k^2}{2}\left[\frac{1}{m_e} + \frac{1}{m_h}\right] \qquad \left[\frac{1}{m_e} + \frac{1}{m_h} = \frac{1}{m_r}\right]$$

$$E_2 - E_1 = E_g + \frac{\hbar^2 k^2}{2m_r}$$

$$h\nu = E_g + \frac{\hbar^2 k^2}{2m_r}$$

$$k = \left[\frac{2m_r(h\nu - E_g)}{\hbar^2}\right]^{\frac{1}{2}}$$

$$\boxed{k = \frac{(2m_r)^{\frac{1}{2}}}{\hbar}\sqrt{h\nu - E_g}}$$

Substitute the value of k in (1) and (2)

$$E_1 = E_V - \frac{\hbar^2 (2m_r)(h\nu - E_g)}{\hbar^2 \, 2m_h}$$

$$\boxed{E_1 = E_V - \frac{m_r}{m_h}(h\nu - E_g)} \quad \text{--- (3)}$$

$$\boxed{E_2 = E_c + \frac{m_r}{m_h}(h\nu - E_g)} \quad \text{--- (4)}$$

we know that $h\nu$ is the Energy taken by Electron to Excite

Let us verify the conservation of energy

$$m_e \cong m_h = m$$

$$\frac{1}{m_r} = \frac{1}{m_e} + \frac{1}{m_h} = \frac{1}{m} + \frac{1}{m} = \frac{2}{m}$$

$$\boxed{m_r = \frac{m}{2}}$$

Put the values in Eq^n ③ and ④ and subtract

$$E_2 - E_1 = E_c + \left[\frac{m}{2m}(h\nu - E_g)\right] - \left[E_v - \frac{m}{2m}(h\nu - E_g)\right]$$

$$E_2 - E_1 = E_c + \left[\frac{1}{2}(h\nu - E_g)\right] - \left[E_v - \frac{1}{2}(h\nu - E_g)\right]$$

$$E_2 - E_1 = E_c - E_v + \frac{1}{2}\left[h\nu - E_g + h\nu - E_g\right.$$

$$E_2 - E_1 = E_g + \frac{2h\nu}{2} - \frac{2E_g}{2}$$

$$\boxed{E_2 - E_1 = E_g - E_g + h\nu = h\nu}$$

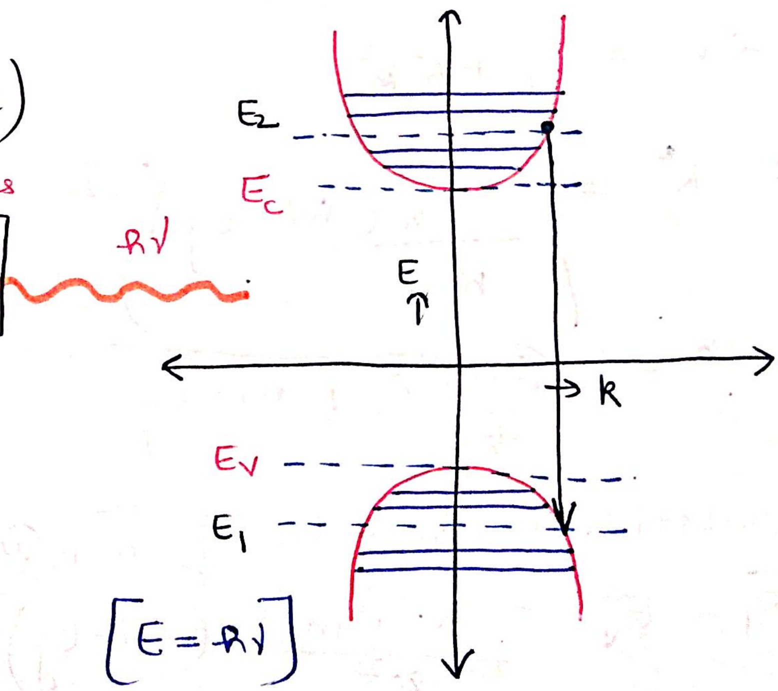
Optical Joint density of states (V. imp)

as $E_2 - E_1 = \hbar\nu$

$$E_2 = E_c + \frac{m_r}{m_e}(\hbar\nu - E_g)$$

differentiate both sides

$$\frac{dE_2}{d\nu} = \frac{dE_c}{d\nu} + \frac{d}{d\nu}\left[\frac{m_r(\hbar\nu - E_g)}{m_e}\right]$$



$$\boxed{\frac{dE_2}{d\nu} = \frac{\hbar m_r}{m_e}} \quad \text{—(5)}$$

$$f(\nu)\, d(\nu) = f(E_2)\, dE_2$$

$[E = \hbar\nu]$

$f(E_2)$ = density of states in conduction band

$$D(E) = 4\pi\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}(E - E_c)^{\frac{1}{2}}$$

$$f(E_2) = 4\pi\left(\frac{2m}{\hbar^2}\right)^{\frac{3}{2}}(E_2 - E_c)^{\frac{1}{2}}$$

$$f(\nu)\, d(\nu) = \frac{4\pi}{\hbar^3}(2m_e)^{\frac{3}{2}}(E_2 - E_c)^{\frac{1}{2}}\, dE_2$$

$$f(\nu) = \frac{4\pi}{\hbar^3}(2m_e)^{\frac{3}{2}}(E_2 - E_c)^{\frac{1}{2}}\, \hbar \frac{m_r}{m_e}$$

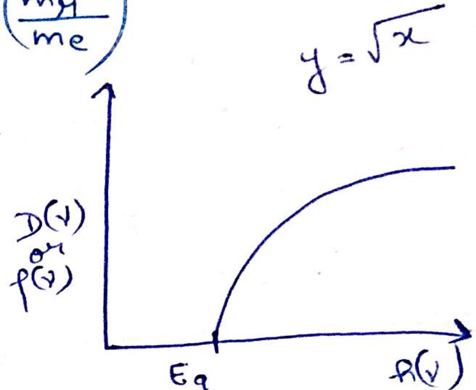
Now $E_2 - E_c = \frac{m_r}{m_e}(\hbar\nu - E_g)$

$$f(\nu) = \frac{4\pi}{\hbar^3}(2m_e)^{\frac{3}{2}}\left(\frac{m_r}{m_e}\right)^{\frac{1}{2}}\sqrt{\hbar\nu - E_g}\;\hbar\left(\frac{m_r}{m_e}\right)$$

$$f(\nu) = \frac{4\pi \times \pi}{\hbar^2\, \pi} \times (m_r)^{\frac{3}{2}}\sqrt{\hbar\nu - E_g}\,(2)^{\frac{3}{2}}$$

$$f(\nu) = \frac{4\pi^2}{\pi\hbar^2} \times (2m_r)^{\frac{3}{2}}\sqrt{\hbar\nu - E_g}$$

$$\boxed{f(\nu) = \frac{1}{\pi\hbar^2}(2m_r)^{\frac{3}{2}}\sqrt{\hbar\nu - E_g}}$$



Significance of optical Joint density of states → It tells us the amount of absorption and Emission.

$$f(\nu) \propto \sqrt{\hbar\nu - E_g}$$

If $\hbar\nu$ is More, $f(\nu)$ will be More, More absorption will takes Place and hence More emission as well.

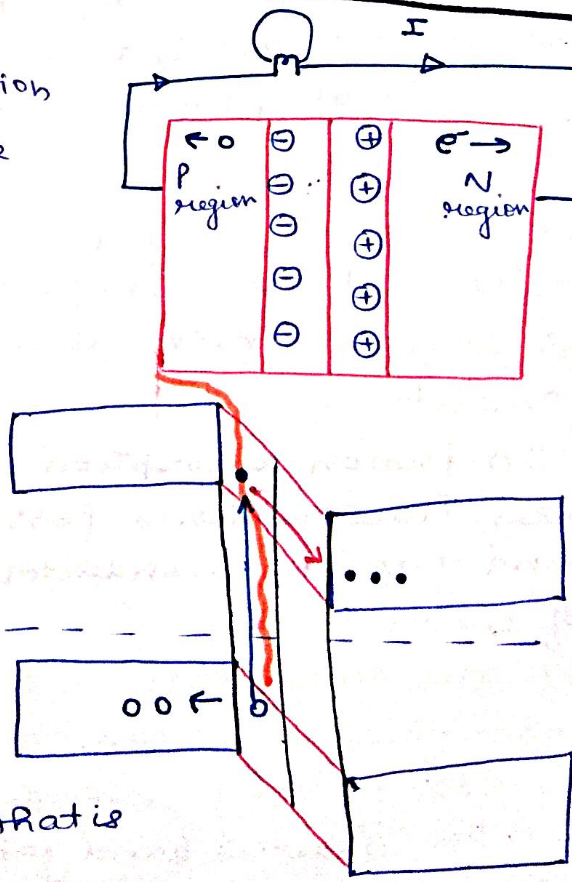
V. Imp

Photo voltaic Effect

Photo voltaic effect is the generation of voltage which results in the flow of electric current

⇒ when light falls on the depletion layer due to heating effect of light covalent Bond inside the depletion layer will break and electron gets the energy and got excited to the conduction band of depletion layer

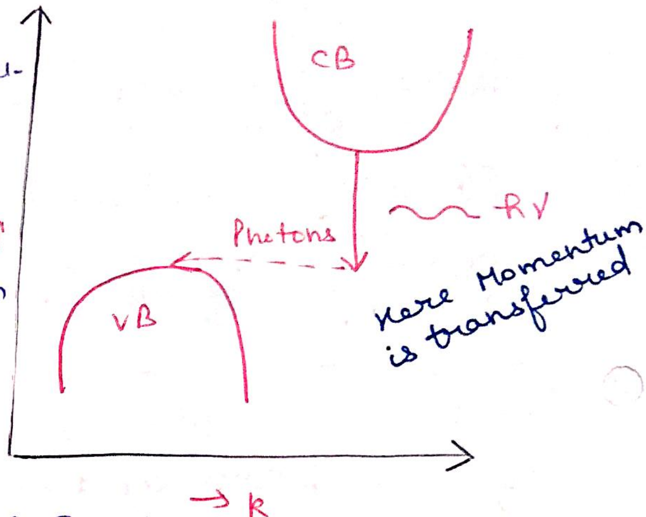
⇒ Due to the Electric field inside the depletion layer electron will go from higher Potential to lower that is towards +ve charge



⇒ where as holes leave behind in the VB of depletion layer will Moves towards higher Potential that is −ve
⇒ Hence Resuets in the flow of current. This is called Photo voltaic effect.

Q- why Photon Emission is Not likely to take Place in indirect band gap semiconductor

Ans In Indirect band gap semiconductor the transistion from the bottom of the Conduction Band to the Top of the Valence Band requires an exchange of Momentum where as in Photon Emission it involves only change of Energy but Not change of Momentum

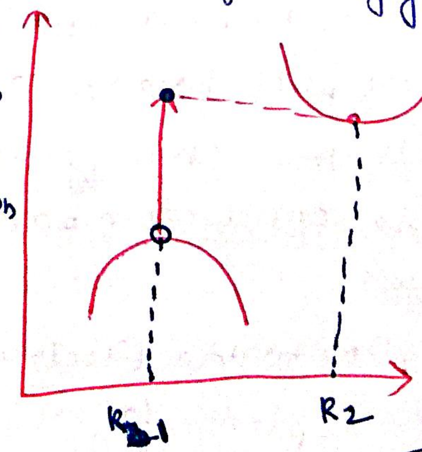


⇒ The change of Momentum can be completed by including Phonon also. Phonon are large Momentum but lower energy and hence represented horizontally in the E-k diagram in this kind of Transistion k-selection rule got violeted which says that $(k_1 \cong k_2)$ (Energy is conserved) (Momentum is conserved)
⇒ Si is also an indirect Band gap Semiconductor. Hence it will Not Produce laser

Q- why Photon absorption Not unlikely to take Place in Indirect Band gap semiconductor

Ans ① Just like Photo emission. Photon absorption is also the Process which involves the conservation of energy and Momentum

② In Photon absorption vertical transistion takes Place which is Possible in direct Band gap semiconductor by the absorption of Photon



(k selection rule states that transistion between two levels can only be Possible when energy and Momentum is conserved)

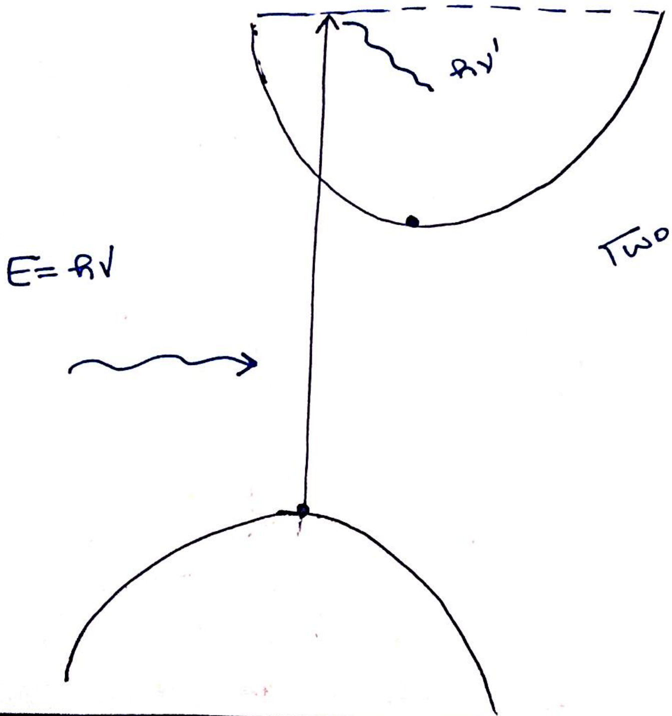
③ In Indirect band gap semiconductor electron electron first excited to higher level showing verticle transistion hence Momentum is conserved

$\boxed{\Delta k = k_2 - k_1}$

After the conservation of Momentum Electron then show thermalization at the conduction band and then its Momentum is trans ferred to the Photon

Phonon → quanta of lattice vibration

Here in this Process two bodies are require (Electron and Phonon)



Two step Process

$$\boxed{h\nu = h\nu' + h\nu''}$$