

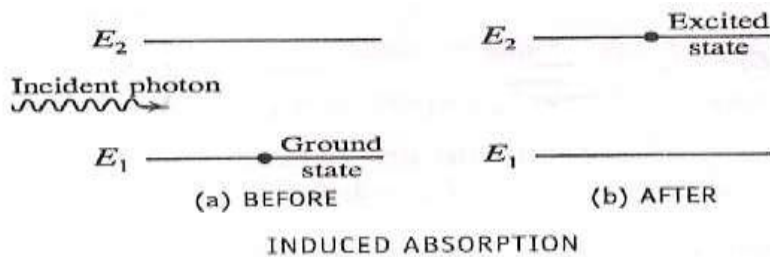
LASERS

LASER is the short form of **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A laser is a highly parallel coherent beam of light of very high intensity. Laser action is achieved by creating population inversion which can be achieved by different means, such as optical pumping, electrical discharge and solar energy. Laser light has four main properties: monochromaticity, coherence, directionality, and high intensity.

Radiation interacts with matter under suitable conditions. The interaction leads to a transition of the quantum system such as an atom or a molecule from one energy state to another. If the transition is from a higher state to a lower one, the system gives out a part of its energy and if the transition is to a higher state from a lower one, then it absorbs the incident energy.

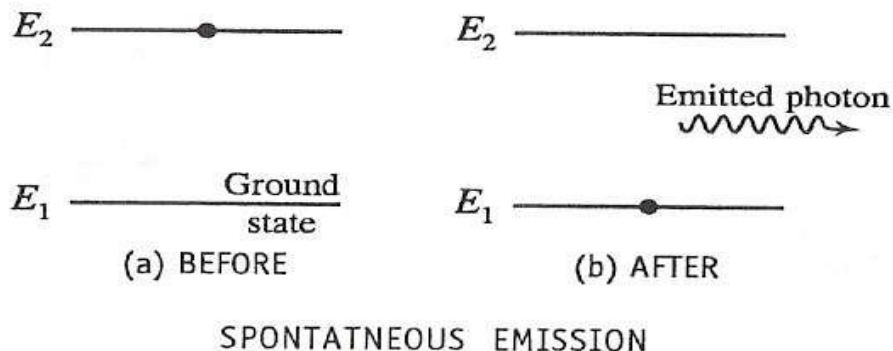
There are three possible ways through which interaction of radiation and matter can take place. Absorption of radiation is known as induced absorption. The emission of radiation can occur in two ways namely the spontaneous emission, and the stimulated emission.

(1) Induced absorption:-



Induced absorption is the absorption of an incident photon by a system as a result of which the system is elevated from a lower energy state to a higher state, wherein the difference in energy of two states is precisely the energy of the photon.

(2) Spontaneous emission:-

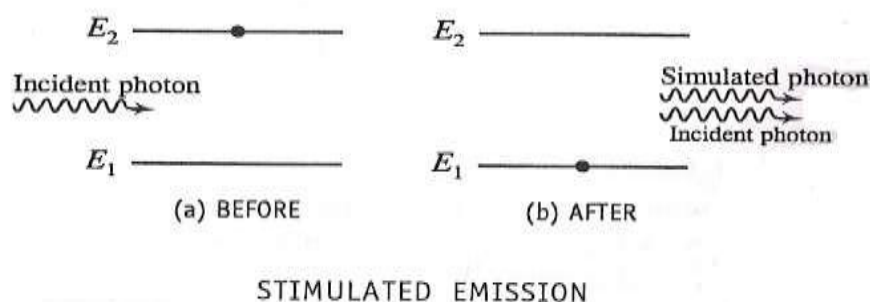


Spontaneous emission is the emission of a photon, when a system transits from a higher energy state to a lower energy state without the aid of any external agency.

When an electron is excited it will go to the higher energy level E_2 . Then the atom is said to be in the excited state. But the electron will not remain in the excited level for a period more than 10^{-8} seconds. Immediately it will come back to the ground state by the emission of the energy what it has absorbed during the excitation process. The emitted energy is in the form of electromagnetic radiation whose frequency is given by

$$E_2 - E_1 = h \gamma$$

(3) Stimulated emission:-



Stimulated emission is the emission of a photon by a system, under the influence of a passing photon of just the right energy, due to which the system transits from a higher energy state to a lower energy state. The photon thus emitted is called the stimulated photon and will have same phase, energy and direction of movement as that of the passing photon called the stimulated photon.

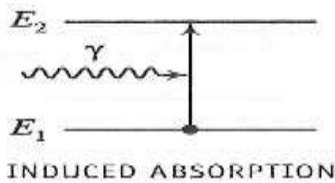
When the electron in the excited level is supplied with an external photon having the same energy as $E_2 - E_1$, then the excited electron is stimulated to come back to the ground level even before 10^{-8} seconds. This is called stimulated emission. During this process, the external photon comes out with the photon produced by the electron transition, both with same phase. That is these two photons are coherent and intensity is more. Thus the supplied light is amplified. This is the basic principle followed in the production of laser ray.

Expression for Energy density in terms Einstein's coefficients A and B

Einstein's co-efficient give the probability associated with the absorption and emission processes.

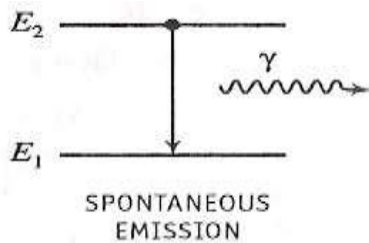
Consider two energy states E_1 and E_2 of a system of atoms. Let N_1 (number density of atoms in the states 1) be number of atoms with energy E_1 , and N_2 (number density of atoms in the states 2) be number of atoms with energy E_2 per unit volume of the system. Let $U_\gamma d\gamma$ be the energy incident / unit volume of the system considering only those radiations whose frequencies lie in the range γ & $\gamma + d\gamma$. Then, U_γ represents the energy density of frequency γ .

(i) Case of Induced Absorption:-



$\therefore$ Rate of absorption $\propto N_1 U_\gamma = B_{12} N_1 U_\gamma$. Where B_{12} is the constant of proportionality called Einstein's co-efficient of induced absorption.

(ii) Case of spontaneous emission:-

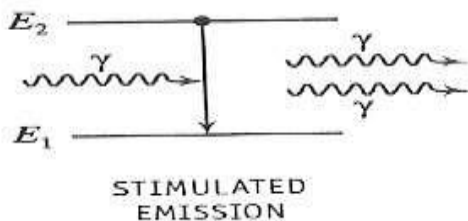


In the case of spontaneous emission, an atom in the higher energy level E_2 undergoes transition to the lower energy level E_1 , voluntarily by emitting a photon. The rate of spontaneous emission (number of spontaneous emissions per unit time, per unit volume) is proportional to only the number density in the higher energy state, i.e., N_2

$\therefore$ Rate of spontaneous emission $= A_{21} N_2$,

Where A_{21} is the constant of proportionality called Einstein's co-efficient of spontaneous emission.

(iii) Case of stimulated emission:-



Since the system requires an external photon of appropriate frequency $\gamma = (E_2 - E_1)/h$, to stimulate the atom for the corresponding downward transition. The rate of stimulated emission (number of stimulated emission per unit time per unit volume), is proportional to (a) the number density N_2 , (b) the energy density U_γ .

$\therefore$ Rate of stimulated emission $= B_{21} N_2 U_\gamma$.

Where B_{21} is the constant of proportionality called the Einstein's co-efficient of stimulated emission.

At thermal equilibrium,

Rate of absorption = Rate of spontaneous emission + Rate of stimulated emission.

$$\therefore B_{12} N_1 U_\gamma = A_{21} N_2 + B_{21} N_2 U_\gamma$$

$$U_\gamma (B_{12} N_1 - B_{21} N_2) = A_{21} N_2$$

$$\therefore U_\gamma = \frac{A_{21} N_2}{B_{12} N_1 - B_{21} N_2} \longrightarrow (1)$$

By rearranging the equation.

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} \frac{N_1}{N_2} - 1} \right] \longrightarrow (2)$$

By Boltzmann's factor we have,

$$\frac{N_2}{N_1} = e^{-\left(\frac{E_2 - E_1}{kT}\right)} = e^{-\frac{h\gamma}{kT}} \quad \therefore \quad \frac{N_1}{N_2} = e^{\frac{h\gamma}{kT}}$$

Therefore equation 2 becomes.

$$U_\gamma = \frac{A_{21}}{B_{21}} \left[\frac{1}{\frac{B_{12}}{B_{21}} e^{\frac{h\gamma}{kT}} - 1} \right] \longrightarrow (3)$$

According to Planck's law, the equation for U_γ is

$$U_\gamma = \frac{8\pi h \gamma^3}{C^3} \left[\frac{1}{e^{\frac{h\gamma}{kT}} - 1} \right] \longrightarrow (4)$$

Compare equation (3) and (4). We have

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \gamma^3}{C^3} \quad \& \quad \frac{B_{12}}{B_{21}} = 1 \quad \text{or} \quad B_{12} = B_{21}$$

The probability of induced absorption is equal to probability of stimulated emission, i.e., $B_{12} = B_{21}$,

A_{21} and B_{21} can be represented as A and B and equation (3) can be rewritten.

$\therefore$ At thermal equilibrium the equation for energy density is

$$U_\gamma = \frac{A}{B} \left[\frac{1}{e^{\frac{h\gamma}{kT}} - 1} \right]$$

Condition for LASER action:-

Population Inversion & Metastable state:-

Let N_1 be the number of atoms in the ground state E_1 . Let N_2 be the number of atoms in the excited state E_2 . Under normal conditions the number of atoms in the ground state is always greater than the number of atoms in the excited state.

E_2 ————— **Excited state** N

E_1 ————— **Ground state** N

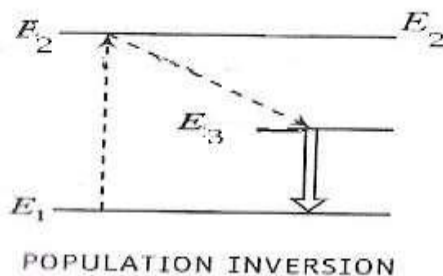
The ratio between these two numbers is given by.

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

Since $E_2 > E_1$, then $e^{-\frac{(E_2 - E_1)}{kT}} < 1$ i.e., $N_2 < N_1$ under ordinary condition or at thermal equilibrium.

If by some means the number in the excited state is more than in the ground state. i.e., $N_2 > N_1$ then it is said that population inversion has taken place. This is one of the main criteria for the production of laser ray.

Population inversion is usually achieved when there is an intermediate energy level called metastable state exists, where the electrons will remain for a longer time for about 10^{-3} sec to 10^{-2} sec. This property helps in achieving the population inversion in the following way.



Consider three energy levels E_1 , E_2 & E_3 of a quantum system which are such that $E_2 > E_3 > E_1$. Let E_3 be a metastable state of the system. Let the atoms be excited from E_1 to E_2 state by supply of appropriate energy from an external source.

Since E_3 is a metastable state, those atoms which get into that state stay over a very long duration, because of which the population of E_3 state increases steadily. Under these conditions a stage will be reached wherein the population of E_3 state overtakes that of E_1 , which is known as population inversion.

Once the population of E_3 exceeds that of E_1 , the stimulated emission outnumber the spontaneous emissions, and soon stimulated photons, all identical in respect of phase, wavelength & direction, grow to a very large number which buildup the laser light. Hence the condition for laser action is achieved by means of population inversion.

-: Requisites of a Laser system:-

The three requisites of a laser system are

- (1) An excitation source for pumping action,
- (2) An active medium which supports population inversion, and
- (3) Laser cavity.

The excitation source provides the appropriate amount of energy for pumping the atoms to higher energy levels. Optical pumping is used in Ruby Laser and electrical pumping is employed in He-Ne laser.

A part of the input energy is absorbed by the active medium in which population inversion occurs at a certain stage. After this stage the medium attains capability to issue laser light. The laser cavity provides the feed back necessary to tap certain permissible part of laser energy from the active medium.

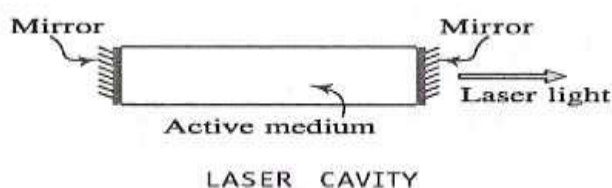
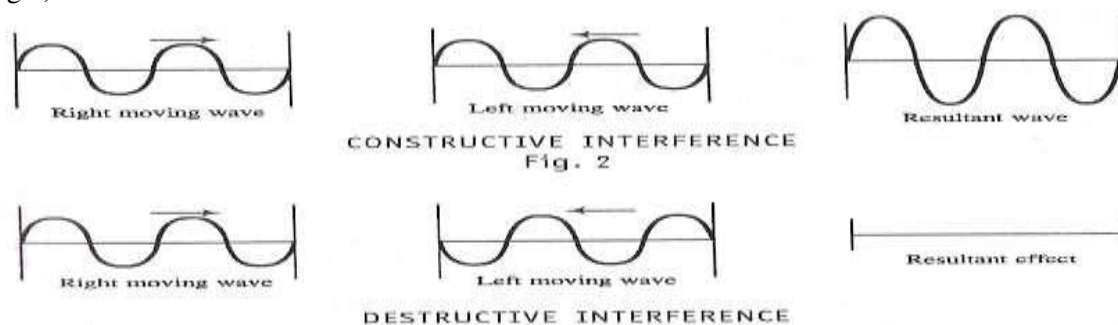
-:LASER CAVITY:-

Fig 1

A Laser device consists of an active medium bound between two mirrors (Fig.1). The mirrors reflect the photons to & fro through the active medium form a cavity inside which two types of waves exist; one type comprises of waves moving to the right, and the other one to the left (Fig. 2 & 3).

The two waves interfere constructively if there is no phase difference between the two (Fig. 2). But, their interference becomes destructive if the phase difference is $\pi/2$. (Fig.3).



In order to arrange for constructive interference, the distance 'L' between the two mirrors should be such that the cavity should support an integral number of half wavelengths.

i.e. $L = m (\lambda / 2)$, where m is an integer > 0 , and λ is the wavelength of the laser light inside the material of the active medium.

In such case, a standing wave pattern is established within the cavity and the cavity is said to be resonant at wavelengths, $\lambda = 2 L / m$.

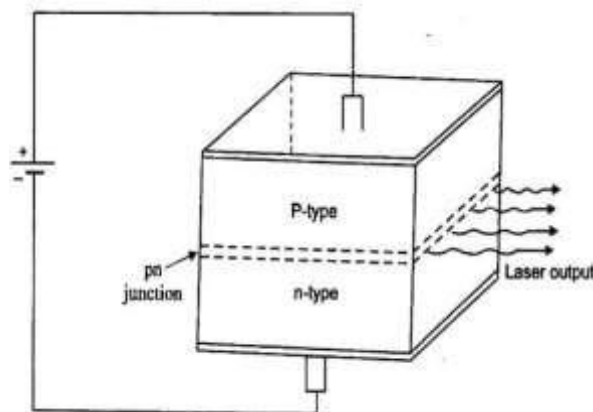
Semiconductor Laser

Principle

A semiconductor laser works by using a forward-biased p-n junction to cause electrons and holes to recombine and emit photons. This process, called stimulated emission, is amplified as photons bounce between mirrors, creating a high-intensity, coherent laser beam. Electrical energy is used to pump the junction, injecting carriers until a population inversion is achieved, where more electrons are in an excited state than in the ground state.

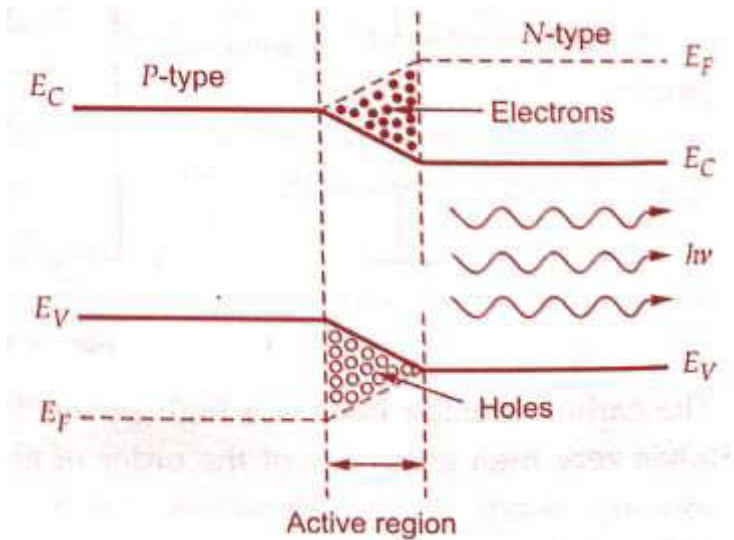
Construction

- Gallium Arsenide laser is a semiconductor laser. The Gallium Arsenide laser diode is a single crystal of GaAs,
- The consists of heavily doped n and p section, n-section is formed by doping with tellurium whereas the p-section, is obtained by doping with zinc. The doping concentration is very high and is of the order of 10^{17} to 10^{19} dopant atoms/cm³.
- The overall size of the diode is very small and each of its sides is of the order of 1 mm. The p-n junction layer has a width varying from $1\mu\text{m}$ to $100\mu\text{m}$ depending upon the diffusion and temperature conditions that exist at the time of fabrication.
- A pair of parallel planes of the crystal are cleaved or polished at right angles to the p-n layer. These planes play the role of reflecting mirrors. These planes provide sufficient reflection to sustain the lasing action through feedback.



Semiconductor laser

Working



Energy level diagram of semiconductor laser

- When a suitable forward bias voltage is applied initially the concentration of electrons in the energy levels at the bottom of the conduction band will still be lesser than that in the energy levels at the top of the valence band, and the recombinations result in only spontaneous emissions.
- But, as the current is increased, a threshold for lasing will be attained beyond which the population gets inverted and an active region is formulated in the junction. The active region will be very thin, and is of the order of $1\ \mu\text{m}$.
- At this stage, a **photon released by a spontaneous emission may trigger stimulated emissions** over a large number of recombinations leading to the buildup of laser radiation of high power. Thus the current flow in essence provides pumping in a semiconductor. **Energy gap of GaAs is 1.4 eV and wavelength is $8400\text{\AA}$.**

Application

- Semiconductor lasers are the smallest and least expensive of all the lasers available. The semiconductor lasers find important use in **optical communications**.

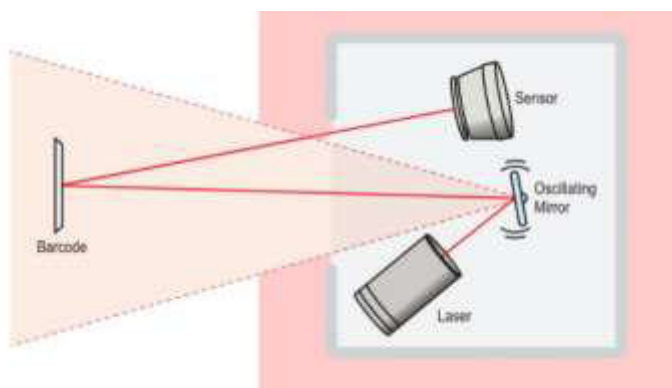
Applications of Lasers

Barcode reader

A laser barcode scanner uses optics, electronics, and mechanics to read barcodes. A laser barcode scanner's main components are a laser diode, prism, photodiode, analog-to-digital converter and decoder.

Laser Diode and Lens

The laser diode in a barcode scanner emits a beam of light, generally in the red spectrum, with a wavelength of around 650 nanometres. This beam passes through a lens that adjusts its width and focus to form a scanning line which moves across the barcode to illuminate the bars and spaces. The scanner's lens ensures that the light reflects back at the right angle so that the receiving photodiode can capture the reflected signal. The laser diode of a typical barcode scanner emits a beam with a power output ranging between 0.5 to 1 milliwatt (mW).



Barcode reader

Rotating Mirror or Prism

After passing through the lens, the laser beam strikes a rotating mirror or a prism. These are made of borosilicate or fused silica and may also have optical coatings to improve reflectivity and wear. Industrial laser barcode scanners have gold or aluminium coatings. The rotating mirror or prism directs the beam across the barcode in a sweeping motion.

The rapid movement of the beam ensures the barcode is scanned multiple times in different positions, improving the chance of a successful read even if the barcode is damaged, poorly printed, or the ambient light is low. Some laser barcode scanners have diodes for lighting up the barcode.

Photodiode

As the laser sweeps across the barcode, it hits the black bars and white spaces differently. The black bars absorb most light, while the white spaces reflect it to the scanner. Before reaching the photodiode, the reflected light passes through optical filters to block most ambient light, ensuring only the barcode's reflection is measured. The photodiode is usually made from silicon, which is sensitive to the laser's wavelength. It converts the reflected light into electrical signals, with the strength of these signals changing based on the barcode's dark and light areas.

The scanner uses a system of beam-splitting optics or polarising filters to prevent interference between the emitted laser and the reflected light. Once the analogue signal is generated, it must be converted into digital form for processing. This conversion is performed by the analogue-to-digital (A/D) converter

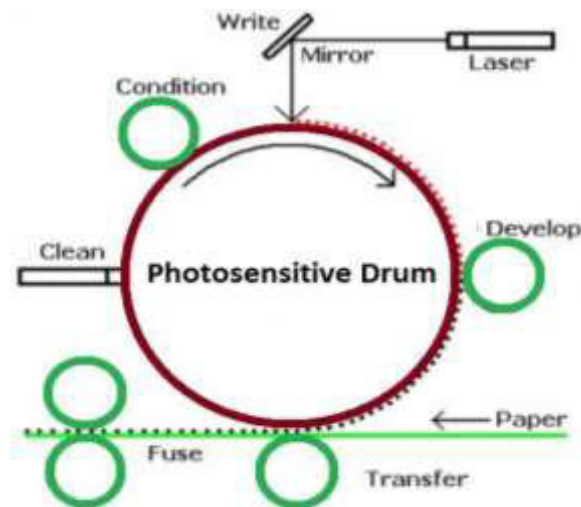
Laser printers

Laser printer acts as photocopier machine that uses laser light and toner to print a document. In laser printer, selenium coated drum uses that allows to print document with using of electrical charges.

This printer provides print with the combination of **electrical charges** and toner, and after completing the printing the extra toner and electrical charges are discard from page.

Principle

Laser printer fires the beams your print on the metal cylinder, it has name the 'Drum'. With the help of static electricity, drum gets to attract with powdered toner from its cartridge. The drum gets to spin the toner on the paper as a format of your sending print commands. Then, toner gets to start melt on the paper by heat from fuser that passed underneath. Finally, laser printer gets out your printout



Block diagram of Laser Printer

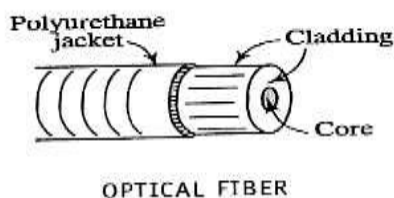
Printing includes following steps

- **Image Processing**: When you fire the print instruction on the specific document or picture, then computer system immediately transfers the all data to internal memory of laser printer. In this memory, output data saved and gets to prepare for processing phases.
- **Charging**: Here, laser printer gets to start warm up, and corona wire is getting to heat up and gets to ready mode for sending its all positive static charge to metal cylinder drum.
- **Writing**: At the same time, laser diode fires a laser to spin mirror that move to draw the image on to drum. Entire image of what you asked for it to print will appear on the drum as it turns.
- **Conditioning**: Electrostatic negative charge get supply on the surface of the drum, and it helps to discard the last latent image from the photosensitive drum, and then gets to condition the drum for fresh latent image.
- **Exposing**: While rotating of drum, it grabs the positive charge throughout on its entire surface. Few laser printers have all in one color models, it means having four drums which catered to every color like as Cyan, Magenta, Yellow & Black. Now, laser printer get activate, and beam reflects off rolling mirror unit that helps to direct beam on the drum unit.

- **Developing**: Toner cartridge gets to release positively charged carbon toner powered particles across the surface of drum when it gets to turn. When toner is attracted with any other areas of negative charge, then it leaves the positively charged areas of drum without touching it.
- **Transferring**: Transfer belt gets to roll the paper with helping of printer, and it is providing the positive charge. Then, tone that negatively charged that attracted with page as a format of your print.
- **Fusing**: Hot roller gets to melt of toner on the surface of paper, it is known as fuser unit. Now you result is ready as a printout.
- **Cleaning and Recharging**: During the cleaning process, remnants of toner on the drum scraped away by electrically neutral soft plastic blade into waste reservoir. Then, newly fresh cleaned drum obtains the new negative charge on it surface from charge roller, and gets to prepare the photosensitive drum for the new print job.

Optical Fibers

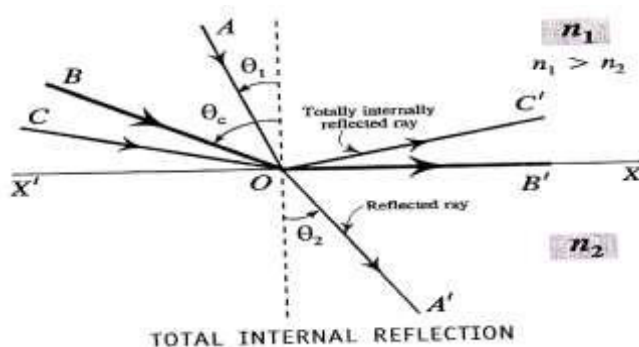
Structure:-



Optical fibers are very thin glass fibers, which consists of the inner core and the outer cladding as shown in figure. The refractive index of the two parts must be such that $n_1 > n_2$ so that light travels through the core only. Both the core and the cladding are made up of glass which contains, 80 – 95% of silicon dioxide (SiO_2) and few other dopants such as P_2O_5 , P_2O_3 , fluorine etc.

Principle of working of Optical fibers: Total Internal Reflection

Light propagates in optical fibers according to the principle of total internal reflection. When light travels from a denser to a rarer medium, it bends away from the normal. Let a ray AO be incident at O at the interface of the two media with refractive indices n_1 and n_2 making an angle of incidence θ_1 . It gets refracted along OA' making an angle of refraction θ_2 . Let OB be an incident ray which makes an angle of incidence θ_c . It gets refracted along OB' which makes an angle of refraction 90° with respect to the normal drawn at the point of incidence. The ray grazes along the interface of two media. Let OC be an incident ray which makes an angle of incidence greater than θ_c , then the light is completely reflected to the same medium along OC' . The entire incident energy is returned along the reflected light. Hence it is called Total Internal Reflection.



From Snell's law we have, $n_1 \sin \theta_1 = n_2 \sin \theta_r$

For the ray AOA'

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \text{ is obeyed.}$$

For the ray BOB¹

$\theta_i = \theta_c$ (critical angle) $\theta_r = 90^\circ$,

$$n_1 \sin \theta_c = n_2 \sin 90^\circ$$

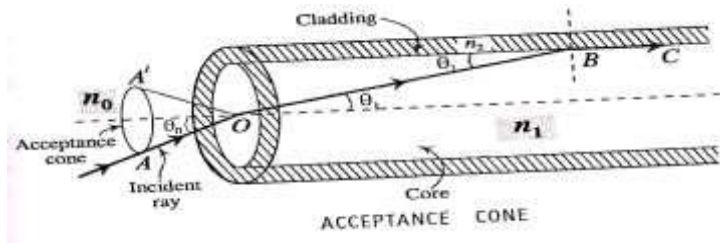
$$\sin \theta_c = n_2/n_1$$

$$\Rightarrow \theta_c = \sin^{-1} (n_2/n_1)$$

Condition for Total Internal reflection:

1. The ray must travel from denser to rarer medium.
2. Angle of incidence must be greater than critical angle, $\theta_i > \theta_c$

Numerical aperture and Ray propagation in the fiber:



Consider a light ray AO entering the fiber core with an angle θ_0 to the fiber axis. It gets refracted along OB at an angle θ_1 in the core and further proceeds to fall at critical angle of incidence (equal to $90 - \theta_1$) at B on the interface between core and cladding. Since it is a critical angle of incidence, the ray is refracted at 90° to normal i.e., it grazes along BC.

Now it is clear from the figure that any ray that enters into the core at an angle of incidence less than θ_0 will have refractive angle less than θ_1 because of which its angle of incidence ($90 - \theta_1$) at the interface will become greater than the critical angle of incidence, and thus undergoes total internal reflection. If the incident ray is greater than θ_0 at O, the angle of incidence at B is less than the critical angle, because of which it will be refracted into the cladding region and thus will be lost.

Now if OA is rotated around the fiber axis keeping θ_0 fixed, then it describes a conical surface. Only those rays, which are funneled into the fiber within this cone, will only be totally reflected and thus confined within the fiber for propagation. The rest of the incident light rays emerge from the sides of the fiber.

The angle θ_0 is called the waveguide acceptance angle or the acceptance cone half angle, and $\sin \theta_0$ is called the numerical aperture (NA) of the fiber. The numerical aperture represents the light gathering capability of the optical fiber.

Let n_0 , n_1 and n_2 be refractive indices of surrounding medium, core of the fiber and cladding respectively.

Now for refraction at point 'O', using Snell's law

$$\begin{aligned} n_0 \sin \theta_0 &= n_1 \sin \theta_1 \\ \sin \theta_0 &= (n_1 / n_0) \sin \theta_1 \\ \text{Then } \sin \theta_0 &= (n_1 \sin \theta_1) / n_0 \longrightarrow (1) \end{aligned}$$

At the point 'B' on the interface, angle of incidence = $90^\circ - \theta_1$.

Applying Snell's law

$$\begin{aligned} n_1 \sin (90^\circ - \theta_1) &= n_2 \sin 90^\circ \\ n_1 \cos \theta_1 &= n_2 \\ \cos \theta_1 &= n_2 / n_1 \longrightarrow (2) \end{aligned}$$

$$\begin{aligned} \text{From eqn (1)} \quad \sin \theta_0 &= \frac{n_1}{n_0} \sin \theta_1 \\ &= \frac{n_1}{n_0} \sqrt{1 - \cos^2 \theta_1} \end{aligned}$$

$$\sin \theta_0 = \frac{n_1}{n_0} \sqrt{1 - \frac{n_2^2}{n_1^2}}$$

$$\text{Therefore } \sin \theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

If the medium surrounding the fiber is air, then $n_0=1$,

$$\sin \theta_0 = \sqrt{n_1^2 - n_2^2}$$

$$\mathbf{N.A = \sin \theta_0 = \sqrt{n_1^2 - n_2^2}}$$

Condition for ray propagation

If θ_i is the angle of incidence of an incident ray, then the ray will be able to propagate,

$$\text{If } \theta_i < \theta_0 \text{ or if, } \sin \theta_i < \sin \theta_0 \text{ or } \sin \theta_i < \sqrt{n_1^2 - n_2^2}$$

This is the condition for propagation, i.e., $\sin \theta_i < \text{N.A.}$

Numerical Aperture: It is the light gathering capacity of the optical fiber. It is given by

$$\text{Numerical aperture} = \text{NA} = \sin \theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

Angle of acceptance: The angle of incidence θ_0 of light on the core for which the angle of incidence on the core-cladding interface will be critical angle is known as **angle of acceptance**.

It is also known as waveguide acceptance angle.

Fractional index change (Δ):

The fractional index change Δ is the ratio of the refractive index difference between the core and cladding to the refractive index of core of an optical fiber.

$$\therefore \Delta = (n_1 - n_2) / n_1$$

Relation between Δ and NA

$$\Delta = (n_1 - n_2) / n_1$$

$$\therefore n_1 - n_2 = n_1 \Delta$$

$$N.A. = \sqrt{n_1^2 - n_2^2}, \quad N.A. = \sqrt{(n_1 + n_2)(n_1 - n_2)} = \sqrt{(n_1 + n_2)n_1 \Delta}$$

Since $n_1 \cong n_2$, $n_1 + n_2 = 2 n_1$

$$\therefore N.A. = \sqrt{2 n_1^2 \Delta}$$

$$N.A. = n_1 \sqrt{2 \Delta}$$

Increase in the value of Δ increases numerical aperture, and thus enhances the light gathering capacity of the fiber.

V – number :

The number of modes supported for propagation in the fiber is determined by a parameter called V – number. If the surrounding medium is air then the V – number is given by

$$V = \frac{\pi d}{\lambda} \sqrt{n_1^2 - n_2^2} = \frac{\pi d}{\lambda} (N.A.)$$

Where, d is the diameter of the core, n_1 is the refractive index of the core, n_2 is the refractive index of the cladding. λ is the wavelength of light propagating in the fiber.

If the fiber is surrounded by a medium of refractive index n_0 , then the expression is,

$$V = \frac{\pi d}{\lambda} \frac{\sqrt{n_1^2 - n_2^2}}{n_0},$$

For $V \gg 1$, the number of modes supported by the fiber is given by,

$$\text{Number of modes} \approx V^2 / 2$$

Types of Optical fibers:

The application of Maxwell's equation shows that, out of the light that enters into the core within the waveguide acceptance angle, only that light waves in terms of certain number of modes will be sustained, for propagation in the fiber. The modes are represented as though they are light rays in the figures. Thus single ray propagation is shown in single mode fiber and so on.

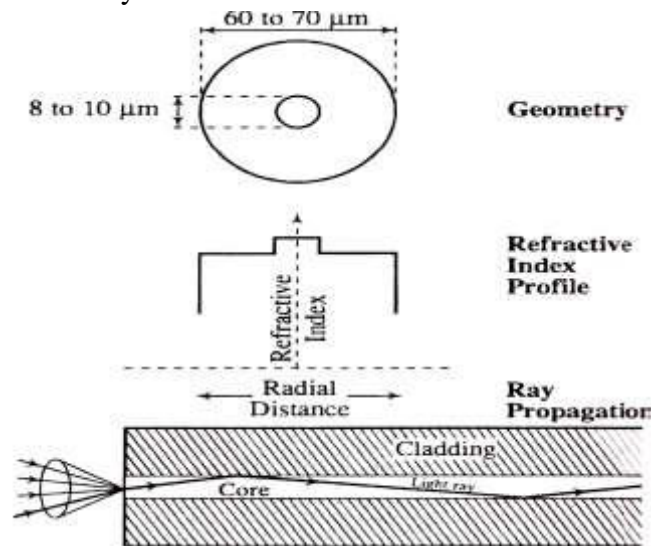
In any optical fiber, the whole cladding material has a uniform refractive index value. But for core material refractive index may either remain constant or subjected to variation in a particular way. The curve which represents the variation of refractive index with respect to the radial distance from the axis of the fiber is called the refractive index profile.

The optical fibers are classified under three categories. This classification is done depending on the refractive index profile and the number of modes that the fiber can guide.

- (a) Single mode fiber
- (b) Step index multimode fiber, and
- (c) Graded index multimode fiber.

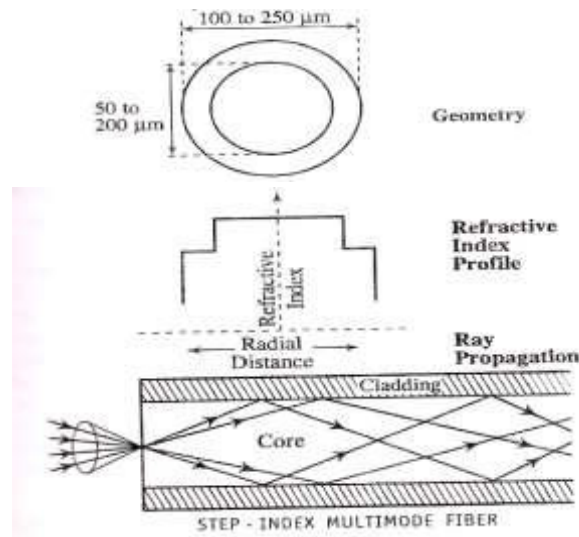
(a) Single mode fiber :

A single mode fiber has a core material of uniform refractive index value. Similarly cladding also has a material of uniform refractive index but of lesser value. This results in a sudden increase in the value of refractive index from cladding to core. Thus its refractive index profile takes the shape of a step. The diameter value of the core is about 8 to 10 μm and external diameter of cladding is 60 to 70 μm . Because of its narrow core, it can guide just a single mode as shown in figure. Hence it is called single mode fiber. Single mode fibers are the most extensively used and they constitute 80% of all the fibers that are manufactured in the world today.



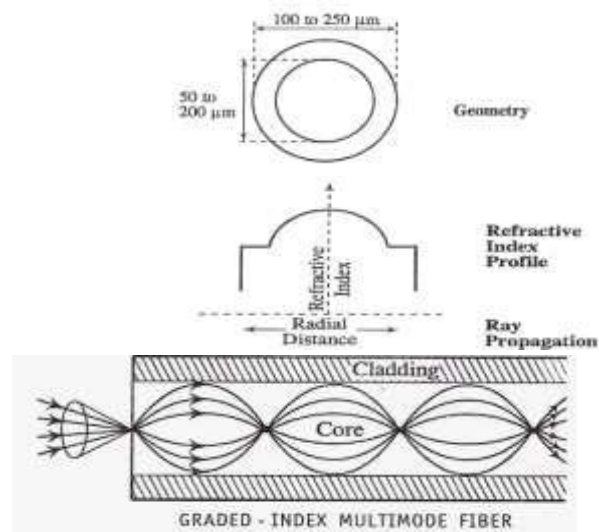
(b) Step index multimode fiber :

The geometry of a step-index multimode fiber is as shown in figure. Its construction is similar to that of a single mode fiber, but its core has much larger diameter to support propagation of large number of modes as shown in the figure. Its refractive index profile is similar to that of a single mode fiber but with a large plane region for the core. The step-index multimode fiber can accept either a laser or Light Emitting Diode (LED) as source of signal. It is least expensive of all.



(c) Graded - index multimode fiber :

The geometry of the graded index (GRIN) multimode fiber is same as that of a step index multimode fiber. But core material refractive index value decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface. The refractive index of the cladding remains uniform. Its refractive index profile is as shown in fig. The laser or LED can be the source of signal for the GRIN multimode fiber. It is the most expensive of all.



Attenuation:

The loss of power suffered by the optical signal as it propagates through the fiber is called attenuation or fiber loss. The three mechanisms through which attenuation takes place are, (1) Absorption, (2) Scattering and (3) Radiation losses.

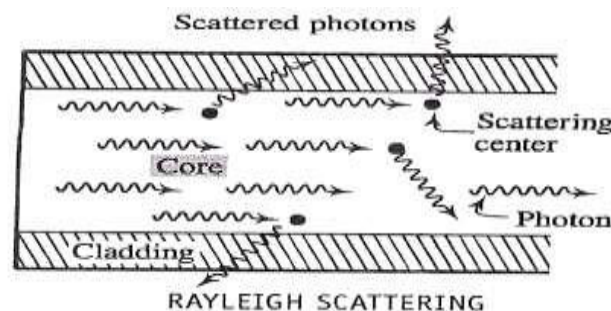
(1) Absorption:-

The loss of signal power occurs due to absorption of photons associated with the signal. Photons are absorbed (a) by impurities in the silica glass of which fiber is made off and (b) by intrinsic absorption by the glass material itself.

The impurities present in fiber glass are iron, chromium, cobalt and copper. During signal propagation when photons interact with these impurities, the electrons absorb the photons and get excited to higher energy level. Later these electrons give up their absorbed energy either as heat energy or light energy, it is of no use. Hence it is a loss. The absorption in fiber occurs predominantly due to the presence of impurities. The other impurity which would cause significant absorption loss is the OH (hydroxy) ion, which enters into the fiber constitution at the time of fiber fabrication.

The fiber itself as a material has a tendency to absorb light energy. The absorption that takes place in the material assuming that there are no impurities and hence it is called intrinsic absorption which sets the lowest limit on absorption for a given material.

(2) Scattering Losses:-



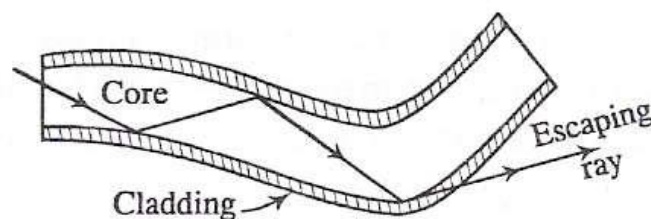
While the signal travels in the fiber, the photons may be scattered because of sharp changes in refractive index values inside the glass over distances that are small compared to wavelength of light. This type of scattering is same as Rayleigh scattering. Rayleigh scattering occurs whenever a light wave travels through a medium having scattering objects whose dimensions are smaller than a wavelength. The Rayleigh scattering is inversely proportional to the 4th power of wavelength. Therefore light of smaller wavelengths are scattered very efficiently. Due to Rayleigh scattering, the photon moves in random directions and in all probabilities leaves the fiber and thus becomes a loss.

Since the Rayleigh scattering has a characteristic λ^{-4} dependence, it increases dramatically, with decreasing wavelength. Below 0.8 nm wavelength, the loss due to this effect alone builds to a prohibitive value for long distance propagation. As the wavelength increases, the scattering loss diminishes. This effect makes the use of light waves of longer wavelengths attractive. The other types of scattering losses are due to the structural inhomogeneities and defects created during fiber fabrication.

(3) Radiation Losses:-

Radiative losses occur due to bending of fiber. There are two types of bends, (a) Macroscopic & (b) Microscopic.

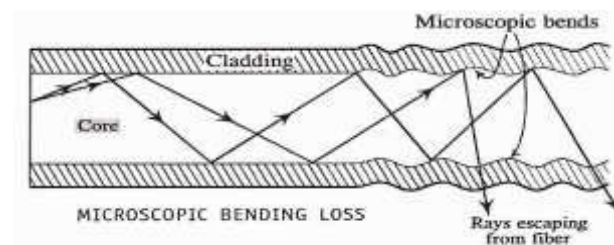
(a) Macroscopic bends :-



RADIATION LEAKS

This refers to bends having radii that are large compared to fiber diameter. Fiber can be bent with radii of curvature as small as 10 cm with negligible loss. Although the loss is negligible for small bends, it increases exponentially until a certain critical radius of curvature. Any bend of radius less than this threshold makes the losses suddenly become extremely large which indicates the absence of total internal reflection.

(b) Microscopic bends :-



These are repetitive small-scale fluctuations in the linearity of the fiber axis. Microscopic bending occurs due to non-uniformities in the manufacturing of the fiber or by non-uniform lateral pressures created during the cabling of the fiber. The micro bends couple light between the various guided modes of fiber and some of them then leak through the fiber. Extruding a compressible jacket over the fiber could minimize micro bending losses.

Attenuation Coefficient:

When light travel in a medium, there will always be a loss in its intensity with distance travelled. The loss of intensity with distance travelled. The loss of intensity is expressed in terms of a quantity called attenuation coefficient denoted as α .

$$\alpha = \frac{-10}{L} \log \frac{P_{out}}{P_{in}} \quad \text{dB/km}$$

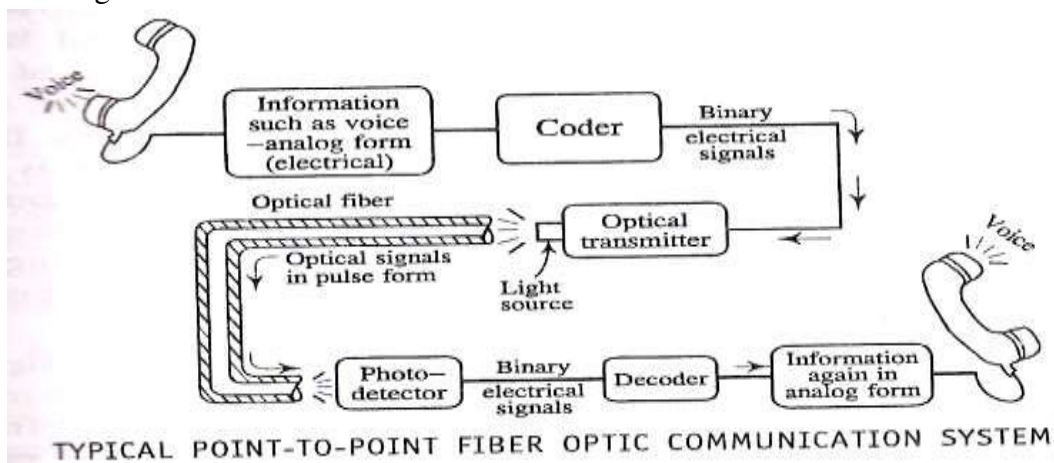
Where, L is the length of the optical fiber is expressed in terms of kilometer.

P_{in} is the initial intensity of light launched into the fiber and P_{out} is the intensity of output received at the other end of the optical fiber.

Power input (P_{in}) and Power output (P_{out}) are expressed in watt.

Fiber optic communication:**Block diagram of Point-to-point Communication:**

Optical fiber communication is the transmission of information by propagation of optical signal through optical fibers over the required distance, which involves deriving optical signal from electrical signal at the transmitting end, and conversion of optical signal back to electrical signal at the receiving end.



A simple point-to-point communication system using optical fibers is shown in figure.

1. The voice is fed into the telephone, which gets converted into electrical signal.
2. The analog electrical signal is fed into a coder, which converts it into binary data.
3. The binary data comes out of the coder as electrical pulses.
4. These pulses are converted into optical signal by modulating the light emitted by an optical source through an optical transmitter.
5. The optical signal is then fed into optical fiber, through which the signal propagates by means of total internal reflection.
6. As the signal propagates it is subjected to attenuation and delay distortion. This is compensated by an optical repeater which converts the distorted optical signal into electrical signal. This electrical signal is sent back to the optical transmitter.
7. The optical signal is received by the photo detector, where it is transformed into pulses of electrical signals (binary data).
8. These pulses are fed into decoder which converts the sequence of binary data into analog electrical signal.
9. This analog electrical signal gets converted into voice through telephone.

Applications of optical fibers:

1. **Sensing device:** Optical fibers can be used as sensing devices where as they can sense parameters like pressure, voltage or current.
2. **Data Link:** In data transfer systems we can make use of optical fibers where the information will be in a secured form.
3. **Local Area networks:** Optical fibers provide more efficient communication facilities in the local area networks.

Advantages of optical communication system:

1. Optical fibers can carry very large amounts of information in either digital or analog form.
2. The materials used for making optical fibers are silicon dioxide and plastic, both of which are easily available at low cost.
3. Because of the greater information carrying capacity by the fibers, the cost/meter/channel for the fiber would be lesser than that for the metallic cable.
4. Because of their compactness, and lightweight, fibers are much easier to transport.
5. The optical fibers are totally protected from interference between different communication channels, since no light can enter a fiber from its sides. Thus the purity of the signals traveling inside the fiber remains unaffected because of which no cross talk takes place.

6. The signals generated from radio and telecommunications stations, or from some electronic equipments, or sometimes radiation from lightning, or sparking, tend to cause disturbance in the metallic cable but cannot do so for the fiber cable.
7. There is no energy radiation from a fiber. Hence the possibility of information tapping by detecting the leaky radiation is ruled out.
8. Fiber communication system is easily compatible with the electronic system. Since the signal is optical, no sparks are generated as it could be in the case of electrical signal. Hence it leads to protection from corrosive and flammable environments.

Limitations of optical communications systems:

1. Splicing (joining two fibers) is a skilful task, which if not done precisely, the signal loss will be so much that it is virtually a break in the communication line. The optic connectors that are used to connect (splicing) two fibers are highly expensive.
2. While system modification is made, or because of accidents, a fiber may suffer line break. Operations required re-establishing the connections are highly skilful and time consuming.
3. Though fibers could be bent to circles of few centimeters radius, they may break when bent to still smaller curvatures. Also for small curvature bends, the loss becomes considerable.
4. Fibers undergo expansion and contraction with temperature that upset some critical alignments, which lead to loss in signal power.