LASERS

Introduction Laser, is an acronym for Light Amplification by Stimulated Emission of Radiation

The first two successful lasers developed during 1960 were. the pulsed ruby laser with wavelength 6943A° and Helium - Neon gas laser with wavelength 11500 A°.

→ A Laser, strictly speaking, is an amplifier of Light.

→ practical utility of laser is an oscillator - a generator of coherent light

→ Lasers are also known as generators of Light

Laser action has been obtained with atoms, ions and molecules in gases, liquids solids, glases, and Semi conductors at wave length spanning from ultraviolet to Radio frequency regions.

Laser output power ranging from a few milliwatts to Several megawatts

Some lasers emit light in pulses while other emit radiations as a continuous wave

Laseraction The following are the steps involved in the lasing atom
(i) Excitation (ii) population inversion (iii) Light amplification.

Excitation when an electromagnetic wave interact with matter (solid, liquid, gas) then the atoms (or) electrons from lower energy level must be excited (or) puped to a higher energy level

populationinversion: It is a process achieved by pumping process { i optical pumping; ii Electrical pumping }

The process which makes the number of atoms (or) electrons in excited level is greater than the Lower for a instant of time. For this to occur a continuous pumping of energy into the system is needed.

Light amplification It is achieved in a resonant cavity where laser action is activated.

Radiation-Interaction: The interaction of radiation with the matter will results the (i) absorption (ii) Spontaneous emission (iii) Stimulated emission

(Q) Explain the characteristics of a Laser-beam
Explain the characteristics of laser beam and explain?
(or) Mention the important characteristics of laser beam.
what are differences between ordinary light and Laser beam.

Laser is compared with any conventional light (ordinary light), it has few outstanding characteristics.

→ Ordinary Light is distributed Uniformly in all directions from the source. It is not possible to make the light (ordinary Light) to travel in a single direction but in case of lasers it is possible.

→ Ordinary light illuminates various objects equally that are at equal distance from the lightsource.

The important characteristics of laser beam over the conventional light sources are (i) Laser is highly monochromatic (ii) Laser is highly directional (iii) Laser is highly coherent (iv) Intensity of laser is very high.

(i) Laser is Highly Monochromatic [Monochromaticity]

Laser is more monochromatic than that of a conventional monochromatic light source.

This is due to stimulated characteristic of the light (laser light)

It has single wavelength ie the line width of laser beam are extremely narrow

The property is Monochromatic is attained by laser beam due to following reseason

(i) only an electromagnetic wave of frequency ν_{12} can be amplified.

(ii) Since the mirror arrangement forms a resonant cavity, oscillations can occurs only at resonant frequencies of this cavity.

(ii) Laser is Highly directional. [Divergence]

Divergence is the significance of the directionality of the laser beam.

If the divergence is small then the directionality of laser beam is high.

$\therefore$ Divergence $\Delta\theta = \frac{r_2 - r_1}{D_2 - D_1}$ where r_2, r_1 are the radii of laserbeam - spots at Distances of D_2 and D_1 resply from the laser source.

For laser beam $\Delta\theta = 0.01$ milliradian.

ie the laserbeam spread less than 0.01 mm. for a distance of one meter

The property of directionality is due to the stimutated emission

ie Laser emit light only in one direction, along cavity direction.

explanation As the active material is placed between plane parallel reflecting surfaces, only electromagnetic wave which is propagated along cavity direction. Thus high directionality (single direction) is achieved.

(iii) Laser highly coherent [Coherence] It is a significance of constant phase difference

In case of laserbeam the property coherence exist between any two (or) more lightwaves of same type.

That is coherence property is the significance about "existence of zero (or) constant phase angle differenle between two (or) more wave. for laser beam.

coherence is of two types (i) Spatial coherence.
(ii) Temporal coherence.

(iv) Intensity of laser beam is very high [Brightness]

In a laser beam lot of energy is concentrated in a small region. Therefore the intensity of laser beam is very high, its brightness is more.

The intensity of laserbeam is very high due to the high directional property of the laser beam.

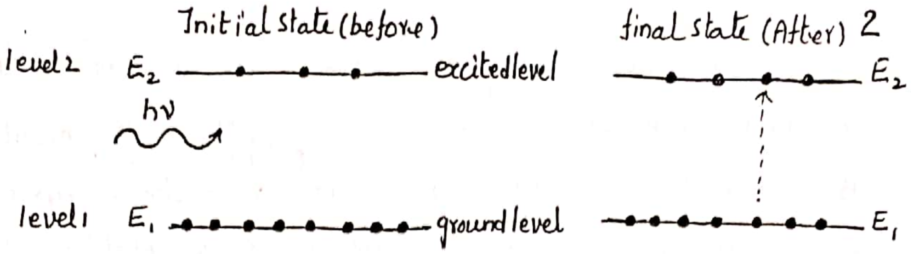
A laser source has brightness many orders of magnitude greater than that of ordinary source.

(Q) Explain with neat diagrams (i) Absorption (ii) Spontaneous emission and (iii) Stimulated emission of Radiation. Derive Einstein coefficients

The interaction of radiation (incident radiation) with the matter will results the processes absortion and emission

emission → Spontaneous, Stimulated.

Absorption



In the above diagram the number of atoms in ground level be N_1 and Number of atoms in the excited level be N_2. Let E_1 be the energy of the ground level and E_2 be the energy of excited level.

If An electromagnetic wave of frequency $h\nu$ is incidenting on the atomic system. Then the atoms in the ground level will absorb the incident frequency of radiation and raised to the excited level. This process is known as absorption.

ie $h\nu = E_2 - E_1$ $h\nu$ is equal to energy difference of level 1 and level 2.

This process is non radiative decay.

The number of atoms undergoing absorption per unit volume per second from level E_2 to level E_1 $= N_1 \rho(\nu) B_{12} \longrightarrow (1)$

where N_1 be the number of atoms in the ground level (level E_1)

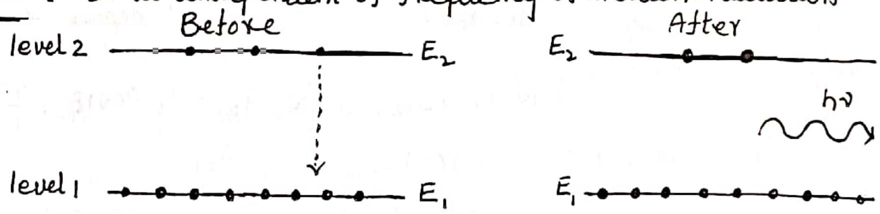
$\rho(\nu)$ is radiation density

B_{12} represents probability of absorption per unit time.

→ Absorption: from level 1 to level 2 depends on the frequency of incident radiation and on the properties of level 1 and level 2 respectively.

Spontaneous emission

: It is independent of frequency of incident radiation



Consider the two atomic level let level 1 be the ground state having energy E_1 and level 2 be the excited level. N_1 be the number of atoms in level 1 and N_2 be the number of atoms in level 2. $N_1 > N_2$;

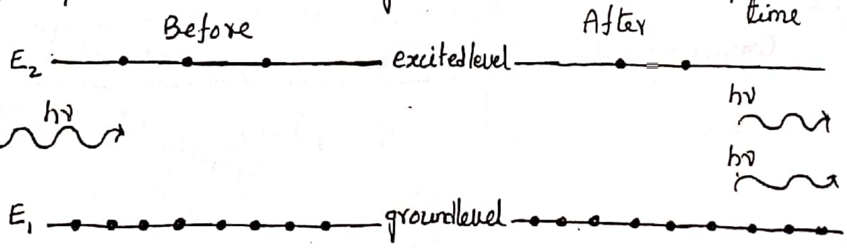
The atom in the level 2 [decay] undergoing transition to the level 1 and emits the electromagnetic wave of energy $h\nu$. This process is called spontaneous emission. The spontaneous process will occur with any input external frequency of incident radiation

Ther number of atoms making spontaneous emission per unit volume per second from level 2 to level 1 ie E_2 to E_1 $= N_2 A_{21} \longrightarrow (2)$

N_2 be the number of atoms present in the level 2

A_{21} represents the probability of spontaneous emission per unit time

Stimulated emission



Let us consider level 1 and level 2 are the two levels of the atomic system N_1 be the number of atoms in level 1 and N_2 be the number of atoms in level 2. By incidenting frequency of radiation $h\nu$ on atomic system, the atoms in the level 2 decay to the level 1 and emits two photons which are in phase. This process is known as <u>stimulated emission</u>.

$$h\nu = E_2 - E_1$$

The number of stimulated emissions per unit volume per second from levels 2 to 1

$$E_2 \rightarrow E_1 \quad \therefore = N_2 \rho(\nu) B_{21} \longrightarrow (3)$$

B_{21} represents probability of stimulated emission per unit time.

Derivation of Einstein's coefficients

(or) Derive the relation between probabilities of Spontaneous emission and stimulated emission in terms of Einstein coefficients

For the atomic system total atoms in the two level be N.

$$\therefore N = N_1 + N_2$$

where N_1 be the number of atoms in the level 1

N_2 be the number of atoms in the level 2.

<u>Equilibrium</u>: In thermal equilibrium the rate of transition from E_1 to E_2 is equal to E_1 to E_1

$\therefore$ Number of atoms undergoing absorption per second = Number of atoms undergoing emission per second.

Hence we have Absorption = Spontaneous emission + Stimulated emission

from (1), (2) and (3)

$$N_1 \rho(\nu) B_{12} = \{N_2 A_{21} + N_2 \rho(\nu) B_{21}\} \longrightarrow (4)$$

$$\Rightarrow N_1 \rho(\nu) B_{12} - N_2 \rho(\nu) B_{21} = N_2 A_{21}$$

$$\rho(\nu) [N_1 B_{12} - N_2 B_{21}] = N_2 A_{21} \longrightarrow (5)$$

Deviding equation (5) on both sides with $N_2 \Rightarrow \frac{\rho(\nu)[N_1 B_{12} - B_{21} N_2]}{N_2} = \frac{N_2 A_{21}}{N_2}$

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

$$\Rightarrow \rho(\nu) = \frac{A_{21}}{\left[\frac{N_1}{N_2}\right] B_{12} - B_{21}} \longrightarrow (6)$$

From Boltzmann distribution law we know that $\frac{N_1}{N_2} = e^{(E_2 - E_1)/K_B T} \longrightarrow (7)$

But energy difference $E_2 - E_1 = h\nu \Rightarrow \frac{N_1}{N_2} = e^{h\nu/K_B T} \longrightarrow (8)$

From eq (8) Substitute $\frac{N_1}{N_2}$ value in eq (6)

$\because B_{12} = B_{21}$

$$\therefore \text{we have } \rho(\nu) = \frac{A_{21}}{\left[e^{h\nu/K_B T}\right] B_{12} - B_{21}} \longrightarrow (9) \quad \rho(\nu) = \frac{A_{21}}{\left[e^{\frac{h\nu}{K_B T}}\right] B_{21} - B_{21}} \longrightarrow (9)$$

From planck's radiation law, we have $\rho(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{(e^{h\nu/K_B T} - 1)} \longrightarrow (10)$

Comparing (9) and (10)

$$\frac{A_{21}}{\left[\left(e^{h\nu/K_B T}\right) - 1\right] B_{21}} = \frac{8\pi h\nu^3}{c^3} \frac{1}{(e^{\frac{h\nu}{K_B T}} - 1)} \longrightarrow (11)$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3} \rightarrow (12)$$ where μ is ~~refractive~~ index of the medium

~~λ is wavelength of light in air~~

c Speed of Light

Let ~~λ_m be the wavelength of light in medium~~ $\therefore \frac{1}{\lambda} = \frac{1}{n}$

$$\therefore \frac{1}{\lambda_m} = \frac{n}{\lambda} \Rightarrow \frac{1}{\lambda_m^3} = \frac{n^3}{\lambda^3} \rightarrow (13)$$

from ~~equations (12) and (13) we have~~ $$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3}} \rightarrow (14)$$

Here A_{21} and B_{21} are called Einstein's coefficients of Spontaneous emission - probability per unit time and Stimulated emission probability per unit time respectively

For Stimulated emission to be predominant we need $\frac{A_{21}}{B_{21}} << 1$

The function $\frac{1}{(e^{\frac{h\nu}{K_BT}} - 1)}$ represents the ratio of Stimulated emission rate to spontaneous emission

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(Q) What do you understand by "Population inversion"? How it is achieved

(or)

What is population inversion? Explain various methods to achieve population - inversion?

Under ordinary conditions of thermal equillibrium the number of atoms in the higher energystate is considerbly smaller than the number of atoms in the lower energystate ie $N_2 < N_1$

N_2 is the number of atoms in higher - energy state

At temperature 17°c $\frac{N_2}{N_1} = 10^{-32}$

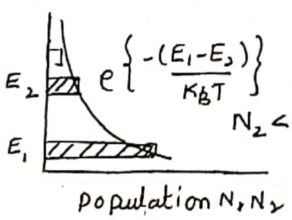
N_1 is the number of atoms in lower - energy state

$\frac{N_2}{N_1}$ is known as ratio of population densities

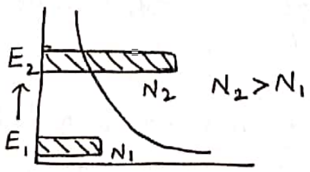
Population inversion: The population inversion is the achievement to obtain the number of atoms in upperstate is more than the number of atoms in the lowerstate ie It is simply the process of achievement that number of atoms in excited state is greater than the number of atoms in ground state.

The process by which population inversion is achieved is known as pumping process

The pumping is achieved through following two ways (i) optical pumping (ii) Electrical pumping.



Population N_1, N_2



After achievement of population inversion.

N_2 be the number of atoms in upper level

N_1 = Number of atoms in lower level

The above two diagrams represents the levels of atomic system and their population densities [Number of atoms in the level]

The population inversion condition achieved on a steady state basis gives rise to continuous wave laser action

From Boltzman's Distribution function $N = N_0 \exp\left(\frac{-E}{K_B T}\right)$

$$N_1 = N_0 \exp\left[\frac{-E_1}{K_B T}\right] \rightarrow (1)$$

N_1 be the number of atoms in energy level (lower) E_1

$$N_2 = N_0 \exp\left[\frac{-E_2}{K_B T}\right] \rightarrow (2)$$

N_2 be the number of atoms in the energy (higher) level E_2

$$\frac{N_2}{N_1} = \frac{N_0 \exp\left(\frac{-E_1}{K_B T}\right)}{N_0 \exp\left(\frac{-E_2}{K_B T}\right)} \rightarrow (3)$$

$$N_2 = N_1 \exp\left(-\frac{(E_2 - E_1)}{K_B T}\right) \rightarrow (4)$$

$E_2 > E_1$ and $N_1 > N_2$.

Population inversion : It is nothing but making $N_2 > N_1$ i.e the number of atoms in higher energy level to be greater than the number of atoms in the lower energy level with the help of pumping method (i) Optical pumping (ii) Electrical pumping (iii) Inelastic collision of atoms (iv) Chemical reaction (v) Direct Conversion

A System in which population-inversion is achieved is called as an Active system

The method of raising the atoms (particles) from lower energy state to higher energy state is called pumping.

Optical pumping method (Used for Solid state laser)

light sources used for optical pumping are (i) Xenon flash lamp (for Ruby Laser) (ii) Tungsten-iodine Krypton (or) high pressure mercury capilliary lamps (for continuous wave laser)

Lamp → Transfer System → Active material

Optical pumping System

In this pumping process energy in the form of light radiation is absorbed by the active material and there by that energy pumps the atoms in to the higher energy level from lower energy level

Electrical pumping method : Electrical pumping is used for gas laser (He-Ne, CO_2) and Semiconductor lasers.

In this case Pumping is achieved by allowing a current of suitable value to pass through the gas. It results in to the generation of ions and electrons.

The electrons are accelarated by the electric field and gain enough additional Kinetic energy from the field to excite the neutral atom by collisions.

Pumping Scheme : Creation of Population Inversion

If we consider a two level system in thermal equilibrium consisting of populations N_1 and N_2. The incoming wave will produce transition $1 \rightarrow 2$ and then $2 \rightarrow 1$ hoping to achieve population inversion

Thus two level system is not appropriate for population inversion and hence multi level system is employed. Three level system and Four level system are commonly employed systems.

(Q) With neat diagrams, describe the construction and action of Ruby laser

(or)

State and explain the construction and working of Ruby laser

Type : Solid state laser

Active material : Ruby Crystal in the form of cylindrical ruby rod

Year : 1960 constructed by T. H. Maiman

Pumping : Optical pumping System is used → Xenon flash discharge tube.

Laser level : Three level laser system.

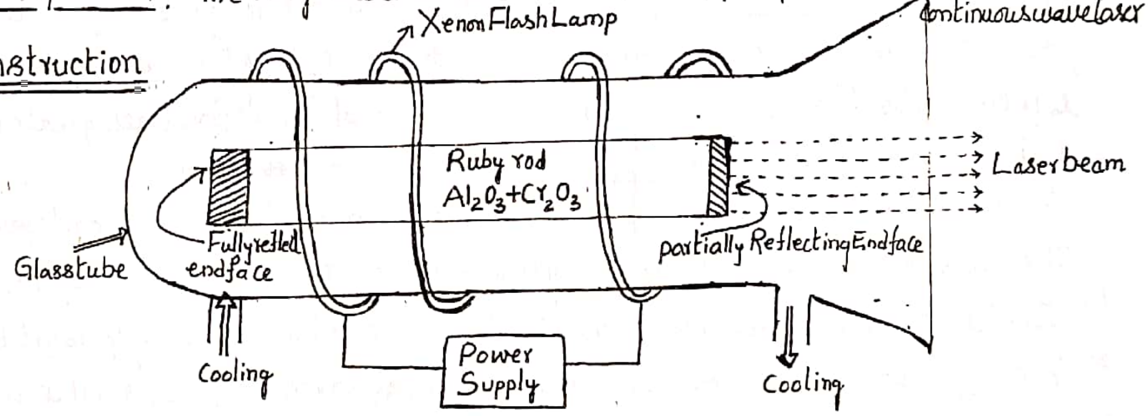
Ruby rod : It is prepared by doping technique ie Ruby rods are prepared from aluminium oxide (Al_2O_3) doped with 0.05% chromium Cr^{3+} replacing Al. This is done by adding small amounts of Cr_2O_3 in the melt of highly purified Al_2O_3.

Due to the chromium ions ruby rod appeared in pink colour. The chromium ions are responsible for emission of light by ruby

Resonant cavity : A fully reflecting surface at the left end of the ruby crystal and partially reflecting end at the right side of the ruby crystal. Both the reflecting surfaces are optically flat and exactly parallel to each other.

Laser operation : The ruby laser is used in the form of pump laser as well as continuous wave laser

Construction



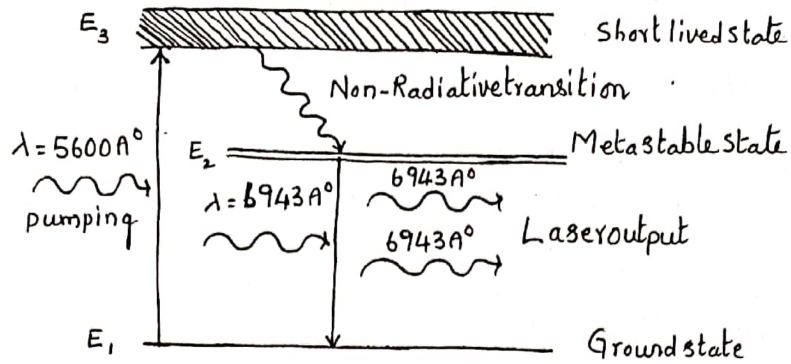
--:-Ruby Laser-:--

Ruby laser consist of a ruby cylindrical rod whose ends are optically flat and parallel. The ruby rod is 4 cm in length and 0.5 cm in diameter. One end is fully silvered and the other end is partially silvered. The rod is surrounded by Glass tube and glass tube is surrounded by a helical Xenon flash tube. Xenon flash tube is acts as the optical pumping system. The laser medium being to be a solid, the laser is also called solid state laser

The ruby rod is crystal of Aluminium Oxide (Al_2O_3) doped with 0.05% of Chromium Oxide (Cr_2O_3). So that the some of the aluminium atoms in the crystal lattice are replaced by Cr^{3+} ions.

Optical pumping system is in the form of helical xenon discharge tube, at the axis of which is placed the ruby rod. The flash tube consist of gas and which is connected to power supply.

Working



Energy level diagram of Cr^{+3} ion

Ruby is madeup of aluminium oxide as host lattice with small percentage of Cr^{+3} ions replacing aluminium ions in the crystal. Chromium acts as dopant. A dopant produces lasing action ie chromium ions are responsible for the emission of laser output. The pumping source for ruby material is Xenon flash lamp which will be operated by some external power supply

The chromium ions are excited from level 1 (E_1) to level 3 (E_3) by the absorption of Light from the Xenon flash discharge tube. The excited ions quickly undergo non radiative transitions with a transfer of energy to the lattice thermal motion to the level 2 (E_2). The level 2 is Metastable state with a lifetime about 3×10^{-3} sec. Now the population of level 2 becomes greater than that of level 1. Thus population inversion is achieved.

Some photons are produced by spontaneous transition from level 2 to level 1. The ends of ruby rod acts as reflecting mirrors. The photons that are not moving parallel to the ruby rod escape from the side, but those are moving parallel to the rubyrod are reflected back and these stimulate the emission of similar other photons ($6943 A^\circ$). The chain reaction quickly develops a beam of photons all moving parallel to the ruby rod, which is mono chromatic and Coherence It emerges through the partially silvered end.

Once all the Cr^{+3} ions are in the metastable level returned to ground state Then one more flash has pumping radiation is sent through the rod. Thus the ruby laser operate only is pulses and so ruby lasers are called pulsed lasers From the metastable state all the Cr^{+3} ions are returned to ground state they will emit laser output. After this action laser action stops. After recieving the flash light energy from xenon flash lamp radiation is sent through the rod. And then the process is Continued for the emission of laser output. So that ruby laser is pulsed laser

Draw backs of Ruby laser (i) It requires high pumping power (ii) Ruby laser is pulsed laser.

The Xenon pulse is of several millisecond duration and the laser pulse is much shorter, less than a millisecond. The power of each peak is of the order of 10^4 to 10^5 watts

→ output power is not continuous.

Uses of Ruby Laser : welding and Drilling : pulsed ruby laser is used successfully for precision welding and drilling of metal, for drilling of industrial diamonds,

It is used for holography and photography of moving objects.

It is for repairing of detached retinas in ophthalmology.

(Q) State and Explain the construction and working of Helium-Neon gas laser.

He - Ne laser is the first gas laser. For continuous laser beam gas lasers are used

Pumping : Electrical pumping system is used.

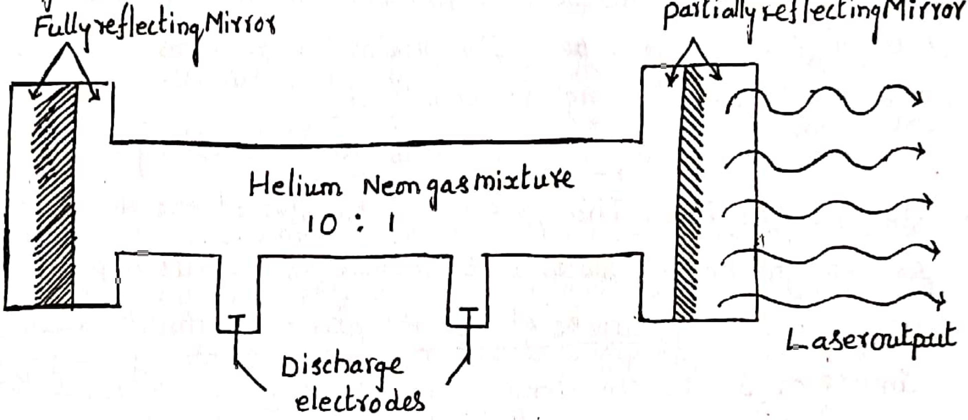
Year : In 1961, Fabricated by Ali Javan and others in Bell Telephone Laboratory

Level : He - Ne gas laser is a Four level laser system

Active medium 10 : 1 Ratio of Helium Neon gas mixture in a Quartz tube

Output power : It depends upon the length of discharge tube and the pressure of gas mixture. The output power for this laser is continuous

Construction :



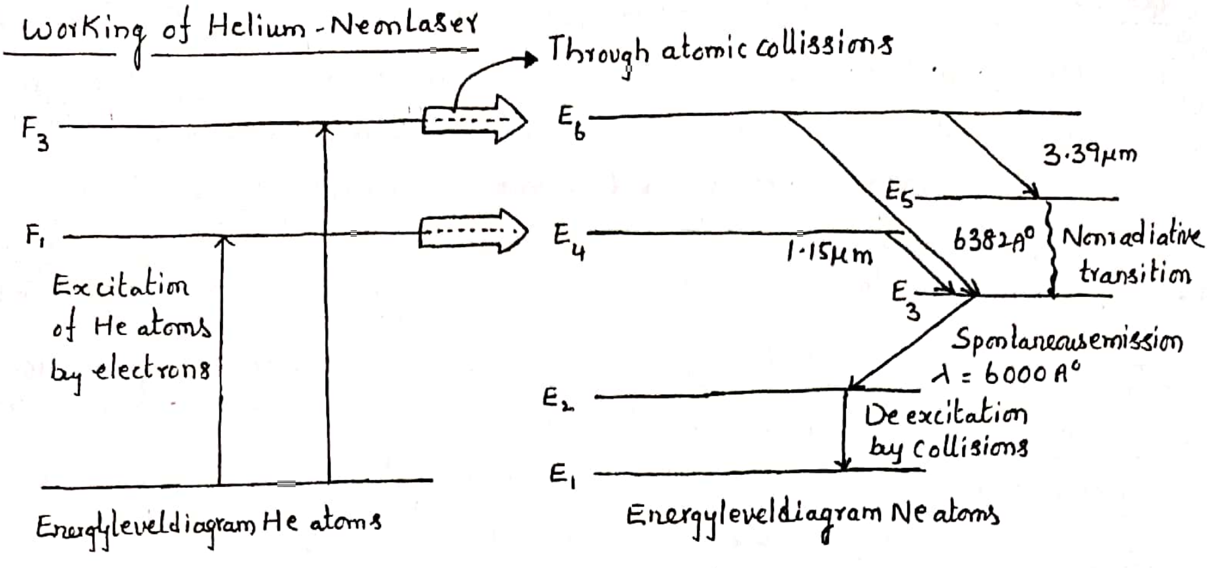
The Helium - Neon laser system consist of a gas discharge tube (Quartz tube) of length about 80 cm and diameter of 1 cm. This tube is filled with the mixture of gas He - Ne at ratio 10 : 1 hence the number of Helium atoms are greater than Neon atoms. Made the arrangement of two mirrors at the both ends of the gas tube. One of the mirror is completely reflecting and the other is partially reflecting in order to amplify the output laser beam.

Made the arrangement of two Discharge electrodes connetted to tube usually with d.c power supply. By making the mirror arrangement one end of the tube is a perfect reflector while the other end is a partial reflector.

These two mirrors at both sides are parallel to each other with respect to the gas tube.

The gas discharge tube is ionised by passing a DC current through the gas. So that for case of He - Ne gas laser the pumping method is electrical pumping method.

Working of Helium-Neon Laser



The output power from these lasers depends upon the length of the dischargetube and the pressure of gas mixture.

when a discharge is passed through the gaseous mixture, electrons are accelarated down the tube. The accelarated electrons collide with the Heliumatoms and excite them to higher energy levels.

Hence the energy of the Heliumatoms is easily transfered to the Neon atoms when they Collide. This preferential transfer of the Neon atoms to Energystate E_6 so that Neonatoms placed at Energylevel E_6 results a population inversion is achieved. The purpose of the He atoms is thus to help achieve population inversion in the Ne atoms. The spontaneous transition takes place from the level E_6 to level E_2 produce wavelength 6000 A°

The stimulated transition photons travelling parallel to the tube are reflected back and between the mirrors placed at the ends and rapidly build up into an intense beam. The photons which are escape through the end with low reflectivity. The Brewster mirrors are allow to pass through without any reflection losses.. The electrons impacts at excite the He and Ne atoms occurs all the time. Due to this reason He-Ne laser operates continuously

After achieveing the population inversion. The various transitions $E_6 \rightarrow E_5$ $E_4 \rightarrow E_3$, $E_6 \rightarrow E_3$ leads to the emission of wave lengths 3.39 μm, 1.15μm and 6328 A°.

The excited Neon atoms drop down from the level E_3 to the level E_2 by spontaneously emitting a photon around wavelength λ = 6000 A°. By the effect of pressure the energy is transfered from Helium atoms to the Neonatoms.
E_2 is a metastable state, in this state atoms (Ne) stay for short time and excite to level E_3 leading to population inversion leads to continuous operation

Advantages of He-Ne Laser : The light from the gas laser as compared to that from solid state lasers are found to be more directional and much more monochromatic

As compared to Ruby laser the Helium-Neon gas laser has the output characteristics that the output laser beam is much more monochromatic.

The He-Ne laser produce a continuous laser beam without the need of cooling arrangement.

Disadvantage : using internal mirrors is that the mirrors are usually eroded by the gas discharge and have to be replaced regularly. when external mirrors are used, the ends of discharge tube also cause an additional loss due to reflections

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(Q) State and explain the construction and working of Semiconductor laser?

(or)

State and explain the construction and working of Gallium Arsenide laser

(or) working of Diode laser (p-n junction laser) GaAs laser [light emitting diode]

Semiconductor laser is also called as diode laser. The light emitting diodes are basically semiconductor laser. These are have important applications in fiberoptic communication

GaAs (Gallium Arsenide) is well known example of a direct band gap semiconductor and hence it is used widely to prepare LED's (light emitting diodes) and laser.

The wavelength of emitted light depend upon the band gap of the material

$$E_g = \frac{hc}{\lambda} \rightarrow (1)$$

E_g is energy gap.

λ is wavelength of photon

c is velocity of light

$E = h\nu$

But $\nu = \frac{c}{\lambda}$

$E = \frac{hc}{\lambda} \Rightarrow E_g = \frac{hc}{\lambda}$

from (1) $\lambda = \frac{hc}{E_g} \Rightarrow \lambda = \frac{1.24}{E_g}\ \mu m$

As E_g increases, it emits shorter wavelengths.

Operation : The Diode lasers are always operated in forward bias

If p and n type materials are prepared from the same material then the p-n junction is called as Homojunction semiconductor laser source.

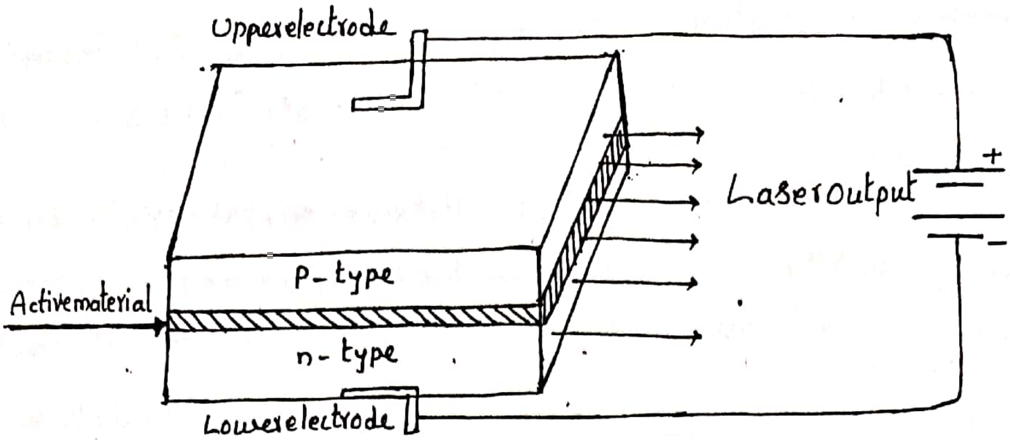
If p and n type materials are prepared from different materials then they are called as Heterojunction semiconductor laser source.

Construction of GaAs Semiconductor diode laser

Mechanism Recombination of electrons and holes at p-n junction when a current is passed through the diode.

Active medium : The active medium is a p-n junction diode made from crystalline Gallium Arsenide. The p-region and n-region in the diode are obtained by heavily doping with suitable dopants.

Since the refractive index of GaAs is high



The arrangements for the construction of GaAs semiconductor diode laser is shown in the figure. Take the p type and n-type materials prepared by adding with suitable dopant elements. The shaded area (the shaded layer) is known as the depletion layer. The thickness of the depletion is usually very small (0.1 μm). To obtain laser action end faces are polished flat and parallel. The other two faces are left unifinished to suppress the oscillations. The active layer consists of a layer of thickness of the order 1 μm, a little wider than the depletion region.

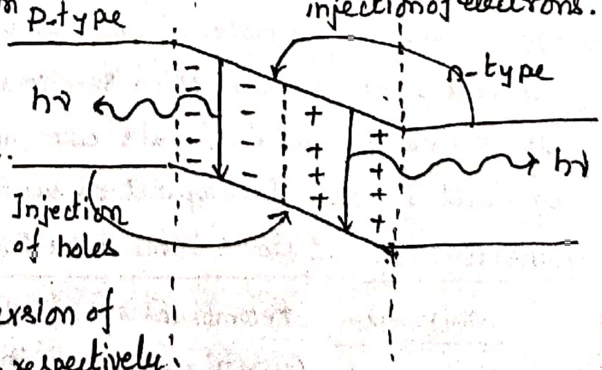
The p-type material is connected to positive terminal of (battery) source and n is connected to negative terminal, which is known as forward bias.

The allowed current for junction is of order of 10^4 amp/cm² is passed through the narrow junction.

Working (operation): Population inversion in semiconductor is achieved is due to heavily doping and due to the operation in forward bias.

when a current is passed through a p-n junction P region is connected to positive terminal of current source and n-region is connected to the negative terminal of the current source. Holes are injected from p-region into n-region and electrons are injected from n-region into p-region.

The electrons and holes recombine and release of light energy takes place in (or) near the junction



The electron-hole recombination takes place in the active region of the device.

The continuous injection of charge carriers creates the population inversion of minority carriers in n and p sides respectively.

The excess minority charge carriers diffuse away from the junction & recombining with majority carriers of n and p material, resulting in the release of photons. Further, the emitted photons increase the recombination of injected electrons from the n-region and holes in p region by inducing more recombinations

Semiconductor laser applications Semiconductor lasers are the cheapest and smallest lasers available. They are easily fabricated into arrays using the same techniques developed for transistor

The laser output can be easily modulated by modulating the ~~curre~~ current through the laser diode. Also they are small in size and highly efficient These properties have made these lasers well suited as light sources for fiber optic communication system.

(Q) State and explain the construction and working of CO_2 laser.

CO_2 laser invented in the year 1963 by C K N patel

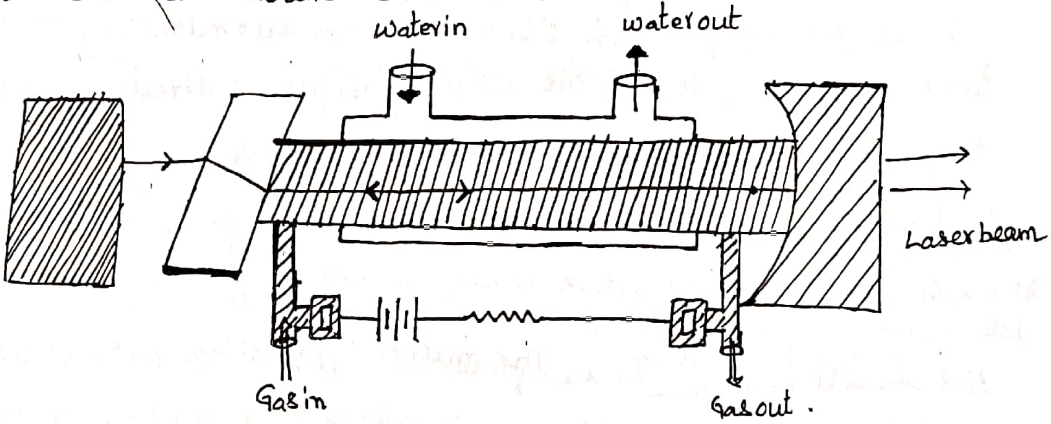
CO_2 has more industrial applications.

Activemedium : The active medium is CO_2 gas.

In CO_2 laser for efficient excitation of CO_2 molecules N_2 (nitrogen) molecules are used.

By the addition of He to gas mixture enhances the efficiency

The ratio of pressure $CO_2 : N_2 : He$ is 1:4:5, optimum value of pressure-tube diameter is around 33 torr mm.

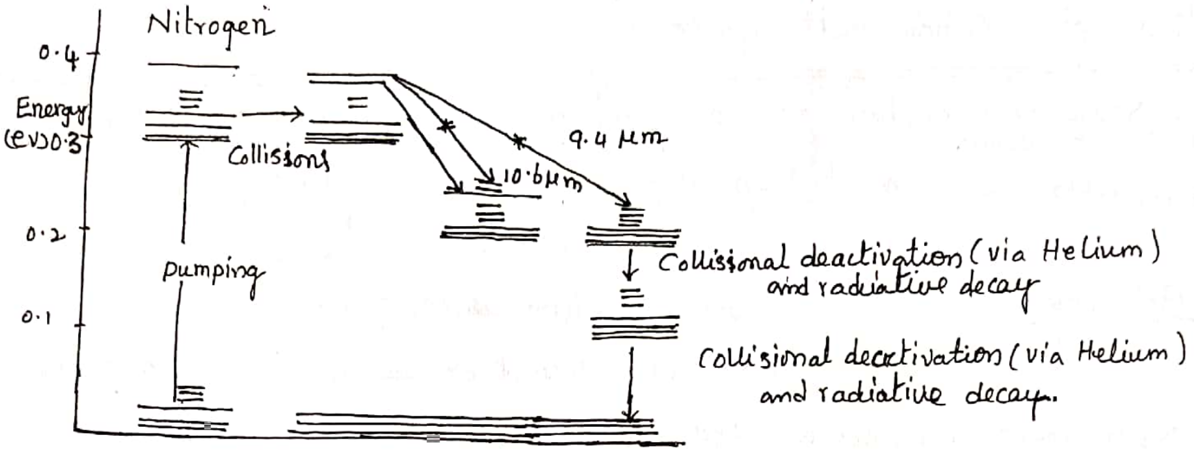


Aschematic of a typical CO_2 laser

The construction of CO_2 laser is made from the special materials must be used for windows, mirrors and other laser components. Germanium gallium arsenide, zinc sulphide, zinc selenide and various alkali halides are used as optical materials. The power output of the CO_2 laser is approximately propotional to the tube length (which contains the gas mixture). For the cooling environment water is circulating around the tube. The gas tube is connected to the electrodes in order to supply the current. So that the pumping system is electrical pumping. The CO_2 laser has continuous wave output.

Working : In CO_2 laser, the excitation is provided by electric discharge The pumping system is electrical pumping.

[Helium is used for excitation of Neon atoms incase of He-Ne laser
In case of CO_2 laser for excitation of CO_2 molecules N_2 molecules are used
The N_2 molecules transfer energy to the CO_2 molecules in resonant collissions
Due to these collissions all these are excited to the metastable levels with longer lifetime.
with sufficient pumping, a population is produced and laser oscillations begin



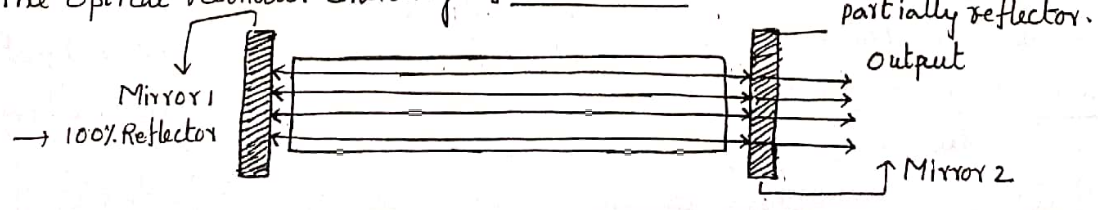
Simplified Energyleveldiagram for the CO_2 laser

The He increases the laser efficiency at 10.6 μm by speeding up the transition there by maintaining a large population
It is relatively easy to obtain continuous wave outputs of 100 W from a laser 1m Long. So that the efficiency of laser is directly propotional to the length of the gas tube.

<u>Applications of CO_2 laser</u>: CO_2 laser are very widely used in industry and in recent years, these lasers are used in the field of medicine also.

(1) <u>Material processing</u>: The material processing such as cutting, drilling, welding, etching, surface hardening etc.
(2) In the field of medicine _ medical CO_2 laser is used as scalpel for bloodless surgery
(3) CO_2 laser are used for pollution monitoring and remote sensing.

(Q) Explain the need of cavity resonator in a laser
<u>Need of cavity resonator</u>: To make stimulated emission in more number of atoms
To obtain directionality to the out put beam. To increase the intensity of the laser beam.
Since the resonators mirrors provide positive feedback to the photons amplified by the active medium, this can be called as "laser oscillator".
The optical resonator consisting of <u>two mirrors</u>



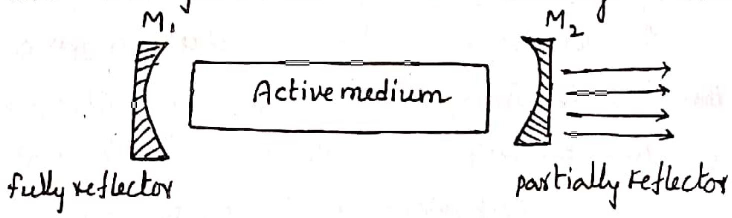
Cavity resonator in a laser essentially consist of two mirrors facing each other. The active medium is placed between two mirrors. One of the mirror is 100% reflecting ie fully reflecting mirror. The other mirror is partially reflecting mirror, which is transperent to let some of the radiation pass through it. The resonant cavity is used to make stimulated emission possible in more number of atoms in the active medium. This naturally increase the intensity of the laser beam.

when the active medium is placed inside an optical resonator, the system acts as an oscillator. A part of the output energy must be feed back into the system. Such a feed back is brought out by placing an active medium between a pair of silver coating mirrors, which are facing each other. The mirrors could be either plane (or) curved deping up on the use.

Such a system formed by a pair of mirrors is reffered to as a cavity resonator. The emerging beam from the resonator after the amplification through material from the two reflectors is known as laser.

Resonator mirrors are generally coated with multilayer dielectric materials to reduce the absorption loss in the mirrors. Moreover these resonators act as frequency selector and also gives rise to directionality to the output beam

Curved mirrors



The schematic diagram consist of two curved mirrors in case of optical resonators with plane mirrors, it is extremely difficult to allign the beam exactly parallel to each other and perpendicular to the cavity axis of the active medium. This problem is overcome by use of curved mirrors to form the resonator cavity instead of plane parallel mirrors.

(Q) Explain the purpose of an active medium in a laser?

The active medium may be a solid, liquid or gas.

The active plays the role in order to achieve population inversion and output of the laser beam. The output of laser be may continuous wave (or) pulsed laser beam it is depend on the nature of the materials taken in active medium.

Ex: Ruby laser Active medium the mixture of Al_2O_3 and Cr_2O_3
The output power incase of Ruby laser is 100 megawatts [10000 watt]
The laser pulse with a width of 10^{-4} sec. The duation of output flash is about 300 microseconds.

Exp 1 2 He - Ne laser

The He - Ne laser emits power in the range 0.5 mW to 50 mW

The laser (He - Ne) has a coherence length of 300 meter which is used in holography.

The active medium which when exited achieves population inversion and subsequently causes energy levels to rise. The active medium may be a solid (or) liquid (or) gas and it may be one of the thousands of materials that have been found to be large.

The energy due to pumping is confined to the active medium, then population inversion is achieved. The entire medium is like a cavity resonator that emits energy. In a laser system the active medium is placed between reflectors like a pair of mirrors making the active medium as a sort of cavity resonator

Oscillations are set in active medium and sustained in the cavity. A laser source is a quantum oscillator

The resonators mirrors provide positive feed back to the photons amplified by the active medium, this can be called as "laser oscillator"

(Q) Applications of Lasers?

(or)

Mention the applications of Lasers in various fields?

Due to the special features of Laser beam that
(i) narrow bandwidth,
(ii) Due to narrow angular spread
(iii) coherence.
(iv) Directionality
(V) High intensity

The Lasers are used in various fields
(a) Industries
(b) Scientific research
(c) Communication System
(d) In Medicine

Applications of Lasers in Industries : In manufacturing industry lasers are used for welding, cutting and drilling applications.

Welding : with increased power output, it is possible to use the laser (CO_2) as a welding tool.

Laser welding has certain advantages over gas welding such as
(i) purity of the material is not altered [purity of material after welding is unchanged]
(ii) Accurate operation : Localized heating by small spot size can be accurately controlled by programming with computer to reproduce exact characteristics.

Example : CO_2 laser with 10 KW output is employed in case of welding of 5mm thickness stainless steel plates can be welded at a speed of 10 cm/sec.

Cutting: Lasers cut through a wide variety of materials, rapidly without noise, Due to high intensity of laserbeam.

example: CO_2 laser employed for cutting of glass, quart, Diamons etc.

with high power levels, 250 watt CO_2 laser 3mm thick quartz plate can be cut at a rate of 2cm/sec.

→ Lasers can be used to blast holes in diamonds and hard steel.

→ A CO_2 laser of 100 w continuous output can cut a cloth at a speed of 1m/sec

→ A CO_2 laser of 3Kw continuous output cuts titanium sheet of 50 m thickness at a velocity of 0.5/minute.

Drilling: Most drilling systems operate in pulsedmode [pulsed lasers are employed]

To get the drill of desired depth and size, number of pulses, and the energy of each pulse are to be controlled.

→ One of the first application of the laser was to drill diamond makes small holes.

Scientific research Applications of Lasers

(i) with the help of laser, it is possible to inverstigate the struct of molecules

(ii) Lasers can be used in rangefinders to find the position of distant object

(iii) Laser is a very useful tool to initiate a fusion reaction.

(iv) with the help of laser it is possible to seperate the isotopic species of an element available in an isotopic combination.

(v) It has been observed that fingerprints can be detected under laser light.

(vi) A compact disc Read only memory is (CDROM) is prepared by using a highpower laser to burn one micron (10^{-6}m) holes in a master disk

(vii) Due to narrow, angular spread, the laserbeam has become a means of communication between earth and moon (or) other satillites.

Communication System - Laser applications

(i) using laser, it is possible to transmit thousands of television programmes simultaneously to the various places.

(ii) Using laser, it is possible to make communication between the Moon and the earth [to another satillies also]

(iii) Lasers are used in optical range finders which notonly give accurate ranging but also size and shape of object with orientation

(iv) Radio telescopes fitted with a ruby laser can amplify very faint radio signals from space, thus extending the range of observation.

In Defence: A Laser beam can be used to destroy very big objects like aircrafts, missiles etc, in a fewseconds by directing the laser beam into the target

A laser ~~be~~ can be used for detection and ranging like RADAR, The only difference is it uses light instead of Radio waves. Hence it is called as Light Detecting And Ranging (LIDAR)

Applications of Laser in Medicine [Mention the medical applications of laser]

Laser	Applied field
Argon	→ Neuro surgery, ophthalmology, dermotology, biological research
Helium-Neon	→ laser holography, Diagnostic applications, permeability of blood containing tissues.
Ruby	→ Ophthalmology and dermatology
CO_2	→ treatment of liver and lungs, elimination of tumors, Nuerosurgery, dermotology, microsurgery
Nd-YAG	→ Neurosurgery, Dermatology.
ultra violet excimer laser neodymium	→ Treatement of liver cancer

→ Argon ion laser : Ophthalmologists used argon ion lasers for welding retinal detachment. The Green beam of Argon ion laser is strongly absorbed by red blood cells of the retina and welds the retina back to the eye ball

Cataract operation For cataract removal lasers are used.

Blood less Surgery : Laser scapels are used for bloodless surgery. when the tissues are cut the blood veins cut are fused at their tips by the infrared laser and hence there is no blood loss.

Angioplasty & ~~By pass~~ Nd-YAG laser application : The Nd YAG laser are used in angioplasty for removal of artery block. The laser radiation is sent through fiber to the region of block, burns the excess growth and regulates the blood flow with out need of bypass surgery.

Destroying Kidney stones and gall stones [CO_2 laser] Lasers are used in destroying Kidney stones and gallstones. Laser pulses sent through optical fibers shatter the stones into small pieces.

Dermotology In dermatology, lasers are used to remove freckles, acne and tattoo. when such regions are illuminated with blue-gree laser light, the radiation is absorbed by the blood and heats up. The blood vessels are closed and excess blood flow is stopped.

Cancer diagnosis and Therapy : For the treatment of cancerous tissues, skin tumors laser are widely used.

when suscept areas are illuminated with laser of approximate wavelength, cancer cells are destroyed.

Laser therapy is completely painless and more advisable for children.

Scaning : Laser is used in endscopy to scan the inner parts of the stomach

Fiberoptics

Introduction → Optical fibers used in signal transmission for communications

→ These are used to transmit light in the manner metal wires are used to transmit electricity.

→ Best features (i) Much greater band width
(ii) Smaller and lighter ie light in weight and small in size
(iii) Immunity from electromagnetic interference
(iv) Stable (or) declining price
(v) These are having capability of carrying a huge amount of information
(vi) No possibility of internal noise
(vii) Small diameter of individual fiber channel
(viii) Can be used very safely even in explosive environment
(ix) Immune to moisture and temperature variation
(x) No dangers of short circuits.

Because of these advantages, fiber optic communication is used in telephones such as loops, trunks, terminals and exchanges, computers, Space vehicles, ships, cable TV, submarines, security, medical field, industrial automations and process controlls, alarm systems.

The fibers are transmitting information on a light beam over very long distances Hundreds of telephone conservations can be transmitted simultaneously at microwave frequencies, many thousands of signals can be carried as a Lightbeam through a fiber optic cable using multiplexing techniques.

Laws are used in fiberoptics The transmission of light in an optical fiber is based on the phenomenon of Total internal reflection

Snell's law $n_1 \sin i = n_2 \sin r$ n_1 n_2 are Refractive indices of rarer and denser medium.
i is angle of incidence.
r is angle of refraction.

The refracted ray bends towards the normal as the ray travels from low dense medium to high dense medium.

The refracted ray bends away from the normal as it travels from high dense medium to low dense medium.

Total internal reflection: There is a possibility to occur total internal reflection provided the angle of incidence is greater than critical angle θ_c

ie $\theta_i < \theta_c$

Critical angle : θ_c : we are incidenting at the critical angle the angle of refraction will be $90°$ if $\theta_i = \theta_c \Rightarrow \theta_r = 90°$

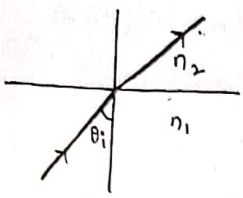
According to Snell's law $n_1 \sin i = n_2 \sin r$

if $i = \theta_c \Rightarrow$ Then $r = 90^\circ \Rightarrow n_1 \sin\theta_c = n_2 \sin 90^\circ$

$\therefore\ n_1 \sin\theta_c = n_2(1) \Rightarrow \boxed{\sin\theta_c = \frac{n_2}{n_1}}\ \boxed{\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)}$

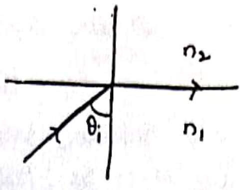
Let n_1 be the Refractive index of core; and n_2 be the Refractive index of the cladding

<u>case a:</u> $\theta_i < \theta_c$



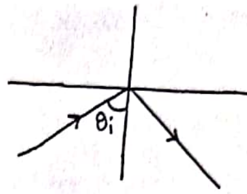
$\theta_i < \theta_c$

<u>case b:</u> $\theta_i = \theta_c$



$\theta_i = \theta_c$

<u>case c:</u> $\theta_i > \theta_c$



$\theta_i > \theta_c$

If the angle of incidence is increased ($\theta_i > \theta_c$) then the ray is totally reflected

---

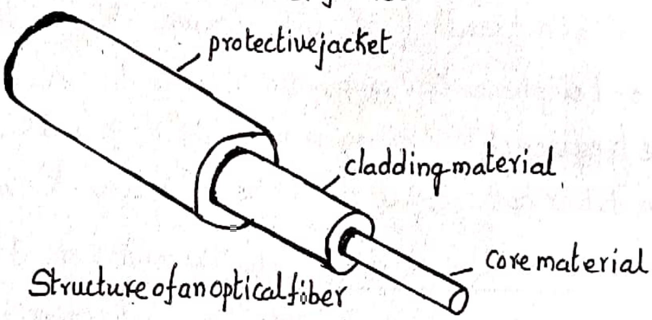
(Q) Describe the construction of a typical optical fiber and give the dimensions of various parts.

(or)

With the help of a suitable diagram explain the principle, construction and working of an optical fiber as a waveguide.

Optical fiber is a very thin and flexible medium having a cylindrical shape consisting of three section
(i) The core material
(ii) The cladding material
(iii) The outer jacket

<u>Construction:</u>



Structure of an optical fiber

Optical fiber is a cylinder of transparent dielectric medium and designed to guide visible and infrared light over long distances.

A typical glass fiber consists of a central core of thick 50 μm surrounded by a cladding.

The cladding is a material having slightly lower refractive index than core's refractive index. The core material is made from glass. The cladding materials are made by the process adding of impurities like Boron, phosphorus (or) germanium are doped.

Silicon coating is provided between buffer jacket and cladding in order to improve the quality of transmission of light.

Finally the fiber cable is covered by black polyurethane outer jacket, because of this arrangement fiber cable will not be damaged during the

Main parts of Optical fiber : (i) The core material.
(ii) The cladding material
(iii) Outer jacket.

Core : it is made with Silica. It has high refractive index than cladding
: The diameter of the core is of few micrometers. It is denser material than cladding. Core is central part of the optical fibre is made of high refractive index glass, to propagate the light by total internal reflection.

Cladding : It is a material, which is having low refractive index than core
The cladding is silica doped with suitable amounts of germanium and fluorine to control the refractive index [Refractive index of cladding is always less than the core]
Diameter : The diameter of the outer cladding is of the order of 100 – 125 μm

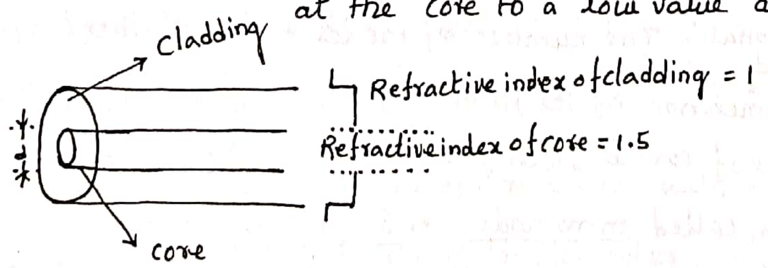
Outer jacket [protective outer covering layer] It is madeup thickness about 60 μm
The outer protective covering is made of polymer. It protects the fibre from the environmental effects.

(Q) How the optical fibres are classified? (or) Types of optical fibers
(or) Describe different types of fibres by giving the Refractive index profiles and propagation detail ?

Depending upon the Refractive index profile of the core optical fibres are classified in two categories (i) Stepindex fibre
(ii) Graded index fibre

Depending upon the number of modes of propagation optical fibres are classified into two categories (i) Single mode optical fibres
(ii) Multimode optical fibres.

STEP INDEX FIBRE : The refractive index changes abruptly from a high value at the core to a low value at the cladding



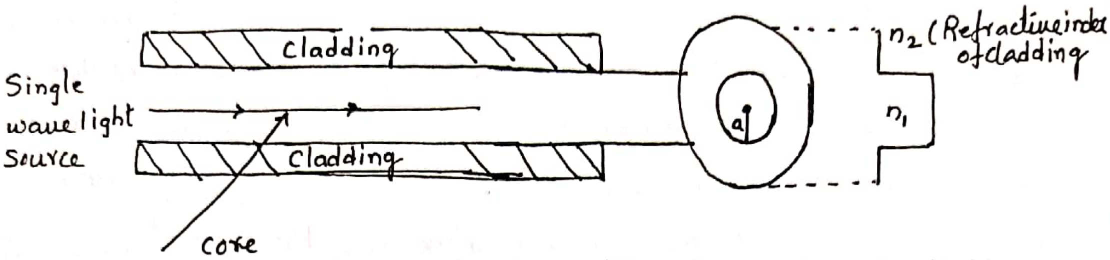
Its structure is like two concentric cylinders. The inner cylinder is called core. The outer one is cladding (air (or) ~~air~~ plastic material (or) glass)
Step index fiber : Fibers in which core of constant refractive index n_1 is surrounded by cladding of slightly lower refractive index at the interface core - clad is known as Step index fiber.

The corediameter will be of the order of 2 - 10 mm.

Light beams entering the fiber at different angles will transvers different total distances before they arrive at the other end of the fiber

Step index fibre support the transmission of transverse electromagnetic radiation

Stepindex Single mode fibre (or) Stepindex monomode fibre



In the case of Single mode stepindex fiber the core has small diameter and the cladding is kept very thick

The characteristics of this type
(i) Very small core diameter
(ii) Low Numerical aperture
(iii) Low attenuation
(iv) Very high band width

Single mode fibers transmit single ray along the axis of the fiber

Advantages of Single mode fibers have the following advantages

(i) Low intermodal dispersion and lower broadening of Light pulses being transmitted

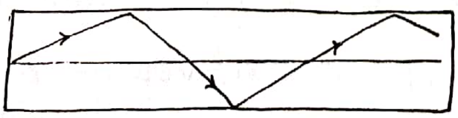
(ii) Larger bandwidth can be attained in these.

Disadvantage: In single mode fiber, a significant amount of the power resides outside the fiber core.

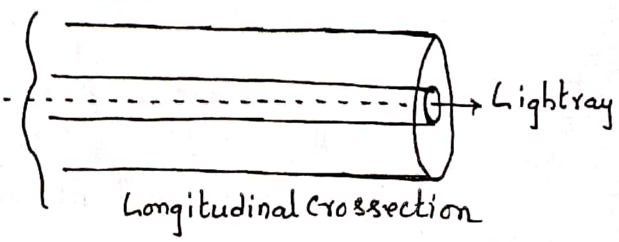
In this type a single light ray is transmitted. In step index single mode fiber core has small diameter and cladding has large diameter than core.

Transmission of Signal: The number of modes that the fiber supports depend on the dimension of the fiber. If the thickness of the fiber is so small (Diameter of core is small) that it supports only one mode then the fiber is called monomode (or) Singlemode fiber

The mono mode fiber has very small core diameter of the order 2 to 8 μm
It requires Coherent Light Source Like laser



Signal transmission

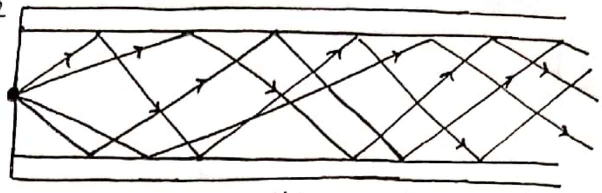


Longitudinal Crossection

Multimode fibre The fibre which supports more than one mode then it is called multimode fibre.

The core diameter of multimode fiber is of the order of 50 μm

i.e. the core diameter is large



Multimode step index fiber

Multimode step index fiber :

Multi mode step index fibers allow finite number of guided modes

Thus, the various lightwaves (in coherent sources) travelling along the core, will have propagation paths of different lengths. Hence they will take different times to reach a given destination

The direction of polarization, alignment of electric and magnetic fields will be different in rays of different modes in multimode fiber. These modes depend on the boundary conditions. Mode volume of a multimode fiber is the number of modes the fiber can support

Advantages : The multimode fibers have the following advantages.

(i) Source : we can ordinary Multimode fibers can use spatially incoherent sources of light like LED's

(ii) Easy to Couple : Due to large Numerical aperture and core diameters it is easy to couple them with other fibers and sources of Light.

(iii) Low tolerance requirements These fibers have lower tolerance requirements on their properties.

GRADED INDEX FIBERS [The refractive index of the core varies continuously]

In graded index multimode fiber, the refractive index of the core varies radially. The refractive index of core is maximum at its centre, which gradually falls (decrease) with increase of radius and at the core.

i.e. Refractive index of core varies with respect to distance (radial)

Let n be the refractive index, 'r' be the radial distance.

n be the function of r i.e. $n = n(r)$

$$n(r) = n_1\left[1 - 2\Delta\left(\frac{x}{a}\right)^{p}\right]^2$$

n_1 refractive index at the centre of the core

p : graded profile index number.

$$\Delta = \frac{n_1 - n_2}{n_1}$$

$$n(r) = n_1\left(1 - 2\Delta\left(\frac{r}{a}\right)^P\right)^{1/2}$$

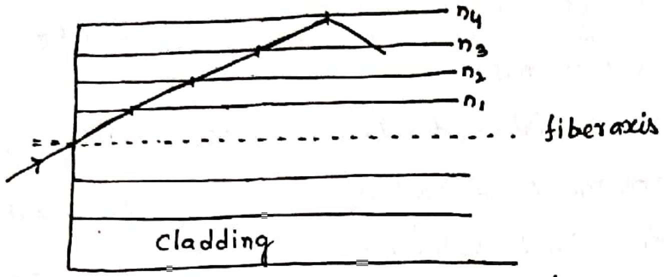
r: radial distance
a: core radius
Δ: index difference. $\Delta \approx \frac{n_1 - n_2}{n_1}$ $(n_1 > n_2)$
P: index profile

Case (a) $r > a$ $\quad n(r) = n_1(1 - 2\Delta)^{1/2} = n_2$

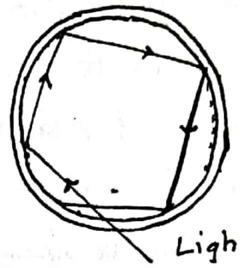
Case (b) $r \ngtr a$

NOTE: The refractive index of the core material is varies with respect to the distance. So that there exist Multiple refractions in graded index fiber with in core material

Advantage: Distortion is minimized by making the variation of the refractive index gradual from the axis of the core



Multiple refractions in graded index fiber with core material



Cross-Section View.

Graded index fiber have the following characteristics

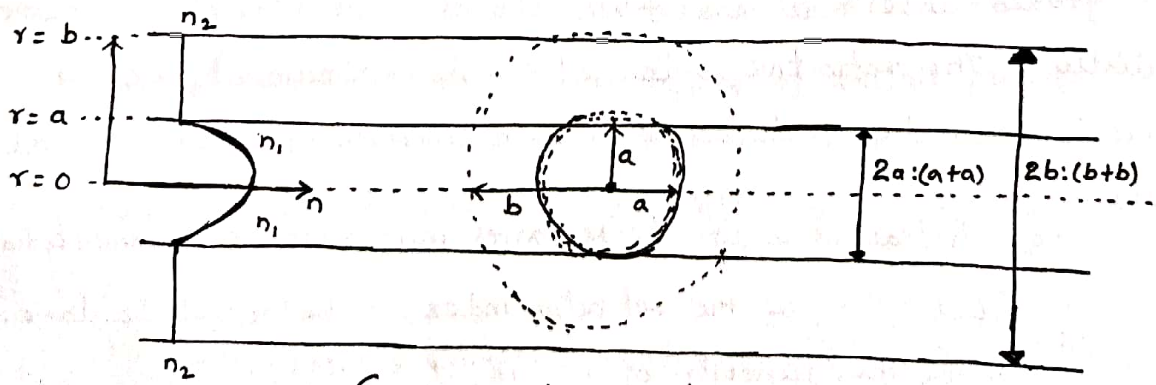
(i) Refractive index profile is circularly symmetric
(ii) Fiber is multimodal with large core diameter
(iii) Total internal reflection and refractive index change with in the core region slowly.
(iv) Refractive index variations are small

Multimode - Graded index fiber

A Graded index fiber is a multimode fiber with a core consisting of concentric layers of diffrent refractive indices $(n_1, n_2, n_3, n_4 \cdots)$ $n_1 > n_2 > n_3 > n_4$

ie Refractive index of the core decreases with distance from the fiber axis $n \propto \frac{1}{r}$

$n \propto \frac{1}{r}$ where r is the radial distance from the fiber axis



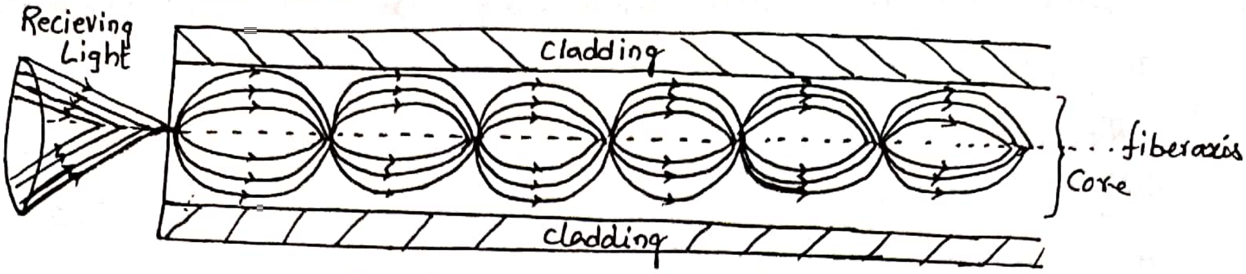
Graded index fiber - refractive index profile

n_1 – Refractive index of core : [it is Non uniform]

n_2. Refractive index of Cladding

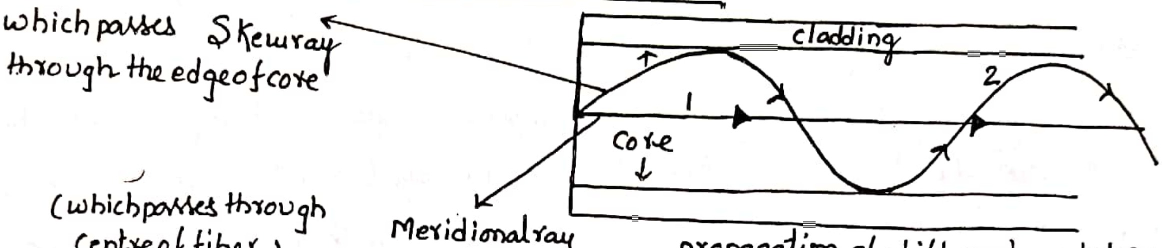
$r \to 0$: at fiber axis $\quad r \to b$ cladding
$r \to a$ with in core (a : core radius)

In Graded index fiber Numerical aperture decrease with radial distance from the axis



Typical Light ray paths in Graded index fiber

Transmission of Signal in Graded index fiber



propagation of different model rays.

Graded index fiber is a multimode fiber that supports propagation of meridional rays. Signal pulse represented by 1^* travelling along the axis of fiber, The Meridional rays travels through a medium of high refractive index, which are parallel to fiber axis. Advantage: Less inter modal dispersion (Than step index multimode fiber)

Skewrays: (refraction takes place): The other pulse represented by 2^*, travelling away from axis, through the edge of the core (from ~~to~~ high refractive index to low refractive index vice versa) The path of this (Skewray) ray is sinusoidal in nature. It travels longer distance

Advantage of G.I fiber Inter model dispersion is reduced to minimum

Disadvantage of G.I fiber : propagate only half the power carried by the Step index fiber (power loss is takes place)

propagation of Modes in the core: The number of possible propagation modes in the core is known as V-number of fiber

V-number for graded index fiber $V = \frac{2\pi}{\lambda} a(NA)$ λ: wavelength
a: radius of core
NA Numerical aperture.

Total Number of Modes through step index fiber $\boxed{N = V^2} \Rightarrow \boxed{N_{SI} = V^2}$

Total Number of modes through Graded index fiber $N = \frac{V^2}{2} \Rightarrow \boxed{N_{GI} = \frac{V^2}{2}}$

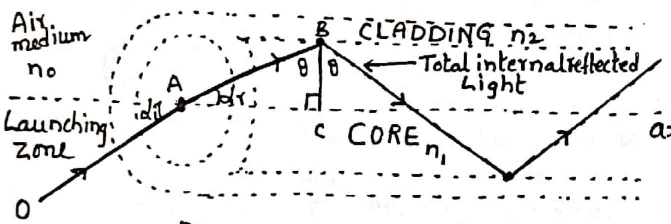
$\therefore \boxed{N_{GI} = \frac{N_{SI}}{2}}$

(Q) what is acceptance angle? what is acceptance cone? Derive an expression for acceptance angle? Derive expression for Numerical aperture

The light is incident at the face of optical fiber at different angles. only a particular amount light is only recieved by the fiber which travels along the interface of core and cladding. For total internal reflection: the incident light is greater than critical angle (θ_c) will undergo total internal reflection and propagate through the core. The other rays are refracted into the cladding material and are lost.

All the incident light rays are not accepted by fiber only particular rays are accepted for propagation. Acceptance angle is nothing but, at which angle the light is accepted for the propagation [* Greater than θ_c]

Acceptance angle (α_m): Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters (coupled) into the core and travels along the interface of core and cladding and will propagate along the fiber.



PATH OF A TYPICAL LIGHT RAY LAUNCHED into FIBER

OA: incident light ray from a medium of Refractive index 'n_0'
α_i: Angle of incidence
α_r: Angle of refraction
n_1: Refractive index of core
n_2: Refractive index of cladding

CASE STUDY: Entering of Light ray to the axis of fiber * Generally $n_1 > n_2$

Let a Light ray OA enters the fiber at an angle α_i to the axis of the fiber (Launching) Consider the light ray enters from a medium of refractive index n_0

The light ray refracts at an angle α_r and strikes the core-cladding-interface at angle θ

*Condition If the angle 'θ' is greater than its critical angle θ_c, the light ray undergoes TOTAL INTERNAL REFLECTION at the interface

According to Snell's law $n_0 \sin\alpha_i = n_1 \sin\alpha_r \rightarrow (1)$

$\left[\because \mu_1 \sin i = \mu_2 \sin r;\ \mu_1 = n_0;\ i = \alpha_i;\ \mu_2 = n_1;\ r = \alpha_r\right]$

From the right angled triangle ABC $\alpha_r + \theta = 90^\circ \rightarrow (2)$

$\alpha_r = 90^\circ - \theta \rightarrow (3)$

[$\because$ Total Subtend angle 180°; 'a' Right angle: 90°; 'b+c' other two angles: 90°; $90^\circ + 90^\circ = 180^\circ$]

Substitute α_r value in (1) $n_0 \sin\alpha_i = n_1 \sin(90^\circ - \theta)$

$n_0 \sin\alpha_i = n_1 \cos\theta \rightarrow (4)$ $[\because \sin(90-\theta) = \cos\theta]$

from (4) $n_0 \sin\alpha_i = n_1 \sin(90-\theta)$

$n_0 \sin\alpha_i = n_1 \cos\theta$

$\sin\alpha_i = \frac{n_1}{n_0}\cos\theta \longrightarrow (5)$

[As per condition] when $\theta = \theta_c$; $\alpha_i = \alpha_m$ = maximum α value

$\therefore$ from (5) $\sin\alpha_m = \frac{n_1}{n_0}\cos\theta_c \rightarrow (6)$ [α_m : Maximum value of angle of incidence]

If n_1 and n_2 are refractive indices of core and cladding

If the angle of incidence = θ_c ; then angle of refraction = $90°$

According to law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2 \rightarrow (7)$

Here $\theta_1 = \theta_c \Rightarrow \theta_2 = 90°$ [As per Definition of critical angle]

$\therefore n_1 \sin\theta_c = n_2 \sin 90° \rightarrow (8)$

$\therefore n_1 \sin\theta_c = n_2(1) \Rightarrow \sin\theta_c = \frac{n_2}{n_1} \rightarrow (9)$

* from equation (9) we can find $\cos\theta_c$ value ie $\cos\theta_c = \sqrt{1-\sin^2\theta_c}$

$\therefore \cos\theta_c = \sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$

$\therefore \cos\theta_c = \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}} = \frac{\sqrt{n_1^2 - n_2^2}}{n_1} \longrightarrow (10)$

* from equation (10) we can substitute $\cos\theta_c$ value in equation (6)

$\therefore \sin\alpha_m = \frac{\cancel{n_1}}{n_0}\left[\frac{\sqrt{n_1^2 - n_2^2}}{\cancel{n_1}}\right]$

* For a medium $\Rightarrow$ $\therefore$ $\boxed{\sin\alpha_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}} \longrightarrow (11)$

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

For air medium $\Rightarrow$ $\therefore \sin\alpha_m = \frac{\sqrt{n_1^2 - n_2^2}}{1} \Rightarrow \boxed{\sin\alpha_m = \sqrt{n_1^2 - n_2^2}}$

$\therefore \boxed{\alpha_m = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)}$

Above expression represent acceptance angle

This maximum angle (α_m) is called the acceptance angle

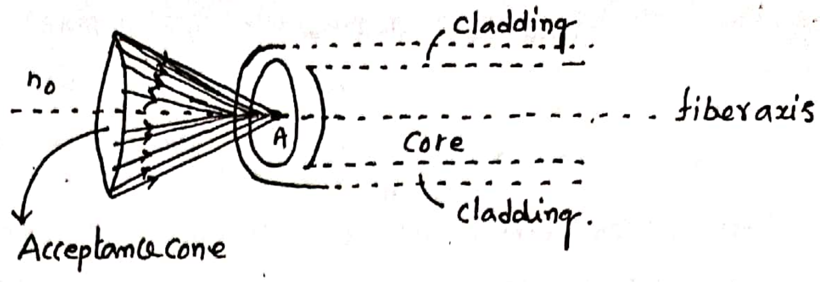
* Acceptance angle (α_m) : Acceptance angle is the angle at which light should be incidented on the fiber for the propagation through it by satifiying the condition total internal reflection (TIR)

NOTE 1 : Light is incident at angle θ greater than θ_c ($\theta > \theta_c$) it undergoes total internal reflection.

NOTE 2 : $\theta < \theta_c$ then the incident light will be lost in the cladding

NOTE 3 propagation of Light through fox as a result of Multiple total internal reflections

Acceptance cone



For the light rays to propagate through optical fiber by total internal -reflection, they must be incident on the fiber core with in acceptance angle defined by conical half angle.

Light launched at the fiber end with in this acceptance cone alone will be accepted and propagated to the other end of the fiber by total -internal reflection

Rotating the acceptance angle about the fiber axis describes the acceptance -cone. - of the fiber

Numerical Aperture Light gathering capacity of the fiber is expressed, interms of maximum acceptance angle (α_m) and is termed as 'Numerical aperture'

or, Numerical Aperture is a measure of its light gathering power.

The Numerical Aperture (NA) is defined as the sine of the maximum acceptance angle thus Numerical Aperture (NA) = $\sin\alpha_m$

Derivation is specified in above question. Derive for $\sin\alpha_m$.

$\therefore$ $NA = \sin\alpha_m \longrightarrow (1)$

we know that $\sin\alpha_m = \sqrt{n_1^2 - n_2^2} \rightarrow (2)$ | In case we consider air medium Light is launched from air to fiber end face

from (1) and (2) $NA = \sqrt{n_1^2 - n_2^2}$

$\therefore$ $NA = \sqrt{(n_1+n_2)(n_1-n_2)} \longrightarrow (3).$

$\Delta = \frac{n_1 - n_2}{n_1}$ where Δ is the relative refractive index difference of an optical fiber.

$\therefore \Delta = \frac{n_1 - n_2}{n_1} \longrightarrow (4)$

$\therefore n_1 - n_2 = \Delta n_1 \longrightarrow (5)$

$\therefore \boxed{NA = \sqrt{(n_1+n_2)\Delta n_1}}$

Numerical aperture is depend on n_1, n_2 and independent on the fiber dimensions.

Value of NA ranges from 0.1 to 0.5

If NA value is large then the fiber will accept large amount of light from the source.

(Q) Define the relative refractive index difference of an optical fiber. Show that it is related to Numerical aperture.

Let us consider the refractive index of core material is n_1 and refractive index of cladding material is n_2.

Relative refractive index difference : It is defined as ~~fractional~~ difference in refractive indices n_1 and n_2 are the refractive indices of core and cladding material respectively.

Let Δn be the relative refractive index difference.

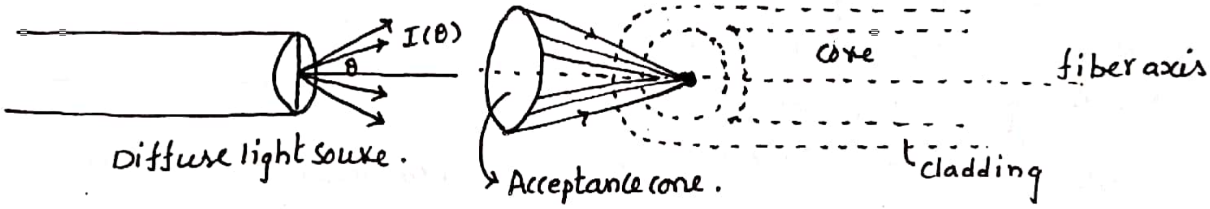
$\Delta n = n_1 - n_2$ ie Δn is related to Numerical aperture of the fiber as $\boxed{NA = \sqrt{2n_1 \Delta n}}$

Let Δ be the fractional difference in refractive indices of core & cladding

$$\Delta = \frac{n_1 - n_2}{n_1} \Rightarrow \Delta = \frac{\Delta n}{n_1} \longrightarrow (1)$$

$$\therefore \text{from (1)} \quad \Delta n_1 = \Delta n \rightarrow (2)$$

Light Source : It emits the power which is coupled by the end face of fiber for propagation. only some amount power can be collected by fibe and propagated along the fiber ie $(NA)^2$ can be colled by the fiber and propagated along the fiber



Consider a small diffuse light source as the isotropic (same in all directions) radiator as shown in above figure is Captured by end face of fiber. Light emitted Normal to end surface of fiber. ie In which the power radiated per unit Solid angle in the direction θ to the normal to the surface is given by $I(\theta) = I_0 \cos\theta \longrightarrow (3)$

$\therefore$ Total power emitted by light source is $\phi_0 = \int_0^{\pi/2} I(\theta) d\Omega \rightarrow (4)$

$$\therefore \quad \phi_0 = \int_0^{\pi/2} (I_0 \cos\theta) d\Omega \rightarrow (4)$$

[$d\Omega$: Small element of Solid angle.]

$$\therefore \quad d\Omega = 2\pi \sin\theta \, d\theta \longrightarrow (5)$$

$$\therefore \phi_0 = \int_0^{\pi/2} I_0 \cos\theta \, 2\pi \sin\theta \, d\theta = \int_0^{\pi/2} I_0 (2\sin\theta\cos\theta) \pi \, d\theta$$

$$\therefore \phi_0 = I_0 \pi \int_0^{\pi/2} \sin 2\theta \, d\theta \qquad [\because \pi, I_0 \text{ constants}]$$

$$\therefore \phi_0 = I_0 \pi \left[-\frac{\cos 2\theta}{2} \right]_0^{\pi/2} = \frac{I_0 \pi}{2} \left[\cos 2\theta \right]_{\frac{\pi}{2}}^{0}$$

$$\phi_0 = \frac{I_0 \pi}{2} [1 + 1] \Rightarrow \phi_0 = \pi I_0$$

$\therefore \phi_0 = \pi I_0 \longrightarrow (6)$

If α_m is acceptance angle, the angle at which the power is accepted by the fiber for propagation

But the power from such a source that can be collected by an adjacent fiber whose core diameter is greater than the diameter of the source is given by $\phi \Rightarrow \phi = \int_0^{\alpha_m} I(\theta)\, d\Omega = \int_0^{\alpha_m} (I_0 \cos\theta) 2\pi \sin\theta\, d\theta$.

$$\therefore \phi = \int_0^{\alpha_m} (I_0 \cos\theta)\, 2\pi \sin\theta\, d\theta \longrightarrow (7)$$

$$\therefore \phi = \int_0^{\alpha_m} I_0 \pi\, 2\sin\theta\cos\theta\, d\theta.$$

$$\therefore \phi = \pi I_0 \sin^2\alpha_m \longrightarrow (8)$$

we know that $\phi = \pi I_0$ [from (6)] substitute in eq (8)

$$\therefore \phi = \phi_0 \sin^2\alpha_m \longrightarrow (9)$$

we know that Numerical aperture (NA) $= \sin\alpha_m \rightarrow (10)$

ie Numerical aperture is directly related to acceptance angle

$$\therefore NA = \sin\alpha_m \Rightarrow \sin^2\alpha_m = (NA)^2 \rightarrow (11)$$

$\therefore$ from (9) and (11) $\phi = \phi_0 (NA)^2 \longrightarrow (12)$

$$\therefore \frac{\phi}{\phi_0} = (NA)^2 = \sin^2\alpha_m \longrightarrow (13)$$

we know that $\sin\alpha_m = \sqrt{n_1^2 - n_2^2} = \sqrt{(n_1+n_2)(n_1-n_2)}$

$$\sin^2\alpha_m = (n_1+n_2)(n_1-n_2) \rightarrow (14)$$

Substitute $n_1 - n_2 = \Delta n =$ Relative refractive index difference of the fiber

$$\therefore \sin^2\alpha_m = (n_1+n_2)\Delta n \longrightarrow (14)$$

$$\therefore \Delta = \frac{n_1 - n_2}{n_1} \Rightarrow \Delta = \frac{\Delta n}{n_1} \Rightarrow \Delta n_1 = \Delta n \rightarrow (15)$$

from (14) and (15) $\sin^2\alpha_m = (n_1+n_2)\Delta n_1 \rightarrow (15)$

As $n_1 \approx n_2$ we can take $n_1 + n_2 = 2n_1 \rightarrow (16)$

from (15) and (16) $\sin^2\alpha_m = (2n_1)\Delta n_1$

$$\therefore \sin^2\alpha_m = 2n_1^2\Delta \longrightarrow (17)$$

$\therefore$ from equations (13) and (17) we can write $\frac{\phi}{\phi_0} = (NA)^2 = 2n_1^2\Delta \rightarrow (18)$

$$\therefore \text{Numerical aperture } (NA)^2 = 2n_1^2\Delta \longrightarrow (19)$$

But $\Delta = \frac{n_1 - n_2}{n_1} = \frac{\Delta n}{n_1} \longrightarrow (20)$

from (19) & (20) $(NA)^2 = (2n_1^{\cancel{2}})\left(\frac{\Delta n}{\cancel{n_1}}\right)$

$$\therefore (NA)^2 = 2n_1\Delta n \Rightarrow NA = \sqrt{2n_1\Delta n}$$

$\boxed{NA = \sqrt{2n_1 \Delta n}}$ Δn is relative refractive index difference

From above equation Numerical aperture of fiber (NA) is related to the relative refractive index difference of an optical fiber.

(Q) Explain the advantages of optical communication system.
[or] Discuss the various advantages of communication with optical fiber over the conventional coaxial cables.

Conventional coaxial cables constitutes copper (or) Aluminium basic raw materials are high cost, and having *disadvantages in communication process as compared to optical fiber (fabrication of fibers with silica)

Conventional coaxial cables:- Communication * loss of power; dispersion; insecurity, high cost; maintenance is difficult; they may pickup line currents Interfering with electromagnetic signals; Leakage of signals; Distortions due to Geographical effects

Optical fiber communication: advantages over conventional coaxial cables
- → Enormous Bandwidth (10^{14} Hz); Low transmission loss.
- → Immunity to crosstalk (crosstalk is negligible)
- → Electric Isolation (No effect by electric and magnetic field)
- → Small size and weight (Easy installation: 10 μm: 50 μm
- → Signal Security (Does not radiate 100% signal security)
- → Ruggedness and Flexibility (Damage rate is very less)
- → Low cost and availability (Compare to copper: Aluminium Cables.
- → Reliability

Let us see the advantages of optical fiber communication over conventional communication system.

Optical fibers are dielectric waveguides (silica glass) so that optical signals (or) Data can be transmitted through the fiber over a very long distances with low loss, low attenuation, low dispersion. Thus one can achieve very high band width (or) high data rate using fiber optic cables.

(a) Enormous Bandwidth: The band width of the optical communication channel is very large as compared to conventional coaxial communication channel. Due to high band width (10^{14} Hz) optical carrier frequency there exist possibility of greater information carrying capacity. There are transmitting different signals with different wavelengths in parallel to the same optical fiber. A fiber has a capacity of 500 channels and its external diameter is not more than 0.5mm.

(b) Low transmission loss : Optical fibers have very low transmission losses Due to the usage of Ultra low loss fibers and erbium doped silical fibers as optical amplifiers, one can achieve almost lossless transmission. The repeaters can be kept at a very long distance like 45 Kms. The coaxial cables requires repeater repeater at every 1.6 Kms. This saves considerable cost

(c) Immunity to crosstalk optical fibers are made out of dielectric materials Hence they are free from electrical and electromagnetic interference (EMI) Since optical interference among different fibers is not possible, crosstalk is negligible even many fibers are cabled together.

(d) Electrical Isolation : Unlike their metallic counterparts optical fibers are electrically insulated. Optical fibers are made from silica which is an electrical insulator. Therefore they do not pickup any current. This makes optical fibers suitable for use in electrically hazardous environments.

(e) Small Size and Weight : The size of the fiber ranges from 10 μm to 50 μm Hence they are compact and little weight in comparision with copper cables. These advantages make them to use in aircrafts and satellites.

(f) Signal Security The transmitted signal through the fiber does not radiate Thus, the optical cable is superior than coaxial conventional cables. This feature (signal security) is attractive for milatary, banking and general secured data transmission applications.

(g) Flexibility The fiber cable can be easily bend or twisted without damaging it. where as conventional cables (Metallic cables) are not flexible It is easy to handle, installation, storage, transportation, mainteinence

(f) Low cost and availability Optical fibers are made out of silica which is glass. available in abundance. Hence they are cheaper compared to metallic wave guides and coaxial cables. Optical fibers offer low cost communication

(g) Reliability The optical fibers are made from silicon glass which does not undergo any chemical reaction or corrosion. Its quality is not affected by external radiation

Due to All the above factors ~~as~~ Optical fiber communication have the advantages over the conventional coaxial cables (copper and metallic(Al) cables)

Describe the Communication process using optical fibers

(OR)

Draw the Block diagram of an optical fiber communication system explain function of each block.

In practice, the optical fibers positioned in supporting cables.

The Signals can be directly transmitted upto 40Km without much attenuation.

Beyond this distance (40Km) "Amplifier(or) Repeaters" are used to amplify the signals at suitable distances.

The optical communication system comprises with Transmitter section Receiver section.

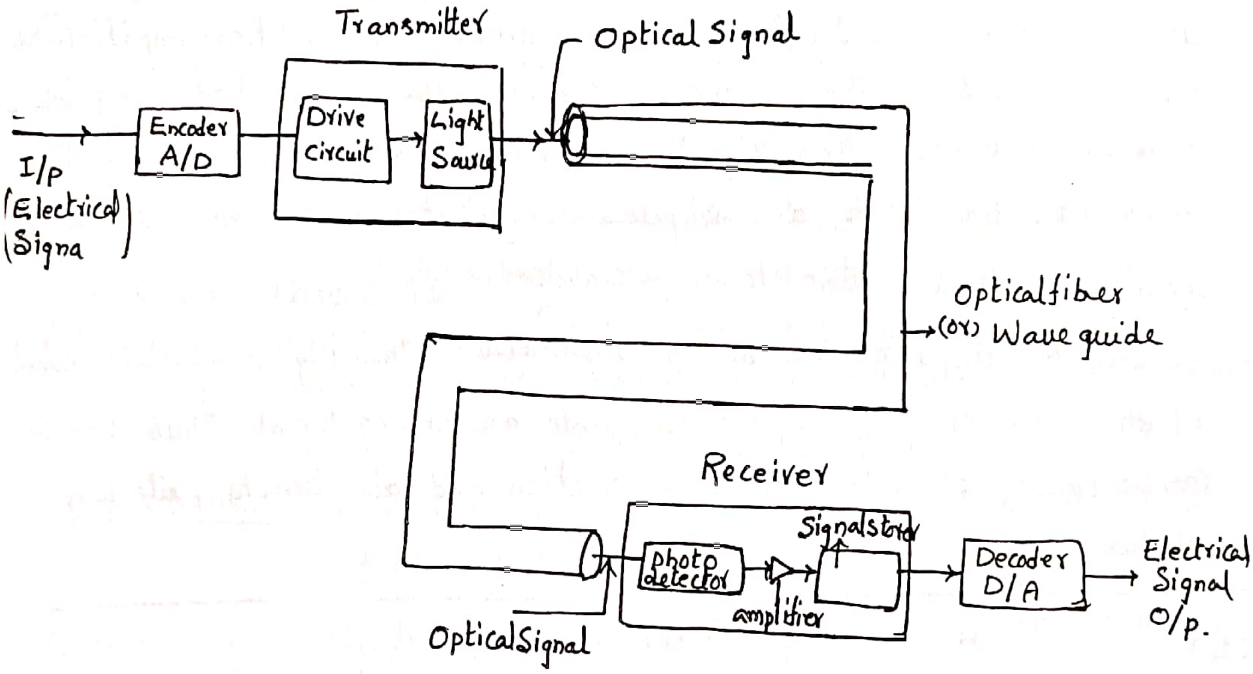


Fig: Block Diagram of fiber Optic Communication System

Function of each block is explained as fallows.

Input: The input analog electrical signal which is the information to be carried is converted to digital signal in A/D converter.

Encoder: It is an electronic system that converts the analog information like voice, figures, objects etc in to binary data. This binary data contains a series of electrical pulses. The information is converted to digital signal in Encoder for transmision. The Digital data is converted in to suitable optical signal in the form of light pulses using the Laser Source

Transmitter: It consists of two parts, they are drive circuit and Light Source. Light source is a semiconductor infrared laser (or) LED's are used. The light pulses are transmitted through long optical fibers. The electrical signals are converted in to optical signals. with the help of specially made connector optical signal will be received by the (receiver) (from the) waveguide from the transmitter.

waveguide (or) optical fiber : It is a non metallic wave guide which carries information in the form of optical signals with the help of specially made connector optical signal will be received by the receiver from the wave guide.

Receiver : It consists of three parts, they are photodetector, amplifier and signal restorer. The photodet converts the optical signals into the equivalent electrical signals and supply them to amplifier. The amplifier amplifies the electric signals as they become weak during the journey through waveguide over long distance. The signal restorer keeps all the electric signals in a sequential form and supplies to detector in the suitable way.

Decoder (D/A convertor Digital to analog convertor) It converts the received electric signals into the analog information. The Digital electrical output of the detector is then converted into an analog signal. Thus signals can be transmitted without much attenuation and distortion to quite long distances.

(Q) what are important features of optical fibers
write the uses of fiber optics in different fields
applications of optical fibers in various fields.

Optical fibers are employed in in various fields.

(i) Communication System
(ii) Sensors. (fiber optic sensors)
(iii) Medical [gastroscopes and other medical instruments]
(iv) Industrial applications.

Communication System Optical fibers are very attractive alternatives to twisted wire or coaxial cables in communication links.

→ They carries information, ie Information-carrying capacity is high as compared to conventional cables [Bandwidth of the order 10^{14} Hz]

→ Fibers are Dielectric wave guides which transmit the optical the optical signal or data through them with very low attenuation and very low dispersion

Thus one can achieve very high band width (or) high data rate using fiber optic cables.

Low transmission loss For long distance communication fibers of 0.002 dB/Km are used. So that one can achieve almost loss less transmission.

Signal Security : Optical fiber communication provides 100% signal security.

Enormous Bandwidth The data rate (or) information carrying capacity of optical fibers is enhanced to many orders of magnitude

Sensors : Fiber optics are used as sensor

Sensors : There are two types of fiber optic sensors → Intrinsic → extrinsic

Sensors are the devices used to measure (or) monitor quantities such as displacement, pressure, temperature, flow rate, liquid level, chemical composition etc. A smoke detector and pollution detector can be made from fibers.

Intrinsic Sensors [produce the macroscopic results]

Intensity-modulated Sensors works on the principle of intensity variation. Represents variation of Intensity of light.

phase sensor It is a temperature sensor which utilizes the principle of phase variations.

Extrinsic Sensors [produce the microscopic results] ex: Magnetic field Sensors

Fiber optic Sensors

Measured parameter	Modulation effect in optical fiber
1. Temperature	Thermoluminescence
2 Magnetic field	Magneto - optic effect
3. pressure	Piezo - optic effect
4 Mechanical force	Stress birefringence.
5 Electric current	Electroluminescence
6 Electric field	Electro optic effect
7. Density	Triboluminescence
8 Nuclear radiation	Radiation induced luminescence

Industrial applications: In laser processing of materials like drilling welding and cutting, the high power laser is located at one place and the laser radiation will be transmitted to different locations in the shop floor through optical fiber cables.

Medical application of fiberoptics [write a Note on fiber optic medical endoscopy]

optical fibers are used in endoscopes to get the image of the particular part of the body. In laser, optical fibers are used to transmit the laser beam to the point of interest where surgery is to be done.

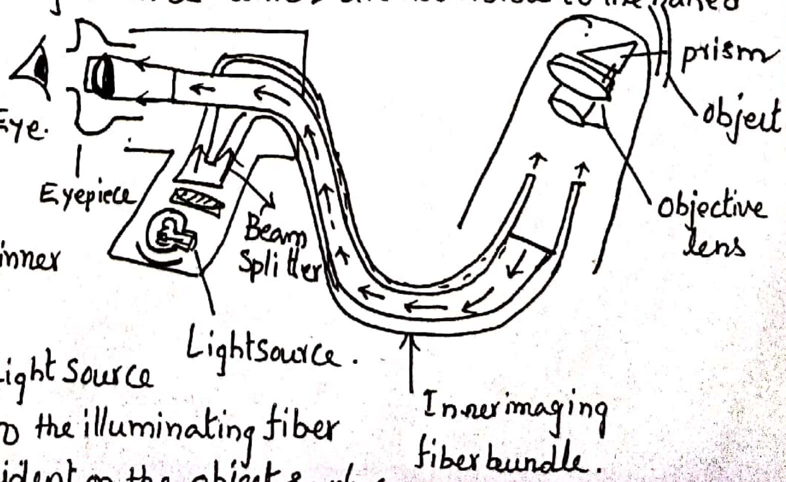
Fiber scopes are employed widely in endoscopic applications.

Fiberoptic endoscope: To view internal body parts without performing surgery

Fiberoptic endoscopes:	Application (use).
(a) Gastroscope: It consists of a long flexible rubber tube and a rigid metal section that has a lens and various contacts	→ To examine the Stomach → photograph tumors, and ulcers → To remove objects that have been swallowed
(b) Branchoscope →	To view the upper passages of Lungs
(c) Anthoscope →	To Study the small spaces within joints.
(d) Cardioscope →	heart cavities; operation ⇒ aspiration of mucus. Valvular defects Septal defect
(e) Cytoscope →	examine tumors, inflammation, Stones
(f) protoscop →	Range of use Rectum Operation hemorrhoids

Working of Endoscopes: The endoscope is a tubular optical instrument to inspect (or) view the body cavities which are not visible to the naked eye normally.

Usually in each endscope there are two fiber bundles. One is used to illuminate the object and other is to view the inner structure of



Light rays emitted from the Light Source are focussed and coupled to the illuminating fiber bundle and finally incident on the object surface.