Unit V: Lasers and Fibre Optics

- A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.
- The term “LASER" originated as an acronym for "light amplification by stimulated emission of radiation".

Characteristics of Laser light:

The most important characteristics of a Laser beams are,

1.High Monochromaticity

2.High directionality

3.High degree of coherence

4.High brightness

1.Monochromaticity:

- Laser light is monochromatic or very pure in color.
- A Laser beam is in single wavelength i.e., the line width of a laser beam is extremely narrow.
- In conventional light sources, the wavelength spread is usually 1 in 10^6
- In case of laser light, the spread will be 1 in 10^{15}

This means that if the frequency of radiation is 10^{15} Hz, then the width of the line will be 1 Hz

2. Directionality:

- Laser beam emits light only in one direction.
- It travels very long distances without divergence. so, Laser communication is carried on between the earth and the moon.
- The directionality of a Laser beam is expressed in terms of divergence.
- Suppose r_1 and r_2 are the radii of a laser beam at distances D_1 and D_2 from a laser, then the divergence, $\Delta\theta = (r_1 - r_2)/ D_2 - D_1$
- The divergence for a laser beam is 0.01 milliradian where as incase of search light it is 0.5 radian.

3. Coherence:

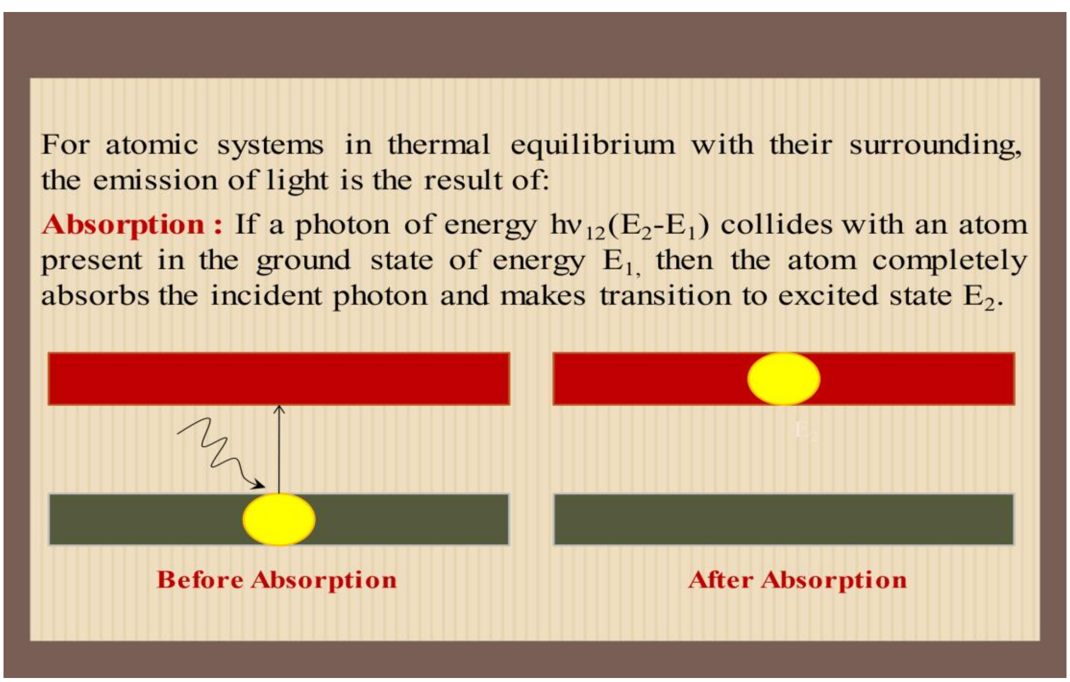
- Two sources of light are said to be coherent if they have zero or a constant phase difference between them.

LASER: One color (monochromatic) and waves in phase (coherent)

4.Brightness:

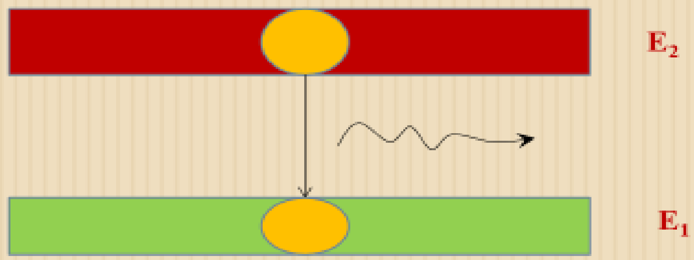
- The Laser beam is highly bright (intense) as compared to the conventional light because more light is concentrated in a small region.
- It is observed that the intensity of 1mV laser light is 10,000 times brighter than the light from the sun at the earth's surface.
- Laser light is coherent and so at a time many photons are in phase and they superimpose to produce a wave of larger amplitude.
- The intensity is proportional to the square of the amplitude and hence the intensity of the resultant laser beam is very high.

Three Quantum Process:

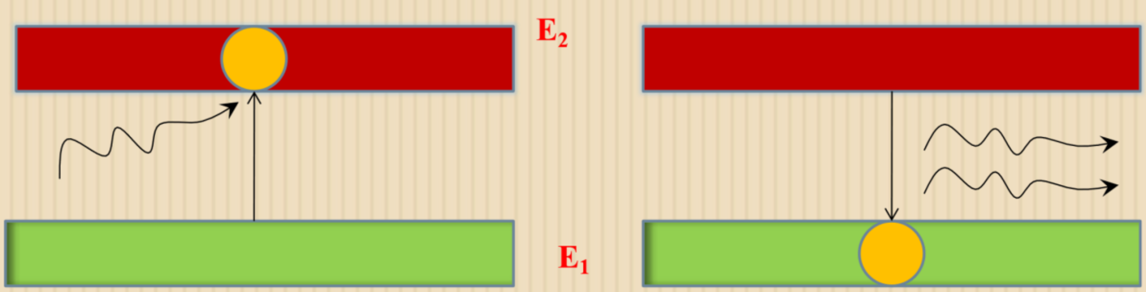


Spontaneous emission: An atom initially present in the excited state makes transition voluntarily on its own ,without any aid of external stimulus or an agency ,to the ground state and emits a photon of energy $h\nu = E_2 - E_1$. The period of stay of the atom (electron) in the excited state is called its life time.

This process of emission of light is called spontaneous emission.



Stimulated Emission: A photon having energy $h\nu_{12}$ $(E_2 - E_1)$ impinges on an atom present in the excited state and the atom is stimulated to make transition to the ground state. This gives off a photon of energy $h\nu_{12}$. The emitted photon is in phase with the incident photon. These are coherent. This type of emission is known as stimulated emission.



Before Stimulated Emission After Stimulated Emission

Einstein Coefficients and their relations:

Einstein's coefficients

Let N_1 be the number of atoms per unit volume with energy E_1 and N_2 the number of atoms per unit volume with energy E_2.

Let 'n' be the number of photons per unit volume at frequency ν such that $h\nu = E_2 - E_1$.

Then the energy density of interacting photons ρ (ν) is given by

$$\rho(\nu) = n\, h\, \nu \qquad \rightarrow (1)$$

When these photons interact with atoms, both upward (absorption) and downward (emission) transitions occur. At equilibrium ,these transition rates must be equal.

Upward Transition(Stimulated Absorption)

Stimulated absorption rate depends on the number of atoms available in the lower energy state for absorption of these photons as well as the energy density of interacting radiation.

i.e., stimulated absorption rate $\alpha\ N_1$

$$\alpha\ \rho\ (\nu)$$

$$= B_{12} N_1\, \rho\ (\nu) \qquad \rightarrow (2)$$

Where, the constant of proportionality B_{12} is the Einstein coefficient of stimulated absorption.

Downward transition

1.Spontaneous Emission:

The spontaneous emission rate depends on the number of atoms in the excited energy state.

i.e., spontaneous emission rate $\alpha\ N_2$

$$= N_2\, A_{21} \qquad \rightarrow (3)$$

Where the constant of proportionality A_{21} is the Einstein coefficient of spontaneous emission.

2.Stimulated emission:

stimulated emission rate depends on the number of atoms available in the excited state as well as energy density of interacting photons.

i.e., stimulated emission rate $\alpha\ N_2$

$\alpha\ \rho(\nu)$

$$=N_2 \rho(\nu) B_{21} \rightarrow (4)$$

Where, the constant of proportionality B_{21} is the Einstein coefficient of stimulated emission.

For a system in equilibrium, the upward and down word transition rates must be equal and hence,

$$N_1 \rho(\nu) B_{12} = N_2 \rho(\nu) B_{21} + N_2 A_{21} \rightarrow (5)$$

$$\text{Now, } \rho(\nu) = [N_2 A_{21}]/N_1 B_{12} - N_2 B_{21} \longrightarrow (6)$$

$$\text{And, } \rho(\nu) = [(A_{21}/B_{21})]/[(B_{12}/B_{21})(N_1/N_2)]-1 \rightarrow (7)$$

According toBoltzmann distribution law, the number of atoms N_1 and N_2 in energy states E1 and E2 in thermal equilibrium at temperature T is given by as,

$$N_1 = N_o \exp(-E_1/KT) \text{ and } N_2 = N_o \exp(-E_2/KT)$$

Now, $N_1/N_2 = \exp[h\nu/KT]$

$$\rho(\nu) = [A_{21}/B_{21}]/\{(B_{12}/B_{21}) \times \exp[h\nu/KT] - 1\} \ (8) \longrightarrow$$

From Planck's law of blackbody radiation, the radiation density is given by

$$\rho(\nu) = [8\pi h\nu^3/C^3] \times [1/\exp(h\nu/KT) - 1] \ (9) \longrightarrow$$

Comparing equations (8) and (9),

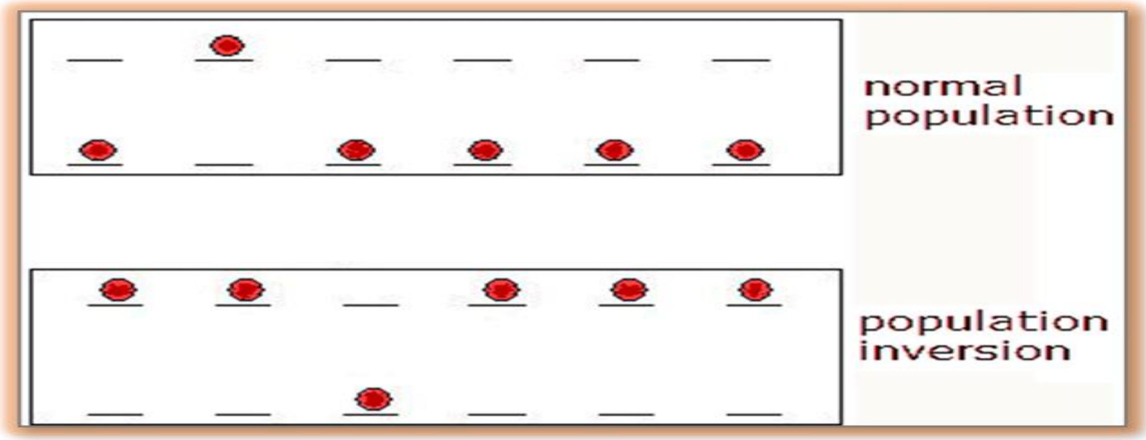
$$B_{12} = B_{21} \longrightarrow (10)$$

And, $A_{21}/B_{21} = 8\pi h\nu^3/C^3 \longrightarrow (11)$

Equation's (10) and (11) are referred to as the Einstein relations.

Population Inversion:

- Usually in a system, the number of atoms (N_1) present in the ground state (E_1) is larger than the number of atoms (N_2) present in the higher energy state. The process of making $N_2>N_1$ is called population inversion.



Conditions for population inversion are:

The system should possess at least a pair of energy levels (E2>E1), separated by an energy equal to the energy of a photon (hν).

There should be a continuous supply of energy to the system such that the atoms must be raised continuously to the excited state.

Pumping Methods:

Some of them are,

(i) Optical pumping

(ii) Electrical discharge

(iii) Inelastic collision of atoms

(iv) Chemical reaction and

(v) Direct conversion

1. Optical pumping

In optical pumping a light source is used to supply luminous energy. Most often this energy comes in the form of short flashes of light. This method was first used by maiman in his ruby laser and is widely used in solid-state lasers.

2. Electric discharge method

In electric discharge, the electrons are emitted by the cathode and are accelerated towards the anode. Some of these electrons will collide with the atoms of the active medium and excite to the higher levels. This method is preferred when the active medium is ion-gas.

3. Inelastic atom- atom collision

This method is used in gas lasers consisting of two species of atoms. Pumping by electrical discharge raises one type atoms to their excited states. These excited atoms collide inelastically with another type of atoms. So these latter atoms are provided the population inversion need for the laser emission. This type of pumping occurs in helium-neon laser.

4. Direct conversion

In this method, electrons and holes are made to combine across the depletion region by applying a forward bias. Electrons and holes recombine to emit radiation. Thus direct conversion of electrical energy into radiation occurs in semiconductor laser and in LED's.

5. Chemical reactions

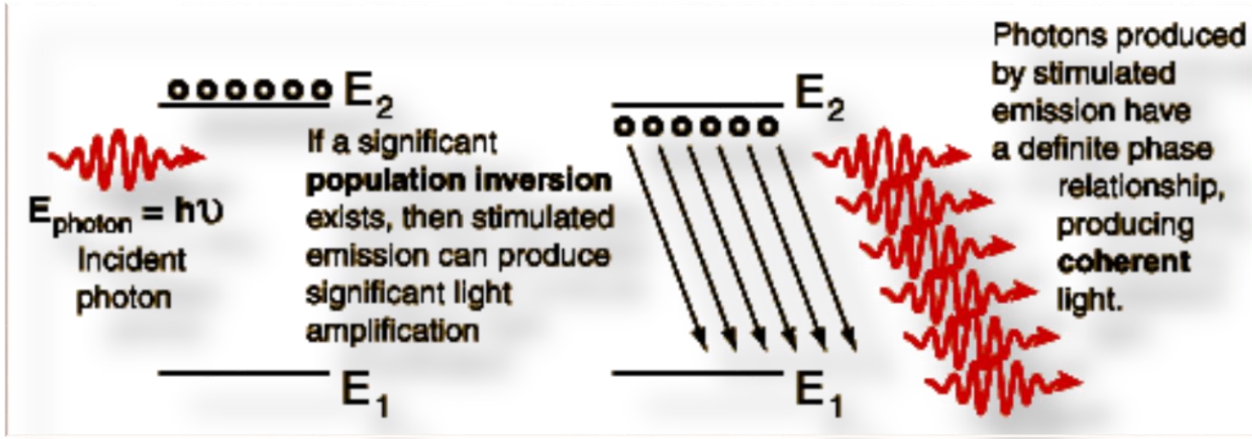
If the energy released through a chemical reaction in the active medium excites the particles of the active medium then it is called chemical pumping. Hydrogen can react with fluorine to produce hydrogen fluoride according to the reaction

Lasing Action:

The steps involved in Lasing action are,

1. **Pumping:** The process of sending atoms from lower energy state to higher energy state is called Pumping. Different pumping mechanisms are adopted depending on the type of the laser. For Ruby laser, Optical pumping is adopted. For He-Ne laser, the pumping mechanism is Electric discharge. In Semi-conductor laser, it is Direct conversion and in the case of CO_2 laser, the mechanism is Chemical reaction.
2. **Population inversion :** Population inversion can be achieved with the presence of a meta stable state.

3. **Stimulated emission of radiation :** Photons produced by stimulated emission are in phase and they produce coherent light.



Ruby Laser:

- Ruby Laser is the first type of laser, demonstrated in the year 1960 by T.H.Maiman.
- Ruby Laser is a solid state laser.
- It is a pulsed three level pumping scheme.

Active medium:

The active medium in Ruby rod (Al2O3+Cr2O3) is Cr3+ions. Some of the Aluminum atoms are replaced by 0.05% of Chromium atoms. Lasing action takes place in Chromium energy levels.

Energy Source: The pumping of ions is through optical pumping, using Xenon flash lamp.

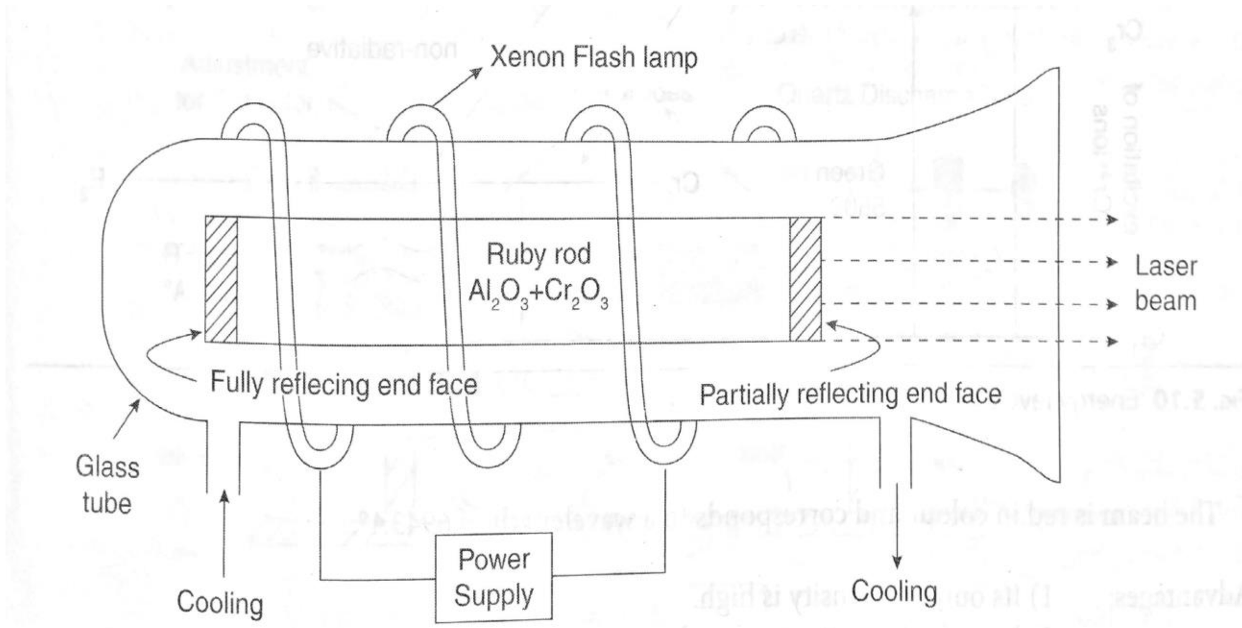
Construction:

Ruby Laser consists of a cylindrical shaped Ruby crystal rod. One of the end faces is highly silvered and the other face is partially silvered so that it transmits 10-25% of the incident light and reflects the rest.

The ruby crystal is placed along the axis of a helical Xenon or Krypton flash lamp of high intensity. This is surrounded by a reflector.

The ruby rod is protected from heat by enclosing it in a hollow tube, through which cold water is circulated.

The ends of the flash lamp are connected to a pulsed high voltage source, so that the lamp gives flashes of an intense light.



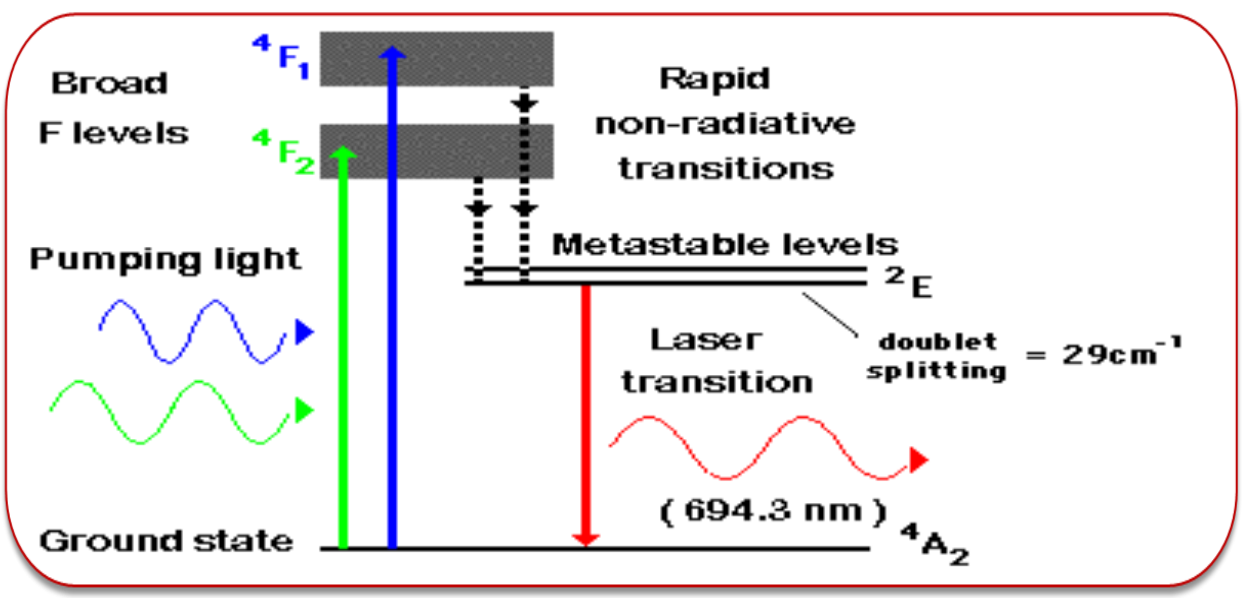
Working:

The Chromium ions are responsible for the stimulated emission of radiation, whereas Aluminum and Oxygen ions are passive, sustaining the lasing action.

The Chromium ions absorb the radiations of wavelength around 5500Ao (Green) and 4000Ao (Blue),emitted by the flash lamp and get excited to 4F2 and 4F1 energy levels respectively, from ground state.

After the life time, the ions make non- radiative transition to the metastable state 2E, consisting of a pair of energy levels (doublet).

Population inversion takes place between metastable and ground state. As a result, stimulated emission takes place giving rise to the emission of light of wavelengths 6929Ao and 6943Ao , of which 6943Ao is the laser radiation of high intensity.



Helium-Neon (He-Ne) Laser:

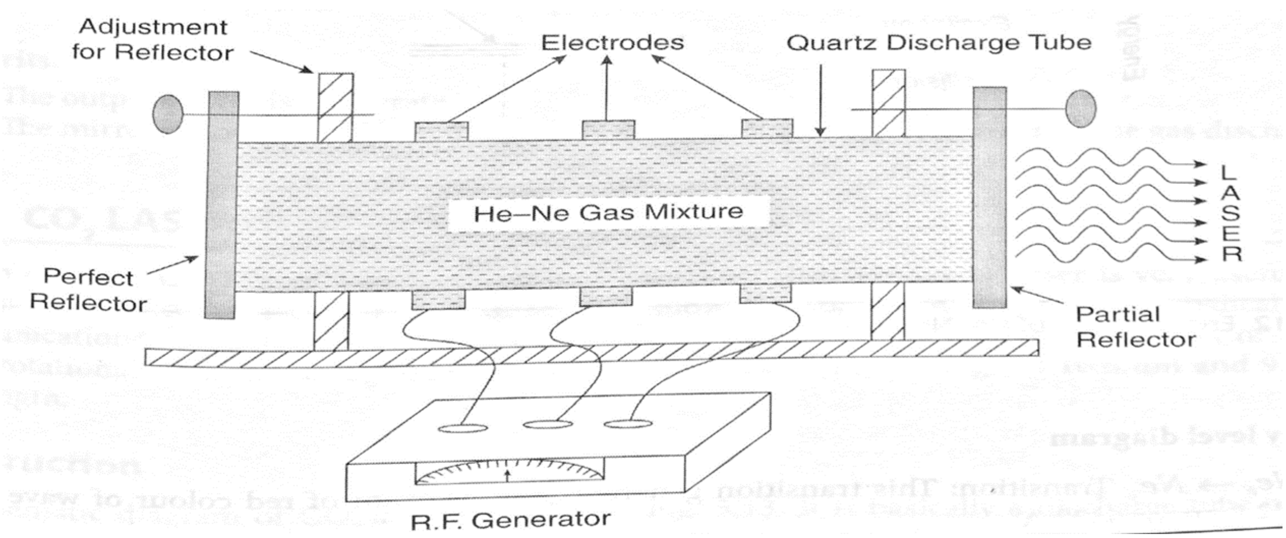
- Helium-Neon is a gas laser.
- It is a continuous four level laser.

Active medium: Helium and Neon gases in the ratio of 10:1respectively. Ne atoms are responsible for lasing action.

Energy Source: Two electrodes are fixed near the ends of the tube to pass electric discharge through the gas.

Construction:

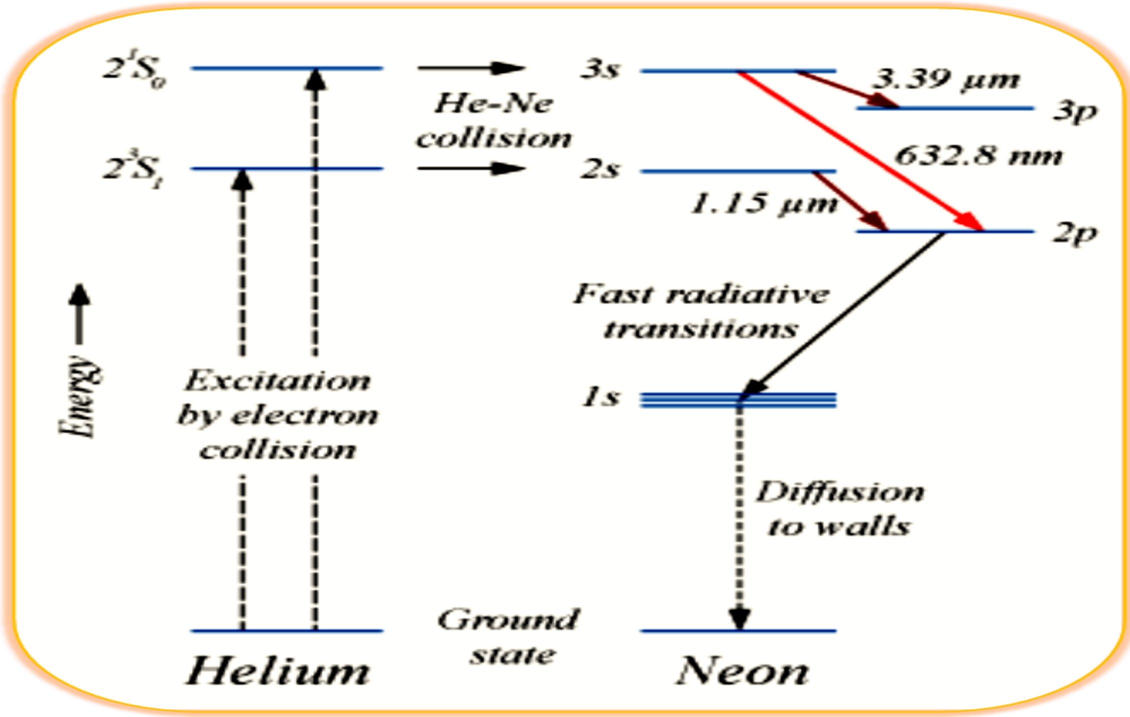
- He-Ne laser consists of a long, narrow cylindrical tube made up of fused quartz, of diameter around 2 to 8 mm and length around 10 to 100 cm.
- The tube is filled with helium and neon gases in the ratio of 10:1. The pressure of the mixture of gases inside the tube is nearly 1 mm of Hg.
- Two electrodes are fixed near the ends of the tube to pass electric discharge through the gas.
- Two optically plane mirrors are fixed at the two ends of the tube.
- One of the mirrors is fully silvered so that nearly 100% reflection takes place and the other is partially silvered, so that 1% of the light incident on it will be transmitted.



Working:

- Lasing action is due to the neon atoms. Helium is used for selective pumping of neon atoms to upper energy levels.
- When a discharge is passed through the gaseous mixture, electrons are accelerated down the tube. These accelerated electrons collide with the ground state helium atoms and excite them to two meta stable states 2^1s and 2^3s.
- The helium atoms in the meta stable state 2^1s collide with the neon atoms in the ground state and excite them to 3s level.

- Similarly, the helium atoms in the meta stable state 2^3s collide with the neon atoms in the ground state and excite them to 2s energy level
- During collisions, the helium atoms transfer their energy to neon atoms and come back to ground state.



- Since 3s and 2s levels of neon atoms are meta stable states, population inversion takes place at these levels. Any of the spontaneously emitted photon will trigger the laser action
- The excited neon atoms transit to ground state in three different ways, leading to three lasers of different wavelengths. They are,
- Transition from 3s to 3p level, giving rise to a radiation of 3.39μm, which lies in the infrared region.
- Transition from 3s to 2p level, giving rise to visible radiation of wavelength 6328A^o, that lies in red region.
- Transition from 2s to 2p level giving rise to a wavelength of 1.15μm, which lies in the infrared region.
- The atoms in the 3p and 2p levels undergo spontaneous emission to 1s level by fast decay, giving rise to photons by spontaneous emission.
- The atoms in the 1s level return back to the ground state, by non-radiative diffusion and collisions with the walls of the discharge tube.
- After arriving to ground state, the neon atoms raise back to 3s and 2s levels by excited helium atoms, for getting a continuous output.

Carbon dioxide (CO2) laser:

Construction

The schematic diagram of CO_2 laser is shown in Fig. 5.13. It is basically a discharge tube having cross-section of about 1.5 cm^2 and a length of about 26 cm. The discharge tube is filled with a mixture of carbon dioxide, nitrogen and helium gases at the ratios of 1:4:5 respectively. A high value of dc voltage is used for electric discharge in the tube due to which CO_2 breaks into CO and O. In order to maintain the equilibrium of CO_2 molecules, a small amount of water vapour is added to the gaseous mixture which regenerates the CO_2 molecules.

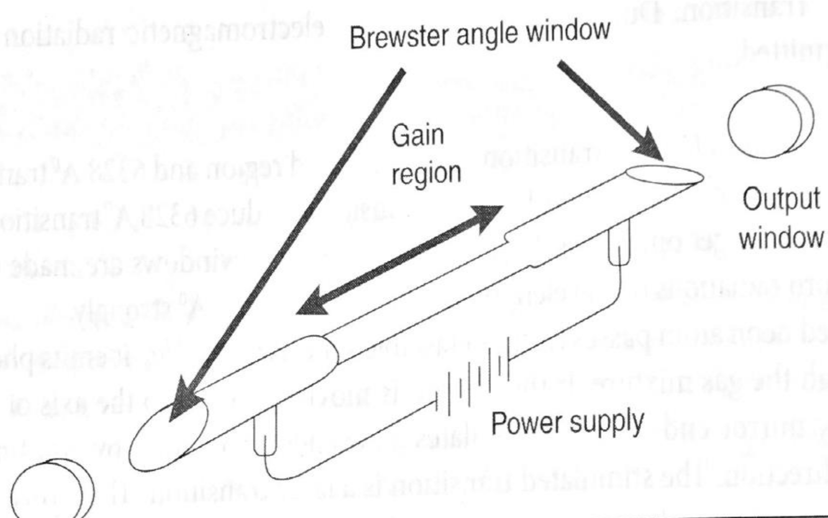


Fig. 5.13 Schematic of CO_2 laser

CO_2 molecule is a linear molecule consisting of a two oxygen atoms and a carbon atom between them. The energy level of each electron is associated with nearly equally spaced vibrational levels and each vibrational level has a number of rotational levels. The three different vibrational modes of CO_2 molecule as shown in below Figure.

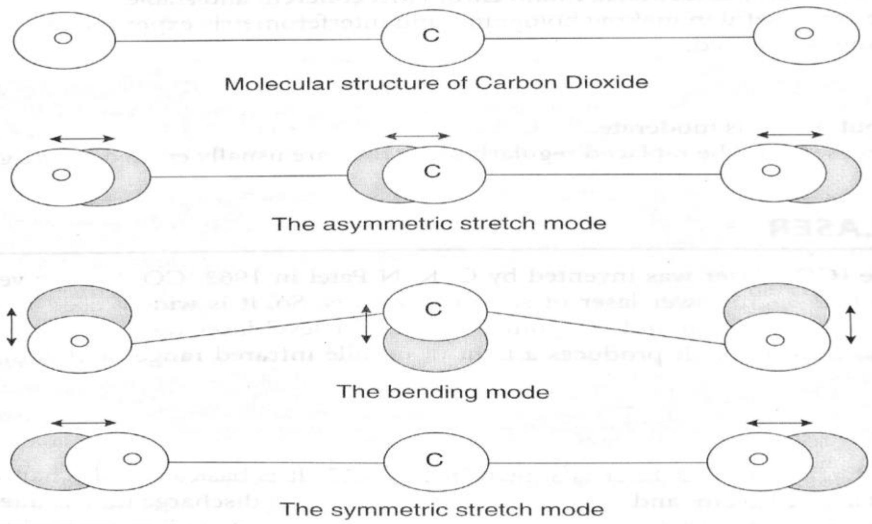


Fig. 5.14 Modes of CO_2

Working

At any one time, the molecules can be vibrating in any combinations of these fundamental modes. A set of three quantum numbers (υ_1, υ_2, υ_3) are used to denote the modes of vibration. Where υ_1 represents symmetric modes of vibration, υ_2 represents bending mode of vibration and υ_3 represents the asymmetric mode of vibration.

in Fig. 5.15. In CO_2 laser, the excitation is provided by electric discharge. Excited N_2 molecules transfer their energy to the CO_2 molecule in resonant collisions exciting them to (001) level which are metastable level with relatively longer life time. With sufficient pumping, a population inversion is produced between (001) state and (100) and (020) states respectively and laser transition begins.

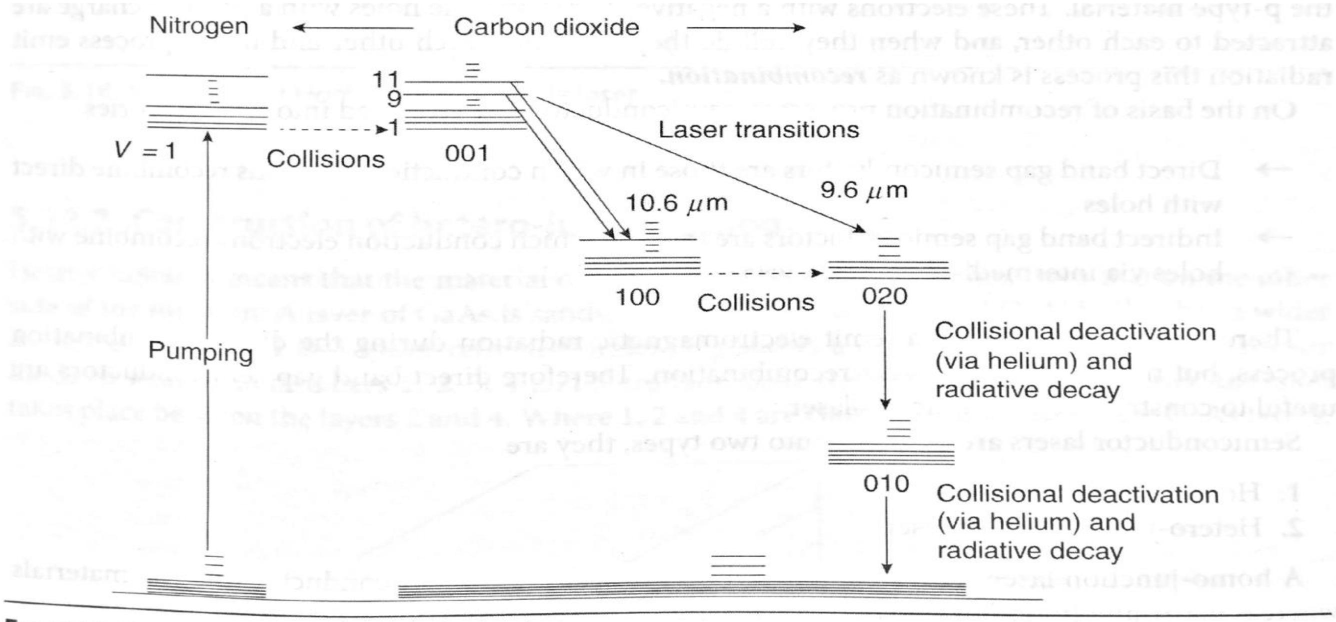


FIG. 5.15 Energy level diagram

through inelastic collisions. The CO_2 laser operates in continuous wave mode and is capable of generating high power of the order of several kilowatts at a relatively high efficiency of about 40%. Therefore it is mostly used laser.

Semi-Conductor Laser:

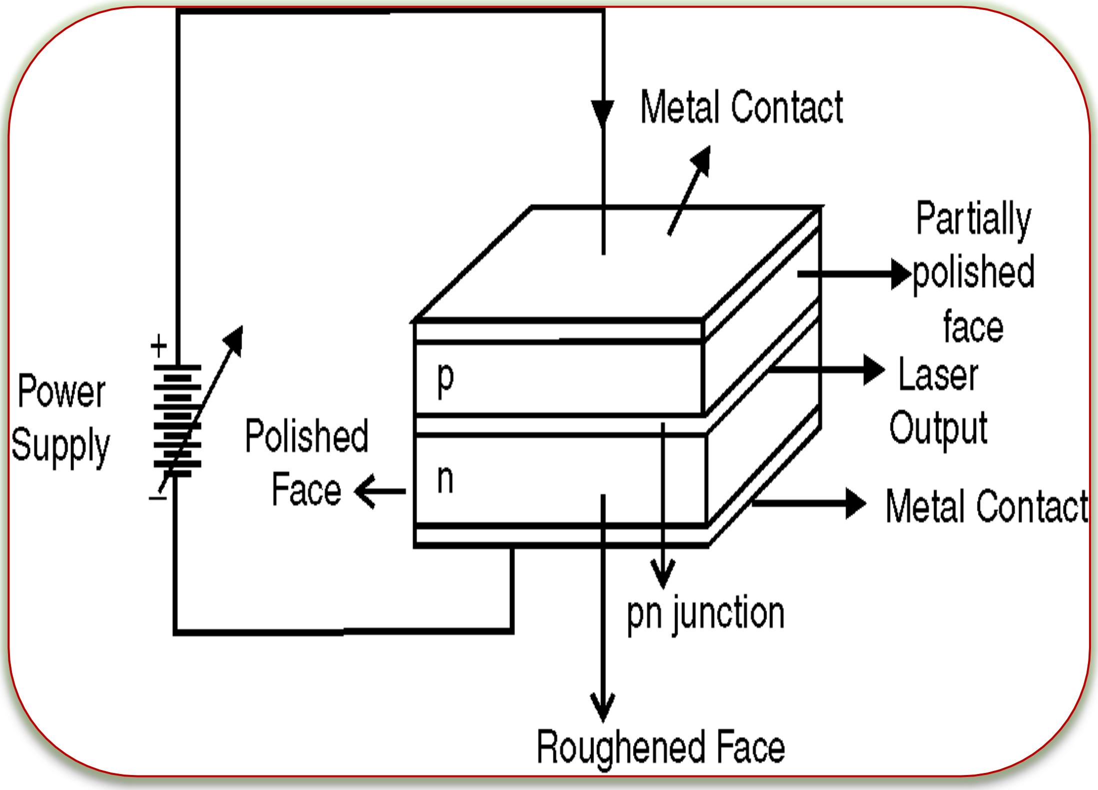
Construction:

Active medium:

- A p-n junction diode made from crystalline Gallium Arsenide is the active medium.
- The p-region and n-region in the diode are obtained by heavily doping Germanium and Tellurium respectively in GaAs.
- At the junction, the sides through which emitted light is coming out, are well polished and are parallel to each other.

Energy Source:

Electric current which is applied to the crystal platelet through a strip electrode fixed to its upper surface, is the energy source.



Working:

- Population inversion is achieved by injecting electrons across the junction from the n-region to the p-region by means of a forward bias voltage.
- When a large amount of current of the order 10^4 amp/cm^2 is passed through the junction to provide excitation, the direct recombination of electrons and holes take place resulting in the emission of photons. These photons further increase the rate of recombination. Thus, more number of photons are emitted.
- The wavelength of the emitted radiation depends upon the concentration of the donor and acceptor atoms in Ga As.
- In reverse bias, no carrier injection takes place and consequently no light is emitted.

Nd: YAG Laser:

Definition: Nd:YAG laser is the short form used for Neodymium-doped Yttrium Aluminium Garnet. It is a solid state and 4 level system as it consists of 4 energy levels.

Nd ion is rare earth metal and it is doped with solid state host crystal like yttrium aluminium garnet (YAG – $Y_3Al_5O_{12}$) to form Nd:YAG laser. Due to doping, yttrium ions get replaced by the Nd^{3+} ions. Also, the doping concentration is around 0.725% by weight.

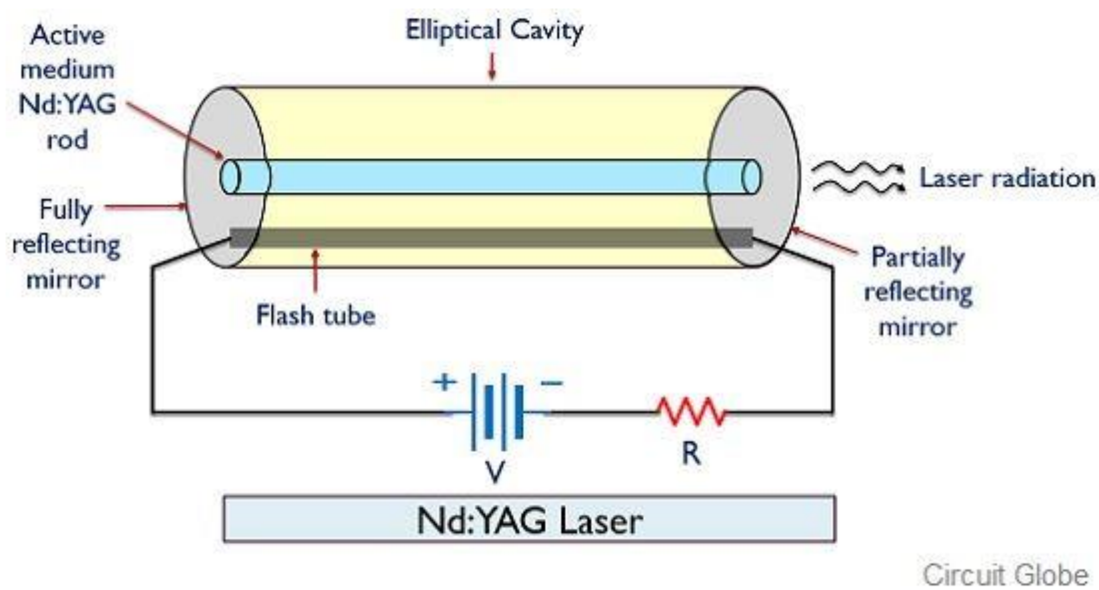
Its working principle is such that when optical pumping is provided to the device. Then the Nd ions get raised to higher energy levels and their transition produces a laser beam.

This laser generally emits light of wavelength of nearly 1.064 μm.

Construction of Nd:YAG laser

Nd:YAG laser is basically categorized into 3 domains that are the active medium, pumping source and the optical resonator.

The figure below shows the road like the structure of Yd:YAG laser:



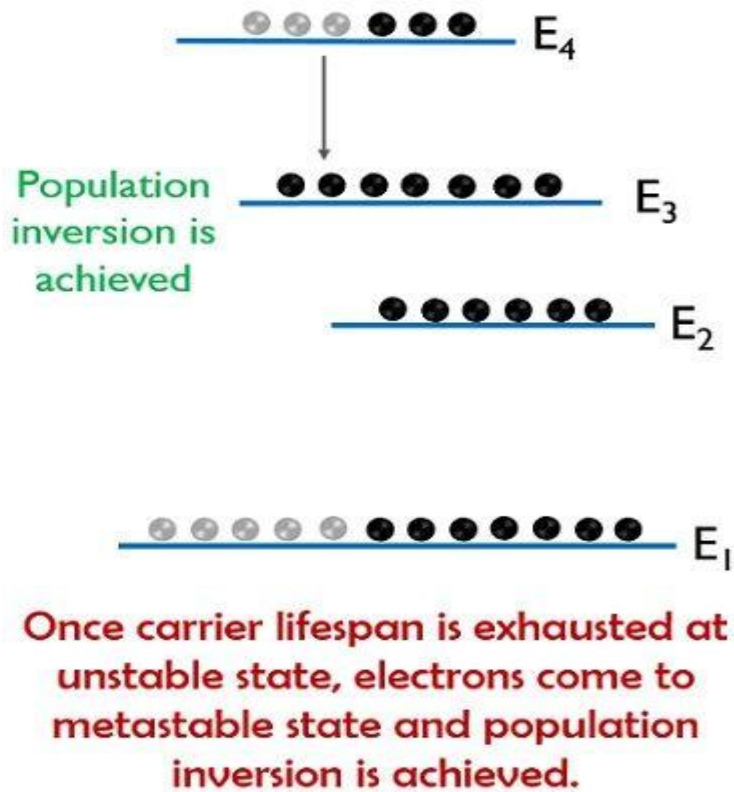
Working of Nd:YAG laser

It is 4 level systems i.e.; it contains 4 energy levels. So, in this section, we will discuss the working of Nd: YAG laser with the help of the energy level diagram.

The figure below shows the 4-state energy level diagram of Nd: YAG laser:

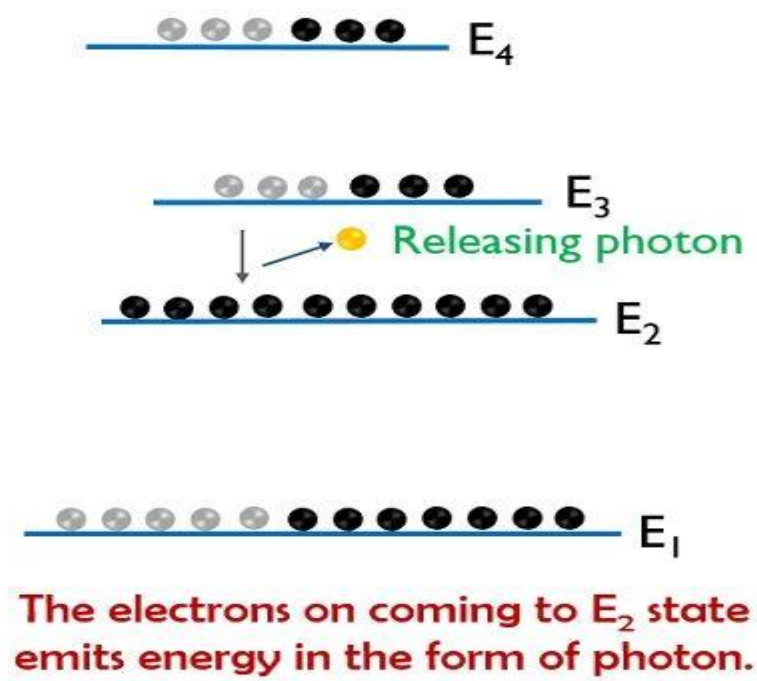
Here, E_1 is the lowest energy state while E_4 is the highest energy level.

E_1 gains energy and moves to energy state E_4. However, as E_4 is an unstable state and it exhibits short lifespan and comes to lower energy state E_3 very fastly but without radiating any photon.



The energy state E_3 is the metastable state and exhibits longer lifespan. So, the electrons in this particular state will last for a longer duration. Due to this more number of electrons will be present at the metastable state E_3. Thereby attaining population inversion.

But once the lifetime of the electrons at the metastable state gets exhausted then these electrons by releasing photons come to lower energy state E_2.



E_2 also exhibit shorter lifespan like E_4. Thus, electrons present in E_2 state will come to E_1 without radiating energy in the form of a photon.

So, in this way electrons by gaining single photon of energy releases the energy of 2 photons. Also, as the system is equipped with optical resonators so, more number of photons will get generated as the pumped energy will get reflected inside the active medium.

In this way, several electrons on stimulation produce photons thereby generating a coherent laser beam of 1.064 µm.

Applications of Nd:YAG Laser

These are used in military applications to find the desired target. This type of laser also finds its application in medical field for the surgical purpose. These are also used in welding and cutting of steel and in communication system also.

Applications of Lasers:

Lasers in Communication:

- Lasers are used in Optical fibre communication as light source to transmit audio, video signals and data to long distances without attenuation and distortion.
- Laser beam can be used for the communication between the earth and the moon or to other satellites.
- Laser beam can be used for under water communication, as laser radiation is not absorbed by water.

Lasers in Industry:

- Lasers are used for welding. Dissimilar metals can be welded using lasers.
- Holes with controlled precision can be drilled in steel, ceramics, diamond and alloys, using lasers.
- Lasers are widely used in electronic industry in trimming the components of ICs.
- Lasers are used in cutting metal sheets, diamond and cloths. In the mass production of stitched clothes, lasers are used to cut the cloth in a desired dimension, all at once.
- Lasers are used for surface treatment. Laser beam is used in selective heat treatment for tempering the desired parts in automobile industry

Lasers in medicine:

- Lasers are used in eye surgery, especially to attach the detached retina.
- Lasers are used for treatments such as plastic surgery, skin injuries and to remove moles, tattoos and tumours developed in skin tissue.
- Lasers are used in stomatology-the study of mouth and its disease.
- Laser radiation is sent through optical fibre to open the blocked artery region.
- Lasers are used to destroy kidney stones and gall stones.
- Lasers are used in cancer diagnosis and therapy.
- Lasers are used in blood loss less surgery.
- Lasers are used to control hemorrhage.

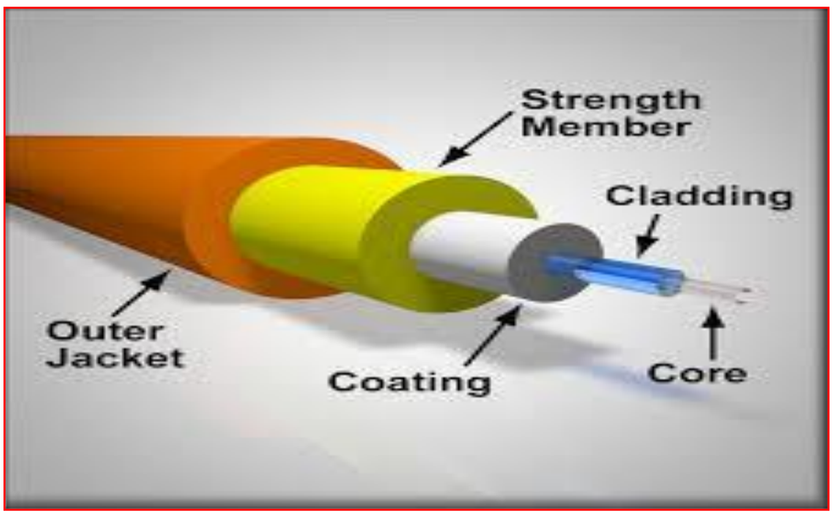
- Using CO_2 laser, liver and lung treatment can be carried out.
- Lasers are used in endoscopes, to detect hidden parts.
- Laser Doppler velocimetry is used to measure the velocity of blood in blood vessels.

Unit: IV (II)

1. Introduction to Fibre Optics:

- Optical Fibre is a flexible, transparent fiber made of extruded glass (silica) or plastic, slightly thicker than a human hair.
- It can function as a waveguide, or “light pipe”, to transmit optical signal between the two ends of the fiber.
- Optical fibers are widely used in fiber-optic communications, where they permit transmission over longer distance.

2. Structure of an Optical Fibre:



Structure of an optical fiber consists of three parts.

The core, the cladding and the coating (or buffer or outer jacket).

The core:

- The core is a cylindrical rod of dielectric material.
- Light propagates mainly along the core of the fiber.
- The core is generally made of glass.
- The core is described as having an index of refraction n_1.

The Cladding:

- The core is surrounded by a layer of material called the cladding, which is generally made of glass or plastic.
- The cladding layer is made of a dielectric material with an index of refraction n_2.
- The index of refraction of the cladding material is less than that of the core material.

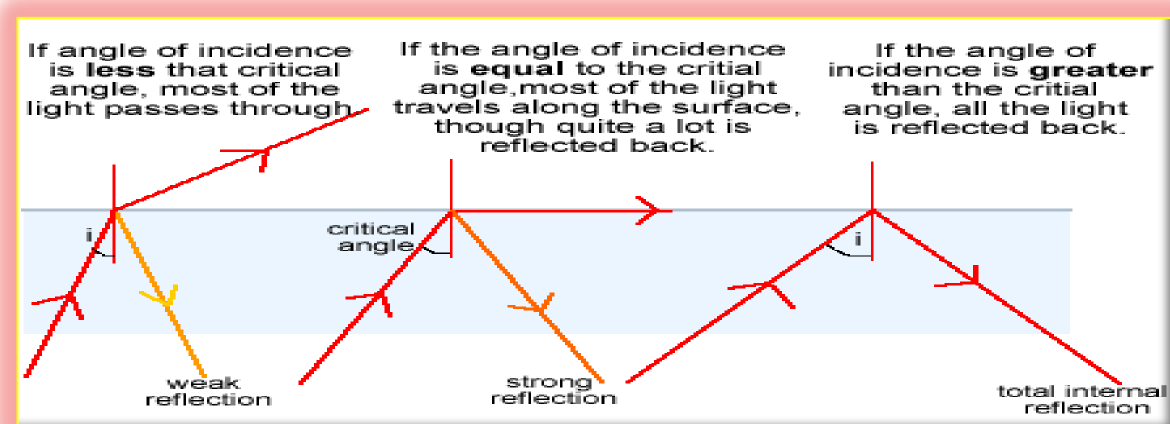
Buffer: (Coating)

- The coating or buffer is a layer of material used to protect an optical fiber from physical damage.
- The material used for a buffer is a type of plastic.
- The buffer is elastic in nature and prevents abrasions.

3. <u>Principle of total internal reflection:</u>

- Optical fibre carries light from one end of the fibre to the other by total internal reflection.
- When a ray of light passes from an optically denser medium into an optically rarer medium, the refracted ray bends away from the normal.

- critical angle (θ_c):When the angle of incidence is increased angle of refraction also increases and a stage is reached when the refracted ray just grazes the surface of separation of core and cladding. At this position the angle of refraction is 90 degrees. This angle of incidence is called the critical angle (θ_c) of the denser medium with respect to the rarer medium.



Condition for total internal reflection:

Let the reflective indices of core and cladding materials be n_1 and n_2 respectively.

According to the law of refraction,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Here, θ_1=, θ_c and θ_2= 90

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

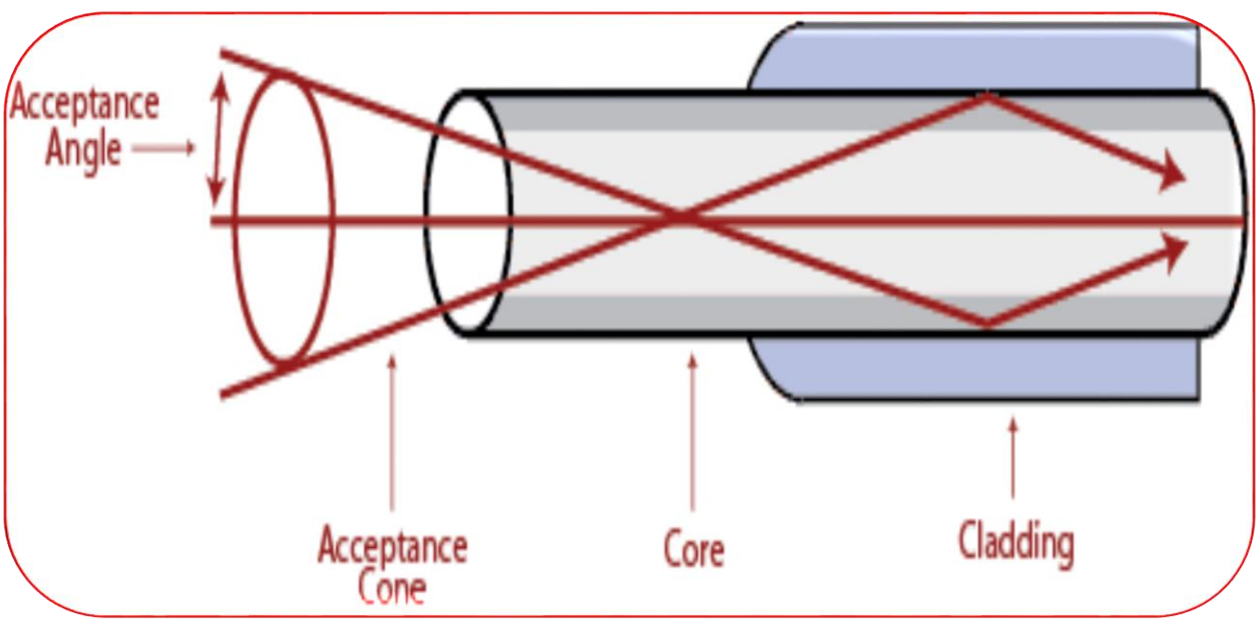
$$\sin\theta_c = {}^{n_2}/n_1$$

$$\theta c = \sin^{-1}({}^{n_2}/n_1) \qquad \rightarrow(1)$$

Equation (1) is the expression for condition for total internal reflection.

4. <u>Acceptance angle and Acceptance cone:</u>

- Acceptance angle: It is defined as the maximum angle of incidence at the end face of the optical fibre, for which the ray can be propagated through the core material.



- **Acceptance cone:** The cone obtained by rotating a ray at the end face of an optical fibre, around the fibre axis with the acceptance angle, is known as acceptance cone.
- Light launched at the fiber end within this acceptance cone alone will be accepted and propagated to the other end of the fiber by total internal reflection.
- Larger acceptance angles make launching easier.

5. <u>Equation for Acceptance angle</u>

- For light rays to propagate through the optical fibre, by total internal reflection, they must be incident on the fibre core within the angle θ_o, called the acceptance angle.
- Applying Snell's law at B,

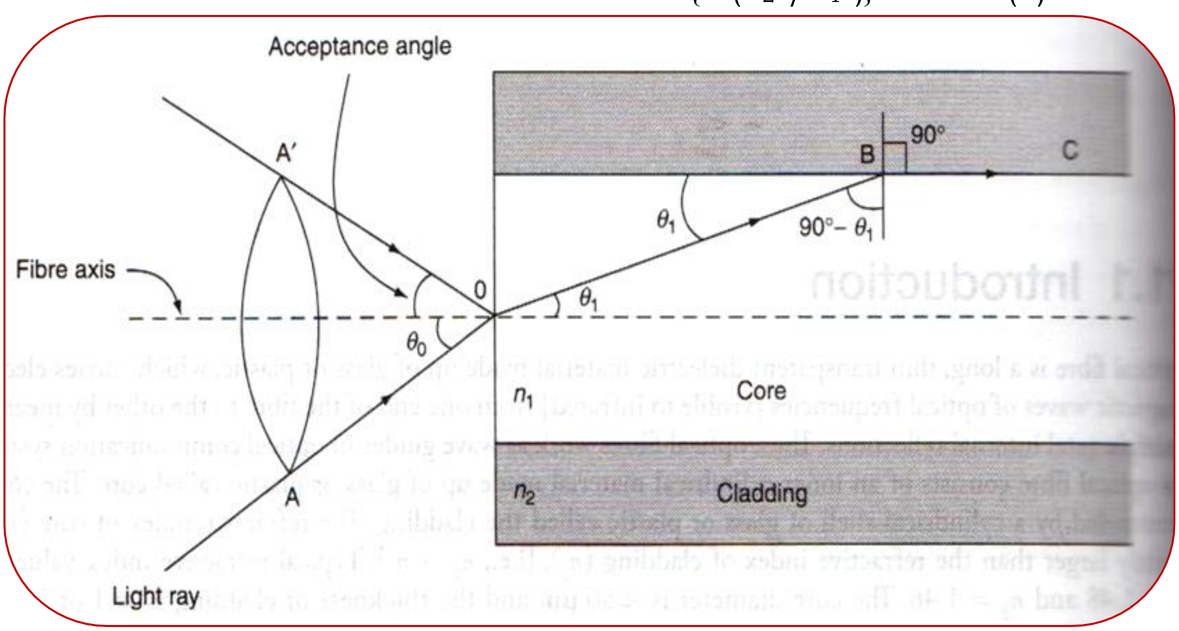
$$n_1 \sin(90^o-\theta_1) = n_2 \sin 90^o$$

$$n_1 \cos \theta_1 = n_2$$

$$\cos \theta_1 = n_2/n_1$$

$$\text{or } \sin\theta_1 = (1-\cos^2\theta_1)^{1/2}$$

$$=\{1-(n_2^2/n_1^2)\}^{1/2} \ldots\ldots\ldots (1)$$



- Applying Snell's law at O,

$$n_o \sin\theta_0 = n_1 \sin\theta_1$$

$$\text{or } \sin\theta_0 = (n_1/n_0)\sin\theta_1 \;\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Substituting eq. (1) in eq. (2),

$$\text{Sin } \theta_0 = (n_1/n_0)\,(1 - n_2^2/n_1^2)^{1/2}$$

$$= \frac{(n_1^2-n_2^2)^{1/2}}{n_0} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (3)$$

- As the fibre is in air, $n_0 = 1$

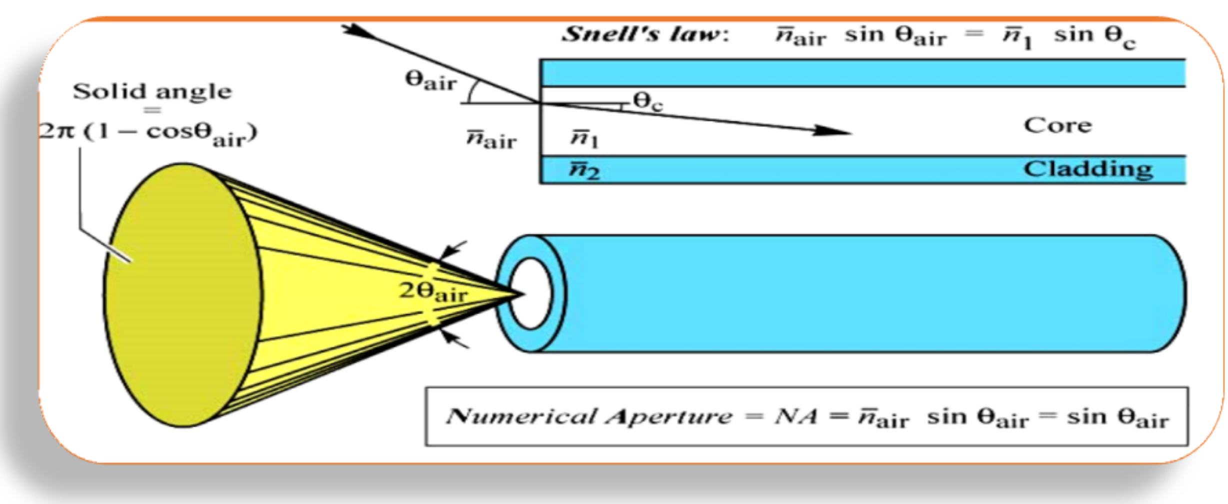
Therefore, eq. (3) becomes

$$\text{Sin } \theta_0 = (n_1^2-n_2^2)^{1/2} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Eq. (4) is the equation for Acceptance angle.

6. <u>Numerical Aperture (NA):</u>

- ✓ Light gathering capacity of the fiber is expressed in terms of maximum acceptance angle and is termed as "Numerical Aperture".
- ✓ Light gathering capacity is proportional to the acceptance angle θ_o.
- ✓ So, numerical aperture can be represented by the sine of the acceptance angle of the fibre i.e., sin θ_o.
- ✓ For example, the light acceptance angle in air is $\theta_{air} = 11.5^o$ for a numerical aperture of NA=0.2.



Expression for Numerical aperture:

- According to the definition of Numerical aperture (NA),

$$NA= \sin \theta_0 = (n_1^2-n_2^2)^{1/2} \quad \rightarrow (1)$$

- Let 'Δ,' the fractional change in the refractive index, be the ratio between the difference in the refractive indices of core and cladding material respectively.

$$\Delta = \frac{n_1-n_2}{n_1} \quad \rightarrow (2)$$

$$\text{or } \Delta n_1 = n_1 - n_2 \quad \rightarrow (3)$$

Eq. (1) can be written as,

$$NA= (n_1^2-n_2^2)^{1/2}$$

$$= \{(n_1-n_2)\ (n_1+ n_2)\}^{1/2} \quad \rightarrow (4)$$

- Substituting eq. (3) in eq. (4),

$$NA = \{(\Delta n_1)\ (n_1+n_2)\}^{1/2}$$

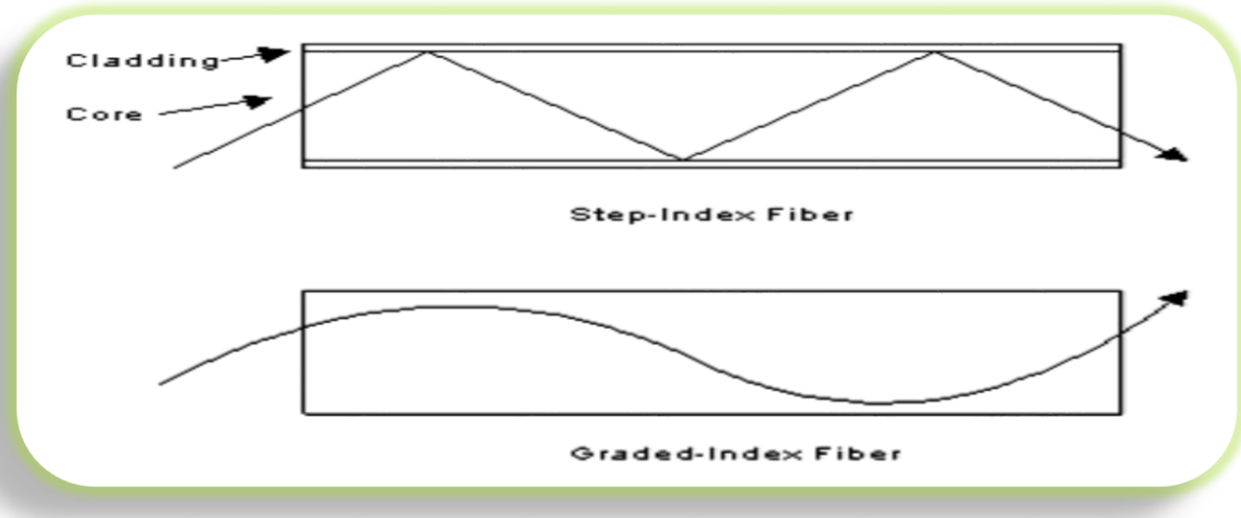
- As $n_1 \approx n_2$, $n_1 + n_2 = 2n_1$

And therefore, Numerical Aperture = $(2n_1^2\Delta)^{1/2} = n_1\ (2\Delta)^{1/2}$ → (5)

From equation (5) it is seen that numerical aperture depends only on the refractive indices of core and cladding materials and it is independent on the fiber dimensions.

7. <u>Types of Optical Fibres:</u>

- Based on the variation of refractive index of core, optical fibers are divided into: (1) step index and (2) graded index fibers.
- In all optical fibers, the refractive index of cladding material is uniform.

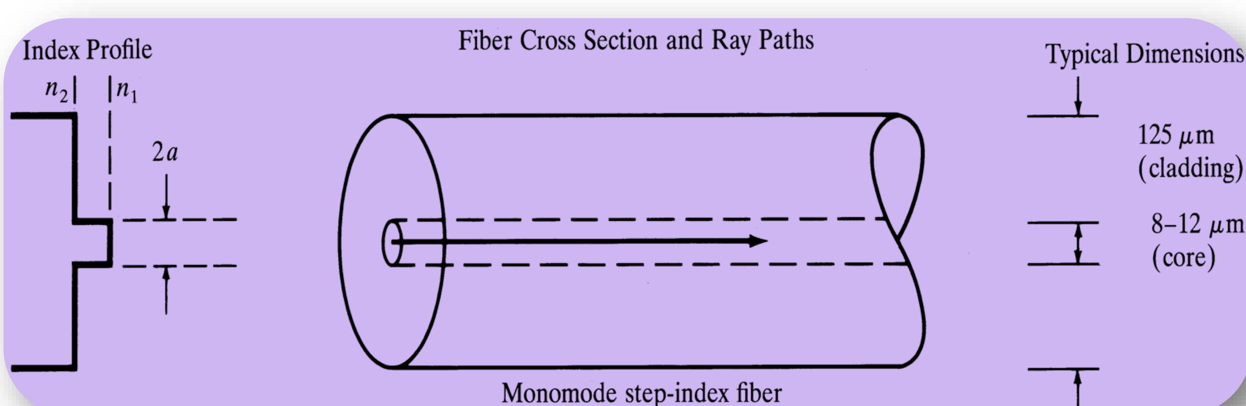


Light path through Step- index and Graded index Fibre

Refractive index profile in Single mode Step index fibre

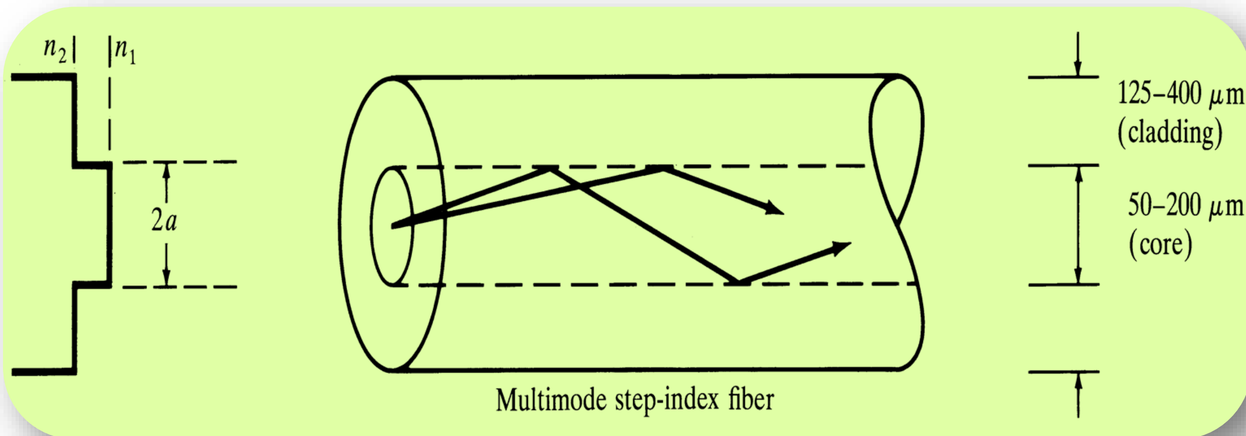
- The refractive index is uniform throughout the core of this fibre.
- As we go radially in this fibre, the refractive index undergoes a step change at the core-cladding interface.
- The core diameter of this fibre is about 8 to 10 μm and outer diameter of cladding is 60 to 70 μm.
- In this fibre, the transmission of light is by successive total internal reflections i.e. it is a reflective type fiber.

These fibres are mainly used in submarine cable system.



Refractive index profile in Multimode Step index fibre

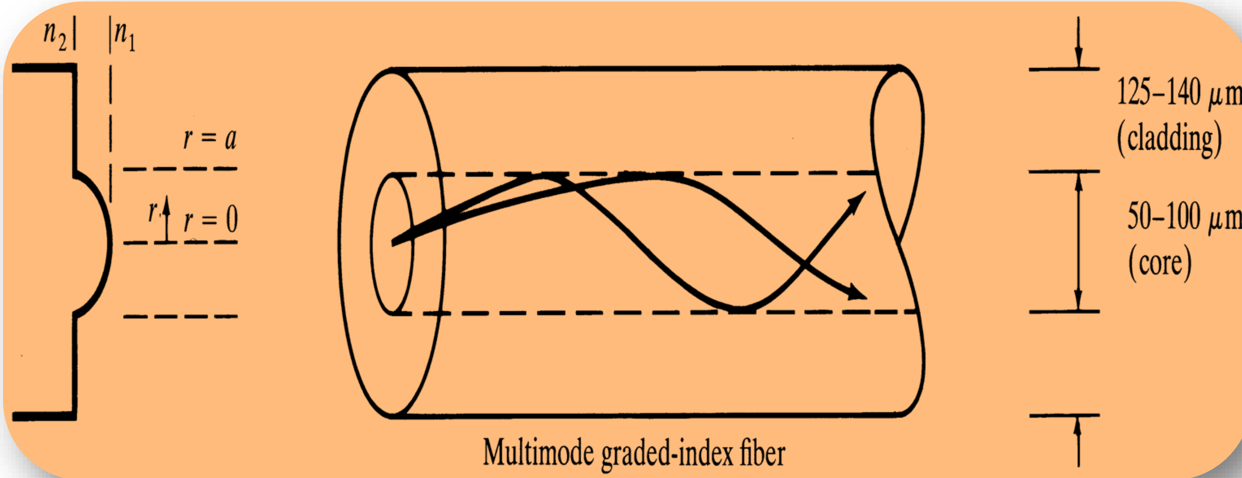
- Its core and cladding diameters are much larger to have many paths for light propagation.
- The core diameter of this fiber varies from 50 to 200 μm and the outer diameter of cladding varies from 100 to 250 μm.
- Light propagation in this fiber is by multiple total internal reflections i.e., it is a reflective type fiber.
- It is used in data links, which have lower band width requirements.



Refractive index profile in Multimode graded index fibre

- In this fiber, the refractive index decreases continuously from center radially to the surface of the core.
- The refractive index is maximum at the center and minimum at the surface of core.
- The diameter of the core varies from 50 to 200μm and the outer diameter of the cladding varies from 100 to 250 μm.

The refractive index profile is circularly symmetric.



8. <u>Attenuation in Optical Fibres:</u>

- Attenuation is the loss of power suffered by the optical signal as it propagates through the fiber.
- It is also called fiber loss.
- Signal attenuation is defined as "the ratio of the input optical power (P_i) into the fiber to the output optical power received (P_o) at the other end of the fiber".
- The attenuation coefficient of the signal per unit length is given as,

$$\alpha = 10/L \log (Pi/Po) \text{ dB/km}$$

Where, L is the length of the fibre.

- The mechanisms through which attenuation takes place are

1. Absorption losses.
2. Scattering losses.
3. Bending losses.
4. Microbending and Wave guide losses.

9. <u>Applications of Optical Fibres:</u>

1. Sensors:

- Fibers have many uses in remote sensing.
- Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities.
- Used as sensors to measure temperature inside aircraft jet engines.
- To measure the internal temperature of electrical transformers.

2. Telecommunication:

- Optics fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals.
- Unlike electrical cables, fiber optics transport information far distances with few repeaters.
- Fiber optic cables can carry a large number of different signals.
- Optical fibers are used in computer and cellular networks.

3. Power transmission:

- Optical fiber can be used to transmit power using a photovoltaic cell to convert the light into electricity.
- Fiber optics are used to connect users and servers in a variety of network
- They are also used in military as hydrophones for seismic and SONAR uses, as wiring in aircraft, submarines and other vehicles and also for field networking.
- Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications.

4. Medical Applications:

- Optical fiber is used in imaging optics. They are used as light guides in medical
- Used as imaging device called an endoscope, which is used to view objects through a small hole.

- Medical endoscopes are used for surgical procedures to view the internal parts of the human body.
- Industrial endoscopes are used for inspecting anything hard to reach, such as jet engine interiors.

5. Spectroscopy:

- Many microscopes use fiber-optic light sources to provide intense illumination of samples being studied.
- In spectroscopy, optical fiber bundles transmit light from a spectrometer to a substance that cannot be placed inside the spectrometer itself, in order to analyze its composition.
- By using fibers, a spectrometer can be used to study objects remotely.