CBCS-2021 Scheme

MODULE 3- LASERS AND OPTICAL FIBERS

LASERS

The word Laser stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. It is a device which amplifies light. It has properties like Coherence, Unidirectional, Monochromatic, Focus ability, etc.

Interaction of an electromagnetic wave with matter leads to transition of an atom or a molecule from one energy state to another. If the transition is from lower state to higher state it absorbs the incident energy. If the transition is from higher state to lower state it emits a part of its energy.

Emission or Absorption takes through quantum of energy called photons. $h\nu$ is called quantum energy or photon energy.

$h = 6.626\times10^{-34}$ Joules Second is Planck's constant and 'ν' is the frequency.

If ΔE is the difference between the two energy levels,

Then $\Delta E = (E_2 - E_1)$ Joule

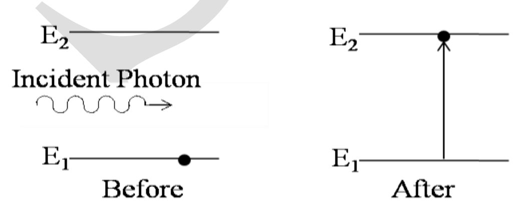
According to Max Planck, $\Delta E = h\nu = (E_2 - E_1)$

$\nu = (E_2 - E_1)/h$ Hz.

Three types of interactions, which are possible, are as follows:

1) ***Induced Absorption:***

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



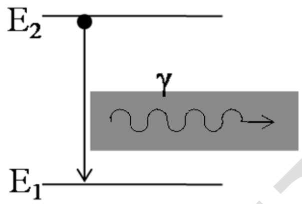
Consider the system having two energy states E_1 and E_2, $E_2 > E_1$. When a photon of energy $h\nu$ is incident on an atom at level E_1, the atom goes to a higher energy level by absorbing the energy.

When an atom is at ground level (E_1), if an electromagnetic wave of frequency ν is applied to the atom, there is possibility of getting excited to higher level (E_2). The incident photon is absorbed. It is represented as

$$\text{Atom} + \text{Photon} \rightarrow \text{Atom}^*$$

2) Spontaneous Emission:

The emission of a photon by the transition of a system from a higher energy state to a lower energy state without the aid of an external energy is called spontaneous emission.



Let 'E_1' and 'E_2' be two energy levels in a material, such that $E_2>E_1$. E_1 is ground level and E_2 is the higher level. $h\nu=E_2-E_1$ is the difference in the energy. The atom at higher level (E_2) is more unstable as compared to that at lower level (E_1).

The life time of an atom is less in the excited state, In spontaneous emission atom emits the photon without the aid of any external energy. It is called spontaneous emission. The process is represented as

$$\text{Atom}^* \rightarrow \text{Atom} + \text{Photon}$$

The photons emitted in spontaneous emission may not have same direction and phase similarities. It is incoherent.

Ex: Glowing electric bulbs, Candle flame etc.

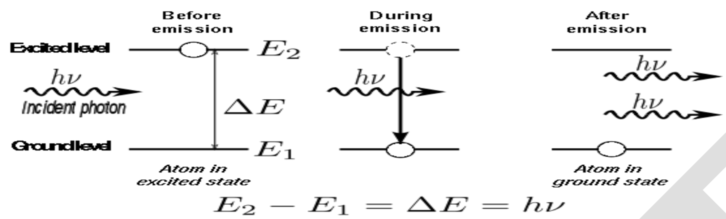
3) Stimulated Emission:

Stimulated emission is the emission of a photon by a system under the influence of a passing photon of just the right energy due to which the system transits from a higher energy state to a lower energy state.

The photon thus emitted is called stimulated photon and will have the same phase, energy and direction of movement as that of the passing photon called the stimulation photon.

Initially the atom is at higher level E_2. The incident photon of energy hν forces the atom to get de-excited from higher level E_2 to lower level E_1.

i.e. $h\nu = E_2 - E_1$ is the change in energy.



The incident photon stimulates the excited atom to emit a photon of exactly the same energy as that of the incident photons. The emitted two photons have same phase, frequency, direction and polarization with the incident photon and results in coherent beam of radiation. This kind of action is responsible for lasing action.

Atom* + Photon → Atom + (Photon + Photon)

Expression for energy density in terms of Einstein's Coefficients

Consider two energy levels E_1 and E_2 of a system of atoms with N_1 and N_2 are population of energy levels respectively.

Let U_ν be the energy density of incident beam of radiation of frequency γ. Let us consider the absorption and two emission process

1) Induced absorption:

Induced absorption is the absorption of an incident photon by system as a result of which the system is elevated from a lower energy state to a higher state.

The rate of absorption is proportional to N_1U_ν

Rate of absorption = $B_{12}N_1U_\nu$ .... (1)

Where 'B_{12}' is the proportionality constant called Einstein Coefficient of induced absorption.

2) Spontaneous emission:

The emission of a photon by the transition of a system from a higher energy state to a lower energy state without the aid of an external energy is called spontaneous emission.

Spontaneous emission depends on N_2 and independent of energy density.

The rate of spontaneous emission = $A_{21}N_2$ …………….(2)

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

3) Stimulated emission:

Stimulated emission is the emission of a photon by a system under the influence of a passing photon of just the right energy due to which the system transits from a higher energy state to a lower energy state

The rate of stimulated emission is directly proportional to N_2U_γ.

The rate of stimulated emission = $B_{21}N_2U_\nu$ …………….. (3)

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

At thermal equilibrium,

Rate of absorption = (Rate of spontaneous emission + Rate of stimulated emission)

$$B_{12}N_1U_\nu = A_{21}N_2 + B_{21}N_2U_\nu$$

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

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

$$\text{i.e. } U_\nu = \frac{A_{21}}{B_{21}}\left[\frac{N_2}{\left(\frac{B_{12}}{B_{21}}N_1 - N_2\right)}\right]$$

$$U_\nu = \frac{A_{21}}{B_{21}}\left[\frac{1}{\left(\frac{B_{12}N_1}{B_{21}N_2}\right) - 1}\right] \quad \rightarrow (4)$$

By Boltzmann's law, $N_2 = N_1 e^{-\left(\frac{E_2 - E_1}{KT}\right)} = N_1\, e^{-h\nu/KT}$

i.e., $N_1/N_2 = e^{h\nu/KT}$

Eqn. (4) becomes
$$U_\upsilon = \frac{A_{21}}{B_{21}}\left[\frac{1}{\left(\frac{B_{12}}{B_{21}}e^{\left(\frac{h\upsilon}{kT}\right)} - 1\right)}\right] \rightarrow (5)$$

By Planck's law,
$$U_\upsilon = \frac{8\pi h\upsilon^3}{c^3}\left[\frac{1}{\left(e^{\left(\frac{h\upsilon}{kT}\right)} - 1\right)}\right] \rightarrow (6)$$

Comparing equation (5) & (6)

$\frac{A_{21}}{B_{21}} = 8\pi h\nu^3/c^3$ & $\frac{B_{12}}{B_{21}} = 1$ i.e. $B_{12} = B_{21}$

The probability of induced adsorption is equal to the stimulated emission.

Therefore, A_{12} is written as A and B_{12}, B_{21} written as B.

Equation (5) becomes

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

Above equation is the expression for energy density

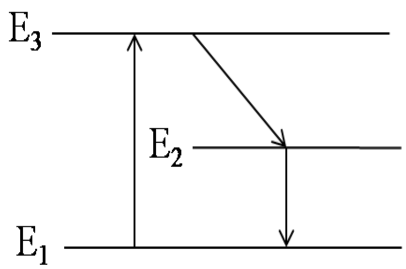
Condition for laser action:

*1)*Meta Stable State:

It is the special type of excited state where in the life time of atom is more than the normal excited state.
This state plays an important role in lasing action. In metastable state, atoms stay of the order of 10^{-3} to 10^{-2} second. In normal excited state other than metastable atom stay of order of 10^{-8} to10^{-9} seconds. It is possible to achieve population inversion condition in certain system which possesses a metastable state.

2) *Population Inversion:*

It is the state of the system at which the population of a higher energy level is greater than that of the lower energy level.



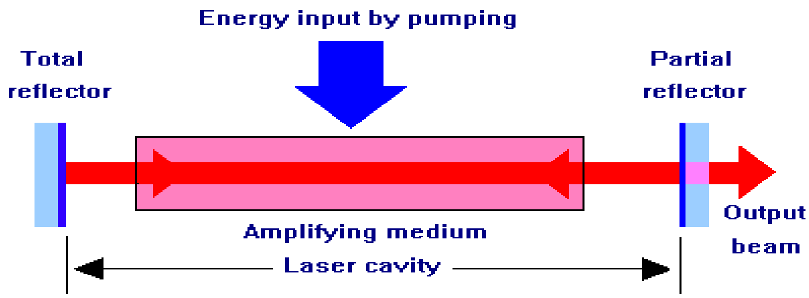
Let E_1, E_2, E_3 be the energy levels of the system $E_3>E_2>E_1$. E_2 is the metastable state of the system. Atoms get excited from the state E_1 to E_3 by means of external source and stay there for short time. These atoms undergo spontaneous transitions to E_2 and E_1. The atoms at the state E_2 stay for longer time. A stage is reached in which the number of atoms at state E_2 is more than the number of atoms at E_1 which is known as population inversion.

Requisites of a Laser System:

1) **The pumping process:**
It is the process of supplying energy to the medium in order to transfer it to the state of population inversion is known as pumping process
Optical Pumping: It is the process of exciting atoms from lower energy level to higher energy level by using high intensity light or by operating flash tube as an external source called optical pumping.
Electrical pumping: It is the process of exciting atoms from lower energy level to higher energy level by using dc power supply as an external source called electrical pumping.

2) **Active medium:**
It is a medium which supports population inversion and promotes stimulated emission leading to light amplification
Active centers: In a medium consisting of different species of atoms only small fraction of the atoms of a particular type are responsible for stimulated emission and consequent light amplification they are known as Active centers

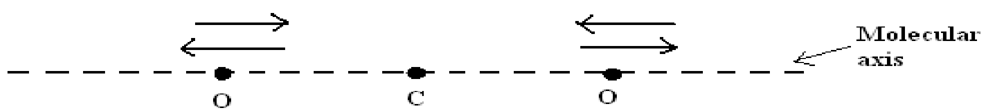
3) **Laser cavity**.
An active medium bounded between two mirrors is called as a laser cavity.



Vibrational modes of CO2 molecule:

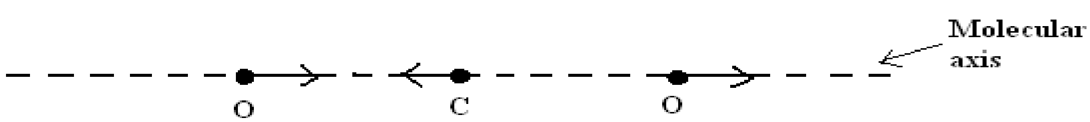
A carbn dioxide molecule has two oxygen atoms between which there is a carbon atom. It has 3 different modes of vibration.

1. **Symmetric stretching mode** : In this mode, carbon atom is stationary and the oxygen atoms oscillate to and fro along the molecular axis. This state is referred as (100) state.



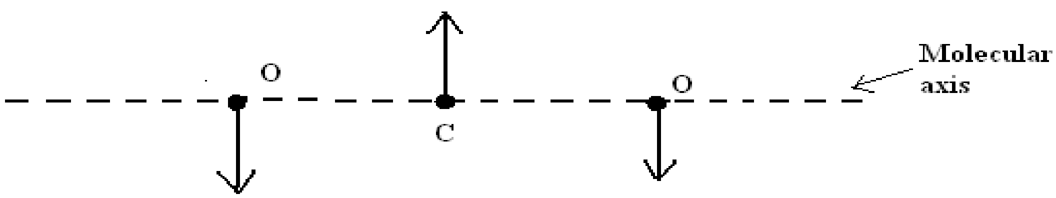
(100 State)
Symmetric stretching mode

2. **Asymmetric stretching mode**: In this mode, both the oxygen atoms moves in one direction while the carbon atom moves in opposite direction along the molecular axis. This state is referred as (001) state.



(001 state)
Asymmetric stretching mode

3. **Bending mode**: In this mode, the carbon atom and oxygen atoms moves perpendicular to molecular axis in the opposite direction. This state is referred to as (010)state.



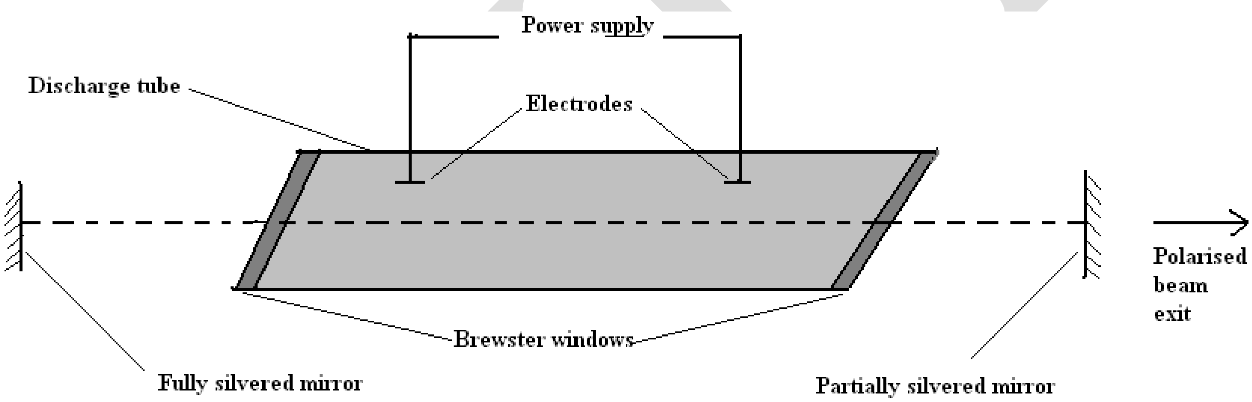
(010 state)

Bending mode

CO_2 LASER:

It was devised by C.K.N Patel in 1924. CO_2 laser is molecular gas laser which operates in the IR region involving a set of vibrational – rotational transitions. It is a four level laser producing both continuous and pulsed laser.

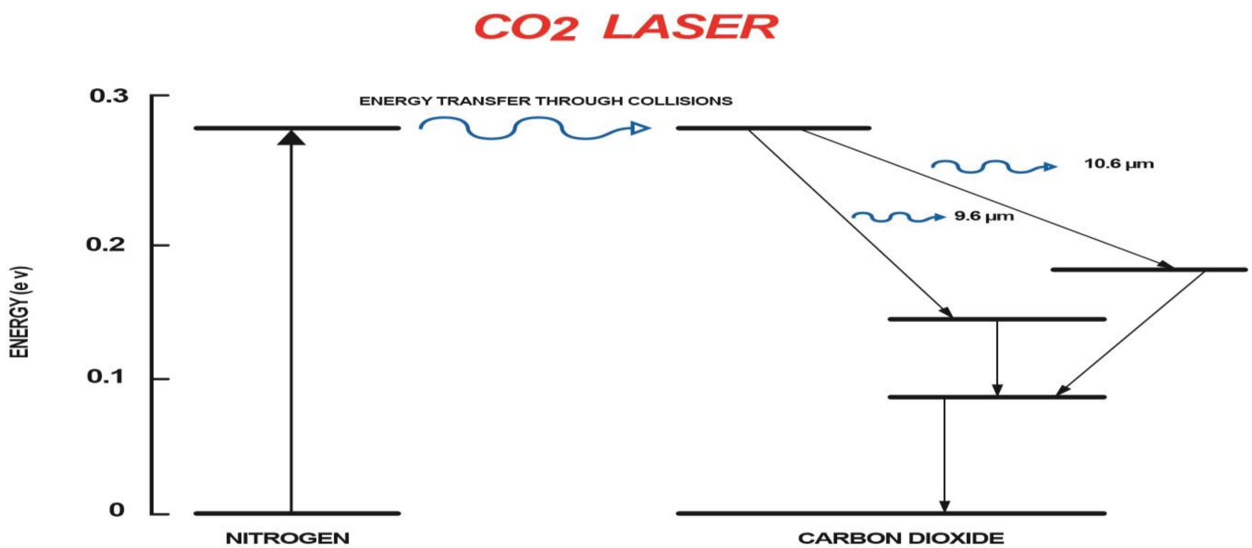
Construction:



CARBON-DIOXIDE LASER

- It consists of discharge tube (quartz) of diameter 2.5cm and length of 5m.
- Either side of the discharge tube fitted with quartz plates function as Brewster's window.
- The tube has got two parallel mirrors. One is partially silvered and the other is fully silvered to function as laser cavity
- External source is connected to discharge tube using the electrodes.
- Sometimes water vapour is added because during discharge CO_2 molecule breaks up into CO and O. The water vapour additives help in deoxidizing CO to CO_2.
- The tube is filled with a mixture of CO_2, N_2 and He gas in the ratio 1:2:3.

Working:



CO_2 laser Energy level diagram

- When an electric field is applied electrons rendered free from atoms, collide with N_2 & CO_2 molecules in their path towards positive electrodes due to which N_2 atoms are excited to the higher energy level ν_1.
- Likewise, it happens to the CO_2 molecule. This is called collision of first kind

$$e_1 + N_2 \rightarrow e_2 + N_2^*$$
$$e_1 + CO_2 \rightarrow e_2 + Co_2^*$$

Where, e_1 and e_2 are the energies of electrons before and after collisions.

- Let the ground state, (010) state, (020) state,(100) state and (001) are represented as E_1,E_2,E_3,E_4 and E_5 levels respectively
- Because of matching energy levels, v = 1 state of N_2 is equal to (001) state of CO_2 , N_2 molecule in the metastable state collide with the CO_2 in the ground state and transfer of energy takes place from N_2 to CO_2 . As a result of which CO_2 molecule moved to (001) state where as the N_2 molecule moved to ground state. This is the collision of second kind.

$$N_2^* + CO_2 \rightarrow N_2 + CO_2^*$$

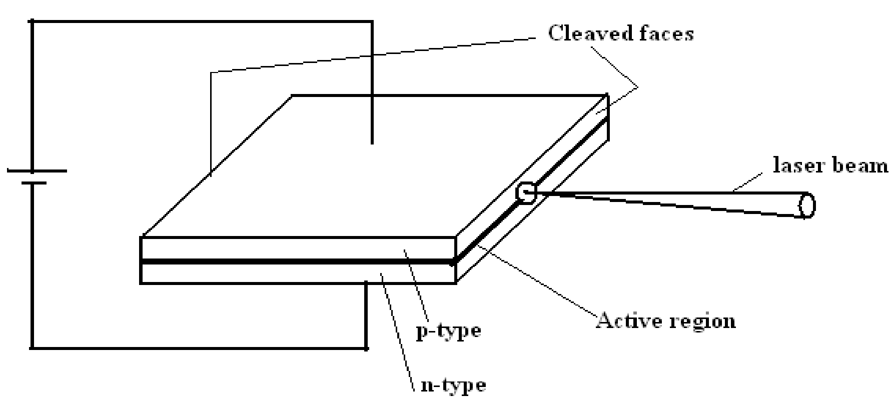
Where, CO_2 and CO_2* are the energies of CO_2 in ground state and excited states.

- Because of the resonant transfer of energy, the population inversion is achieved in (001) state with respect to (100) and (020)
- The transition from E_5 to E_4 levels gives wavelength of 10.6μm (in far IR region)
- The transitions from E_5 to E_3 level gives wavelength of 9.6 μm (in far IR region)
- Following these transitions the CO_2 molecules in E_4 and E_3 collide with the ground state CO_2 molecules (because of the matching energy levels) and arrive at E_2 state.
- The molecules in the E_2 state collide with He and water vapour molecules, so that come down to the ground state.
- The cycle of operation gives both continuous and pulsed laser.

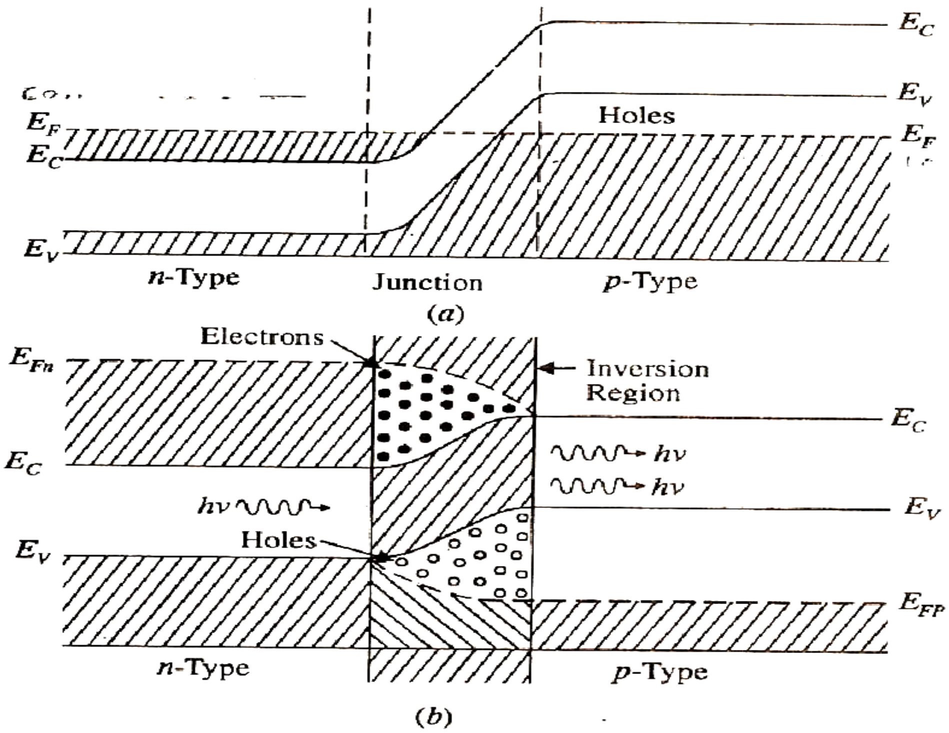
Gallium-Arsenide Laser Semiconductor laser:

A Semiconductor diode laser is one in which the active medium is formulated by semiconducting materials.

Construction: Gallium-Arsenide Laser is a single crystal of GaAs consists of heavily doped n-type and p-type. The diode is very small size with sides of the order of 1mm. The width of the junction varies from 1-100μm. The top and bottom surfaces are metalized and Ohmic contacts are provided for external connection. The front and rear faces are polished. The polished faces functions as the resonant cavity. The other two faces are roughened to prevent lasing action in that direction.



Working:



Energy level diagram of p-n junction Ga-As semi conductor diode laser
(a) Before biasing (b) After biasing

- The energy band diagram of heavily doped p-n junction is as shown. At thermal equilibrium the Fermi level is uniform.
- Because of very high doping on **n- side**, the Fermi level is pushed in to the conduction band and electrons occupy the portions of the conduction band that lies below the Fermi level and on **p-side**, the Fermi level lies within the valence band and holes occupy the portions of the valence band that lies above the Fermi level.
- A suitable forward bias is applied to overcome the potential barrier. As a result electrons from n-region and holes from p-region injected into the junction.
- The current begins to flow following which there will be a region in junction in which the population inversion can be achieved.
- Initially concentration of electrons in the energy levels at the bottom of the conduction band will be less than that of energy levels at top of valence

band. So that the recombination of electrons and holes result only in spontaneous emission then junction works as LED.

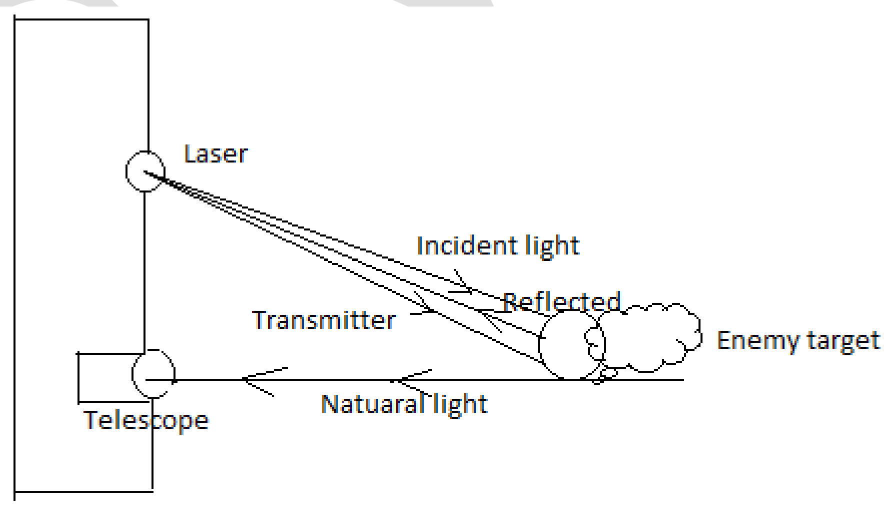
- When the current exceeds the threshold value, population inversion is achieved in the active region which is formulated in the junction.
- At this stage the photons emitted by spontaneous emission triggers stimulated emission, over a large number of recombination leading to build up laser.
- Since the energy gap of GaAs is 1.4eV, the wavelength of emitted light is 8400 A^o .

Properties of laser:

1. ***Coherence*:** The emitted radiation after getting triggered is in phase with the incident radiation.
2. ***Monochromaticity*:** The laser beam is highly monochromatic than any other radiations.
3. ***Unidirectionality*:** Laser beam travels in only one direction. It can travel long distance without spreading.
4. ***Focusability*:** A laser beam can be focused to an extremely fine spot.

Applications of laser:

1) Lasers in Defense - Laser range finder in defense



A high power pulsed laser (Nd-YAG) beam is directed towards the enemy target from the transmitter. The beam bounces back from the surface of the target as a reflection. A part of the reflected beam is received as a signal by the receiver. The unwanted noise signal will be filtered by the optical filter and pure signal is amplified by the photomultiplier in the receiver. The range finders high speed clock measures the exact time of incident and reflection of the pulse and then convert it in to distance.

2. Medical Applications- Eye Surgery and Skin Treatment

a) Eye Surgery:

LASIK, which stands for laser in-situ keratomileusis, is a popular surgery that can correct vision in people who are nearsighted or farsighted, or who have astigmatism.

It’s one of many vision correction surgeries that work by reshaping your cornea, the clear front part of your eye, so that light focuses on the retina in the back of your eye.

The LASIK procedure:

There are three essential steps to a LASIK procedure:

1. A mechanical surgical tool called a microkeratome or a femtosecond laser is used to create a thin, circular flap in the cornea. The surgeon then folds back this hinged flap to access the underlying cornea (called the stroma).
2. An excimer laser is used to reshape the corneal stroma. This highly specialized laser uses a cool ultraviolet light beam to remove ("ablate") microscopic amounts of tissue from the cornea to reshape it so it more accurately focuses light on the retina for improved vision.
3. The corneal flap is laid back in place, where it adheres to the corneal stroma without stitches.

b) Skin Treatment:

Laser therapy is also used cosmetically to:

- remove warts, moles, birthmarks, and sun spots
- remove hair
- lessen the appearance of wrinkles, blemishes, or scars
- remove tattoos

Laser toning and tightening is a non-surgical cosmetic correction method that uses lasers to penetrate the deeper layers of the skin.

Skin damage due to sun burning or aged skin is removed by directing an intense wavelength of light. Most of the times CO_2, Yttrium Aluminium-Garnet lasers are used.

Carbon dioxide (CO_2) lasers make shallow cuts. They're often used for superficial cancers, such as skin cancer.

OPTICAL FIBERS

An optical fiber is a cylindrical wave guide made of transparent dielectric material (glass or plastic) which guides light waves along its length by total internal reflection.

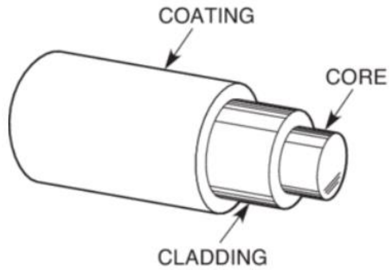
Principle

The propagation of light in an optical fiber from one end to the other end is based on the principle of Total internal reflection (TIR). They are used in optical communication.

When a light enters one end of the fiber, it undergoes successive total internal reflections from side walls and travels down the length of the fiber along zigzag path.

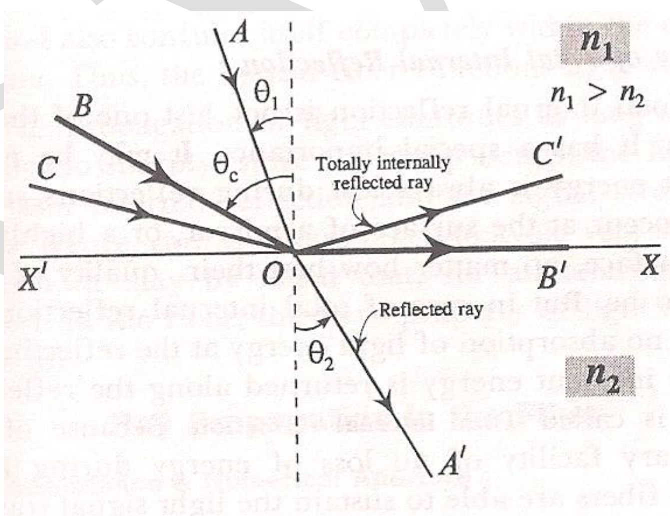
Construction

- A practical optical fiber is cylindrical in shape and has three regions.
- The innermost cylindrical region is the light guiding region called as core which is usually made up of glass or plastic.
- The outer part which is a concentric cylinder surrounding the core is called as cladding and is also made up of similar material but of lesser refractive index.
- The outermost region is called a Sheath or Protective buffer coating, nothing but the plastic coating providing a physical and environmental protection for the fiber. Number of such fibers is grouped to form a cable.



Total Internal Reflection

- When a ray of light travels from denser to rarer medium it bends away from the normal.
- As the angle of incidence increases in the denser medium, the angle of refraction also increases. For a particular angle of incidence called the "*critical angle*" (θ_c), the refracted ray grazes the surface separating the media or the angle of refraction is equal to 90°.
- If the angle of incidence is further increased beyond the critical angle, the light ray is reflected back to the same medium. This is called *"Total Internal Reflection".*
- In total internal reflection, there is no loss of energy. The entire incident ray is reflected back.



TOTAL INTERNAL REFLECTION

Let XX^1 is the surface separating medium of refractive index n_1 and medium of refractive index n_2, $n_1 > n_2$. AO and OA^1 are incident and refracted rays. θ_1 and θ_2 are angle of incidence and angle of refraction, $\theta_2 > \theta_1$. For the ray BO, θ_c is the critical angle. OB^1 is the refracted ray which grazes the interface. The ray CO incident with an angle greater than θ_C is totally reflected back along OC^1.

From Snell's law,

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

For total internal reflection, $\theta_1=\theta_c$ and $\theta_2=90°$

$$n_1 \sin\theta_c = n_2 \text{ (because } \sin 90°=1)$$

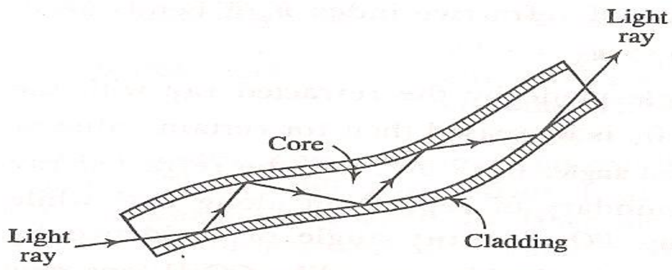
$$\therefore \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

In total internal reflection there is no loss or absorption of light energy. The entire energy is returned along the reflected light. Thus is called Total internal reflection.

Propagation mechanism

- The cladding in an optical fiber always has a lower refractive index than that of the core.
- The light signal which enters into the core and strikes the interface of the core and cladding with an angle greater than the critical angle will undergo total internal reflection.
- Thus the light signal undergoes multiple reflections within the core and propagates through the fiber.
- Since each reflection is a total internal reflection, there is no absorption of light energy at the reflecting surface.

- Therefore the signal sustains its strength and also confines itself completely within the core during the propagation.

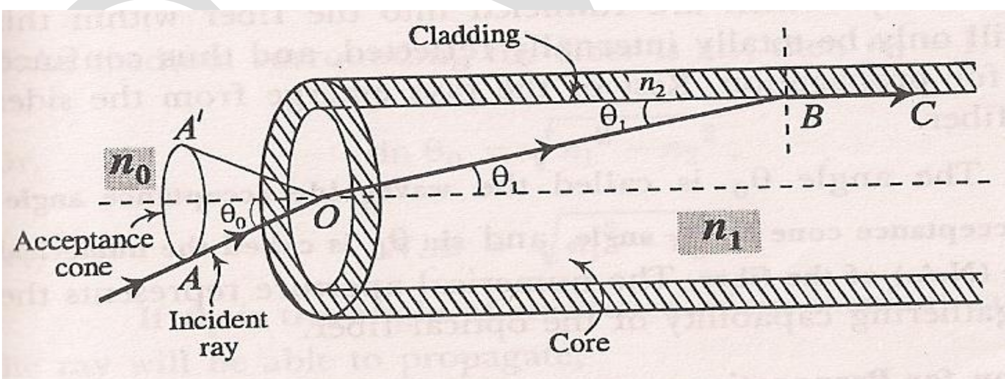


FIBER AS A WAVEGUIDE

- After series of such total internal reflection, it emerges out of the core. Thus the optical fiber works as a waveguide. Care must be taken to avoid very sharp bends in the fiber because at sharp bends, the light ray fails to undergo total internal reflection.

Expression for Numerical aperture and condition for propagation

Consider a light ray AO incident at an angle 'θ_0' enters into the fiber. Let 'θ_1' be the angle of refraction for the ray OB. The refracted ray OB incident at a critical angle (90°- θ_1) at B grazes the interface between core and cladding along BC. If the angle of incidence is greater than critical angle, it undergoes total internal reflection. Thus θ_0 is called the waveguide acceptance angle and $\sin\theta_0$ is called the numerical aperture.



ACCEPTANCE CONE

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

Applying Snell's law at O, $n_o \sin\theta_0 = n_1 \sin\theta_1$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Applying Snell's law at B,

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

$$n_1 \cos\theta_1 = n_2$$

$$\Rightarrow \cos\theta_1 = \frac{n_2}{n_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From expression (1) $\sin\theta_0 = \frac{n_1}{n_0}\sqrt{1-\cos^2\theta_1}$

Substituting for $\cos\theta_1$ from (2)

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

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

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

If n_0=1 i.e., surrounding medium if it is air

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

Where, $\sin\theta_0$ is called numerical aperture

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

Condition for propagation:

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

$$\text{if } \theta_i < \theta_0$$

$$\Rightarrow if \sin\theta_i < \sin\theta_0$$

$$or\ sin\,\theta_i < \sqrt{n_1^2 - n_2^2}$$

$$i.e., sin\,\theta_i < N.A.$$

Acceptance angle is defined as the maximum angle that a light ray can have relative to the axis of the fiber and propagate through the fiber.

Numerical aperture indicates the ability of the optical fiber to accept light i.e the light gathering capability of the optical fiber. The sign of the acceptance angle also called numerical aperture.

Fractional index change (Δ)

The ratio of the difference in refractive index of core and cladding to the refractive index of core of an optical fiber.

$$i.e., \Delta = \frac{n_1 - n_2}{n_1}$$

Mode of Propagation:

The number of light signals passing through an optical fiber is called mode of propagation. If only one light wave passing through an optical fiber then it is single mode fiber, if more than one light wave passing through an optical fiber then it is call multimode fiber.

V- number

The number of modes supported for propagation in the fiber is determined by a parameter called V-number.

If the surrounding medium is air, then V-number is given by,

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

Where, d is the core diameter,

n_1 and n_2 are refractive indices of core and cladding respectively,

λ is the wavelength of light propagating in the fiber.

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

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

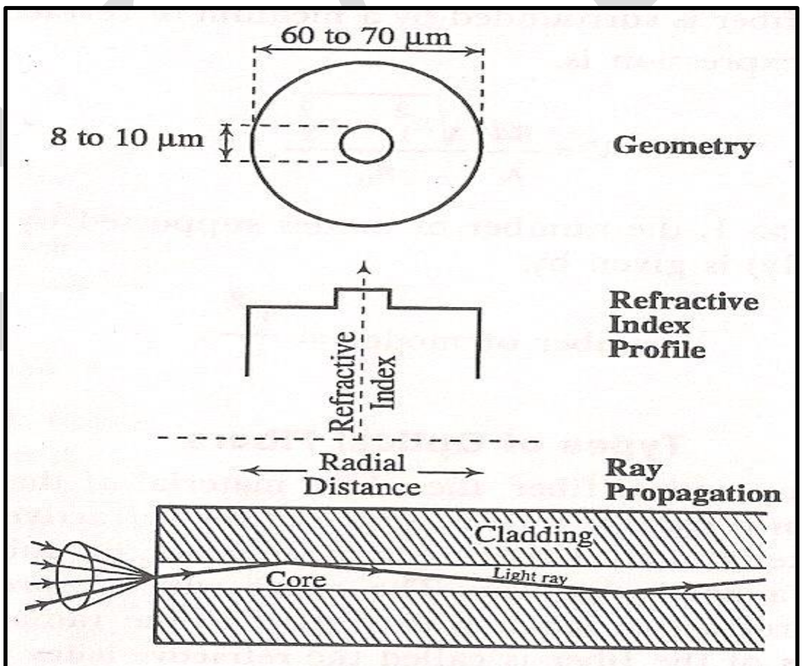
For V ≫1, the number of modes supported by the fiber is given by, number of modes $\cong \frac{V^2}{2}$

Types of optical fibers

Based on the refractive index profile and mode of propagation, There are three types of optical fibers,

1. Single mode fiber
2. Step index multimode fiber
3. Graded index multimode fiber

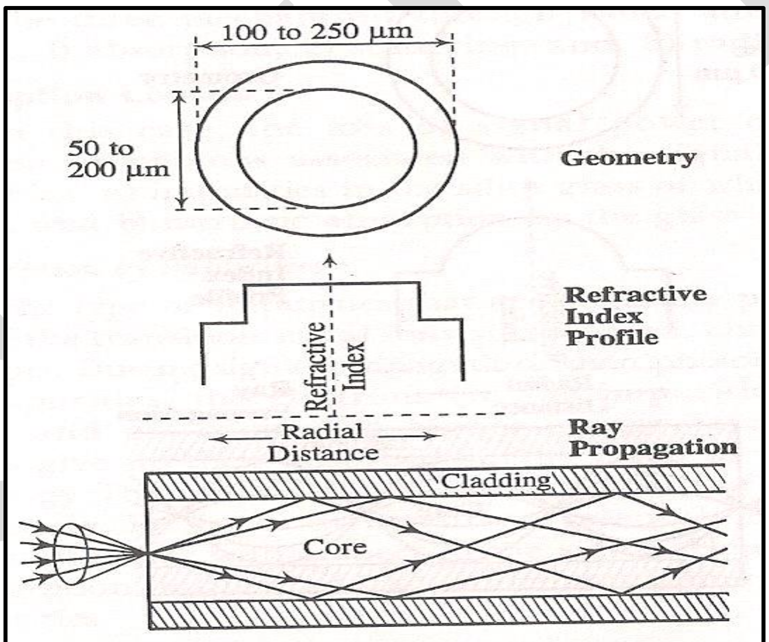
(i) Single mode fiber



SINGLE MODE FIBER

- Single mode fibers have a core material of uniform refractive index value.
- Cladding material also has a uniform refractive index but of lesser value than that of core.
- Thus its refractive index profile takes a shape of a step. The diameter of the core is about 8-10 μm and the diameter of the cladding is about 60-70 μm.
- Because of its narrow core, it can guide just a single mode as shown in above figure.
- Single mode fibers are the extensively used ones ant they are less expensive. They need LASERs as the source of light.

(ii) <u>Step index multimode fiber</u>



STEP - INDEX MULTIMODE FIBER

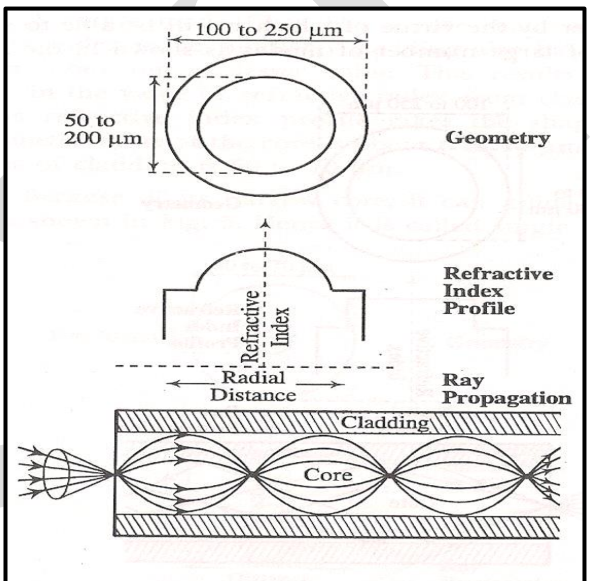
- A step index multimode fiber is very much similar to the single mode fiber except that its core is of large diameter. A typical fiber has a core diameter 50 to 200 μm and a cladding about 100 to 250μm outer diameter.
- Its refractive index profile is also similar to that of a single mode fiber but with a larger plane region for the core.
- Due to the large core diameter it can transmit a number of modes of wave

propagation.

- The step index multimode fiber can accept either a LASER or an LED as source of light.
- It is the least expensive of all and its typical application is in data links which has lower bandwidth requirements.

(iii) Graded index multimode fiber

- It is also called GRIN..
- The refractive index of core decreases in the radially outward direction from the axis of the fiber and becomes equal to that of cladding at the interface but the refractive index of the cladding remains uniform.
- Laser or LED is used as a source of light.
- It is the expensive of all. It is used in telephone trunk between central offices.



GRADED - INDEX MULTIMODE FIBER

Signal attenuation in optical fibers

- Attenuation is the loss of optical power suffered by the optical signal as it propagates through a fiber also called as the fiber loss.
- There are three mechanisms through which attenuation takes place.

Attenuation can be caused by three mechanisms.

(i) Absorption losses

- Absorption of photons by impurities like metal ions such as iron, chromium, cobalt and copper in the silica glass of which the fiber is made of.
- During signal propagation photons interact with electrons of impurity atoms and the electrons are excited to higher energy levels.
- Then the electrons give up their absorbed energy either in the form of heat or light energy.

- The re-emission of light energy will usually be in a different wavelength; hence it is referred as loss of energy.
- The other impurity such as hydroxyl (OH) ions which enters into the fiber at the time of fabrication causes significant absorption loss.
- The absorption of photons by fiber itself assuming that there are no impurities and in-homogeneities in it is called as *intrinsic absorption.*

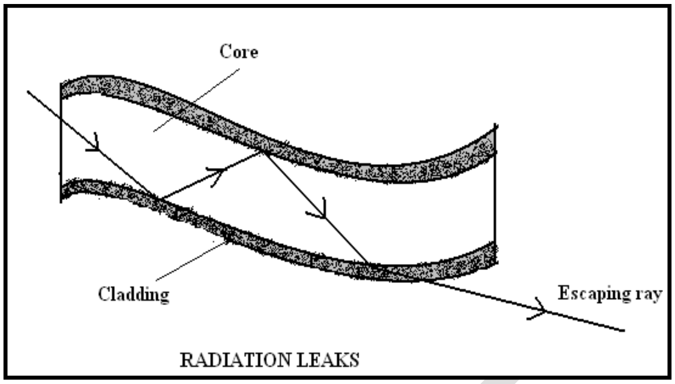
(ii) Scattering losses

- Scattering of light waves occurs whenever a light wave travels through a medium having scattering objects whose dimensions are smaller than the wavelength of light.
- Similarly when a light signal travels in the fiber, the photons may be scattered due to the sharp changes in refractive index values inside the core over distances and also due to the structural impurities present in the fiber material.
- This type of scattering is called as Rayleigh scattering. Scattering of photons also takes place due to trapped gas bubbles which are not dissolved at the time of manufacturing.
- A scattered photon moves in random direction and leaves the fiber.

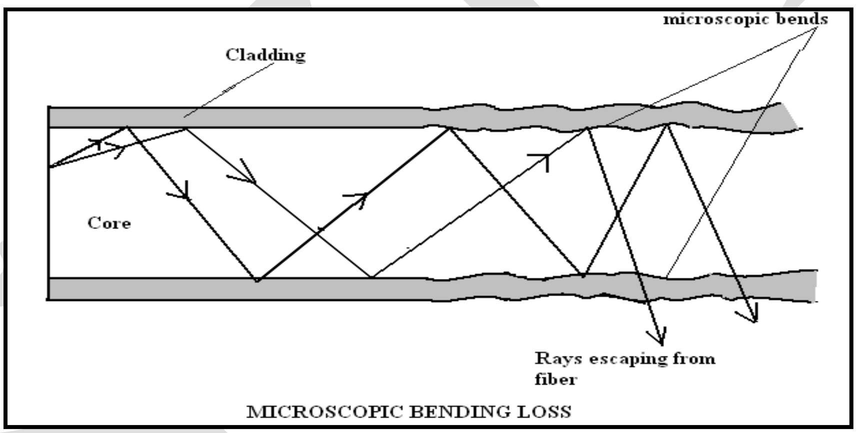
(iii) Radiation losses

Radiation losses occur due to macroscopic bends and microscopic bends.

- ***Macroscopic bending:*** All optical fibers are having critical radius of curvature provided by the manufacturer. If the fiber is bent below that specification of radius of curvature, the light ray incident on the core cladding interface will not satisfy the condition of total internal reflection. This causes loss of optical power.



- ***Microscopic bending:*** Microscopic bends are repetitive small scale fluctuations in the linearity of the fiber axis. They occur due to non-uniformities in the manufacturing and also lateral pressure built up on the fiber. They cause irregular reflections and some of them leak through the fiber. The defect due to non-uniformity (micro-bending) can be overcome by introducing optical fiber inside a good strengthen polyurethane jacket.



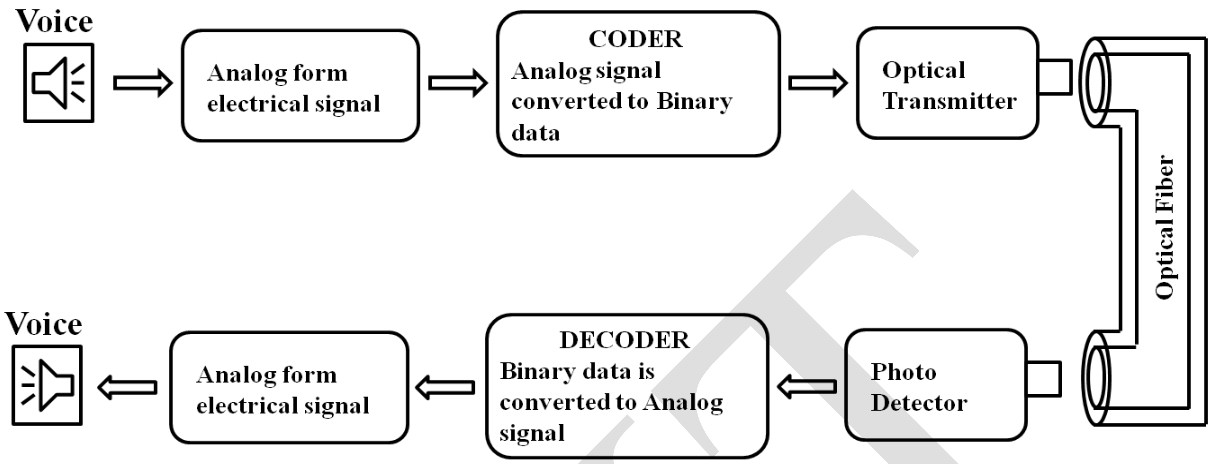
Attenuation co-efficient

- The attenuation of a fiber optic cable is expressed in decibels.

i.e., $$\alpha = -\frac{10}{L} log\left[\frac{P_{out}}{P_{in}}\right]\frac{dB}{km}$$

- The main reasons for the loss in light intensity over the length of the cable is due to light absorption , scattering and due to bending losses.

Point to point optical fiber communication System



- In point to point communication analog information such as voice of a telephone coming out of the transmitter section of the telephone are fed to the coder.
- The coder converts analog information into binary data which comes out as electrical pulses.
- The electrical pulses from the coder are fed to optical transmitter which converts signals into pulses of optical power.
- These optical pulses are fed into the fiber. The incident light which is funneled into the core within the acceptance angle propagate within the fiber by means of total internal reflection.
- The photo detector converts optical signals into electrical pulses in binary form and the decoder converts the binary data into analogue signal which will be the same information such as voice.

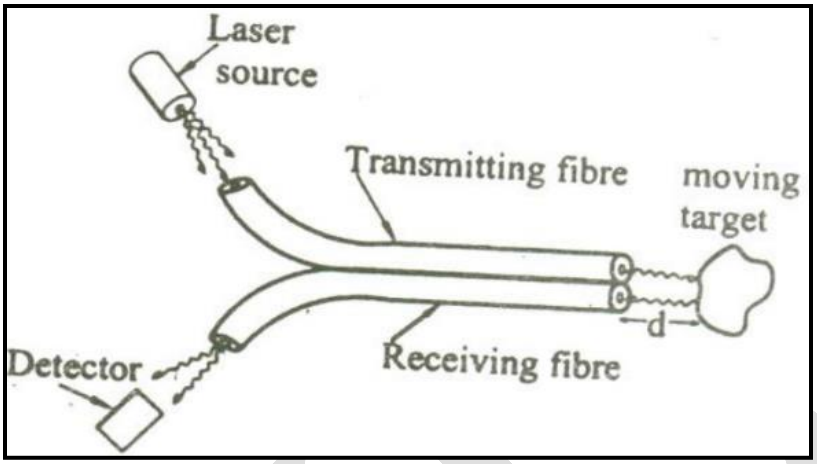
Optical Fiber Sensors

Optical Fiber sensors are meant for measuring and sensing the rate of data transmission, change in phase, intensity and wavelength and in the case of incentive conditions as noise, unstable environment conditions, high vibration and extreme heat etc.

On the basis of operating principle, Optical Fiber sensors are classified into

1. Intensity based Displacement Sensor.
2. Temperature Sensor based on Phase Modulation.

1. *Intensity based Displacement Sensor*



Principle:
Light is sent through a transmitting fiber and is made to fall on a moving target. The reflected light from the target is sensed by a detector. With respect to intensity of the reflected light from the target, displacement of the target is measured.

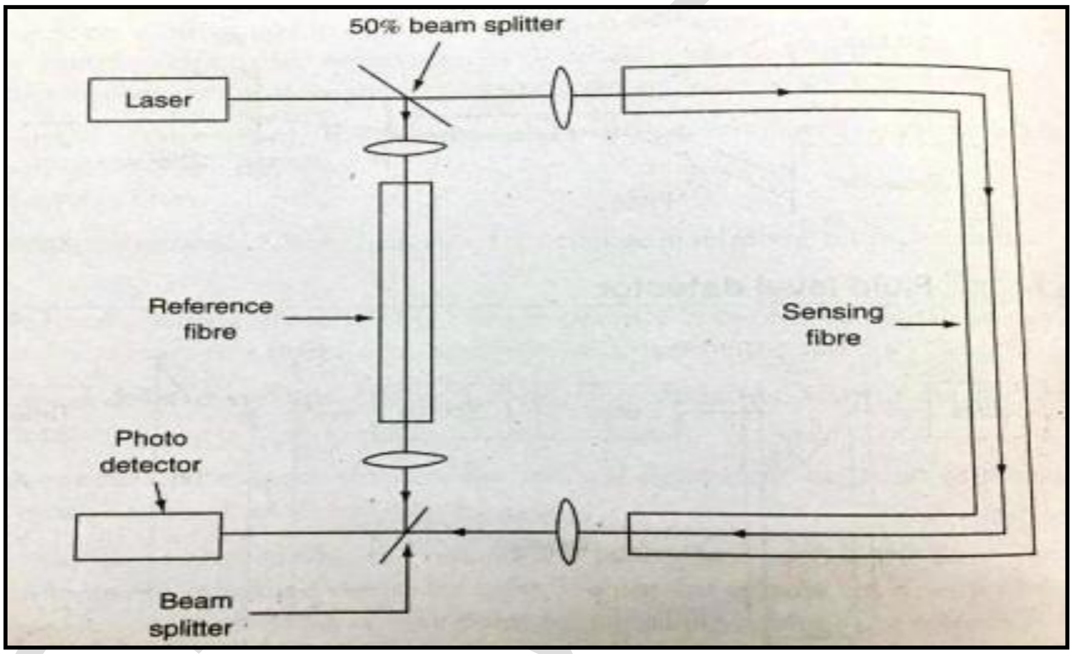
Description:
It consists of a bundle of transmitting fibers coupled to the laser source and a bundle of receiving fibers coupled to the detector as shown in the figure.
The axis of the transmitting fiber and the receiving fiber with respect to the moving target can be adjusted to increase the sensitivity of the sensor.

Working:
Light from the source is transmitted through the transmitting fiber and is made to fall on the moving target. The light reflected from the target is made to pass through the receiving fiber and the same is detected by the detector.

Based on the intensity of the light received, the displacement of the target can be measured, (i.e.) if the received intensity is more than we can say that the target is moving towards the sensor and if the intensity is less, we can say that the target is moving away from the sensor.

2. Temperature Sensor based on Phase Modulation

- When a single optical fiber is subjected to temperature or pressure variations, then its length and refractive index changes. This causes change in phase of light at the end of the fiber.
- The change in phase of light is proportional to the magnitude of the change in temperature or pressure. The phase changes can be measured by an interferometer method as shown in fig.



- The light from the laser source splits into two beams approximately equal in amplitude by a 50% beam splitter.
- One beam is passed through sensing fiber, which is subjected to temperature variations and the other beam through reference fiber, which is not subjected to any changes and is used for comparison.
- Light from these two fiber is superimposed using another beam splitter. Interference of these two waves gives fringes.
- The intensity of the fringe depends on the phase relation between two waves.
- If the waves are in phase, then the intensity is maximum. This happens when the sensing fiber is not disturbed.
- The intensity is minimum if the waves are out of phase due to $\lambda/2$ change in the length of the sensing fiber.

- The intensity of interference fringes can be measured with a photodetector and pressure or temperature changes can be measured.

Merits of optical communication system:

- It carries very large amount of information in either digital or analog form due to its large bandwidth.
- The materials used for making optical fiber are dielectric nature. So, it doesn't produces or receives any electromagnetic and R-F interferences.
- Fibers are much easier to transport because of their compactness and lightweight.
- It is easily compatible with electronic system.
- It can be operated in high temperature range.
- It does not pick up any conducted noise.
- Not affected by corrosion and moisture.
- It does not get affected by nuclear radiations.
- No sparks are generated because the signal is optical signal.

Demerits of optical communication system:

- **Low power** — Light emitting sources are limited to low power. Although high power emitters are available to improve power supply, it would add extra cost.
- **Fragility** — Fiber optic cable is made of glass, which is more fragile than electrical wires such as copper cabling. Not only that, but glass can be damaged by chemicals such as hydrogen gas that can affect transmission. Particular care has to be taken with laying undersea fiber cabling because of its fragility.
- **Attenuation and Dispersion ----** The distance between the transmitter and receiver should keep short. With long distance transmission, light will attenuate and disperse, which means additional components such as EDFA (Erbium-doped fiber amplifier – an optical repeater device that is used to boost the intensity of optical signals being carried through a fiber optic communications system) are required.

*******************ALL THE BEST*******************