ENGINEERING PHYSICS

MODULE – 3

Lasers & Optical Fibers **08 Hours**

Lasers: Interaction of radiation with matter, Einstein's coefficients (derivation of expression for energy density). Requisites of a Laser system. Conditions for Laser action. Principle, Construction and working of CO_2 and semiconductor Lasers. Application of Lasers in Defence (Laser range finder) and medical applications- Eye surgery and skin treatment.

Optical Fibers: Propagation mechanism, angle of acceptance, Numerical aperture, Modes of propagation, Types of optical fibers, Attenuation and Mention of expression for attenuation coefficient. Discussion of block diagram of point to point communication, Optical fiber sensors-Intensity based displacement sensor and Temperature sensor based on phase modulation, Merits and demerits, Numerical problems.

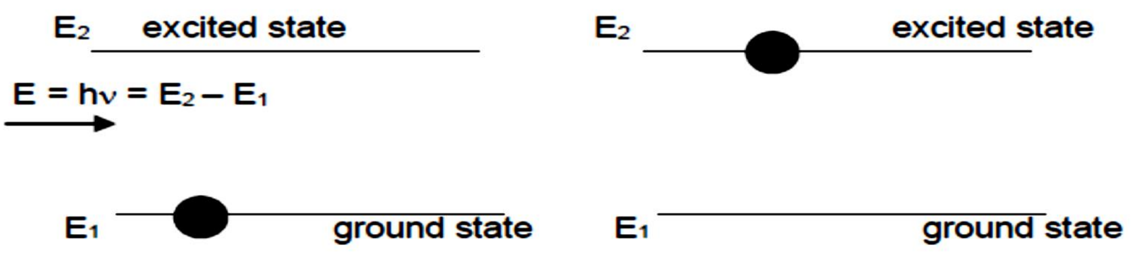
LASER:

LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The device producing laser beams is also called LASER. Laser is a very intense, concentrated, highly directional monochromatic and coherent beam of light with very small divergence.

Interaction of radiation with matter:

Induced Absorption:

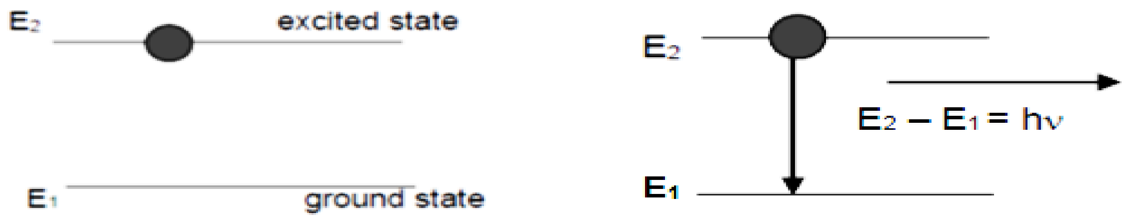
When radiation is incident on an atom, which is in its ground state of energy E_1, it can absorb a photon of energy $h\nu$ and get raised to an excited state of energy E_2, provided $h\nu = E_2 - E_1$. This process is called induced or stimulated absorption.



Atom + Photon → Atom*

Spontaneous Emission of Radiation:

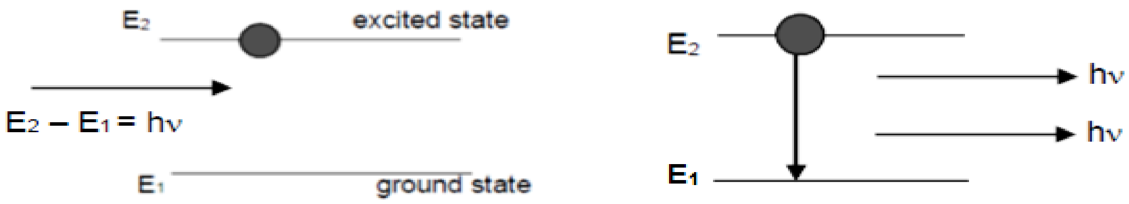
An atom in the excited state, of energy E_2 makes a transition to the ground state of energy E_1 on its own within a fraction of a second, typically 10^{-8} s, resulting in the emission of radiation of energy $h\nu = E_2 - E_1$. This is known as spontaneous emission. The photons which are spontaneously emitted by different excited atoms have random phases and hence they are incoherent.



Atom* → Atom + Photon

Stimulated Emission of Radiation:

If an atom is in the excited state, an incident photon of energy exactly equal to the energy difference between the two levels may cause the atom to jump to lower energy state by emitting an additional photon along with the incident photon .Thus two photons of the same frequency are emitted. This is called **stimulated emission**. The emitted photon will be in phase with the incident photon and is called stimulated photon. These two photon are coherent and travel in the same direction.



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

Expression for Energy Density in terms of Einstein's Coefficients:

Consider two energy states E_1 and E_2 of a system of atoms ($E_2 > E_1$). Let there be N_1 atoms with energy E_1 and N_2 atoms with energy E_2, per unit volume of the system. N_1 and N_2 are called the number densities of atoms in the states 1 and 2 respectively. Let there be radiation of frequency $\nu = \frac{(E_2 - E_1)}{h}$ Hz, and let U_ν be the energy density of radiations.

The Rate of Induced absorption = $B_{12}N_1U_\nu$ ----------------- (1)

The Rate of spontaneous emission = $A_{21}N_2$------------------ (2)

The Rate of stimulated emission =$B_{21}N_2U_\nu$ ------------ (3)

where B_{12} is the Einstein's coefficient for stimulated absorption, B_{21} is the Einstein's coefficient for stimulated emission and A_{21} is Einstein's coefficient for spontaneous emission.

At thermal equilibrium,

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

∴ From Eqs. (1), (2) & (3), we have,

$$B_{12}N_1U_\nu = A_{21}N_2 + B_{21}N_2U_\nu,$$
$$B_{12}N_1U_\nu - B_{21}N_2U_\nu = A_{21}N_2$$
$$U_\nu(B_{12}N_1 - B_{21}N_2) = A_{21}N_2$$
$$U_\nu = \frac{A_{21}N_2}{(B_{12}N_1 - B_{21}N_2)}$$

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

By Boltzmann's law,

$$\frac{N_2}{N_1} = e^{-\left(\frac{h\nu}{kT}\right)}$$

Eqn. (1) becomes

$$U_\nu = \frac{A_{21}}{B_{21}\left(\frac{B_{12}}{B_{21}}e^{\left(\frac{h\nu}{kT}\right)} - 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

By Planck's Law

$$U_\nu = \frac{8\pi h\nu^3}{c^3}\left[\frac{1}{\left(e^{\left(\frac{h\nu}{kT}\right)} - 1\right)}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Now, comparing the equations (5) and (6) term by term on the basis of positional identity, we have,

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

And, $$\frac{B_{12}}{B_{21}} = 1,$$

Or, $$B_{12} = B_{21},$$

Which implies that the probability of induced absorption is equal to the probability of stimulated emission. Because of the above identity, the subscripts could be dropped, and A_{21} and B_{21} can be represented simply as A and B, and Eq (5) can be rewritten.

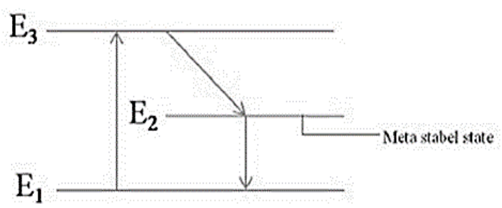
∴ At thermal equilibrium the equation for energy density is,

$$U_\nu = \frac{A}{B\left(e^{\left(\frac{h\nu}{kT}\right)} - 1\right)}$$

This is the Einstein's expression for energy density of radiation.

Population Inversion:

Under normal conditions of thermal equilibrium in an atomic system, the number of atoms in the lower energy state will be more than that in the excited state. In other words if N_1 and N_2 are the number densities of atoms in the lower and excited states respectively then $N_1 > N_2$. If E_1 and E_2 are the energy of the atoms in the ground and excited states respectively, then according to Boltzmann's distribution function,



$\frac{N_2}{N_1} = e^{-\left(\frac{h\nu}{kT}\right)}$, where k is Boltzmann's constant and T is temperature.

As $E_2 > E_1$, the RHS of the above equation is always less than unity, hence $N_2 < N_1$.

For stimulated emission to dominate, population of atoms in the higher energy state must be greater than that in the lower energy state. i.e. $\mathbf{N_2 > N_1}$ .Such a situation is known as ***population inversion*.**

In some substances which contain meta-stable states, this may be achieved practically.

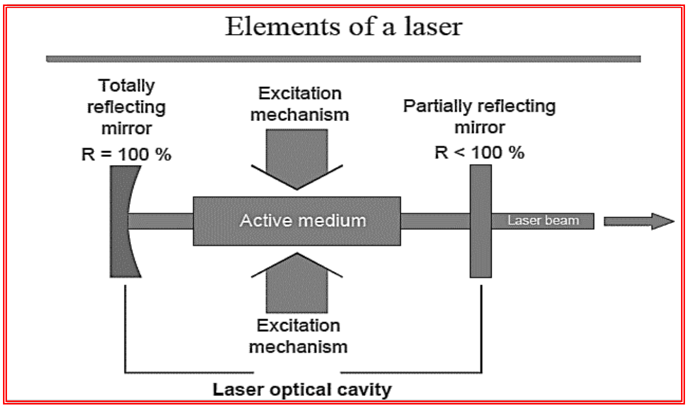
Pumping:

Population inversion can be achieved by pumping action. The act of exciting atoms from lower energy state to a higher energy state by supplying energy from an external source is called *pumping*.

Requisites of a laser system:

The main components of laser are:

1. An active medium having metastable state which supports Population Inversion.
2. An excitation source for pumping action, by which population inversion can be achieved.
3. Resonant or Laser cavity



Active Medium:

The quantum system between whose energy levels, the pumping and lasing action occur is called an active medium.

Excitation source:

To achieve population inversion, atoms in the lower energy state have to be raised to the higher energy state by supplying energy. This process is called *pumping*. Pumping can be done in different ways such as optical pumping, electrical pumping and chemical pumping.

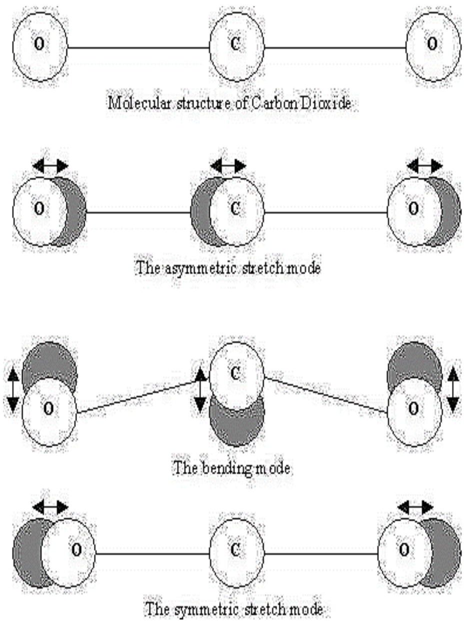
Laser Cavity:

The system containing the active medium between two mirrors of high reflectivity is called **laser cavity**. The mirrors reflect the photons produced due to stimulated emission to and fro through the active medium. Thus the radiation inside the laser cavity builds up resulting in amplification of stimulated emission of radiation. Hence the output of the system is a laser coherent light. Length of the optical cavity L= n $\lambda/2$.

Carbon dioxide LASER (CO_2):

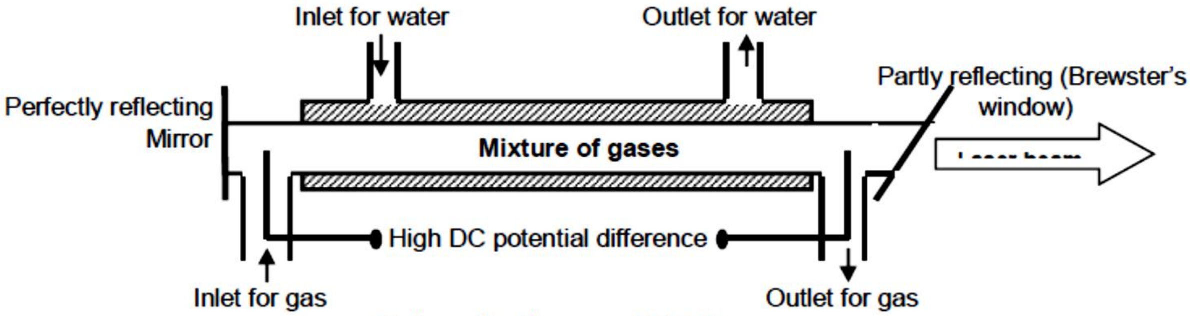
From the Diagram:

1. **Asymmetric Stretching Mode**: All the three atoms oscillate along the molecular axis, but while both oxygen atoms move in one direction, carbon atoms moves in the opposite direction.
2. **Bending Mode**: Atoms move perpendicular to the molecular Axis. The bending vibration is doubly degenerate it can occur in the plane of figure and the plane of perpendicular.
3. **Symmetric Stretching Mode**: Both of the oxygen atoms oscillate along the axis of the molecule simultaneously approaching and departing the carbon atom which is stationary.



Carbon dioxide LASER:

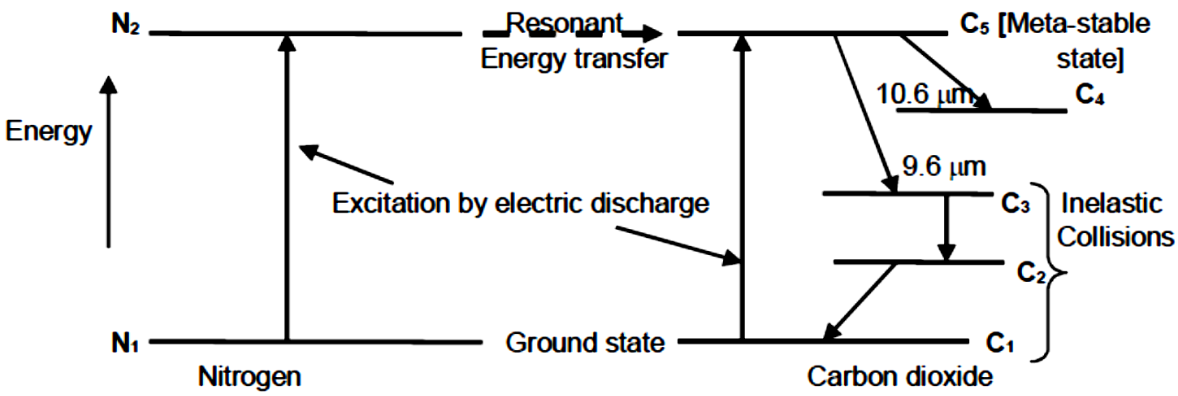
The carbon dioxide laser consists of a tube of about 5 m length and 2.5 cm diameter. The ends of the tube are closed with Brewster's windows. Outside the ends of the tube, two optically plane mirrors are fixed on either side of the tube normal to its axis out of which one is perfectly reflecting and the other is partly reflecting. This forms the resonant cavity. The active medium in this laser is a mixture of CO_2, N_2 and He gases in the ratio 1:2:3. The pressure inside the tube is about 6-17 torr. The discharge tube containing the mixture of gases is continuously cooled by circulating water as shown in the diagram.



Schematic diagram of CO_2 laser

Pumping mechanism employed here is electric discharge. When a high voltage is applied to the gas, electric discharge takes place through the gas mixture and N_2 and CO_2 atoms collide with the electrons and get excited to higher energy levels. For CO_2 gas, it so happens that there is a close coincidence in energy of its C_5 state with the N_2 state of nitrogen gas. Therefore when a N_2 molecule in the metastable state collides with a CO_2 molecule in the ground state, because of the matching of the energy levels, resonant transfer of energy takes place form N_2 molecule to a CO_2 molecule. As a result the CO_2 molecules get elevated to C_5 state whereas, the N_2 molecules return to the ground state. Thus the population of C_5 level of CO_2 increases rapidly which leads to population inversion with respect to the two lower lasing levels C_3 and C_4. Transition from the level C_5 to C_4 produces laser of wavelength 10.6 μm and that from C_5 to C_3 results in a laser beam of wavelength 9.6 μm. Both these radiations lie in the IR region. The CO_2 molecules present in C_4, C_3 and C_2 levels may make non-radiative transition to the ground state quickly by colliding with the helium atoms.

Carbon dioxide molecules are the active molecules in which lasing action takes place. The purpose of nitrogen gas in the tube is to create the condition of population inversion in CO_2 whereas helium gas is passed through the tube in order to avoid population in the lower levels by thermal excitation as helium gas possesses high thermal conductivity, it helps to conduct heat away to the walls, keeping the CO_2 temperature low. Thus nitrogen helps to increase the population of upper levels and helium helps to depopulate the lower levels.



Energy level diagram

The laser output is about few kilowatts and operates with an efficiency of up to 30%.

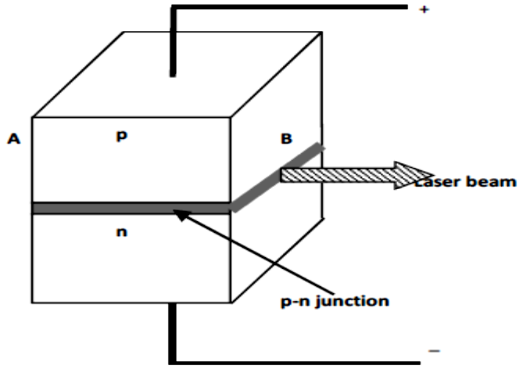
Application of CO2 laser

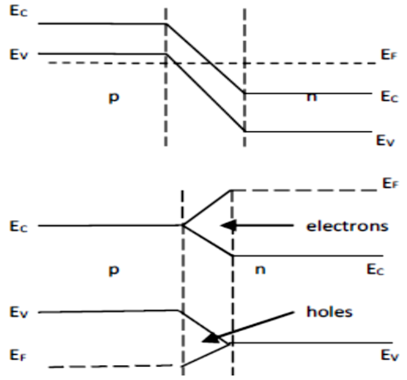
- *It is used in material processing (welding, cutting and drilling).*

- *It is used in open air communication systems.*
- *It is used in micro surgery and bloodless operation.*
- *It is used in laser remote sensor.*

Semiconductor Diode Laser:

A semiconductor diode laser is a specially fabricated pn-junction device that emits coherent light when it is forward biased.





Construction:

A schematic diagram of a homo junction semiconductor laser is shown in the figure. The laser diode is a single crystal consisting of a heavily doped n & p sections. The doping concentration is very high and is of the order of 10^{17} to 10^{19} dopant atoms/cm^3.

The diode is extremely small in size with sides of the order of 1mm. The junction lies in a horizontal plane through the center. The p-n layer has a width varying from 1μm to 100μm depending upon the diffusion and temperature conditions that exists at the time of fabrication. The end surfaces of the p & n sections parallel to the plane of junction are provided with electrodes in order to facilitate application of a forward bias voltage with the help of a voltage source. The front and rear faces are polished. The polished faces play the role of reflecting mirrors. The other two opposite faces are roughened to prevent lasing action in that direction.

Working:

In a diode laser, the p & n sections are heavily doped. Because of heavy doping, the Fermi level lies within the conduction band in the n-type material and it lies within the valence band in the p-type material. A simple way of achieving population inversion in a semiconductor is to use it in the form of heavily doped pn-junction and to forward bias the junction.

When the junction is forward biased, the energy levels shift as shown in the energy level diagram. The width of depletion region decreases due to injection of electrons and holes. At low forward currents, the electron-hole recombination causes spontaneous emission of radiation and the diode acts as a LED. When current is increased and reaches a threshold value, population inversion is achieved in the depletion region due to large concentration of electrons in conduction band and holes in valence band. The narrow region where population inversion is achieved becomes the active region where lasing action takes place. The forward bias applied to the junction is thus the pumping mechanism which produces population inversion. The photons traveling in the junction along the resonant cavity stimulate recombination of electron-hole pairs due to which the intensity of coherent light builds up along the axis of the cavity.

The semiconductor lasers have low power consumption, are compact and highly efficient. But the laser output is less monochromatic and more divergent compared to other lasers.

Application of Semiconductor laser:

- *Fiber Optical Communications.*
- *Produce Laser Diodes which are more powerful & coherent than LED.*
- *Pain Killers.*
- *Printers for Computers, printouts, writing, Reading & CD'S.*

Characteristics of laser beams:

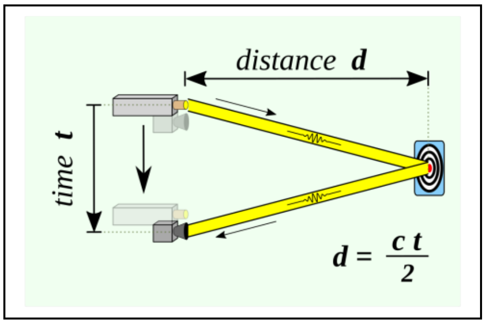
1. **Intensity:** Since a large number of photons are emitted by stimulated emission continually, the laser beam is highly intense.
2. **Monochromaticity:** Since laser results from stimulated emission, all the photons in the beam are of the same frequency and the line width of radiation is negligible.
3. **Coherence:** Coherence is another important characteristic that distinguishes laser from other types of monochromatic light. Coherence means constancy in phase difference between any two points in a wave separated by the same distance, in any of the waves emitted by the source.
4. **Directionality:** The laser cavity mirrors can reflect only those photons incident normal to their planes. Due to this, photons moving even at slightly different angles fail to return to the lasing medium and form standing waves. Such beams are therefore suppressed and hence the laser beam is highly directional.
5. **Focussability:** Since laser beam is highly monochromatic and collimated, it can brought to a sharp focus by a lens.

Applications of LASER:

laser rangefinder

A **laser rangefinder** is also known as a **laser telemeter**, It uses a laser beam to determine the distance to an object. The most common form of laser rangefinder operates on the time of flight principle by sending a laser pulse in a narrow beam towards the object and measuring the time taken by the pulse to be reflected off the target and returned to the sender. Due to the high speed of light, this technique is not appropriate for high precision sub-millimeter measurements,

Despite the beam being narrow, it will eventually spread over long distances due to the divergence of the laser beam, as well as due to scintillation and beam wander effects, caused by the presence of air bubbles in the air acting as lenses ranging in size from microscopic to roughly half the height of the laser beam's path above the earth.



These atmospheric distortions coupled with the divergence of the laser itself and with transverse winds that serve to push the atmospheric heat bubbles laterally may combine to make it difficult to get an accurate reading of the distance of an object, say, beneath some trees or behind bushes, or even over long distances of more than 1 km in open and unobscured desert terrain.

Laser eye surgery

Lasik (*laser-assisted in situ keratomileusis*), commonly referred to as **laser eye surgery** or **laser vision correction**, is a type of refractive surgery for the correction of myopia, hyperopia, and astigmatism. LASIK surgery is performed by an ophthalmologist who uses a laser or microkeratome to reshape the eye's cornea in order to improve visual acuity. For most people, LASIK provides a long-lasting alternative to eyeglasses or contact lenses.

Laser Skin Treatment

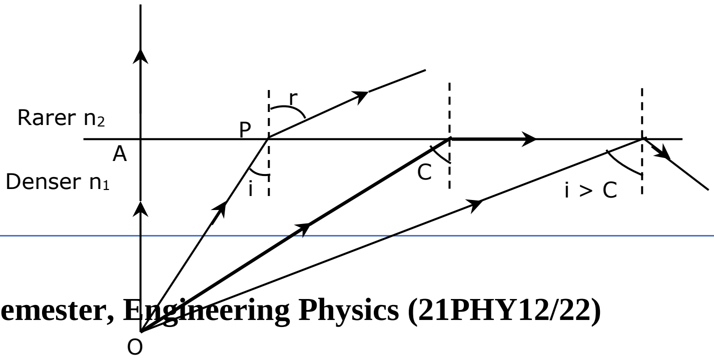
Laser resurfacing is a **treatment to reduce facial wrinkles and skin irregularities**, such as blemishes or acne scars. The technique directs short, concentrated pulsating beams of light at irregular skin, precisely removing skin layer by layer.

The two types of lasers most commonly used in laser resurfacing are carbon dioxide (CO2) and erbium. Each laser vaporizes skin cells damaged at the surface-level. The newest version of CO_2 laser resurfacing uses very short pulsed light energy (known as ultrapulse) or continuous light beams that are delivered in a scanning pattern to remove thin layers of skin with minimal heat damage.

Erbium laser resurfacing is designed to remove surface-level and moderately deep lines and wrinkles on the face, hands, neck, or chest. One of the benefits of erbium laser resurfacing is minimal burning of surrounding tissue. This laser causes fewer side effects -- such as swelling, bruising, and redness.

OPTICAL FIBERS

An optical fiber is a device which can conduct light along any desired curved path Or optical fiber is a device to transmit light through bundle of thin fibers of transparent material from one end to other end covering a very long distance. It works on the principle of ***total internal reflection.***



Let a luminous object O be placed in a denser medium. A ray of light from O incident normally on the interface of the two media proceeds undeviated. A ray OP while passing from the denser medium into the rarer medium bends away from the normal. As the angle of incident increases, the angle of reflection also increases and for a particular angle of incidence the refracted ray just grazes the surface of separation of the media, i.e., angle of refraction is 90°. This angle of incidence in the denser medium for which the angle of refraction is 90° is known as the ***critical angle (C)*** for the given pair of media and for the given colour of the light. For further increase in the angle of incidence (i.e., i > C) the ray is not refracted but gets reflected back into the medium. This phenomenon is known as ***total internal reflection (TIR).***

Condition of TIR:

1. The ray of light must travel from a denser medium into a rarer medium.
2. The angle of incidence in the denser medium must be greater than the critical angle for the given pair of media and the given colour of light.

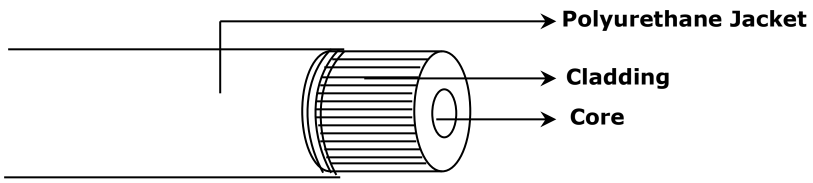
Note: From law of refraction we have, $n_1 \sin i = n_2 \sin r$ (i = C, r = 90°)

$$n_1 \sin C = n_2 \sin 90° \Rightarrow n_1 \sin C = n_2$$

$$\sin C = \frac{n_2}{n_1} \text{ or } C = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Optical Fiber Construction

Fiber that are used for optical communication are waveguides made up of transparent dielectrics whose function is to guide visible and infrared light over long distances.



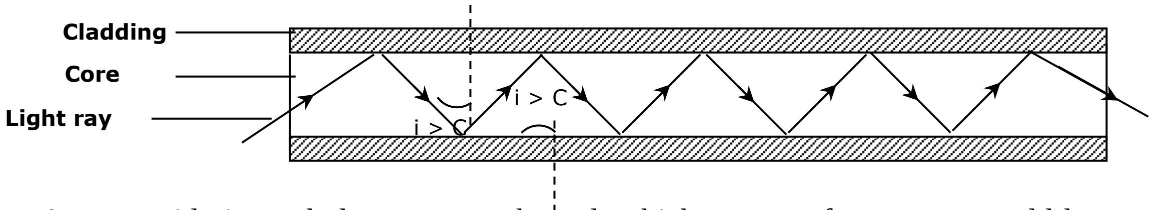
An optical fiber consist of a cylinder of glass or plastic called the ***core***, surrounded by a cylindrical shell of glass or plastic of lower refractive index called ***cladding***. The cladding in turn is covered by polyurethane jacket. Light is transmitted within the core. The cladding helps to keep the light waves confined to the core on account of its lower refractive index than that of the core. In addition the cladding provides some mechanical strength to the core. The additional jacket provided, protects the fiber from moisture and abrasion (rubbing or scrapping away).

Many such fibers, each one protected by individual jackets are grouped to form a cable. A cable may consist of one to several hundred fibers.

In optical fiber, the core and cladding are made up of either plastic or glass and it is found that plastic fibers are flexible and inexpensive. Usually there are 3 types of optical fibers.

1. Glass core with glass cladding
2. Plastic core with plastic cladding
3. Glass core with plastic cladding

Optical fiber as wave guides: (Principle of propagation/working mechanism)



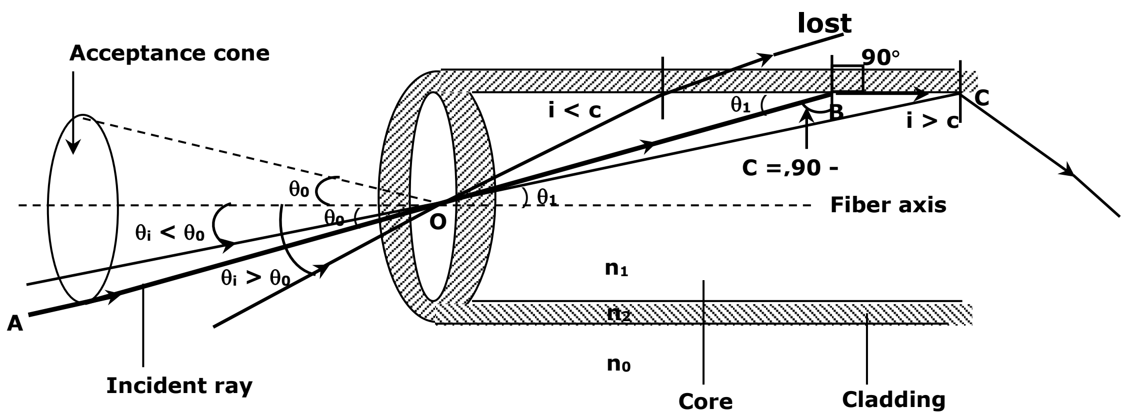
A waveguide is a tubular structure through which energy of some sort could be guided in the form of waves. Since light waves can be guided through a fiber, it is called ***light guide***. It is also called ***fiber wave guide*** or ***fiber light guide.***

The wave guide works in the following way:

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 can strike the interface of the core and cladding only at large angle of incidence (greater than critical angle), because of the ray geometry shown in the figure. Therefore the light signal undergoes total internal reflections many times and the signal sustains its strength and also confines itself completely within the core during propagation. Thus the optical fiber functions as waveguide**.** Any sharp bends in the core is avoided, since for sharp bends, the light fails to undergo total internal reflections because of which the signal strength comes down drastically.

Note: In case of total internal reflection, there is absolutely no absorption (loss) of light energy at the reflecting surface. The entire incident energy is returned along the reflected light. Because this phenomenon there will be a no loss of energy during reflection the optical fiber are able to sustain the light signal transmission over very long distance in spite of large number of reflections that occurs within the fiber.

Numerical Aperture & Ray propagation in the fiber



Let us consider a ray having critical incidence at the core – cladding interface.

Consider ray AO entering into the core at an angle θ_0 to the fiber axis. Let it be refracted along OB at an angle θ_1 in the core and proceeds to fall at the critical angle of incidence $(= 90 - \theta_1)$

at B. Since it is a critical angle of incidence, the ray is refracted at 90° to the normal drawn at the interface i.e., it grazes along BC.

Hence it is clear, that any ray which enters at an angle less than θ_0 will have refracting angle less than θ_1 because of which its angle of incidence $(90 - \theta_1)$ at the interface will become more than critical angle of incidence, and it undergoes total internal reflection.

If any ray enters at an angle greater than θ_0, it will be incident at the core-cladding aperture at an angle less than critical angle and will be refracted into the cladding region, which will be lost.

If OA is rotated, keeping θ_0 constant, it describes a conical surface. Only those rays which fall into the fiber within the acceptance cone will be totally internally reflected and are confined within the fiber for propagation. Angle θ_0 is called the ***acceptance angle*** and its sine i.e., sin θ_0 is called the ***numerical aperture (N.A)*** of the fiber.

The light gathering capacity of the fiber is represented by numerical aperture.

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

Applying Snell's law at the point of entry of the ray AO we have

$n_0 \sin\theta_0 = n_1 \sin\theta_1$ ---------------- (1)

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

$\therefore$ Again applying Snell's law at B,

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

or $n_1 \cos\theta_1 = n_2$ $\quad$ ($\because \sin 90° = 1$)

or $\cos\theta_1 = \frac{n_2}{n_1}$ --------------------- (2)

Rewriting equation (1) we have

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

$\sin^2\theta + \cos^2\theta = 1$

$\therefore \sin^2\theta = 1 - \cos^2\theta$

$\therefore \sin\theta = \sqrt{1-\cos^2\theta}$

Substituting for $\cos\theta_1$ from equation (2), we have

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

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

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

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

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

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

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

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

if $\theta_i < \theta_0$, or $\sin\theta_i < \sin\theta_0$

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

or $\sin\theta_i <$ N.A

This is the condition for propagation.

Fractional index (Δ):

The ratio of the difference between the refractive indices of core and cladding to the refractive index of core of an optical fiber is called ***fractional index***.

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

Relation between N.A and Δ:

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

Or $n_1 - n_2 = n_1\Delta$ ----------- (A)

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

$= \sqrt{(n_1 + n_2)(n_1 - n_2)}$

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

From (A), Since $n_1 \approx n_2$, $(n_1 + n_2) \approx 2n_1$

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

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

Therefore the value of numerical aperture (N.A) can be increased by increasing the value of fractional index (Δ), so as to receive maximum light into the core. But fibers with large Δ will not be useful for optical communication due to the occurrence of a phenomena inside the fiber called **multipath dispersion or intermodal dispersion.** This phenomenon introduces a time delay factor, in the travel length and may cause distortion of the transmitted optical signal. This leads to pulse broadening, which in turn limits the communication distance.

V – Number: (based on the theory proposed by Van – Cittert – Zernike theorem)

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

$$V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2} \quad \text{or} \quad V = \frac{\pi d}{\lambda}(NA)$$

where d is the core diameter & NA is the numerical aperture

n_1 is the refractive index of the core

n_2 is the refractive index of the cladding

λ is the wavelength of light propagating in the fiber

Number of modes $\cong \frac{V^2}{2}$

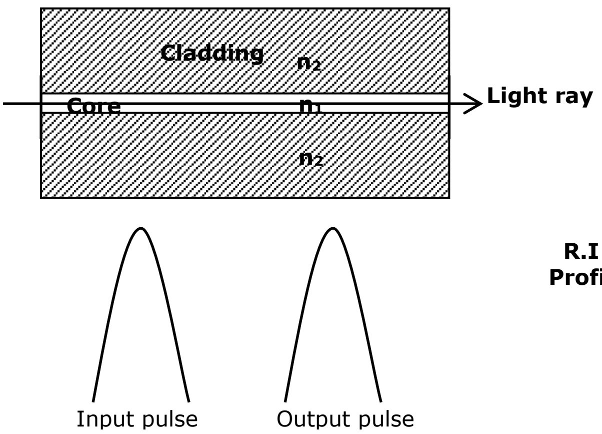
Types of optical fibers and modes of propagation:

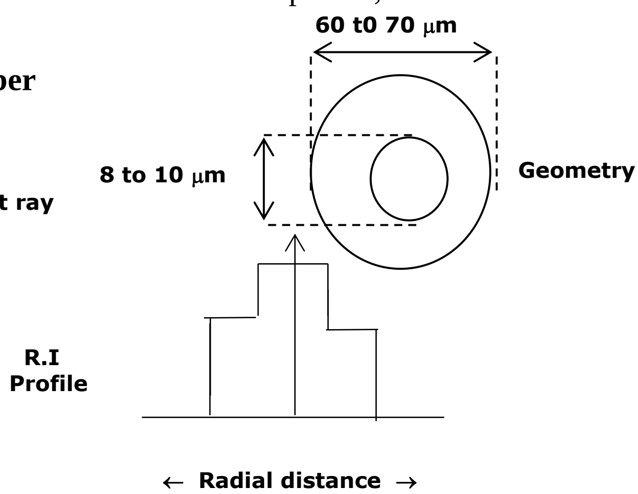
There are mainly three types of optical fibers, they are

1. Step – index single mode fiber
2. Step – index multi-mode fiber
3. Graded – index multimode fiber

This classification is done depending on the refractive index profile, and the number of modes that the fiber can guide.

1. **Step – index single – mode fiber**



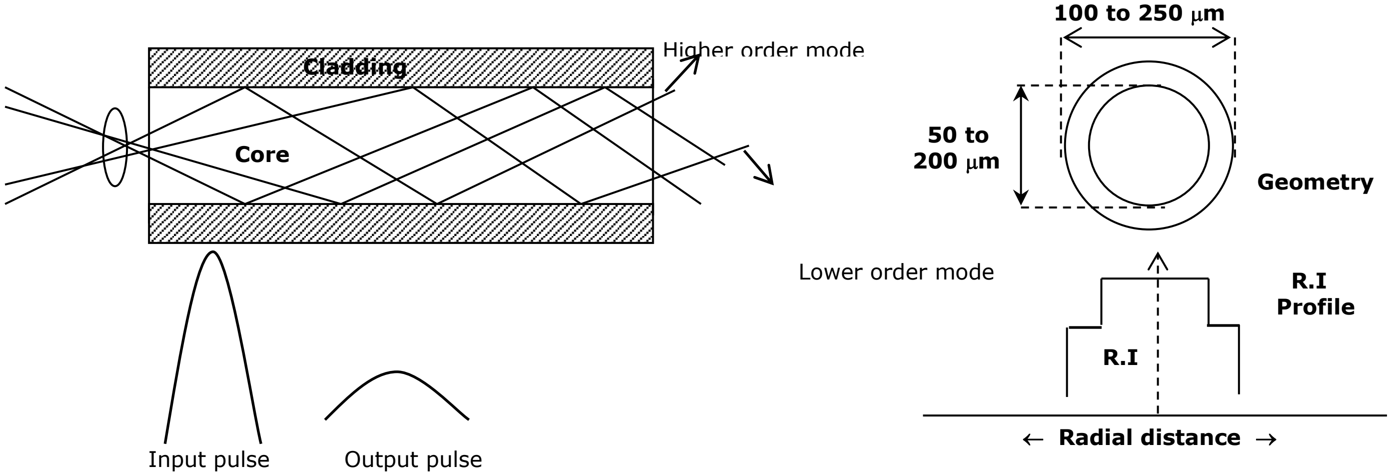


It consists of a core material of uniform refractive index (n_1). The core is surrounded by a cladding which is made up of a material of uniform refractive index (n_2). But the refractive index of cladding is lower than the refractive index of core. This results in a sudden decrease in the value of refractive index from core to cladding. Thus its R.I. profile takes the shape of a step. The diameter of the core is about 8 – 10 μm and external diameter of cladding is about 60 – 70 μm

Since the core is narrow, it can guide just a single mode as shown in figure. Hence it is called single mode fiber. Single mode fibers are most commonly used and it is less expensive. They need lasers as the source of light.

They find particular application in submarine cable system.

2. Step – index Multimode fiber:

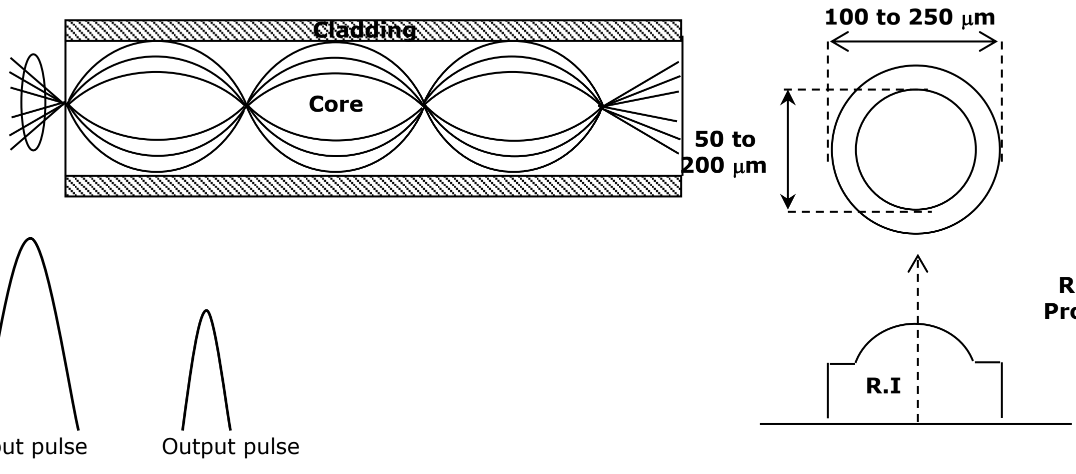


It is similar to step index single mode fiber except the diameter of the core is very large compared to the single mode fiber. The diameter of the core is about 50 t0 200 μm. Thus a large number of rays propagate in the fiber. Its refractive index profile is also similar to that of a single mode fiber, but with longer plane regions for the core.

Source used in this type of fiber is either LED or laser.

The rays travel in a zig-zag manner, in which the high angle modes travel a longer distance as compared to the low angle modes, causing intermodal dispersion. Therefore a sharp pulse broadens as it travels long distances in the fiber, which inturn limits the communication distance

3. Graded index Multimode fiber



Graded index multimode fiber is similar to that of the step-index multimode fiber in geometry. But its core material has a special feature that its refractive index value decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface. The refractive index of the cladding remains uniform. Its refractive index profile is shown in the figure. The source used is either a laser or LED.

In this fiber, a number of modes can be transmitted. The rays move in a sinusoidal path through the core. Light travels at a lower speed in the high refractive index region of the core (n = c/v) than that in the low refractive index region. Since the fastest components of the rays take the longer path and the slower components take the shorter path in the core, the time of travel of the different modes will be almost same. This reduces the effect of intermodal dispersion. Therefore losses are minimum with little pulse broadening.

ATTENUATION:

The loss of power suffered by the optical signal as it propagates through the fiber is called attenuation. It is also called fiber loss.

Factors contributing to the attenuation in optical fiber are –

a) Absorption losses.

b) Scatting losses.

c) Bending losses (Radiation loss)

d) Coupling losses.

a. Absorption losses: The loss of signal power occurs due to absorption of photons associated with signal. Photons are absorbed by

1) Impurities in the silica glass of which the fiber is made of &

2) Intrinsic absorption by the glass material itself.

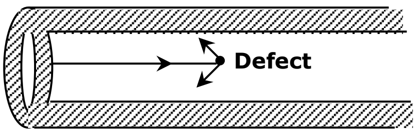
1. Absorption by impurities:

The impurities that are generally present in fiber glass are iron, chromium, cobalt & copper. During signal propagation when photons interact with these impurities, the electrons (in the impurities) absorb the photons and get excited to higher energy level. Later these electrons give up their absorbed energy either as heat or light energy. The re-emission of light is of no use, since it will usually be in a different wavelength or in different phase with respect to the signal. Hence it is a loss.

2. Intrinsic absorption:

The fiber itself has a tendency to absorb light energy however small it may be. Hence there will be a loss and is termed as intrinsic absorption.

b. Scattering losses:



(Rayleigh Scattering)

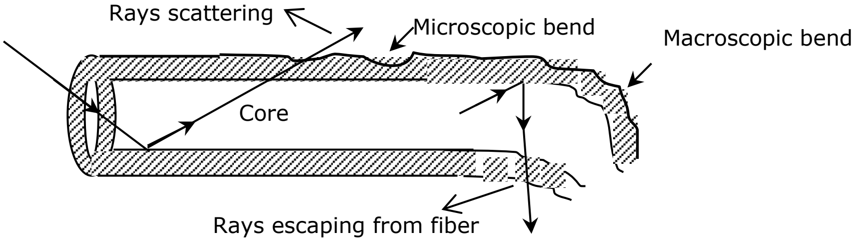
The power loss due to the scattering of light energy due to the obstructions caused by imperfections and defects, which are of molecular size, present in the fiber itself. The scattering of light by the obstructions is inversely proportional to the 4^{th} power of the wavelength of light transmitted through the fiber. Such a scattering is called **Rayleigh scattering**. The loss due to the scattering can be minimized by using the optical source of large wave length.

c. Bending Losses (Radiation losses):

Radiation losses occur due to bending of fiber. There are two types of bends.

1. Microscopic bend.
2. Macroscopic bend

These bends are caused during manufacture as well as due to the applied stress on the fiber. At the point of bend the light will escape to the surrounding medium due to the fact that the angle of incidence at that point becomes lesser than the critical angle. Hence it will not undergo total internal reflection. In order to avoid this type of losses, the optical fiber has to be laid without sharp bends and they should be freed from the external stresses by providing mechanical strength by external encasements.



d. Coupling losses: Coupling losses occur when the ends of the fibers are connected. At the junction of coupling, a film may exist or joint may be inclined or may be mismatched and they can produce a loss. This is known as coupling loss. This loss can be minimized by a technique called **splicing**.

Note:

The net attenuation is given by a factor called **attenuation coefficient** (α), in dB/km

It is expressed by the relation, $\alpha \text{ (dB/km)} = -\frac{10}{L}\log\left(\frac{P_{out}}{P_{in}}\right)$

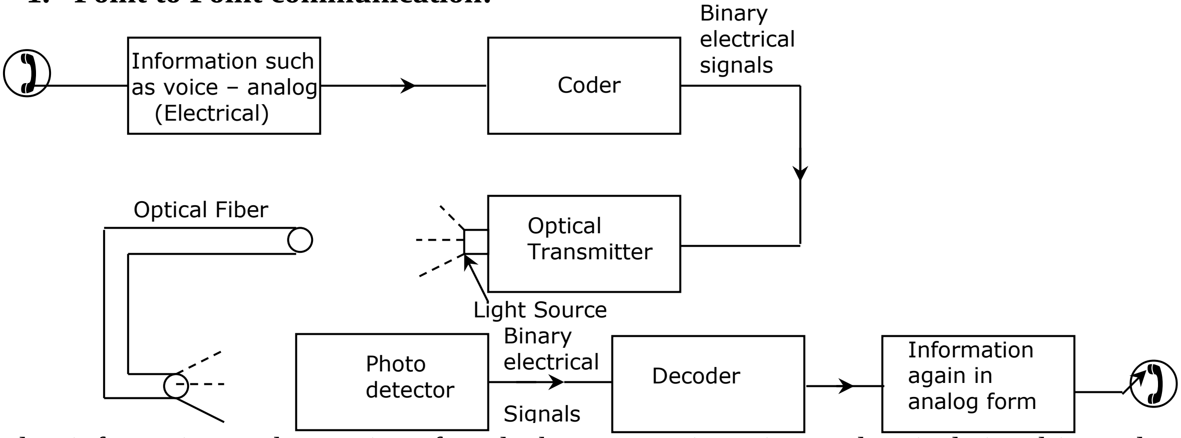
Where P_{in} is the power coupled into the power (power of the input signal)

P_{out} is the power output at the end (power of the output signal)

L is the length of the fiber in km

Application of Fiber Optics:

1. Point to Point communication:



Analog information such as voice of a telephone user gives rise to electrical signal in analog form. This analog signal is converted into binary data using coder. The binary data comes out as a stream of electrical pulses from the coder. These electrical pulses are transformed into optical power with the help of an optical source such as LED or lasers. This unit is called as optical transmitter from which the optical power is fed into the fiber.

Only certain modes of the incident light, which enters into the core within the acceptance cone will be sustained for propagation within the fiber by means of total internal reflection.

Finally at the receiving end, the optical signal from the fiber is fed into a photo detector, where the signal is converted into pulses of electric current which is then fed to decoder which converts the binary data into analog signal which will be the same information as voice.

2. **Sensing device:** Optical fiber can be used as sensing devices wherein they are employed to sense parameter such as Temperature, displacement, pressure, voltage or current and the information is then fed to a processor from which the information is obtained.

3. **Local area networks:** Optical fibers provides more efficient communication facilities in local area networks, wherein the information is required to be exchanged between terminals which are located at different places.

4. **Fiber – Optic endoscope (Fibroscope):** It is an optical instrument by using which a visual inspection or photography of internal parts of human body could be carried out.

5. Fiberscope with suitable modification is sued in industry for examining welds, nozzles and combustion chambers in jet aircraft which will be inaccessible for direct observation

Intensity Based displacement sensor

Fiber-based devices are widely studied for the advantage in their response to many physical parameters such as displacement, pressure, temperature and electric field. Recently, intensity-based fiber displacement sensors have received significant attention from the research community for their inherent advantages such as compactness, light weight, small size, non-contact measurement and immunity to a hostile environment. (WDM- Wavelength Division Multiplexing is a fiber-optic transmission technique that enables the use of multiple light wavelengths (or colors) to send data over the same medium).

Different Types of Optical Sensor :

Radio-frequency self-referencing WDM intensity-based optical sensor operating in reflective configuration.

Utilizing intensity modulation mechanisms, a bent-tip optical fiber and a reflector that can either laterally slide or longitudinally move with reference to the central axis of the fibers.

a plastic displacement sensor optical fiber based on the received light intensity after the reflection from the target whose displacement has to be measured.

Features

Non-contact detection : Detects an object without contact. Non-contact sensing ensures longer life for the sensor and absolutely no damage to the object.

Short response time : The use of an optical beam for detection and complete electronic circuitry makes the sensors respond so quickly that they can be easily used on a high-speed production line.

High accuracy detection : Advanced optical system and electronic circuit technology have achieved a sensing accuracy of up to 0.01 µm

Detection according to workpieces : Stable detection is possible by using the minute spot light for minute objects, such as IC pins, and the line spot light for diffusely reflecting surfaces, such as cutting surfaces.

Optical fiber temperature sensor based on the self-phase modulation effect

Temperature sensors of high sensitivity, small size and low cost are high demand because temperature plays a important role in areas of meteorology, biology, environmental monitoring and manufacturing. Temperature measurement based on microstructured optical fiber (MOF) has advantages such as wide detection range, high sensitivity, simple configuration and are easy to integrate with other devices. There are many methods to improve the temperature sensing performance, such as Fabry-Perot interferometer, Mach-Zehnder interferometer, surface plasmon resonance, etc.but these temperature sensors are often complex in structure, require a strict design and fabrication process, and usually suffer from poor mechanical strength and high cost.

As an important nonlinear optical phenomenon, self-phase modulation (SPM) occurs in single-wavelength systems with high pump power, leading to phase change of propagation pulse. Commonly observed in optical fibers, SPM can cause spectrum broadening: in the normal dispersion region, it causes the optical signal to experience larger broadening, while in the abnormal dispersion region, the signal broadening could be smaller due to the compensation of the dispersion effect and the SPM effect. SPM has been widely applied to all-optical regeneration, frequency comb generation, optical signal switching, optical pulse compression, etc.

A highly sensitive temperature sensor is designed based on self-phase modulation (SPM) in an in-house fabricated microstructured optical fiber (MOF) which had three rings of air holes. The temperature sensing performance was evaluated by detecting the 3 dB bandwidth of SPM spectrum with the variation of temperature at different pump wavelengths and average pump power. At the pump wavelength of 1400 nm with the average pump power of 600 mW, the temperature sensitivity was obtained to be as high as 1.296 nm/°C.

. This SPM-based temperature sensor has the features of low cost, simple design, and easy detection. It can be widely used in the biological field and harsh industrial environment for real-time temperature detection.

Advantages of optical fibers:

1. Optical fiber material are easily available.
2. Optical fiber carries very large amount of information in either digital or analog form
3. Cost of optical fiber is less compared to the other modes of communication.

4. Optical fiber are light in weight and compact, so the transformation easy.
5. Optical fiber are not effected by lightening or sparkling.
6. Optical fiber do not radiate energy.
7. Optical fibers protect the electrical signal from corrosive and flammable environments.

Limitations of optical fibers:

1. Optical connectors used for connecting two fibers are highly expensive.
2. Whenever a fiber suffers a line break, operations required to establish the connections are highly skillful and time consuming.
3. Fibers undergo expansion and contraction with temperature that upset some critical alignments, which lead to loss in signal power.
4. Maintenance cost of the systems with optical fiber is very high.
5. Optical fiber break if sharply bent.

QUESTION BANK

1. Obtain an expression for energy density of radiation under equilibrium condition in terms of
2. Einstein coefficients
3. Discuss the conditions required for laser action.
4. Write a note on requisites of the laser system.
5. Describe the different modes of vibration of CO_2 laser.
6. Describe the construction & working of CO_2 laser with the help of energy level diagram.
7. Describe the principle, construction & working of semiconductor laser.
8. Describe briefly the application of lasers in range finder and eye surgery.
9. Define induced absorption, spontaneous emission & stimulated emission.
10. Define metastable state, active medium & population inversion.
11. What is TIR?
12. Define critical angle.
13. Define acceptance angle and numerical aperture.
14. Derive the expression for NA and state the condition for propagation of light through the OF.
15. Explain the different types of OFs based on propagation and index profile.
16. What is attenuation? write down the expression for attenuation coefficient.
17. Write a short note on point to point communication using OF
18. Write short notes on displacement sensor and temperature sensor using OF.