UNIT-V

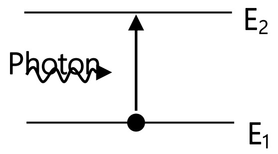
LASERS AND OPTICAL FIBERS:

LASERS

Laser is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Laser is a highly "monochromatic coherent beam of light of very high intensity". In 1960 Theodore Mainmann built the first "LASER" using Ruby as active medium.

Interaction of Radiation with matter:

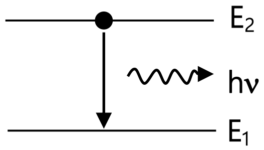
1. Stimulated Absorption: -



When an atom in the ground state say E_1 absorbs a photon of energy (E_2 - E_1) it makes transition into exited state E_2. This is called Stimulated or Induced absorption. It is represented as follows,

Atom + Photon = Atom*.

2. Spontaneous Emission: -Spontaneous emission is one in which atom in the excited state emits a photon when it returns to its lower energy state without the influence of any external energy.



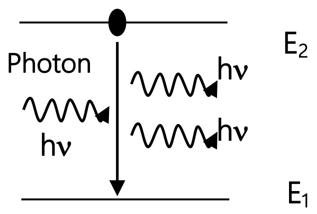
Consider an atom in the excited state E_2. Excited state of an atom is highly unstable. Within a short interval time, of the order of 10^{-8} s atom returns to one of its lower energy state say E_1 and emits difference in energy in the form of photon of energy hv = E_2 - E_1 spontaneously.

If the two atoms are in the same excited state and returns to some lower energy states two photons of having same energy are emitted. These Two photons may not travel in the same direction. They produce in-coherent beam of light. Spontaneous emission is represented as follows,

Atom* = Atom + Photon.

3. **Stimulated Emission**: -Consider an atom in the excited state E_2. If a photon of energy E_2 - E_1 is made to incident on the atom in the excited state E_2. The incident photon forces (stimulates) the atom in the excited state to make transition in to ground state E_1 by

emitting difference in energy in the form of a photon.



This type of emission in which atom in the excited state is forced to emit a photon by the influence of another photon of right energy is called stimulated emission. Stimulated emission can be represented as follows.

Atom* + Photon = Atom + (photon + photon).

When stimulated emission takes place, incident photon and the emitted photon are in phase with each other and travel along the same direction. Therefore they are coherent.

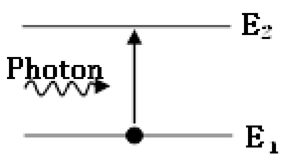
<u>Einstein's A & B coefficients</u>

The theory behind lasers was established by Albert Einstein. He explored the basic mechanism involved in the interaction between radiation and matter. He assumed that matter is in thermodynamically equilibrium with a black body radiation field. His theory involved important parameters known by his name Einstein's coefficients. These coefficients give the probability associated with the absorption and emission processes.

<u>Expression for Energy density in terms of Einstein's coefficients</u>

Consider a system under thermal equilibrium. Let E_1 and E_2 be the ground energy state and excited energy state. Let N_1 and N_2 be the number density of atoms in E_1 and E_2 respectively. Let U_ν be the energy density per unit volume of the system of frequency ν.

a) **Induced absorption**: *In this process, when photon of suitable frequency ν is incident, the atom in E_1 absorbs the photon and gets excited to energy state E_2. Such absorptions per unit time, per unit volume are called Rate of Induced Absorption* (shown in figure).

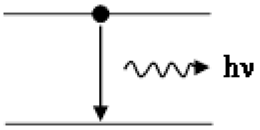


Therefore, rate of induced absorption $\propto$ {number of atoms in E_1 and the energy density U_ν}.

Therefore, Rate of induced absorption = $B_{12}. N_1. U_\nu$, (1)

Where, B_{12} is a constant characteristics of atom and called as Einstein's coefficient of induced absorption.

b) **Spontaneous emission:** *In this process, the atom in excited energy state E_2 voluntarily emits photon and transits to lower energy state E_1. Such emissions per* *unit time, per unit volume are called Rate of spontaneous emission*. As shown in figure

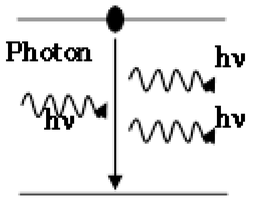


Therefore, Rate of spontaneous emission $\propto$ number of atoms in E_2.

Therefore, Rate of spontaneous emission = A_{21}. N_2, (2)

Where, A_{21} is a constant characteristic of atom and is known as Einstein's coefficient of spontaneous emission.

c) **Stimulated emission:** *In this process, an incident external photon of suitable energy stimulates the excited atom, to make a downward transition (from E_2 to E_1) by emitting a photon. Such emission per unit time per unit volume is called Rate of stimulated emission* (shown in figure).



Therefore, Rate of stimulated emission $\propto$ {number of atoms in E_2 and the energy density U_ν }.

Therefore, Rate of stimulated emission = B_{21}. N_2. U_ν, (3)

Where, B_{21} is a constant characteristics of atom and represents the properties of energy states E_1 and E_2 and is known as Einstein's coefficient of stimulated emission.

Since the system is under thermal equilibrium, Rate of Induced absorption = [Rate of Spontaneous emission + Rate of Stimulated emission],

From equation 1, 2 and 3, we have,

$B_{12}.N_1.U_\nu = A_{21}.N_2 + B_{21}.N_2\ .U_\nu$

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

or $U_\gamma = \dfrac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$

By rearranging the above equation, we get,

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

(4)

But by Boltzmann's law, we have

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

Equation 5 becomes,

$$U_\gamma = \frac{A_{21}}{B_{21}}\left[\frac{1}{\frac{B_{12}}{B_{21}} e^{\frac{h\gamma}{kT}} - 1}\right] \tag{5}$$

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

$$U_\gamma = \frac{8\pi h\gamma^3}{c^3}\left[\frac{1}{e^{\frac{h\gamma}{kT}} - 1}\right] \tag{6}$$

Now, comparing equations 6 and 7, term by term on the basis of position identity, we have,

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

and $\frac{B_{12}}{B_{21}} = 1$ or $B_{12} = B_{21}$.

This implies that the probability of induced absorption is equal to the probability of stimulated emission. Because of this, A_{21} and B_{21} can be simply represented as A and B and equation 6 can be rewritten.

Therefore, at thermal equilibrium the equation for energy density is,

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

Characteristics of laser

The significant feature of a laser is the enormous difference between the character of its light and other sources such as the Sun, a flame or an incandescent lamp. The most striking features are:-

a) **Directionality** The conventional light sources emit light in all directions for example, bulb, tube light, sun, candle flame, etc.. But Lasers emit light only in one direction. The beam divergence of laser is less than 0.01 milli radian. That is, the beam spreads less than 0.01 mm for every meter. Hence light emitted by a laser is directional.

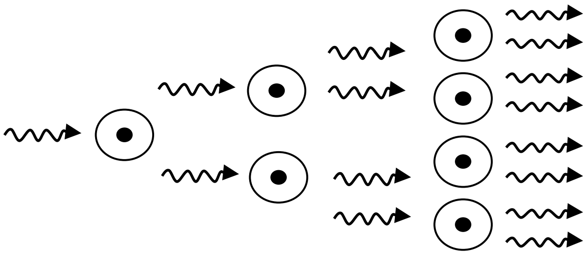
b) **Intensity** The light from a lamp streams out more or less uniformly in all directions. If we look at a 100 watt lamp filament at a distance of 30 cm, the power entering the eye is less than a thousand of a watt. The laser gives out light in to a narrow beam and its energy is concentrated in a small region. Thus even a 1 watt laser would appear many thousand times more intense than 100 watt ordinary lamp. It is said that a few milli watt laser is hundred times brighter than the sun at the earth's surface.

c) **Monochromatic** Light having single color (single frequency or wavelength) is said to be monochromatic. The light emitted by a laser is vastly more monochromatic than that of any conventional monochromatic source.

d) **Coherence** Laser radiation is characterized by a high degree of the light field than the other sources. The coherence length of light from a sodium lamp is of the order of 0.3 mm, while that of laser is 100 m. Radiation of such intensity.

<u>Lasing Action (Laser Action)</u> : -

Let an atom in the excited state is stimulated by a photon of right energy so that atom makes stimulated emission. Two coherent photons are obtained. These two coherent photons if stimulate two atoms in the exited state to make emission then four

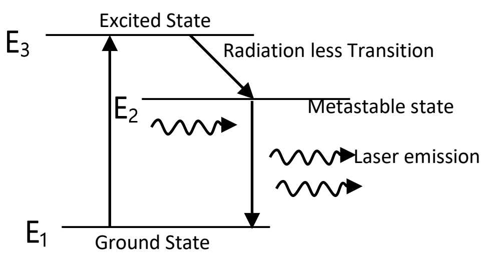


coherent photons are produced. These four coherent photons so that stimulates 4 atoms in the excited state, 8 coherent photons are produced and so on. As the process continues number of coherent photons increases. These coherent photons constitute an intense beam of laser. This phenomenon of building up of number of coherent photons so as to get an intense laser beam is called lasing action.

Population inversion and optical pumping: - In an order to produce laser beam there should be more number of stimulated emissions when compared to spontaneous emission. It is possible only if number of atoms in the exited states is greater than that is the ground state. When system is in thermal equilibrium, then number of atoms in the higher energy level is always less than the number of atoms in the lower energy level. If by some means number of atoms in the exited slate is made to exceed number of atoms in the ground state then **population inversion** is said to have established between excited state and ground state. The method of achieving the population inversion is called **pumping**. If light is used to pump electrons to the higher level then, the method is called **Optical Pumping**. If the electric field is used to pump electrons to the higher level then, the method is called **Electrical Pumping**.

Metastable State: -

Population inversion can be created with the help of three energy levels as follows.



Let E_1 is the ground state of an atom. Let E_2 and E_3 are the two excited states. If an atom is excited into the energy state, within a short interval of time of 10^{-8} sec, atom makes a transition into the energy state E_2. Let lifetime of the atom in the energy level E_2 is of the order of 10^{-2} to 10^{-3} sec. Then atoms stay in the excited state E_2 for sufficiently long time without making any spontaneous emission.

As more and mare atoms are excited from the ground state to E_1 more and more atoms are transferred from E_3 to E_2. As a result, within a short interval of time population inversion is established between energy level E_2 and E_1. The energy level E_2 in which atoms remain for unusually longer time is called **Metastable state.** When transition from E_3 to E_2 takes place excited atom loses energy in the form of heat without emitting any radiation. Such transitions are called radiation less transition (Non-radiative transitions).

Requisites of a Laser System: -

The Three requisites of a Laser system are

1) Energy Source or Excitation Source for Pumping action
2) Medium Supporting population inversion called Active Medium
3) The Laser Cavity

Appropriate amount of energy is to be supplied for the atoms in order excite them to higher energy levels. If the Input energy is in the form of light energy then pumping is called optical pumping. If it is in the form of electrical energy then pumping is called electrical pumping.

Population inversion occurs at certain stage in the Active medium due to the absorption of energy. After this stage the Active medium is capable of Emitting laser light.

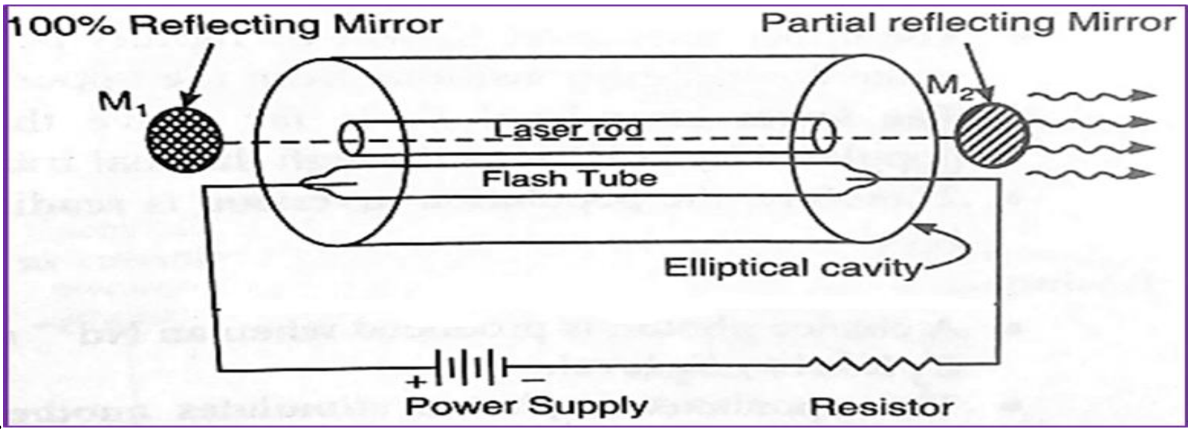
The Laser Cavity consists of an active medium bound between two mirrors. The Mirrors reflect the light two and fro through the active medium. This also helps to tap certain permissible part of laser energy from the active medium.

Nd: YAG laser

Construction: Nd: YAG laser is a neodymium based laser. Nd stands for Neodymium (rare earth element) and YAG stands for Yttrium Aluminum Garnet.

This active element is cut into a cylindrical rod. The ends of the cylindrical rod are highly polished and they are made optically flat and parallel. This cylindrical rod (laser rod) and a pumping source (flash tube) are placed inside a highly (reflecting) elliptical reflector cavity.

The optical resonator is formed by using two external reflecting mirrors. One mirror (M1) is 100% reflecting while the other mirror (M2) is partially reflecting.



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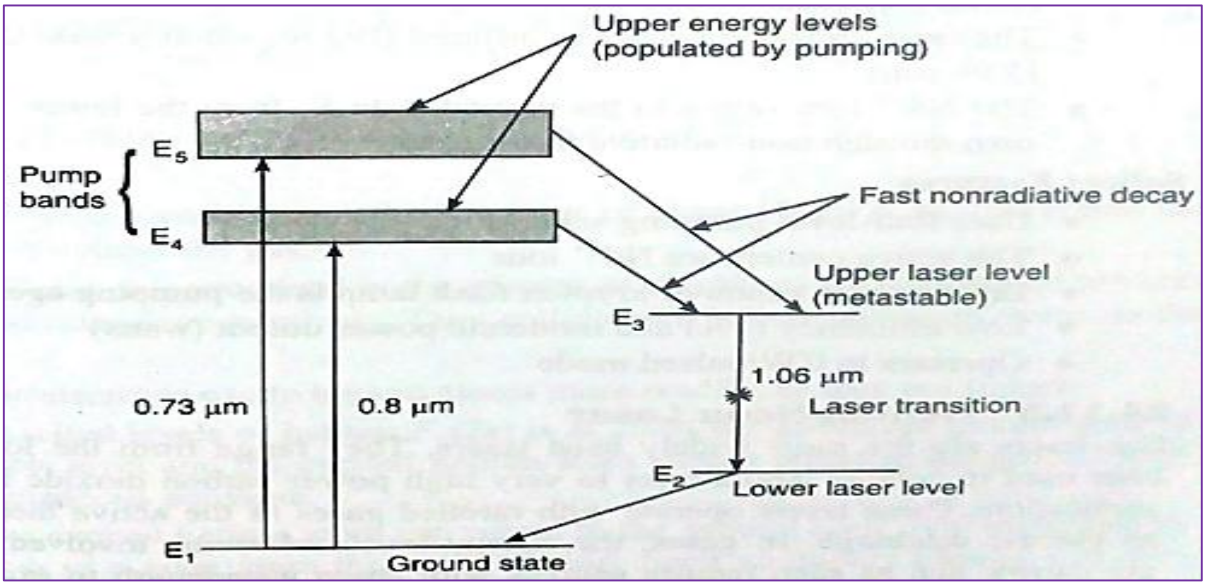
Working: When the krypton flash lamp is switched on, by the absorption of light radiation of wavelength 0.73μm and 0.8μm, the Neodymium (Nd^{3+}) atoms are raised from ground level E1 to upper levels E4 and E5. The Neodymium ions atoms make a transition from these energy levels E3 by non-radiative transition. E3 is a metastable state. The Neodymium ions are collected in the level E3 and the population inversion is achieved between E3 and E2. An ion makes a spontaneous transition from E3 to E2, emitting a photon of energy hν. This emitted photon will trigger a chain of stimulated photons between E3 and E2. The photons thus generated travel back and forth between two mirrors and grow in strength. After some time, the photon number multiplies more rapidly. After enough strength is attained (condition for laser being satisfied), an intense laser light of wavelength 1.06μm is emitted through the partial reflector. It corresponds to the transition from E3to E2.

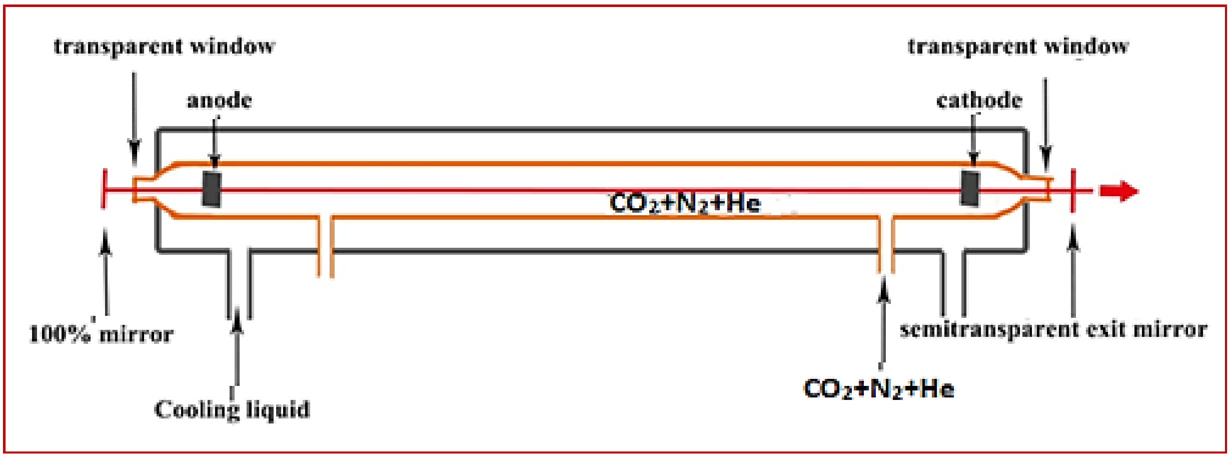


Energy Levels of Nd-YAG Laser

Carbon dioxide Laser (CO_2)

It was the first molecular gas laser developed by Indian born American scientist Prof. C. K. N.Pillai. It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser.

Construction: It consists of a quartz tube around 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2 (active medium), Helium (He) and Nitrogen (N_2) with suitable partial pressures. The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized. Two concave mirrors one fully reflecting and the other partially form an optical resonator or a laser cavity.



Working: When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

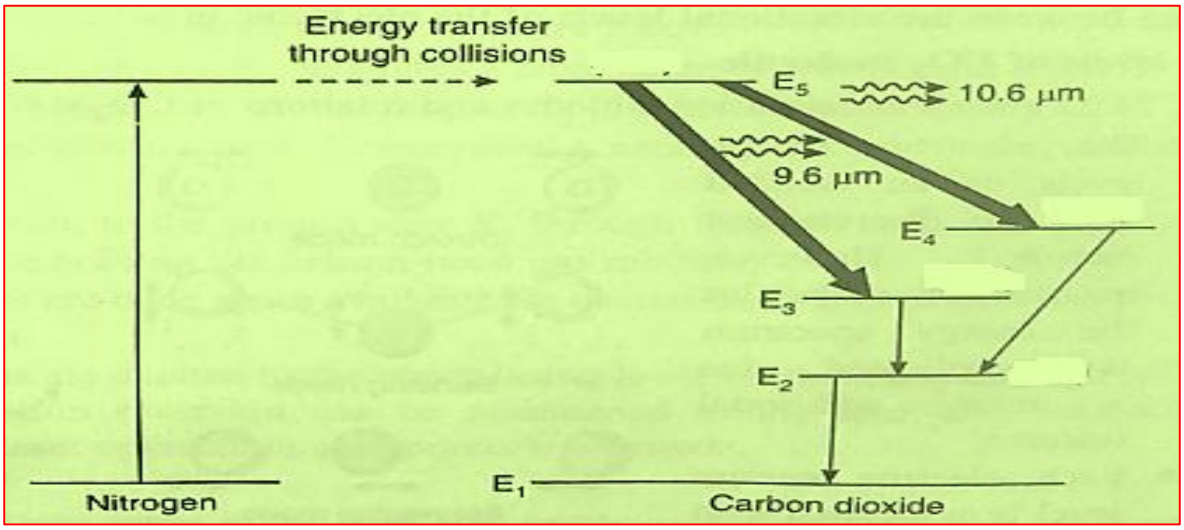
N_2 + e* = N_2* + e

N_2 = Nitrogen molecule in ground state.   e* = Energy of electron Before collision
N_2* = Nitrogen molecule in excited state. e = Energy of electron After collision.
Now N_2 molecules in the excited state collide with CO_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.
This process is represented by the equation N_2* + CO_2 = CO_2* + N_2

N_2* = Nitrogen molecule in excited state. CO_2 = Carbon dioxide atoms in ground state CO_2* = Carbon dioxide atoms in excited state N_2 = Nitrogen molecule in ground state.

Since the excited level of nitrogen is very close to the E5 level of CO_2 atom, population in E5 level increases. As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1. Transition E_5 to E_4 :
This will produce a laser beam of wavelength 10.6µm
2. Transition E_5 to E_3
This transition will produce a laser beam of wavelength 9.6µm. Normally 10.6µm transition is more intense than 9.6µm transition. The power output from this laser is 10 kW.



Energy levels of nitrogen and carbon dioxide molecules.

Applications of Laser

Because of high intensity, high degree of monochromaticity and coherence, lasers find remarkable applications in medicine, communication, defense, photography, material processing etc.

Laser Welding

In performing the task of welding, laser welding is superior to other welding such as arc welding, gas welding, electron welding, etc.

- Focus the laser beam on to the spot to be welded.
- Due to the excess of heat generated, only focused portion melts.
- The heat produced by the beam is so intense that, impurities in the material such as oxides float up on the surface and upon cooling the material becomes homogeneous solid structure and it makes a strong joint.

Advantages:

- Laser welding is a contact less process and thus no foreign materials can enter into the welded joint.
- In this type of welding, no destruction occurs in the shape of work piece and the heat is dissipated immediately (since the total amount of heat supplied is very small compared to the regular welding)
- The laser beam can be controlled to a great precision, so that we can focus the laser beam precisely to the welding spot. Even we can weld difficult to reach the locations in the material.
- Since the heat affected zones are very small, laser welding is ideal at places which are surrounded by heat sensitive components.

Laser Cutting

Laser cutting of metals is generally associated by gas blowing. The oxygen gas is passed through the nozzle and the tip of the nozzle is pointed at the spot, where the laser beam is focused.

- The combustion of the gas burns the metal thus reducing the laser power required for cutting.
- Also the tinny splinters along with the molten part of the metal will blow away by the oxygen jet.
- The blowing action increases the depth and also the speed of cutting.
- The laser, which controls the accuracy of the cutting thus, the cut edges will be high quality.

Advantages:

- The quality of cutting is very high
- There will be no thermal damage and chemical change when cutting is done in inert atmosphere.
- 3-d cutting can also be done very easy.

Drilling:

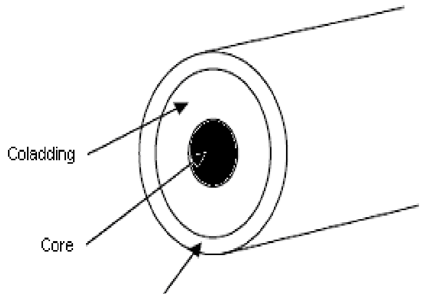
- Drilling of holes is achieved by subjecting the material to 10^{-4} to 10^{-3}S duration pulse.
- The intense heat generated over a short duration by the pulses evaporates the material locally, thus leaving a hole.

Advantages:

Conventional Method	Laser
The tools wear out while drilling	This problem doesn't exist in laser setup
Whereas it could be done only to a limited extent	Drilling can be achieved at any oblique angle
It is difficult	Very fine holes 0.2 to 0.5mm diameter can be drilled. The holes may be even adjacent to each other
Large force has to apply to drill the hard materials or brittle materials.	Very hard material or brittle materials can be drilled. There is no mechanical stress with a laser beam.

Optical Fibers

Optical fiber is a device used to transmit light signals through the transparent medium made up of dielectric materials like glass from end to other end over a long distance.



Construction:

1) The innermost Light guiding region called **Core**.

2) The middle region-covering core made of material similar to Core is called **Cladding**.

The RI of Cladding is less than that of Core.

3) The outermost protecting layer for Core and Cladding from moisture, crushing and chemical reaction etc., is called **Sheath**.

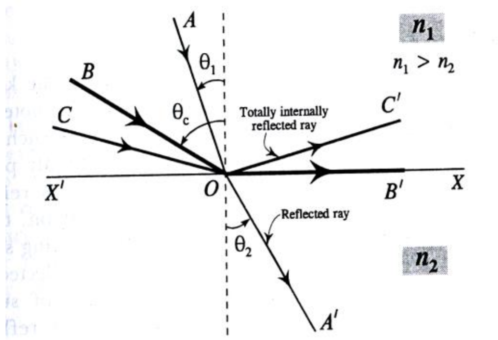
The Optical Fibers are either made as a single fiber or a **flexible bundle** or **Cables.**

A **Bundle fiber** is a number of fibers in single jacket.

Principles of Optical fibers

It is based on the principle of Total Internal reflection.

Consider a ray of light passing from denser medium to rarer medium. As the angle of incidence increases the angle of refraction also increases. For a particular angle of incidence called Critical Angle the refracted ray just grazes the interface (Angle of refraction is 90^o). If the angle of incidence is greater than Critical Angle then the ray reflected back to the denser medium. This phenomenon is called Total Internal Reflection.



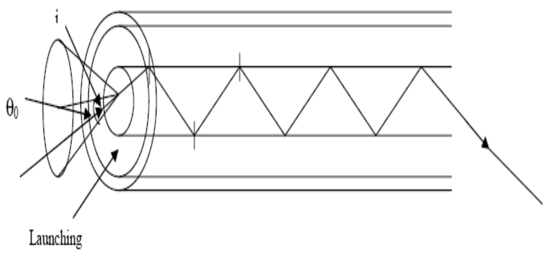
TOTAL INTERNAL REFLECTION

TIR is not just one kind of reflections. It may be noted that, some light energy is always lost during reflections occur at the surface of mirror, polished metallic surface.

But in case of TIR, there is no loss of light energy at the reflecting surface. The entire incident energy is returned along the reflected light. Hence, it is called TIR. Because of no loss of energy during reflection, the optical fibers are able to sustain the light signal transmission over long distance in spite of infinite number of reflections that occur within the optical fiber.

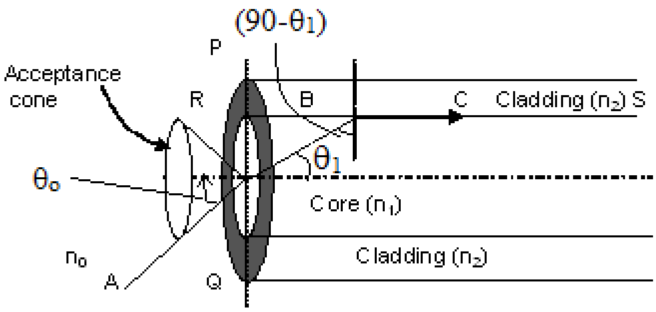
Propagation of light through fiber Optical fiber as a light guide

The incident light enters the core and strikes the interface of the Core and Cladding at large angles as shown in fig. Since the Cladding has lower RI than Core the light suffers multiple Total Internal Reflections. This is possible since by geometry the angle of incidence at the interface is greater than the Critical angle. Since the Total internal reflection is the reflection at the rarer medium there is no energy loss. Entire energy is transmitted through the fiber. The propagation continues even the fiber is bent but not too sharply. Since the fiber guides light it is called as **fiber light guide** or **fiber waveguide.**



Expression for Numerical Aperture in an optical fiber

Consider an optical fiber consisting of inner cylindrical core made of glass of refractive index n_1 and is surrounded by another material called cladding of refractive index n_2 such that $n_2 < n_1$.



Consider a ray of light AO incident on the core at 'O' at an angle θ_o with the fiber axis. Then it refracts along OB at an angle of θ_1 in the core. The refracted ray is incident on the interface between core and cladding at B an angle of incidence $(90 - \theta_1)$. Assuming this angle $(90 - \theta_1)$ is equal to critical angle, then the ray is refracted at 90^0 to the normal drawn to the interface. i.e. it grazes along BC. Now, it is clear from the figure that any ray that enters into the core at angle $\theta_i < \theta_o$ will have refractive angle less than θ_1 because of which its angle of incidence at the interface (=90 - θ_1) will become greater than critical angle of incidence and thus undergoes total internal reflection.

If the angle of incidence at 'O' is greater than θ_o, then the refracted ray pass through the cladding and it will be lost.

If AO is rotated around the fiber axis keeping θ_o as constant, then it forms a conical surface called acceptance cone. One those rays which enter within this acceptance cone will undergo total internal reflection and propagates through the fiber.

"The angle θ_0 is called waveguide acceptance angle or acceptance cone half angle and Sinθ_0 is called Numerical Aperture of the fiber". The N.A. represents the amount of light rays that can be transmitted along the optical fiber.

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

Apply Snell's law to the surface PQ, which separates surrounding medium and core:

$$n_0 \, Sin\theta_0 = n_1 \, Sin\theta_1$$

$$Sin\theta_0 = \frac{n_1}{n_0} \, Sin\theta_1 \qquad \dots (1)$$

Apply the Snell's law to surface RS which separates core and cladding:

$$n_1 \, Sin(90-\theta_1) = n_2 \, Sin 90$$

$$n_1 \, Cos\theta_1 = n_2$$

$$Cos\theta_1 = \frac{n_2}{n_1} \qquad \dots (2)$$

Rewrite the equation (1) => $Sin\theta_0 = \frac{n_1}{n_0}\sqrt{1-\cos^2\theta_1}$

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

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

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

$$Sin\theta_0 = \text{N.A.} = \sqrt{n_1^2 - n_2^2}$$

The condition for propagation is the angle of incidence θ_i should be less than acceptance angle θ_0. i.e. $\theta_i < \theta_0$

i.e. $Sin\theta_i < Sin\theta_0$

$Sin\theta_i <$ N.A.

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

Sine of the angle of incidence must be less than numerical aperture.

Fractional Index Change (Δ):

It is the Ratio of the refractive index difference between Core and Cladding to the Refractive index of core of an optical fiber.

$$\Delta = \frac{n_1 - n_2}{n_1} \text{......(1)}$$

Relation between N A and Δ:

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

$$\Delta n_1 = n_1 - n_2 \text{........(2)}$$

$We know that,$

$$NA = \sqrt{n_1^2 - n_2^2}$$

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

$from equation (2)$

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

$$if\ n_1 \cong n_2$$

$$NA = \sqrt{(\Delta n_1)(2n_1)}$$

$$NA = n_1\sqrt{2\Delta}$$

Modes of Propagation

Light propagates as an electromagnetic wave through an optical fiber. It is true that all waves, having directions above the critical angle, will be trapped within the fiber due to TIR. But is not true that all such waves propagate along the fiber and only certain ray directions are allowed to propagate. The allowed directions correspond to the modes of the fiber i.e. Mode refers to the number of paths for the light rays to propagate in the fiber. The number of modes that a fiber will support depends on d/λ. Where d – diameter of the core and λ is the wavelength of the wave transmitted.

[**Note:** As a ray gets repeatedly reflected at the walls of the fiber, phase shift occurs. Consequently, the waves traveling along certain zigzag paths will be in phase and intensified, however, some other paths will be out of phase and hence the signal strength diminishes due to destructive interference. The light ray paths along which the waves are in phase inside the fiber are known as modes.]

V- Number

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

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

d – diameter of the core, λ - wavelength of the light,

n_0 – R.I. of the surrounding medium, n_1 – R.I. of the core, n_2 – R.I. of the cladding

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

Types of Optical Fiber

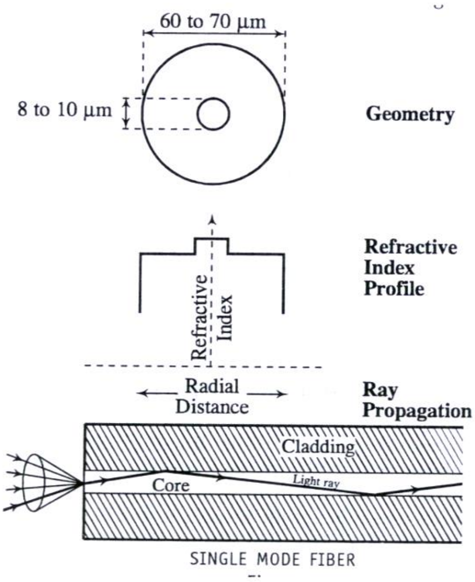
Optical fibers are classified into 3-types based on their R.I. of core and cladding and number of modes of propagation in the fiber.

(1) Step index single mode fiber

(2) Step index multi mode fiber

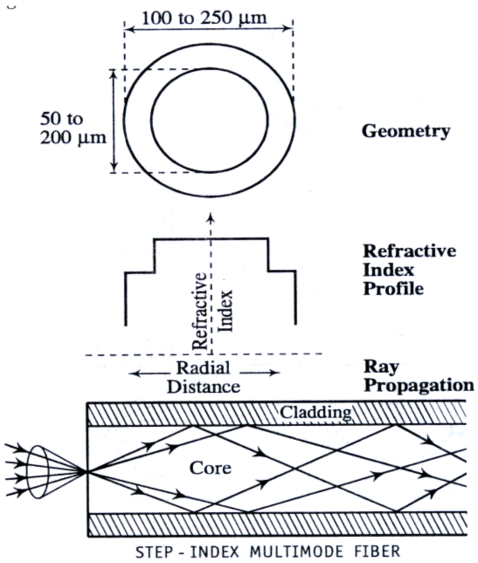
(3) Graded Index multi mode fiber

(1) Step Index Single Mode optical fiber



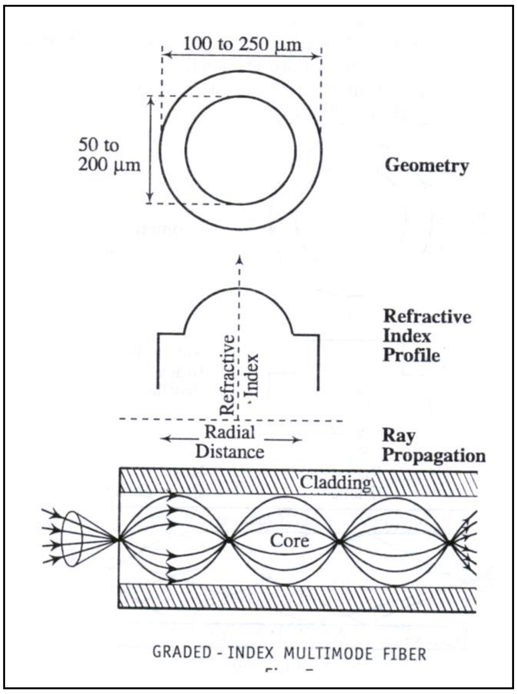
- It consists of a core of uniform refractive index n_1
- The diameter of the core is about 10 μm
- The core is surrounded by a material of uniform R.I. n_2 called cladding such that $n_2 < n_1$. The external diameter of the cladding is 60 – 70 μm
- The variation of R.I.s of core and cladding takes the shape of step as shown in fig.
- Since the core diameter is very small, therefore, it can guide a single mode as shown in figure.
- Laser can be used as a source.
- There are used for long distance communications and submarine cable system.

(1) Step index multi mode fiber



- It consists of a core of uniform refractive index n_1
- The diameter of the core is about 50 - 200 μm
- The core is surrounded by a material of uniform R.I. n_2 called cladding such that $n_2 < n_1$. The external diameter of the cladding is 100 – 250 μm
- The variation of R.I.s of core and cladding takes the shape of step as shown in fig.
- Since the core diameter is very large, therefore, it will be able to support propagation of large number of modes.
- LED or Laser can be used as a source.
- Applications: It can be used in data links which has lower band width requirements.

(3)Graded Index multi mode fiber (GRIN)



- The core material has a special feature that its R.I. value decreases in the radially outward direction from the axis and becomes equal to that of the cladding at the interface.
- It is obvious from the figer that a ray is continuously bent and travels a periodic path along the axis. The ray entering at different angles follow different paths with the same period.
- The diameter of the core is about 50 - 200 μm
- The core is surrounded by a material of uniform R.I. n_2 called cladding such that $n_2 < n_1$. The external diameter of the cladding is 100 – 250 μm
- Since the core diameter is very large, therefore, it will be able to support propagation of large number of modes.
- LED or Laser can be used as a source.
- Applications: It can be used in the telephone trunk between central offices and it is most expensive compared to other two types.

Attenuation in optical fibers

The loss of light energy of the optical signal as it propagates through the fiber is called attenuation or fiber loss.

The main reasons for the loss of light intensity over the length of the cable is due to

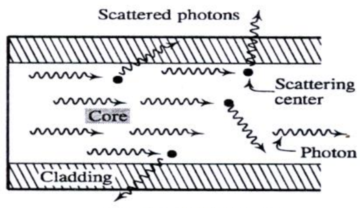
(i) absorption (ii) Scattering (iii) Radiation loss

(i) **Absorption Losses**: In this case, the loss of signal power occurs due to absorption of photons associated with the signal. Photons are absorbed by (a) impurities in the silica glass (b) Intrinsic absorption by the glass material.

(a) Absorption by impurities: During the light propagation the electrons of the impurity atoms like copper, chromium, iron etc, present in the fiber glass absorb the photons and get excited to higher energy level. Later these electrons give up the absorbed energy either as heat or light energy. But the emitted light will have different wavelength with respect to the signal. Hence it is loss.

(b) Intrinsic Absorption: sometimes even if the fiber material has no impurities, but the material itself may absorb the light energy of the signal. This is called intrinsic absorption.

(ii) **Scattering Loss: (Rayleigh scattering)** since, the glass is heterogeneous mixture of many oxides like SiO_2, P_2O_5, etc, the compositions of the molecular distribution varies from point to point. In addition to it, glass is a non-crystalline and molecules are distributed randomly. Hence, due to the randomness in the molecular distribution and in homogeneities in the material, there will be sharp variation in the density (refractive index value) inside the glass over distance and it is very small compared to the wavelength of light. Therefore, when the light travels in the fiber, the photons may be scattered. (This type of scattering occurs when the dimensions of the object are smaller than the wavelength of the light. Rayleigh scattering $\alpha \frac{1}{\lambda^4}$). Due to the scattering, photons moves in random direction and fails to undergo total internal reflection and escapes from the fiber through cladding and it becomes loss.

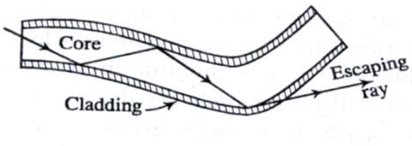


RAYLEIGH SCATTERING

(i) **Radiation loss:** Radiation losses occur due to bending of fiber.There are two types of bends

(a) **Macroscopic bends**

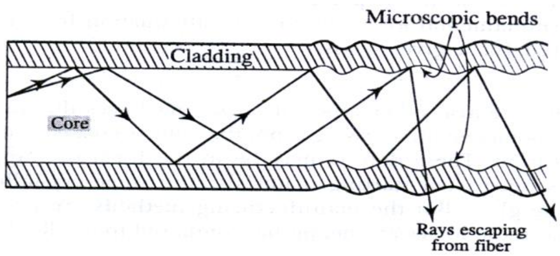
When optical fiber is curved extensively such that incident angle of the ray falls below the critical angle, and then no total internal reflection occurs. Hence, some of the light rays escape through the Cladding and leads to loss in intensity of light



RADIATION LEAKS

(b) **Microscopic bends**

The microscopic bending is occur due to non-uniformities in the manufacturing of the fiber or by non-uniform lateral pressures created during the cabling of the fiber. At these bends some of the radiations leak through the fiber due to the absence of total internal reflection and leads to loss in intensity.



Attenuation co-efficient

The net attenuation can be determined by a factor called **attenuation co-efficient (α).**

When light travels in a material medium, there will always be loss in its intensity with distance traveled. The rate of decrease of intensity of light with distance traveled in the homogeneous medium is proportional to the initial intensity called Lamberts's law, i.e. if P is the initial intensity and L is the distance propagated in the medium, then,

$-\frac{dP}{dL}$ α P (negative sign indicates that it is a decrement)

Or $-\frac{dP}{dL} = \alpha$ P (1)

where α is a constant called attenuation coefficient, or simply as attenuation.

Equation (i) can be rewritten as $\frac{dP}{P} = -\alpha$

By integrating on both side $\int \frac{dP}{P} = -\alpha \int dL$ (2)

If P_{in} is the initial intensity with which light is entering into the fiber and P_{out} be the intensity of light at the end of the fiber then equation (2) becomes,

$$\int_{P_{in}}^{P_{out}} \frac{dP}{P} = -\alpha \int_{0}^{L} dL$$

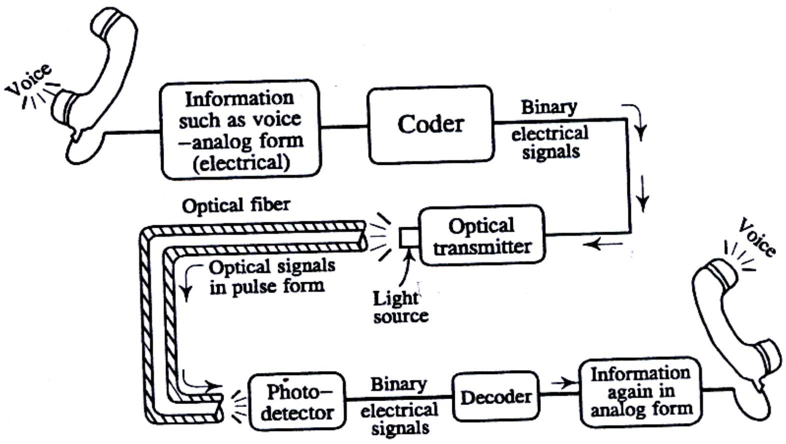
The unit of attenuation for light in optical fiber is Bel.

Or $\alpha = -\frac{1}{L} \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$ Bel / unitlength

In optical fiber technology, it is customary to express α in terms of decibel/kilometer. P is in watt and 1B = 10decibel Therefore, $\alpha = -\frac{10}{L} \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$ dB / km

Applications of Optical Fiber

A typical point to point communication system is shown in figure.



TYPICAL POINT-TO-POINT FIBER OPTIC COMMUNICATION SYSTEM

The analog information such as voice of telephone user is converted into electrical signals in analog form and is coming out from the transmitter section of telephone. The analog signal is converted into binary electrical signal using coder. The binary data comes out as a stream of electrical pulses from the coder. These electrical pulses are converted into pulses of optical power by modulating the light emitted from an optical source like LED. This unit is called an Optical transmitter.

Then optical signals are fed into the optical fiber. Only those modes of light signals, which are funneled into the core within the acceptance angle, are sustained for propagation through the fiber by means of TIR. The optical signals from the other end of the fiber are fed to the phtodetector, where the signals are converted into binary electrical signals. Which are directed to decoder to convert the stream of binary electrical signals into analog signal which will be the same information such as voice received by another telephone user.

Note: As the optical signals propagating in the optical fiber are subjected to two types of degradation – attenuation and delay distortion. Attenuation is the reduction in the strength of the signal because of loss of optical power due to absorption, scattering of photons and leakage of light due to fiber bends. Delay distortion is the reduction in the quality of signal because of spreading of pulses with time. These effects cause continuous degradation of signal as light propagates and hence it may not possible to retrieve the information from the light signal. Therefore, a repeater is needed in the transmission path. An optical repeater consists of receiver, amplifier and transmitter.

Advantages of Optical Fiber

1. Optical fibers can carry very large amounts information. The materials used for making optical fibers are silicon oxide and plastic, both are available at low cost.
2. Because of the greater information carrying capacity by the fibers, the cost, length, channel for the fiber would be lesser than that for the metallic cable.
3. Because of their compactness, and light weight, fibers are much easier to transport.
4. There is a possibility of interference between one communication channel and the other in case of metallic cables. However, the optical fiber are totally protected from interference between different communication signals, since, no light can enter a fiber from its sides. Because of which no cross talk takes place.
5. The radiation from lightning or sparking causes the disturbance in the signals which are transmitting in the metallic cable but cannot do for the fiber cable.
6. The information cannot be tapped from the optical fiber.
7. Since signal is optical, no sparks are generated as it could in case of electrical signal.
8. Because of it superior attenuation characteristics, optical fibers support signal transmission over long distances.

Limitations of Optical fiber communications system

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