ST. JOSEPH UNIVERSITY IN TANZANIA

ST. JOSEPH COLLEGE OF ENGINEERING &TECHNOLOGY

DEPARTMENT OF BASIC ENGINEERING

DEGREE SEMESTER I

MODULE NAME: PH1103
MODULE CODE: ENGINEERING PHYSICS

LECTURE NOTES

UNIT IV -LASERS, OPTICAL FIBERS:

LASERS: Interaction of radiation with matter – Absorption - spontaneous emission and stimulated emission - Expression for energy density of radiation in terms of Einstein coefficients at thermal equilibrium - Requisites of a laser system - Three and four level lasers - Principle and operation of He-Ne and semi-conductor Lasers - Holography.

OPTICAL FIBERS: Propagation mechanisms in optical fibers, Angle of acceptance and Numerical aperture –Types of optical fibers - Step index and graded index fibers - Intermodal dispersion - Attenuation in optical fibers - Optical fiber communication system (Block diagram).

INTRODUCTION:

LASER stands for Light Amplification by Stimulated Emission of Radiation. Laser technology started with Albert Einstein in 1917, he has given theoretical basis for the development of Laser. The technology further evolved in 1960 when the very first laser called Ruby Laser was built at Hughes Research Laboratories by T.H. Mainmann.

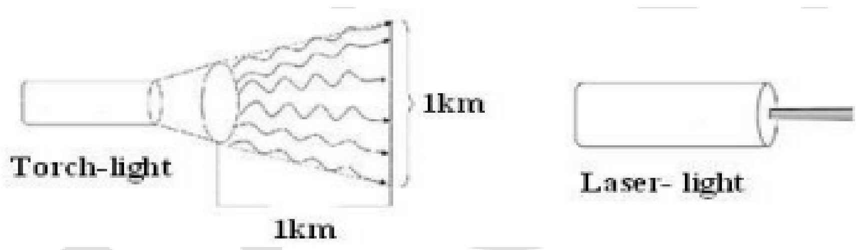
CHARACTERISTIC OF LASER RADIATION:

The laser beam has the properties given below which distinguish it from an ordinary beam of light. Those are

1. Highly directional
2. Highly monochromatic
3. Highly intense
4. Highly coherence

1. Highly directional

A conventional light source emits light in all directions. On the other hand, Laser emits light only in one direction. The width of Laser beam is extremely narrow and hence a laser beam can travel to long distances without spreading.



The directionality of laser beam is expressed in terms of divergence

$$\Delta\theta = \frac{r_2 - r_1}{d_2 - d_1}$$

Where r_1 and r_2 are the radii of laser beam spots at distances of d_1 and d_2 respectively from laser source.

2. Highly monochromatic

A monochromatic source is a single frequency or single wavelength source of light. The laser light is more monochromatic than that of a convectional light source. This may be due to the stimulated characteristic of laser light. The band width of convectional monochromatic light source is $1000A^0$. But the band width of ordinary light source is 10 A^0. For highly sensitive laser source is $10^{-8}A^0$.

3. Highly intense

Laser light is highly intense than the conventional light. A one milli-Watt He-Ne laser is highly intense than the sun intensity. This is because of coherence and directionality of laser.

Suppose when two photons each of amplitude 'A' are in phase with other, then young's principle of superposition, the resultant amplitude of two photons is 2A and the intensity is $4a^2$. Since in laser many numbers of photons are in phase with each other, the amplitude of the resulting wave becomes 'nA' and hence the intensity of laser is proportional to n^2A^2. So 1mw He-Ne laser is highly intense than the sun.

4. Highly coherence

A predictable correlation of the amplitude and phase at any one point with other point is called coherence. In case of conventional light, the property of coherence exhibits between a source and its virtual source where as in case of laser the property coherence exists between any two sources of same phase.

There are two types of coherence

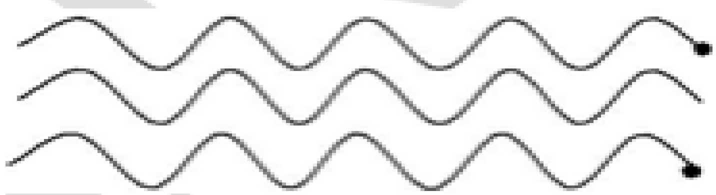
i) Temporal coherence
ii) Spatial coherence.

i) Temporal coherence (or longitudinal coherence):

The predictable correlation of amplitude and phase at one point on the wave train w.r. t another point on the same wave train, then the wave is said to be temporal coherence.

ii) Spatial coherence (or transverse coherence):

The predictable correlation of amplitude and phase at one point on the wave train w. r .t another point on a second wave, then the waves are said to be spatial coherence (or transverse coherence). Two waves are said to be coherent when the waves must have same phase & amplitude.



INTERACTION OF LIGHT WITH MATTER AND THE THREE QUANTUM PROCESSES:

When the radiation interacts with matter, results in the following three important phenomena. They are

(i) Induced or Stimulated Absorption

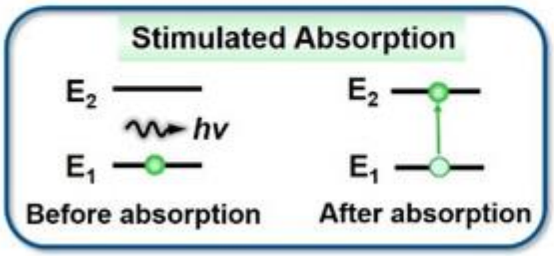
(ii) Spontaneous Emission

(iii) Stimulated Emission

STIMULATED ABSORPTION (OR) INDUCED ABSORPTION (OR) ABSORPTION:

An atom in the lower energy level or ground state energy level (E_1) absorbs the incident photon and goes to excited state (E_2) as shown in figure below. This process is called induced or stimulated absorption.

Let E_1 and E_2 be the energies of ground and excited states of an atom. Suppose, if a photon of energy $E_2 - E_1 = h\gamma$ interacts with an atom present in the ground state, the atom gets excitation form ground state E_1 to excited state E_2 . This process is called stimulated absorption.

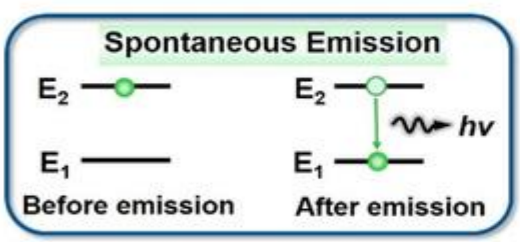


Stimulated absorption rate depends upon the number of atoms available in the lowest energy state as well as the energy density of photons.

SPONTANEOUS EMISSION:

The atom in the excited state returns to ground state emitting a photon of energy (E) = $E_2 - E_1 = h\gamma$, without applying an external energy spontaneously is known as spontaneous emission.

Let E_1 and E_2 be the energies of ground and excited states of an atom. Suppose, if photon of energy $E_2 - E_1 = h\nu$ interacts with an atom present in the ground state, the atom gets excitation form ground state E_1 to excited state E_2.



The excited atom does not stay for a long time in the excited state. The excited atom gets de-excitation after its life time by emitting a photon of energy $E_2 - E_1 = h\nu$. This process is called spontaneous emission.

The spontaneous emission rate depends up on the number of atoms present in the excited state. The probability of spontaneous emission (P_{21}) is independent of $u(\vartheta)$.

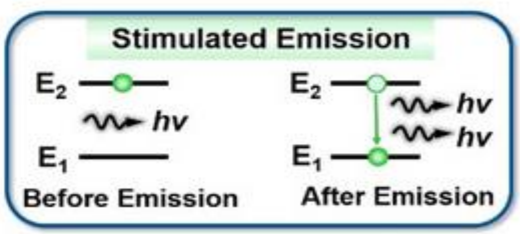
$$P_{21} = A_{21}$$

STIMULATED-EMISSION:

The atom in the excited state can also returns to the ground state by applying external energy or inducement of photon thereby emitting two photons which are having same energy as that of incident photon. This process is called as stimulated emission.

Stimulated emission was postulated by Einstein. Let E_1 and E_2 be the energies of ground and excited states of an atom. Let a Photon of energy E_2-E_1=hυ interacts with the excited atom with in their life time The atom gets de-excitation to ground state by emitting of another photon.

These photons have same phase and it follows coherence. This phenomenon is called stimulated emission.



Stimulated emission rate depends upon the number of atoms available in the excited state as well as the energy density of photons.

The process of stimulated emission has the following properties.

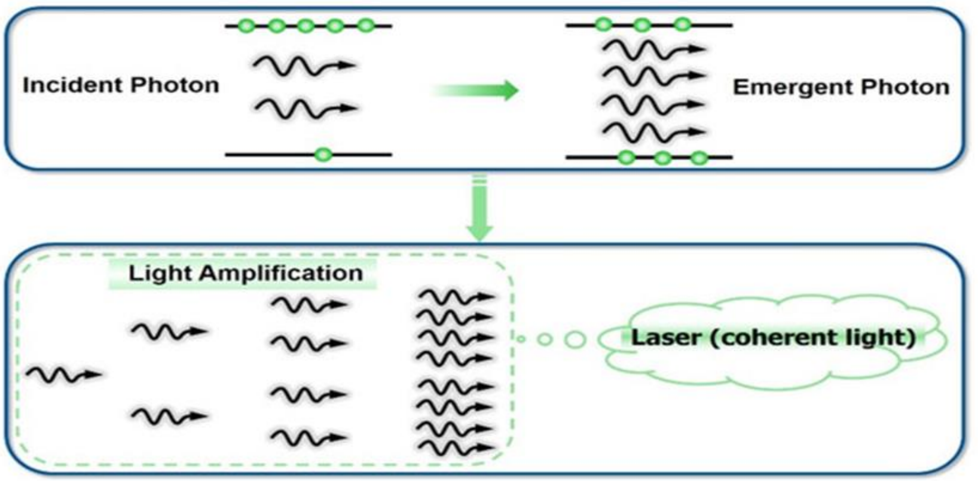
(i) The emitted photon is identical to the incident photon in all respects. (It has the same frequency; it will be in phase and will travel in the same direction and will be in the same state of polarization).

(ii) The process can be controlled externally.

(iii) Stimulated emission is responsible for laser.

LIGHT AMPLIFICATION:

Light amplification requires stimulated emission exclusively. In practice, absorption and spontaneous emission always occur together with stimulated emission. The laser operation is achieved when stimulated emission exceeds the other two processes due to its higher transitions rates of atomic energy levels.



COMPARISON BETWEEN SPONTANEOUS AND STIMULATED EMISSION:

S.NO	SPONTANEOUS EMISSION	STIMULATED EMISSION
1	stimulated emission was Postulated by Bohr.	The stimulated emission was Postulated by Einstein.
2	Additional photons are not required in spontaneous emission.	Additional photons are required in Stimulated emission.
3	One Photon is emitted in spontaneous emission.	Two photons are emitted in stimulated emission.
4	The emitted radiation is incoherent.	The emitted radiation is coherent.
5	The emitted radiation is less intense.	The emitted radiation is high intense.

EINSTEIN COEFFICIENTS & THEIR RELATIONS

In 1917, about 9 years before the development of the relevant quantum theory, Einstein postulated on thermodynamic grounds that the probability for spontaneous emission, A, was related to the probability of stimulated emission, B, by the relationship

$$A/B = 8\pi h\nu^3/c^3$$

From the development of the theory behind blackbody radiation, it was known that the equilibrium radiation energy density per unit volume per unit frequency was equal to

$$\rho(\nu) = 8\pi h\nu^3/c^3$$

Expression for energy density of incident radiation in terms of Einstein coefficients:

Einstein mathematically expressed the statistical nature of the three possible radiative transition routes (spontaneous emission, stimulated emission, and absorption) with the so-called Einstein coefficients and quantified the relations between the three processes.

Let N_1 be the number of atoms per unit volume with energy E_1 and N_2 be the number of atoms per unit volume with energy E_2. Let 'n' be the number of photons per unit volume at frequency 'υ' such that $E_2 – E_1 = h\vartheta$ Then, the energy density of photons $E = h\vartheta$.

- **Stimulated absorption:** When the photons interact with the atoms it leads to absorption transition which is called as stimulated absorption. Stimulated absorption rate depends upon the number of atoms available in the lowest energy state as well as the energy density photons.

  $$\text{Stimulated absorption rate} = N_1 B_{12} u(\nu)$$

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

- **Spontaneous emission:** The atom in the excited state returns to ground state emitting a photon of energy $(E) = E_2 – E_1 = h\nu$, without applying an external energy spontaneously is known as spontaneous emission. The spontaneous emission rate depends up on the number of atoms present in the excited state.

  $$\text{Spontaneous emission rate } N_2 = A_{21} N_2$$

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

- **Stimulated emission:** The atom in the excited state can also returns to the ground state by applying external energy or inducement of photon thereby emitting two photons which are having same energy as that of incident photon. This process is called as stimulated emission. Stimulated emission rate depends upon the number of atoms available in the excited state as well as the energy density of incident photons.

$$\text{Stimulated emission rate} = B_{21} N_2 u(\nu)$$

- Einstein showed that the A and B coefficients are related. In equilibrium, the rate of change of upper and lower populations must be 0,

$$\frac{dN_2}{dt} = \frac{dN_1}{dt} = 0$$

- $\frac{dN_2}{dt}$ = Spontaneous Emission 'Flow' + Stimulated Emission 'Flow' - Stimulated Absorption 'Flow.

$$\frac{dN_2}{dt} = A_{21} N_2 + B_{21} N_2 u(\nu) - N_1 B_{12} u(\nu) = 0$$

- Likewise

$$\frac{dN_1}{dt} = - A_{21} N_2 - B_{21} N_2 u(\nu) + N_1 B_{12} u(\nu) = 0$$

$$N_1 B_{12} u(\nu) = A_{21} N_2 + B_{21} N_2 u(\nu)$$

- Re-arrange for $\rho(\nu)$

$$u(\nu) = \frac{A21\ N\ 2}{B12\ N\ 2 - B21\ N\ 2}$$

$$u(\vartheta) = \left(\frac{A_{21}}{B_{21}} \times \frac{1}{\left[\frac{N_1}{N_2} \times \frac{B_{12}}{B_{21}} - 1\right]}\right)$$

- According to Boltzmann distribution law

$$N = N_0 e^{-\frac{E}{k_B T}}$$

$$N_1 = N_0 e^{-\frac{E_1}{k_B T}}$$

$$N_2 = N_0 e^{-\frac{E_2}{k_B T}}$$

$$\frac{N_1}{N_2} = \frac{N_0 e^{-\frac{E_1}{k_B T}}}{N_0 e^{-\frac{E_2}{k_B T}}} = e^{\frac{E_2 - E_1}{k_B T}} = e^{\frac{h\vartheta}{k_B T}}$$

$$u(\vartheta) = \frac{A_{21}}{B_{21}} \times \frac{1}{[e^{\frac{h\vartheta}{k_B T}}\left(\frac{B_{12}}{B_{21}}\right) - 1]} \text{-----}(1)$$

According to Planck's radiation formula the energy density of photon is given by,

$$u(\vartheta) = \frac{8\pi h\vartheta^3}{c^3} \times \left(\frac{1}{\left[e^{\frac{h\vartheta}{k_B T}} - 1\right]}\right) \text{-----}(2)$$

Comparing eq.(1) & eq.(2), we get

$$(i) \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h\vartheta^3}{c^3} \quad or \quad \frac{A_{21}}{B_{21}} \propto \vartheta^3$$

$$(ii) \quad \frac{B_{12}}{B_{21}} = 1 \quad or, \quad B_{12} = B_{21}$$

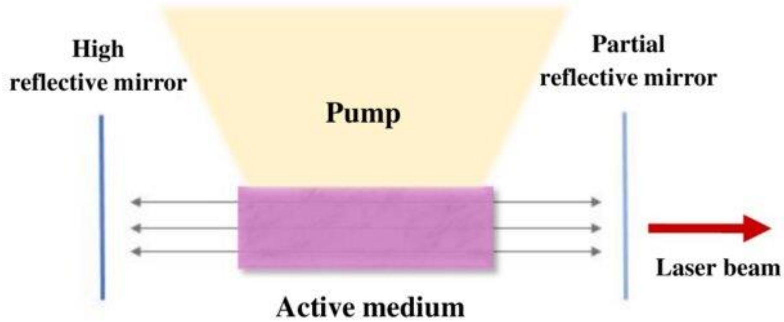
REQUISITES OF A LASER SYSTEM

The essential components of lasers are

1. An active medium to support population inversion.
2. Pumping mechanism to excite the atoms to higher energy levels.
3. Population inversion
4. Metastable state
5. An optical cavity or optical resonator.

1.ACTIVE MEDIUM

It is the material medium composed of atoms or ions or molecules in which the laser action is made to take place, which can be a solid or liquid or even a gas. In this, only a few atoms of the medium (of particular species) are responsible for stimulated emission. They are called active centers and the remaining medium simply supports the active centers.



2. PUMPING MECHANISM

To achieve the population inversion in the active medium, the atoms are to be raised to the excited state. It requires energy to be supplied to the system. The process of supplying energy to the medium with a view to transfer the atoms to higher energy state is called pumping.

The most commonly used pumping methods are

- Optical pumping
- Electrical discharge pumping
- Chemical pumping
- Injection current pumping

Optical pumping:

Optical pumping is used in solid laser. Xenon flash tubes are used for optical pumping. Since these materials have very broad band absorption, sufficient amount of energy is absorbed from the emission band of flash lamp and population inversion is created. Examples of optically pumped lasers are ruby, Nd: YAG Laser (Y_3 AL_5G_{12})

(Neodymium: Yttrium Aluminum Garnet), Nd: Glass Laser

Electrical discharge pumping: Electrical discharge pumping is used in gas lasers. Since gas lasers have very narrow absorption band pumping them any flash lamp is not possible. Examples of Electrical discharge pumped lasers are He-Ne laser, CO_2 laser, argon-ion laser, etc.

Chemical pumping:

Chemical reaction may also result in excitation and hence creation of population inversion in few systems. Examples of such systems are HF and DF lasers.

Injection current pumping:

In semiconductors, injection of current through the junction results in creates of population inversion among the minority charge carriers. Examples of such systems are InP and GaAs.

3.POPULATION INVERSION

The number of atoms present in the excited (or higher) state is greater than the number of atoms present in the ground energy state (or lower state) is called population inversion.

Let us consider two level energy systems of energies $E_1$and E_2 as shown in figure. Let N_1 and N_2 be the population (means number of atoms per unit volume) of E1and E2 respectively.

According to Boltzmann's distribution the population of an energy level E, at temperature T is given by

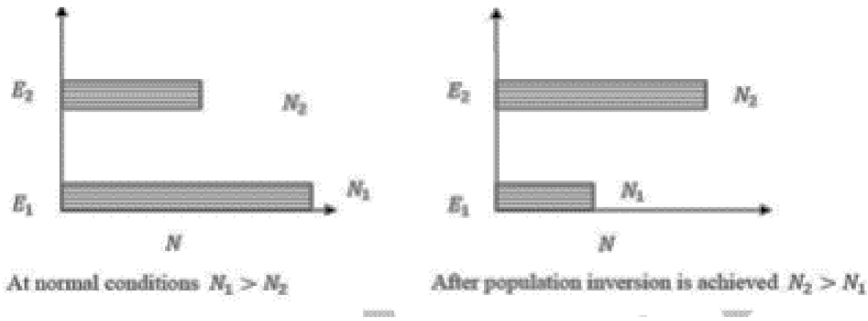
$$N_i = N_o e^{\left(-\frac{E_i}{k_B T}\right)} where i = 1,2,3, \ldots . N_i$$

where 'N_0' is the number of atoms in ground or lower energy states & k is the Boltzmann constant. From the above equation the population of energy levels E_1& E_2 are given by

$$N_1 = N_o e^{\left(-\frac{E_1}{k_B T}\right)}$$

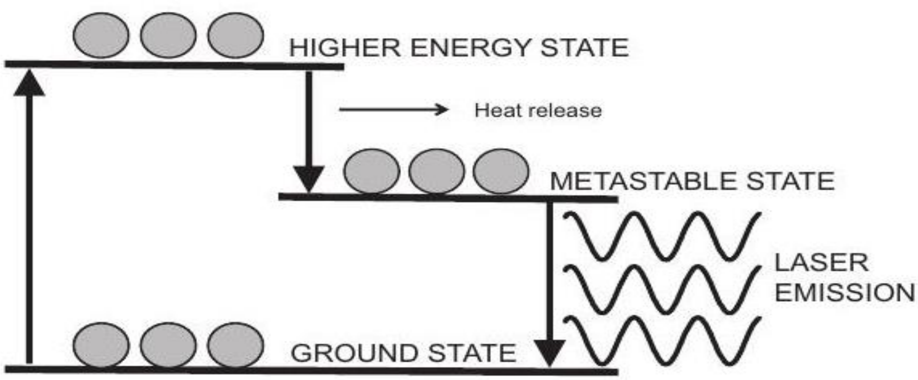
$$N_2 = N_o e^{\left(-\frac{E_2}{k_B T}\right)}$$

At ordinary conditions $N_1 > N_2$ i.e., the population in the ground or lower state is always greater than the population in the excited or higher states. The stage of making, population of higher energy level greater than the population of lower energy level is called population inversion i.e., $N_2 > N_1$.



4.METATABLE STATE

In general, the number of excited particles in a system is smaller than the non-excited particles. The time during which a particle can exist in the ground state is unlimited. On the other hand, the particle can remain in the excited state for a limited time known as life time.



The life time of the excited hydrogen atom is of the order of 10^{-8} sec. However there exist such excited states in which the life time is greater than 10^{-8} sec. These states are called as Meta stable states.

5.OPTICAL RESONATOR

- An optical resonator generally consists of two plane mirrors, with the active material placed in between them. One of the mirrors is semi-transparent while the other one is 100%reflecting. The mirrors are set normal to the axis of the active medium and parallel to each other.
- The optical resonant cavity provides the selectivity of photon states by confining the possible direction of photon propagation, as a result lasing action occurs in this direction.

- The distance between the mirrors is an important parameter as it chooses the wavelength of the photons. Suppose a photon is traveling between two reflectors, it undergoes reflection at the mirror kept at the other end. the reflected wave superposes on the incident wave and forms stationary wave such that the length L of the cavity is given by

$$L = n\frac{\lambda}{2}$$

Hence $\lambda = \frac{2L}{n}$

Where, L- is the distance between the mirrors.

λ- is the wavelength of the photon,

n - is the integral multiple of half wavelength

The wavelengths satisfying the above condition are only amplified. Hence the cavity is also called resonant cavity.

The main Role of the optical resonator is to

- Provide positive feedback of photons into the active medium to sustain stimulated emission and hence laser acts as a generator of light.
- Select the direction of stimulated photons which are travelling parallel to the axis of optical resonator and normal to the plane of mirrors are to be amplified. Hence laser light is highly directional.
- Builds up the photon density (Uν) to a very high value through repeated reflections of photons by mirrors and confines them within the active medium.
- Selects and amplifies only certain frequencies of stimulated photons which are to be highly monochromatic and gives out the laser light through the partial reflector after satisfying threshold condition.

PRINCIPLE OF LASER/LASING ACTION

Let us consider many no of atoms in the excited state. Now the stimulating photon interacts with any one of the atoms in the excited state, the stimulated emission will occur. It emits two photons, having same energy & same frequency move in the same direction. These two photons will interact with another two atoms in excited state & emit 8- photons. In a similar way chain reaction is produced this phenomenon is called “Principle of lasing –action”. We get a monochromatic, coherent, directional & intense beam is obtained. This is called laser beam. This is the principle of working of a laser.

COMPONENTS OF A LASER

Any laser system consists of 3-important components.

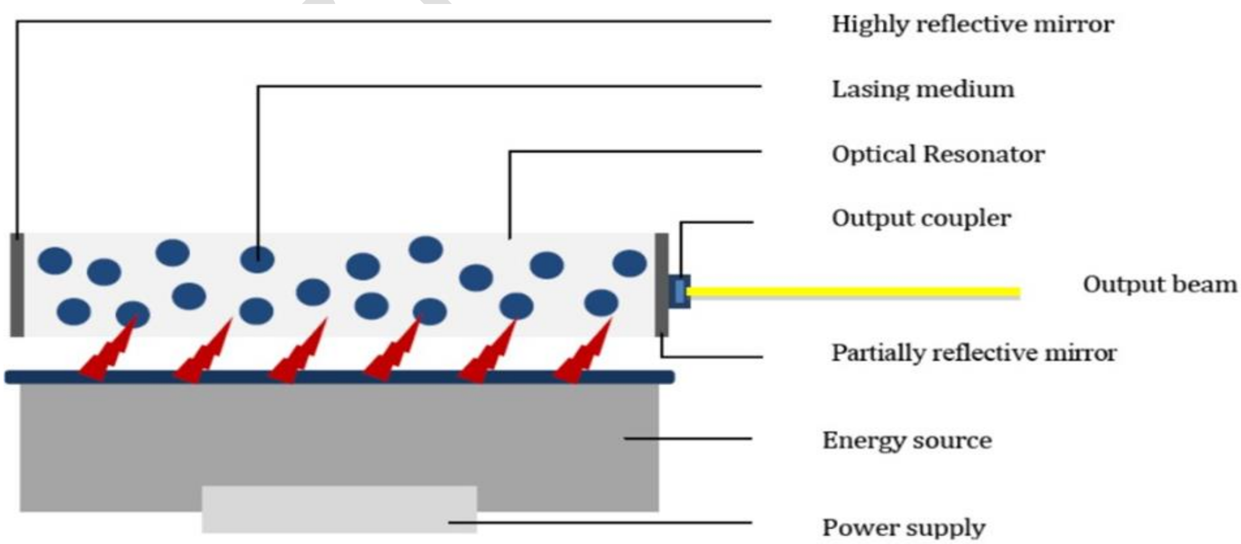
They are

- Source of energy or pumping source
- Active-medium (Laser Material)
- Optical cavity or resonator

Energy Source: It supplies energies & pumps the atoms or molecules in the active medium to excited states. As a result, we get population inversion in the active medium which emits laser. Ex: Xenon flash lamp, electric field.

Active medium: The medium in which the population inversion takes place is called as active medium.

Active-center: The material in which the atoms are raised to excited state to achieve population inversion is called as active center.



Optical-cavity or resonator: The active medium is enclosed between a fully reflected mirror & a partially reflective mirror. This arrangement is called as cavity or resonator. As a result, we get highly intense monochromatic, coherence laser light through the non-reflecting portion of the mirror.

DIFFERENT TYPES OF LASERS

On the basis of active medium used in the laser systems, lasers are classified into several types

I. Solid lasers: Ruby laser, Nd; YAG laser, Nd; Glass

II. Liquid lasers: Europium Chelate laser, $SeOCl2$

III. Gas lasers: $CO2$, He-Ne, Argon-Ion Laser

IV. Dye lasers: Rhodamine 6G

V. Semiconductor lasers: InP, GaAs.

RUBY LASER

Ruby laser is a three-level solid state laser and was developed by Mainmann in 1960. Ruby ($Al_2O_3+Cr_2O_3$) is a crystal of Aluminium oxide, in which 0.05% of Al^{+3} ions are replaced by the Cr^{+3} ions. The color of the ruby rod is pink. The active medium in the ruby rod is Cr+3 ions.

Principle or Characteristics of a ruby laser:

Due to optical pumping, the chromium atoms are raised to excited states then the atoms come to metastable state by non-radiative transition. Due to stimulated emission the transition of atoms takes place from metastable state to ground state and gives a laser beam.

Construction:

- In ruby laser 4cm length and 5mm diameter rod is generally used.
- Both the ends of the rods are highly polished and made strictly parallel.
- The ends are silvered in such a way, one becomes partially reflected and the other end fully reflected.
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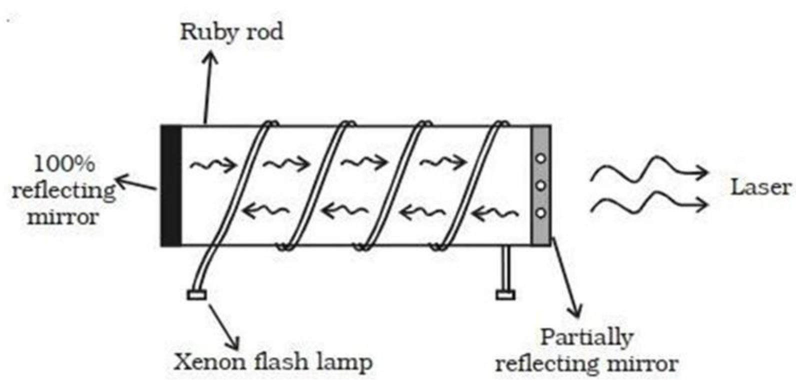
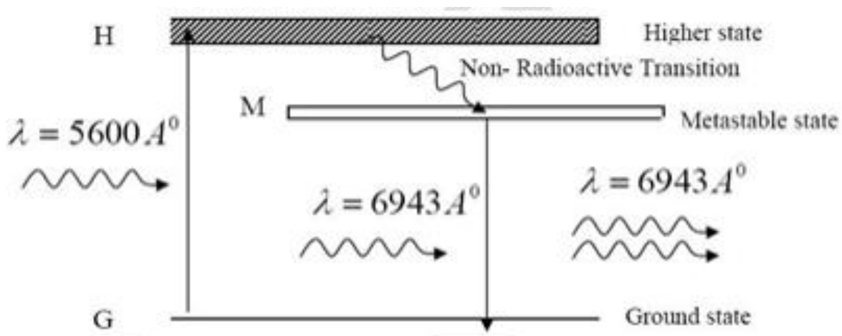


- The ruby rod is surrounded by xenon flash tube, which provides the pumping light to excite the chromium ions in to upper energy levels.
- Xenon flash tube emits thousands of joules of energy in few milli seconds, but only a part of that energy is utilized by the chromium ions while the rest energy heats up the apparatus.
- A cooling arrangement is provided to keep the experimental set up at normal temperatures.

Working:

- The energy level diagram of chromium ions is shown in figure.
- The chromium ions get excitation into higher energy levels by absorbing of $5600A^0$ of wave length radiation.
- The excited chromium ions stay in the level H for short interval of time (10^{-8} Sec).
- After their life time most of the chromium ions are de-excited from H to G and a few chromium ions are de-excited from H to M.
- The transition between H and M is non-radioactive transition i.e., the chromium ions give their energy to the lattice in the form of heat.
- In the Meta stable state, the life time of chromium ions is 10^{-3} sec.
- Due to the continuous working of flash lamp, the chromium ions are excited to higher state H and returned to M level.
- After few milli seconds the level M is more populated than the level G and hence the desired population inversion is achieved.
- The state of population inversion is not a stable one.



- The process of spontaneous transition is very high.
- When the excited chromium ion passes spontaneously from H to M it emits one photon of wave length 6943A^0.
- The photon reflects back and forth by the silver ends and until it stimulates an excited chromium ion in M state and it to emit fresh photon in phase with the earlier photon.
- The process is repeated again and again until the laser beam intensity is reached to a sufficient value.
- When the photon beam becomes sufficient intense, it emerges through the partially silvered end of the rod.
- The wave length 6943A^0 is in the red region of the visible spectrum on returning to ground state (G).

Uses of Ruby laser:

- Used in distance measurement using 'pulse echo technique'
- Used for measurement of plasma properties such as electron density and temperature.
- Used to remove the melanin of the skin.
- Used for recording pulsed holograms.
- Used as target designators and range finders in military.

Draw backs of Ruby laser:

- It requires high pumping power.
- The efficiency of ruby laser is very small. It is a pulse laser.

He-Ne LASER

It was discovered by A. Javan & his co-workers in 1960. It is a continuous wave gas laser. It consists of mixture of He & Ne in 10:1 ratio as a active medium.

Principle/Characteristics of He-Ne laser

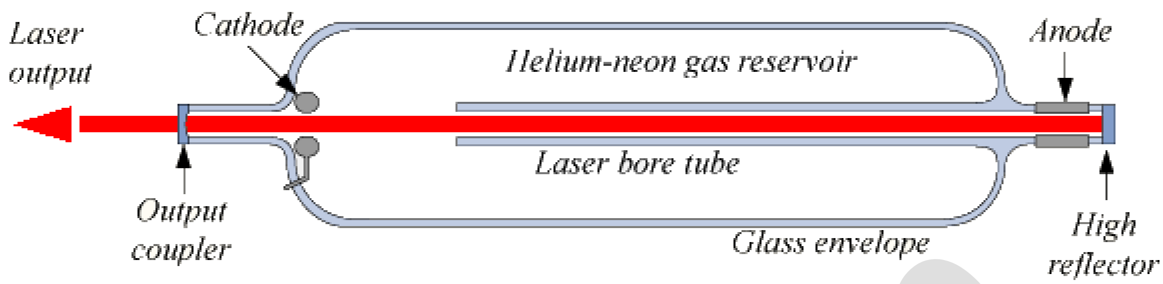
This laser is based on the principle of stimulated emission, produced in the He & Ne. The population inversion is achieved due to the interaction between He & Ne gases. Using gas lasers, we can achieve highly coherent, directional and high monochromatic beam.

Characteristics Of He-Ne Laser

- The He-Ne laser is a relatively low power device with an output in the visible red portion of the spectrum.
- The most common wavelength produced by He-Ne lasers is 632.8nm, although two lower power (1.152μm and 3.391μm) infrared wavelengths can be produced if desired.
- Majority of He-Ne lasers generate less than 10m watt of power, but some can be obtained commercially with up to 50m watts of power.
- For He-Ne lasers the typical laser tube is from 10 to 100 cm in length and the life time of such a tube can be as high as 20,000 hours.

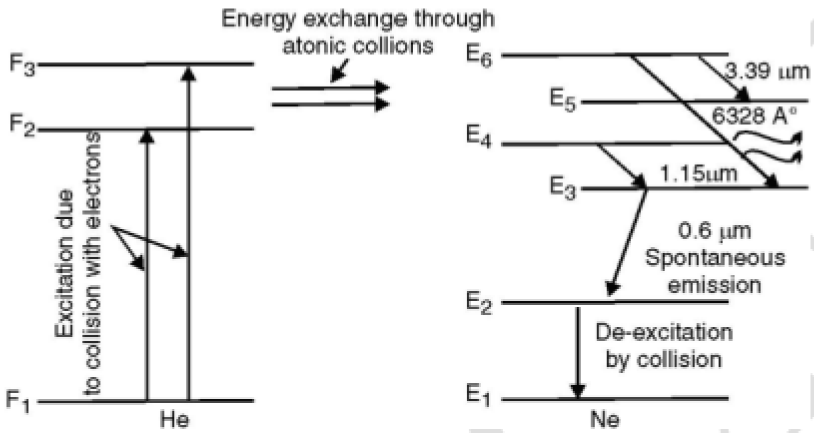
Construction

- In He-Ne gas laser, the He and Ne gases are taken in the ratio 10:1 in the discharge tube.
- Two reflecting mirrors are fixed on either ends of the discharge tube, in that, one is partially reflecting and the other is fully reflecting.
- In He-Ne laser 80cm length and 1cm diameter discharge tube is generally used.
- The output power of these lasers depends on the length of the discharge tube and pressure of the gas mixture.
- Energy source of laser is provided by an electrical discharge of around 1000V through an anode and cathode at each end of the glass tube.



Working

- When the electric discharge is passing through the gas mixture, the electrons accelerated towards the positive electrode.
- During their passage, they collide with He atoms and excite them into higher levels.
- F_2 and F_3 form F_1. In higher levels F_2 and F_3, the life time of He atoms is more.
- So there is a maximum possibility of energy transfer between He and Ne atoms through atomic collisions.
- When He atoms present in the levels F_2 and F_3 collide with Ne atoms present ground state E_1, the Ne atoms gets excitation into higher levels E_4 andE_6.
- Due to the continuous excitation of Ne atoms, we can achieve the population inversion between the higher levels E_4 (E_6) and lower levels E_3 (E_5).
- The various transitions $E_6 \rightarrow E_5$, $E_4 \rightarrow E_3$ and $E_6 \rightarrow E_3$ leads to the emission of wavelengths 3.39A^o, 1.15 A^o and 6328A^0
- The first two corresponding to the infrared region while the last wavelength is corresponding to the visible region.
- The Ne atoms present in the E_3 level are de-excited into E_2 level, by spontaneously emission of photon.
- When a narrow discharge tube is used, the Ne atoms present in the level E_2 collide with the walls of the tube and get de-excited to ground level E_1.



Advantages of helium-neon laser

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability
- Low cost
- Operates without damage at higher temperatures

Disadvantages of helium-neon laser

- Low efficiency
- Low gain
- Helium-neon lasers are limited to low power tasks

Uses of He-Ne laser

- Used in laboratories foe all interferometric experiments.
- Used widely in metrology in surveying, alignment etc.
- Used to read barcodes and He-Ne laser scanners also used for optical character recognition.
- Used in holography

CO_2 LASER

The CO_2 laser was one of the gas laser, these are the highest power continuous wave lasers that are currently available, they are also quite efficient .The ratio of output power to pump power can be as large as 20%.

The CO_2 laser produces a beam of infrared light with the Principle wavelength bands centering around 9.6 and 10.6 μm.

Principle

The principle of carbon di oxide laser is transition between vibrational states of the same electronic states by achieving population inversion between these states. For the laser action two points are important, one is the population inversion between the two levels and second increased density of the incident radiation.

Vibrational states in co_2 molecules

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations.

They are

a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

a) Symmetric stretching mode

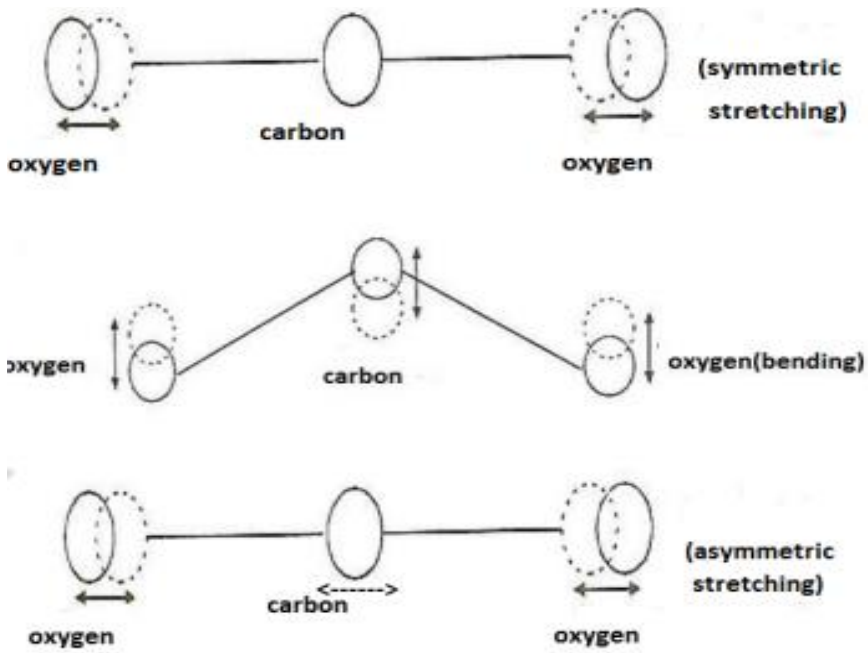
In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

b) Bending mode

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.

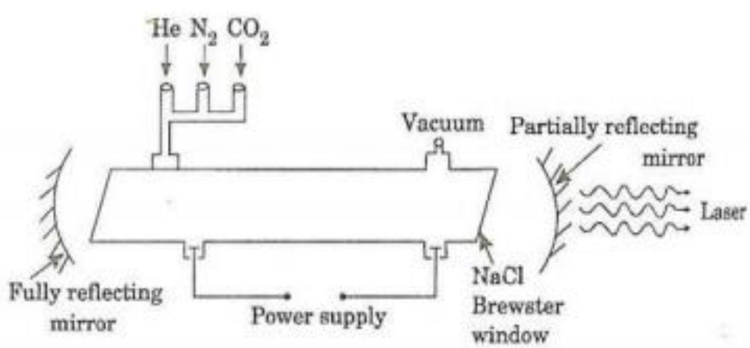
c)Asymmetric Stretching Mode

In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.



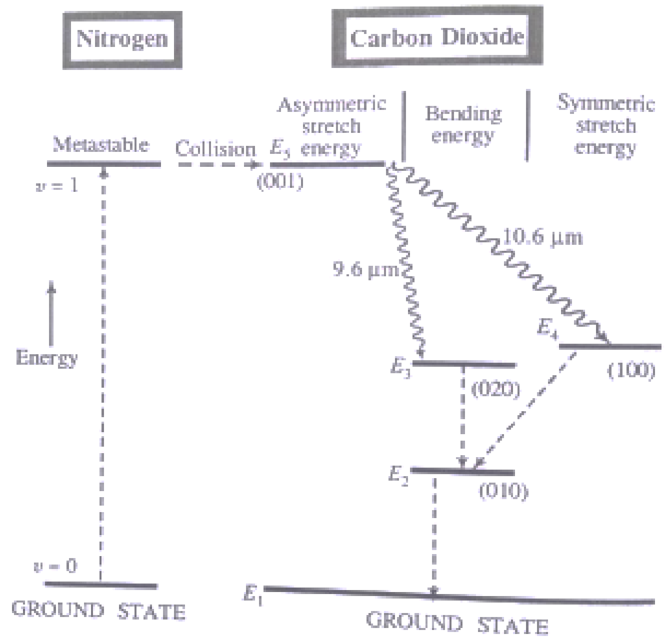
Construction

- It consists of a quartz tube 5 m long and 2.5 cm in the diameter.
- This discharge tube is filled with gaseous mixture of CO2 (active medium), helium and nitrogen 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.



Working

Figure shows energy levels of nitrogen and carbon dioxide molecules.



- A mixture of CO_2, N_2 and helium or water vapor is used as active medium here.
- 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* = electron with kinetic energy

  N_2^* = nitrogen molecule in excited state e= same electron with lesser energy.
- Now N_2 molecules in the excited state collide with CO2 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 E_5 level of CO_2 atom, population in E_5 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 far IR radiation of laser beam at the wavelength 10.6μm
2. **Transition E5 to E3:** This laser transition will produce a laser beam of wavelength 9.6μm in IR region. Normally 10.6μm transition is more intense than 9.6μm transition. The power output from this laser is 10kW.

- E_3 and E_4 levels also metastable states and the co2 molecules at these levels fall to the lower level E_2 through inelastic collisions with unexcited co_2 molecules, then again tends to closer ground state through thermal excitations. The nature of output may be continuous wave or pulsed wave.

Advantages

- The construction of CO_2 laser is simple and the output of this laser is continuous.
- It has high efficiency
- It has very high output power.
- The output power can be increased by extending the length of the gas tube.

Disadvantages

- The contamination of oxygen by carbon monoxide will have some effect on laser action
- The operating temperature plays an important role in determining the output power of laser.
- The corrosion may occur at the reflecting plates.
- Accidental exposure may damage our eyes, since it is invisible (infrared region) to our eyes.

Applications

- High power CO2 laser finds applications in material processing, welding, drilling, cutting soldering etc.

- The low atmospheric attenuation (10.6μm makes CO_2 laser suitable for open air communication.
- It is used for remote sensing.
- It is used for treatment of liver and lung diseases.
- It is mostly used in neuro surgery and general surgery.
- It is used to perform microsurgery and bloodless operations.

APPLICATIONS OF LASERS

Due to high intensity, high mono-chromaticity and high directionality of lasers, they are widely used in various fields like,

1. communication
2. computers
3. chemistry
4. photography
5. industry
6. medicine
7. military
8. scientific research

1. Communication

- In case of optical communication, semiconductors laser diodes are used as optical sources.
- More channels can be sent simultaneously Signal cannot be tapped as the band width is large, more data can be sent.
- A laser is highly directional and less divergence, hence it has greater potential use in space crafts and submarines.

2. Computers

- In LAN (local area network), data can be transferred from memory storage of one computer to other computer using laser for short time.
- Lasers are used in CD-ROMS during recording and reading the data.

3. Chemistry

- Lasers are used in molecular structure identification.
- Lasers are also used to accelerate some chemical reactions.
- Using lasers, new chemical compound can be created by breaking bonds between atoms or molecules.

4. Photography

- Lasers can be used to get 3-D lens less photography.
- Lasers are also used in the construction of holograms.

5. Industry

- Lasers can be used to blast holes in diamonds and hard steel.
- Lasers are also used as a source of intense heat.
- Carbon dioxide laser is used for cutting drilling of metals and nonmetals, such as ceramics plastics, glass etc.
- High power lasers are used to weld or melt any material.
- Lasers are also used to cut teeth in saws and test the quality of fabric.

6. Medicine

- Pulsed neodymium laser is employed in the treatment of liver cancer.
- Argon and carbon dioxide lasers are used in the treat men of liver and lungs.
- Lasers used in the treatment of Glaucoma.

7. Military

- Lasers can be used as a war weapon.
- High energy lasers are used to destroy the enemy air-crafts and missiles.
- Lasers can be used in the detection and ranging likes RADAR.

8. Scientific research

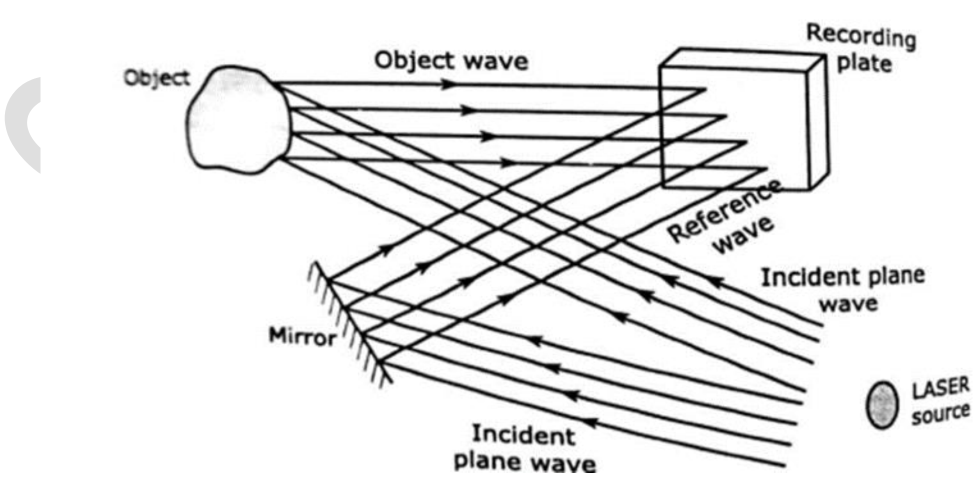
- Lasers are used in the field of 3D-photography.
- Lasers used in Recording and reconstruction of hologram.
- Lasers are employed to create plasma.
- Lasers used to produce certain chemical reactions.
- Lasers are used in Raman spectroscopy to identify the structure of the molecule.
- Lasers are used in the Michelson- Morley experiment.
- A laser beam is used to confirm Doppler shifts in frequency for moving objects.

HOLOGRAPHY

In conventional photography, a negative is made first and using it a positive print is produced later. The positive print is only a 2D record of light intensity received from 3D object. Only intensity of light recorded and information of phase is lost. Denis Gabor introduced a new technique where intensity and phase both are recorded. This technique is called holography. Holography is done in two stages:

1.CONSTRUCTION OF IMAGE(FREEZING) (RECORDING OF HOLOGRAM)

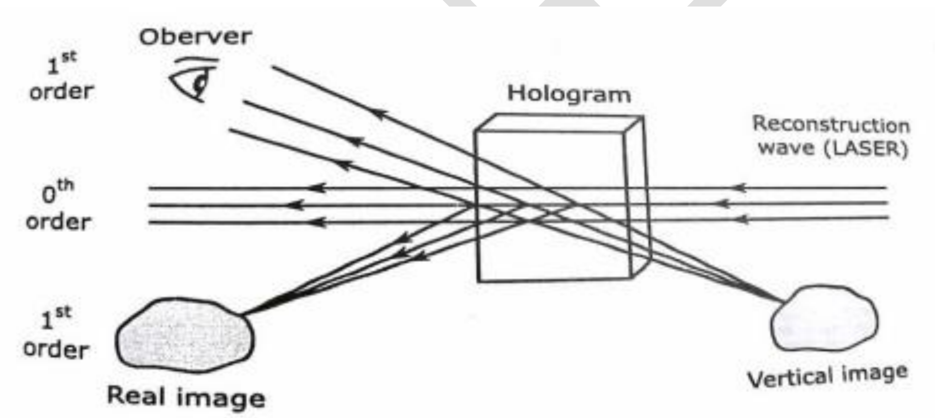
A weak but broad beam of laser light is splitted into wo beams by means of beam splitter. One beam directly goes to the photographic film is called as reference beam and second beam illuminates the object called as object beam.



The light scattered by the object moves towards the photographic plate and interferes with the reference beam. The photographic plate carrying complex interference pattern of the object is called hologram. The object is stored in the hologram in the form of interference.

2.RECONSTRUCTION (UNFREEZING):

A laser beam identical to the reference beam is used for reconstruction of the object. This read out bream illuminates the hologram at the same angle as the reference beam. The hologram acts as a diffraction grating and secondary waves from hologram interferes constructively in certain directions and destructively in other directions. They form a real image in front of the hologram and a virtual image behind the hologram at the original site of the object. An observer sees light waves diverging from the virtual image. An image of the object appears where the object once stood and the image is identical to what our eyes would have perceived in all its details of the object.



APPLICATION

- Hologram is reliable medium for data storage
- Hologram is used in concerts
- Hologram are used for authentication
- Holograms are used in exhibitions to avoid possible thefts.

FIBER-OPTICS

INTRODUCTION TO OPTICAL FIBER

Fiber optics is a branch of physics which deals with the transmission & reception of light waves using optical fibers which acts as a guiding media. The transmission of light waves by fiber optics was first demonstrated by John Tyndall in 1870.

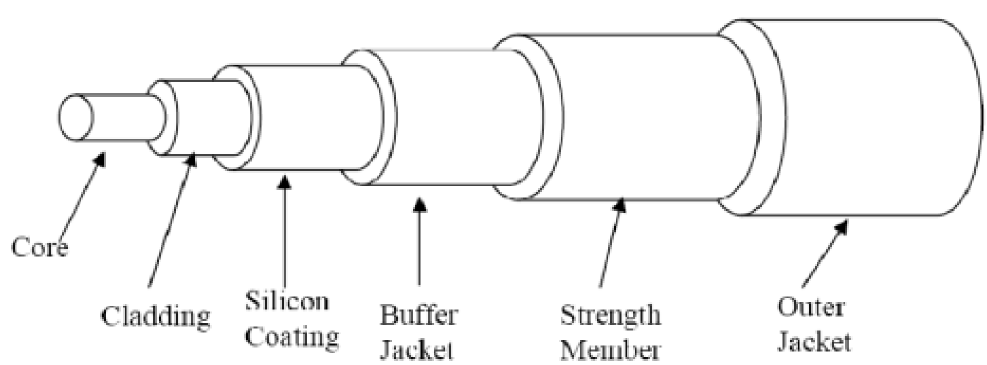
Optical Fiber

Optical fiber is a thin & transparent guiding medium or material which guides the information carrying light waves. It is a cylindrical wave-guide system which propagates the data & speech signals in the optical frequency range.

A light beam acting as a carrier wave is capable of carrying more information than radio waves & microwaves because of its high frequency as shown below. Radio waves - 10^4 Hz, Micro waves - 10^{10} Hz, Light waves - 10^{15} Hz.

CONSTRUCTION OF OPTICAL FIBER:

The optical fiber mainly consists the following six parts as shown in figure. The most commonly used optical fiber is single solid di-electric cylinder of radius a and index of refraction n_1. The following figure explains the parts of an optical fiber.



1.Core

A typical glass fiber consists of a central core material. Generally, core diameter is 50 µm. The core is surrounded by cladding. The core medium refractive is always greater than the cladding refractive index.

2.Cladding

Cladding refractive index is lesser than the cores refractive index. The overall diameter of cladding is 125 µm to 200 µm. A solid di-electric material surrounds the core, which is called as Cladding. Cladding has a refractive index n2 which is less than n1.

Cladding helps in –

- Reducing scattering losses.
- Adds mechanical strength to the fiber.
- Protects the core from absorbing unwanted surface contaminants.

3. Silicon Coating

Silicon coating is provided between buffer jacket and cladding. It improves the quality of transmission of light.

4. Buffer Jacket

Silicon coating is surrounded by buffer jacket. Buffer jacket is made of plastic and protects the fiber cable from moisture.

5. Strength Member

Buffer jacket is surrounded by strength member. It provides strength to the fiber cable.

6. Outer Jacket

Finally, the fiber cable is covered by polyurethane outer jacket. Because of this arrangement fiber cable will not be damaged during pulling, bending, stretching and rolling through the fiber cable is made up of glasses.

Working Principle of Optical Fiber

Total Internal Reflection:

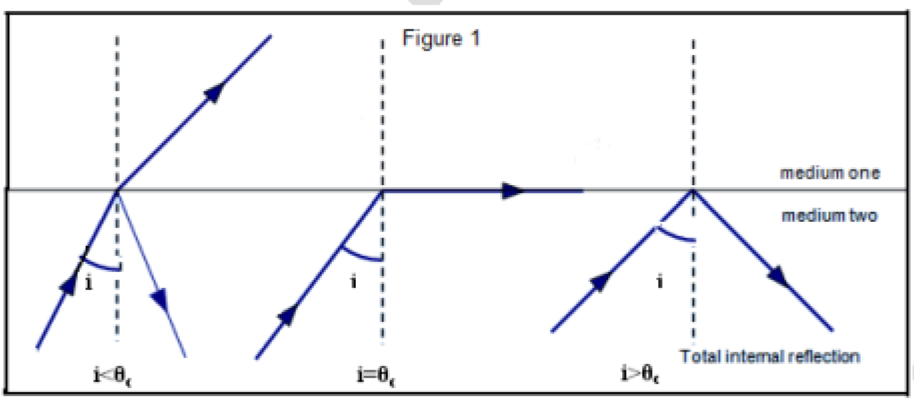
The principle of optical fiber is total internal reflection.

Condition for Total Internal Reflection:

1. The light ray should move from denser to rarer medium.
2. The refractive index of core must be greater than cladding i.e. $n_1>n_2$
3. The angle of incidence (i) must be greater than the critical angle(θc) i.e. $i>\theta_c$.
4. The critical angle $\theta c = sin^{-1}\ n_2/n_1$

Explanation

Let us consider a denser medium & rarer medium of refractive indices n_1 & n_2 respectively and $n_1>n_2$. Let a light ray move from denser to rare medium with 'i' as the angle of incidence & 'r' as angle of refraction. The refracted ray bends away from the normal as it travels from denser to rarer medium with increase of angle of incidence 'i'.



In this we get three cases

Case-1: When $i\ <\ \theta_c$ then the light ray refracts into rarer medium as shown in figure.

Case-2: When i= θc then the light ray traverses along the two media as shown in figure. For the two media, applying Snell's law

$$n_1 sin i = n_2 sin\ r$$

$$(\therefore i = \theta_c \;\&\; r = 90°)$$

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

$$n_1 sin\theta c = n_2$$

$$sin\ \theta c = n_2 / n_1$$

Where $n_1 > n_2$

For air, $n_2 = 1$,

$$\theta c = sin{-1} \frac{1}{n_1}$$

Case-3: When i> θc, then the light ray reflected back into the medium as shown in figure.

ACCEPTANCE ANGLE & ACCEPTANCE CONE

Def: Acceptance angle is the maximum angle of incidence at the core of an optical fiber so that the light can be guided though the fiber by total internal reflection. This angle is called as acceptance angle. It is denoted by 'αi'.

- Consider a cross-sectional view of an optical fiber having core & cladding of refractive indices n_1 and n_2.
- Let the fiber be in air medium (no). The incident light while entering into the core at 'A' makes an incident angle of 'αi' with the fiber-axis.
- In core it travels along AB & is incident at part B on cladding interface.
- Let αr be the angle of refraction at part 'A' & 'θ' be the angle of incidence at 'B'.
- When 'θ' is greater than the critical angle 'θc', then total internal reflection takes place into the core & light takes the path BD.
- Due to multiple total internal reflections the propagation of light ray takes place through the fiber.

Applying Snell's law at AC core-air interface: -

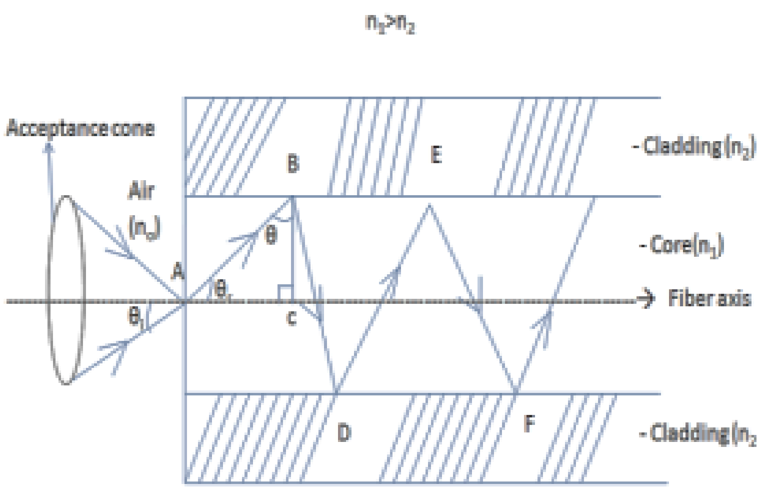
$$\frac{sin\alpha_i}{sin\alpha_r} = \frac{n_1}{n_o}$$

$$n_o sin\alpha_i = n_1 sin\alpha_r \rightarrow (1)$$

Let a normal 'BC' be drawn from the point 'B' to the fiber axis. Then from ΔABC, \

we get $\alpha_r = 90° - \theta \rightarrow (2)$

Substitute eq - (2) in eq - (1)



$$n_o sin\alpha_i = n_1 sin\,(90° - \theta)$$

$$n_o sin\alpha_i = n_1 cos\theta \rightarrow (3)$$

- To get total internal reflection at point B (Core-Classing Interface) i.e.

$$\theta > \theta_c$$

- Let the maximum angle of incidence at point A be αi(max)for which.$\theta > \theta_c$

  From eqn (3), we get

$$n_o sin\alpha_i = n_1 cos\theta \rightarrow (4)$$

$$\alpha_i(\max) = \alpha_i, \text{when } \theta = \theta_c$$

$$sin\ \alpha_i(\max) = \frac{n_1}{n_o} cos\theta_c \rightarrow (5)$$

We know that $sin\theta_c = \frac{n_2}{n_1}$

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

Substitute the eq(6) in eq(5) , we get

$$sin\ \alpha_i(\max) = \frac{n_1}{n_0}\sqrt{\frac{n_1^2 - n_2^2}{n_1}}$$

$$sin\ \alpha_i(\max) = \sqrt{\frac{n_1^2 - n_2^2}{n_0}}$$

(OR)

$$\alpha_i(\max) = sin^{-1}\sqrt{\frac{n_1^2 - n_2^2}{n_0}} \rightarrow (7)$$

For air medium, n_0=1 $\alpha_i(\max) = sin^{-1}\sqrt{n_1^2 - n_2^2} \rightarrow (8)$

Fractional Index Change (Δ):

It is the ratio of refractive index difference in core & cladding to the refractive index of core.

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

$$n_1 - n_2 = \Delta n_1 \rightarrow (1)$$

NUMERICAL APERTURE (N.A.)

Def: It is defined as light accepting efficiency of the fiber and is equal to sine of the acceptance angle of the fiber i.e., $N.A. = sin\ \alpha_i(\max)$

$$N.A = sin\ \alpha_i(\max) = \sqrt{\frac{n_1^2 - n_2^2}{n_0}}$$

$$\text{We know that } \Delta = \frac{n_1 - n_2}{n_1}$$

$$n_1 - n_2 = \Delta n_1 \rightarrow (2)$$

$$We know, N.A. = Sin\ \alpha_i(\max) = \sqrt{n_2^2 - n_1^2} \quad \text{for air } n_0=1$$

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

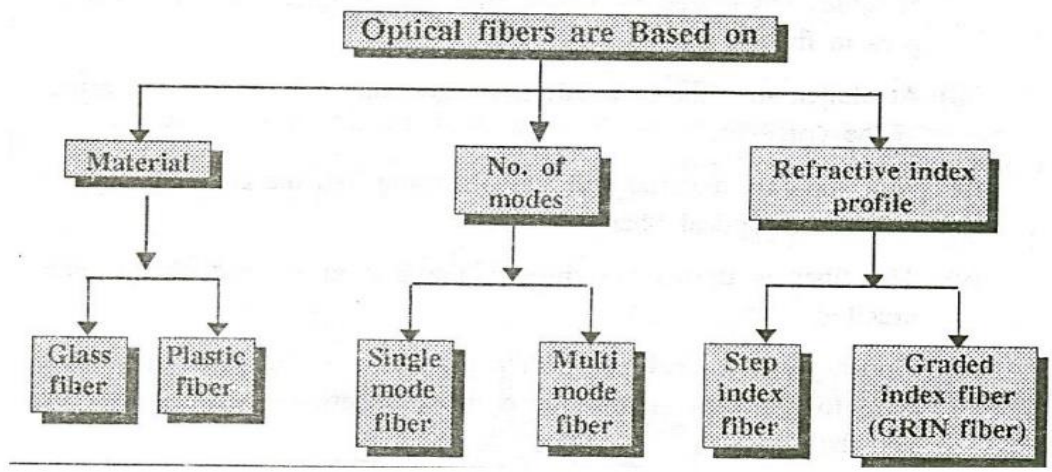
$$If n_1 = n_2, then N.A. = \sqrt{2n_1 \times \Delta n_1}$$

$$N.A. = n_1\sqrt{2\Delta} \rightarrow (3)$$

TYPES OF OPTICAL FIBERS

Optical fibers are classified into three major categories

i. The type of material used
ii. The number of modes
iii. The refractive index profiles

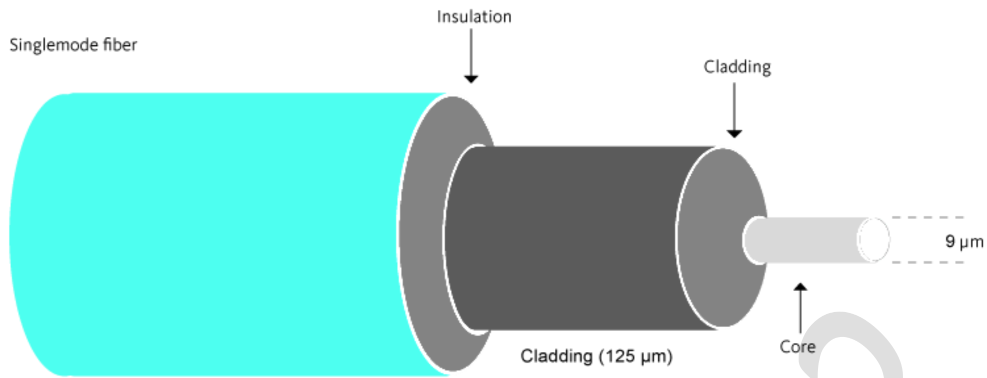


1.Based on Mode

The rays travelling in the fiber by total internal reflection are called modes.

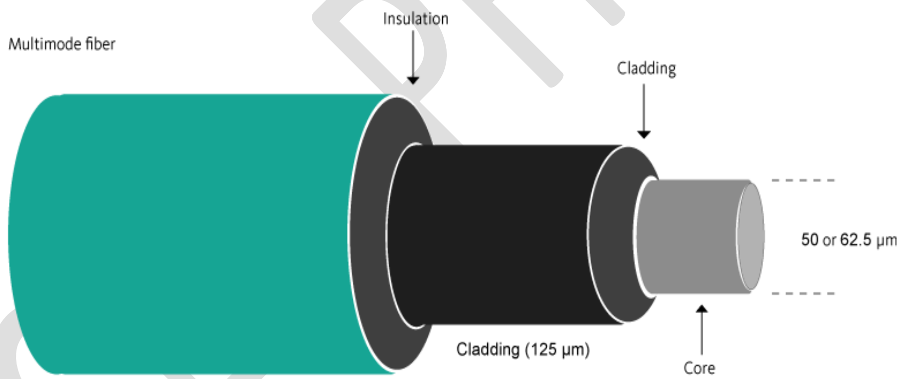
1) Single mode fibers

- If the thickness of the fiber is so small that it supports only one mode then the fiber is called single mode fiber or mono mode fiber.
- The core diameter of this fiber is about 8 to 10µm and the outer diameter of cladding is 60 to 70µm.
- Single-mode fiber optic cable excels at long-distance communication. Single-mode cable is designed to carry a single signal source with low transmission loss over great distances. It is frequently used for communication systems due to the clarity it provides. This type of fiber optic cable has the smallest core and the thickest sheathing.



2)Multi mode fibers:

- If the thickness of the fiber is very large that it supports more than one mode then the fiber is called multi-mode fiber.
- The core diameter of this fiber is about 50 to 200µm and the outer diameter of cladding is 100 to 250µm.



2.Based on refractive index profile

1) Step-Index Optical fiber

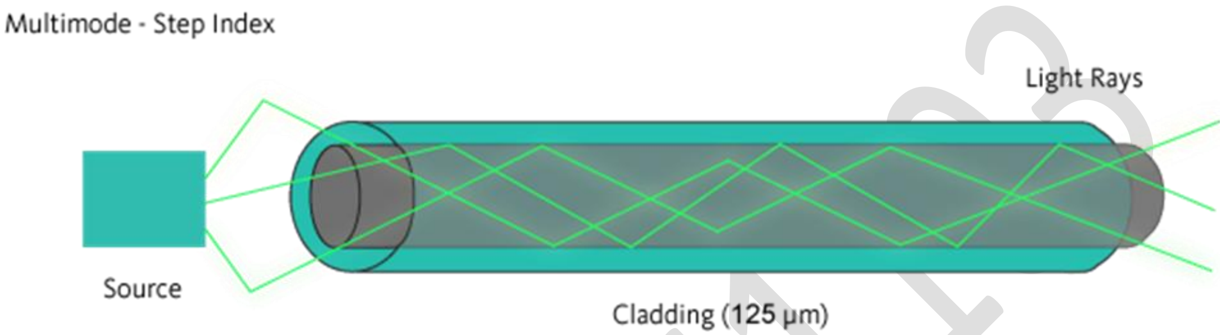
- In a step-index optical fiber, the entire core has uniform refractive index n1 slightly greater than the refractive index of the cladding n_2.
- Since the index profile is in the form of a step, these fibers are called step-index fibers.
- The transmission of information will be in the form of signals or pulses.
- These are extensively used because distortion and transmission losses are very less.

- Step-index optical fibers are of two types. They are

\(i) Single mode step-index fiber

(ii) Multi-mode step-index fiber

Transmission / propagation of signal in Step-index fibers



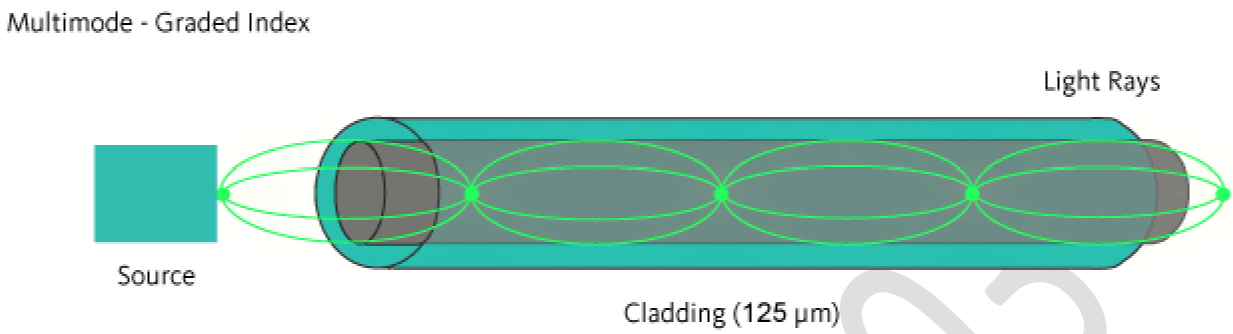
Generally, the signal is sent through the fiber in digital form i.e., in the form of pulses.

- The same pulsed signal travels in different paths.
- Let us now consider a signal pulse travelling through step index fiber in two different paths (1) and (2).
- The pulse (1) travelling along the axis of the fiber and pulse (2) travelling away from the axis.
- At the receiving end only the pulse (1) which travels along the fiber axis reaches first while the pulse (2) reaches after some time delay.
- Hence the pulsed signal received at the other end is broadened. This is called internal dispersion. This reduces transmission rate capacity of the signal.
- This difficulty is overcome by graded index fibers.

2) Graded index optical fiber:

- In this fiber, the refractive index of the core varies radially.
- It has maximum refractive index at its center, which gradually falls with increase of radius and at the core-cladding interface matches with refractive index of cladding.
- Variation of refractive index of the core with radius is given by

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



This fiber divided into two types.

(i) Single-mode graded index fiber

(ii) Multi-mode graded index fiber

Transmission / propagation of signal in Step-index fibers

- Let us now consider a signal pulse travelling through graded index fiber in two different paths (1) and (2).
- The pulse (1) travelling along the axis of the fiber though travels along shorter route it travels through higher refractive index.
- The pulse (2) travelling away from the axis undergo refraction and bend as shown in fig. though it travels longer distance, it travels along lesser refractive index medium.
- Hence both the pulses reach the other end simultaneously.
- Thus, the problem of inter model dispersion can be overcome by using graded index fibers.

3.Based on types of materials:

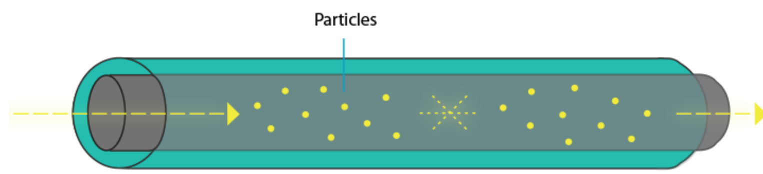
1) glass-glass optical fiber

2) glass-plastic optical fiber

3) plastic-plastic optical fiber

ATTENUATION (POWER-LOSS) IN OPTICAL FIBERS

When light propagates through an optical fiber, then the power of the light at the output end is found to be always less than the power launched at the input end. The loss of power is called Attenuation. It is measured in terms of decibels per kilometer.



Attenuation: It is defined as the ratio of the optical power output (P_{out}) from a fiber of length 'L' to the power input (P_{in}).

$$Attenuation(\alpha) = -\frac{10}{L}\left(\frac{P_{in}}{P_{out}}\right) dB/km$$

Attenuation occurs because of the following reasons

(1) Absorption

(2) Scattering loss

(3) Bending loss

(1) Absorption

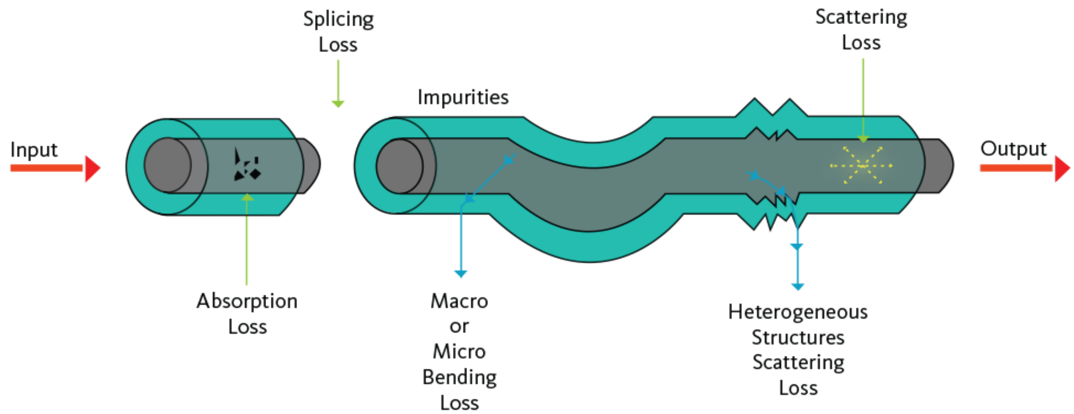
It occurs in two ways,

i)Absorption by impurity or impurity absorption

ii) Intrinsic absorption or internal absorption

Impurity absorption: The impurities present in the fiber are transition metal ions, such as iron, chromium, cobalt & copper. During signal propagation when photons interact with these impurity atoms, then the photons are absorbed by atoms. Hence loss occurs in light power.
Intrinsic absorption or internal absorption: The fiber itself as a material has a tendency to absorb light energy however small it may be. The absorption that takes place in fiber material assuming that there are no impurities in it, is called intrinsic absorption.

(2) Scattering loss



When the signals travels in the fiber, the photons may be scattered due to variations in the refractive index inside the fiber. This scattering is called as Rayleigh scattering. It is also a wavelength dependent loss.

$$Rayleigh scattering loss \propto 1/\lambda^4$$

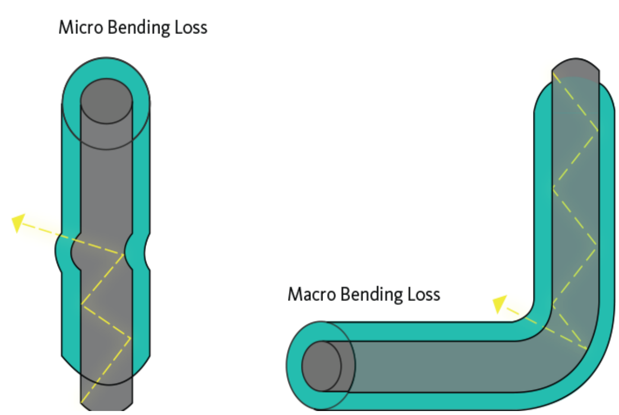
(3) Bending losses:

These losses occur due to

(a) Macroscopic bending

(b) Microscopic bending

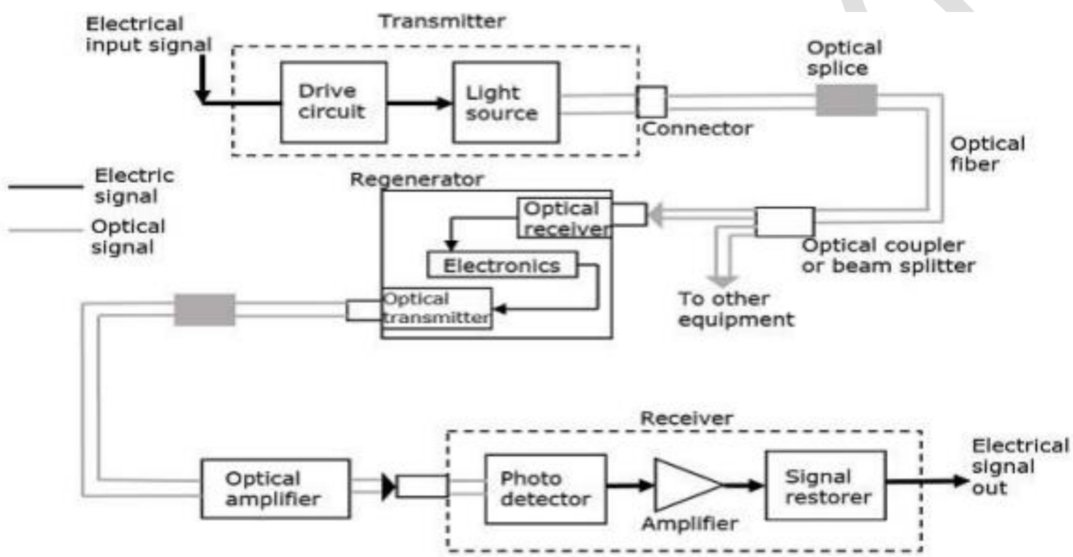
Macroscopic bending: If the radius of core is large compared to fiber diameter causes large curvature at the bends. At these bends, the light will not satisfy the condition for total internal reflection & light escapes out from the fiber. It is called as macroscopic bending.



Microscopic bending: These are caused due to non-uniform pressures created during the cabling of the fiber or during the manufacturing the fiber. It causes irregular reflections. This led to loss of light by leakage through the fiber.

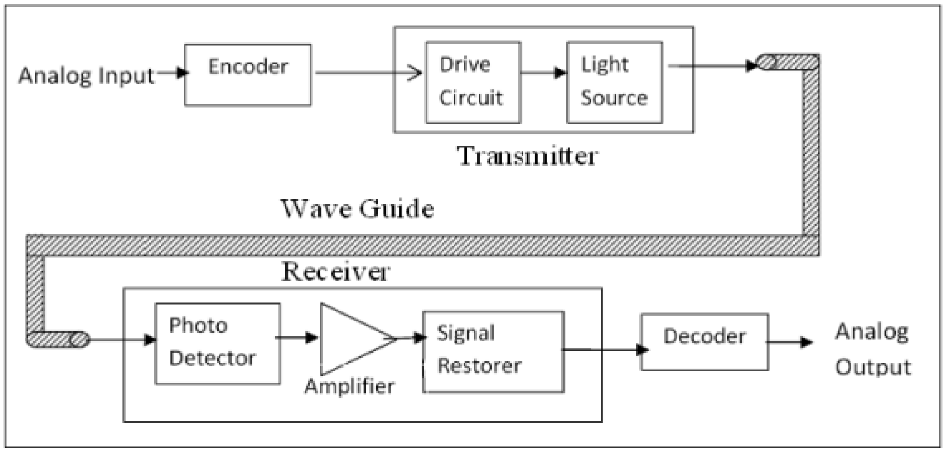
FIBER OPTIC COMMUNICATION SYSTEM

The communication system of fiber optics is well understood by studying the parts and sections of it. The major elements of an optical fiber communication system are shown in the following figure.



The basic components are light signal transmitter, the optical fiber, and the photo detecting receiver. The additional elements such as fiber and cable splicers and connectors, regenerators, beam splitters, and optical amplifiers are employed to improve the performance of the communication system. An optical fiber communication system mainly consists of the following parts as Shown in figure.

- Encoder
- Transmitter
- Wave guide.
- Receiver.
- Decoder



1.Encoder

Encoder is an electronic system that converts the analog information like voice, figures, objects etc., into binary data.

2.Transmitter

It contains two parts; they are drive circuit and light source. Drive circuit supplies the electric signals to the light source from the encoder in the required form. The light source converts the electrical signals into optical form. With the help of specially made connector optical signals will be injected into wave guide from the transmitter.

3.Wave guide.

It is an optical fiber which carrier's information in the form of optical signals over distances with the help of repeaters. With the help of specially made connector optical signals will be received by the receiver from the wave guide.

4.Receiver

It consists of three parts; they are photo detector, amplifier and signal restorer. The photo detector converts the optical signal into the equivalent electric signals and supply to hem to amplifier. The amplifier amplifies the electric signals as they become weak during the long journey through the wave guide over longer distance. The signal restorer deeps the electric signals in a sequential form and supplies to the decoder in the suitable way.

5.Decoder

It converts electric signals into the analog information.

FUNCTIONAL ADVANTAGES

The functional advantages of optical fibers are

- The transmission bandwidth of the fiber optic cables is higher than the metal cables.
- The amount of data transmission is higher in fiber optic cables.
- The power loss is very low and hence helpful in long-distance transmissions.
- Fiber optic cables provide high security and cannot be tapped. • Fiber optic cables are the most secure way for data transmission.
- Fiber optic cables are immune to electromagnetic interference.
- These are not affected by electrical noise.

PHYSICAL ADVANTAGES

The physical advantages of fiber optic cables are –

- The capacity of these cables is much higher than copper wire cables.
- Though the capacity is higher, the size of the cable doesn't increase like it does in copper wire cabling system.
- The space occupied by these cables is much less.
- The weight of these FOC cables is much lighter than the copper ones.
- Since these cables are di-electric, no spark hazards are present.
- These cables are more corrosion resistant than copper cables, as they are bent easily and are flexible.
- The raw material for the manufacture of fiber optic cables is glass, which is cheaper than copper.
- Fiber optic cables last longer than copper cables.

DISADVANTAGES:

Although fiber optics offer many advantages, they have the following drawbacks –

- Though fiber optic cables last longer, the installation cost is high.
- The number of repeaters is to be increased with distance.

- They are fragile if not enclosed in a plastic sheath. Hence, more protection is needed than copper ones.

APPLICATIONS OF OPTICAL FIBER COMMUNICATIONS

The optical fibers have many applications. Some of them are as follows

- Used in telephone systems
- Used in sub-marine cable networks
- Used in data link for computer networks, CATV Systems
- Used in CCTV surveillance cameras
- Used for connecting fire, police, and other emergency services.
- Used in hospitals, schools, and traffic management systems.
- They have many industrial uses and also used for in heavy duty constructions.

DIFFERENCIATION

Step index fiber	Graded index fiber
1. In step index fibers the refractive index of the core medium is uniform through and undergoes an abrupt change at the interface of core and cladding.	1. In graded index fibers, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.
2. The diameter of core is about 10micrometers in case of single mode fiber and 50 to 200 micrometers in multi mode fiber.	2. The diameter of the core is about 50 micro meters.
3. The transmitted optical signal will cross the fiber axis during every reflection at the core cladding boundary.	3. The transmitted optical signal will never cross the fiber axis at any time.
4. The shape of propagation of the optical signal is in zigzag manner.	4. The shape of propagation of the optical signal appears in the helical or spiral manner
5. Attenuation is more for multi mode step index fibers but Attenuation is less in single mode step index fibers	5. Attenuation is very less in graded index fibers
6. Numerical aperture is more for multi mode step index fibers but it is less in single mode step index fibers	6. Numerical aperture is less in graded index fibers

Single mode fiber	Multi mode fiber
1. 1. In single mode optical fibers only one mode of propagation is possible	1. In multi mode optical fibers many mummer of modes of propagation are possible.
2. In case of single mode fiber the diameter of core is about 10micrometers	case of in multi mode fiber the diameter of core is 50 to 200 micrometers.
3. The difference between the refractive indices of core and cladding is very small.	2. The difference between the refractive indices of core and cladding is also large compared to the single mode fibers.
4. 3. In single mode fibers there is no dispersion, so these are more suitable for communication.	3. Due to multi mode transmission, the dispersion is large, so these fibers are not used for communication purposes.
5. 4. The process of launching of light into single mode fibers is very difficult	4. The process of launching of light into single mode fibers is very easy.
6. The condition for single mode operation is $V = \frac{2\pi}{\lambda} a\, NA$	5. The condition for multi mode propagation is $N = 4.9\left(\frac{d \bullet NA}{\pi}\right)^2$
7. 6. Fabrication is very difficult and the fiber is costly.	6. Fabrication is very easy and the fiber is cheaper.

1.Name the factors that are responsible for generating attenuation of optical power in fiber.

Following are the factors that are responsible for generating attenuation of optical power in fiber.

- Absorption
- Scattering
- Waveguide effect

2.What are the benefits of optical fiber cable?

- The data security is excellent
- It is cost-effective
- It won't be affected by interference

3.Why are plastic-clad silica fiber optic cables not user-friendly?

- The fibers are insoluble in organic solvents
- Bonding becomes difficult
- Connector application becomes difficult as there is excessive plasticity in the cladding.