UNIT – IV OPTICS AND LASERS

LASER PRINCIPLES

PART – A QUESTIONS

1. State the properties of laser beam (or) fundamental characteristics of lasers (or) Name the properties of laser which are making it suitable for industrial applications.

(i) The laser beam is highly directional.
(ii) It has high intensity.
(iii) It has purely monochromatic.
(iv) It has coherence.

2. What do you mean by population inversion?

The state of achieving more number of atoms in the excited state than that of the atoms in the ground state is called population inversion.

3. Why is population inversion necessary for laser action? (or) Explain the need of population inversion in the production of lasers.

When population inversion is achieved, the majority of atoms are in the excited state. So the absorption coefficient will be negative. The negative absorption coefficient causes the amplification of the incident beam by stimulated emission. Thus the laser beam is produced. Hence, population inversion is a must for the production of laser beam.

4. What is active medium and active center?

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

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

5. What is pumping action? List out some pumping methods.

The process of raising more number of atoms to excited state by artificial methods is called pumping action.

(i) Optical pumping
(ii) Direct electron excitation
(iii) Inelastic atom-atom collision
(iv) Direct conversion
(v) Chemical process

6. What are Einstein's coefficients?

The Einstein's coefficients A and B accounts for spontaneous and stimulated emission / absorption probabilities of light by a system of particles. It also explains the importance of metasatble states.

7. What is meant by optical resonator? (or) resonance cavity?

An optical resonator is a system containing a 100% reflecting mirror and a partial reflecting mirror. The active medium is placed in between these two mirrors. The laser light produced by the active medium is bounced back and forth between the mirrors. Hence the intensity of laser light increased enormously. Finally, the laser beam comes out through the partial mirror.

8. Can a two-level system be used for the production of laser? Why?

No, two level system cannot be used for the production of laser. Because for population inversion to be achieved at least three levels are required.

9. List out the conditions to achieve laser action.

(i) Population inversion should be achieved.
(ii) Stimulated emission should be predominant over spontaneous emission.

10. Distinguish between spontaneous emission and stimulated emission.

Spontaneous emission	Stimulated emission
1. If the atom in the excited state returns to ground state without any external triggering, it is called **spontaneous emission**.	1. If the atom in the excited state returns to ground state by external triggering, it is called **stimulated emission**.
2. Emitted photon travels in random direction.	2. Emitted photon travels in a particular direction.
3. The radiation is less intense and incoherent.	3. The radiation is highly intense, monochromatic and coherent.
4. The photons are not in phase.	4. The photons are in phase.
5. This process is a key factor for ordinary light emission.	5. This process is a key factor for laser operation.

11. What is the principle of semiconductor laser?

The electrons in the conduction band combines with a hole in the valence band and hence the recombination of electron and hole produces energy in the form of light. This photon, in turn may induce another electron in the conduction band to valence band and thereby stimulate the emission of another photon.

12. Distinguish between homojunction and heterojunction semiconductor lasers.

Homojunction laser	Heterojunction laser
1. If a diode laser is made of a single crystalline material on both sides of the junction, it is called **homojunction laser**.	1. If a diode laser is made up of different crystalline material on both sides of the junction, it is called **heterojunction laser**.
2. Power output is low.	2. Power output is high.
3. Pulsed output (Sometimes continuous)	3. Continuous output.
4. It has high threshold current density.	4. It has low threshold current density.
5. Cost is less.	5. Cost is more.
6. Life time is less.	6. Life time is more.

13. What are the functions of N_2 and He in CO_2 laser?

In CO_2 laser, the nitrogen (N_2) helps to increase the population of atoms in the upper level of CO_2. Helium is used to depopulate the atoms to the ground state.

PART – C QUESTIONS

1. For atomic transitions, derive Einstein relations and hence derive the expressions for the ratio of spontaneous emission rate to the stimulated emission rate.

Einstein considered when the photons interact with atoms, the atoms go to excited state and the excited state atoms produce stimulated emission in addition to spontaneous emission.

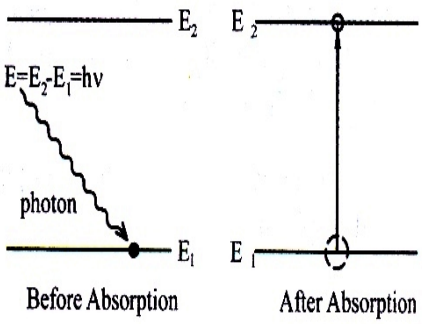
Consider two energy levels.
E_1 – Ground state energy level
E_2 – Excited state energy level
N_1 – Number of atoms in the ground state
N_2 – Number of atoms in excited state

When a material is exposed to light, three different processes take place.

(i) Absorption
(ii) Spontaneous emission
(iii) Stimulated emission

(i) Absorption

An atom in the ground state E_1 absorbs a photon of energy $h\nu$ and goes to excited state. This is called **absorption.**



The rate of absorption is directly proportional to energy density of incident photons (ρ) and number of atoms in the ground state E_1.

$$R_{AB} \propto \rho N_1$$

$$R_{AB} \propto B_{12}\rho N_1 \quad \text{------------ (1)}$$

B_{12} – Einstein's coefficient of absorption

Emission

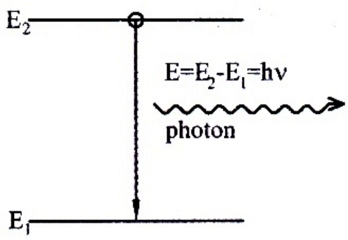
The excited state is unstable state. So the atoms in the excited state return to ground state quickly by following methods.

Spontaneous emission

Stimulated emission

(ii) Spontaneous emission

The atom in the excited state returns to ground state by emitting a photon of energy $h\nu$ without any help of external triggering. This is called **spontaneous emission**.



The rate of emission is proportional to the number of atoms in the excited state.

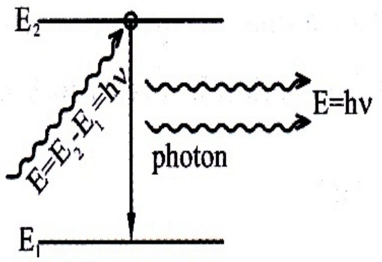
$$R_{SP} \propto N_2$$

$$R_{SP} = A_{21}N_2 \quad \text{-------------- (2)}$$

B_{12} – Einstein's coefficient of spontaneous emission

(iii) Stimulated emission

The atom in the excited state returns to ground state with the help of external triggering. During this process, two photons will be emitted. This is called **stimulated emission**.



The rate of emission is directly proportional to energy density of incident photons (ρ) and number of atoms in the excited state E_2.

$$R_{ST} \propto \rho N_2$$

$$R_{ST} = B_{21}\rho N_2 \quad \text{-------------- (3)}$$

B_{21} – Einstein's coefficient of stimulated emission

At thermal equillibrium

$$\boxed{\textbf{Rate of absorption = Rate of emission}}$$

$$R_{AB} = R_{SP} + R_{ST}$$

$$B_{12}\,\rho N_1 = A_{21}\,N_2 + B_{21}\,\rho N_2$$

$$B_{12}\,\rho N_1 - B_{21}\,\rho N_2 = A_{21}\,N_2$$

$$\rho\left(B_{12}\,N_1 - B_{21}\,N_2\right) = A_{21}\,N_2$$

$$\rho = \frac{A_{21}\,N_2}{\left(B_{12}\,N_1 - B_{21}\,N_2\right)}$$

÷ all the terms by N_2 in RHS

$$\rho = \frac{\dfrac{A_{21}\cancel{N_2}}{\cancel{N_2}}}{\dfrac{B_{12}\,N_1}{N_2} - \dfrac{B_{21}\cancel{N_2}}{\cancel{N_2}}}$$

$$\rho = \frac{A_{21}}{B_{12}\left(\frac{N_1}{N_2}\right) - B_{21}} \qquad -----(4)$$

According to Boltzmann distribution law, number of atoms in an energy level

$$N = N_0\, e^{-E/K_BT}$$

It can be written as for N_1 & N_2

$$N_1 = N_0\, e^{-E_1/K_BT}$$

$$N_2 = N_0\, e^{-E_2/K_BT}$$

$$\frac{N_1}{N_2} = \frac{\cancel{N}_0\, e^{-E_1/K_BT}}{\cancel{N}_0\, e^{-E_2/K_BT}}$$

$$\frac{N_1}{N_2} = \left(e^{-E_1/K_BT}\right)\left(e^{-E_2/K_BT}\right)$$

$$\frac{N_1}{N_2} = e^{-E_1/K_BT + E_2K_BT}$$

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)K_BT}$$

$$\frac{N_1}{N_2} = e^{(h\nu)K_BT} \qquad -----(5) \qquad [\because E_2 - E_1 = h\nu]$$

Sub. (5) in (4)

$$\rho = \frac{A_{21}}{B_{12}\left(e^{h\nu/K_BT}\right) - B_{21}}$$

$\div$ all the terms by B_{21}

$$\rho = \frac{\frac{A_{21}}{B_{21}}}{\frac{B_{12}}{B_{21}}\left(e^{h\nu/K_BT}\right) - \frac{B_{21}}{B_{21}}}$$

$$\rho = \frac{A_{21}}{B_{21}} \frac{1}{\frac{B_{12}}{B_{21}}\left(e^{h\nu/K_BT}\right) - 1} \qquad ------(6)$$

W.K.T. Planck's radiation law,

$$\rho = \frac{8\pi h\nu^3}{c^3} \frac{1}{\left(e^{h\nu/K_BT}\right) - 1} \qquad -----(7)$$

Compare (6) & (7)

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \qquad -----(8)}$$

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

$$\boxed{B_{12} = B_{21} \qquad -----(9)}$$

(8) & (9) are the expressions for the Einstein's Coefficients.

2. Discuss the various pumping methods employed to achieve population inversion.

Population inversion

The state of achieving more number of atoms in the excited state than that of the atoms in the ground state is called population inversion.

Pumping process (or) action (or) method

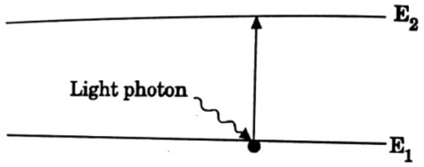
The process of raising more number of atoms to excited state by artificial means is called as pumping process.

The process to achieve population inversion in the medium is called pumping action.

Methods of Pumping process

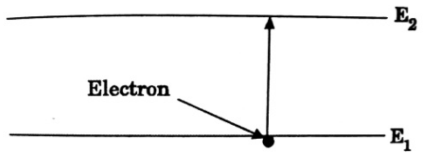
(i) Optical pumping (Photon excitation)
(ii) Electrical discharge (Electron excitation)
(iii) Inelastic atom-atom collision
(iv) Direct conversion
(v) Chemical process

(i) Optical pumping (Photon excitation)



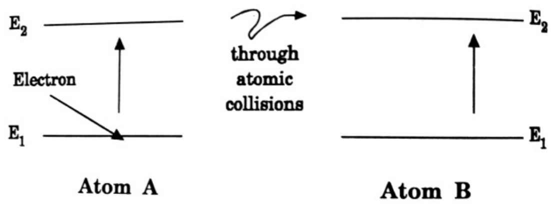
- In this method, an external optical source is used to produce photons.
- The atoms in the ground state absorb photons and go to excited state.
- **Example:** Ruby laser, Nd-Yag laser etc.

(ii) Electrical discharge (Electron excitation)



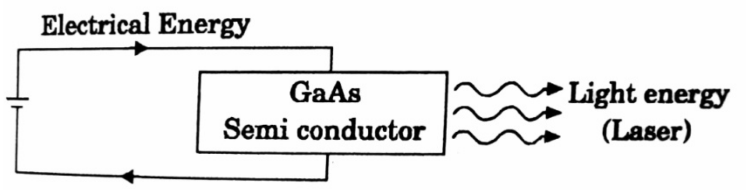
- In this method, a high amount of electric field is applied.
- The electrons in the electric field collide with gas atoms.
- So, gas atoms get energy from the electrons and go to excited state.
- **Example:** Argon laser, He-Ne laser, CO_2 laser etc.

(iii) Inelastic atom-atom collision



- In this method, a mixture of gases (A and B) is used.
- Due to electron bombardment, one gas atom (A) goes to excited state.
  $A + e^* \longrightarrow A^* + e$
- This excited gas atom (A^*) collides with another gas atom (B).
- So, it (B^*) also goes to excited state.
  $A^* + B \longrightarrow A + B^*$
- **Example:** He-Ne laser, CO_2 laser etc.

(iv) Direct conversion



- In this method, the electrical energy is applied to direct bandgap semiconductor.
- Due to applied to electrical field, recombination of electrons and holes takes place.
- During the recombination, electrical energy is converted into light energy directly.
- **Example:** Semiconductor laser.

(v) <u>Chemical process</u>

- In some chemical lasers, the product is left in the excited state.
- In HCl laser, the following chemical reaction

  $$H_2 + Cl_2 \longrightarrow 2\,(HCl)^*$$

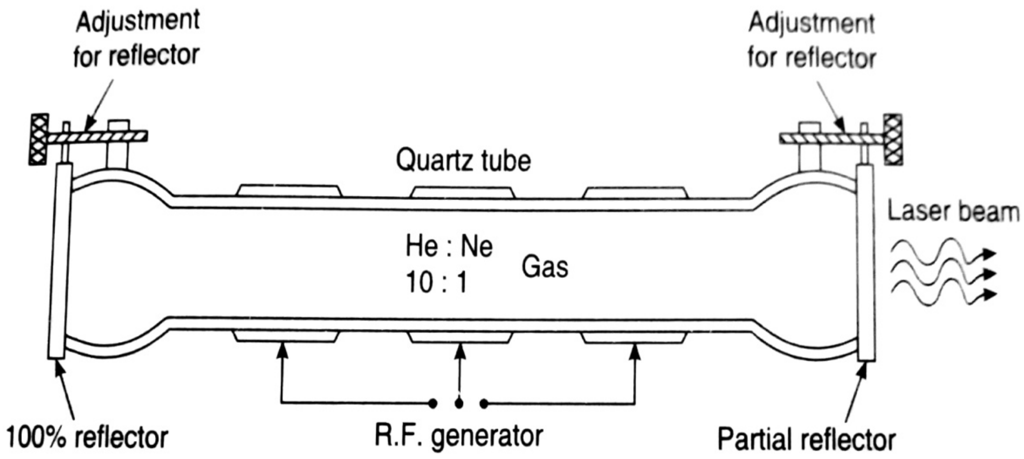
  brings the HCl molecule into excited state.
- **Example:** Dye laser.

3. Explain the construction and working of He-Ne laser.

<u>Principle</u>

The basic principle of He-Ne laser is gaseous discharge. Here, the population inversion is achieved due to the interaction between two gases.

<u>Diagram</u>



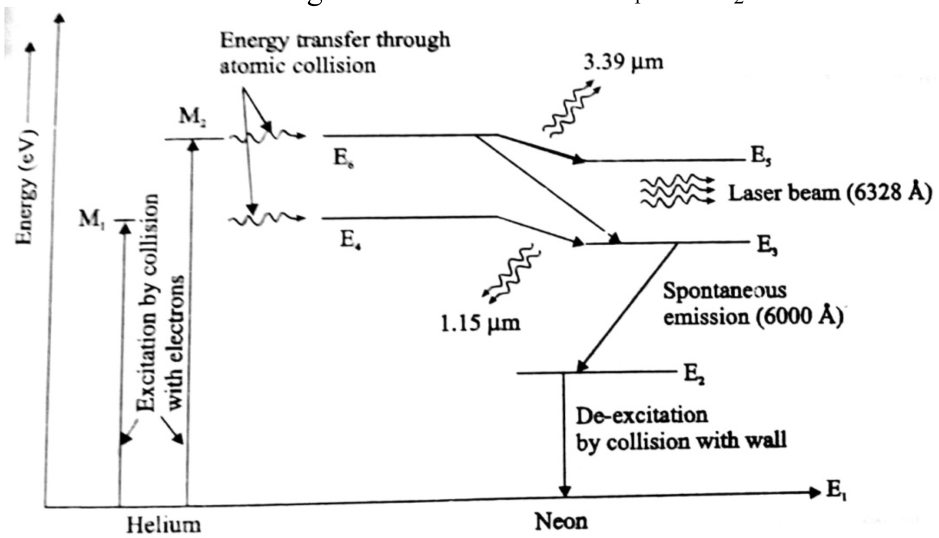
<u>Construction</u>

- It consists of a gas discharge tube.
- This tube is made up of quartz.

- This tube is filled with the mixture of helium and neon gases.
- The ratio of gas mixture is 10:1 (Number of He atoms is greater than Ne atoms).
- The electrodes are fitted with the ends of the discharge tube.
- These electrodes are connected to the R.F. generator.
- It is used to produce electrical discharge in the He-Ne mixture.
- A 100% reflecting mirror and a partially reflecting mirror are placed at the left and right ends of the tube respectively.
- It acts as a resonant cavity.

Working

- The R.F. generator is switched ON to produce electric field.
- The electric field is applied (discharged) to the gas mixture.
- Then the helium atoms get some energy from the electric field go to excited state.
- The excited helium atoms go to metastable states M_1 and M_2.



- These excited helium atoms collide with neon atoms.
- Due to collision, neon atoms go to excited state.
- E_6 and E_4 are the metastable states of neon atoms.
- The laser beam is produced by the following transitions.
  E_6 to E_3 transition – Laser beam of wavelength 6328 Å is produced.
  E_4 to E_3 transition – Laser beam of wavelength 11500 Å is produced.
  E_6 to E_5 transition – Laser beam of wavelength 33900 Å is produced.

Advantages

- The output power of He – Ne laser is in the order of a few mW.
- Continuous output laser beam can be produced.
- The monochromaticity and directionality are high.

Applications

- Because of its high power, it is used in open air communication.
- It is used to produce holograms (D photographs).
- It is used in determining the size of tiny particles.

4. Explain in detail how the laser is produced by Nd-YAG laser.

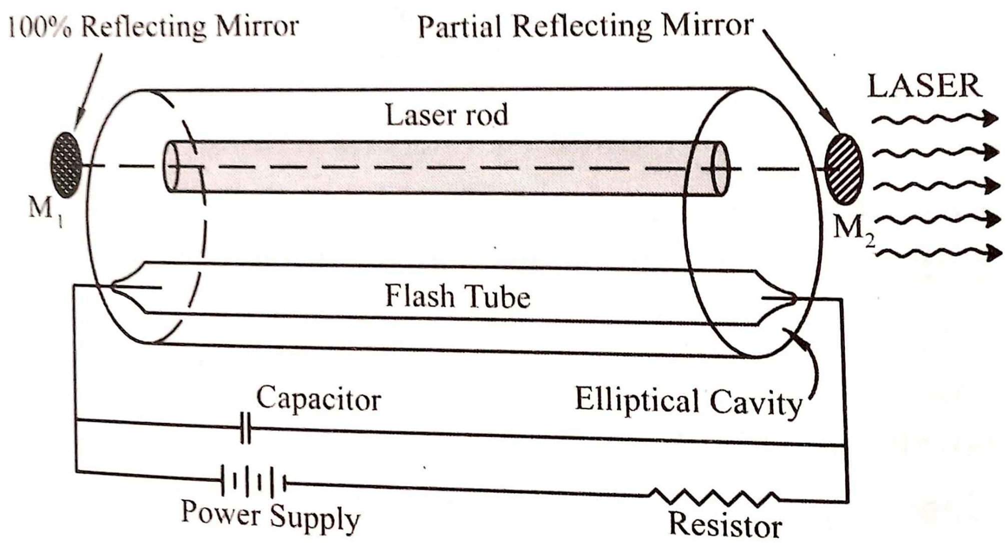
Nd-YAG Laser

- **Nd-YAG** – **N**eodymium-**Y**ttrium **A**luminium **G**arnet
- Nd-YAG laser is doped insulator laser.
- It is a four-level solid state laser.
- Nd-YAG rod is taken as an active medium.

Principle

The active medium of Nd-YAG rod is optically pumped by xenon flash tube. Due to optical pumping the neodymium ions (Nd^{3+}) go to excited state and population inversion is achieved. During the transition from metastable state to ground state, the laser beam of wavelength 1.064 µm is emitted.

Diagram

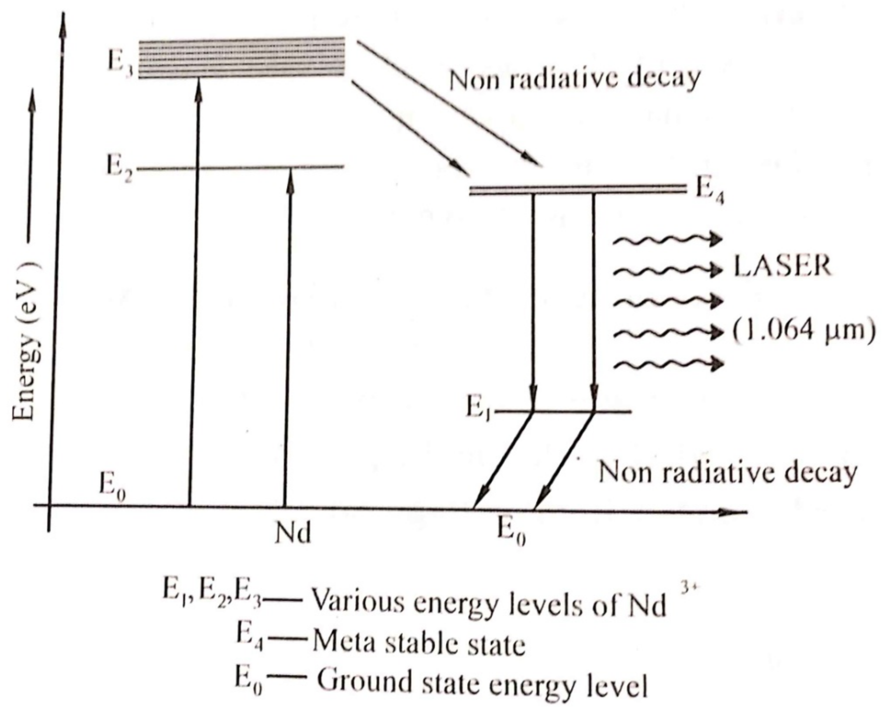


Construction

1. The Nd-YAG crystal is used in the form of rod for producing laser beam.
2. The is prepared by doping neodymium ions (Nd^{3+}) with Yttrium Aluminium Garnet.
3. The rod is kept inside the elliptical reflector cavity.
4. Optical pumping method is used to increase the atoms to the excited state.

5. Xenon or Krypton flash lamp is used as a source for optical pumping.
6. It is placed near by the rod in order to focus the most of the light towards the rod.
7. A fully reflecting (100%) and partially reflecting mirror are placed at both ends of the tube. It acts as an optical resonator.

Energy Level Diagram



Working

1. The xenon flash lamp is switched ON.
2. The light is focused towards the laser rod.
3. The neodymium ions in the ground state E_0 go to excited states E_3 and E_4.
4. The neodymium ions in these excited states make a non-radiative decay.
5. Now the neodymium ions are collected in the metastable state E_4.
6. Then population inversion is achieved between E_4 and E_1.
7. A neodymium ion emits a photon spontaneously.
8. This photon stimulates the other ions to emit photons.
9. These photons are reflected back and forth in between the mirrors and gets more intensity.
10. An intense laser light of wavelength 1.064 μm is emitted.

Applications

1. It is used in transmitting the signals to a longer distance.
2. It is used in long haul communication system.
3. It is used in endoscopy, urology and neurosurgery applications.

4. It is used in micro-machining operations such as welding, drilling etc.

5. Explain the modes of vibrations of CO_2 molecule. Describe the construction and working of CO_2 laser with necessary diagrams.

Carbon Dioxide (CO_2) Laser [Molecular Laser]

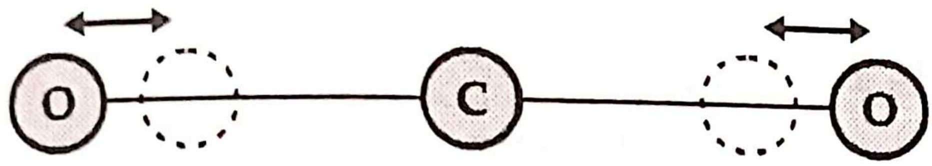
- It is a first molecular CO_2 gas laser.
- It was developed by C.K.N.Patel.
- It is a four-level molecular gas laser.

Fundamental modes of vibration of the CO_2 molecule

1. Symmetric stretching mode
2. Bending mode
3. Asymmetric stretching mode

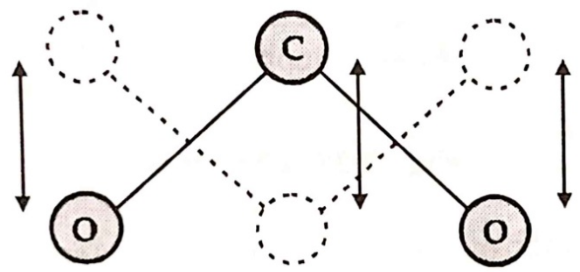
1. Symmetric stretching mode

In this mode, carbon atom is at rest. Both oxygen atoms vibrate along the axis of the molecule.



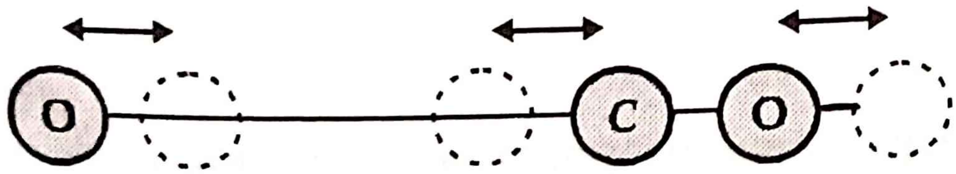
2. Bending mode

In this mode, both oxygen atoms and carbon atom vibrate perpendicular to molecular axis.



3. Asymmetric stretching mode

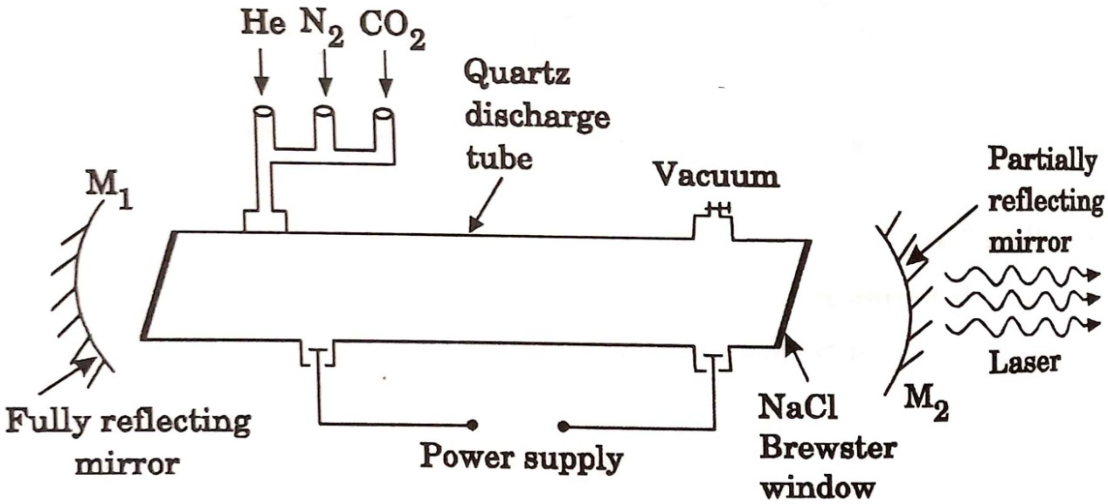
In this mode, both oxygen atoms and carbon atom vibrate asymmetrically, i.e. oxygen atoms in one direction while carbon atom moves in the opposite direction.



Principle

In this laser, the nitrogen atoms initially go to excited state. The nitrogen atoms deliver the energy to CO_2 atoms. Then, transition takes place between the vibrational energy levels of CO_2 atoms and hence laser beam is emitted.

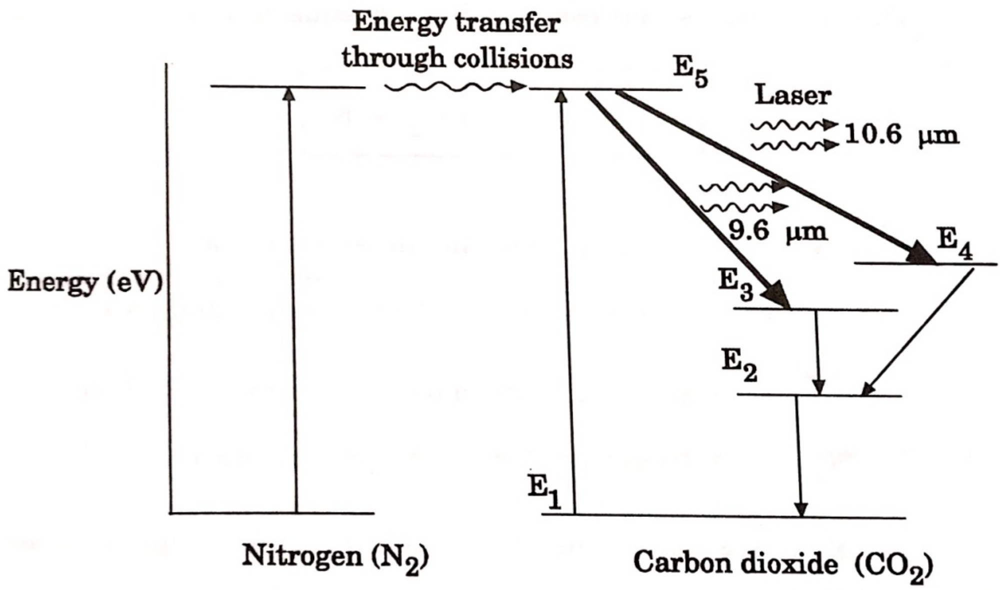
Diagram



Construction

1. Consider a discharge tube made up of quartz.
2. This tube is filled with the gas mixture of CO_2, nitrogen and helium atoms.
3. The terminals of the discharge tube are connected to a power supply.
4. The ends of the discharge tube are fitted with NaCl Brewster windows.
5. N_2 atoms help to increase the atoms in the excited state of CO_2.
6. Helium helps to depopulate the atoms in the ground state of CO_2.
7. A fully (100%) reflecting and partially reflecting mirror are placed at both ends of the tube. It acts as an optical resonator.

Energy Level Diagram



Working

1. When the power supply is switched on, electrons are discharged (produced) in the discharge tube.
2. These electrons collide with N_2 molecules and N_2 molecules go to excited state.
$$N_2 + e^- \rightarrow N_2^*$$
3. The excited state N_2 molecules collide with ground state CO_2 molecules and CO_2 molecules go to excited state. Then population inversion is achieved.
$$N_2^* + CO_2 \rightarrow CO_2^* + N_2$$
4. Any one of the spontaneously emitted photons stimulate the excited state CO_2 molecules.
5. The laser beam is produced by the following transitions.
   E_5 to E_4 transition – Laser beam of wavelength 10600 Å is produced.
   E_5 to E_3 transition – Laser beam of wavelength 9600 Å is produced.

6. With suitable diagram, how laser action is achieved in homojunction semiconductor (GaAs) laser?

Principle

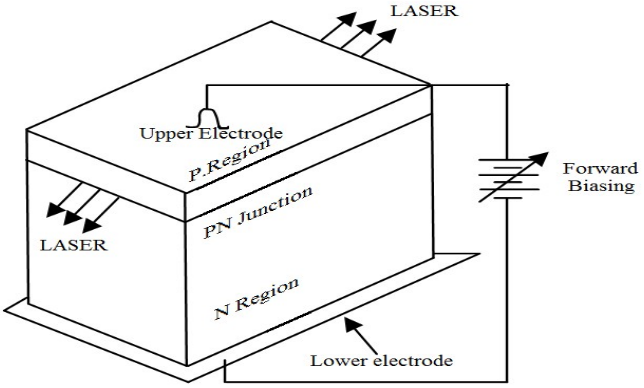
When the pn junction is forward biased, the electrons in the n-region and the holes in the p-region cross the junction and recombine each other. During the recombination process, energy in the form of light (photon) is released. This photon stimulates other electrons and holes to recombine. As a result, stimulated emission takes place and laser light is produced.

Construction

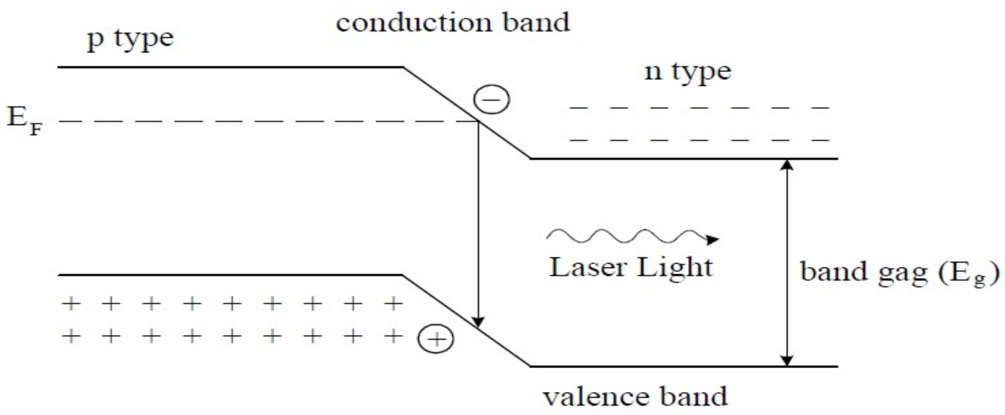
1. The active medium is a p-n junction. It is made up of gallium arsenide (GaAs) crystal.

2. The thickness of pn junction is very narrow.
3. The upper and lower electrodes are fixed with 'p' and 'n' regions of the semiconductor diode.
4. It helps for the flow of current to the diode while biasing.
5. The ends of the pn junction are well polished and parallel to each other.
6. It acts as an optical resonator.

Diagram



Energy level diagram



Working

1. The diode is forward biased with the help of upper and lower electrodes.
2. Due to forward biasing, a large number of electrons and holes (charge carriers) are produced around the junction region.
3. These electrons and holes are injected into the active medium.
4. The electrons and holes are continuously injected until the population inversion is achieved.
5. Now some of the electrons and holes recombine with each other.
6. They emit photons spontaneously during recombination.
7. These photons stimulate the injected charge carriers to emit more photons.
8. These photons are reflected back and forth between the pn junctions.
9. It increases the intensity of the laser beam.
10. Finally the laser beam of wavelength 8400 Å is emitted from the junction.

Advantages

1. It is easy to manufacture the diode.
2. It has high efficiency.
3. The cost is low.
4. It is operated with less power.

Disadvantages

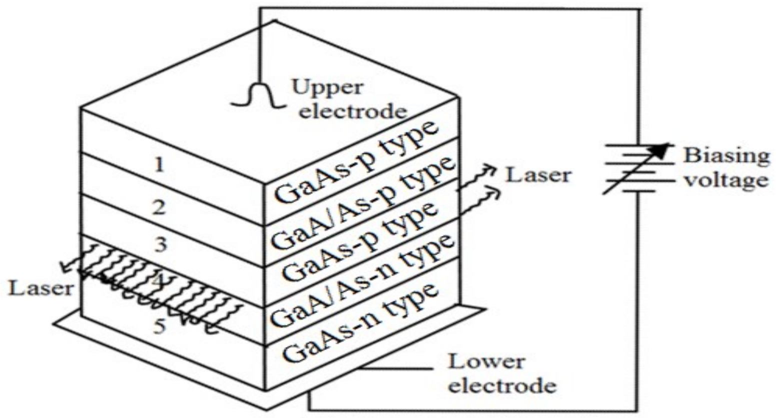
1. The purity and monochromaticity are poor.
2. The beam has large divergence.
3. It has poor coherence and stability.
4. The output wave is pulsed and will be continuous only for sometime.

7. Explain the lasing schemes and working of a heterojunction laser.

Principle

When the pn junction is forward biased, the electrons in the n-region and the holes in the p-region cross the junction and recombine each other. During the recombination process, energy in the form of light (photon) is released. This photon stimulates other electrons and holes to recombine. As a result, stimulated emission takes place and laser light is produced.

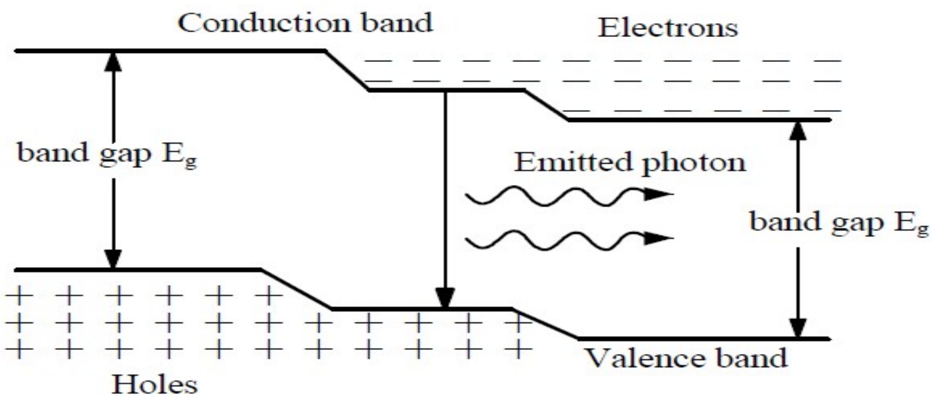
Diagram



Construction

1. This laser consists of five layers.
2. The 3rd layer (Ga As p-type) acts as a active medium.
3. This layer is kept between 2nd (Ga Al As p-type) and 4th (Ga Al As n-type) layers.
4. The upper and lower electrodes help for the flow of current to the diode while biasing.
5. The ends of 3rd and 4th layers are well polished and parallel to each other.
6. It acts as an optical resonator.

Energy level diagram



Working

1. The diode is forward biased with the help of upper and lower electrodes.
2. Due to forward biasing, a large number of electrons and holes (charge carriers) are produced in the 2nd and 4th layers.
3. These electrons and holes are injected into the 3rd layer (active medium).
4. The electrons and holes are continuously injected into the 3rd layer, until the population inversion is achieved.
5. Now some of the electrons and holes recombine with each other.
6. They emit photons spontaneously during recombination.
7. These photons stimulate the injected charge carriers to emit more photons.
8. These photons are reflected back and forth between the pn junctions.
9. It increases the intensity of the laser beam.
10. Finally the laser beam of wavelength 8000 Å is emitted from the junction.

Advantages

1. The output is continuous.
2. Power output is high.
3. It has high directionality and coherence.

Disadvantages

1. The cost is high.
2. It is very difficult to grow different layers of pn junction.

8. Explain the advanced applications of Laser.

Property: Narrow band width & angular spred

- It is used in communications to transmit thousands of programmes and transmitting signals to longer distances.

Property: Not absorbed by water

- It is used in underwater communication between the submarines. It is very useful for military.

Property: High penetrating power

- It is used to blast holes in diamonds and hard steels.
- It is used to drill minute holes in cell walls of human body.
- Cancer treatment can be done.
- It is used to destroy tumors.

Property: Directionality

- It is used to produce laser gun and laser torches.
- It is used to do micro surgery and blood less operations.
- It is used in laser printing and in computer storage devices.

Property: High Intensity

- They are used in endoscopic applications in medical field.

OPTICAL FIBER

PART – B QUESTIONS

1. What is optical fiber?

Optical fibre is a thin hair like structure made up of transparent material. It guides the light beam from one end to another by total internal reflection. It consists of a **core** glasses surrounded by a **cladding.** The cladding is covered by a **buffer jacket**. It acts as a protective skin for core and cladding.

2. State the features or advantages of optical fiber?

(i) Light in weight.
(ii) Smaller in size.
(iii) It is flexible. So it can be bent to any position.
(iv) Non-conductive, non-radiative and non-inductive.
(v) No short circuit as in metal wires.
(vi) No internal noise / cross talks.
(vii) It is inexpensive.

3. What is meant by rarer medium and denser medium? Give examples.

If the speed of light is more in a medium, it is called rarer medium. Light travels faster in this medium. It is a low density medium. **Example:** Air

If the speed of light is less in a medium, it is called denser medium. Light travels slower in this medium. It is a high density medium. **Example:** Glass & Water.

4. Bring out the differences between rarer medium and denser medium.

Rarer medium	Denser medium
1. If the speed of light is more in a medium, it is called rarer medium.	1. If the speed of light is less in a medium, it is called denser medium.
2. Light travels faster in this medium.	2. Light travels slower in this medium.
3. It is a low density medium.	3. It is a high density medium.
4. The particles are loosely packed.	4. The particles are densely packed.
5. **Example:** Air	5. **Examples:** Glass, water etc.

5. What is the basic principle of fiber optic communication?

Principle:

Total internal reflection is the basic principle of fiber optic communication system.

When the light travels from a denser medium to a rarer medium, it strikes the interface of core and cladding at greater angle of incidence called critical angle. When angle of incidence exceeds the critical angle, the incident ray is reflected in the same medium. This phenomenon is called total internal reflection.

6. List the conditions to be satisfied for total internal reflection.

(i) Light should travel from denser medium to rarer medium.

(ii) The angle of incidence (ϕ) on core should be greater than the critical angle (ϕ_c).

$$\text{i.e. } \phi > \phi_c.$$

(iii) The refractive index of the core (n_1) should be greater than the refractive index of the cladding (n_2).

$$\text{i.e. } n_1 > n_2$$

7. What is critical angle in an optical fiber?

The minimum angle of incidence (ϕ) required to produce the total internal reflection is known as critical angle. It is represented as ϕ_c.

8. Define Numerical Aperture.

Numerical Aperture (NA) is defined as the sine of the acceptance angle. If n_1 and n_2 are the refractive index of the core and cladding respectively,

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

It is a measure of the amount of light that can be accepted by a fiber.

9. Distinguish between single mode fiber and multimode fiber.

Single mode Fiber	Multimode fiber
1. If the fibre can allow only one mode of propagation, it is called **single mode fibre**.	1. If the fibre can allow more than one mode to propagate, it is called **multimode fibre**.
2. It is made up of doped silica.	2. It is made up of doped silica and glass – clad glass.
3. It has a very small core diameter (5 – 10 μm).	3. It has very large core diameter (50 – 350 μm).
4. Its cladding diameter is around 125 μm.	4. Its cladding diameter is around 125 – 500 μm.
5. It is used in long haul communication. E.g. Telephone	5. It is used in short haul communication. E.g. Bluetooth

10. Distinguish between step index fiber and graded index fiber.

Step Index Fiber	Graded Index fiber
1. The difference in refractive indices between the core and cladding is obtained in a single step and hence called as step index fiber.	1. The difference in refractive indices between the core and cladding gradually increases from centre to interface and hence called graded index fiber.
2. The light propagation in the form of meridional rays.	2. The light propagation in the form of skew rays.
3. The light rays pass through the fiber axis.	3. The light rays do not cross the fiber axis.
4. It follows a zig-zag path of light propagation.	4. It follows a helical path of light propagation.
5. It has low bandwidth.	5. It has high bandwidth.
6. Distortion is more.	6. Distortion is very less.

11. A step index fiber has a numerical aperture of 0.3905 and core refractive index of 1.55. Calculate the refractive index of the cladding and acceptance angle.

Ans:

Given: Numerical Aperture (NA) = 0.3905
Core refractive index (n_1) = 1055

Formula:

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

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

$$n_2 = \sqrt{(1.55)^2 - (0.3905)^2}$$

$$n_2 = \sqrt{2.4025 - 0.15249}$$

$$n_2 = \sqrt{2.25001}$$

$$\text{Re}\,fractive\ index\ of\ cladding\ n_2 = 1.5$$

Acceptance Angle $i_m = \text{Sin}^{-1}$ NA

$i_m = \text{Sin}^{-1}(0.3905)$

$i_m = 22.9856$

(or) $i_m = 22^0\ 59'$

(i)	**Refractive index of cladding = 1.5**
(ii)	**Acceptance Angle =**

12. Mention any four advantages of fiber optic sensors.

(i) It has no external interference
(ii) It is used in remote sensing.
(iii) Safety of data transfer.
(iv) It is small in size.

PART – C QUESTIONS

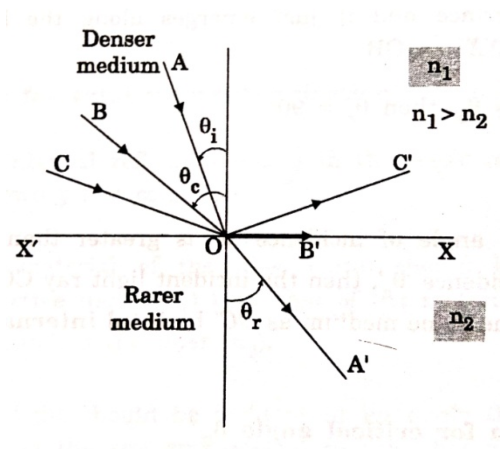
1. State the principle and explain the propagation of light through optical fiber in detail.

Principle

Total internal reflection is the basic principle of fiber optic communication system.

When the light travels from a denser medium to a rarer medium, it strikes the interface of core and cladding at greater angle of incidence called critical angle. When angle of incidence exceeds the critical angle, the incident ray is reflected in the same medium. This phenomenon is called total internal reflection.

During this phenomenon, most of the light waves travel over a long distance without much loss of energy.



Propagation of light

- Consider an optical fiber.
- It contains core and cladding.
- The core is considered as a denser medium.
- The cladding is a rarer medium.
- n_1 – Refractive index of the core.
- n_2 – Refractive index of the cladding.
- A light ray travels from denser medium to rarer medium.
- This light ray is
  reflected back into the core (or)
  refracted into the cladding (or)
  travelling on the interface.
- It depends upon the angle of incidence of the light ray.
- Consider a ray 'AO'.
- XX' – Interface between the core and cladding.

- AO, BO, CO $\}$ – Incident rays at different angles.
- OA' – Refracted ray.
- OB' – Ray travelling along the interface.
- OC' – Reflected ray.
- θ_i – Angle of incidence.
- θ_r – Angle of refraction.
- θ_c – Critical Angle

<u>Case: 1</u> $\theta_i < \theta_r$

- In this case, the light ray (AO) is refracted into the core.

<u>Case: 2</u> $\theta_i < \theta_c$ $\theta_c = 90^o$

- In this case, θ_i is increased to θ_c the light ray (AO) is refracted into the core.
- The light ray (BO) passes along the interface (XX') of the core and cladding.

<u>Case: 3</u> $\theta_i > \theta_c$

- Here θ_i is increased further than θ_c.
- The ray (CO) is reflected back into the core.

Expression for Critical angle

According to Snell's law,

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

Here, $\theta_1 = \theta_c$ & $\theta_r = 90^o$

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

$$n_1 \sin\theta_c = n_2 (1)$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

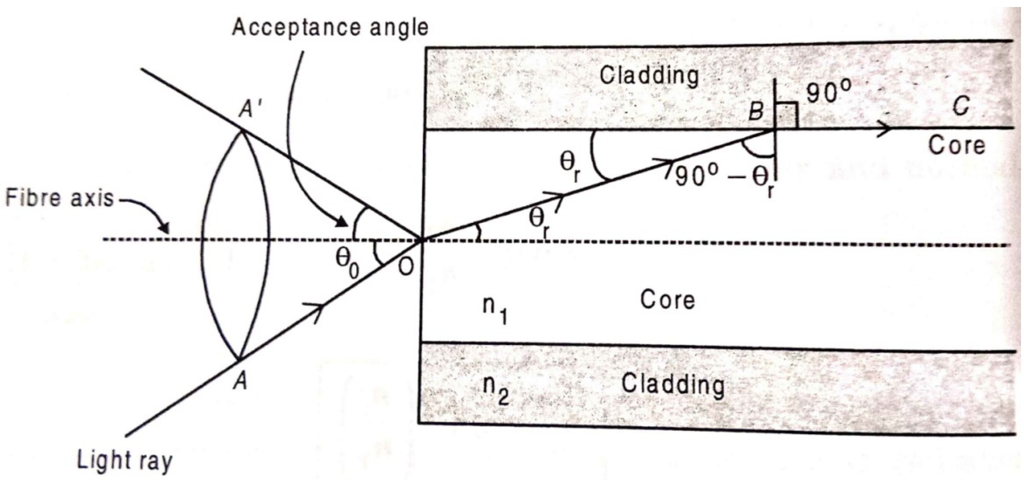
$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

2. Derive an expression for acceptance angle and numerical aperture of an optical fiber.

Acceptance angle – Definition

Acceptance angle is the maximum angle to the axis at which light may enter into the fibre so that it can have total internal reflection inside the fibre.

Diagram



- Consider an optical fiber.
- It contains core and cladding.
- n_0 – Refractive index of the air.

- n_1 – Refractive index of the core.
- n_2 – Refractive index of the cladding.
- A ray is incident on the optical fiber and enters into the core at an angle θ_i.
- AO – Incident ray.
- θ_i – Angle of incidence.
- The incident ray AO is refracted along OB.
- OB – Refracted ray
- θ_r – Angle of refraction.
- If the ray is allowed further, it fall on the interface at an angle $(90^o - \theta_r)$.
- $(90^o - \theta_r)$ – Angle of incidence of the refracted ray.
- At this point, the ray just moves along BC.
- If the angle of incidence $(90^o - \theta_r)$ of the refracted ray is increased further than critical angle, the ray is totally reflected back (internally) into the core.

According to Snell's law,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \text{------------ (1)}$$

At the ray 'AO',

$$\theta_1 = \theta_i \quad \& \quad \theta_2 = \theta_r$$

$$n_1 = n_0 \quad \& \quad n_2 = n_1$$

(1) Becomes,

$$n_0 \sin\theta_i = n_1 \sin\theta_r$$

$$\sin\theta_i = \frac{n_1}{n_0} \sin\theta_r$$

$$\sin\theta_i = \frac{n_1}{n_0} \sqrt{1-\cos^2\theta_r} \qquad \text{---------------- (2)}$$

At the point 'B',

$$\theta_1 = 90^o \theta_r \quad \& \quad \theta_2 = 90^o$$

$$n_1 = n_1 \quad \& \quad n_2 = n_2$$

(2) Becomes,

$$n_1 \sin\left(90^o - \theta_r\right) = n_2 \sin 90^o$$

$$n_1 \cos\theta_r = n_2 \,(1)$$

$$\cos\theta_r = \frac{n_2}{n_1} \qquad \text{---------------- (3)}$$

Sub. (3) in (2),

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

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

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

$$\sin\theta_i = \frac{1}{n_0}\sqrt{(n_1^2-n_2^2)} \qquad \text{----------------- (4)}$$

$$\theta_i = \sin^{-1}\frac{\sqrt{(n_1^2-n_2^2)}}{n_0}$$

If $n_0 = 1$, (4) becomes

$$\sin\theta_i = \sqrt{(n_1^2-n_2^2)}$$

Numerical Aperture

Numerical aperture is the light gathering capacity of the fiber. It is defined as the sine of the acceptance angle of the fiber.

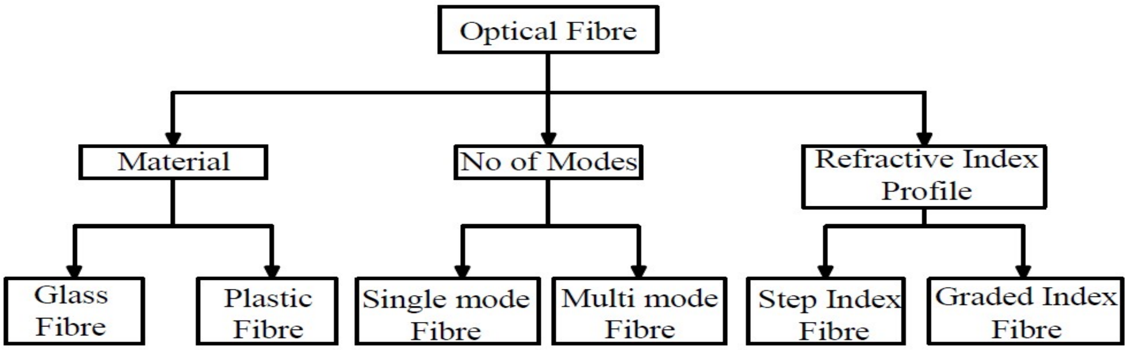
$$NA = \sin\theta_i = \sqrt{(n_1^2-n_2^2)}$$

3. What is optical fiber? How are fibres classified? Explain the classification in detail (or) Explain the different types of optical fibers.

Optical fibre

Optical fibre is a thin hair like structure made up of transparent material. It guides the light beam from one end to another by total internal reflection. It consists of a **core** glasses surrounded by a **cladding.** The cladding is covered by a **buffer jacket**. It acts as a protective skin for core and cladding.

Classification of Optical fibres



Glass fibre

If the fibres are made up of silica glasses and mixture of metal oxides, it is called **glass fibre**.

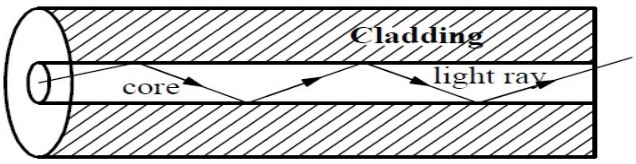
E.g. Core : SiO_2 Cladding : $P_2O_3 – SiO_3$

Plastic fibre

If the fibres are made up of plastics, it is called **plastic fibre.**

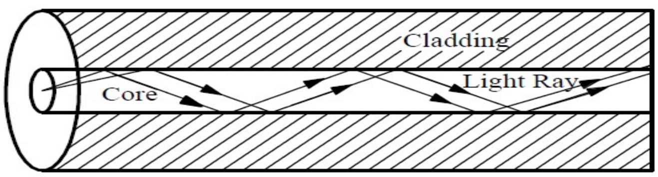
E.g. Core : Polymethyl methacrylate Cladding : Co-polymers

Single mode fibre



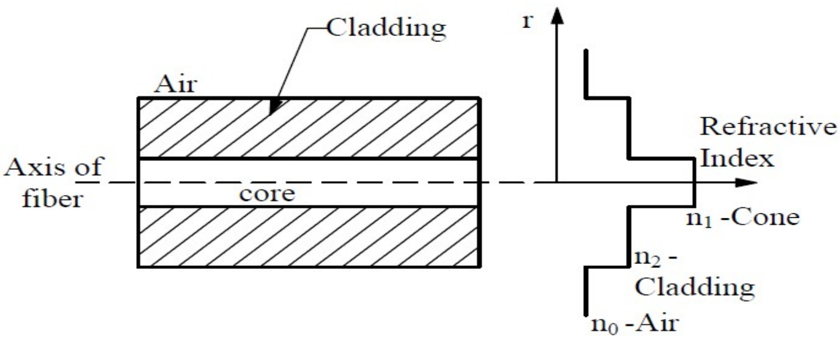
- If the fibre can allow only one mode of propagation, it is called **single mode fibre**.
- It is made up of doped silica.
- It has a very small core diameter (5 – 10 μm).
- Its cladding diameter is around 125 μm.
- It is used in long haul communication.

Multimode fibre

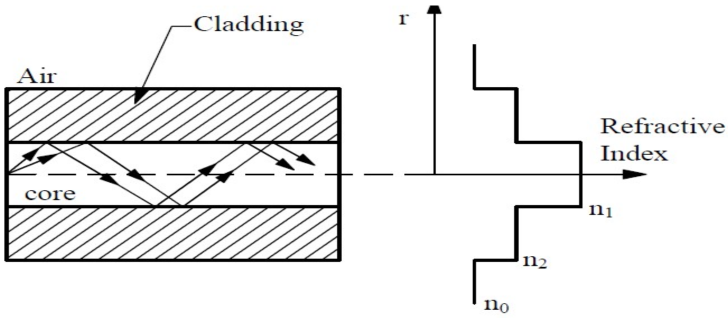


- If the fibre can allow more than one mode to propagate, it is called **multimode fibre**.
- It is made up of doped silica and glass – clad glass.
- It has very large core diameter (50 – 350 μm).
- Its cladding diameter is around 125 – 500 μm.
- It is used in short haul communication.

Step index fibre



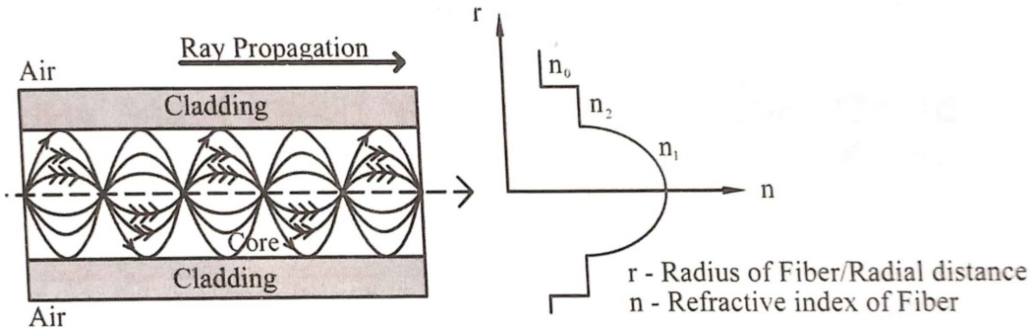
Single mode step index fiber



Multimode step index fiber

- If the refractive indices of air, core and cladding varies by step by step, it is called **step index fibre**.
- The light ray propagation is in the form of meridional rays.
- The path of light propagation is in zig-zag manner.

Graded index fibre



- If the refractive index is maximum at the fiber axis and minimum at the interface.
- The refractive index decreases gradually from centre to interface. Then it is called **graded index fibre**.
- The light ray propagation is in the form of skew rays.
- The path of light propagation is in spiral manner.

4. Explain the fibre optical communication system with a neat block diagram (or) What are the different units of fibre optic communication system? Explain.

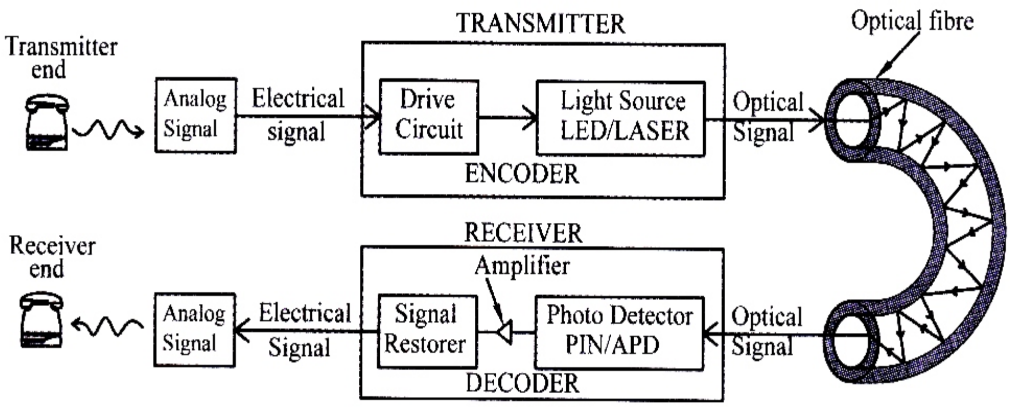
Principle

The principle of fibre optic communication system is transmission of information over a required distance by the propagation of optical signal through optical fibres.

Main parts of the fibre optic communication system

(i) Information signal source
(ii) Transmitter
(iii) Optical fibre
(iv) Receiver

Block diagram



(i) Information signal source

- The information signal may be voice, music, video signals etc.
- This signal is in analog form.
- It is first converted into electrical signal.

(ii) Transmitter

- The transmitter consists of drive circuit and light source.
- The drive circuit converts the electrical signal into digital pulses.
- The light source converts the digital pulses into optical pulses.
- LED or Laser is used as a light source.
- The optical pulses are focused towards optical fibre.

(iii) Optical fibre

- Optical fibre acts as a waveguide.
- It transmits the optical pulses towards the receiver by the principle of **total internal reflection**.

(iv) Receiver

- The receiver consists of a photo detector, an amplifier and a signal restorer.
- The photo detector converts the optical pulses electrical pulses.
- The amplifier amplifies the electrical pulses.
- These electrical pulses are decoded, i.e., the digital signals are converted into analog signals by the signal restorer.
- These analog signals contain the original information.
- By this way, the information is transmitted from one end to other end.

5. Explain the construction and working of temperature and displacement fibre optic sensors.

Fibre optic sensor

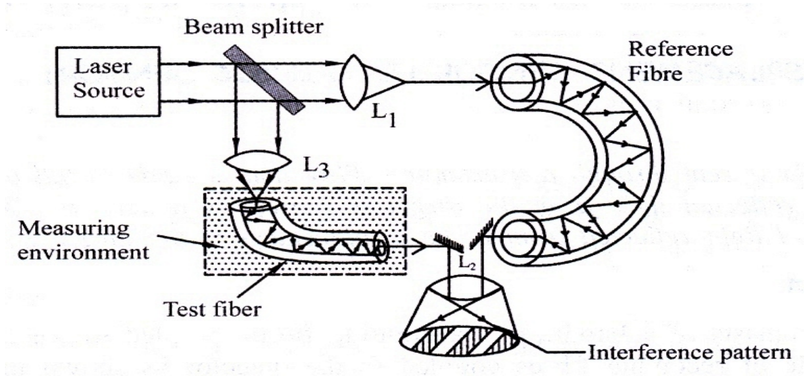
Fibre optic sensor is a transducer which converts any form of signal into optical signal in the measurable form.

TEMPERATURE SENSOR (OR) PRESSURE SENSOR

Principle

It works based on the principle of **interference** between the beams emerging out from the reference fibre and the fibre kept in the measuring environment.

Diagram



Construction

(i) It consists of laser source to emit laser beam.
(ii) A beam splitter is kept at an angle of 45° to the direction of laser beam.
(iii) The beam splitter splits the laser beam into two beams,
(a) Main beam
(b) Splitted beam

(iv) In this sensor, two fibres are used,
  (a) Reference fibre
  (b) Test fibre
(v) Reference fibre is isolated from the environment
(vi) Test fibre is kept inside the environment to be sensed.
(vii) Separate lens systems are provided to split and collect the laser beam.

Working

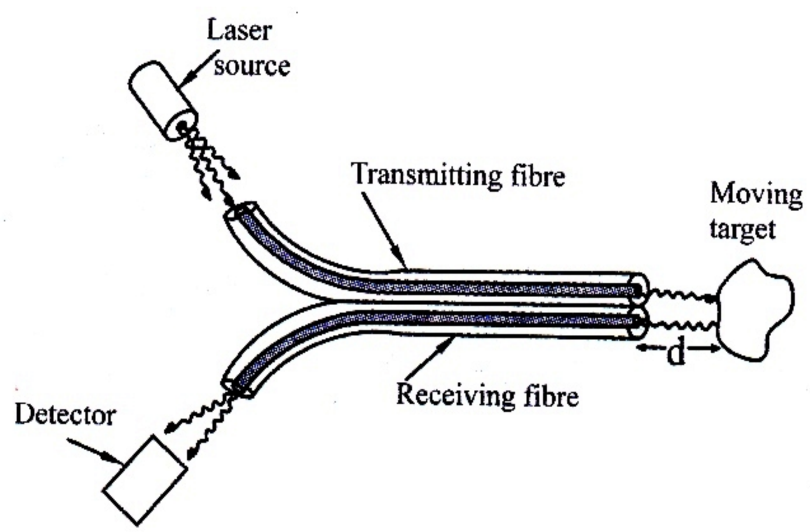
(i) The laser beam is emitted by the laser source.
(ii) The beam splitter splits the laser beam into two beams.
(iii) The main beam is passed into the reference fibre through the lens L_1.
(iv) The splitted beam is passed into the test fibre through the lens L_3.
(v) The beams from these two fibers are focussed into the lens L_2.
(vi) It produces a path difference due to temperature change in the environment.
(vii) Due to path difference, interference pattern is obtained.
(viii) The change in temperature can be measured from the interference pattern.

DISPLACEMENT SENSOR

Principle

Laser light is transmitted through a transmitting fibre and focused towards the moving target. The reflected light from the target is sensed by a detector. From the intensity of reflected light, the displacement of the target can be measured.

Diagram



Construction

(i) This sensor consists of two fibres,
  (a) Transmitting fibre

(b) Receiving fibre

(ii) The transmitting fibre is coupled with the laser source and moving target.

(iii) The receiving fibre is coupled with the moving target and a detector.

Working

(i) Laser source emits the laser light.

(ii) The laser light is transmitted through the transmitting fibre and made to fall on the moving target.

(iii) The light reflected from the target is made to pass through the receiving fibre and this light is detected by the detector.

(iv) If the received intensity is more, it is understood that the target is moving towards the sensor.

(v) If the received intensity is less, it is understood that the target is moving away from the sensor.

(vi) From the received intensity of light, the displacement of the target can be measured.