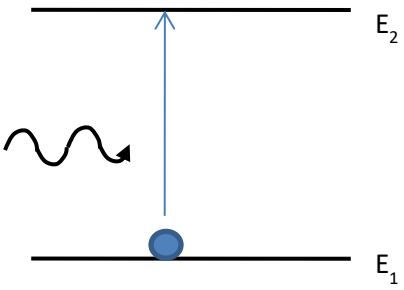
LASER AND FIBRE OPTICS

Q. Explain the term absorption, spontaneous emission, stimulated emission, population inversion and pumping.

Ans. Absorption:

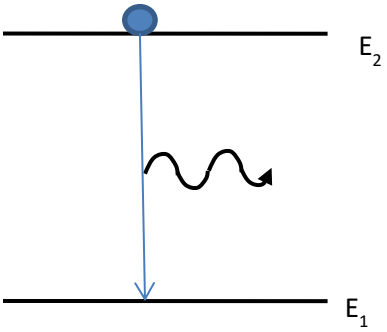
Suppose the atom is in ground state E_1. If a photon of energy ($E = E2 - E1 = h\nu$) is incident on the atom, it absorbs the energy and jumps to excited state E_2. This phenomenon is known as absorption. It can be expressed as

$$A + h\nu \rightarrow A^*$$



Spontaneous emission:

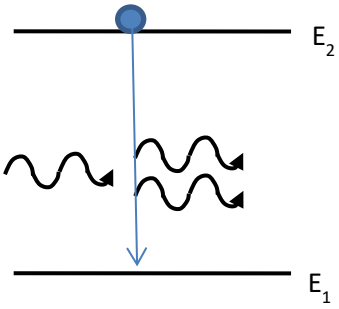
If the atom is in excited state E_2, it is unstable and its life time (time for which atom stays in excited state) is 10^{-8} s. Hence there is transition of atom from energy state E_2 to E_1 with emission of photon with energy $h\nu = E_2 - E_1$ as shown below. It is spontaneous emission.



Stimulated emission:

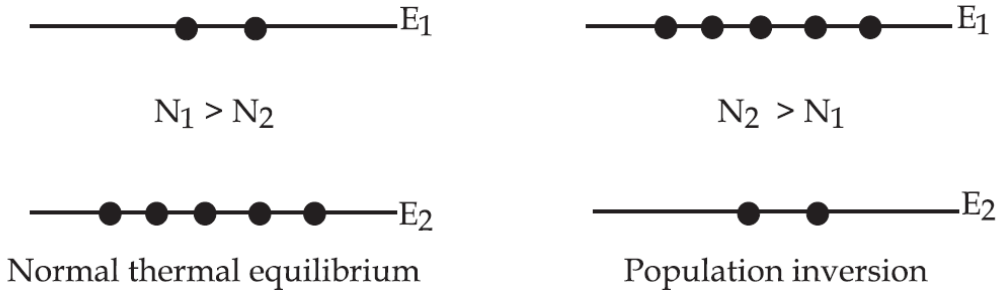
If a photon with energy ($h\nu = E_2 - E_1$) is incident on an excited atom before 10^{-8} s, incident photon plays the role of trigger and it induces the downward transition of atom with the emission of two photons as shown in fig. below. It can be expressed as,

$$A^* + h\nu \rightarrow A + 2h\nu$$

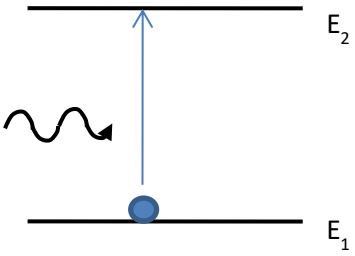


Population inversion:

Let N_1 and N_2 be the populations of energy E_1 and E_2. In thermal equilibrium, lower energy states are densely populated. Hence $N_1 > N_2$. "If number of atoms in higher energy state is greater than number of atoms in lower energy state ($N_2 > N_1$), it is known as population inversion."



Pumping : It is a method of exciting the atoms to higher energy level. It can be done by subjecting the atoms to non uniform electric field, flooding the gas with high intensity light etc.



Q. State and explain characteristics of laser.

Ans. 1. Coherence : Waves emitted by laser are in same phase and gives coherent beam of light. This coherence is described in terms of temporal (coherence in time) and spatial (coherence in space) coherence.

2. Directionality : All the waves in laser travel in same direction and thus it is highly directional.

3. Divergence : Laser is highly directional, hence its divergence or angular spread is extremely small. It shows a little divergence due to diffraction from semisilvered face.

4. Intensity : Laser is highly concentrated beam with small divergence and hence it is highly intense beam of light and energy is concentrated in small region. Moreover its intensity remains constant over long distance.

5. Monochromaticity : The light from normal monochromatic source spreads over a wavelength range of the order of 100 A^0 to 1000 A^0. In laser, the spread of wavelength range is very small (<10 A^0).

Q. With neat diagram explain construction and working of Ruby Laser

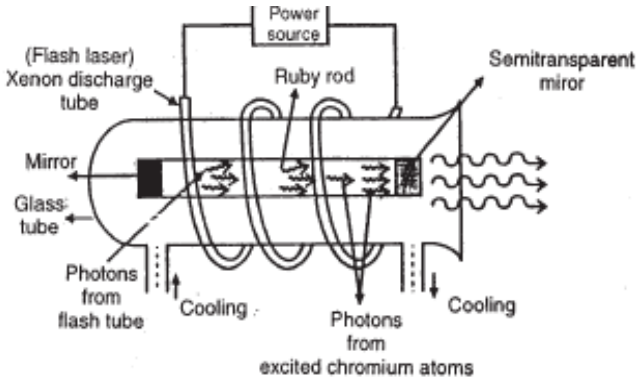
Ans. Ruby laser :

Ruby is naturally occurring red coloured precious stone. Ruby laser is made up of ruby crystal - Al_2O_3 with some of the Al^{+3} ions replaced by Cr^{+3} ions. Concentration of Cr^{+3} ions is 0.05% by weight.

Chromium atoms are excited by absorbing photons in blue green region. When atoms fall back to ground state by spontaneous emission, it gives red light. Hence it has natural red colour.

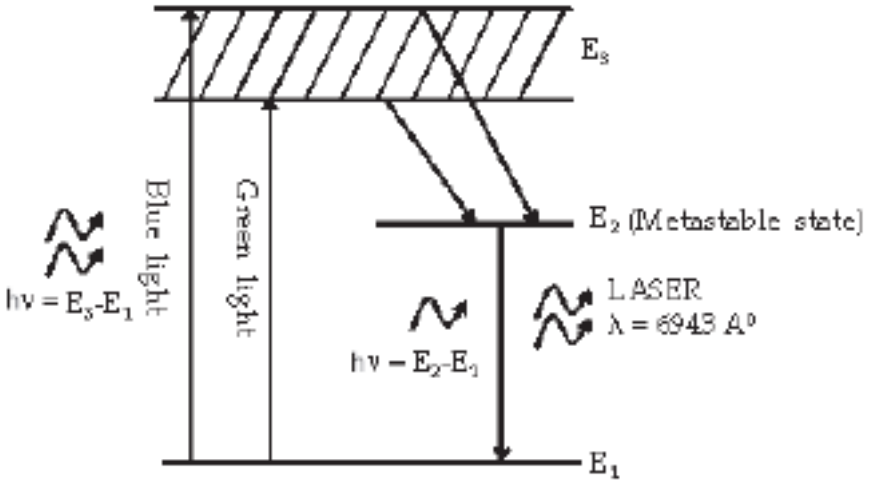
Construction:

It consists of ruby rod, several cm in length and few mm in diameter. Its one end is fully silvered while other is semisilvered. It is surrounded by helical Xenon flash tube. Liquid nitrogen used as coolant.



Working: When flash light falls upon the ruby rod, radiations are absorbed by chromium atoms and are pumped to state E_3. The uppermost band is fairly wide and can accept a wide range of wavelengths, but has short life time. The excited atoms rapidly relax and drop to next lower state, which is metastable with life time 10^{-3}s (Non-radiative transition). If it continues, it gives more number of atoms in E_2 i.e population inversion. If some suitable photon is incident on the system, it triggers stimulated emission. Once started, this cumulative process continues and coherent laser beam penetrates through the semisilvered face.

The characteristic wavelength of ruby laser is 6943 A^0.



Q Modes in Laser:

In optical resonant cavity, there are discrete resonant conditions determined by dimensions of the cavity. So, only the waves oscillating at modes that match the oscillation modes of the laser cavity can be produced. The modes determined by axial dimensions of laser cavity are called longitudinal modes and the modes determined by cross sectional dimensions of laser cavity are transverse modes.

Q. Write a note on holography.

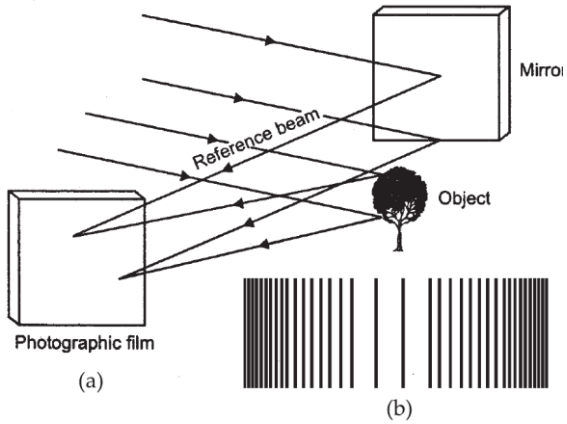
Ans.

Holography : It is three dimensional photography. It is based on the principle of interference between two coherent beams - object beam and reference beam.

It is two step process.

Recording of hologram :

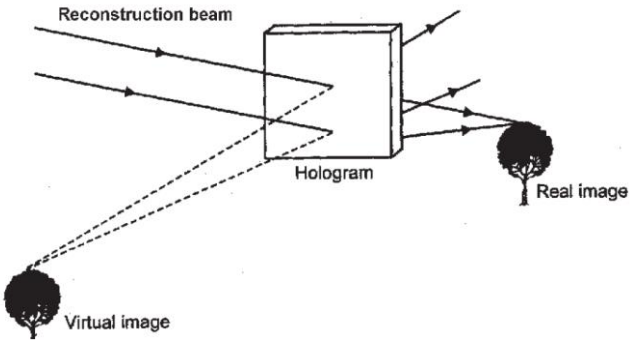
The principle of holography is illustrated in fig.



Using beam splitter laser beam is split into two beams viz a reference beam and object beam. The reference beam after reflection from the mirror is made incident on photographic plate. The object beam is incident on the object and scattered by object. The beam scattered from the object travels towards photographic plate and interferes with reference beam producing an interference pattern

on photographic plate. The photographic plate carrying interference pattern is called hologram as shown in (b).

Reconstruction of image : Reconstruction is as shown in figure.



A laser beam identical to the reference beam is used which is known as reconstruction beam. The hologram acts as diffraction grating. The diffracted rays form two images: a real image in front of hologram and virtual image behind the hologram at the original site of object. It has three dimensional characteristics and it is viewed from different angles.

Features of holography :

i) Information is stored in coded form i.e. interference pattern.

ii) It is a reliable medium for data storage because a small part of hologram (1/10th to 1/8th part) can reconstruct the entire image.

Applications of holography :

i) In artistic and commercial display.

ii) It is used in non-destructive testing to study distortion in object.

Virtual Reality and Holography:

Virtual reality is computer simulated reality. It engages all five senses (taste, sight, smell, touch and sound). A simulation is the imitation of the operation of a real-world process or system over time. Simulations require the use of models that represents the key characteristics of the selected system or process. Valid sources of information about the key characteristics and behavior of the model is very important issue in virtual reality. In physical simulation, real object is substituted by physical object small in size and cheap. In interactive simulation, physical simulation includes human operator. E,g. A flight simulator is a device that artificially re-creates aircraft flight and the environment in which it flies. It is used for pilot training, design, or other purposes.

The Three dimensional technology is the key aspect of virtual reality technology. In stereoscopic 3D display technology, left and right eyes get two images with binocular parallax. The human brain combines these two images into a 3D image. However it may cause visual fatigue. Holographic technique to obtain three dimensional images can replace stereoscopic optics. In holography, the image has a certain depth of field, which is the distance between the nearest and the furthest objects that are in acceptably-sharp

focus in an image. The viewing angle of the reconstructed images, θ, is twice the maximum diffraction angle, which is the maximum angle at which an image can be viewed with acceptable visual performance.

Virtual reality has applications in gaming world, education, military to train medical personals to treat patients on battle field.

Drawbacks of Virtual reality:

- Fear of cyber attack
- Motion sickness if used for long time.

Q. State industrial and medical applications of LASER.

Ans:

Industrial applications:

i) Laser is primarily used for cutting, welding, drilling and marking with high accuracy. In electronics, to cut circuit for calculator, computer etc.

ii) Lasers found wide applications in the development and manufacturing of screens of smart phones, tablet computers and LED TVs.

iii) Heat treatment is necessary in the tooling and automotive industry. Lasers are very useful when it is desirable to treat only a small portion of large item.

iv) In jewellary, to drill hole in diamond and repair flaw.

v) In surveying as a reference beam.

Medical applications:

i) Dentists use lasers for removal of caries. Tooth whitening and oral surgeries like root-cannel can be carried out with the help of laser treatment.

ii) Dermatologists use laser beam to remove birth marks, freckles, acne and tattoo.

iii) Laser angioplasty is used for removal of artery block and to maintain regular blood flow without bypass surgery.

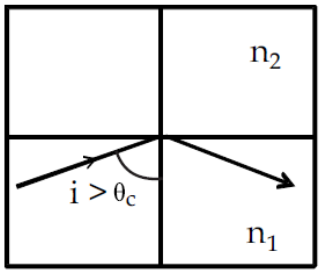
iv) Lasers are used in cancer diagnosis and its therapy. They are also used in destroying kidney stones.

v) Ophthalmologists use it in treatment of detached retina and lasik surgery

Q. What is total internal reflection? Explain how this phenomenon is used to guide light in an optical fiber

Ans.

Total internal reflection: "If light ray is incident on rarer medium (low R.I.) from denser medium (high R.I) at particular angle 'critical angle' or greater than critical angle, it will be totally reflected at the surface and it is known as total internal reflection."



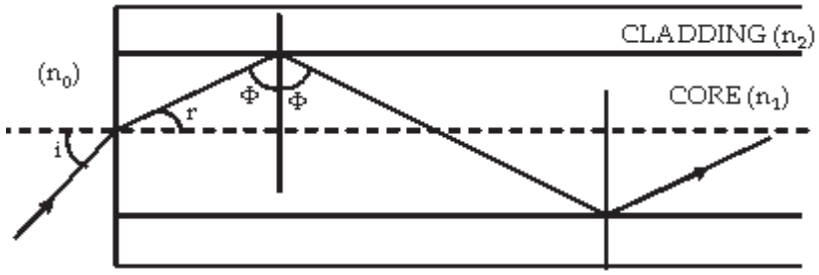
For particular angle, $i = \theta c$, $r = 90^0$

$n_1 \sin \theta c = n_2 \sin 90^0$

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

Principle used in optical fibre: Multiple total internal reflection.

Fibre consists of central core surrounded by cladding. Refractive index of core is greater than that of cladding. If the ray is incident at the aperture of optical fibre at angle less than acceptance angle, it undergoes total internal reflection at core – cladding interface and propagates through fibre along a zig – zag path as shown in fig.

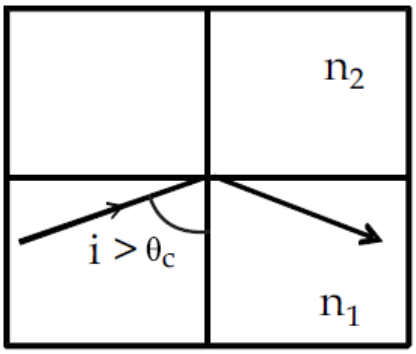


Acceptance angle $\sin i_m = \sqrt{n_1^2 - n_2^2}$

Q. Explain the principle and construction of optical fibre.

Ans.

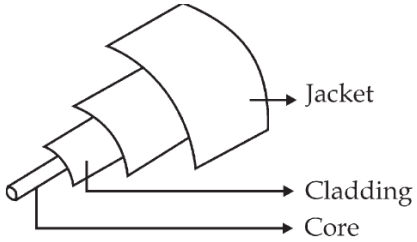
Principle of optical fibre is total internal reflection. "If light ray is incident on rarer medium (low R.I.) from denser medium (high R.I) at particular angle 'critical angle' or greater than critical angle, it will be totally reflected at the surface and it is known as total internal reflection."



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

Construction of optical fibre :

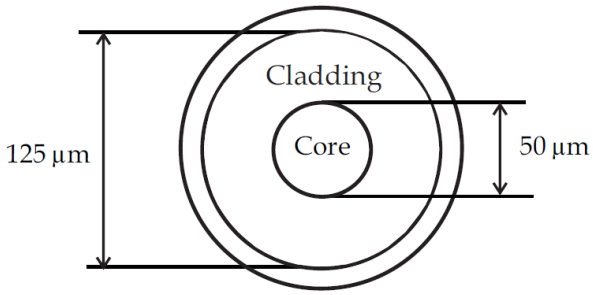
1) Optical fibre is a very thin flexible thread of transparent plastic or glass through which light is transmitted by multiple total internal reflection.



2) It consists of central cylinder - core - surrounded by a layer of material called cladding which is in turn surrounded by jacket. The refractive index of cladding is less than that of core and it keeps the light waves within the core and jacket protects the fibre from moisture and abrasion.

3) The core and cladding are made of either glass or plastic. Based on the material, there are three types - 1) Plastic core with plastic cladding, 2) Glass core with plastic cladding, 3) Glass core with glass cladding.

4) Length of optical fibre is generally 1 km and can be suitably connected. Its outer diameter is 0.1 to 0.15 mm. Core diameter is 5 to 100 μm and cladding diameter is 125 μm.



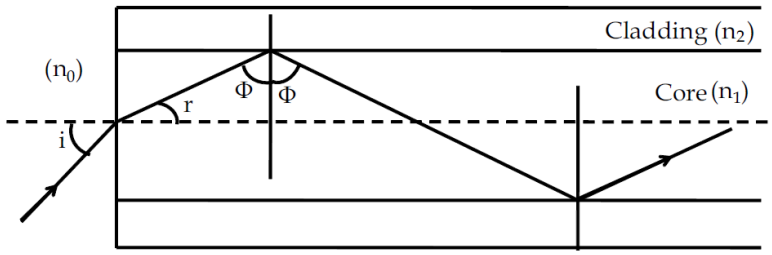
5) Ordinary glass is brittle in nature, but the optical fibres are tough and have high tensile strength. Optical fibres are as strong as steel wire, yet they can be bent unlike steel wires.

Q. Define the terms acceptance angle and Numerical Aperture. Obtain equation for the same.

Ans. Acceptance angle: It is the maximum angle made by the incident ray with the axis of optical fibre and propagates down the fibre by total internal reflection.

Numerical aperture: It is sine of acceptance angle. It gives light gathering capacity of fibre.

Consider a ray incident on the entrance aperture of the fibre (as shown in fig below) making angle i with the axis of fibre. Let r be the angle of refraction at the aperture.



n_0 - R.I. of outer medium

n_1 - R.I. of core

n_2 - R.I. of cladding ($n_1 > n_2$)

$$N.A. = \sin i_m = (n_1^2 - n_2^2)^{1/2}$$

Q. Define fractional refractive index change and derive relation between fractional refractive index change and numerical aperture.

Ans. Fractional refractive index change is the fractional difference between the refractive indices of the core and cladding. It is also called as relative index difference. It is expressed as,

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

For effective transmission of light through fibre $\Delta \ll 1$

$$N.A. = \left(n_1^2 - n_2^2\right)^{1/2}$$

$$= \left[(n_1 + n_2)(n_1 - n_2)\right]^{1/2}$$

$$= \left[n_1 \frac{(n_1 + n_2)(n_1 - n_2)}{n_1}\right]^{1/2} \quad \because n_1 \approx n_2 \,,\, (n_1 + n_2) = 2n_1$$

$$\therefore \quad N.A. = \left[2n_1^2 \frac{(n_1 - n_2)}{n_1}\right]^{1/2}$$

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

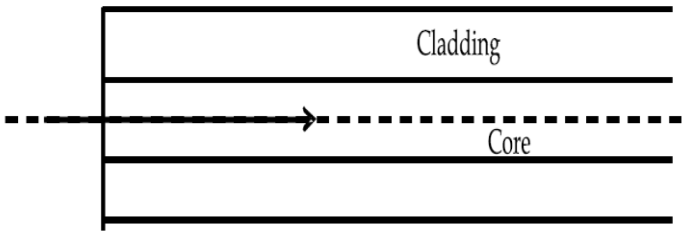
Q. Explain the classification of optical fiber.

Ans. Optical fibres are classified on the basis of different parameters.

A) On the basis of modes of propagation:

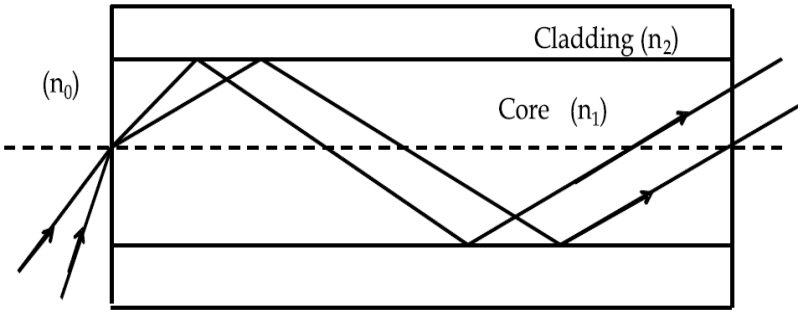
1. Single mode fibre or monomode fibre :

It has very thin core (8 μm to 12 μm). Light travels along a single path along axis as shown in fig. below.



2. Multimode fibre :

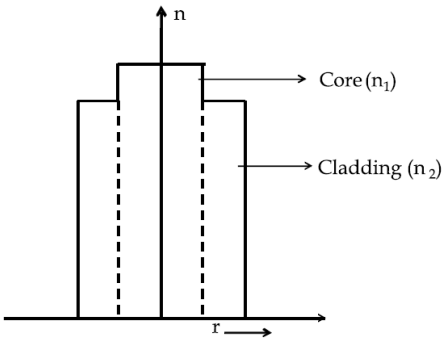
Core is of larger diameter (50 mm to 100 mm). In this fibre, number of zigzag paths are possible.



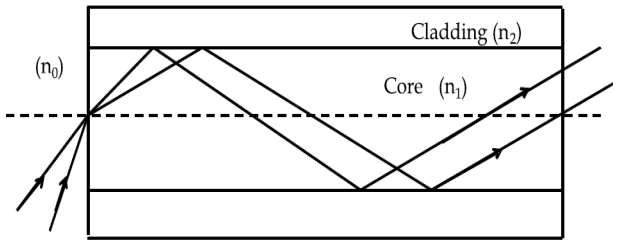
Axial rays have shorter path length while other zigzag paths are longer, hence time of transit for all the waves is not same and it causes signal distortion

B) On the basis of refractive index profile :

1. Step index optical fibre : In step-index fibre the core has uniform refractive index n_1 and cladding has uniform refractive index n_2. Refractive index profile abruptly changes at the core cladding interface. It can be single mode or multimode fibre.



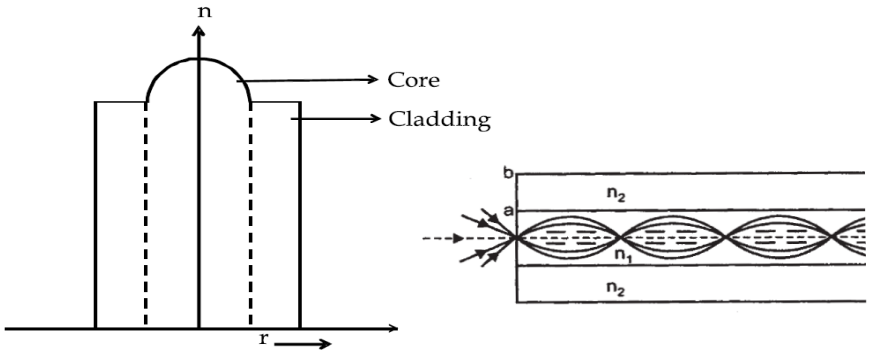
R.I.profile



Propagation of light

2. Graded index (GRIN) fibre :

In GRIN fibre, refractive index of core gradually changes. It is maximum along the axis and gradually decreases towards cladding interface and cladding has uniform refractive index. It can be only multimode.



Due to continuous refraction, rays are periodically focused as shown in figure and time of transit for all the rays is same.

Q. State different advantages of optical fibre.

Ans. 1. Optical fibres are made from silica glass which is easily available. It is cheaper.

2. It is small in size and light in weight, flexible and mechanically strong. Its weight is 6 kg/km and diameter few mm. Hence it is easy to transport and install.

3. It is not hazardous. Because of insulating nature, accidents like short circuit, sparking do not occur. Additional circuit to protect against grounding is not necessary.

4. Immune to EMI and RFI - Information is carried by photons which are not affected by high voltage field, lightening etc. Hence fibres are immune to background noise generation through electromagnetic interference (EMI) and radio frequency interference (RFI).

5. Lack of cross talk- Light waves are completely trapped within the fibre and can not leak out and couple into neighbouring fibre, thus reducing the possibility of cross talk. Thus it offers high degree of security and privacy.

6. Extremely wide band width – The rate of transmission of information is directly proportional to frequency of signal. Light has a frequency in the range of 10^{14}-10^{15} Hz, while radio wave frequency is 10^6 Hz and microwave frequency is 10^8-10^{10} Hz. Hence information carrying capacity of optical fibre using light is extremely high.

7. Low loss per unit length- Transmission loss per unit length is only 4 dB/km.

8. It is not affected by moisture or corrosion and can be used for underground cable.

9. It can withstand at high temperature.

10. It has longer life span about 20-30 years while copper cables can live for 12-15 years.

Q. Give applications of optical fibre.

Ans. 1. Military applications :

- Conventional copper cables are heavy in weight and are to be transported by an aircraft, a ship or a tank. However optical fibres are light in weight, small in size and easy to transport and handle. It offers high degree of security and privacy and hence used in military communication.
- Fibre guided missiles are in use. Sensors are mounted on the missile which transmit video information through fibre to a ground control van and receive commands from van.

2. Medical applications :

- For diagnostic purpose, an endoscopy is used to study internal body organs. It consists of bundle of fibres that carries light to body organ and transfer an image of internal part of organ to the screen.
- It is used in treatment of detached retina and correct defects in vision.
- Cardiology : Laser angioplasty is expected to put end to balloon angioplasty and bypass surgery. A special catheter is developed that consists of three channels- 1) To visualize the various veins, 2) To supply power for laser, 3) An open tube to remove blocks in veins.
- In laparoscopic surgery
- for the diagnosis of carious lesions

3. Entertainment application :

Optical fibre bundle is used to enlarge the image displayed on T.V. screen.

4. In communication :

Optical fibre communication system consists of three major parts -

1. Transmitter - Transforms electric signal into optical signal.
2. Information channel- It is optical fibre that carries the signal from transmitter to receiver.
3. Receiver- Converts the optical signal into the electric signal.

It is used in military and civilian communication system.

5. Optical fibre as sensor:

Refractive index of fibre can be changed under influence of external force, it makes optical fibre to use it as a sensor. It can be used as a temperature sensor, pollution, smoke, liquid level detector etc.

Numerical problems

1) Refractive index of core is 1.5 and fractional index change is 0.03. Find refractive index of cladding and numerical aperture. (1.45, 0.38)

2) The numerical aperture of optical fibre is 0.24 and refractive index of core is 1.58. Find the refractive index of cladding. (1.56)

3) The light gathering capacity of fibre is 0.479. If relative core – cladding index difference is 0.05, calculate refractive index of the cladding. (1.42)

4) The refractive index of core is 1.5 and relative index difference is 0.003. Calculate acceptance angle. (6039')

5) The acceptance angle of optical fibre is 17.50. Find the angle of incidence at core – cladding interface, if the ray is incident at 17.50 at the aperture. n1 = 1.5, n2 = 1.49.

(83021')

6) A catheter is required for operation of tumor of 40μm diameter. Laser is to be incident from 100 μm distance. What should be refractive index of cladding, if R.I. of core is 1.45?

(1.43)