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Introduction to Fiber optics

Since ancient times, man has needed to communicate with others. Prehistoric man made sounds by beating hollow logs with heavy sticks to commuicate messages to others. Reed pipes were also used for the same purpose as hallow logs and drums beaten with sticks.

Smoke signals were also used for the communication purposes.

The first optical signals, have been used whenever civilization has spring up. Man used flashes of reflected sunlight by day and lanterns by night. In the earliest civilizations various combinations of torches on high mountain peaks were used to communicate rapidly over considerable distances. Coded messages to other ships are still transmitted by using powerful blinker lights by Navy signal men during the periods of radio silence.

In early days, Shutter was used to control white light but this method was not adequate for communication. The discovery of Laser solved this problem. Laser is very intense and coherent beam of light. Now the problem arises how this light is transmitted to others? A wave guide was used to transmitt light from one place to the others so that light signal do not effect by rain, fog and clouds etc.

In 1966, Charles H. Kao and George A. Hochman gave an idea that glass fibre can be used for the transmission of light signals. Earlier there were some minor problems but they were solved successfully. Ultimately, a fibre was formed by which thousands of signals were transmitted simultaneously with an extremely high speed from one part of the world to the other. Such glass fibre is known as optical fibre.

Optical fibre principle

Propagation of light in an optical fibre requires that the light should be totally confined within the fibre. This can be achieved by two different ways.

(i)- Total internal reflection.

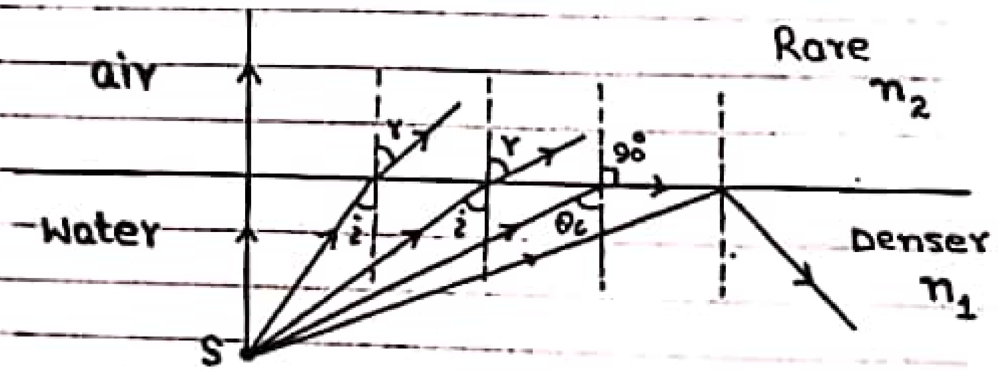
(ii)- Continuous refraction.

(i)- Total internal reflection:

Media through which light can pass are called optical media. Air is the most effective optical medium through which speed of light has the greatest value. An optical medium in which speed of light is less than that in air is called optical denser medium. Familiar examples are glass, water, thin oil or soap film etc. Speed of light in an optical denser medium depends on the refractive index of the medium. Refractive index is the ratio of the speed of light in free space to that in a given medium i.e.

$$n = \frac{c}{v}$$

Its value is nearly equal to unity for air but is greater than unity for all other optical media.



When light enters from a denser medium to a rare medium, then it bends away from the normal. In this case, the angle of refraction is always greater than angle of incidence. If we increase the angle of incidence, the corresponding angle of refraction also increases. For a particular value of angle of incidence, the corresponding angle of refraction becomes 90°. So the angle of incidence for which the angle of refraction is 90° is called critical angle. It is denoted by 'θ_c'.

According to Snell's law,

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

When $\theta_1 = \theta_c$ then $\theta_2 = 90^\circ$

So $n_1 \sin\theta_c = n_2 \sin 90^\circ$

$$n_1 \sin\theta_c = n_2 \cdot 1$$

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

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

For glass-air boundary, we have,

$$\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right)$$

$$\theta_c = \sin^{-1}(0.67)$$

$$\theta_c = 41.8^\circ$$

When in a denser medium the angle of incidence becomes greater than critical angle, then light did not refract but reflection take place from the boundary of two media as shown in above fig. Such a phenomenon is known as <u>total internal reflection</u>. For this phenomenon, following conditions must be fulfilled.

1- Light should travel from a denser to rare medium.

2- Angle of incidence should be greater than the critical angle.

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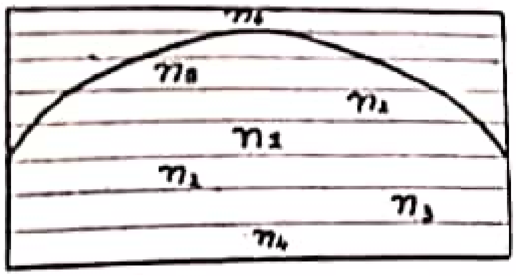
(ii)- Continuous Refraction:

There is another method for the propagation of light in optical fibres in which light is continuously refracted within the fibre.

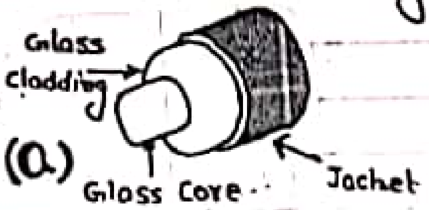


A core has high refractive index than cladding, so when a light ray passes from a denser medium to the rare, it is continuously refracted and is reflected from the outer layer as shown in fig. Hence light is transmitted by continuous refraction and total internal reflection.

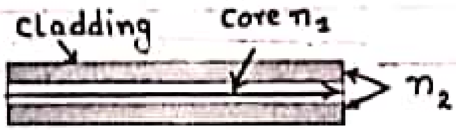
Structure of optical Fibre

In optical fibre, information is transmitted in the form of light. optical fibre consists of two parts which are,

(i)- Core
(ii)- Cladding



(a)



(b)

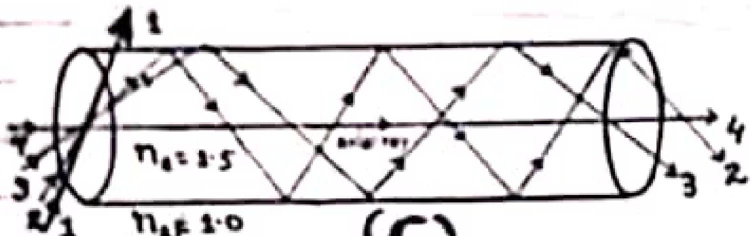
The central portion of the optical fibre is called Core. Core is wrapped by cladding. Both are made of silica SiO_2. The refractive index of the core is slightly greater than that of cladding. The basic parts of optical fibre are shown in fig(a)&(b). Core and cladding is covered by a jacket. The diameter of the core usually ranges from ~~10~~ 5 μm to 50 μm.

The refractive index of the core is increased by the dopping of Germanium.

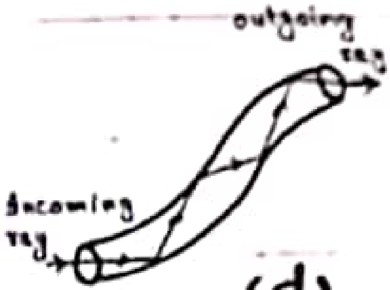
The cladding is made of pure silica as it has low refractive index. However the refractive index can be minimized by the dopping of Boron.

Propagation of Light:

In case of a long round glass rod all the light rays striking its internal surface at angles greater than 41.8° (critical angle). will be reflected back in to the glass, while those with angles less than 41.8° will escape from the glass as shown in fig(c).



(C)



(d)

In fig(c) ray 1 strikes the glass-air boundary at an angle of 30° less than the critical angle and hence it escapes from the rod and is lost. However, ray 2 striking the glass-air boundary at an angle of 42° greater than critical angle, will be reflected back in to the rod. The same is the case with ray 3. Since the angle of reflection equals the angle of incidence, these two rays will continue propagating down the rod along the path determined by the original angles of incidence. Ray 4 is called an axial ray as it moves parallel to the axis of the rod if it is straight rigid rod.

However, in a flexible glass fibre as in fig(d), the ray will be subjected to the laws of reflection.

N.B.

Optical fibres which cause propagation of light through total internal reflection are most commonly used.

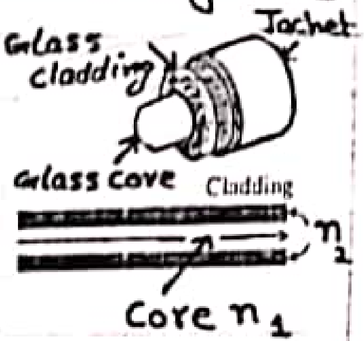
Types of Optical Fibre

On the basis of propagation of light, the optical fibre is classified into three types

1- Single mode step index fibre.
2- Multi-mode step index fibre.
3- Multi-mode graded index fibre.

1- Single Mode step index Fibre:

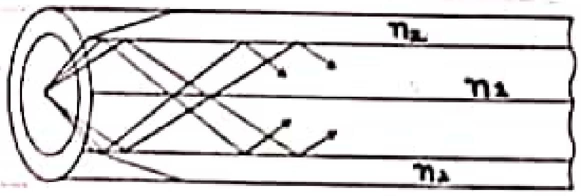
Single mode or mono mode step index has a very thin core of 5 µm and has a relatively larger cladding (of glass or plastic) as shown in fig. The refractive indices of core and cladding are constant.



As it has a thin core, therefore a strong mono-chromatic light source (Laser source) has to be used for sending light signals through it. It can carry more than 14 TV channels or 14000 phone calls.

2- Multi-Mode step index Fibre:

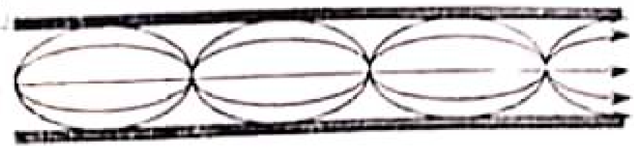
It has core of relatively Larger diameter such as 50 µm and it has smaller cladding.



It is mostly used for carrying white light but due to dispersion effect it is useful for a short distance only. The fibre core has a constant refractive index n_1 such as 1.52 from its centre to the boundary with the cladding as shown in fig. The refractive index then decreases from $n_1 = 1.52$ to $n_2 = 1.48$ which remains constant throughout the thickness of the cladding. It is called step index multimode fibre as the refractive index step down from 1.52 to 1.48 at the boundary with the cladding.

3- Multi-Mode Graded index Fibre:

The diameter of the core of such fibre ranges from 50 µm to 1000 µm. It has a core of relatively high refractive index which gradually decreases from the middle to the outer surface of the fibre. There is no clear-cut boundary between core and cladding. This type of fibre is called the multimode graded index fibre as shown in fig.



It is very useful for long distance and white light is used to carry the signal. The mode of transmission through this type of fibre is due to continuous refraction from the surfaces of uniformly decreasing index of refraction and total internal reflection from the boundary of the outer surface.

Signal Transmission And Conversion to Sound

The optical fibre communication system has three major components, namely:

1- Transmitter.
2- optical fibre.
3- Receiver.

The transmitter converts electrical signals into light signals. These light signals are transmitted through an optical fibre. The receiver at the other end of the fibre captures the light signals and reconverts them into electrical signals.

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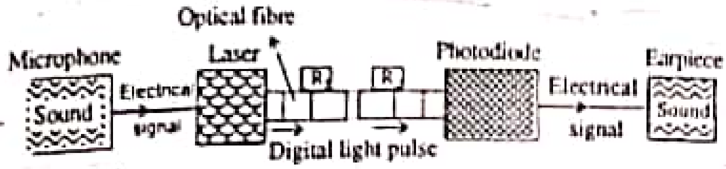


A semiconductor Laser or LED (light emitting diode) can be used as a light source in the transmitter which emits an invisible infra-red signals of typical wave length 1.3 um. The infra-red light travels faster than visible or ultra-violet light. The Lasers and LEDs used are tiny units of size less than half the size of thumb nail to match the size of the fibres.

In order to transmit information by light waves, whether it is an audio signal, a television signal or a computer data signal, it is necessary to modulate the light waves. The most common method of modulation is called digital modulation in which the Laser or LED is flashed on and off at an extremely fast rate. A pulse of light represents the number '1' and the absence of Light represents zero. So instead of flashes of light travelling in optical fibres, ones (1s) and zeros (0s) are travelling down the fibre. With computer type equipment, any communication can be represented by the code of these 1s and 0s.

The receiver is programmed to decode the 1s and 0s, it receives into sound, pictures or data as required. Digital modulation is expressed in bits (binary digit) or megabits (10^6 bits) per second, where a bit is a 1 or a 0.

In spite of the ultra-purity (99.99% glass) of the optical fibre, the light signals becomes dim and they are regenerated by repeaters (amplifiers). Repeaters are typically placed about 30 km apart, but in the newer system they may be separated about 100 km. At the end of the fibre, a photodiode converts the light signals into electrical signals. which are then amplified and decoded, if necessary to reconstruct the signals originally transmitted.

Losses of Power

The power in optical fibre is losses due to the following reasons, which are,

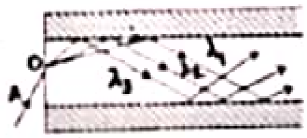
1- By absorption and Scattering:

When a light signal travels along the fibres by multiple reflections, some light is absorbed due to impurities in the glass. Some of it is scattered by groups of atoms which are formed at places such as joints when fibres are joined together. Careful manufacturing can reduce the power loss by scattering and absorption.

2- By Dispersion or spreading:

Dispersion or spreading of light signals make the information received at the other end of a fibre inaccurate and faulty.

If the light signals are not purely monochromatic, a narrow band of wavelengths are refracted in different directions when the light signals enters the glass fibre and the light spread. As a result different wavelengths present in the light signals have different paths and when reach the other end of the fibre at different time and we get faulty or distorted signals as shown in fig. This is the disadvantage of step-index fibre.



Removel of this defect:

Graded index fibre has removed this defect to greater extent as shown in Fig (b). In this case, the different wavelengths still follow different paths and suffer total internal reflection at different Layers. However, they are focused at the same points like 'x' and 'y' etc. as shown in fig. It is possible because the speed of light varies inversly with the index of refraction. Therefore, the wavelength 'λ_1' travels a longer path than 'λ_2' or λ_3 but at a greater speed. Inspite of the different dispersion, all the wavelengths arrive at the other end of the fibre at the same time.

In step-index fibre the overall time difference is about 33 ns per Km length of the path. However, in a graded-index fibre this time difference is reduced to about 1 ns per Km of path length.

Advantages of optical Fibre

A device known as "photophone" invented by Graham Bell just four years after the invention of the telephone. Bell was able to transmit a voice message via a beam of light. The transmission of light through thin optical fibres is now being used in communication technology. The use of light as a transmission carrier wave in fibre optics has several advantages over radio wave carries.

1- High Bandwidth:

The information carrying capacity of a carries wave increases with carrier frequency. In optical fibre transmission the carrier is light which has several orders of magnitude greater than the highest radio frequencies. Optical fibre can have bandwidth of several GHz Km allowing very high transfer of data. Several signals can be transmitted through one fibre. For example, a single fibre has the transmission capacity of 900 pair copper cable.

2. Low Loss:

Optical fibre suffer less loss than copper wires. It is due to the fact that the loss in optical fibre is independent of frequency whereas copper cables exhibit high losses as frequency increases.

3. Immunity to interference:

optical fibres are fabricated from a dielectric material (glass) and are therefore free from electromagnetic pulses arising from switching transients. Thus a fibre cable does not produce any noisy environment.

4. Cross-talk:

Being non inductive there is no induction of signal into or from other circuits so that possibilities of crosstalk is virtually eliminated.

5. Small size and light weight:

optical fibres have diameters of the same order as a human hair, so ever when covered with necessary protective coatings they are far smaller and lighter than copper cable.

6. Abundance of raw material:

The manufacturing material of optical fibre is silica, which is naturally available in sea sand, roches in form of different chemical compositions of silica of different materials.

7- Temperature/loss characteristics:

The properties of conductors changes with temperature variations. The optical fibre is made of glass (silica) which has a melting point above 1000 C°. So at normal temp the fibre transmission properties does not change therefore no additional measures are required in this regard.

Disadvantages of Optical Fibre

The disadvantages of optical fibre are as follows.

1- Cost:

Although the raw material of optical fibre is enough but the manufacture of optical fibre is extremely difficult and involves complete setup for heat and chemical treatment of SiO_2 to reach the desired purity required to produce optical fibre.

2- Mechanical problems:

Since optical fibre is fragile, it needs extra care in handling, special cabling and protection against contamination and high degree of precision for splicing.

3- Hazards with Lasers:

Laser is transmitted through optical fibres. These radiations are extremely dangerous. Their exposure to eyes or skin can cause irreparable damage. Safety precautions must be follow while working with optical fibre system.

Promise is a snowball, was to make but hard to keep.

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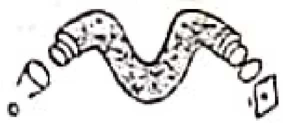
Applications of optical fibre

(i)- Fibre optics is used to transmit light around corners and into inaccessible places. Fiber optic tools are commonly used in industory and in medical science for diagnostic purposes especially in endoscopy to get the optical fibre image of the stomach interior as shown in fig.



(ii)- Fibre optics technology has given a communication system of enormous capab-ilities. This system has the ability to transmit thousands of telephone conversations, several television programmes and numerous data signals between stations through one or two flexible hair thin threads of optical fibre.

(iii)- The tremendous information carrying capacity called band width of the optic fibre system has made practically possible the two way television services which was too costly before the development of fibre optics. These systems also allow word processing, image transmitting and receiving equipment to operate efficiently.

(iv)- The light from optical fibres does not radiate significantly and therefore they provide a high degree of signal security. This feature is obviously attractive for military, banking and general data transmission appl-ications.

A teacher affects eternity; he can never tell where his influence stop.