UNIT – II WAVES AND OPTICS

TOPIC – VII TYPES AND LOSSES IN AN OPTICAL FIBER

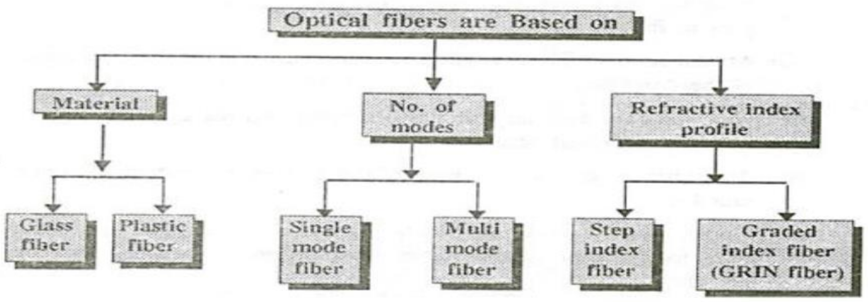
5.18 TYPES OF OPTICAL FIBERS

Optical fibers are classified into three major categories

i. The type of material used

ii. The number of modes

iii. The refractive index profile



5.19 GLASS AND PLASTIC FIBERS

Based on the type of the material used, they are classified into two types.

Glass fibers:

The glass fibres are made up of mixture of metal metal oxides and silica glasses.

Example: The glass fibres are made by the following combinations of core and cladding.

Core: SiO_2, Cladding: SiO_2

Core: GeO_2- SiO_2, Cladding: SiO_2

Plastic fibers:

The fibers which are made up of plastics can be handled without any care due to its toughness and durability is called plastic fiber.

Example: The plastic fibres are made by the following combinations of core and cladding.

Core: polymethyl methacrylate , Cladding: Co- Polymer

Core: Polystyrene, Cladding: Methyl methacrylate

5.20 SINGLE AND MULTIMODE FIBER

Light propagates as electromagnetic waves through an optical fiber. Based on the modes of propagation the fibers are classified into two types.

1. Single mode fiber
2. Multimode fiber

1. Single mode fiber

In general, the single mode fibers are step – index fibers. These types of fibers are made from doped silica.

It has a very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.

The cladding diameter must be very large compared to the core diameter. Thus in the case of single mode fiber, the optical loss is very much reduced. The structure of a single mode fiber as shown in figure 5.26.

Structure

Core diameter : 5-10μm

Cladding diameter : Around 125μm

Protective layer : 250 to 1000μm

Numerical aperture : 0.08 to 0.10

Band width : More than 50MHz km.

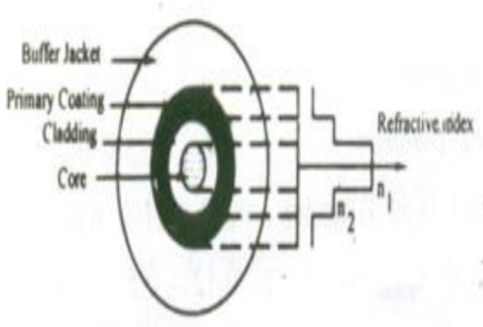


Fig.5.26

Application:

Because of high bandwidth, they are used in long haul communication systems.

2. Multimode fiber

The multi modes fibers are useful in manufacturing both for step – index and graded index fibers. The multi-mode fibers are made by multi-component glass compounds such as Glass – Clad Glass, Silica – Clad – Silica, doped silica etc. Here the core diameter is very large compared to single mode fibers, so that it can allow many modes to propagate through it and hence called as Multi mode fibers. The cladding diameter is also larger than the diameter of the single mode fibers. The structure of the multimode fiber is as shown in the figure 5.27.

Structure

Core diameter : 50-350μm

Cladding diameter : 125μm - 500μm

Protective layer : 250 to 1100μm

Numerical aperture : 0.12 to 0.5

Band width : Less than 50MHz km.

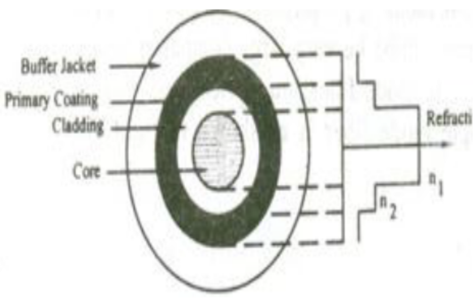


Fig.5.27

Application:

Because of its less band width it is very useful in short haul communication systems.

5.21 DIFFERENCE BETWEEN SINGLE AND MULTIMODE FIBER

S. No.	SINGLE MODE FIBER	MULTI MODE FIBER
1.	In single mode fiber only one mode can propagate through the fiber	In multimode it allows a large number of paths or modes for the light rays travelling through it.
2.	It has smaller core diameter and the difference between the refractive index of the core and cladding is very small.	It has larger core diameter and refractive index difference is larger than the single mode fiber.
3.	**Advantages:** No dispersion(i.e. there is no degradation of signal during propagation)	**Disadvantages:** Dispersion is more due to degradation of signal owing to multimode.
4.	The fiber can carry information to longer distances.	Information can be carried to shorter distances only.
5.	**Disadvantages:** Launching of light and connecting of two fibers difficult.	**Advantages:** Launching of light and also connecting of two fibers is easy.
6.	Installation (fabrication) is difficult as it is more costly	Fabrication is easy and the installation cost is low.

5.22 STEP INDEX AND GRADED INDEX FIBERS

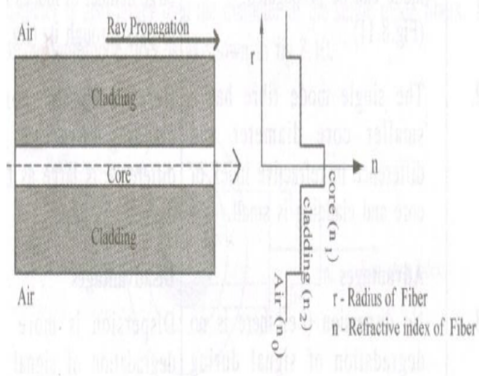
Based on the variation in the refractive index of the core and the cladding, the fibers are classified into two types

i. Step index fiber

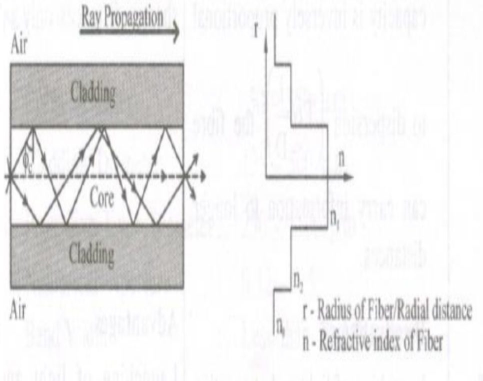
ii. Graded index fiber

Step index fiber

The refractive indices of air, cladding and core vary by step by step and hence it is called as step index fiber. In step index fiber we have both single mode and multimode fibers as shown in figure 5.28.



Single mode step index fiber



Multi mode step index fiber

Graded index fiber

The refractive index of the core varies radially from the axis of the fiber. The refractive index of the core is maximum along the fiber axis and it gradually decreases. Thus it is called as graded index fiber. Here the refractive index becomes minimum at the core-cladding interface. In general the graded index fibers will be of multi mode system. The multi mode graded index fiber has very less intermodal dispersion compared to multi mode step index fiber. A typical multi mode graded index fiber is as shown in figure 5.29.

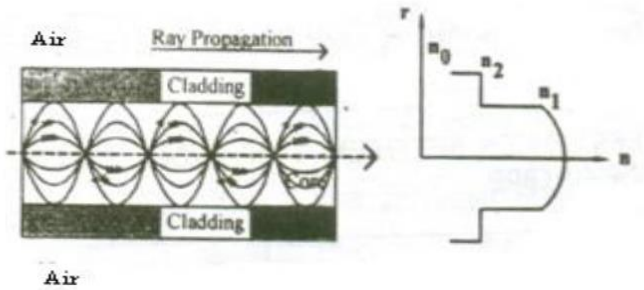


Fig. 5.29

Propagation of light in GRIN fiber

Let n_a, n_b,n_c,n_d etc be the refractive index of different layers in graded index fiber with $n_a > n_b > n_c > n_d$ etc. then the propagation of light through the graded index fiber is as shown in the figure 5.30.

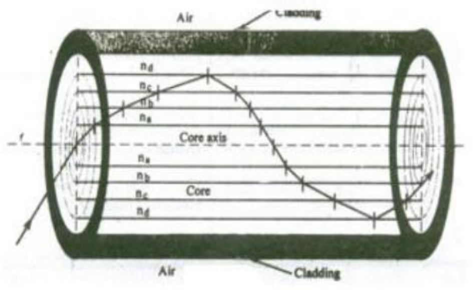


Fig.5.30

Here, since $n_a > n_b$ the ray gets refracted. Similarly since $n_b > n_c$, the ray gets refracted and so on. In a similar manner, due to decrease in refractive index the ray gets gradually curved towards the upward direction and at one place, where in it satisfies the condition for total internal reflection,($\phi > \phi_c$) it is totally internally reflected. The reflected rays travels back towards the core axis and without crossing the fiber axis, it is refracted towards downwards direction and again gets totally internally reflected and passes towards upward direction. In this manner the ray propagates inside the fiber in a helical or spiral manner.

5.23 DIFFERENCE BETWEEN STEP INDEX FIBER & GRADED INDEX FIBER

S. No.	STEP INDEX FIBER	GRADED INDEX (GRIN) FIBER
1.	The difference is refractive indices is obtained in single step and hence called as step-index fiber.	Due to non-uniform refractive indices, the difference in refraction index is obtained gradually from centre towards interface and hence called graded index fiber.
2.	The light ray propagation is in the form of meridional rays and it passes through the fiber axis.	The light ray propagation is in the form of skew rays and it will not cross the fiber axis.
3.	The path of light propagation is in zig-zig manner.	The path of light is **helical** in manner
4.	This fiber has **lower bandwidth**	This fiber has **higher bandwidth**
5.	**Attenuation is more** for multimode step index fiber but for single mode it is very less. Explanation: When a ray travels through the longer distances there will be some difference in reflected angles. Hence high angle rays arrive later than low angle rays causing dispersion resulting in distorted output.	**Attenuation is less.** Explanation: Here the light rays travel with different velocity inn different paths because of their variation in their refractive indices. At the outer edge it travels faster than near the center. But almost all the rays reach the exit at the same time due to helical path. Thus, there is no dispersion.
6.	**No of modes of Propagation** $N_{step} = 4.9\left(\frac{d\,x\,NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Where d= diameter of the fiber core λ= wavelength NA = Numerical Aperture V- V-number is less than or equal to 2.405 for single mode fibers & greater than 2.405 for multimode fibers.	**No of modes of Propagation** $N_{step} = 4.9\left(\frac{d\,x\,NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Or $N_{graded} = \frac{N_{step}}{2}$

5.24 LOSSES IN OPTICAL FIBERS- ATTENUATION

When light propagates through an optical fiber, a small percentage of light is lost through different mechanisms. The loss of optical power is measured in terms of decibels per kilometer for attenuation losses.

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})

ie. Attenuation (α) = $\frac{-10}{L}\log\frac{P_{in}}{P_{out}}$ dB/km

Since attenuation plays a major role in determining the transmission distance, the following attenuation mechanisms are to be considered in designing an optical fiber.

(1) Absorption

(2) Scattering

(3) Radiative losses.

1. Absorption

Usually absorption of light occurs due to imperfections of the atomic structure such as missing molecules, (OH^-) hydroxyl ions, high density cluster of atoms etc., which absorbs light. Absorption also depends on the wavelength of the light used. The three bands of wavelength at which the absorption increases drastically is 950 nm, 1250 nm and 1380 nm. For example, at the wavelength say 850 nm the absorption is 1.5 dB/Km and for 1500 nm, it is 0.5 dB/Km.

2. Scattering

Scattering is also a wavelength dependent loss, which occurs inside the fibers. Since the glass is used in fabrication of fibers, the disordered structure of glass will make some variations in the refractive index inside the fiber. As a result, if is passed through the atoms in the fiber, a portion of the light is scattered (elastic scattering). This type of scattering is called Rayleigh scattering. i.e., Rayleigh scattering loss $\alpha \frac{1}{\lambda^4}$

3. Radiative losses

Radiative loss occurs in fibers, due to bending of finite radius ofc curvature in optical fibers. The types of bends are

(a) Macroscopic bend and

(b) Microscopic bend

(a) Macroscopic bends

If the radius of core is large compared to fiber diameter as shown in fig 5.31. it may cause large-curvature at the position where the fiber cable turns at the corner. At these corners the light will not satisfy the condition for total internal reflection and hence it escapes out from the fiber. This is called as macroscopic/macro bending losses. Also note that this loss is negligible for small bends.

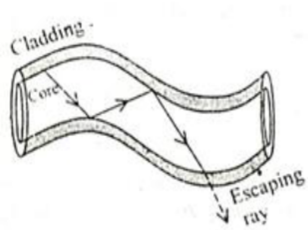


Fig.5.31

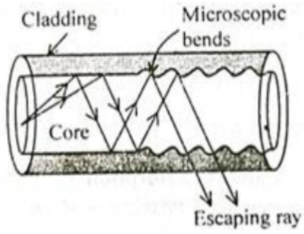


Fig. 5.32

(b) Microscopic bends

Micro-bends losses are caused due to non-uniformities (or) micro-bends inside the fiber as shown in fig 5.32. This micro bends in fiber appears due to non uniform pressures created during the cabling of the fiber (or) even during the manufacturing itself. This lead to loss of light by leakage through the fiber.

Remedy

Micro-bend losses can be minimized by extruding (squeezing out)a compressible jacket over the fiber. In such cases even when the external forces are applied, the jacket will be deformed but the fiber will tend to stay relatively straight and safe, without causing more loss.