



# **18PYB101J    MODULE-5    LECTURE 14**

- Types of optical fibre
- Optical fibre based on mode types
- Losses in Fiber optics



## Types of optical fibers

Optical fibers are classified based on

- Material
- Number of modes
- Refractive index profile



## Optical fibers based on material

Optical fibers are made up of materials like silica and plastic. The basic optical fiber material must have the following properties:

- (i) Efficient guide for the light waves
- (ii) Low scattering losses
- (iii) The absorption, attenuation and dispersion of optical energy must be low.

Based on the material used for fabrication, they are classified into two types:

- Glass fibers and
- Plastic fibers



## *Glass fibers*

- The glass fibers are generally fabricated by fusing mixtures of **metal oxides and silica glasses**.
- Silica has a refractive index of **1.458 at 850 nm**. To produce two similar materials having slightly different indices of refraction for the core and cladding, either **fluorine** or various oxides such as  $B_2O_3$ ,  $GeO_2$  or  $P_2O_3$  are added to silica.
- **Examples:**
  - $SiO_2$  core;  $P_2O_3 - SiO_2$  cladding
  - $GeO_2 - SiO_2$  core;  $SiO_2$  cladding
  - $P_2O_5 - SiO_2$  core;  $SiO_2$  cladding



## *Plastic fibers*

- The plastic fibers are typically made of plastics and are of low cost.
- Although they exhibit considerably greater signal attenuation than glass fibers, the plastic fibers can be handled without special care due to its toughness and durability.
- Due to its high refractive index differences between the core and cladding materials, plastic fibers yield high numerical aperture and large angle of acceptance.



## Examples:

- A polymethyl methacrylate core ( $n_1 = 1.59$ ) and a cladding made of its co-polymer ( $n_2 = 1.40$ ).
  - A polystyrene core ( $n_1 = 1.60$ ) and a methylmethacrylate cladding ( $n_2 = 1.49$ ).



## *Optical fibers based on modes or mode types*

- Mode is the one which describes the nature of propagation of electromagnetic waves in a wave guide.
- i.e. it is the allowed direction whose associated angles satisfy the conditions for total internal reflection and constructive interference.
- Based on the number of modes that propagates through the optical fiber, they are classified as:
  - Single mode fibers
  - Multi mode fibers



## ***Single mode fibers***

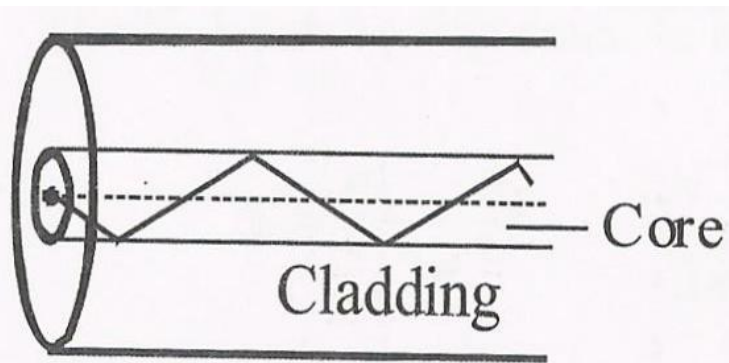
- In a fiber, if only one mode is transmitted through it, then it is said to be a single mode fiber.
- A typical single mode fiber may have a core radius of 3  $\mu\text{m}$  and a numerical aperture of 0.1 at a wavelength of 0.8  $\mu\text{m}$ .
- The condition for the single mode operation is given by the V number of the fiber which is defined as  $V \leq 2.405$  such that
$$V = \frac{2\pi n_1 a (\sqrt{2\Delta})}{\lambda}$$
- Here,  $n_1$  = refractive index of the core;  $a$  = radius of the core;  $\lambda$  = wavelength of the light propagating through the fiber;  $\Delta$  = relative refractive indices difference.



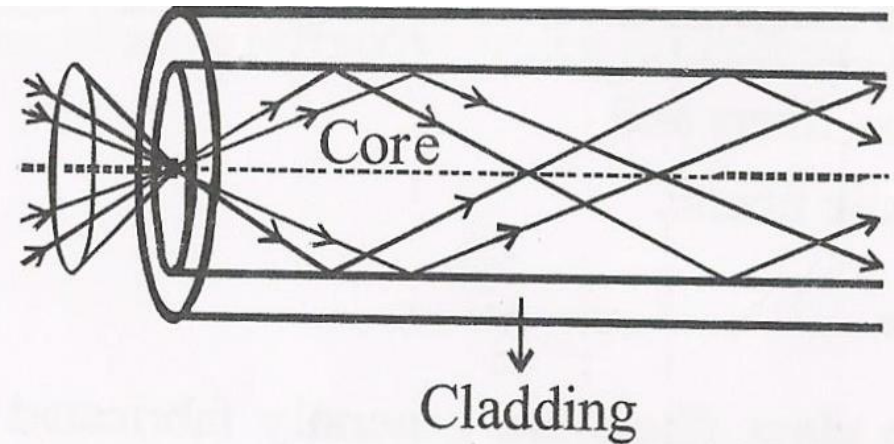


The single mode fiber has the following characteristics:

- Only one path is available.
- V-number is less than 2.405
- Core diameter is small
- No dispersion
- Higher band width (1000 MHz)
- Used for long haul communication
- Fabrication is difficult and costly



**Fig. 3.26 Single mode fiber**



**Fig. 3.27 Multi mode fiber.**



## *Multi mode fibers*

- If more than one mode is transmitted through optical fiber, then it is said to be a multimode fiber.
- The larger core radii of multimode fibers make it easier to launch optical power into the fiber and facilitate the end to end connection of similar powers.

Some of the basic properties of multimode optical fibers are listed below:

- More than one path is available
- V-number is greater than 2.405



- Core diameter is higher
- Higher dispersion
- Lower bandwidth (50MHz)
- Used for short distance communication
- Fabrication is less difficult and not costly

### ***Optical fibers based on refractive index profile***

Based on the refractive index profile of the core and cladding, the optical fibers are classified into two types:

- Step index fiber
- Graded index fiber.



## ***Step index fiber***

- In a step index fiber, the refractive index changes in a step fashion, from the centre of the fiber, the core, to the outer shell, the cladding.
- It is high in the core and lower in the cladding. The light in the fiber propagates by bouncing back and forth from core-cladding interface.
- The step index fibers propagate both single and multimode signals within the fiber core.
- The light rays propagating through it are in the form of meridional rays which will cross the fiber core axis during every reflection at the core – cladding boundary and are propagating in a zig – zag manner.

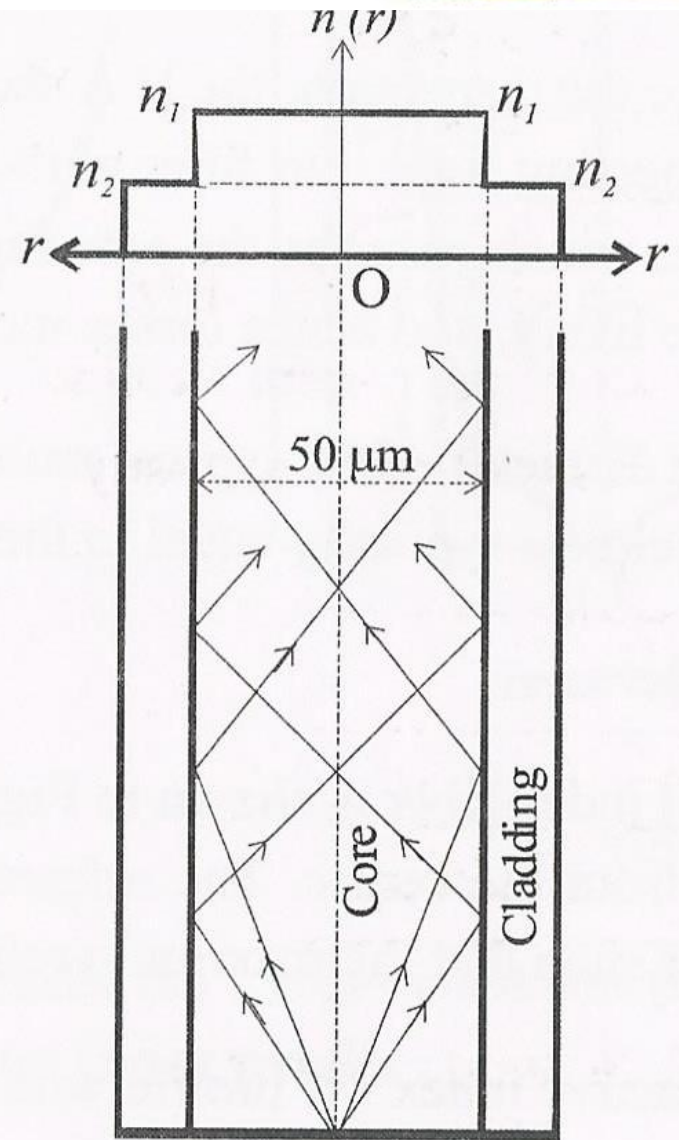
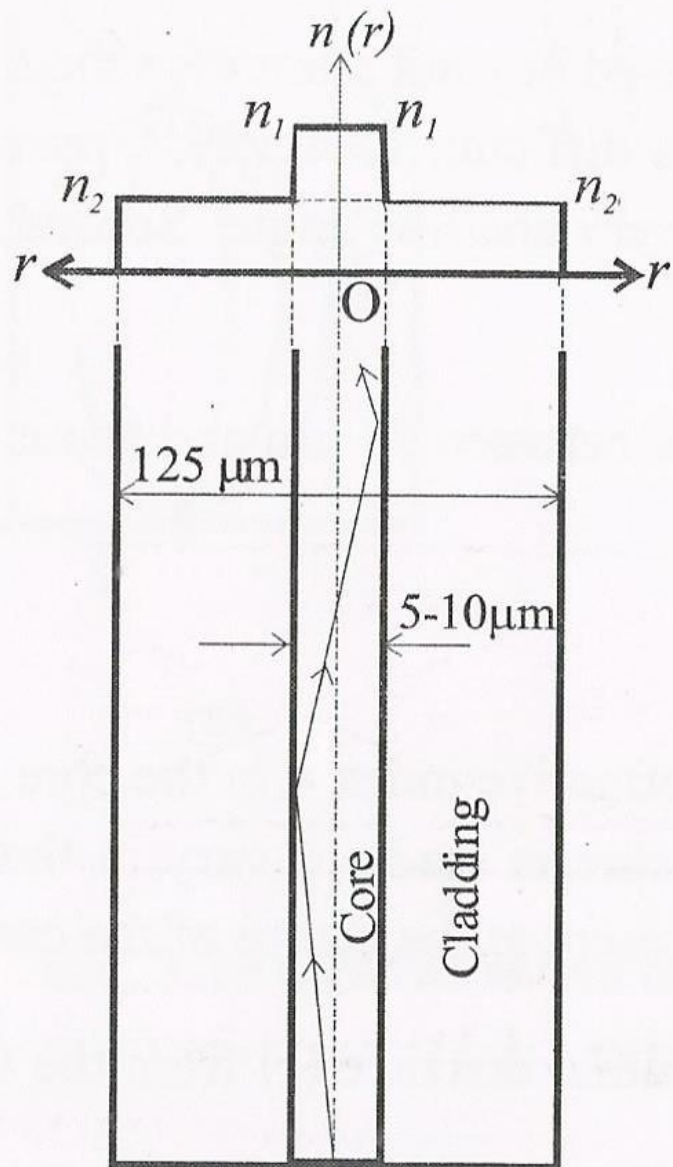


The refractive index ( $n$ ) profile with reference to the radial distance ( $r$ ) from the fiber axis is given as:

when  $r = 0$ ,  $n(r) = n_1$

$$r < a, \quad n(r) = n_1$$

$$r \geq a, \quad n(r) = n_2$$







## *Step index single mode fibers*

- The light energy in a single-mode fiber is concentrated in one mode only.
- This is accomplished by reducing  $\Delta$  and or the core diameter to a point where the  $V$  is less than 2.4.
- In other words, the fiber is designed to have a  $V$  number between 0 and 2.4.
- This relatively small value means that the fiber radius and  $\Delta$ , the relative refractive index difference, must be small.
- No intermodal dispersion exists in single mode fibers because only one mode exists.





- With careful choice of material, dimensions and  $\lambda$ , the total dispersion can be made extremely small, less than 0.1 ps / (km  $\times$  nm), making this fiber suitable for use with high data rates.
- In a single-mode fiber, a part of the light propagates in the cladding.
- The cladding is thick and has low loss.
- Typically, for a core diameter of 10  $\mu\text{m}$ , the cladding diameter is about 120  $\mu\text{m}$ .
- Handling and manufacturing of single mode step index fiber is more difficult.



## *Step index multimode fibers*

- A multimode step index fiber is shown.
- In such fibers light propagates in many modes.
- The total number of modes  $MN$  increases with increase in the numerical aperture.
- For a larger number of modes,  $MN$  can be approximated by

$$M_N = \frac{V^2}{2} = 4.9 \left[ \frac{dn_1 \sqrt{2\Delta}}{\lambda} \right]^2$$



where  $d$  = diameter of the core of the fiber and  $V = V$  – number or normalized frequency.

The normalized frequency  $V$  is a relation among the fiber size, the refractive indices and the wavelength.  $V$  is the normalized frequency or simply the  $V$  number and is given by

$$V = \left( \frac{2\pi a}{\lambda} \right) \times \text{N.A} = \left( \frac{2\pi a}{\lambda} \right) \times n_1 \times (2\Delta)^{\frac{1}{2}}$$

where  $a$  is the fiber core radius,  $\lambda$  is the operating wavelength,  $n_1$  the core refractive index and  $\Delta$  the relative refractive index difference.



To reduce the dispersion, the N.A should not be decreased beyond a limit for the following reasons:

- First, injecting light into fiber with low N.A becomes difficult. Lower N.A means lower acceptance angle, which requires the entering light to have a very shallow angle.
- Second, leakage of energy is more likely, and hence losses increase.

The core diameter of the typical multimode fiber varies between  $50\text{ }\mu\text{m}$  and about  $200\text{ }\mu\text{m}$ , with cladding thickness typically equal to the core radius.



## ***Graded index fibers***

- A graded index fiber is shown in Fig.3.30. Here, the refractive index  $n$  in the core varies as we move away from the centre.
- The refractive index of the core is made to vary in the form of parabolic manner such that the maximum refractive index is present at the centre of the core.
- The refractive index ( $n$ ) profile with reference to the radial distance ( $r$ ) from the fiber axis is given as:



$$\begin{aligned} \text{when } r = 0, n(r) &= n_1 \\ r < a, n(r) &= n_1 \left[ 1 - \left( 2\Delta \left[ \frac{r}{a} \right]^2 \right) \right]^{\frac{1}{2}} \\ r \geq a, n(r) &= n_2 = n_1 (1 - 2\Delta)^{\frac{1}{2}} \end{aligned}$$

At the fiber centre we have  $n_1$ ; at the cladding we have  $n_2$ ; and in between we have  $n(r)$ , where  $n$  is the function of the particular radius as shown in Fig. simulates the change in  $n$  in a stepwise manner.

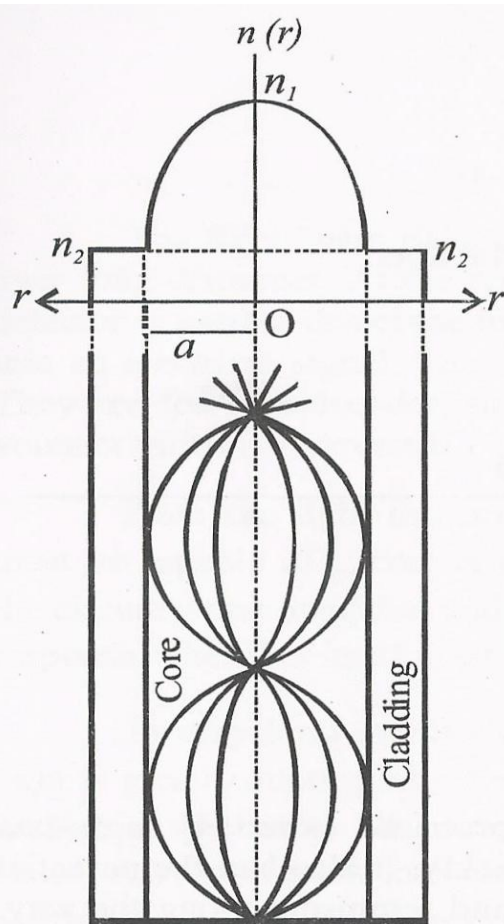


- Each dashed circle represents a different refractive index, decreasing as we move away from the fiber center.
- A ray incident on these boundaries between  $n_a - n_b$ ,  $n_b - n_c$  etc., is refracted.
- Eventually at  $n_2$  the ray is turned around and totally reflected.
- This continuous refraction yields the ray tracings as shown in Fig.

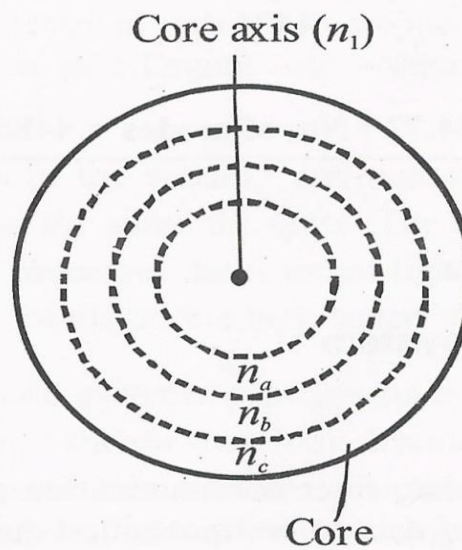


- The light rays will be propagated in the form skew rays (or) helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical or spiral manner.
- The effective acceptance angle of the graded-index fiber is somewhat less than that of an equivalent step-index fiber. This makes coupling fiber to the light source more difficult.

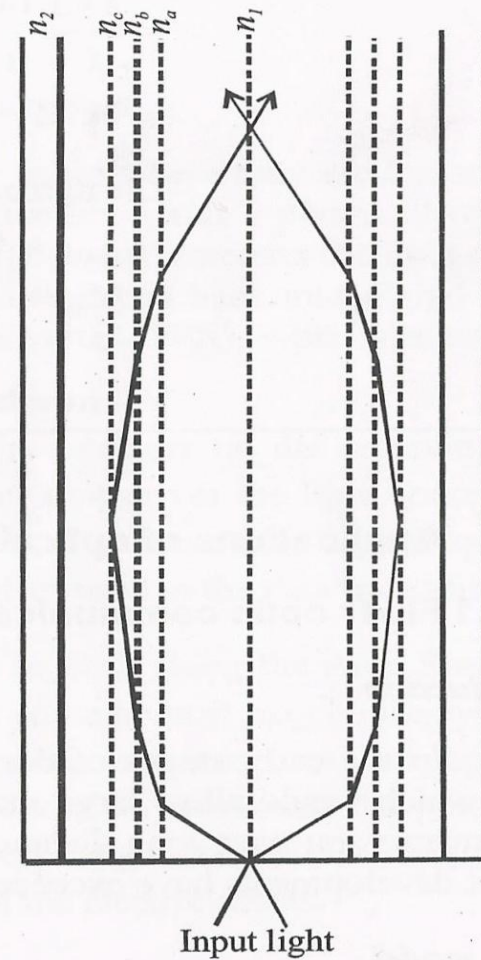




(a)



(b)



(c)

(a) index profile (b) stepwise index profile (c) ray tracing in stepwise index profile



The number of modes in a graded-index fiber is about half that in a similar step-index fiber,

$$M_N = \frac{V^2}{4}$$

The lower the number of modes in the graded-index fiber results in lower dispersion than is found in the step-index fiber. For the graded-index fiber the dispersion is approximately (Here  $L$  = Length of the fiber;  $c$  = velocity of light).

$$\Delta t = \frac{Ln_1\Delta^2}{8c}$$

(Here  $L$  = Length of the fiber;  $c$  = velocity of light).



- The size of the graded-index fiber is about the same as the step-index fiber. The manufacture of graded-index fiber is more complex. It is more difficult to control the refractive index well enough to produce accurately the variations needed for the desired index profile.