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Topic:

Electromagnetic Theory: Optical Fibres Numerical Aperture. Step and Graded Indices (Definitions Only). Single and Multiple Mode Fibres (Concept and Definition Only).

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OPTICALFIBRES

1. Objective &Relevance of the Section:

Fibre optics is one of the most advanced significant technologies for high-performance data networking as well as transferring of the information from one end to another end. Optical fibre cables can transmit information for longer transmission distances owing to its much greater bandwidth as well as low power loss property than metal cables. Consequently, optical fibres have different potential applications in fibre lasers, fibre optic sensors, fiberscope, etc. In this section, our main objective is to learn the Optical Fibres Numerical Aperture. Step and Graded Indices (Definitions Only). Single and Multiple Mode Fibres (Concept and Definition Only) as per CBCS syllabus of C13T of Physics (H) under Vidyasagar University.

2. Introduction:

An **optical fibre**is a flexible as well as structured transparentfibrematerial made throughthinglassotherwise plastic.The diameter of an optical fibre is slightly thicker than that of a human hair. These fibres are capable of propagation of light waves from one place to another through successive total internal reflections from its walls.

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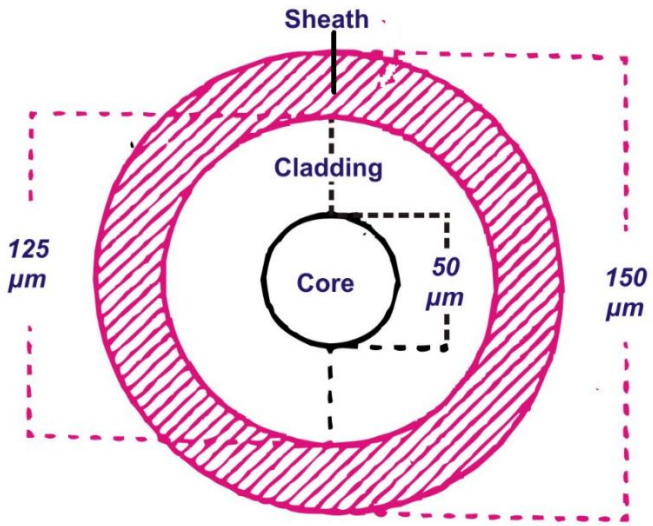
There are three parts in optical fibre- (a) **Core**, (b) **Cladding** (c) **Sheath**. In the middle-centre of optical fibre, there consist a thin glass circular region which having

diameter ~50 μm is called "**Core**". The core is surrounded by another glass coating having diameter ~125 μm which is called "**Cladding**". The refractive index of core(μ_1) is always greater than refractive index of cladding (μ_2) for occurrence of total internal reflection. Finally, the total structure is covered by plastic layer called **'Seath'** that having thickness~12.5 μmto protects the optical fiber from any outside harmful impact.



Transvers view of an optical fibre

Let we consider, LMis an optical fibre. The light travels from the outside medium havingthe refractive index (μ_a). After that the light incident at an angle (i) at core, then

refracted at an angle (r) as well as finally, strikes on the core-cladding interface at an angle (φ), which will be $\geq$ the critical angle (c) of core-cladding surface. Hence, the ray suffers total internal reflection and finally backs into the core. As a result, the wave will rebound in addition to propagate through the optical fibre as the angle of incidence and reflection are alike. Mathematically-

$$\mu_1/\mu_a = Sini/Sin\ r$$

Also, $Sin\ r = Cos\ \varphi$

Therefore, $Sin\ i = (\mu_1/\mu_m)\ Cos\ \varphi$

When, $\varphi = c$; [c= the critical angle]

Then, $Sin\ i_{max} = (\mu_1/\mu_a)\ Cos\ c$

But $Sin\ c = \mu_2/\mu_1$

Then $Cos\ c = \sqrt{(\mu_1^2-\mu_2^2)}/\mu_1$

Therefore, $Sin\ i_{max} = \sqrt{(\mu_1^2-\mu_2^2)}/\mu_m$

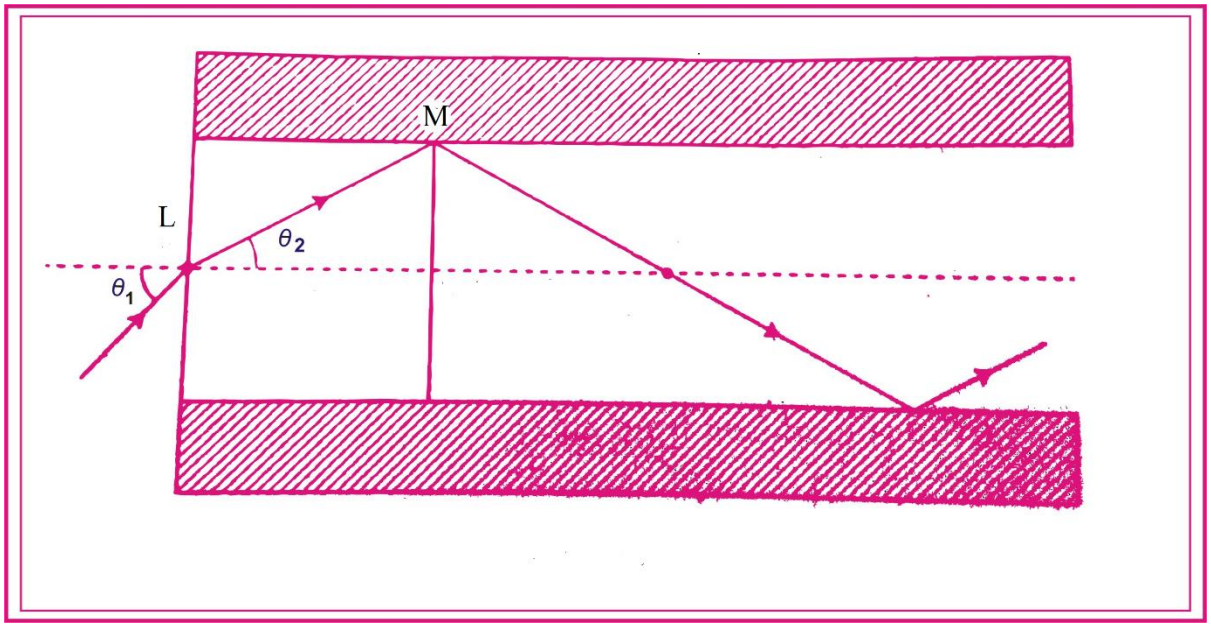
Taking, μ_a=1 for air

$Sin\ i_{max} = Sin\ \phi_a = \sqrt{(\mu_1^2 - \mu_2^2)}$

3.**Acceptance AngleandNumerical Aperture:**

Acceptance Angle: The maximum angle of incidence for which the incident ray can propagate through the optical fibre is called the*Acceptance angle*(ϕ_a).

Numerical Aperture:$Sin\ \phi_a = \sqrt{(\mu_1^2 - \mu_2^2)}$is called the numerical aperture (N.A.) which is defined as the measure of accepted light by the optical fibre.



Numerical aperture (N.A.) = $\mu_1\sqrt{2\Delta}$

The fractional refractive index change (Δ) = $(\mu_1 - \mu_2)/\mu_1$

For optical fibre, the normalised frequency, V-number = $\frac{2\pi r}{\lambda}\sqrt{(\mu_1^2 - \mu_2^2)}$

r= diameter of core, μ_1 = refractive index of core

μ_2 = refractive index of cladding

λ= wavelength of the light used for propagation

Number of modes= $V^2/2$

4. **Step Index and Graded Index Optical Fibre (Definition only):**

On the basis of refractive index profile of core cladding, the optical fibre generally, can be classified into two types-

i. *Step index optical fibre*

ii. *Graded index optical fibre*

(i) *Step index optical fibre*: In step index optical fibre, the refractive index of core (μ_1) changes in a step manner to refractive index of cladding (μ_2) at core-cladding interface. Here, the refractive index of core (μ_1) is greater than the refractive index of cladding (μ_2). Since, the refractive index of core (μ_1) changes in a step manner to refractive index of cladding (μ_2) at core-cladding interface, the fibre is called Step-Index Optical Fibre.

(ii) Graded index optical fibre:In case of graded index optical fibre, we can find the gradual variation of refractive index by following an increasing manner from the outside of the fibre core to the centre (core) of it.

The nature of variation becomes-

Here, $\mu(r) = \mu_1 [1-2\Delta(r/a)^p]^2$

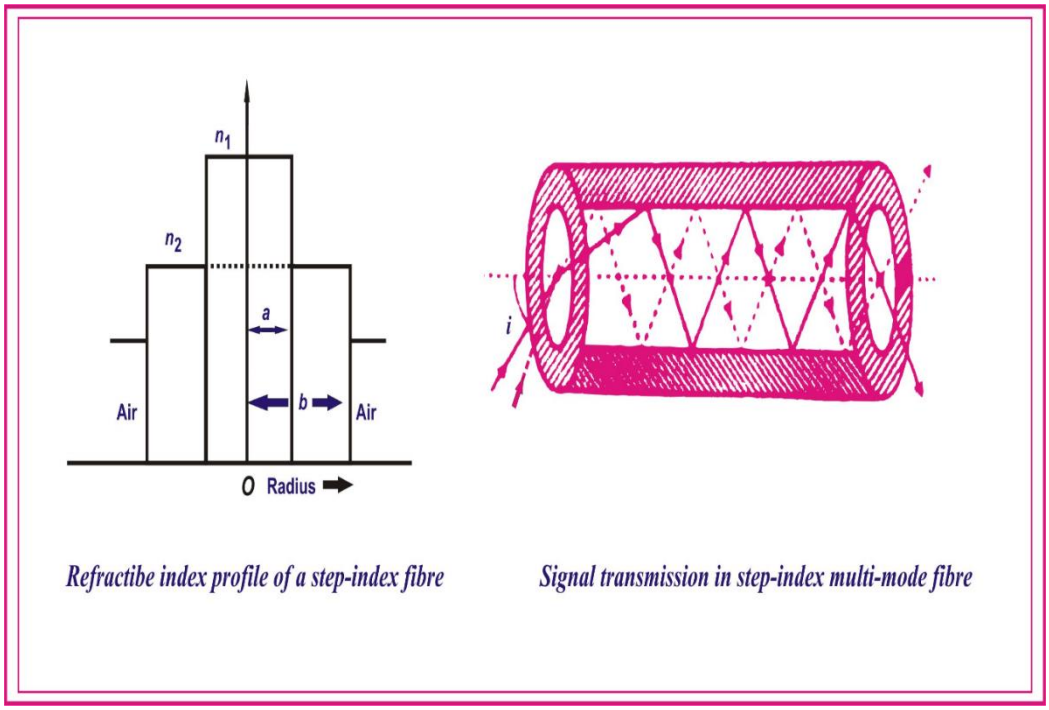
$\mu(r)$ = refractive index is function of radius r which is measured from the centre of the core, p= index profile, μ_1=refractive index of core, Δ= change of relative refractive index, a= the radius of the core.

5. Single & Multimode Optical Fibres (Concept and Definition Only):

The path followed by a light wave when travelling through an optical fibre is called "*The Mode of Propagation*". Mode defines the nature of the electromagnetic wave propagation in waveguide. Mode is nothing but the associated angles of allowed direction for the propagation of electromagnetic wave through the optical fibre which is considered as cylindrical waveguide to satisfy the conditions for total internal reflection. Depending upon the mode of propagation of light wave through the optical fibres, they can be classified in two ways, which are (a) Single mode optical fibre, (b) Multimode optical fibre.

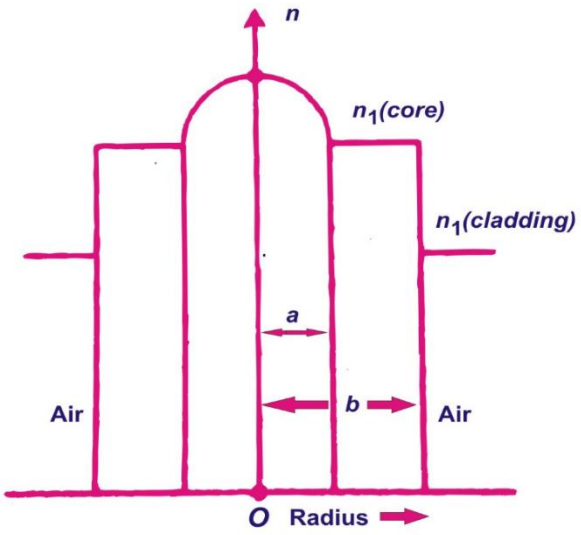
Single mode optical fibre: A single mode optical fibre follows one mode for propagation of electromagnetic wave and the core diameter of this type of fibre is very small, compared to cladding.

Multi-mode optical fibre: A multi-mode optical fibre follows more than one mode for propagation of light wave and the core diameter of this type of fibre is high, compared to cladding.



Refractibe index profile of a step-index fibre

Signal transmission in step-index multi-mode fibre



Multi-mode graded index fibre of a graded index

6. Summary:

An **optical fibre** is a flexible as well as structured transparentfibre material made by thinglassotherwise plasticare capable of propagation of light waves from one place to another through successive total internal reflections from its walls.There are three parts in optical fibre- (a) **Core**, (b) **Cladding** (c) **Sheath**.On the basis of refractive index profile of core cladding, the optical fibre generally, can be classified into two types-*step index optical fibre* and *graded index optical fibre*. Depending upon the mode of propagation of light wave through the optical fibres, they can be classified in two ways, which are - single mode optical fibre and multimode optical fibre.

7. Frequently Asked Questions (FAQ):

(i) What is optical fibre?
(ii) What is its advantages in communication system than cable?
(iii) Explain the construction of optical fibre.
(iv) What are core, cladding &sheath?
(v) What are the different types of optical fibre? Explain.
(vi) Define step index and graded index optical fibre.
(vii) Define and derive the expression of acceptance angle, acceptance cone, N.A.
(viii) Define single mode and multimode optical fibre.
(ix) Draw the refractive index profile of step index and graded index optical fibre.
(x) What are the application of optical fibre?

8. Numerical:

i. An optical fibre made of silica glass has a core of refractive index 1.6 and the cladding of refractive index is 1.5. Calculate the critical angle for the core-cladding interface.
ii. Calculate the angle of acceptance of a given optical fibre, if the refractive indices of the core and the cladding are 1.653 and 1.538, respectively. Also, calculate the fractional change in refractive index.
iii. The numerical aperture of an optical fibre is 0.55 and the refractive index of the core is 1.64. Find the refractive index of the cladding.

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