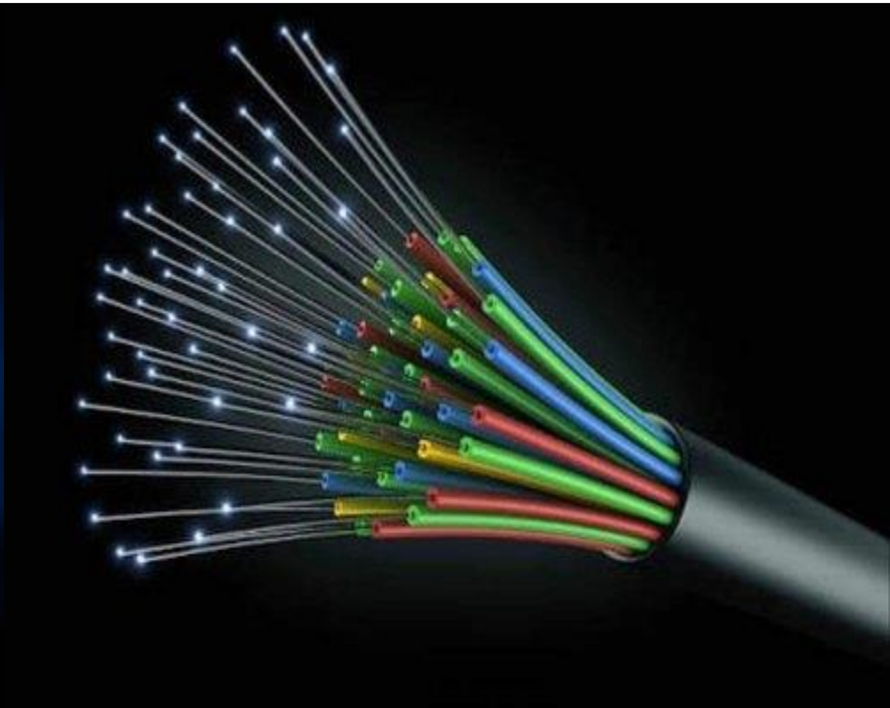
UNIT-IV

Laser Holography and Optical Fibre

Lecture-6: Optical Fibre



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FRACTIONAL REFRACTIVE INDEX CHANGE

- Fractional refractive index change is defined as the ratio of the difference between the refractive indices of the core and the cladding to the refractive index of the core.

- It is denoted by Δ and is given as

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

- The value of Δ is always positive and less than one because $n_1 > n_2$ (always), otherwise the phenomena of total internal reflection will not be fulfilled.

WHAT IS NUMERICAL APERTURE?

- Numerical aperture (NA) is a number, which defines the light acceptance or light propagating capacity of a fiber. It is also known as figure of merit. It is expressed a

$$\mathrm{NA} = \sin\theta_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

- Usually n_0 is the refractive index of the air and is given as $n_0 = 1$. Hence, the value of NA can be given as

$$\mathrm{NA} = \sin\theta_m = \sqrt{n_1^2 - n_2^2}$$

Where n_1 and n_2 are the refractive indices of core and cladding, respectively.

NUMERICAL APERTURE AND FRACTIONAL REFRACTIVE INDEX CHANGE

- Numerical aperture can also be expressed in terms of fractional refractive index change (Δ)as follows:

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

$$= \frac{(n_1 + n_2)(n_1 - n_2)}{(n_1 + n_2)n_1}$$

- Since the difference in n_1 and is n_2 small, so we can write

$$= \frac{(n_1^2 - n_2^2)}{(n_1 + n_2)\, n_1}$$

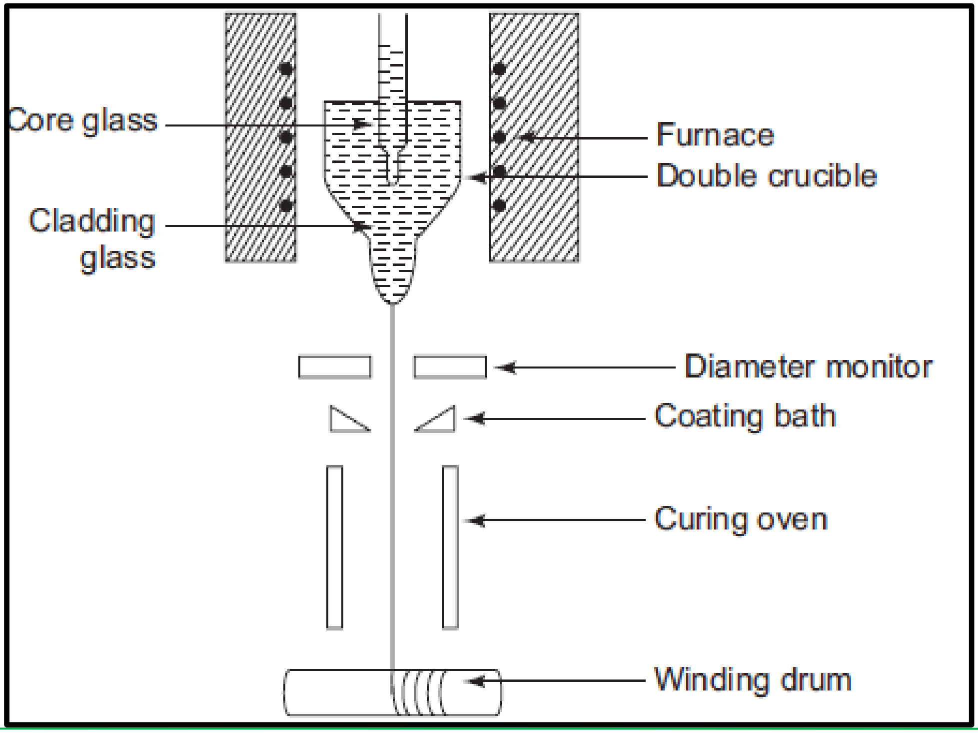
$$n_1 + n_2 \simeq 2n_1$$

Hence $\Delta = \frac{n_1^2 - n_2^2}{2\, n_1^2} = \frac{(NA)^2}{2n_1^2}$ or $NA = n_1 \sqrt{2\Delta}$

FIBER FABRICATION

•Double crucible method is used to fabricate an optical fiber produced by the liquid phase technique.

•It is much suitable for the fabrication of graded index optical fibers.



FIBER FABRICATION

- In this method, the material glass for core and cladding is fed to two separate concentric platinum crucibles as shown in Fig

- The assembly is placed in a furnace capable of heating the crucible contents to a temperature between 80°C and 1200°C.

- Clad fiber is drawn directly from the melt through the nozzles in the bases of crucibles. Index grading is achieved by the diffusion of mobile ions across the core–cladding interface within the molten glass.

- Graded index fibers produced by this technique are subsequently less dispersive than step index fibers.

TYPES OF FIBERS:

- On the basis of refractive index profile and modes propagated through core, optical fibers are classified mainly into two categories. These are as follows:

- **(i)** Step index (SI) optical fiber
- **(ii)** Graded index (GI) optical fiber

Step Index Optical Fiber

- In step index optical fiber, there is a step discontinuity of the refractive index profile at the core–cladding interface.
- The refractive index of these fibers is defined as
- **n(r)** = n_1 when $r < a$ (where $n_1 > n_2$)
- n_2 when $r > a$
- where n_1 and n_2 are the refractive indices of core and cladding respectively, and a is the core radius.

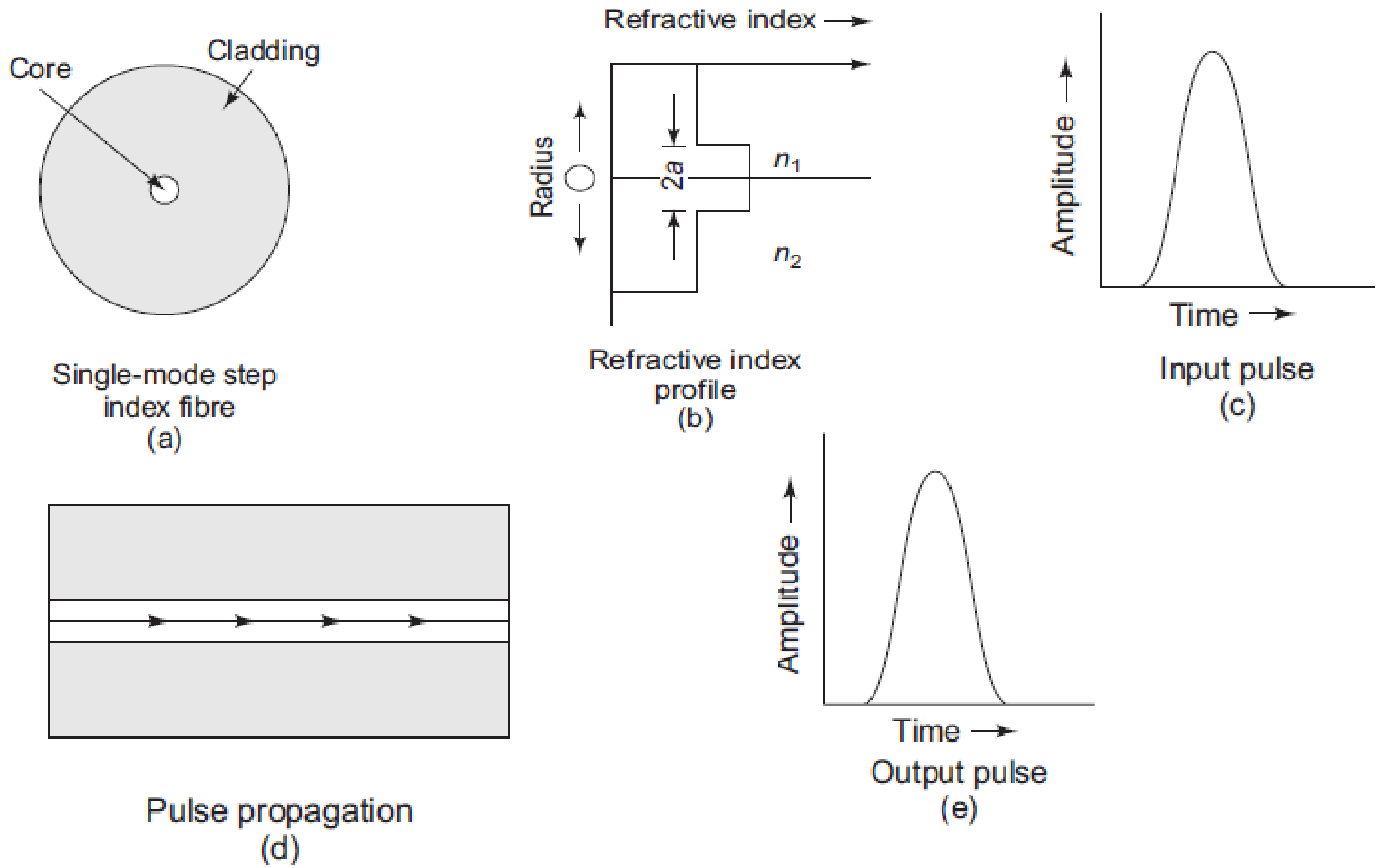
➢ SI optical fibers can be further classified into two categories:

- **(i)** Single-mode step index (SMSI) optical fiber
- **(ii)** Multimode step index (MMSI) optical fiber

Single-Mode Step Index Optical Fiber

- In the SMSI optical fiber the refractive index difference between core and cladding is very small.
- Due to this, only a single mode is propagated through the core of fiber. These fibers are also known as mono mode fibers.
- In general, the mono mode optical fiber has a core diameter of 8 mm to 10 mm and is designed for use in the infrared region.
- Single-mode optical eliminates the modal dispersion because only single mode can travel through the core.
- Hence, the information transmission capacity of a single-mode fiber is much larger than that of a multimode fiber.
- Such fibers are used for communication longer than 200 m, and these are frequently used under sea water.

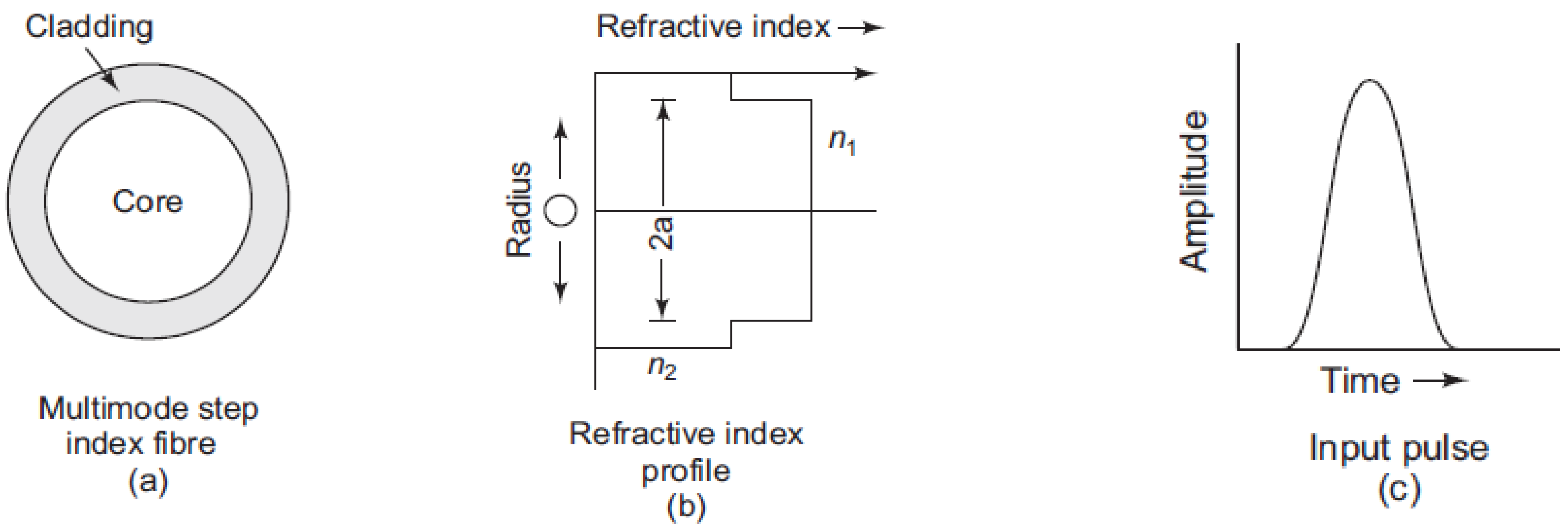
Single-Mode Step Index Optical Fiber



Multimode Step Index Optical Fiber

- In general, an MMSI optical fiber has larger core diameter than an SMSI optical fiber.
- The diameter of core is about 20 mm–100 mm and the diameter of cladding is about 100 mm–200 mm. The standard overall diameter of the MMSI optical fiber is about 125 mm.
- In order to achieve the minimum angle for total internal reflection, the difference between the refractive index of core and cladding material is kept relatively large.
- The interface between the core and the cladding acts as a cylindrical mirror at which the reflection of the transmitted light takes place.
- Due to this structure, there are many paths available for light signals to travel through the fiber.

Multimode Step Index Optical Fiber

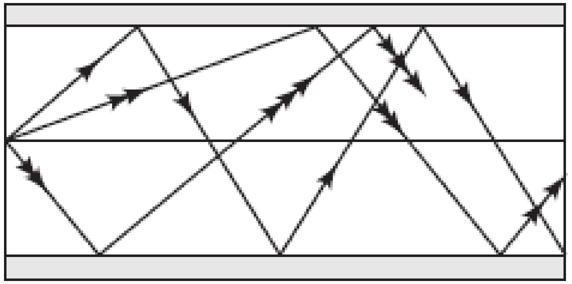


•Since the refractive index of the core is constant, so all the rays making an angle equal to or greater than critical angle travel with the same velocity in the core.

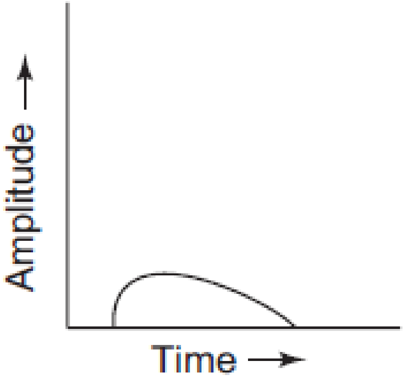
• They take different times to reach the output end of the fiber as their path lengths are different (shown in Fig.d).

Multimode Step Index Optical Fiber

- Due to the time difference between the rays arriving at the end of the optical fiber, modal dispersion takes place.
- It reduces the information carrying capacity of the fiber.
- Hence, Multimode optical fibers are used for short distances (less than 200 m), where high power transmission is needed.



Pulse propagation
(d)



Output pulse
(e)

Example-1: An optical fibre has the core refractive index $n_1 = 1.36$ and the relative difference in index $\Delta = 0.025$.

Find the

(i) refractive index of cladding, i.e., n_2,

(ii) numerical aperture, and

(iii) acceptance angle.

Solution

(i) We know that

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

Given that $\Delta = 0.025$ and $n_1 = 1.36$. Therefore,

$$0.025 = \frac{1.36 - n_2}{1.36}$$

$$\Rightarrow \quad 0.034 = 1.36 - n_2$$

$$\Rightarrow \quad n_2 = 1.36 - 0.034 = 1.326$$

(ii) We know that

$$\text{NA} = n_1 \sqrt{2\Delta}$$

Given that $n_1 = 1.36$ and $\Delta = 0.025$. Therefore,

$$\text{NA} = 1.36 \sqrt{2 \times 0.025} = 1.36 \times 0.2236 = 0.304$$

(iii) Acceptance angle α can be given as

$$\alpha = \sin^{-1}(\text{NA}) = \sin^{-1}(0.304) = 17.7^\circ$$

An optical fibre core and its cladding have refractive indices of 1.545 and 1.495, respectively. Calculate the critical angle ϕ_c, the acceptance angle $\phi_{in\ (\max)}$, and the numerical aperture.

Solution

Using Snell's law at the boundary of core and cladding, we can write

$$n_1 \sin \phi_c = n_2 \sin 90 \qquad \text{(for total internal reflection } \theta = 90°\text{)}$$

Now,
$$\sin \phi_c = \frac{n_2}{n_1} = \frac{1.495}{1.545}$$

or
$$\phi_c = \sin^{-1}(0.9676) = 83.75°$$

Acceptance angle

$$\phi_{in\ (\max)} = \sin^{-1}\left[\sqrt{(1.545)^2 - (1.495)^2}\right] = \sin^{-1}\left[\sqrt{0.152}\right] = \sin^{-1}[0.3899] = 25.498°$$

Numerical aperture

$$\text{NA} = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.545)^2 - (1.495)^2} = \sqrt{0.152} = 0.3899$$

Assignment Based on this Lecture

- Define the fractional refractive index change.
- What is numerical aperture?
- Obtain the relation between numerical aperture and fractional refractive index change.
- Explain the process of fiber fabrication.
- What are the types of optical fibers?
- Explain step index optical fiber.
- What is single-mode step index optical fiber?
- Explain multimode step index optical fiber.