Engineering Physics

(PHY1701)

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- Light propagation through fibers,
- Acceptance angle,
- Numerical Aperture,
- Types of fibers - step index, graded index, single mode & multimode*,
- Attenuation, &
- Dispersion-intermodal and intramodal (AG 29-40, 65, 78)

❖ Introduction to Fiber Optics, Ajoy Ghatak and K. Thyagarajan, Cambridge University Press, 2010 (AG)

Types of Optical fibers

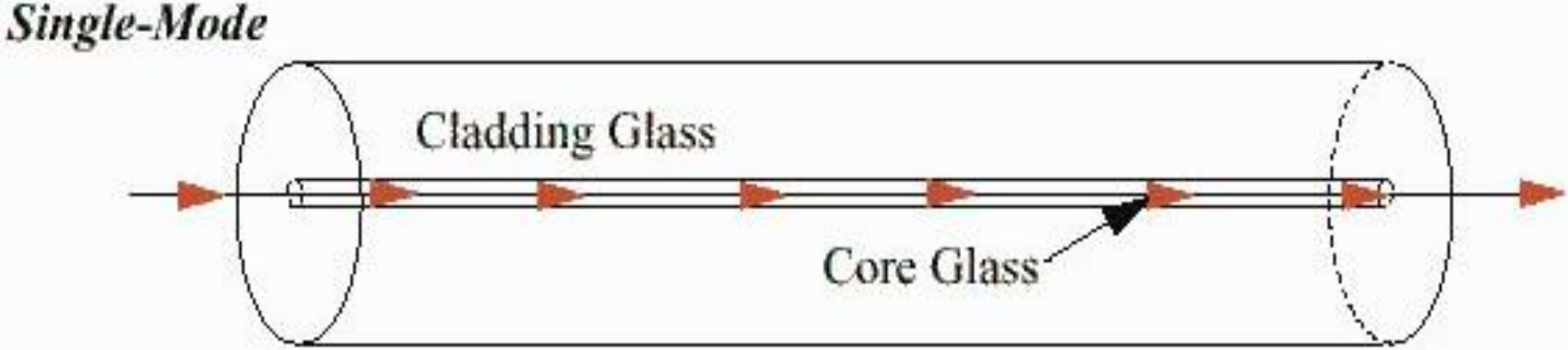
Optical fibers based on modes or modes types:

- Mode is the one which describes the nature of propagation of electromagnetic waves in a wave guide.
- 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** can propagate only the **fundamental mode.**
- **Multimode fibers** can propagate **hundreds of modes.**

Single Mode Fiber:

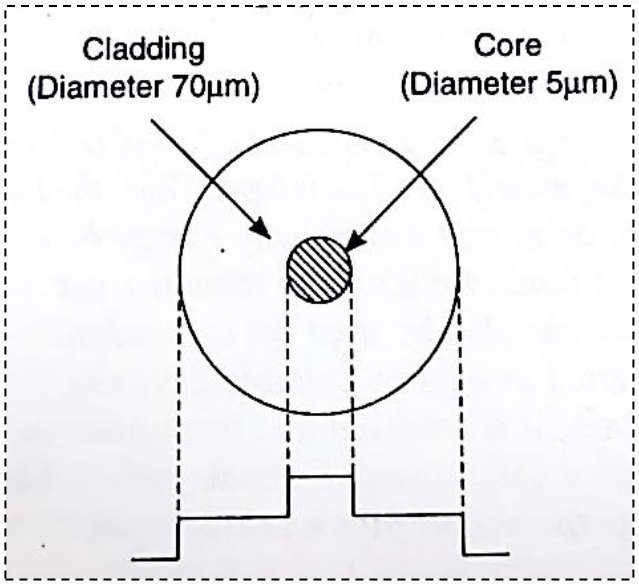
In a fiber, if only **one mode** is transmitted through it, then it is said to be a **single mode fiber.**

A typical **single mode fiber** may have a **core radius of 3 μm** and a **numerical aperture of 0.1** at a **wavelength of 0.8 μm.**



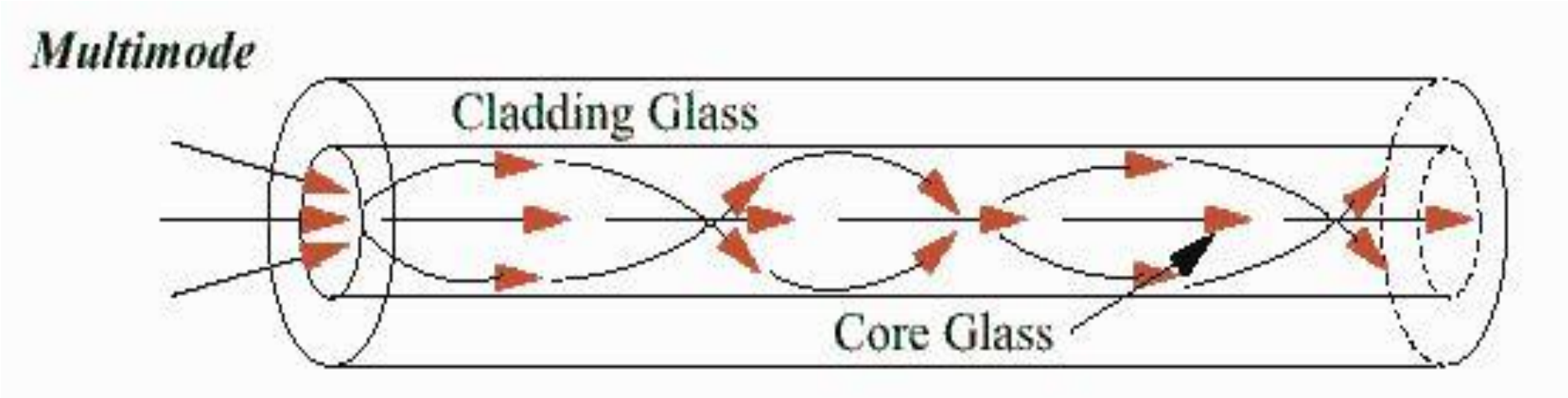
Characteristics of single mode Optical fibers

- **The single mode fiber has the following characteristics:**
- Only one path is available.
- Core diameter is small
- No dispersion
- Higher band width (1000 MHz)
- Used for long haul communication
- Fabrication is difficult and costly



Multi Mode Optical Fibers

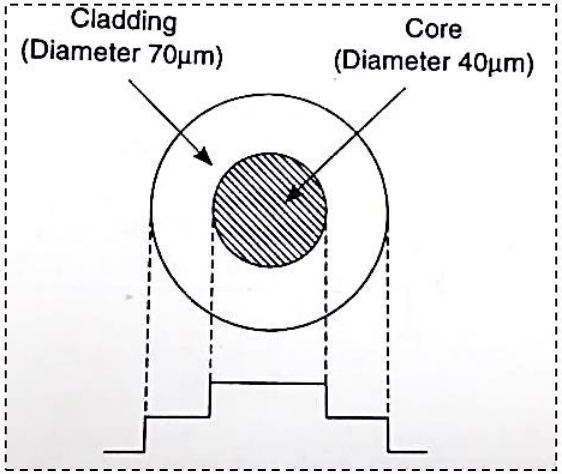
- If more than one mode is transmitted through optical fiber, then it is said to be a multimode fiber.
- The larger core radius of multimode fibers make it easier to launch optical power into the fiber and facilitate the end to end connection of similar powers.



Characteristics of Multi mode Optical fibers

The Multimode fibers has the following characteristics:

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

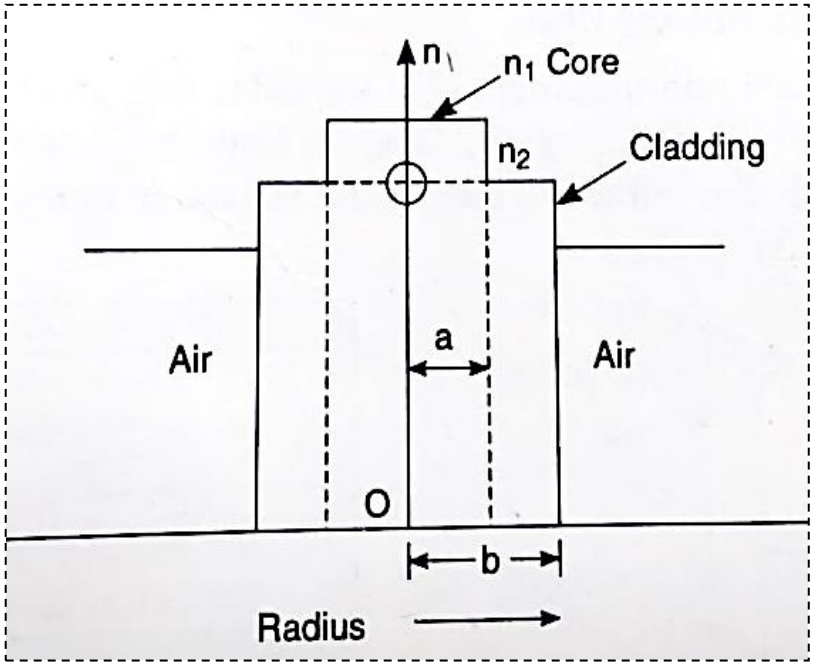


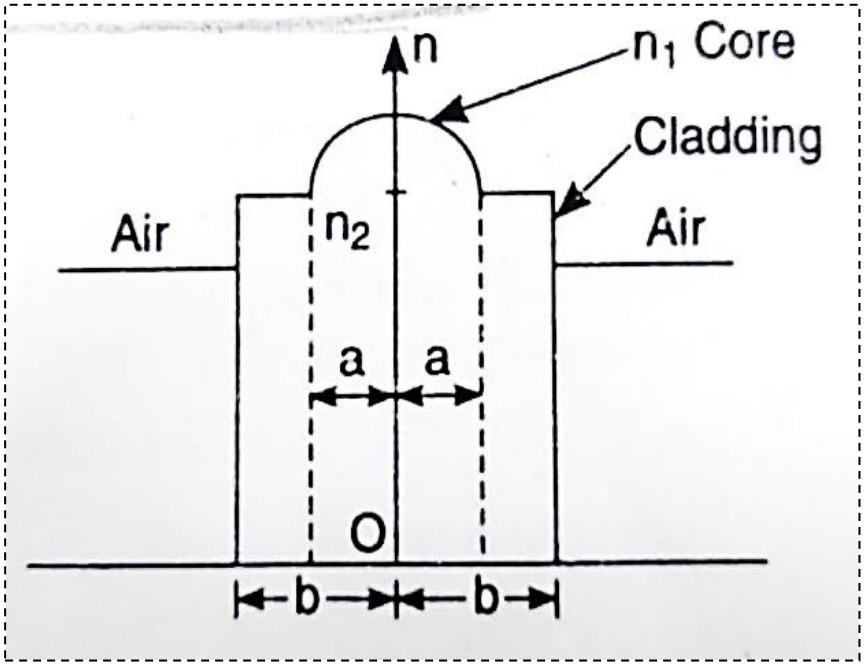
Types of Optical fibers

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:

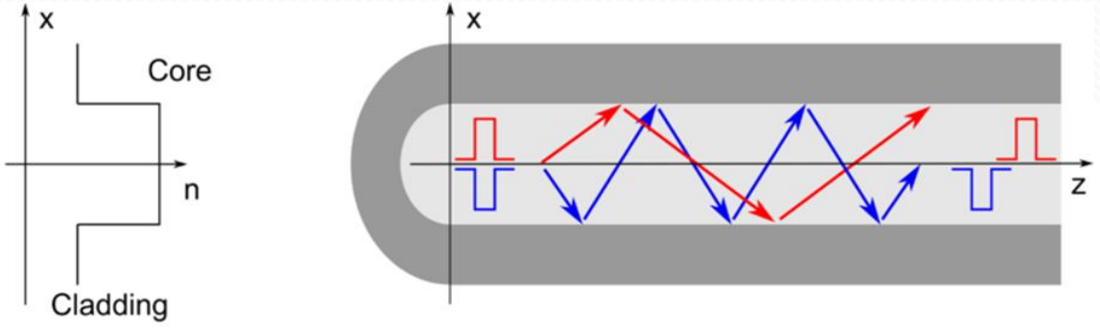
- Step index fiber
- Graded index fiber



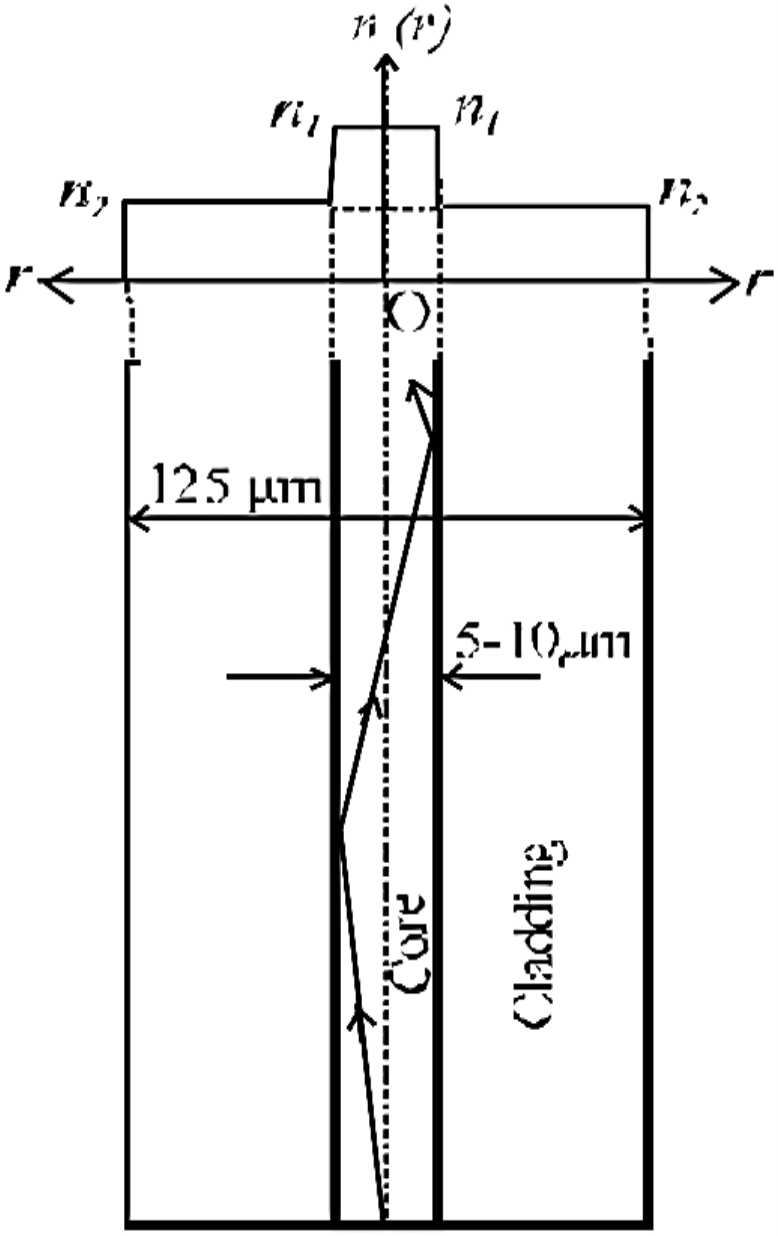


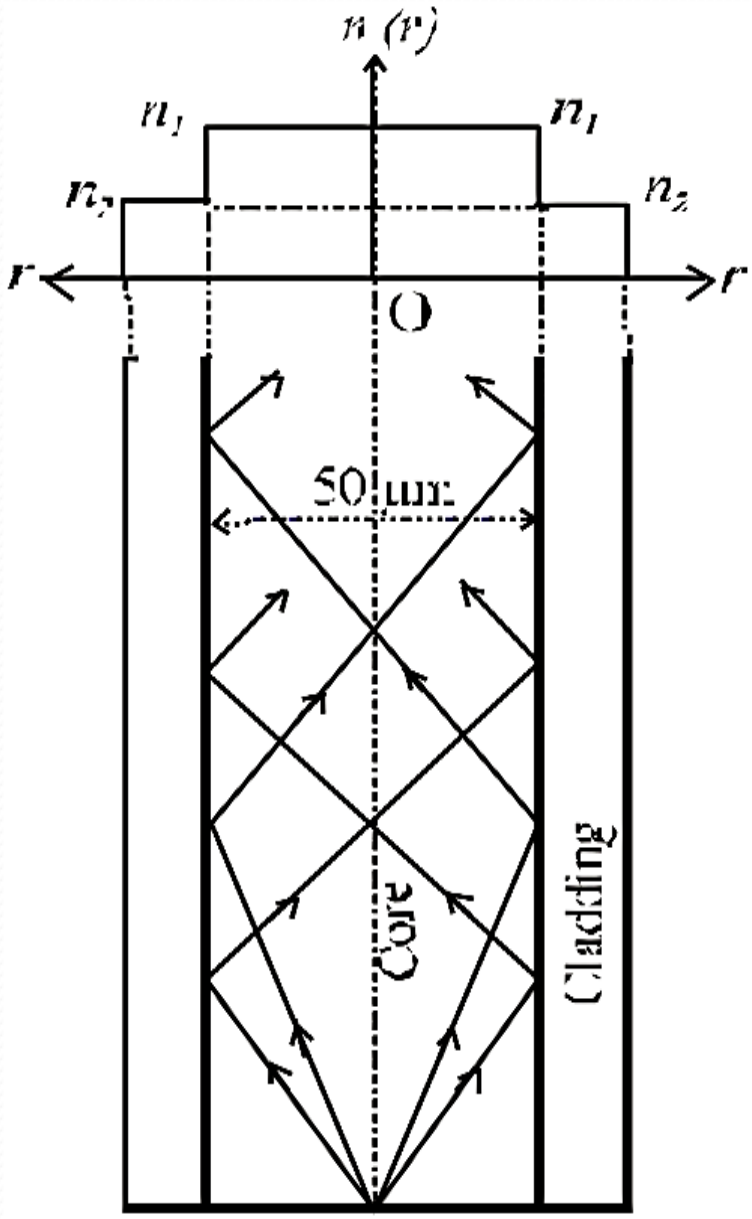
Step Index Fiber

- 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 meridinal rays which will cross the fiber core axis during every reflection at the core – cladding boundary and are propagating in a zig – zag manner.



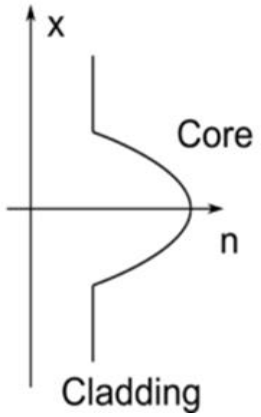
Step index Single mode and multi modes:

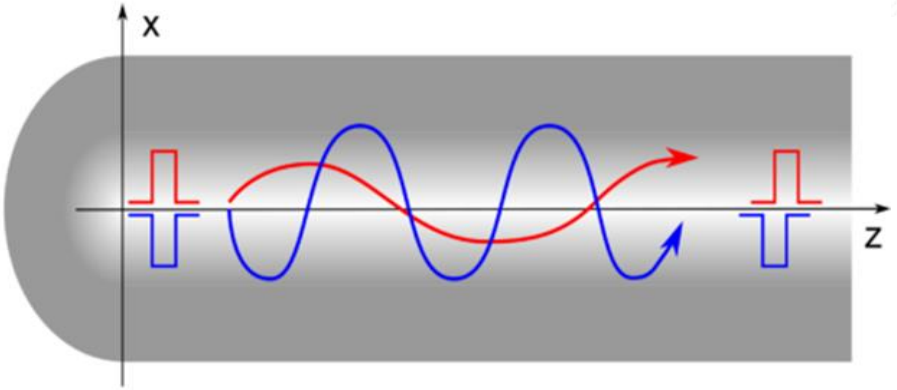




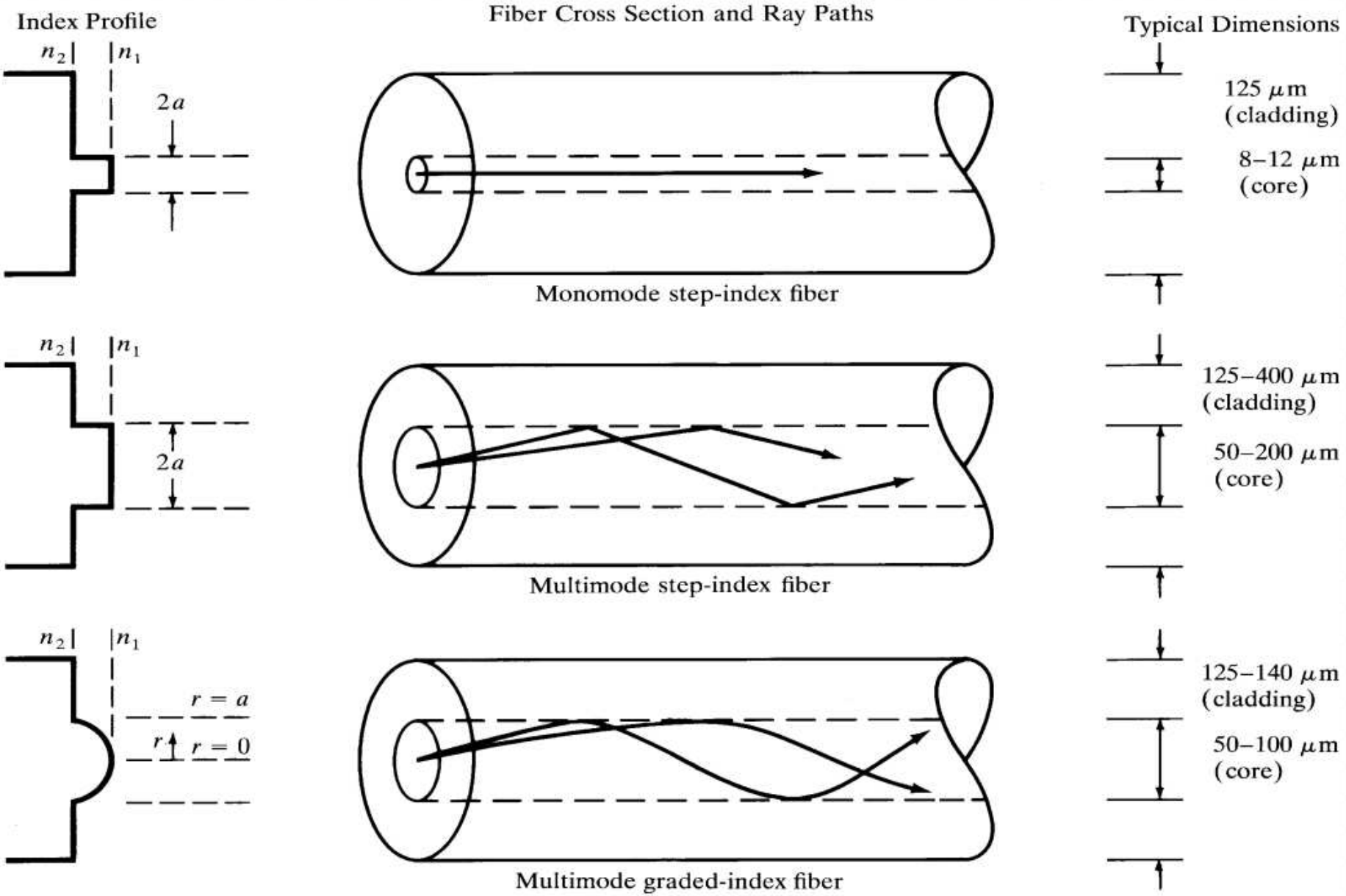
Graded Index Fiber:

- In graded index fibers, the refractive index of the core varies gradually as a function of radial distance from the fiber center.
- The refractive index of the core decreases 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.



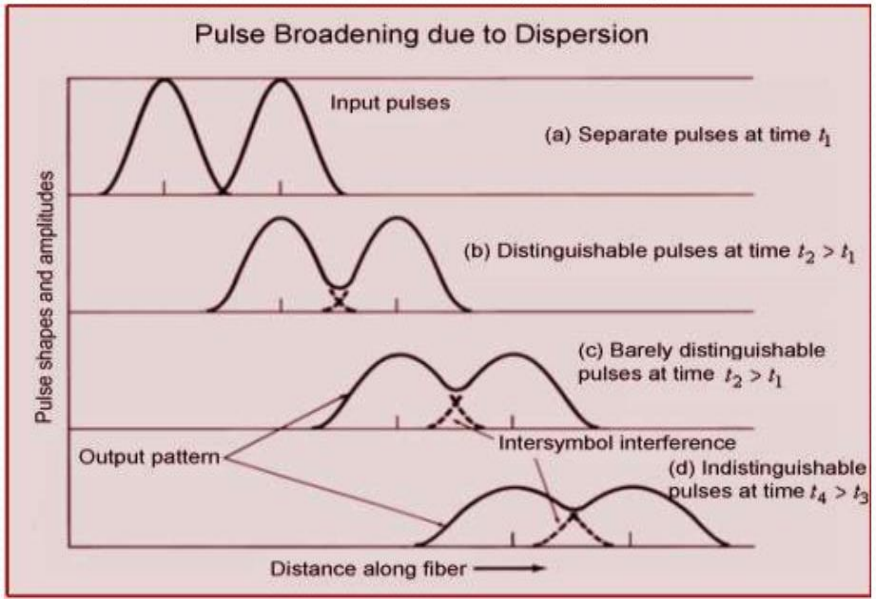


Different Structures of Optical Fiber



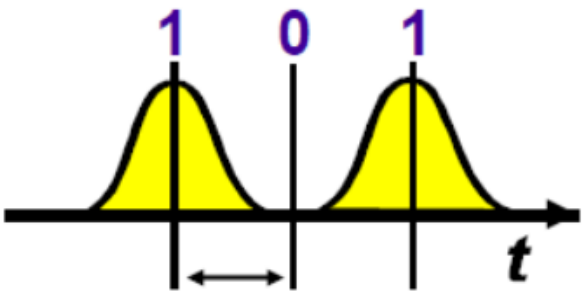
Dispersion Effect in Optical Fiber

- In communication, dispersion is used to describe any process by which any electromagnetic signal propagating in a physical medium is degraded because the various wave characteristics (i.e., frequencies) of the signal have different propagation velocities within the physical medium.
- The dispersion cause that optical pulses to broaden as they travel along a fiber, the overlap between neighboring pulses, creating errors in the receiver output, resulting in the limitation of information-carrying capacity of a fiber.



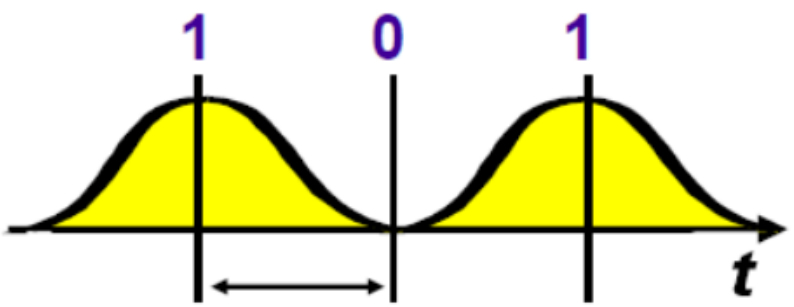
Dispersion and Bit rate

Fibre output with no Dispersion



Bit interval "T"

Fibre output with Dispersion



Longer bit interval

- The higher dispersion the longer the bit interval which must be used
- A longer the bit interval means fewer bits can be transmitted per unit of time
- A longer bit interval means a lower bit rate

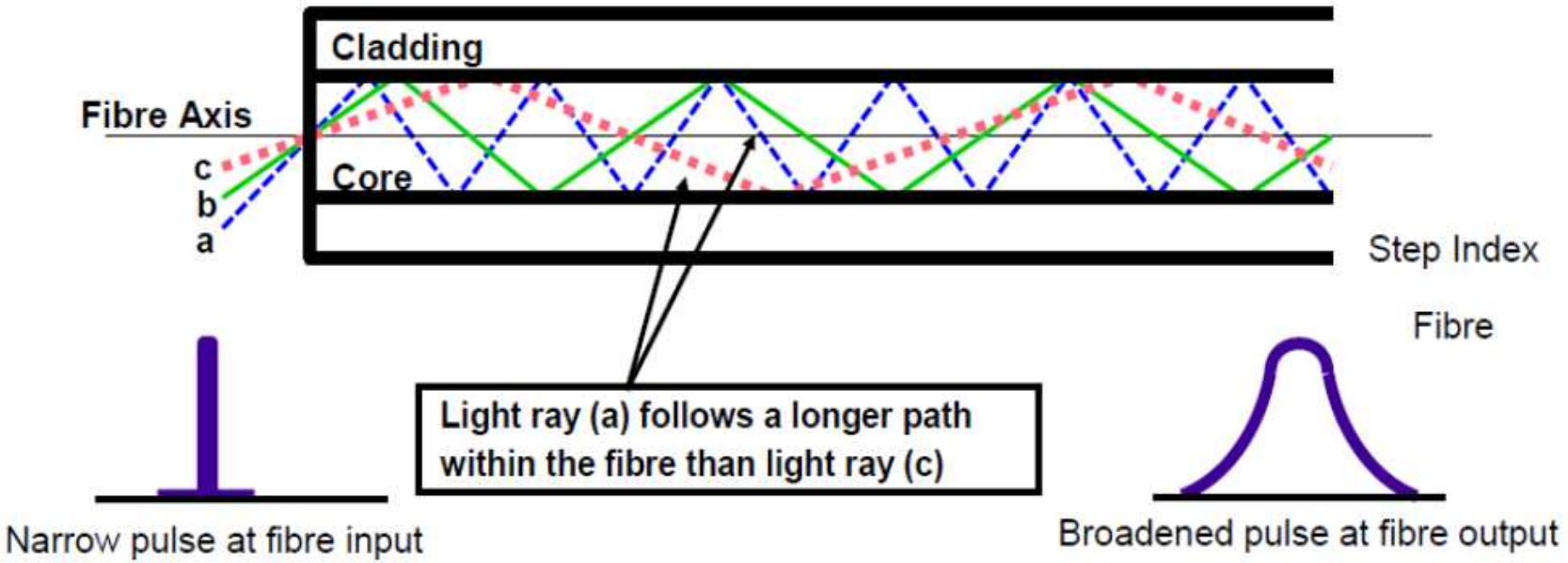
Conclusion: The higher the dispersion the lower the bit rate

Types of Dispersion:

- **Intermodal dispersion**: Different modes propagate at different group velocities.
- **Intramodal or Chromatic Dispersion**
  - **Material dispersion**: The index of refraction of the medium changes with wavelength.
  - **Waveguide dispersion**: The index change across waveguide means that different wavelengths have different delays.
- **Polarization mode dispersion**: If waveguide is birefringent. Birefringent is a optical property of a material having a refractive index that depends on the polarization and propagation direction of light.

Intermodal Dispersion

- In a multimode fiber different modes travel at different velocities.
- If a pulse is constituted from different modes then intermodal dispersion occurs.
- Modal dispersion is greatest in multimode step index fibers.
- The more modes the greater the modal dispersion.
- Typical bandwidth of a step index fiber may be as low as 10 MHz over 1 km.



Intramodal or chromatic Dispersion

- **Intramodal or Chromatic dispersion** (CD) is caused by the fact that single mode glass fibers transmit light of different wavelengths at different speeds. The ratio of the speed of light in a medium to the speed in a vacuum defines the index of refraction or refractive index of the material.
- **Material Dispersion**
- This is due to intrinsic properties of the material, glass.
- Glass is a dispersive medium. We can recall from our high school physics that glass has different refractive index for different colors.
- Different colors (wavelengths) have different velocity in glass.
- A type of dispersion that occurs in optical fiber due to the interaction of various wavelengths with the physical matter in the crystalline structure of the glass.
- The refractive index of the glass varies according to the wavelength of the optical signal.
- Material dispersion is the phenomena whereby materials cause a "bundle" of light to spread out as it propagates.

Intramodal or chromatic Dispersion

Waveguide Dispersion

- This is due dispersive nature of the bound medium. In a bound medium like the optical fiber, the velocity is a function of frequency.
- Waveguide dispersion is chromatic dispersion which arises from waveguide effects: the dispersive phase shifts for a wave in a waveguide differ from those which the wave would experience in a homogeneous medium. Waveguide dispersion is important in waveguides with small effective mode areas. But for fibers with large mode areas, waveguide dispersion is normally negligible, and material dispersion is dominant.