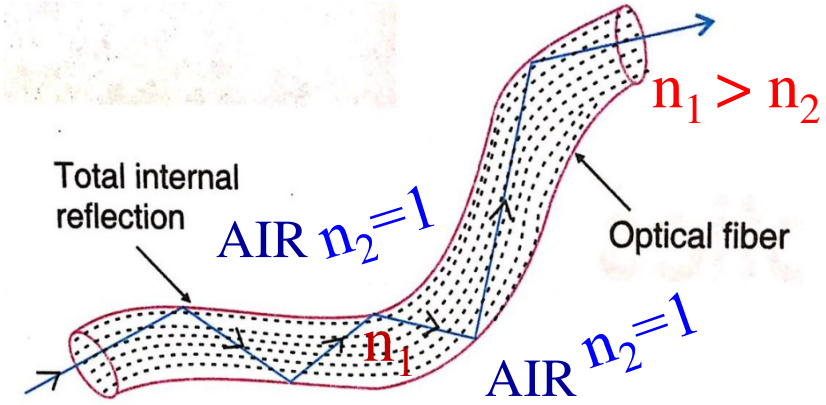
PHY109 UNIT III: Fiber optics

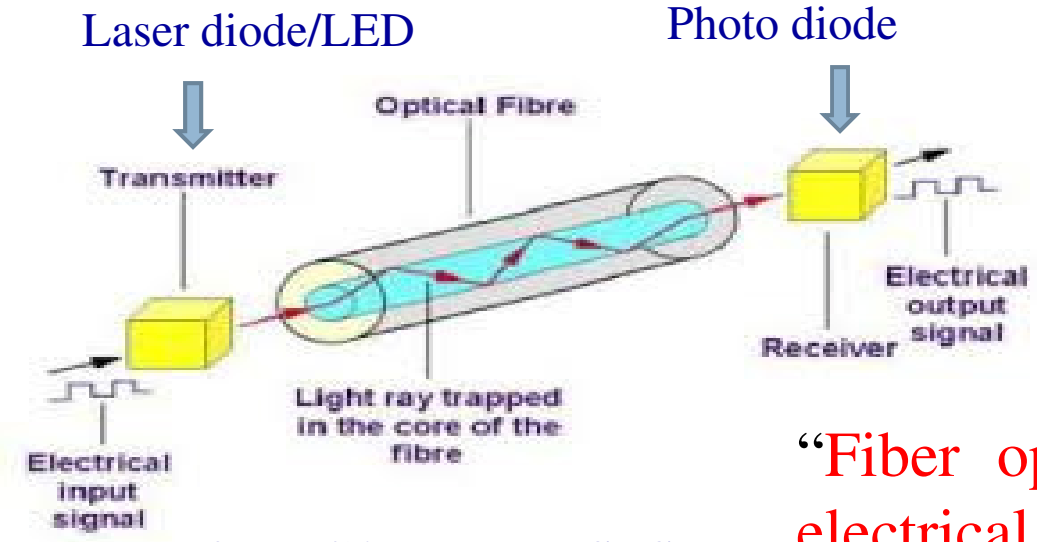
LECTURE 2

Revision Lecture 1

Fiber- Thin strand of **dielectric** material (*transmission of light*)
Wire: *The stand of* **metal** (*transmission of electricity*)

Laser diode: Forward biased
Photo diode: Reverse biased?



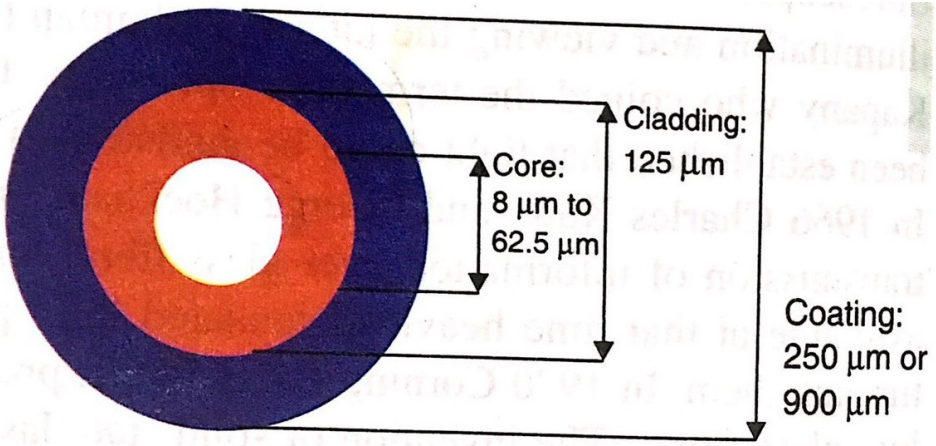


OPTICAL FIBER SYSTEM

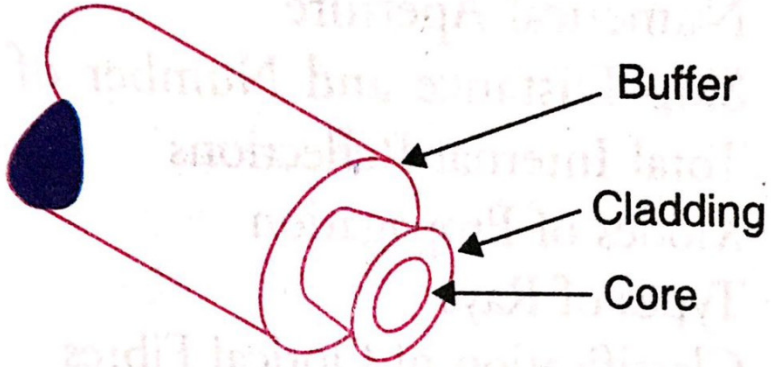
"Fiber optics is a technology in which electrical signal is converted to optical signals and transmitted through fibers and reconverted back into electrical signals"

Revision Lecture 1

Optical Fiber: Structure



Human hair thickness ~ 100µm



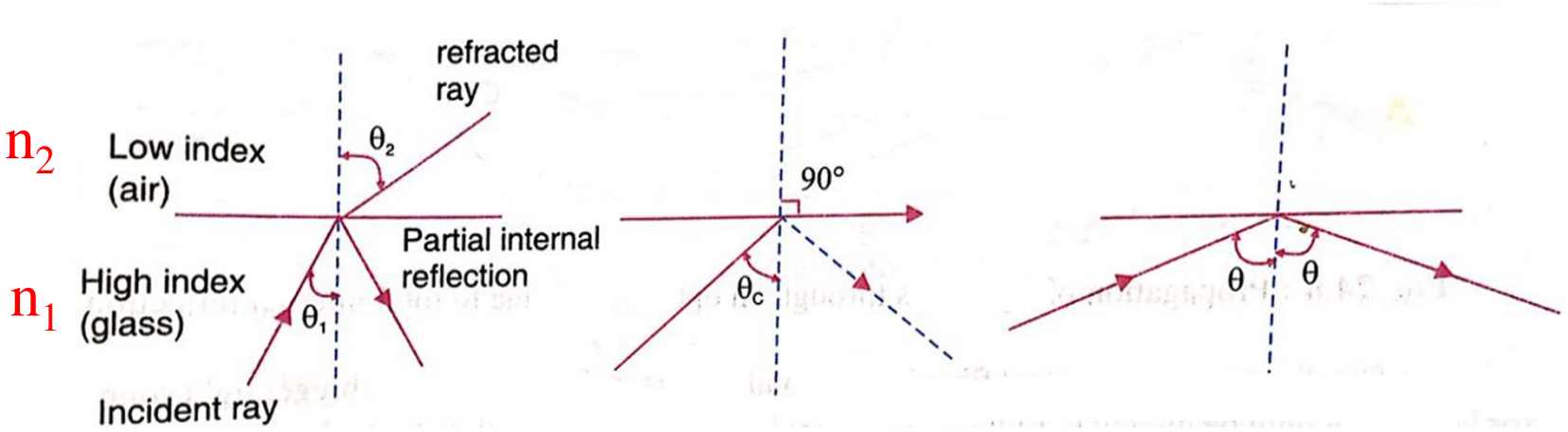
1. Core - *Light guiding region*
2. Cladding- *confine the light to the core*
3. Buffer or Sheath - *protect the fiber from physical and environmental damage*

Additional functions of cladding

- ✓ *To maintain the uniformity along the length of the fiber*
- ✓ *To protect the outer surface of the core*
- ✓ *To reduce the cone of the light*

Revision Lecture 1

TOTAL INTERNAL REFLECTION happens when a ray light pass from the denser medium to rarer medium:



TOTAL INTERNAL REFLECTION

Critical angle $\theta > \theta_c$

Snell's law

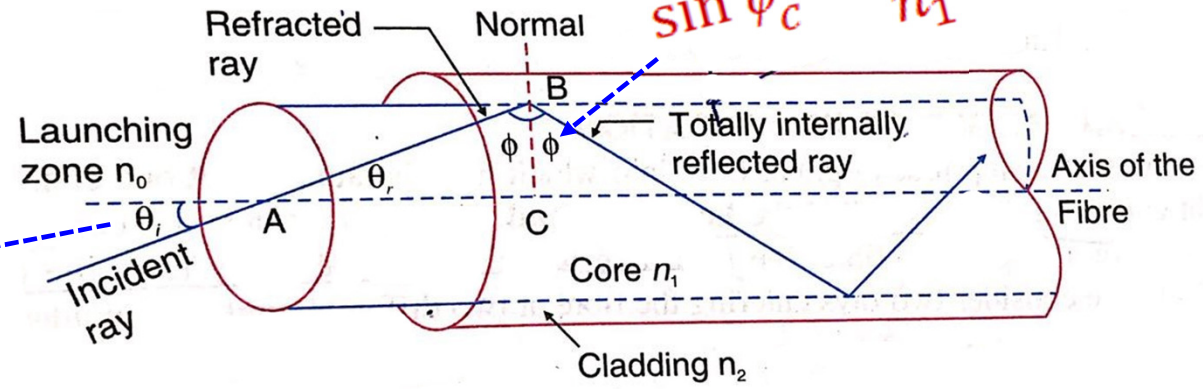
$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

$$\sin\theta_c = \frac{n_2}{n_1}$$

Principle on which Fiber optic communication rely on is **TOTAL INTERNAL REFLECTION**

Revision Lecture 1

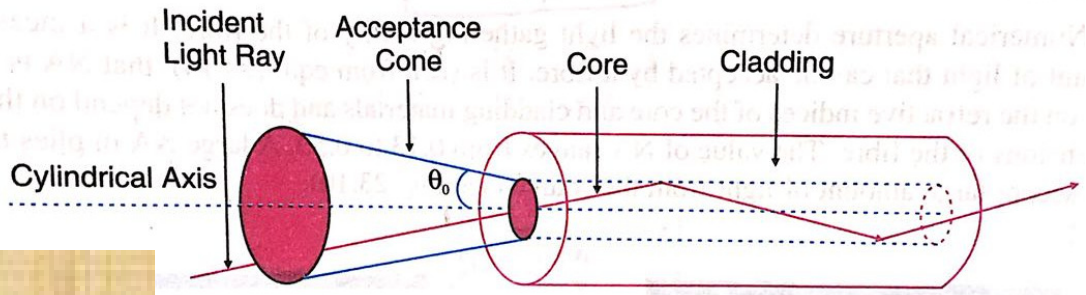
$$\sin \phi_c = \frac{n_2}{n_1}$$



$$\text{Sin } \theta_{imax} = \sqrt{n_1^2 - n_2^2}$$

$$\theta_{imax} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

θ_{imax} is the acceptance angle of the fiber.



$2\theta_{imax}$ = acceptance cone

Revision Lecture 1

Relative Refractive Index

- Δ is always positive because $n_1 > n_2$.
- Typically value of Δ is the order of 0.01
- For effective light transmission through the fiber, $\Delta << 1$.

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

Numerical aperture

$$\text{Sin } \theta_{imax} = \sqrt{n_1^2 - n_2^2}$$

$$NA = sin\theta_{imax}$$

$$\text{NA} = \sqrt{n_1^2 - n_2^2}$$

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

- Measure of the light gathering ability of the fiber
- Depends only on the refractive indices of the core and cladding.
- Independent of the dimension of the fiber
- Typical values are in the range 0.13 to 0.50

Quick QUIZ

Quick Quiz Response on the 9/07/2018 Lecture

No	Question	Attempts	Right	Wrong
1	What is the principle of fiber optical communication?	55	44	11
2	What is the other name for maximum external incident angle?	56	6	50
3	A Fiber optic telephone transmission can handle more than thousands of voice channels. True or false?	55	51	4

What is the principle of fiber optical communication?

a) Frequency modulation
b) Population inversion
c) Total internal reflection
d) Doppler Effect

Ans: C

What is the other name for maximum external incident angle?

a)Optical angle

b)Total internal reflection angle

c)Refraction angle

d) Wave guide acceptance angle

Ans: D

A Fiber optic telephone transmission can handle more than thousands of voice channels. True or false?

(a) True
(b) False

Ans: A

Fiber optics

Lecture 1: ***Fiber optics introduction, optical fibers, Total internal reflection, acceptance angle, relative refractive index numerical aperture.***

Lecture 2:***Classification of fibers, Step index and graded index fibers, V-number, optical fiber as a dielectric wave guide and modes of propagation.***

Learn fundamentals of optical fiber, the fundamental parameters of optical fibers and propagation of light through optical fiber, and types of fibers

Lecture 3: ***Losses associated with optical fibers; Application of optical fibers.***

learn the reason for data loss. Learn about the applications,… endoscopy

TYPES OF OPTICAL FIBER

Optical Fibers are classified into three major categories based on

1. **The material from which it is made**
   - i. **Glass optical fibers**
   - ii. **Plastic Optical fibers**
   - iii. **Plastic Clad Silica (PCS) optical fibers**
2. **The propagation modes through it**
   - *i.* ***Single mode optical fibers***
   - *ii.* ***Multimode optical fibers***
3. **The refractive index profile of the material used**
   - *i.* ***Step-index optical fibers***
   - *ii.* ***Graded index optical fibers***

Cont'd

TYPES OF OPTICAL FIBER

An additional classifications is also made by considering 2 and 3 together.. So we have the 4th category

4. the modes and refractive index profile

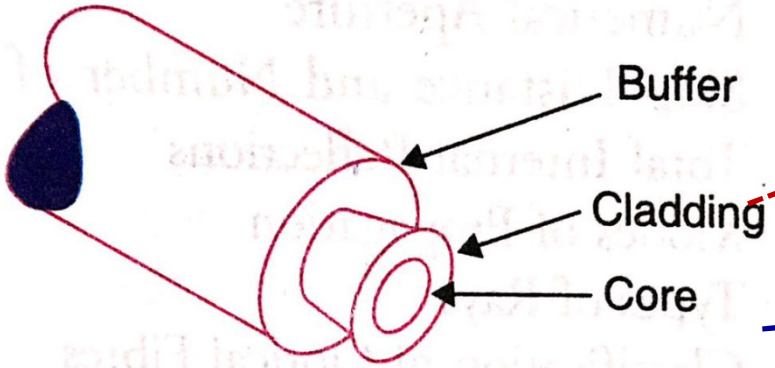
i. **Step-index single mode(SISM) optical fiber**
ii. **Step index multimode (SIMM) optical fiber**
iii. **??? GISM☺**
iv. **Graded-index multimode (GIMM) optical fiber**

We would expect GISM why not given above? It is there but..

As far as single mode fibers are concerned, advantages for GISM fibers compared to SISM fibers are relatively small.

TYPES OF OPTICAL FIBER

ALL GLASS optical fibers



Glass 2 with n_2

Glass 1 with n_1

but $n_1 > n_2$ for Total Internal Function

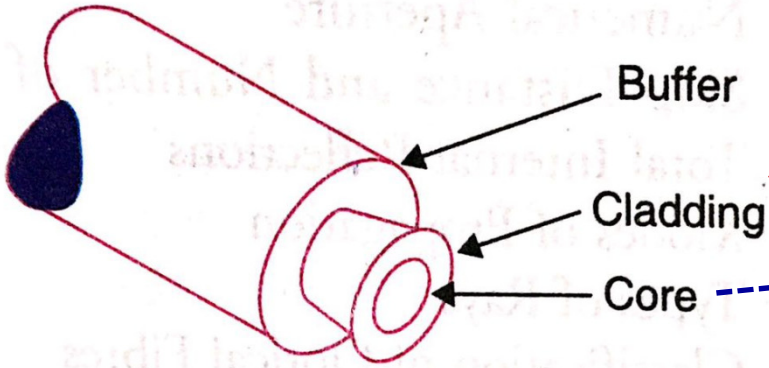
Glass SiO_2.. So abundant on earth crust.. so cheap.. easily available..

You had computer just because of Si and SiO_2 did good with each other up to 2007

SiO_2 core : B_2O_3 : SiO_2 cladding
GeO_2-SiO_2 core: SiO_2 cladding

TYPES OF OPTICAL FIBER

ALL PLASTIC optical fibers



Fluro-carbon polymer or silicone

PMMA or POLYSTERENE

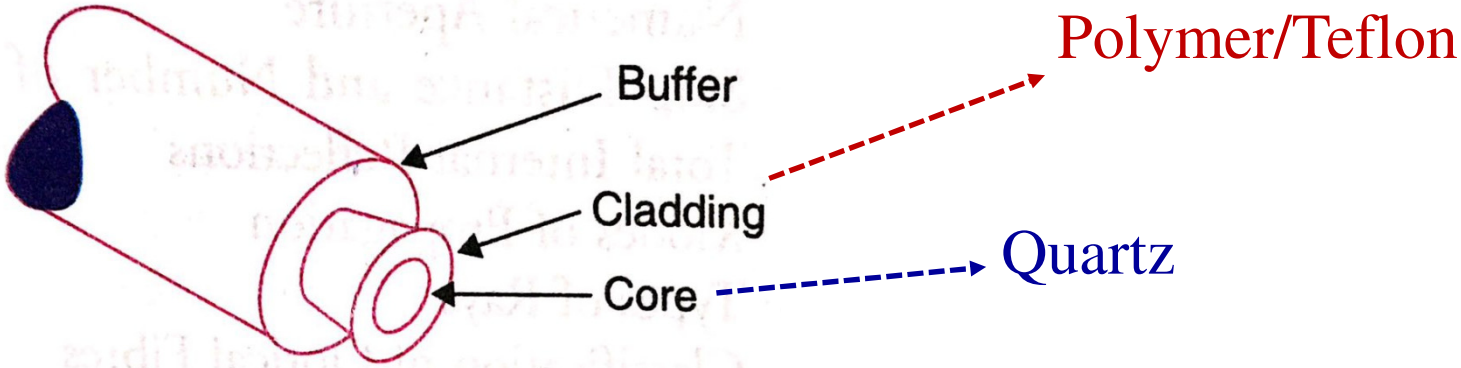
but $n_1 > n_2$ for Total Internal Function

High NA 0.6 and large acceptance angle of 77°

- ✓ Low cost
- ✓ High mechanical stability

TYPES OF OPTICAL FIBER

PLASTIC CLADD SILICA (PCS) optical fibers



but $n_1 > n_2$ for Total Internal Function

High NA 0.6 and large acceptance angle of 77°

- ✓ Low cost
- ✓ High mechanical stability

- ✓ But High loss
  - ✓ Used for low distance

TYPES OF OPTICAL FIBER

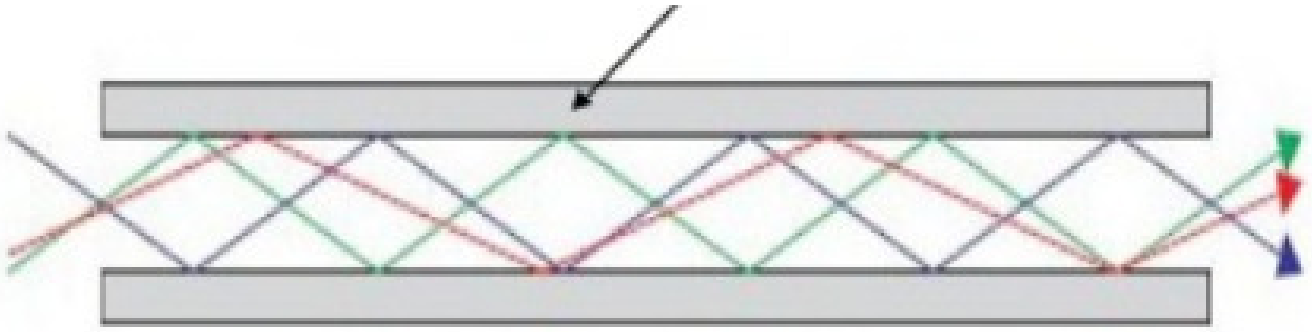
SINGLE MODE OPTICAL FIBER

- ✓ Only one path for light to pass
- ✓ Very small core diameter (~10 µm)
- ✓ Low band width 40 GHz
- ✓ Mostly used in long distance and low cost circuits, like T.V. cable

TYPES OF OPTICAL FIBER

Multimode optical fiber

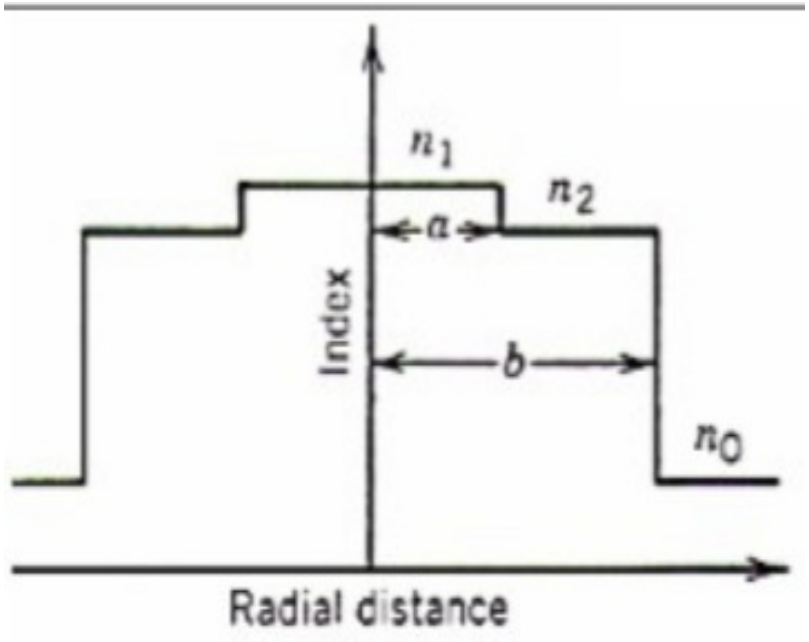
- Light takes more than one path to travel .
- Core is having diameter of 20 to 100μm.
- Usually use for medium distance and high bandwidth.

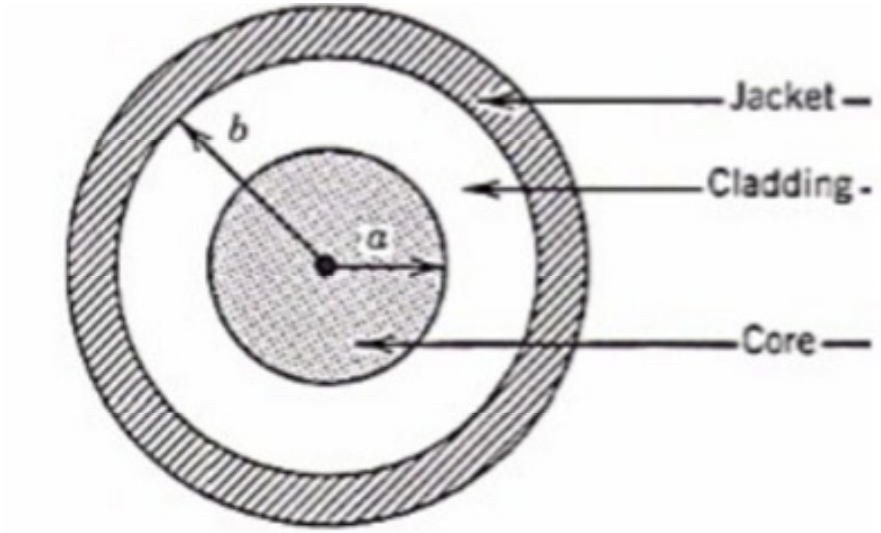


Multimode Fiber

TYPES OF OPTICAL FIBER

Step-index Optical fiber

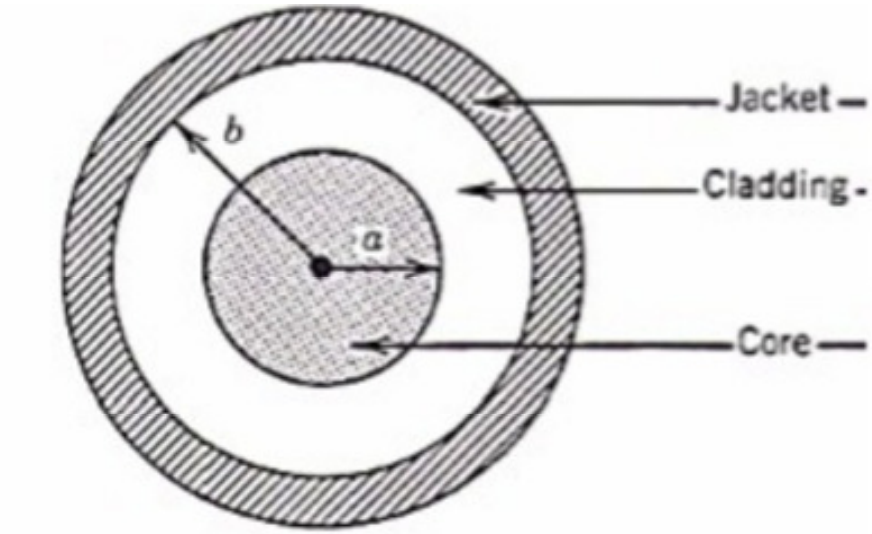


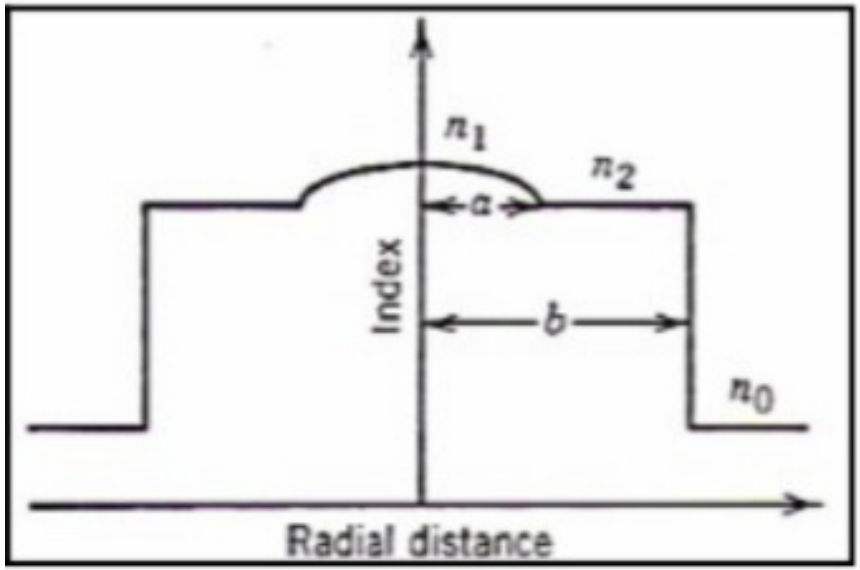


- ✓ Uniform/constant refractive index of the core
- ✓ Core have higher refractive index than cladding
- ✓ Abrupt change in 'n' at the interface
- ✓ Graph of radial distance vs. refractive index seems like a step

TYPES OF OPTICAL FIBER

Graded-index Optical fiber





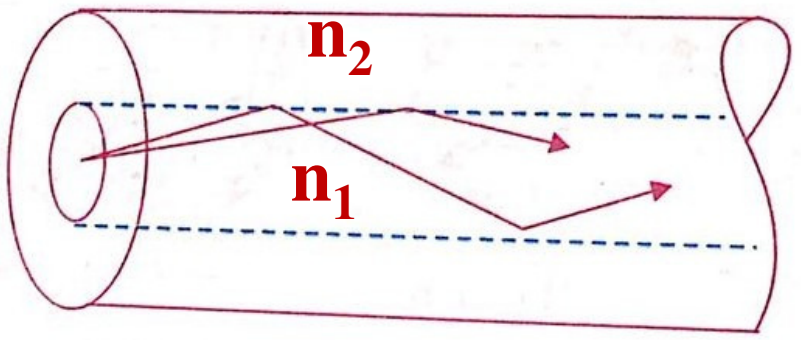
- ✓ Refractive index is highest at the center and decrease towards core-cladding **interface**- n varies gradually with radial distance
- ✓ Symmetric distribution along the diameter- **concentric circles**
- ✓ Same 'n' at the interface- **core material and cladding material have nearly same n**
- ✓ Coaxial tube of material with different n

V-number

V-number gives the upper limit of the number of modes that can be transmitted in a multi mode optical fiber.

$$V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$V = \frac{\pi d}{\lambda}(NA) = \frac{\pi d}{\lambda} n_1 \sqrt{2\Delta}$$



d - the diameter of the core and λ- wavelength of the light

V-number

Maximum number of modes N_m supported by

Step index fiber

$$N_m = \frac{1}{2}V^2$$

Graded Index fiber

$$N_m \cong \frac{1}{4}V^2$$

For a fiber to be single mode $V \leq 2.4$. and the wavelength with which the fiber becomes single mode is called cutoff wavelength λ_c

$$\lambda_c = \frac{\pi d}{2.4}(NA)$$

Single mode transmission in a multimode fiber can be realized by reducing the diameter or decreasing the Δ

Optical fiber as a dielectric wave guide

- Light propagate through an Optical fiber as an electromagnetic wave
- Propagation governed by Maxwell's equations /wave equations

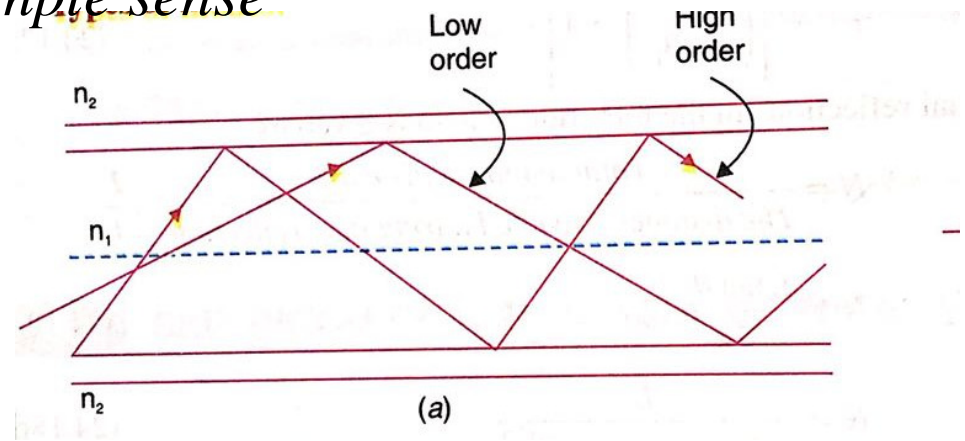
$$\nabla^2\vec{E} = \mu_0\varepsilon_0\frac{\partial^2\vec{E}}{\partial t^2} \qquad \nabla^2\vec{B} = \mu_0\varepsilon_0\frac{\partial^2 B}{\partial t^2}$$

$\varepsilon_r = n^2$ at optical frequency

  - ✓ Light waves in free space are transverse electromagnetic (TEM) waves
  - ✓ In Optical fiber light is guided and hence a different electromagnetic field configurations, either transverse electric (TE) mode or transverse magnetic (TM) mode or hybrid mode.

Optical fiber as a dielectric wave guide

Modes: possible number of allowed paths of light in the optical fiber..*in a simple sense*



Launching angle

$0 \leq \theta \leq \theta_{imax}$

Accepted by the fiber to propagate

Light rays path along which waves (E field or B field) are in phase inside the fiber are knows as mode *in real sense*.

Optical fiber as a dielectric wave guide

- Light rays launched at an angle $\theta = \theta_{imax}$ are higher order modes
- Light rays launched at an angle $\theta << \theta_{imax}$ are lower order modes
- In the lower order fields are concentrated near the center of the waveguide (core).. Less chance to loose light
- In the higher order modes concentrated towards the edge of the wave guide (interface) and more chance of loosing light to the cladding
- Higher order modes travels more distance compared to lower order modes

Quick QUIZ

How does the refractive index vary in Graded Index fiber?

a) Tangentially

b) Radially

c) Longitudinally

d) Transversely

The core of an optical fiber has a

a) Lower refracted index than air

b) Lower refractive index than the cladding

c) Higher refractive index than the cladding

d) Similar refractive index with the cladding

The numerical aperture of a fiber if the angle of acceptance is 15 degrees, is

a) 0.17

b) 0.26

c) 0.50

d) 0.75

Dispersion is used to describe the

a) Splitting of white light into its component colors
b) Propagation of light in straight lines
c) Bending of a beam of light when it goes from one medium to another
d) Bending of a beam light when it strikes a mirror

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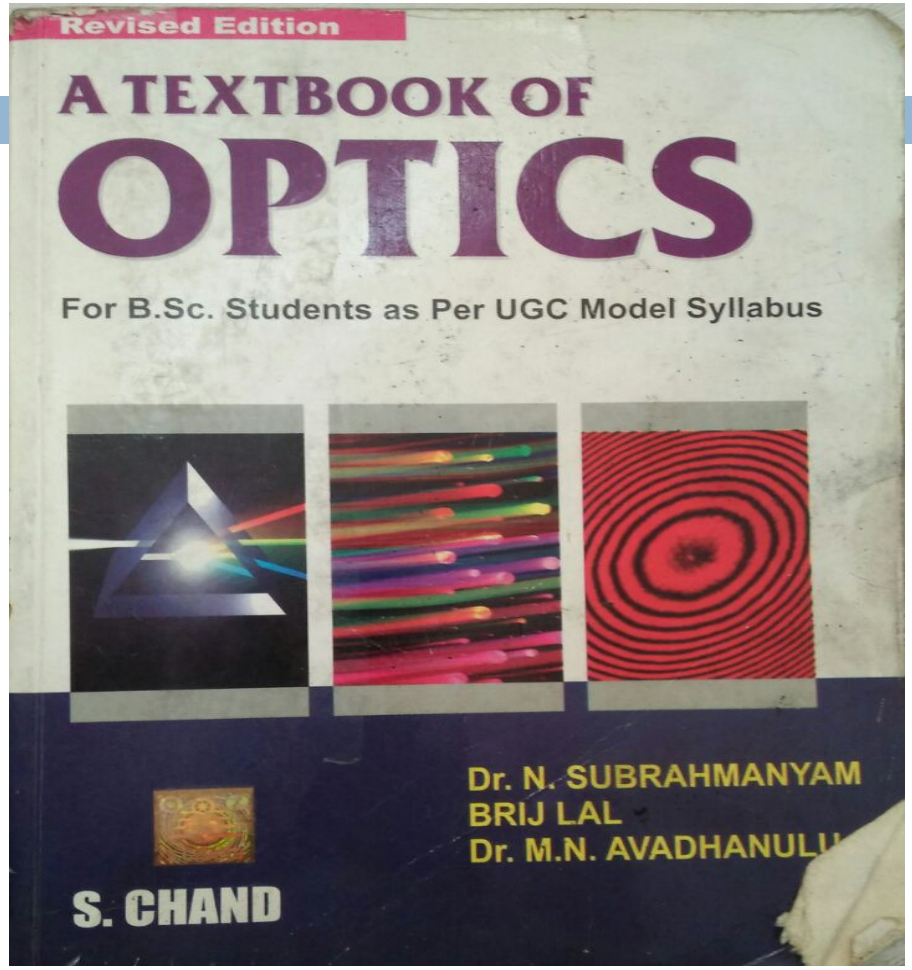
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