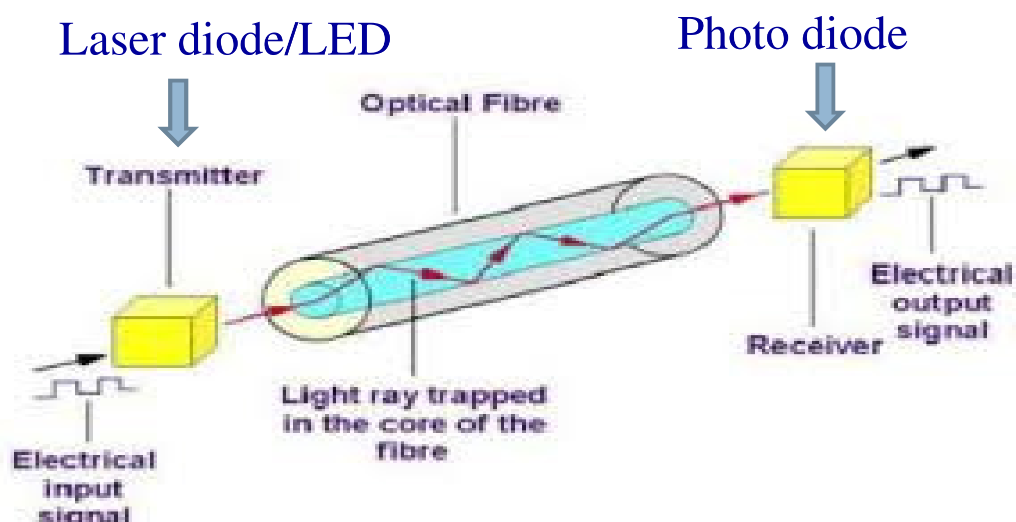
PHY109 UNIT III: Fiber optics

LECTURE 3

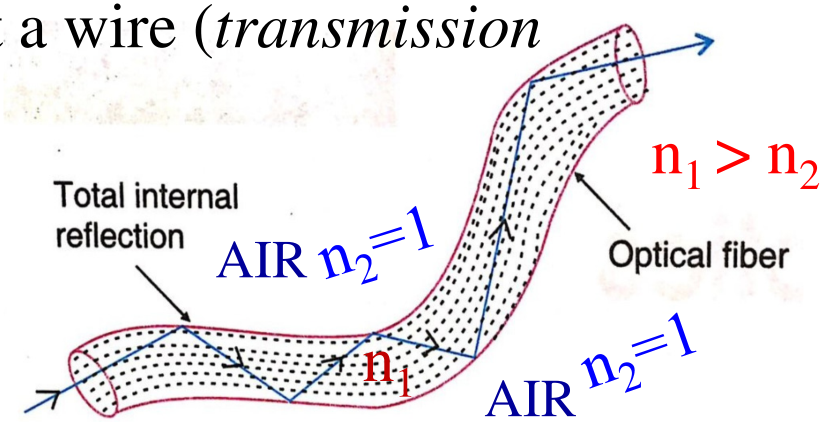
Revision Lecture 1

Thin strand of **dielectric** material we call fiber (*transmission of light*) *where as* if it is of **metal** we call it a wire (*transmission of electrical signal*)

Laser diode: Forward biased
Photo diode: Reverse biased?



OPTICAL FIBER SYSTEM



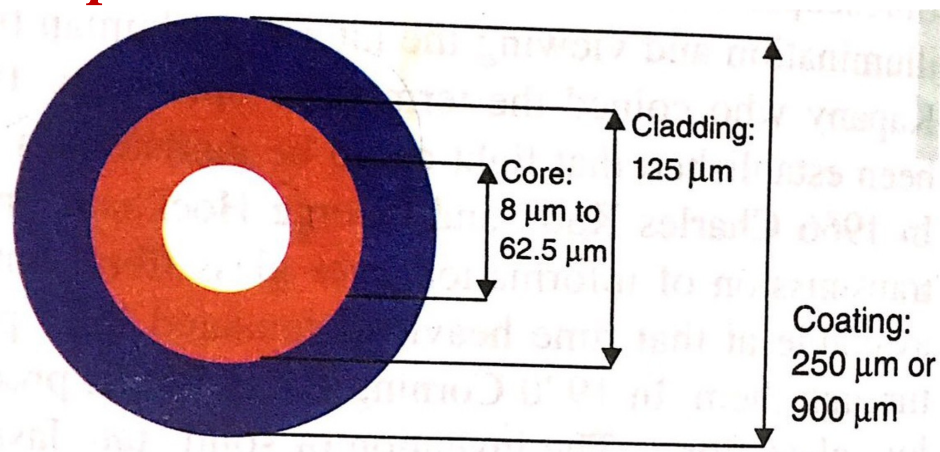
n= refractive index

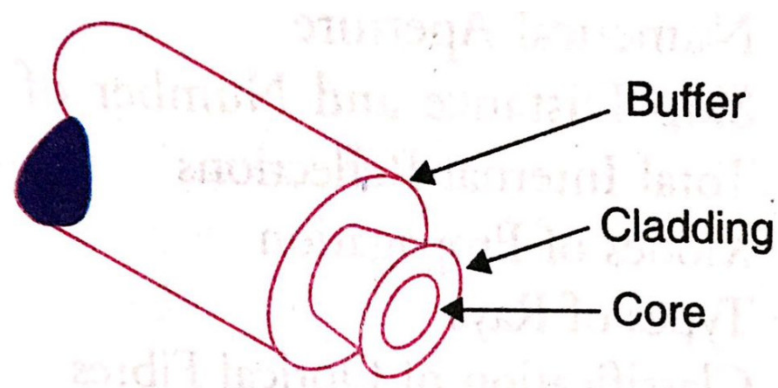
"Fiber optics is a technology in which electrical signal is converted to optical signals and transmitted through fibers and reconverted back into electrical signals"

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*

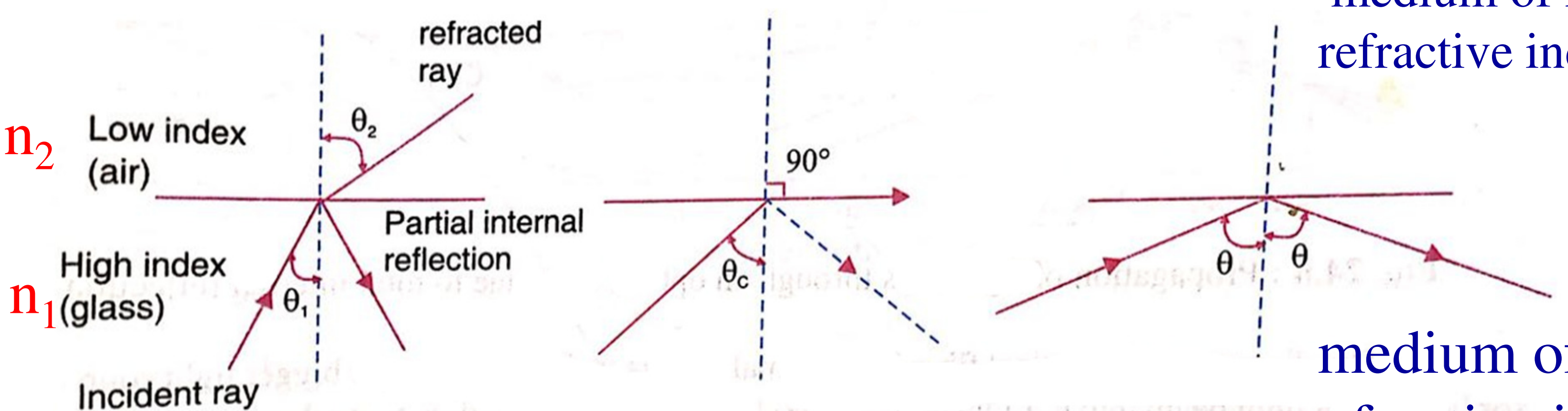
Additional functions of cladding

- ✓ *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:

medium of Low refractive index n_2



medium of High refractive index n_1

Snell's law

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

Critical angle

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

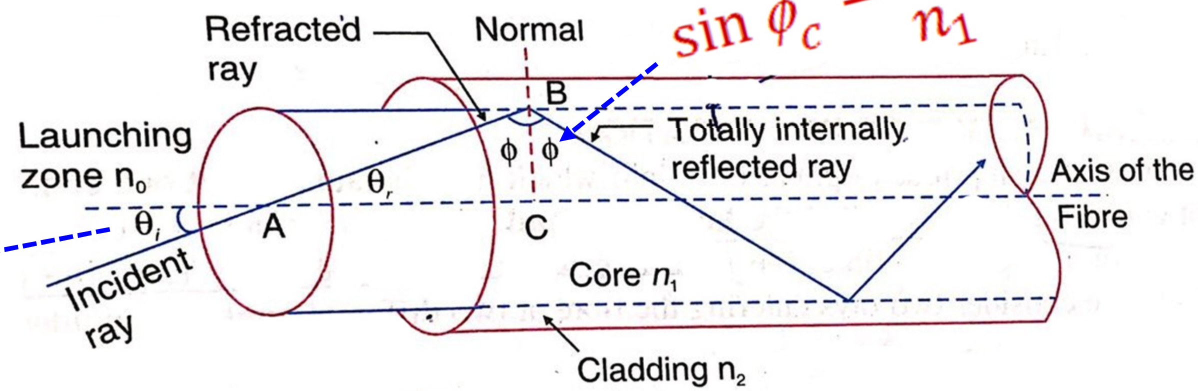
TOTAL INTERNAL REFLECTION

$$\theta > \theta_c$$

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

Revision Lecture 1

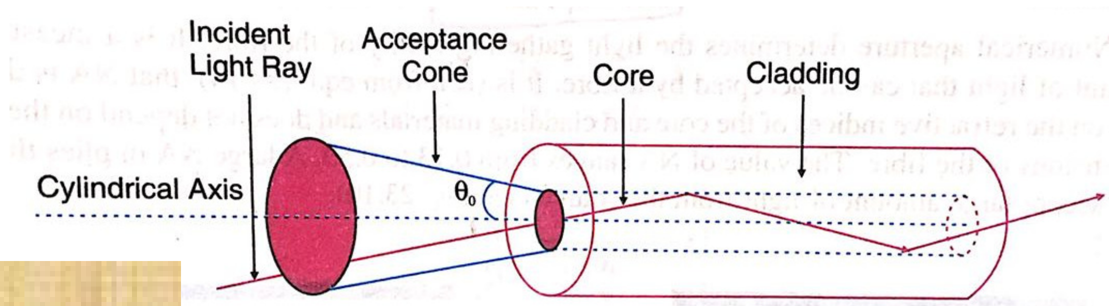
$\sin \phi_c = \frac{n_2}{n_1}$



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

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

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, Δ<<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

Revision Lecture 2

Classification of Optical Fibers

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

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

Revision Lecture 2

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

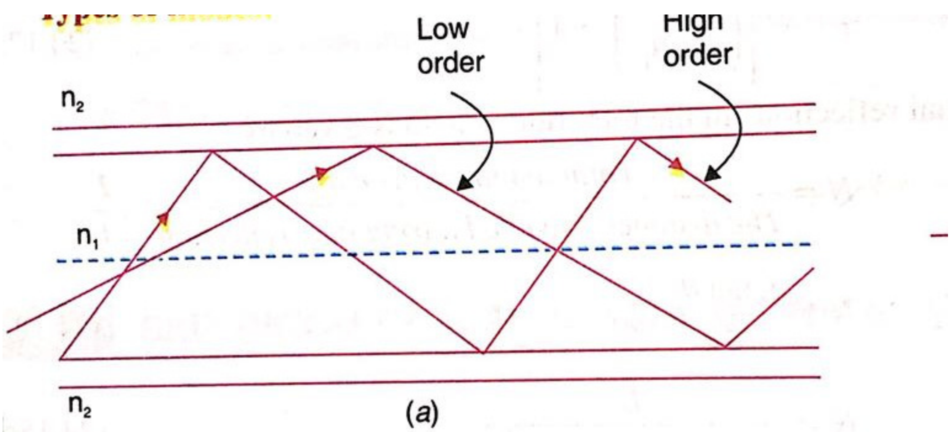
$$N_m = \frac{1}{2}V^2$$

Step index fiber

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

Graded Index fiber

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

Quick QUIZ

Quick Quiz Response on the 9/13/2018 Lecture

No	Question	Attempts	Right	Wrong
1	How does the refractive index vary in Graded Index fiber?	56	14	42
2	The core of an optical fiber has a	56	25	31
3	The numerical aperture of a fiber if the angle of acceptance is 15 degrees, is	56	9	47
4	Dispersion is used to describe the	56	29	27

How does the refractive index vary in Graded Index fiber?

a) Tangentially
b) Radially
c) Longitudinally
d) Transversely

Ans: B

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

Ans: C

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

Ans: B

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

Ans: A

LECTURE SCHEDULE

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

LOSSES IN OPTICAL FIBERS

ATTENUATION

The loss of signal amplitude is known as attenuation

The loss of optical power as light travels down the fiber exponentially depends on the distance

$$P_0 = P_i e^{-\alpha L} \qquad \alpha = \frac{1}{L} ln \frac{P_i}{P_0}$$

P_o is the power at distance L, P_i input power and α is the **fiber attenuation constant**

In unit of dB/km, is defined as,

$$\alpha_{dB/km} = \frac{10}{L} log \frac{P_i}{P_0}$$

In ideal case, $P_i = P_o$ and attenuation is zero

Losses in optical fibers

When the optical signal is made to propagate through the optical fiber, signal strength reduces due to

1. **Attenuation** → ***Intrinsic loss/attenuation***
   a) ***Material absorption***
   b) ***Rayleigh scattering***

2. **Bending of optical fiber** → ***Extrinsic loss/attenuation***

- Loss of amplitude of the signal: attenuation
- Change in shape of the signal: Distortion/dispersion
  Which we are not considering

LOSSES IN OPTICAL FIBERS

1. Losses due to Attenuation

a) Material absorption

- Imperfection and impurities in the fiber account for **3-5 %** loss
  - OH- common impurity-
    - Due to water trapped during the manufacturing process
    - Humidity from the atmosphere
- Cu, Ni,Cr,V, Mn impurities in glass absorb visible wavelength

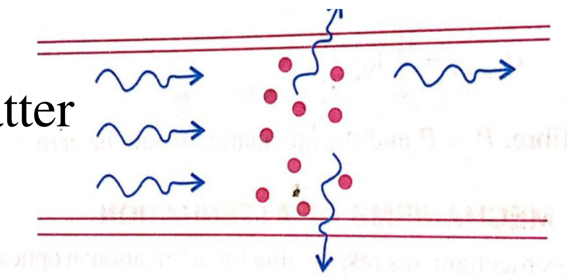
- Electronic absorption at UV and vibrational absorption at IR wavelengths are un avoidable
- Absorption found to be minimum around 1.3 μm
- Propagation of light with wavelength above **1700nm** is not possible due to infrared (IR) absorption

LOSSES IN OPTICAL FIBERS

1. Losses due to Attenuation

b) Rayleigh scattering

- Account for the **96%** of attenuation in the fiber
- Microscopic density variation causes changes in refractive index locally in the fiber
- These obstructions act as scattering centers and scatter light in all direction- Rayleigh scattering
- It varies as $1/\lambda^4$ – high at lower wavelength
- Lower wavelength limit is **800 nm**

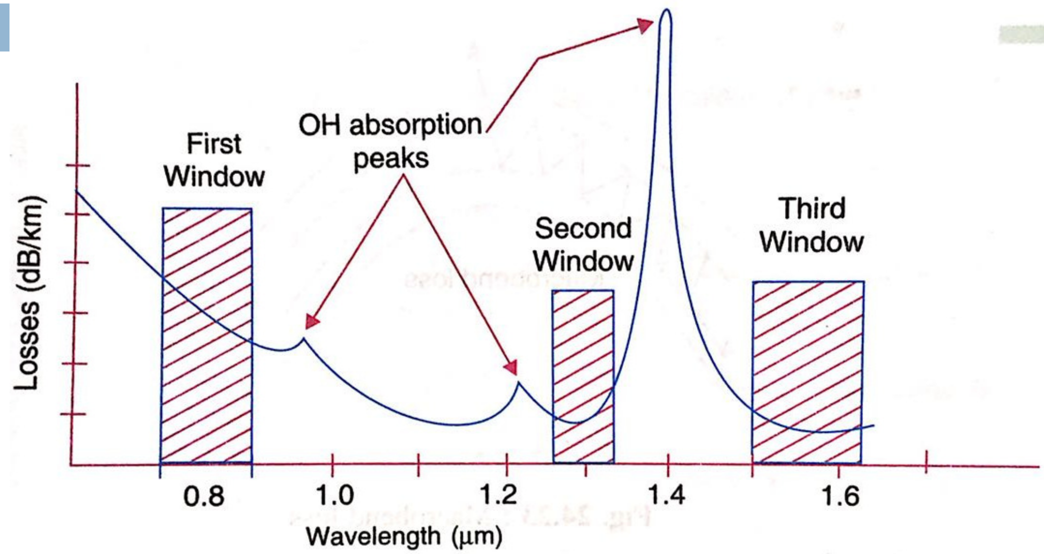


Material absorption set the upper wavelength limit at 1700 nm and Rayleigh scattering set the lower wavelength limit at 800 nm. So light having wavelength in the range **800-1700nm** is used in optical communication!

LOSSES IN OPTICAL FIBERS

1. Losses due to Attenuation

λ nm	loss dB/km
820-880	2.2
1220-1320	0.6
1550-1610	0.2



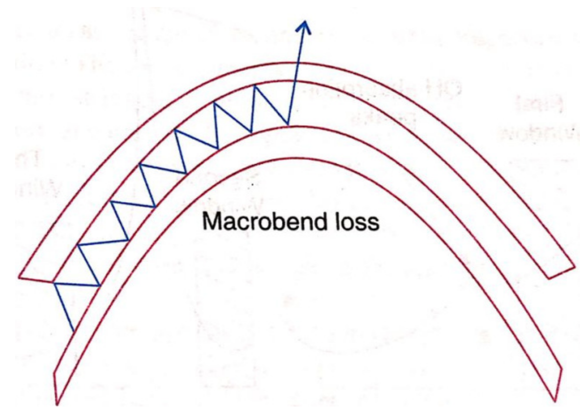
- ✓ The band of wavelength at which the attenuation is a minimum is called optical window or transmission window or low-loss window
- ✓ The range 1550-1610 is most preferable
- ✓ 1300 nm is suitable as the dispersion is minimum

LOSSES IN OPTICAL FIBERS

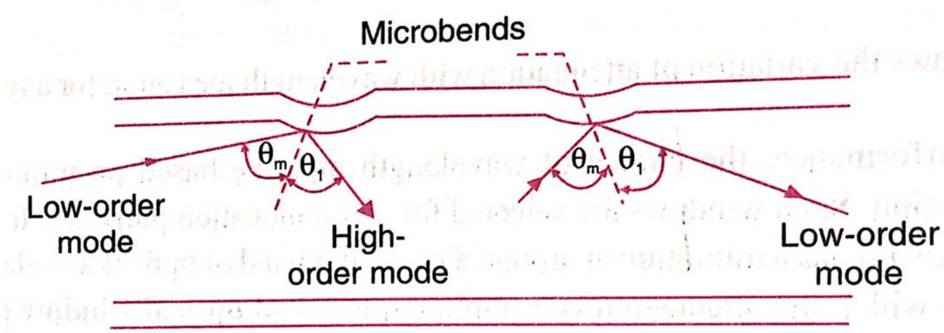
2. Losses due to bending of Optical fiber

a) Macrobend

Fiber is bend in noticeable way and strain induced ‘n’ change TIR conditions and light escape



b) Microbend



- Small scale local bend on the fiber
- Not clearly visible
- Indicative of pressure on the fiber
- Light refracted into the cladding as TIR condition get changed

Applications of optical fiber

1 In communication system

hundred thousands times better than other transmission lines (microwave, radio waves) or wires in carrying the amount of information- higher band width

2. In Fiber optic sensors

Temperature sensor
Mechanical strain sensor
Vibration sensor
Pressure sensor
Acceleration sensor
Chemical sensor

Light beam is changed in five optical properties like, intensity, phase, polarization, wavelength, and spectral distribution. These are sensed

3. Military applications

Wiring of the communication equipment
used in guided missiles

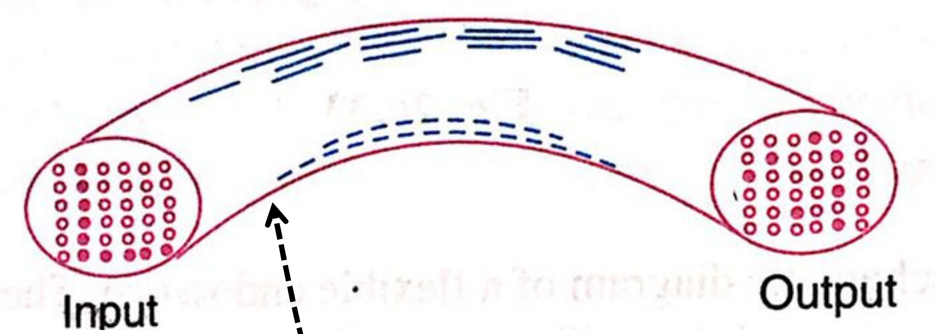
Applications of optical fiber

4. In Medical applications

- Diagnostics- **Endoscopy**
- Ophthalmology- guiding lasers
- Cardiology- optical energy guided to evaporate plaque (blocking the blood circulation in the body)
- Cancer treatment- IR energy transmission line (Infrared laser used)

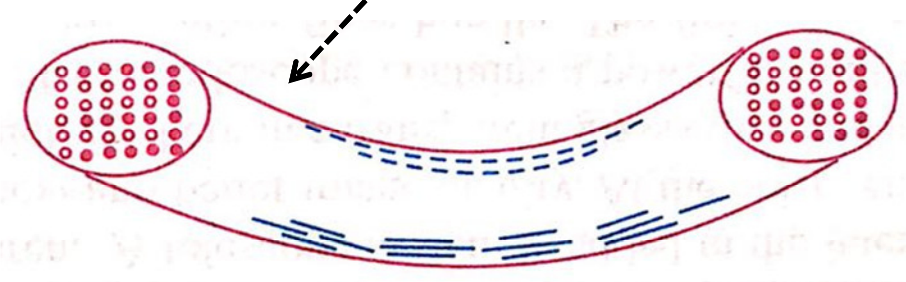
endoscopy (*looking inside*) to look inside the body- We will have a look at the ENDOSCOPY technique now.

OPTICAL ENDOSCOPES



When large number of fibers are bounded together

- ❑ Flexible incoherent bundles
  - ✓ Used for the illumination purpose
- ❑ Flexible coherent bundles:
  - ✓ Capable of sending undistorted image to a distant place
  - ✓ Flexible image carrier



Both forms the interface between the Doctor and the patient's inside body parts to be imaged

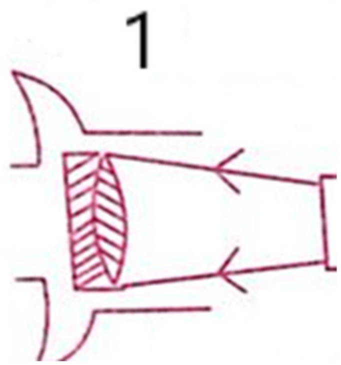
ENDOSCOPE

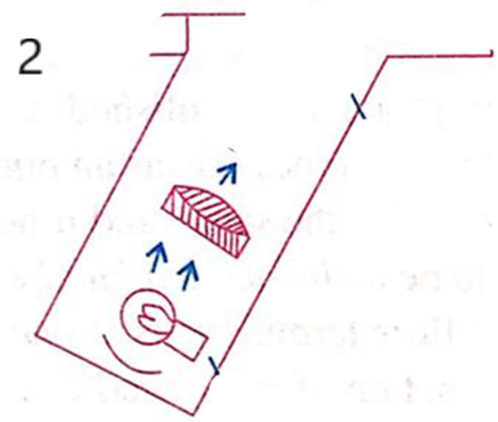
- Fiber bundles (incoherent bundles) used for illuminating the object inside the body
- and another bundle (coherent bundle) used to obtain the image of the object to be seen/scanned
- 10,000 fibers forms the bundle of 1 mm diameter
- Visual inspection of internal parts of a human body

Type of endoscopy

a) Broncho- endoscope
b) Gastrointestinal endoscope
c) Laparoscope

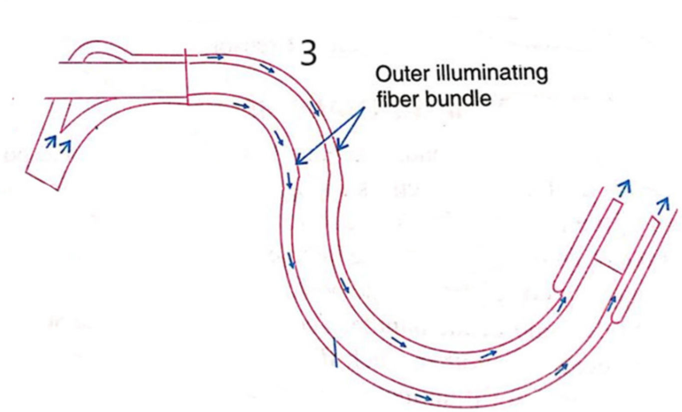
ENDOSCOPES- Parts

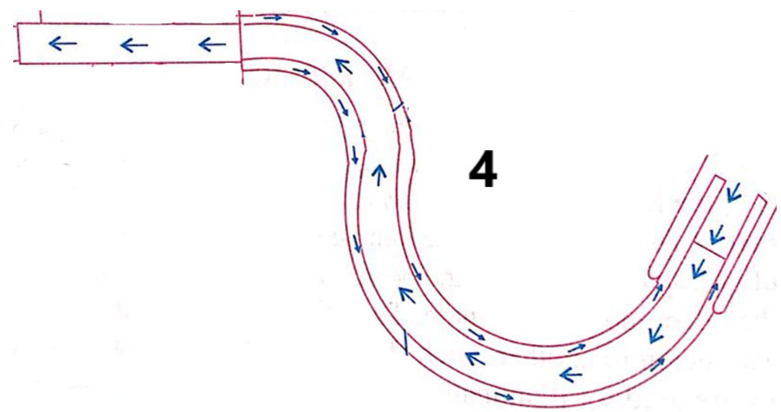




1. Viewing accessories
   - ✓ connected to the coherent optical fiber bundle
   - ✓ Can be connected to a TV screen or just look with your eyes
2. Light source with a focusing lens
   - ✓ connected to the incoherent optical fiber bundle through a beam splitter

ENDOSCOPES- Parts

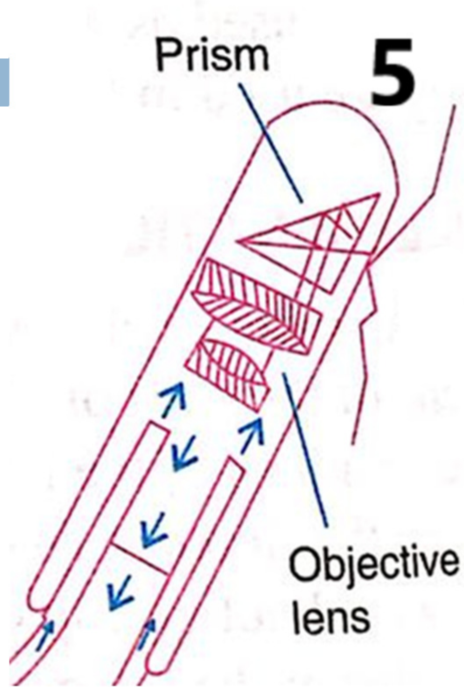




3. Incoherent bundle of optical fiber- receive light from the light source and illuminate the inside body parts
   - ✓ *It include a beam splitter that pass through the both sides of coherent optical fiber bundle*

4. Coherent bundle of optical fiber receive the reflected light from the body parts and the image is fed to the screen

ENDOSCOPE- Parts

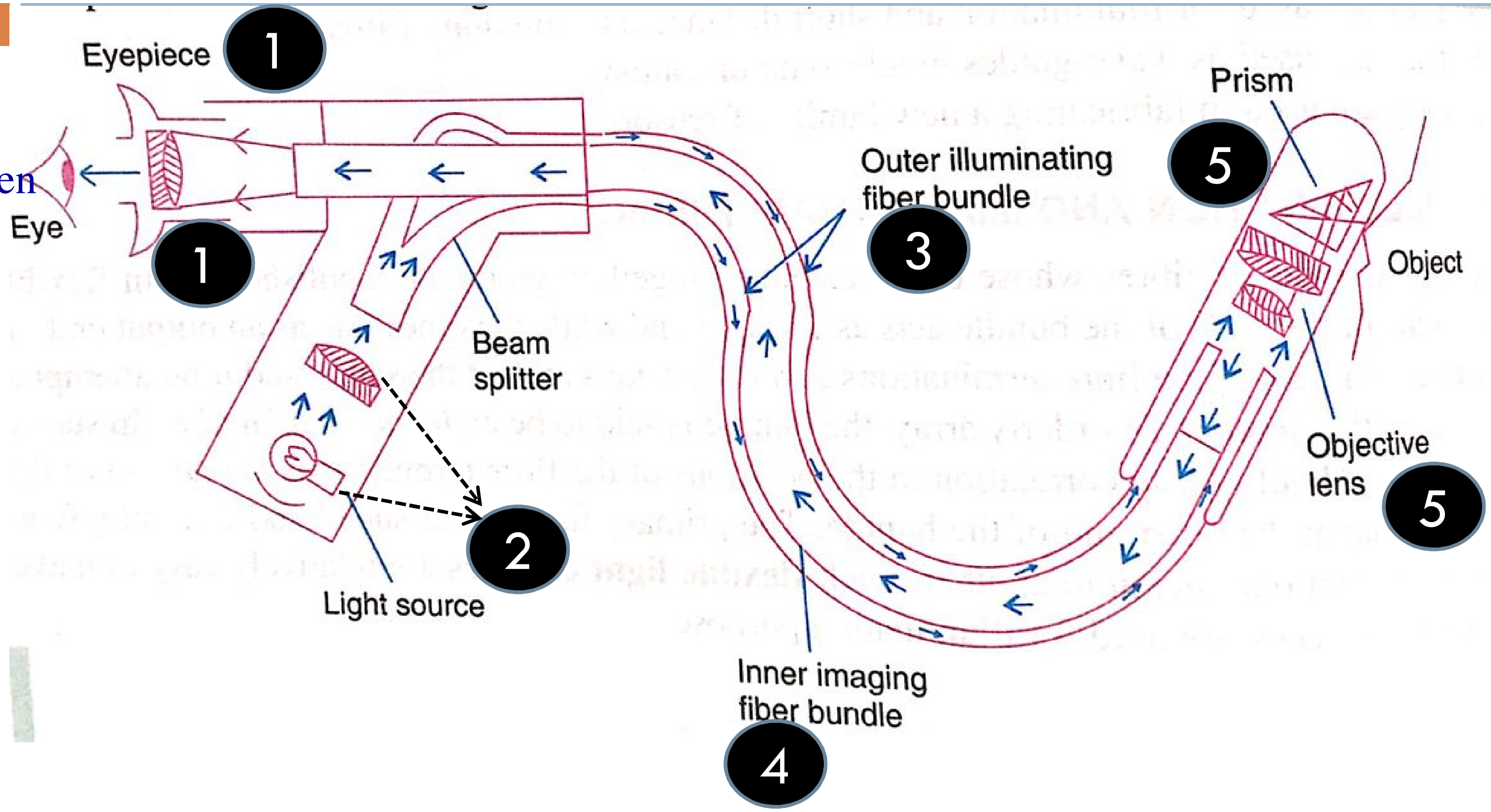


5. Imaging accessories (Prism and lenses encapsulated in the transparent tube) at other end of the coherent and incoherent fiber optic bundles
   - ✓ feed focused light from the incoherent fiber optic bundles to the body parts
   - ✓ receive the reflected light from the illuminated body
   - ✓ and feed back those light to the coherent fiber optic bundles.. *Remember this light not coupled to the incoherent optical fiber bundle*

Now we connect the these five component together in the 'right way' we get a an ENDOSCOPE as can been in the next slide

ENDOSCOPE and ENDOSCOPY

TV screen



Now you do some imaging with this instrument (ENDOSCOPE) and it is ‘ENDOSCOPY’☺

Quick QUIZ

The loss in signal power as light travels down a fiber is called

a. Dispersion
b. Scattering
c. Absorption
d. Attenuation

A dielectric waveguide for the propagation of electromagnetic energy at light frequencies is know as

a. Stripline
b. Microstrip
c. Laser beam
d. Optical Fiber

Which of the following is used as an optical transmitter on the Fiber Optical Communications?

a. Avalanche Photo Diode APD

b. Tunnel diode

c. PIN diode

d. Light Emitting Diode

Which of the following is used as an optical receiver in fiber optics communications?

a. Avalanche Photo Diode (APD)

b. Tunnel diode

c. Laser diode

d. Light Emitting Diode (LED)

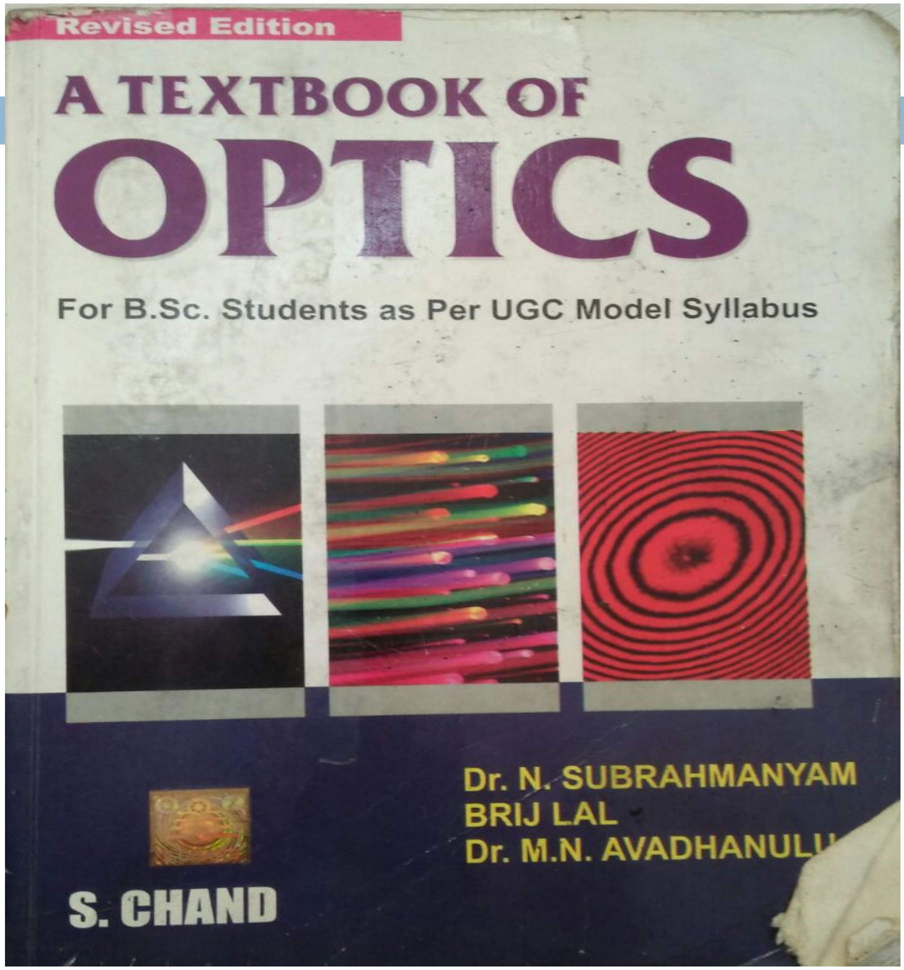
UNIT III: Fiber optics

Syllabus

Fiber optics introduction, optical fiber as a dielectric wave guide, total internal reflection, acceptance angle, numerical aperture, relative refractive index, V-number, step index and graded index fibers, losses associated with optical fibers, application of optical fibers.

So we uncovered the UNIT III- and hence you are all now the masters of 'Optical fiber' and the science behind it…

And.. My job done… and you study well and score high and start loving physics☺.. Good engineers are good physicist as well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