# Chapter 6: Optical fibers

Er.Hom Nath Tiwari

Pashchimanchal Campus,

Lamachaur, Pokhara

homnath@wrc.edu.np

Department of Electronics and Computer Engineering

# Course structure

1. Optical fiber communication system and its advantages and disadvantages over Metaled wire communication system

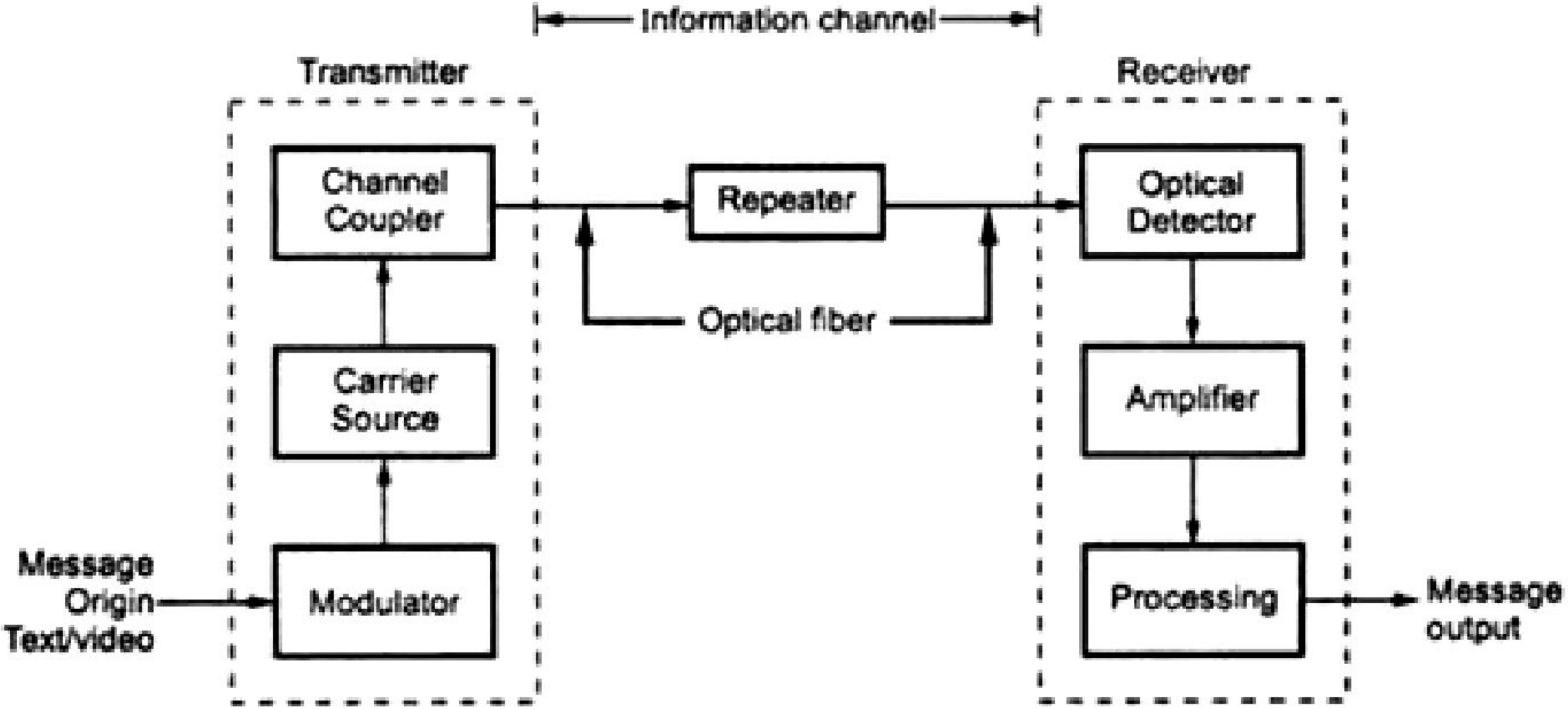
2. Types of optical fiber and its structural difference

3. Light propagation characteristics and Numerical Aperture (NA) in optical fiber

4. Losses

5. Light source and photo detector

# Block diagram of optical communication



## Message origin:

- Generally message origin is from a transducer that converts a non-electrical message into an electrical signal. Common examples include microphones for converting sound waves into currents and video (TV) cameras for converting images into current. For data transfer between computers, the message is already in electrical form.

## Modulator:

- The modulator has two main functions.

1) It converts the electrical message into proper format.

2) It impresses this signal onto the wave generated by the carrier source.

- Two distinct categories of modulation are used i.e. analog modulation and digital modulation.

## Carrier source:

- Carrier source generates the wave on which the information is transmitted. This wave is called the carrier. For fiber optic system, a laser diode (LD) or a light emitting diode (LED) is used. They can be called as optic oscillators, they provide stable, single frequency waves with sufficient power for long distance propagation.

## Channel coupler:

- Coupler feeds the power into information channel. For an atmospheric optic system, the channel coupler is a lens used for collimating the light emitted by the source and directing this light towards the receiver. The coupler must efficiently transfer the modulated light beam from the source to the optical fiber. The channel coupler design is an important part of fiber system because of possibility of high losses.

## Information channel:

- The information channel is the path between the transmitter and receiver. In fiber optic communications, a glass or plastic fiber is the channel. Desirable characteristics of the information channel include low attenuation and large light acceptance cone angle. Optical amplifiers boost the power levels of weak signals. Amplifiers are needed in very long links to provide sufficient power to the receiver. Repeaters can be used only for digital systems. They convert weak and distorted optical signals to electrical ones and then regenerate the original digital pulse trains for further transmission.
- Another important property of the information channel is the propagation time of the waves travelling along it. A signal propagating along a fiber normally contains a range of fiber optic frequencies and divides its power along several ray paths. This results in a distortion of the propagation signal. In a digital system, this distortion appears as a spreading and deforming of the pulses. The spreading is so great that adjacent pulses begin to overlap and become unrecognizable as separate bits of information.

## Optical detector:

- The information begin transmitted is detected by detector. In the fiber system the optic wave is converted into an electric current by a photodetector. The current developed by the detector is proportional to the power in the incident optic wave. Detector output current contains the transmitted information. This detector output is then filtered to remove the constant bias and then amplified.
- The important properties of photodetectors are small size, economy, long life, low power consumption, high sensitivity to optic signals and fast response to quick variations in the optic power.
- Signal processing includes filtering, amplification. Proper filtering maximizes the ratio of signal to unwanted power. For a digital system decision circuit is an additional block. The bit error rate (BER) should be very small for quality communications.

## Signal processing:

Signal processing includes filtering, amplification. Proper filtering maximizes the ratio of signal to unwanted power. For a digital syst5em decision circuit is an additional block. The bit error rate (BER) should be very small for quality communications.

## Message output:

The electrical form of the message emerging from the signal processor is transformed into a sound wave or visual image. Sometimes these signals are directly usable when computers or other machines are connected through a fiber system.

## Advantages of Fiber Optic Transmission

- Optical fibers have largely replaced copper wire communications in core networks in the developed world, because of its advantages over electrical transmission. Here are the main advantages of fiber optic transmission.
- **Extremely High Bandwidth:** No other cable-based data transmission medium offers the bandwidth that fiber does. The volume of data that fiber optic cables transmit per unit time is far great than copper cables.
- **Longer Distance:** in fiber optic transmission, optical cables are capable of providing low power loss, which enables signals can be transmitted to a longer distance than copper cables.
- **Resistance to Electromagnetic Interference:** in practical cable deployment, it’s inevitable to meet environments like power substations, heating, ventilating and other industrial sources of interference. However, fiber has a very low rate of bit error (10 EXP-13), as a result of fiber being so resistant to electromagnetic interference. Fiber optic transmission is virtually noise free.

- **Low Security Risk:** the growth of the fiber optic communication market is mainly driven by increasing awareness about data security concerns and use of the alternative raw material. Data or signals are transmitted via light in fiber optic transmission. Therefore there is no way to detect the data being transmitted by "listening in" to the electromagnetic energy "leaking" through the cable, which ensures the absolute security of information.
- **Small Size:** fiber optic cable has a very small diameter. For instance, the cable diameter of a single OM3 multimode fiber is about 2mm, which is smaller than that of coaxial copper cable. Small size saves more space in fiber optic transmission.
- **Light Weight:** fiber optic cables are made of glass or plastic, and they are thinner than copper cables. These make them lighter and easy to install.
- **Easy to Accommodate Increasing Bandwidth:** with the use of fiber optic cable, new equipment can be added to existing cable infrastructure. Because optical cable can provide vastly expanded capacity over the originally laid cable. And WDM (wavelength division multiplexing) technology, including CWDM and DWDM, enables fiber cables the ability to accommodate more bandwidth.

# Disadvantages of Fiber Optic Transmission

- Though fiber optic transmission brings lots of convenience, its disadvantages also cannot be ignored. **Fragility:** usually optical fiber cables are made of glass, which lends to they are more fragile than electrical wires. In addition, glass can be affected by various chemicals including hydrogen gas (a problem in underwater cables), making them need more cares when deployed under ground.
- **Difficult to Install:** it's not easy to splice fiber optic cable. And if you bend them too much, they will break. And fiber cable is highly susceptible to becoming cut or damaged during installation or construction activities. All these make it difficult to install.
- **Attenuation & Dispersion:** as transmission distance getting longer, light will be attenuated and dispersed, which requires extra optical components like EDFA to be added.
- **Cost Is Higher Than Copper Cable:** despite the fact that fiber optic installation costs are dropping by as much as 60% a year, installing fiber optic cabling is still relatively higher than copper cables. Because copper cable installation does not need extra care like fiber cables. However, optical fiber is still moving into the local loop, and through technologies such as FTH (fiber to the home, premises, etc.) and PONs (passive optical networks), enabling subscriber and end user broadband access.
- **Special Equipment Is Often Required:** to ensure the quality of fiber optic transmission, some special equipment is needed. For example, equipment such as OTDR (optical time-domain reflectometry) is required and expensive, specialized optical test equipment such as optical probes and power meter are needed at most fiber endpoints to properly provide testing of optical fiber.

## Applications of Optical Fiber Communications

- Fiber optic cables find many uses in a wide variety of industries and applications. Some uses of fiber optic cables include:
- **Medical** Used as light guides, imaging tools and also as lasers for surgeries
- **Defense/Government** Used as hydrophones for seismic waves and SONAR , as wiring in aircraft, submarines and other vehicles and also for field networking
- **Data Storage** Used for data transmission
- **Telecommunications** Fiber is laid and used for transmitting and receiving purposes
- **Networking** Used to connect users and servers in a variety of network settings and help increase the speed and accuracy of data transmission
- **Industrial/Commercial** Used for imaging in hard to reach areas, as wiring where EMI is an issue, as sensory devices to make temperature, pressure and other measurements, and as wiring in automobiles and in industrial settings
- **Broadcast/CATV** Broadcast/cable companies are using fiber optic cables for wiring CATV, HDTV, internet, video on-demand and other applications
- Fiber optic cables are used for lighting and imaging and as sensors to measure and monitor a vast array of variables. Fiber optic cables are also used in research and development and testing across all the above mentioned industries

**The optical fibers have many applications. Some of them are as follows –**

- Used in telephone systems
- Used in sub-marine cable networks
- Used in data link for computer networks, CATV Systems
- Used in CCTV surveillance cameras
- Used for connecting fire, police, and other emergency services.
- Used in hospitals, schools, and traffic management systems.
- They have many industrial uses and also used for in heavy duty constructions.

# Ray Theory Transmission

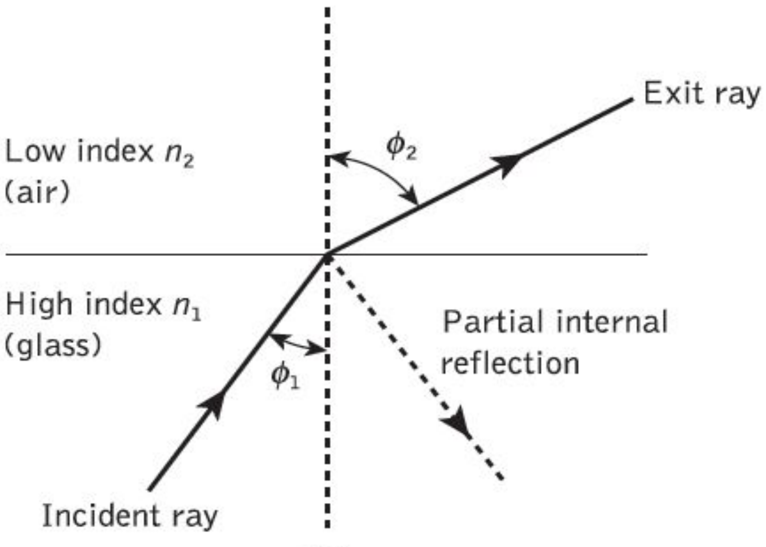
$$\text{Refractive index of a medium} = \frac{\text{Velocity of light in a medium}}{\text{Velocity of light in a vacuum}}$$

## Total internal reflection

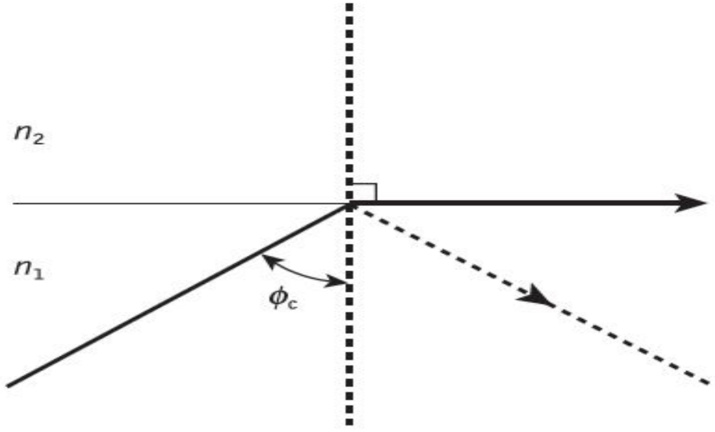
- **Refraction**
  - When a ray is incident on the interface between two dielectrics of differing refractive indices (e.g. glass – air) refraction occurs shown in Fig. a.
  - The angle of incidence φ1 and angle of refraction φ2 is related by Snell's law of refraction

$$n_1 \sin\varphi_1 = n_2 \sin\varphi_2 \quad \text{(or)}$$

$$\frac{\sin \varphi_1}{\sin \varphi_2} = \frac{n_2}{n_1}$$

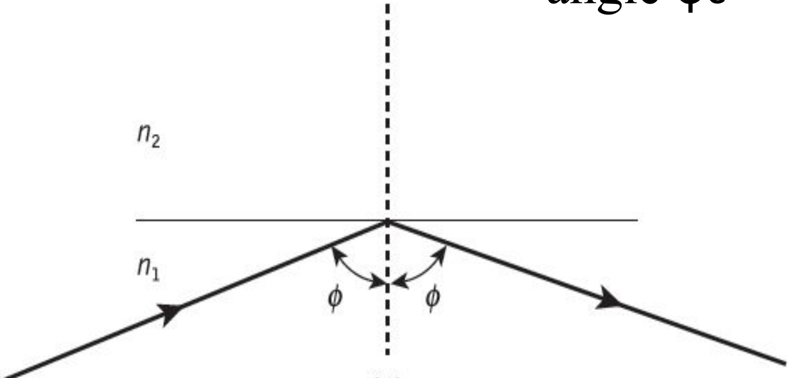



(a) Refraction




(b)

Limiting case of refraction- critical ray at angle φc




(c)

Total internal reflection

- **Critical angle**

  - As n1 is greater than n2,the angle of refraction is always greater than the angle of incidence.
  - Thus when the angle of refraction is 90° and the refracted ray emerges parallel to the interface between the dielectrics, the angle of incidence must be less than 90°. This is the limiting case of refraction and the angle of incidence is now known as the critical angle φc (Fig. b),

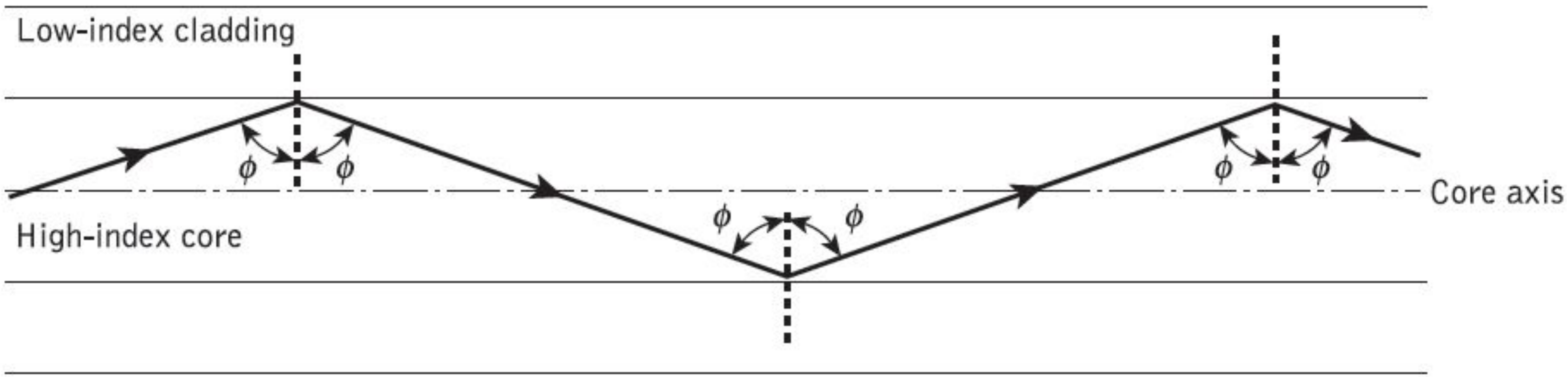
$$\sin \phi_c = \frac{n_2}{n_1}$$

- **Total internal reflection**

  - When light is incident on the dielectric of lower index from the dielectric of higher index an at angles of incidence greater than critical angle. (Fig. c)

# Propagation of light wave through Optical fiber

- Any light wave which travels along the core and meets the cladding at the critical angle of incidence will be totally internally reflected. Therefore light wave is propagated along the fiber core by a series of total internal reflections.



# Fiber Structure

- It has
  - Core
  - Cladding.
- Core
  - Single solid dielectric cylinder
  - Refractive index – n1
- Cladding
  - Core is surrounded by cladding.
  - Refractive index – n2 & n2<n1.
- Need for cladding
  - Reduces scattering loss
  - Provides mechanical strength
  - Protects core from absorbing surface contaminants.

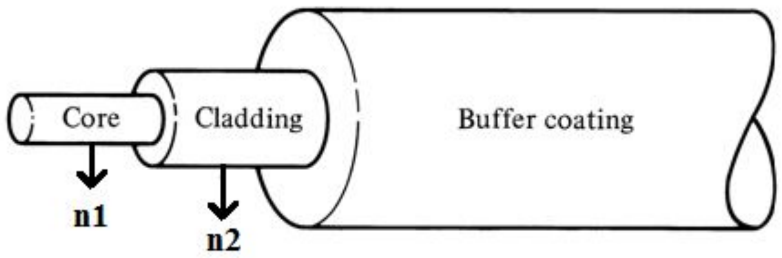


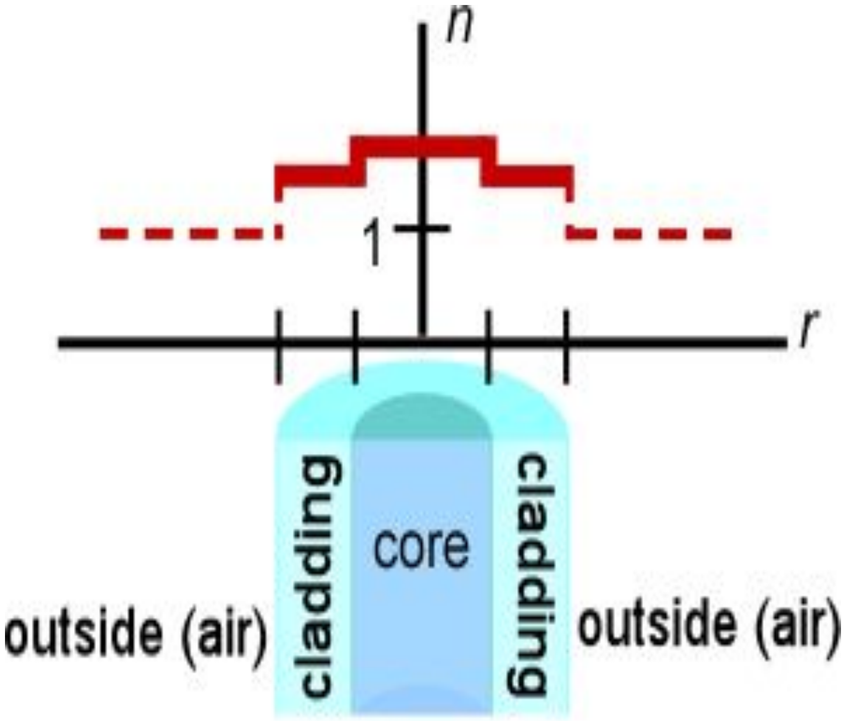

Fig. Schematic of single fiber structure

- Buffer coating
  - Elastic, absorption resistant material
  - Use- add further strength to the fiber

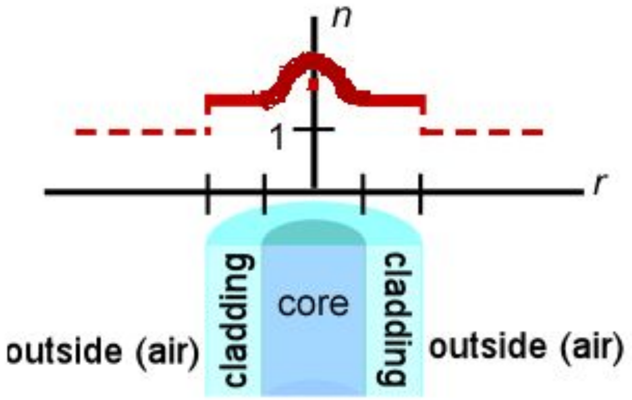
# Types of Optical Fiber

✔ Variation in material composition of the core gives 2 types of fiber.

- **Step index fiber**
  - Refractive index of core is uniform throughout and undergoes an abrupt change at the core cladding boundary.



- **Graded index fiber**
    - Refractive index of core is made to vary as a function of radial distance from the centre of the fiber.




✔ Based on modes 2 types of fibers are available.

- ✔ Single Mode Fiber.
- ✔ Multi Mode Fiber.

# Modes Of Optical Fibers

- There are two modes of optical fibers

1. Single Mode(Mono Mode) Fiber
2. Multi Mode Fiber

- A single mode fiber has a smaller core diameter and can support only one mode of propagation. On the other hand, a multimode fiber has a larger core diameter and supports a number of modes.
- Multimode fibers are further distinguished on the basis of index-profile. A multimode fiber can be either a step index type or graded index GRIN type. Single mode fiber is usually a step index type.

**1. Single Mode(Monomode) Step Index Fiber**

- A single mode step index fiber has a very fine thin core of uniform refractive index of a higher value which is surrounded by a cladding of lower refractive index. The refractive index changes abruptly at the core cladding boundary because of which it is known as step index fiber.

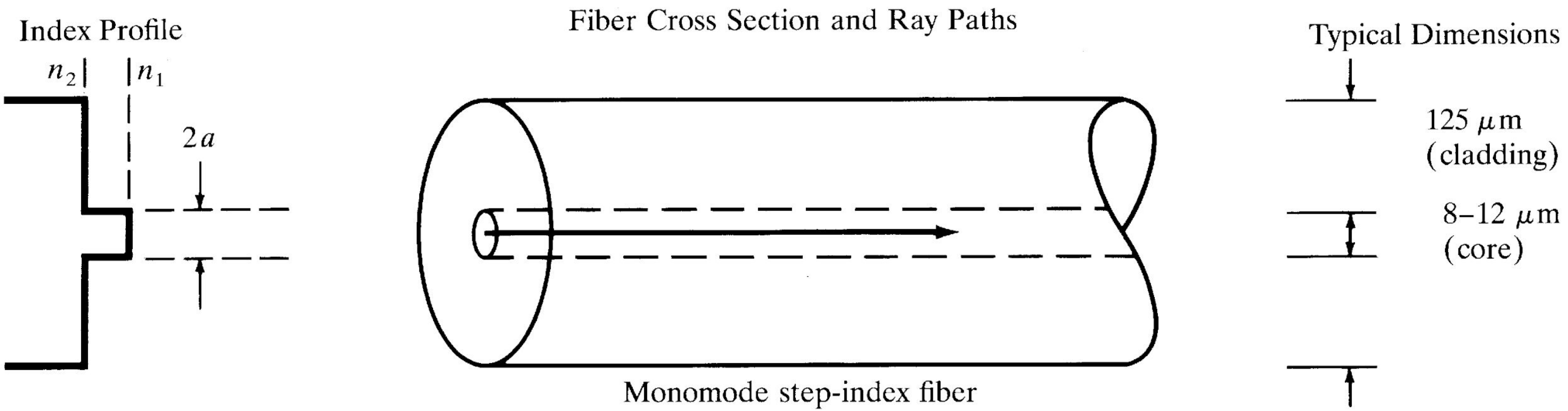



**Fig: 2.5**

The fiber is surrounded by an opaque protective sheath. A typical SMF has a core diameter of 8-12 µm. Light travels in SMF along a single path, i.e., along the axes obviously it is zero order mode that is supported by a SMF. A SMF is characterized by a very small value of D. It is of the order of 0.002.

## 2. Multimode Step Index Fiber

- A multimode step index fiber is very much similar to the single mode step index fiber except that its core is of bigger diameter. A typical fiber has a core diameter of 50-200 μm. Light follows zigzag paths inside the fiber. Many such zigzag paths of propagation are permitted in a MMF. The *NA* of a MMF is larger as core diameter of the fiber is larger, it is of the order of 3.

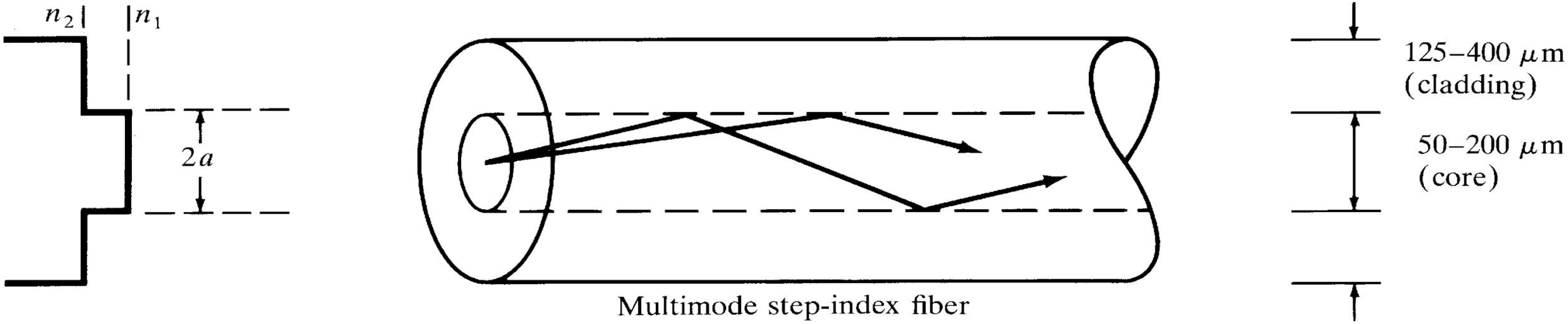



**Fig: 2.6**

## 3. Multimode Graded Index Fiber

- A graded index fiber is a multimode fiber with a core consisting of concentric layers of different refractive indices therefore the refractive index of the core varies with distance from the fiber axis. It has high value at the center and falls off with increasing radial distance from the axis. In case of GRIN fibers, the acceptance angle and numerical aperture decrease with radial distance from the axis (Fig. 2.8). For fibers of parabolic index profile, the numerical aperture is given by

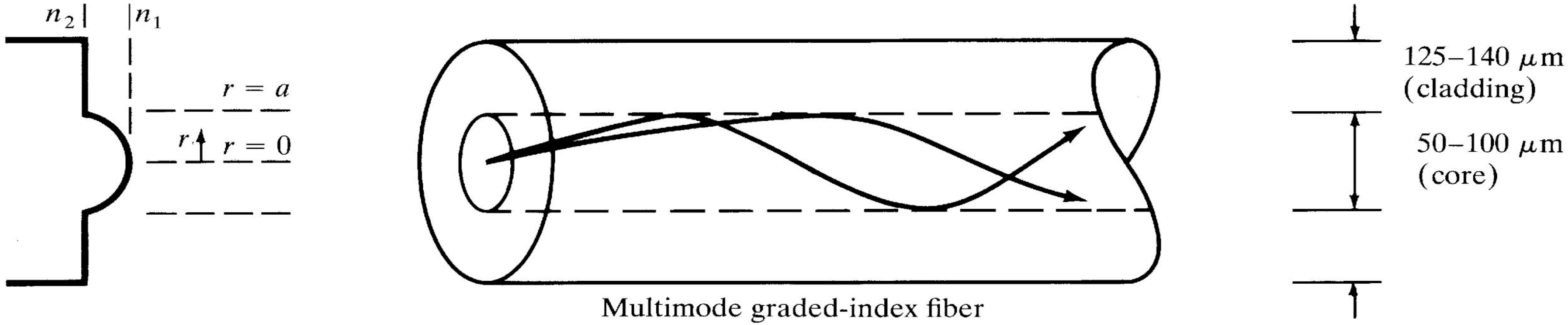



**Fig : 2.8**

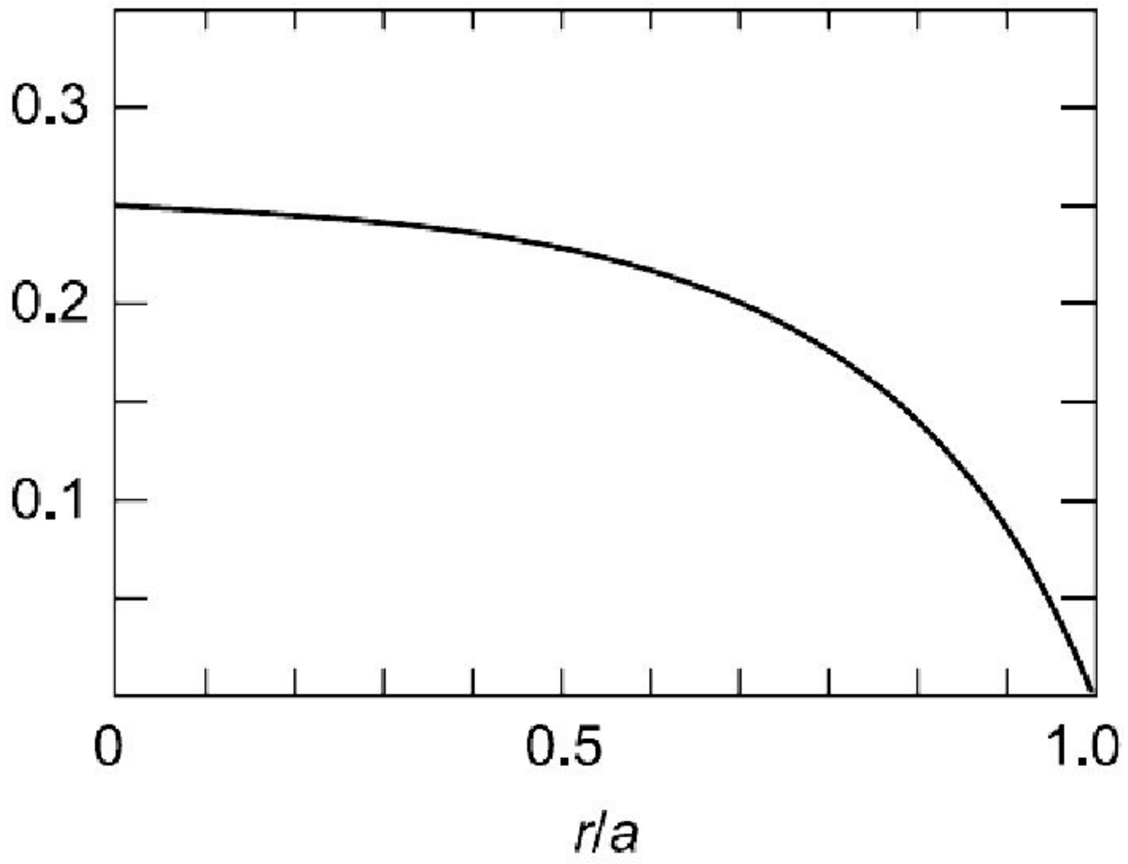



**Fig. 2.8** Illustration of variation of numerical aperture of a parabolic index fibre.

$$NA = n_1 (2\Delta)^{1/2} \sqrt{1-(r/a)^2}$$

## Comparison between Single Mode and Multimode Fibres

| Single Mode | Multimode |
|---|---|
| 1. It supports only one mode of of propagation. | 1. It supports a large number of modes propagation |
| 2. It has very small core diameter of the order of 5 to 10 μm. | 2. It has larger core diameter of the order of 50 to 150 μm. |
| 3. Transmission losses are very small. | 3. Transmission losses are more. |
| 4. It has higher bandwidth. | 4. It has lower bandwidth. |
| 5. It requires laser diode as source of light. | 5. It can work with LED also. |
| 6. It is used for long distance | 6. It is used for short distance communication. |
| 7. It is by default step index fibre. | 7. It can be step index or graded index fibre. |
| 8. Mostly it is made up of glass. | 8. It is made preferably from plastic. |

# Comparison between Step Index and Graded Index Fibres

| Step Index Fibre | Graded Index Fibre |
|---|---|
| 1. Refractive index is uniform fort the core and suddenly charges at core cladding boundary. | 1. Refractive index of core is not uniform. It is maximum along the axis of core and decreases towards core cladding boundary. |
| 2. Pulse distortion is present. | 2. Pulse distortion is minimum. |
| 3. It can be single mode or multimode. | 3. It is only multimode. |
| 4. It can be manufactured easily. | 4. Manufacturing is not easy. |
| 5. It has high numerical aperture. | 5. It has low numerical aperture. |
| 6. Attenuation is higher. | 6. Attenuation is lower. |
| 7. It offers lower bandwidth. | 7. It offers higher bandwidth. |
| 8. Reflection losses are present. | 8. Reflection losses are absent. |

## 2.4 Numerical Aperture Of A Fibre

- A glass fiber consists of a cylindrical central core, clad by a material of slightly lower m. Light rays impinging on the core cladding interface at an angle greater than the critical angle are trapped inside the core of the wave guide rays making larger angle with the axis take longer amount of time to travel the length of the fiber.
- For a ray entering the fiber, if the angle of incidence at the core – cladding interface f is greater than the critical angle f *c*, then the ray would undergo total internal reflection at that interface. Further because of the cylindrical symmetry in the fiber structure, the ray would suffer total internal reflections at the lower interface also and would therefore get guided through the core by repeated total internal reflections.

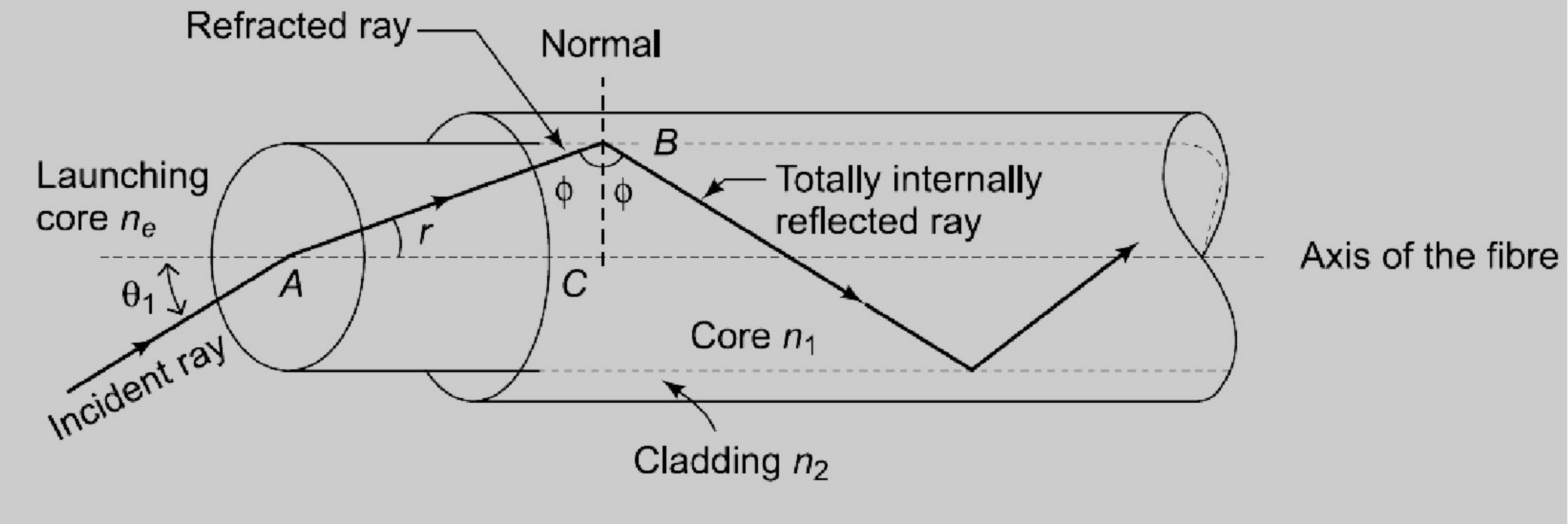



**Fig. 2.9**

*i* = angle made by the incident ray in entrance aperture of the fiber.

*r* = angle made by refracted ray with the axis.

$$\therefore \qquad \frac{\sin i}{\sin r} = \frac{n_1}{1} = n_1 \qquad (1)$$

The condition for total internal reflection to take place is

$$\sin \phi \geq \frac{n_2}{n_1}$$

$$\sin (90 - r) \geq \frac{n_2}{n_1} \text{ as from Fig. 2.9}$$

$$\cos r \geq \frac{n_2}{n_1}$$

$$= \sqrt{1 - \sin^2 r} \geq \frac{n_2}{n_1}$$

$$\sin^2 r \leq 1 - \left(\frac{n_2}{n_1}\right)^2$$

$$\sin r \leq \sqrt{1-\left(\frac{n_2}{n_1}\right)^2} \qquad (2)$$

But from (1) $\dfrac{\sin i}{n_1} = \sin r.$

Putting in (2), we get

$$\frac{\sin i}{n_1} \leq \sqrt{1-\frac{n_2^2}{n_1^2}}.$$

$$\sin i \leq \sqrt{n_1^2 - n_2^2}$$

If $i_{max}$ is the maximum angle of incidence for which total internal refraction can occur

$$\sin i_m = \sqrt{n_1^2 - n_2^2} \quad \text{for } n_1^2 - n_2^2 < 1$$

$$= 1 \quad \text{for } n_1^2 - n_2^2 \geq 1$$

- If a core of light is incident on one end of the fiber, it will be guided through it provided the semi-angle of the core is less than *im*. This angle is a measure of the light gathering power of the fiber and as such one defines the *NA* of the fiber by the following equation.

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

## Numerical Aperture Definition

The numerical aperture ($NA$) is defined as the sine of the acceptance angle.

$$\therefore \qquad NA = \sin i_m$$

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

$$n_1^2 - n_2^2 = (n_1 + n_2)(n_1 - n_2)$$

$$= \left(\frac{n_1 + n_2}{2}\right)\left(\frac{n_1 + n_2}{n_1}\right).2n_1$$

approximate $\dfrac{n_1 + n_2}{2} \approx n_1$

$$\therefore \qquad (n_1^2 - n_2^2) = 2n_1^2 \Delta$$

$$\therefore \qquad NA = n_1 \sqrt{2\Delta} \rightarrow \Delta = \left(\frac{n_1 - n_2}{n_1}\right)$$

$$= \text{fractional refractive index change.}$$

$\Delta$ has to be + ve as $n_1 > n_2$. In order to guide light rays effectively through a fibre $\Delta << 1$.

Typically D is of the order of 0.01.

Numerical aperture determines the light gathering ability of the fiber. It is a measure of the amount of light that can be accepted by a fiber. It is seen that *NA* is dependent only on the refractive indices of the core and cladding material. Its value ranges from 0.13 to 0.50. A large *NA* implies that a fiber will accept large amount of light from the source.

# CRITICAL ANGLE

- When the angle of refraction is 90° and the refracted ray emerges parallel to the interface between the dielectrics, the angle of incidence must be less than 90°. This is the limiting case of refraction and the angle of incidence is now known as the critical angle φc, the value of the critical angle is given by

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

At angles of incidence greater than the critical angle the light is reflected back into the originating dielectric medium (total internal reflection) with high efficiency (around 99.9%)

## Acceptance Angle

- We know that the maximum angle of incidence for which the total internal refraction can occur is

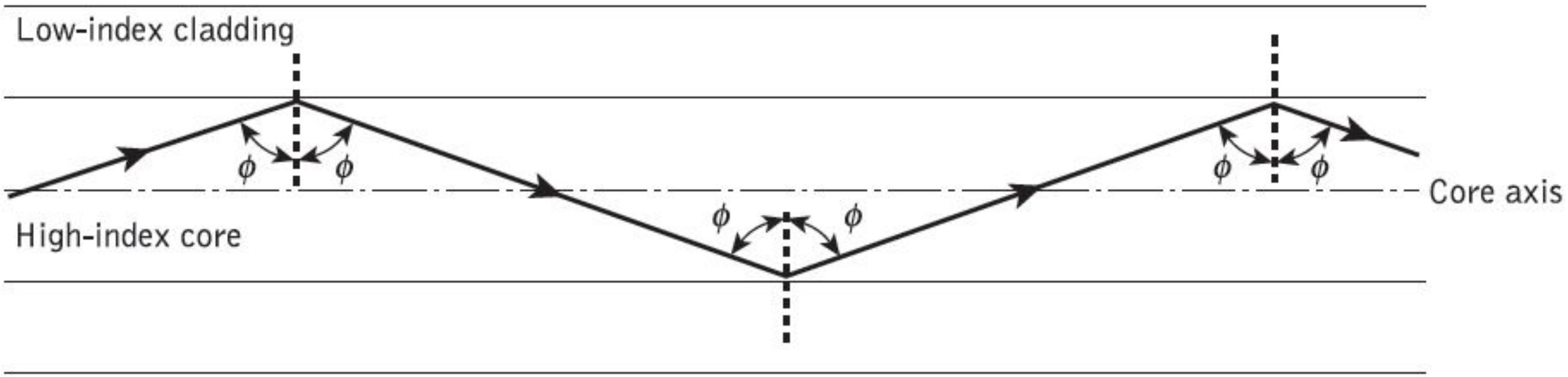
$$\sin i_m = \sqrt{n_1^2 - n_2^2}$$

$$i_m = \sin^{-1}\sqrt{n_1^2 - n_2^2}\ .$$

The angle $i_m$ is called the acceptance angle of the fibre. Acceptance angle may be defined as the maximum angle that a light ray can have relative to the axis of the fibre and propagate down the fibre.

# Types of Rays

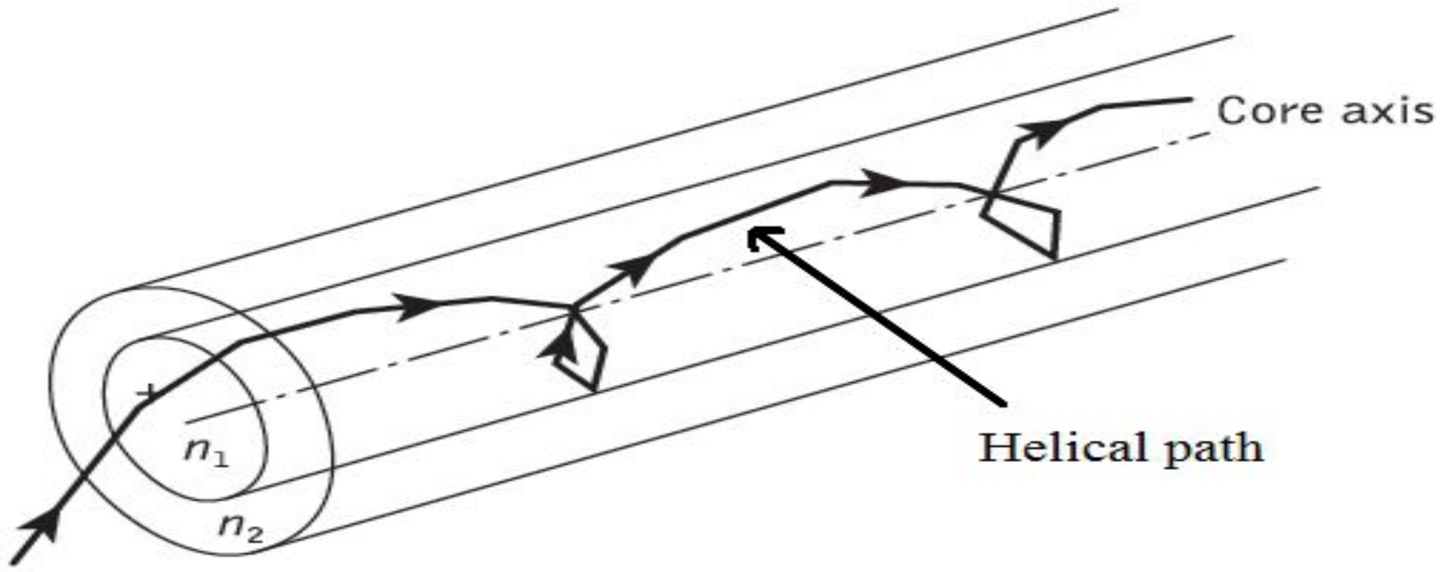
- 2 types.
  - **Meridional rays** – confined to the Meridional planes of the fiber, which are the planes that contain the axis of symmetry of the fiber.
    - Types
      - **Bound rays** – propagates along the fiber axis according to the law of geometric optics.
      - **Unbound rays** – that are refracted out of the fiber.



❑ **Skew rays**

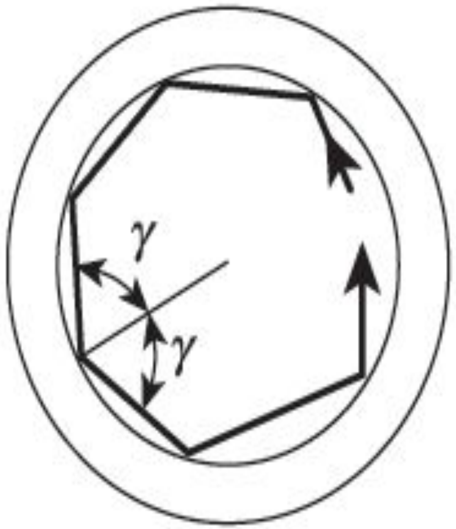
# Skew Rays

✔ Skew rays are the rays following the helical path around the fiber axis when they travel through the fiber and they would not cross the fiber axis at any time.



- It is not easy  to visualize them in two dimensions and hence they are observed in fig.

- **The helical path traced through the fiber gives change in direction of 2γ at each reflection.**




Where, γ – **angle b/w the projection of ray and the radius of the fiber core at the point of reflection.**

- Skew rays **depend on the number of reflections** they undergo rather than input conditions of the fiber.
- When the **light input is non-uniform**, skew rays tend to have a **smoothing effect** on the distribution of light as it is transmitted giving a **more uniform output**.
- The amount of **smoothing depends on the number of reflections** encountered by the skew rays.
- **In order to calculate acceptance angle for a skew ray, it is necessary to define the direction of ray in 2 perpendicular planes.**

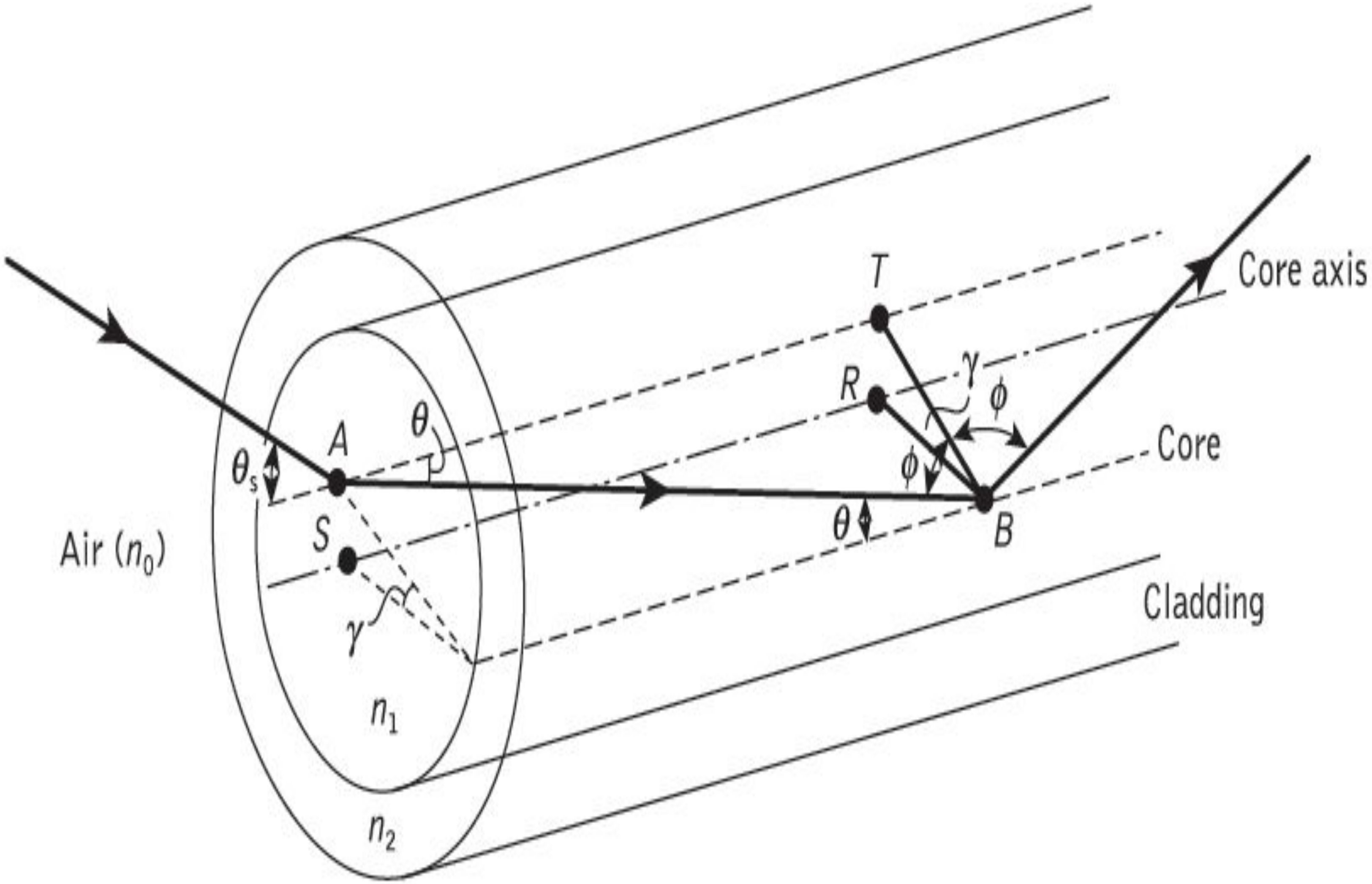



Fig : The ray path within the fiber core for a skew ray incident at an angle θs to the normal at the air-core interface

- **θa for skew rays**

$$\sin \theta_{as} = (n_1^2 - n_2^2)^{1/2} / \cos \gamma$$

$$\sin \theta_{as} = NA / \cos \gamma$$

- **θa for meridional rays**

$$\sin \theta_a = (n_1^2 - n_2^2)^{1/2}$$

# Fiber losses

## MATERIAL LOSS

**Due to impurities:** The material loss is due to the impurities present in glass used for making fibers. Inspite of best purification efforts, there are always impurities like Fe, Ni,Co, Al which are present in the fiber material. The Fig. shows attenuation due to various molecules inside glass as a function of wavelength. It can be noted from the figure that the material loss due to impurities reduces substantially beyond about 1200nm wavelength.

**Due to OH molecule:** In addition, the OH molecule diffuses in the material and causes absorption of light. The OH molecule has main absorption peak somewhere in the deep infra-red wavelength region. However, it shows substantial loss in the range of 1000 to 2000nm.

**Due to infra-red absorption :** Glass intrinsically is a good infra-red absorber. As we increase the wavelength the infra-red loss increases rapidly.

**Attenuation**

- Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of the fiber.
- In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfection within the fiber. Nearly 90 % of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.
- The rate at which light is absorbed is dependent on the wavelength of the light and the characteristics of particular glass. Glass is a silicon compound, by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.
- The Rayleigh scattering is wavelength dependent and reduces rapidly as the wavelength of the incident radiation increases.
- The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. Attenuation loss is measured in dB/km.
- As attenuation leads to a loss of power along the fiber, the output power is significantly less than the couples power. Let the couples optical power is p(0) i.e. at origin (z = 0).

Then the power at distance z is given by,

$$P(z) = P(0)e^{-\alpha_p z}$$

## Absorption

Absorption loss is related to the material composition and fabrication process of fiber. Absorption loss results in dissipation of some optical power as hear in the fiber cable. Although glass fibers are extremely pure, some impurities still remain as residue after purification. The amount of absorption by these impurities depends on their concentration and light wavelength.

Absorption in optical fiber is caused by these three mechanisms.

- 1. Absorption by atomic defects in the glass composition
- 2. Extrinsic absorption by impurity atoms in the glass material
- 3. Intrinsic absorption by the basic constituent atoms of the fiber material.

**Absorption by Atomic Defects**

- Atomic defects are imperfections in the atomic structure of the fiber materials such as missing molecules, high density clusters of atom groups. These absorption losses are negligible compared with intrinsic and extrinsic losses.
- The absorption effect is most significant when fiber is exposed to ionizing radiation in nuclear reactor, medical therapies, space missions etc. The radiation dames the internal structure of fiber. The damages are proportional to the intensity of ionizing particles. This results in increasing attenuation due to atomic defects and absorbing optical energy. The total dose a material receives is expressed in rad (Si), this is the unit for measuring radiation absorbed in bulk silicon.
- 1 rad (Si) = 0.01 J.kg

**Extrinsic Absorption**

- Extrinsic absorption occurs due to electronic transitions between the energy level and because of charge transitions from one ion to another. A major source of attenuation is from transition of metal impurity ions such as iron, chromium, cobalt and copper. These losses can be up to 1 to 10 dB/km. The effect of metallic impurities can be reduced by glass refining techniques.
- Another major extrinsic loss is caused by absorption due to **OH (Hydroxil)** ions impurities dissolved in glass. Vibrations occur at wavelengths between 2.7 and 4.2 µm.
- The absorption peaks occurs at 1400, 950 and 750 nm. These are first, second and third overtones respectively.

**Intrinsic Absorption**

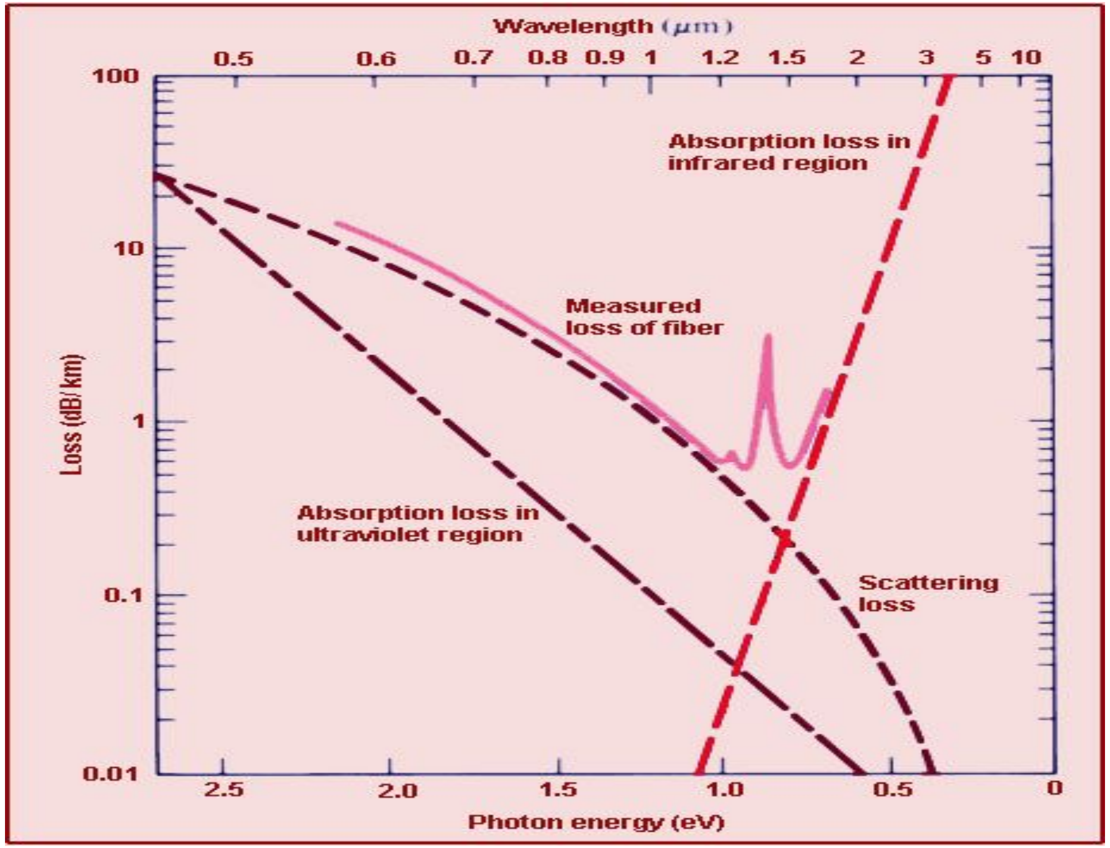
- Intrinsic absorption occurs when material is in absolutely pure state, no density variation and inhomogeneity. Thus intrinsic absorption sets the fundamental lower limit on absorption for any particular material.
- Intrinsic absorption results from electronic absorption bands in UV region and from atomic vibration bands in the near infrared region.
- The electronic absorption bands are associated with the band gaps of amorphous glass materials. Absorption occurs when a photon interacts with an electron in the valence band and excites it to a higher energy level. UV absorption decays exponentially with increasing wavelength (λ).
- In the IR (infrared) region above 1.2 μm the optical waveguide loss is determined by presence of the OH ions and inherent IR absorption of the constituent materials. The inherent IR absorption is due to interaction between the vibrating band and the electromagnetic field of optical signal this results in transfer of energy from field to the band, thereby giving rise to absorption, this absorption is strong because of many bonds present in the fiber.

## SCATTERING LOSS

- The scattering loss is due to the non-uniformity of the refractive index inside the core of the fiber. The refractive index of an optical fiber has fluctuation of the order of over spatial scales much smaller than the optical wavelength. These fluctuations act as scattering centers for the light passing through the fiber. The process is, **Rayleigh Scattering** . A very tiny fraction of light gets scattered and therefore contributes to the loss. The Rayleigh scattering is a very strong function of the wavelength. The scattering loss varies as . This loss therefore rapidly reduces as the wavelength increases. For each doubling of the wavelength, the scattering loss reduces by a factor of 16. It is then clear that the scattering loss at 1550nm is about factor of 16 lower than that at 800nm.

The given Fig. shows the infrared, scattering and the total loss as a function of wavelength.

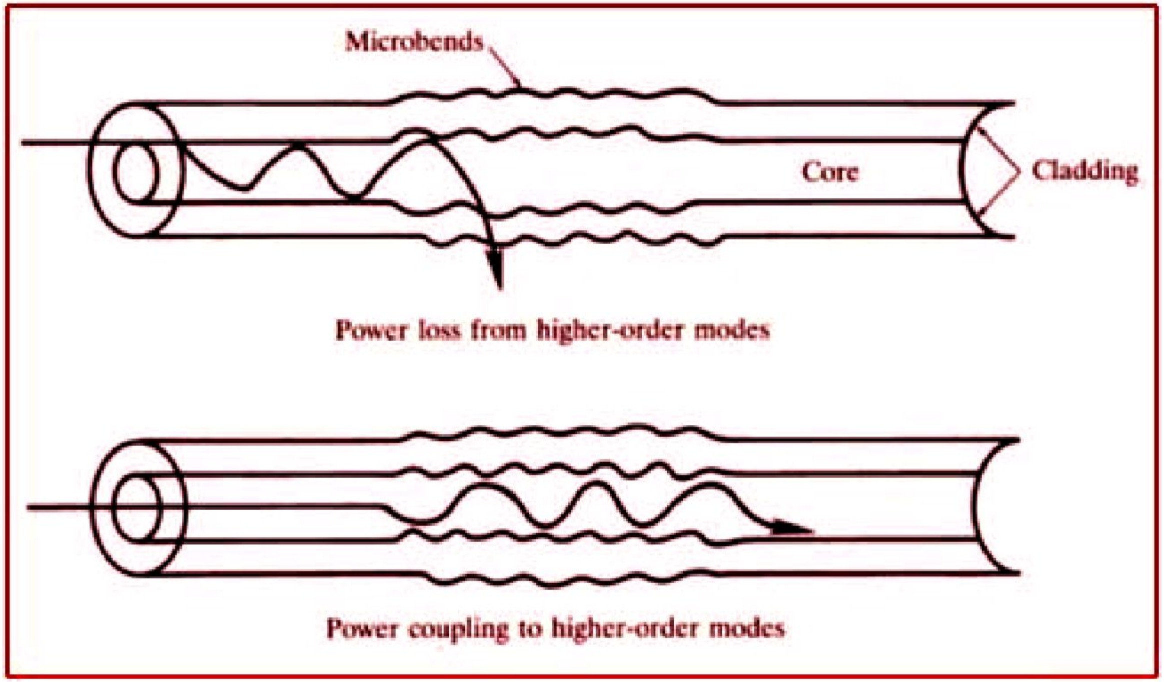
- It is interesting to see that in the presence of various losses, there is a natural window in the optical spectrum where the loss is as low as 0.2-0.3dB/Km. This window is from 1200nm to 1600nm.
- There is a local attenuation peak around 1400nm which is due to OH absorption. The low loss window therefore is divided into sub-windows, one around 1300nm and other around 1550nm. In fact these are the windows which are the II and III generation windows of optical communication.



# BENDING LOSSES

## MICRO-BENDING LOSSES

- While commissioning the optical fiber is subjected to micro-bending as shown in Fig.
- The analysis of micro-bends is a rather complex task. However, just for basic understanding of how the loss takes place due to micro-bending, we use following arguments.
- In a fiber without micro-bends the light is guided by total internal reflection (ITR) at the core-cladding boundary.
- The rays which are guided inside the fiber has incident angle greater than the critical angle at the core-cladding interface In the presence of micro bends however, the direction of the local normal to the core-cladding interface deviates and therefore the rays may not have angle of incidence greater than the critical angle and consequently will be leaked out.
- A part of the propagating optical energy therefore leaks out due to micro-bends.
- Depending upon the roughness of the surface through which the fiber passes, the micro bending loss varies. Typically the micro-bends increase the fiber loss by 0.1-0.2 dB/Km.



**Macrobending**

- For slight bends, the loss is extremely small and is not observed. As the radius of curvature decreases, the loss increases exponentially until at a certain critical radius of curvature loss becomes observable. If the bend radius is made a bit smaller once this threshold point has been reached, the losses suddenly become extremely large. It is known that any bound core mode has an evanescent field tail in the cladding which decays exponentially as a function of distance from the core. Since this field tail moves along with the field in the core, part of the energy of a propagating mode travels in the fiber cladding. When a fiber is bent, the field tail on the far side of the centre of curvature must move faster to keep up with the field in the core, for the lowest order fiber mode. At a certain critical distance xc, from the centre of the fiber; the field tail would have to move faster than the speed of light to keep up with the core field. Since this is not possible the optical energy in the field tail beyond xc radiates away.
- The amount of optical radiation from a bent fiber depends on the field strength at xc and on the radius of curvature R. Since higher order modes are bound less tightly to the fiber core than lower order modes, the higher order modes will radiate out of the fiber first.

- The change in spectral attenuation caused by macrobending is different to microbending. Usually there are no peaks and troughs because in a macrobending no light is coupled back into the core from the cladding as can happen in the case of microbends.
- The macrobending losses are cause by large scale bending of fiber. The losses are eliminated when the bends are straightened. The losses can be minimized by not exceeding the long term bend radii. Fig. 2.4.3 illustrates macrobending.

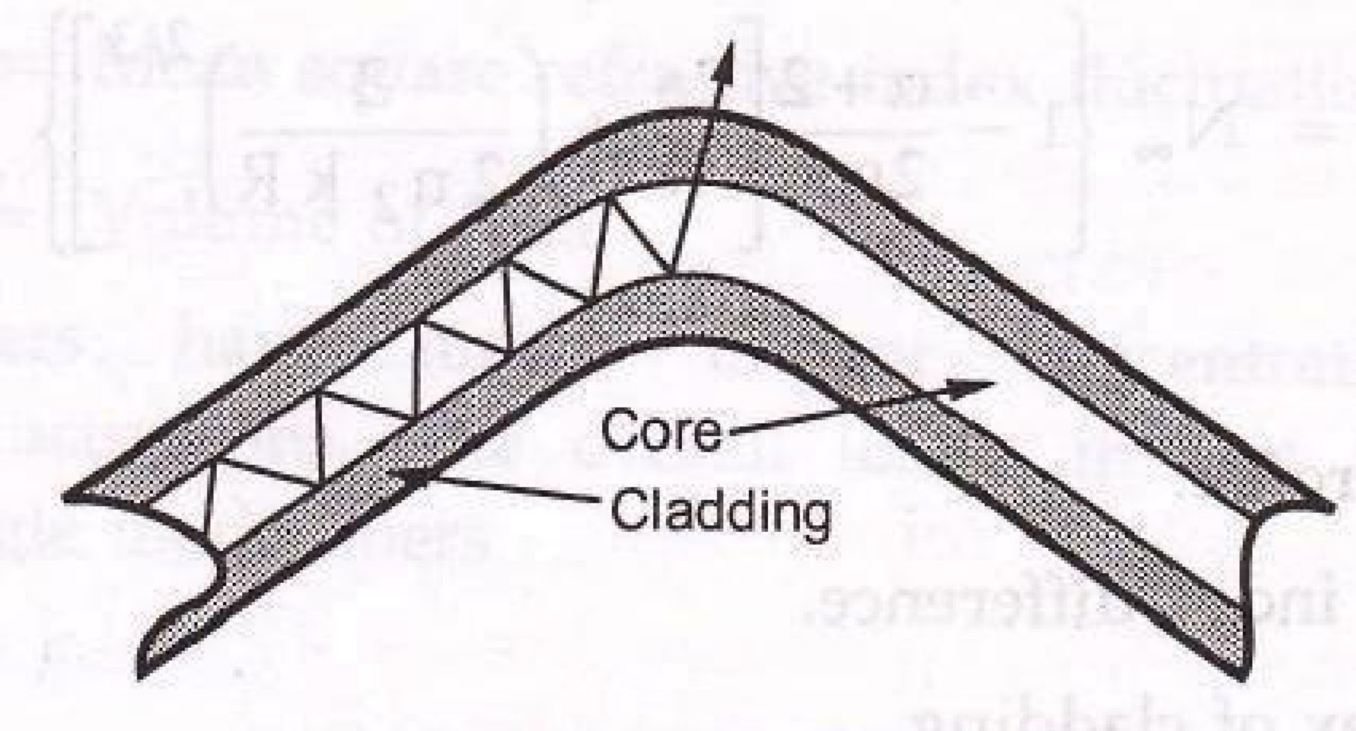
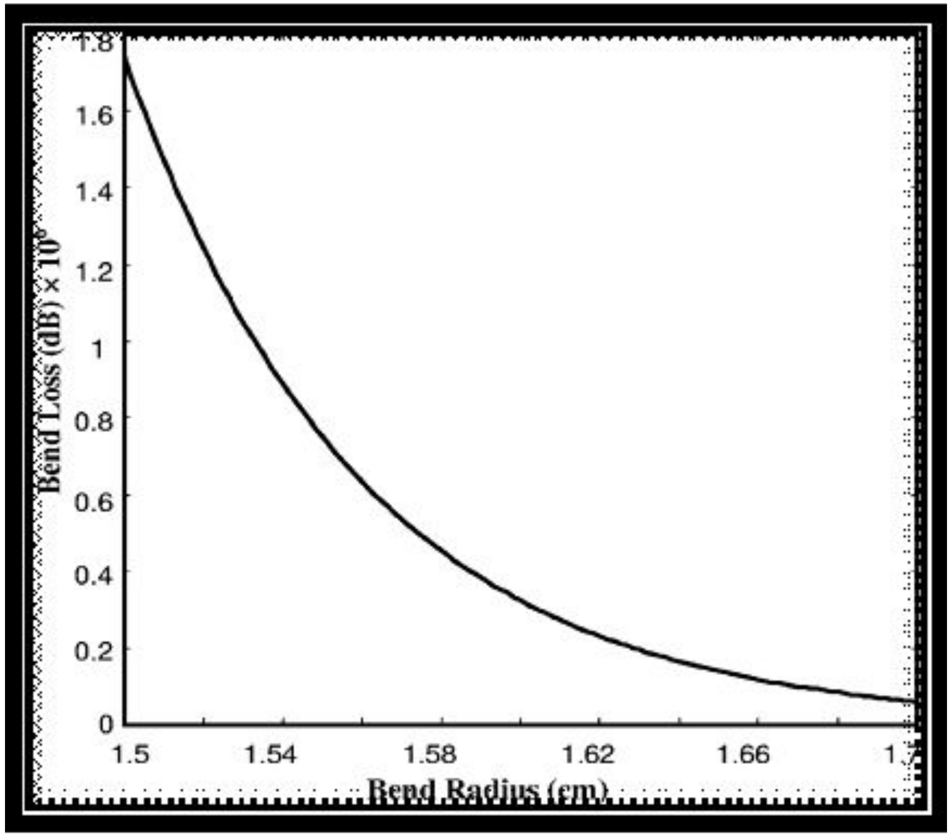



Fig. 2.4.3 Macrobending




Macro bending Loss

# Thank you