UNIT V

OPTICAL FIBER TRANSMISSION MEDIA

Mr. M SREEDHAR REDDY

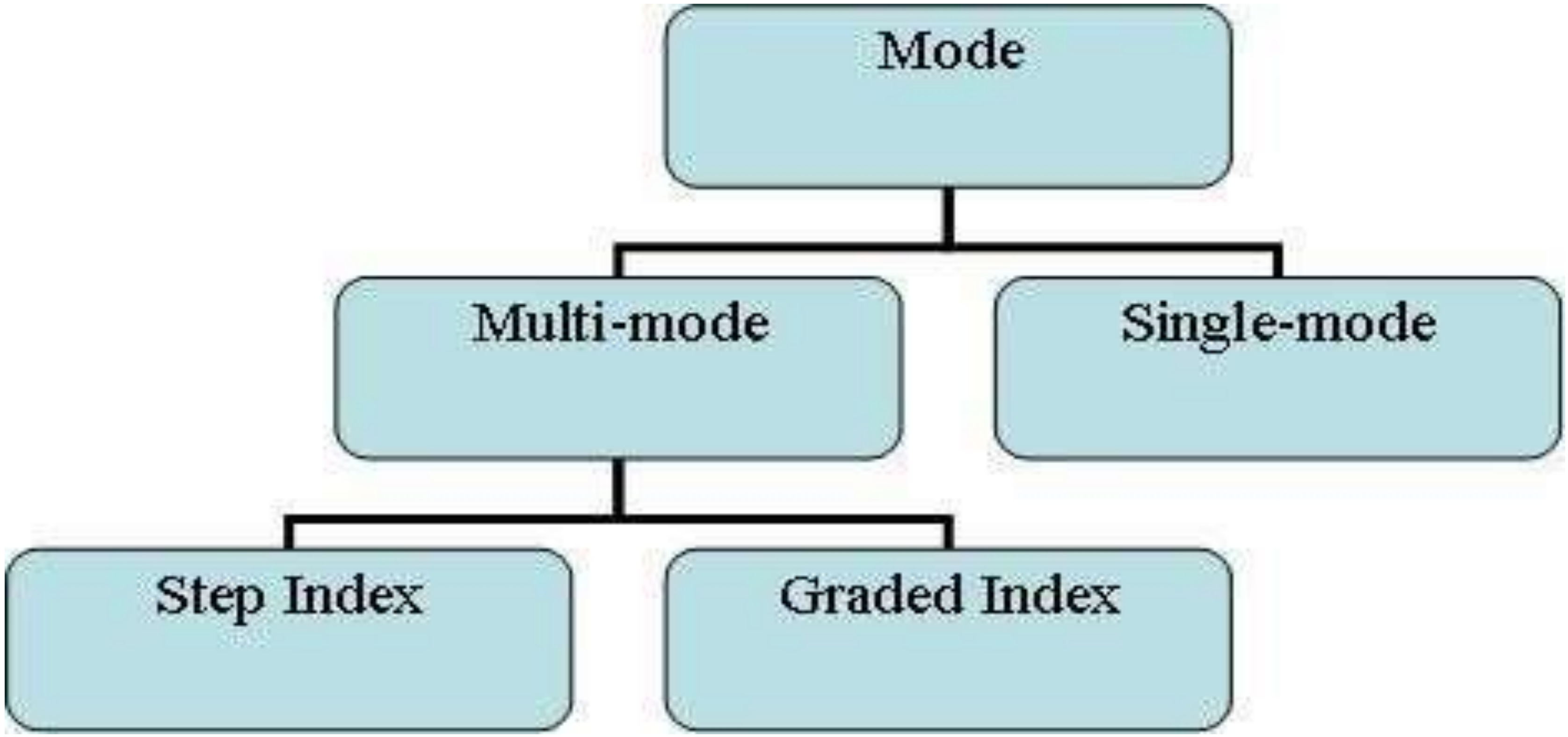
Assistant Professor, ECE
Narsimha Reddy Engineering College (Autonomous)
Secunderabad, Telangana, India- 500100.

UNIT-V

Optical Fiber Transmission Media

Optical Fiber Transmission Media: Optical Fiber types, Light Propagation, Optical fiber Configurations, Optical fiber classifications, Losses in Optical Fiber cables, Light Sources, Optical Sources, Light Detectors, LASERS, WDM Concepts, Optical Fiber System link budget.

OPTICAL FIBER TYPES



OPTICAL FIBER TYPES

- **Mode of Transmission:**
- **a. Single-mode Fiber (SMF):**
- **Core diameter:** ~8-10 µm
- **Transmits:** Only one mode of light
- **Wavelengths used:** 1310 nm, 1550 nm
- **Applications:** Long-distance communication (up to 100 km or more), high bandwidth
- **Example use:** Internet backbone, telecom

OPTICAL FIBER TYPES

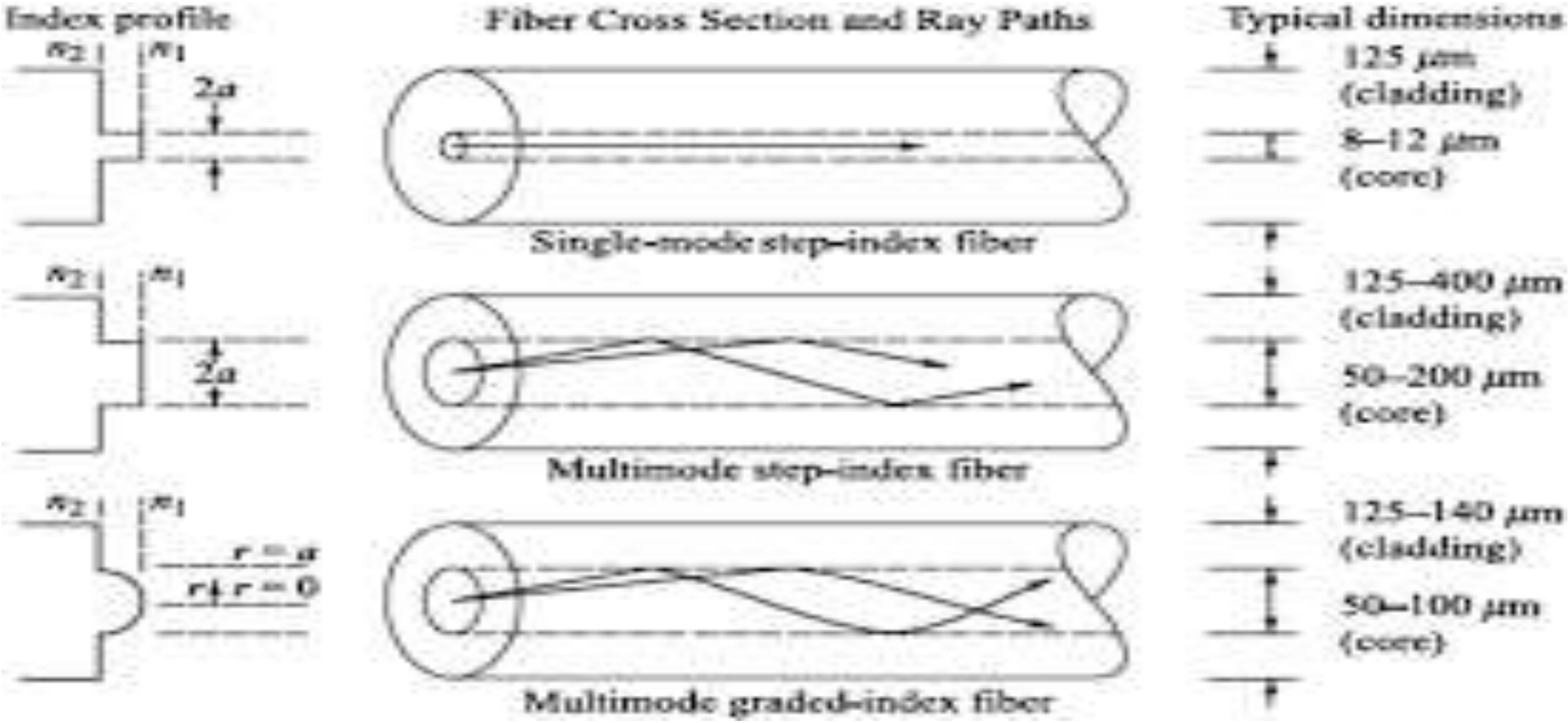
- **Multimode Fiber (MMF):**
- **Core diameter:** ~50 or 62.5 μm
- **Transmits:** Multiple modes of light
- **Wavelengths used:** 850 nm, 1300 nm
- **Applications:** Short-distance data transmission (up to 2 km)
- **Example use:** LAN, data centers

OPTICAL FIBER TYPES

- **Material Composition:**
- **a. Glass Fiber:**
- Core and cladding made of silica
- Used in high-speed, long-distance communication
- **b. Plastic Optical Fiber (POF):**
- Made of polymer/plastic
- Less expensive, easy to install
- Short-distance, low-speed applications (e.g., home networking, automotive)

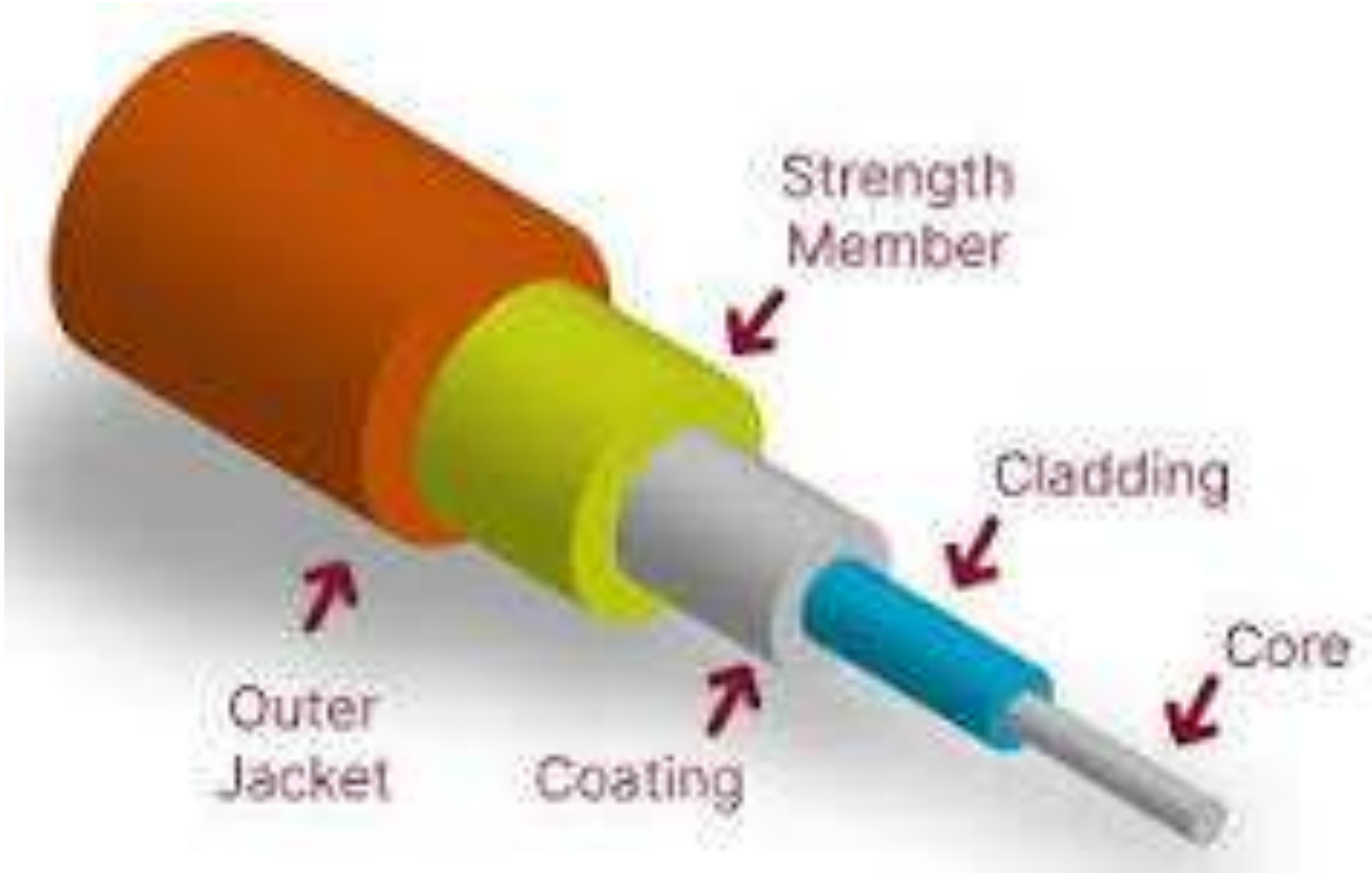
OPTICAL FIBER TYPES

- **Index Profile:**
- **a. Step Index Fiber:**
- Refractive index changes abruptly between core and cladding
- Used in both single-mode and multimode fibers
- Simpler design, more dispersion in MMF
- **b. Graded Index Fiber:**
- Refractive index gradually decreases from center to cladding
- Reduces modal dispersion
- Common in multimode fibers for better performance


Index profile
Fiber Cross Section and Ray Paths
Typical dimensions
n_2
n_1
2a
125 µm
(cladding)
8–12 µm
(core)
Single-mode step-index fiber
125–400 µm
(cladding)
50–200 µm
(core)
Multimode step-index fiber
r = a
r = 0
125–140 µm
(cladding)
50–100 µm
(core)
Multimode graded-index fiber

OPTICAL FIBER TYPES

Type	Core Size	Distance	Modal Types	Applications
Single-mode	~9 µm	Long (>10 km)	One mode	Telecom, WAN
Multimode Step Index	~50/62.5 µm	Short (<2 km)	Multiple modes	LAN, CCTV
Multimode Graded Index	~50/62.5 µm	Medium	Multiple modes	Enterprise networks
Plastic Optical Fiber	~1 mm	Very short	Multiple modes	Home, car electronics


Strength
Member
Cladding
Core
Outer
Jacket
Coating

OPTICAL FIBER COMMUNICATION BLOCK DIAGRAM

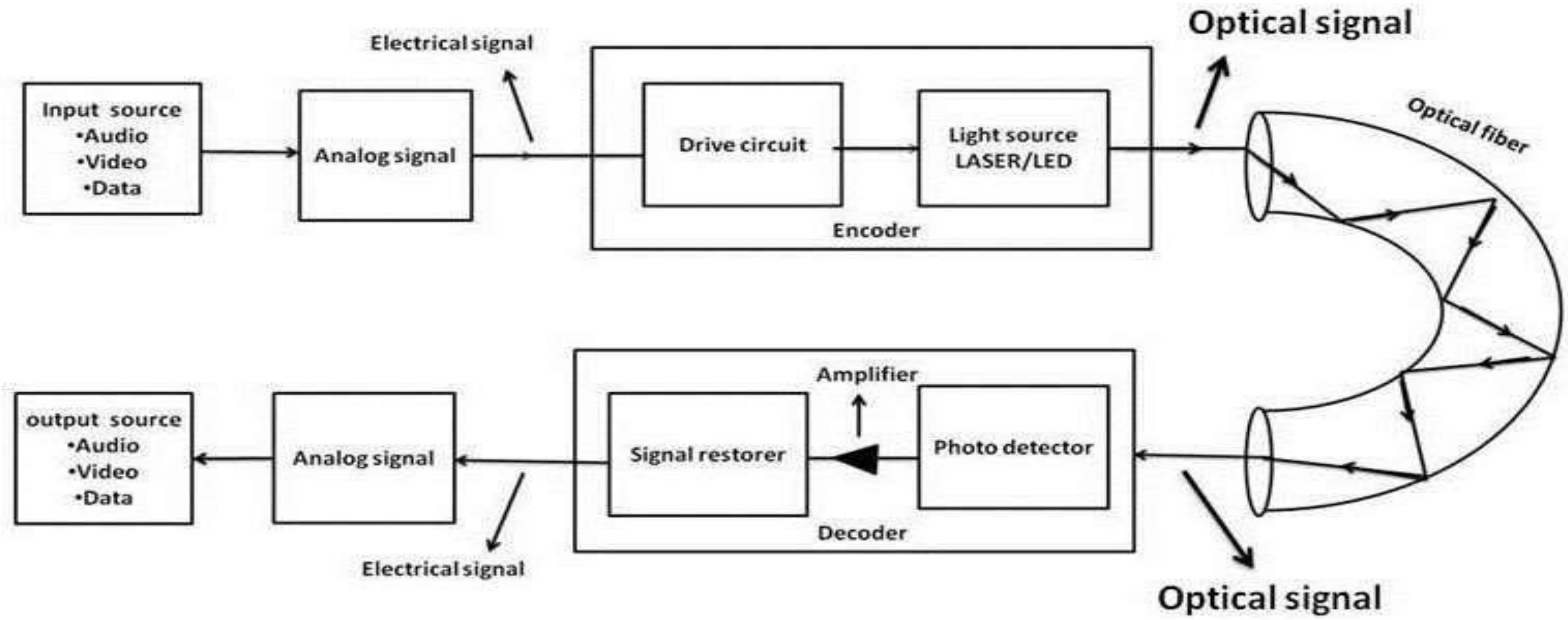


Fig: Fiber optical communication system

Advantages of optical fiber communication

- 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.

- **Safety**

- The fiber is non-conducting, and is therefore safe in all environments.
- It uses light waves for communication hence it is shockproof.
- Since it is shockproof, it is very useful in sensitive areas like petroleum industries, oil and natural gas industries, cotton industries etc.

- **Weight**
- Fiber optic cables are made of glass or plastic, and they are thinner than copper cables.These make them lighter weight and easy to install.
- **Low Power Loss**
- An optical fiber offer slow power loss, which allows for longer transmission distances than comparison to copper cable.

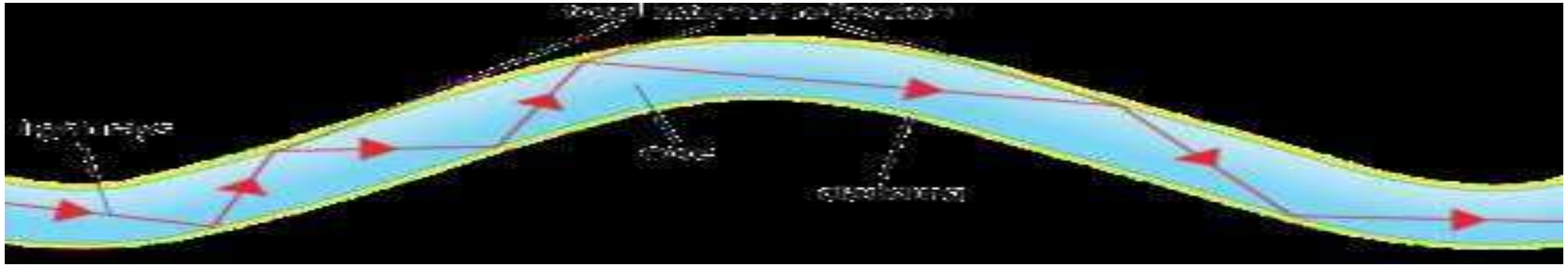
LIGHT PROPAGATION IN OPTICAL FIBER

- Principle of optical fiber:

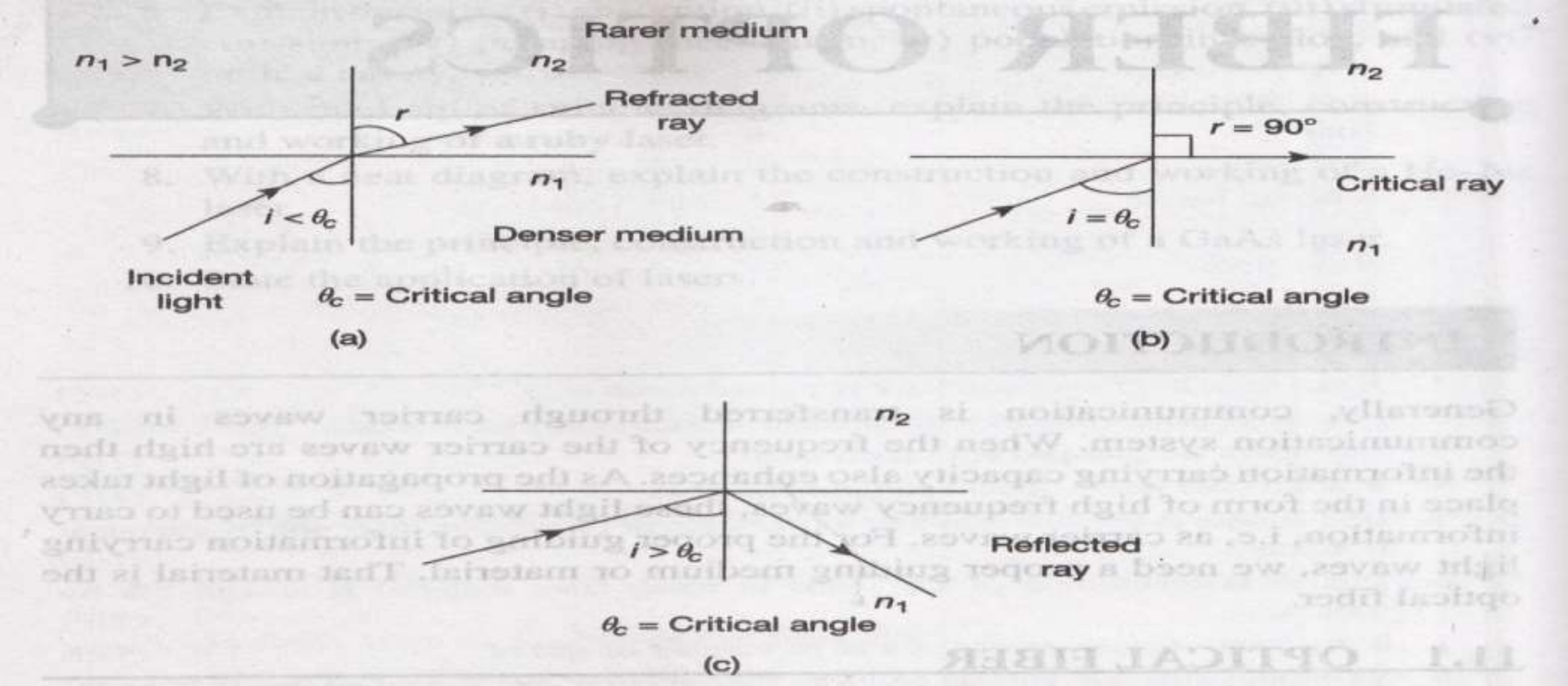
❖ An optical fiber works on the principle of total internal reflection

- **Definition:**

- When a light ray travels from denser medium to rarer medium and angle of incidence is greater than the critical angle, then the light ray reflects totally, this phenomenon is known as total internal reflection.



PRINCIPLE OF OPTICAL FIBER



CONDITION FOR TOTAL INTERNAL REFLECTION

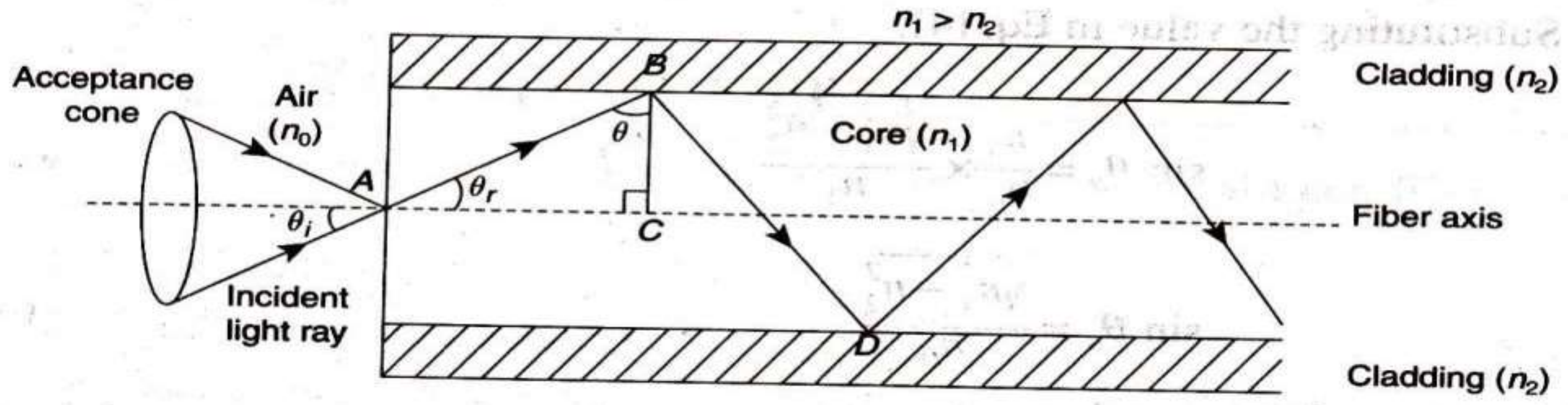
1. The light ray should move from denser to a rarer medium.

2. When i < ϴc, then the light ray refracts into a rarer medium.
3. When I = ϴc, then the refracted light ray passes along the interface of the two media.

4. When i > ϴc, then the light ray is reflected back into the denser medium and we get total internal reflection.

Acceptance angle and acceptance cone:

- The maximum angle at which the light can suffers total internal refection is called as acceptance angle.
- The acceptance cone is derived by rotating the Acceptance Angle about the fiber axis.



- **Numerical aperture (N.A):**

➢ Numerical aperture represents the light-gathering power of an optical fiber. It is a measure of the amount of light that can be accepted by a fiber.

➢ The value of NA ranges from 0.13 to 0.50.

➢ Numerical aperture is proportional to the acceptance angle. So, numerical aperture is equal to the sine of the acceptance angle.

OPTICAL FIBER CONFIGURATIONS

Optical fibers can be configured in various ways depending on their design and usage. The main **configurations** include

- **Single Fiber Configuration**
- **Description:** Uses only one optical fiber
- **Purpose:** Transmit data in one direction
- **Used in:** Simple point-to-point communication systems

OPTICAL FIBER CONFIGURATIONS

- **Duplex Fiber Configuration**
- **Description:** Two fibers are used — one for transmitting and one for receiving
- **Purpose:** Enables **full-duplex** communication
- **Used in:** LANs, data centers, telecommunications

OPTICAL FIBER CONFIGURATIONS

- **Ribbon Fiber Configuration**
- **Description:** Multiple fibers arranged in a flat ribbon-like structure
- **Purpose:** High fiber count in compact space
- **Used in:** High-density applications (e.g., backbone networks)

OPTICAL FIBER CONFIGURATIONS

- **Loose Tube Configuration**
- **Description:** Fibers are placed loosely inside a tube filled with gel or water-blocking materials
- **Purpose:** Protects fibers from moisture and physical stress
- **Used in:** Outdoor installations, long-distance communication
- **Tight Buffered Configuration**
- **Description:** Each fiber is tightly coated with buffer material
- **Purpose:** Easier to handle and terminate
- **Used in:** Indoor applications like building backbones

OPTICAL FIBER CONFIGURATIONS

- **Hybrid Fiber Configuration**
- **Description:** Mix of single-mode and multimode fibers in one cable
- **Purpose:** Flexible use for different network equipment
- **Used in:** Enterprise networks

LOSSES IN OPTICAL FIBER

- **Attenuation**
- **Dispersion-intermodel, Intramodel, Bending loss-micro ,macro scattering losses-Linear, Non linear, Absorption-Intrinsic, Extrinsic Coupling**

- **Attenuation**
- Attenuation means loss of light energy as the light pulse travels from one end of the cable to the other.
- It is also called signal loss or fiber loss.
- It also decides the number of repeaters required between transmitter and receiver.
- Attenuation is directly proportional to the length of the cable.

ATTENUATION

- Attenuation is defined as the ratio of optical output power to the
- input power in the fiber of length L. α= 10log10Pi/Po

[in db/km]

  - where,
  - P_i= Input Power
  - P_o= Output Power, α is attenuation constant
- The various losses in th e cable are due to
- Absorption
- Scattering
- Dispersion
- Bending

BENDING LOSSES

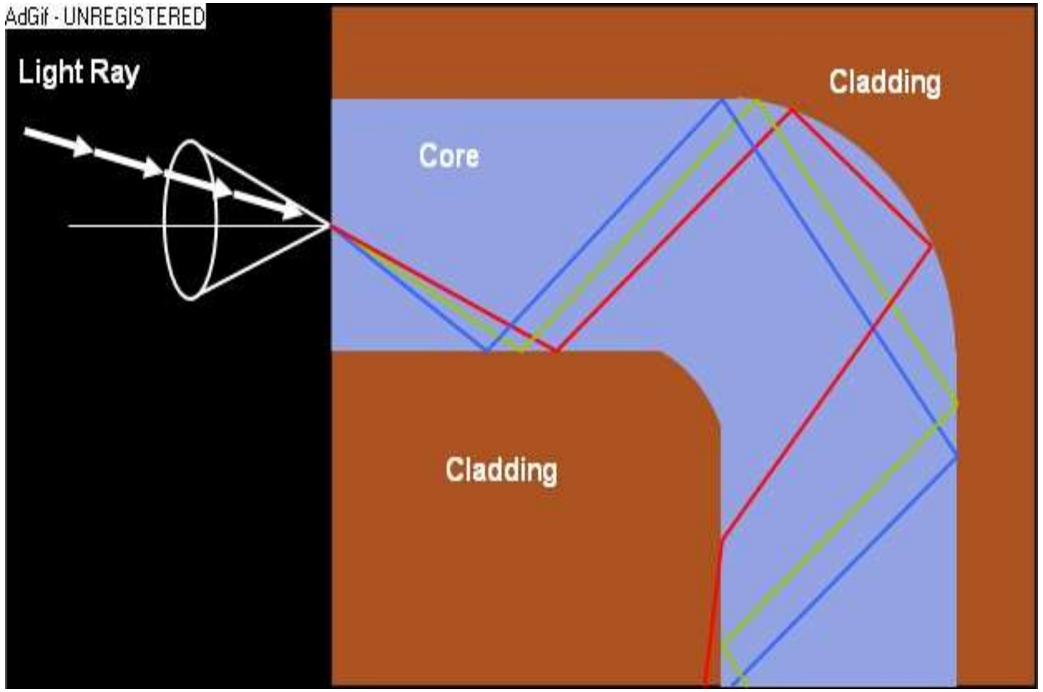
- The loss which exists when an optical fiber undergoes bending is called bending losses. There are two types of bending.

i) Macroscopic bending

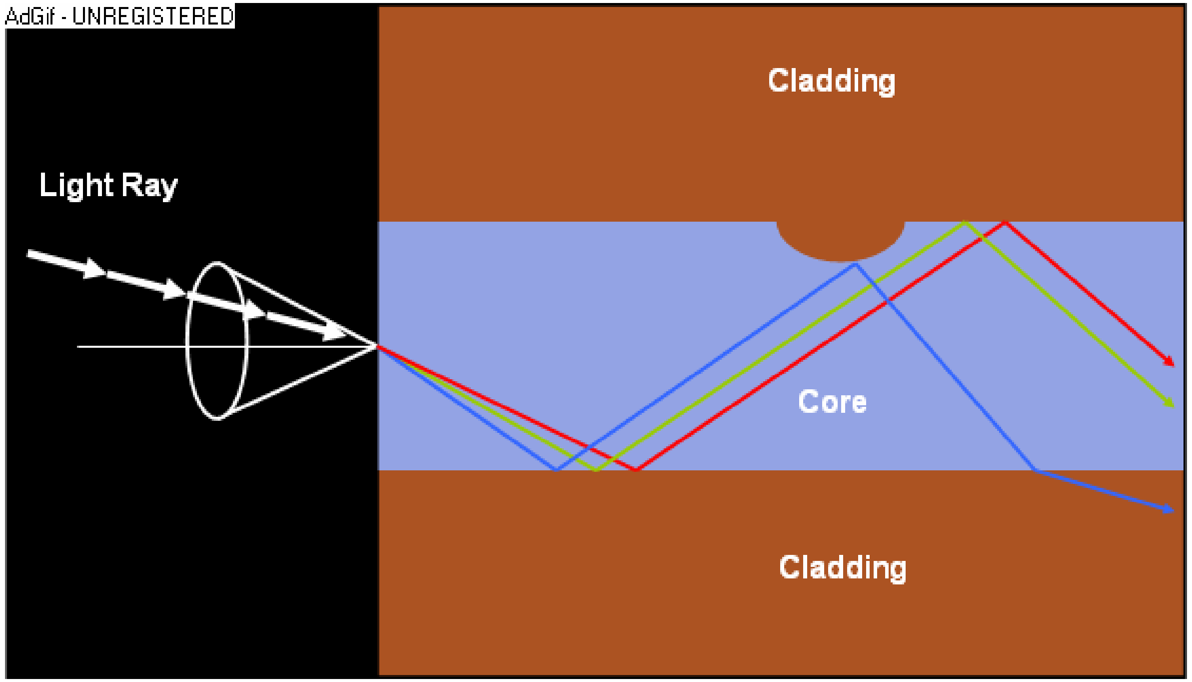
- Bending in which complete fiber undergoes bends which causes certain modes not to be reflected and therefore causes loss to the cladding.

ii) Microscopic Bending

- Either the core or cladding undergoes slight bends at its surface. It causes light to be reflected at angles when there is no further reflection.



Macroscopic Bending



Microscopic Bending

ABSORPTION LOSSES

- Absorption of light energy due to heating of ion impurities results in dimming of light at the end of the fiber.

Two types:

- 1.Intrinsic Absorption

2.Extrinsic Absorption

- **Intrinsic Absorption:**

- Caused by the interaction with one or more components of the glass
- Occurs when photon interacts with an electron in the valence band & excites it to a higher energy level near the UV region.

ABSORPTION LOSSES

- **Extrinsic Absorption:**
- Also called impurity absorption.
- Results from the presence of transition metal ions like iron, chromium, cobalt, copper & from OH ions i.e. from water

- **Scattering Losses**
- It occurs due to microscopic variations in the material density, compositional fluctuations, structural in homogeneities and manufacturing defects.

- **Coupling Losses**
- The mechanical losses due to the coupling of optical fiber cables is called coupling losses

DISPERSION LOSSES

- As an optical signal travels along the fiber, it becomes increasingly distorted.
- This distortion is a sequence of intermodal and intramodal dispersion.

Two types:

- 1.Intermodal Dispersion

2.IntramodalDispersion

- **Intermodal Dispersion:**

- Pulse broadening due to intermodal dispersion results from the propagation delay
- differences between modes within a multimode fiber.

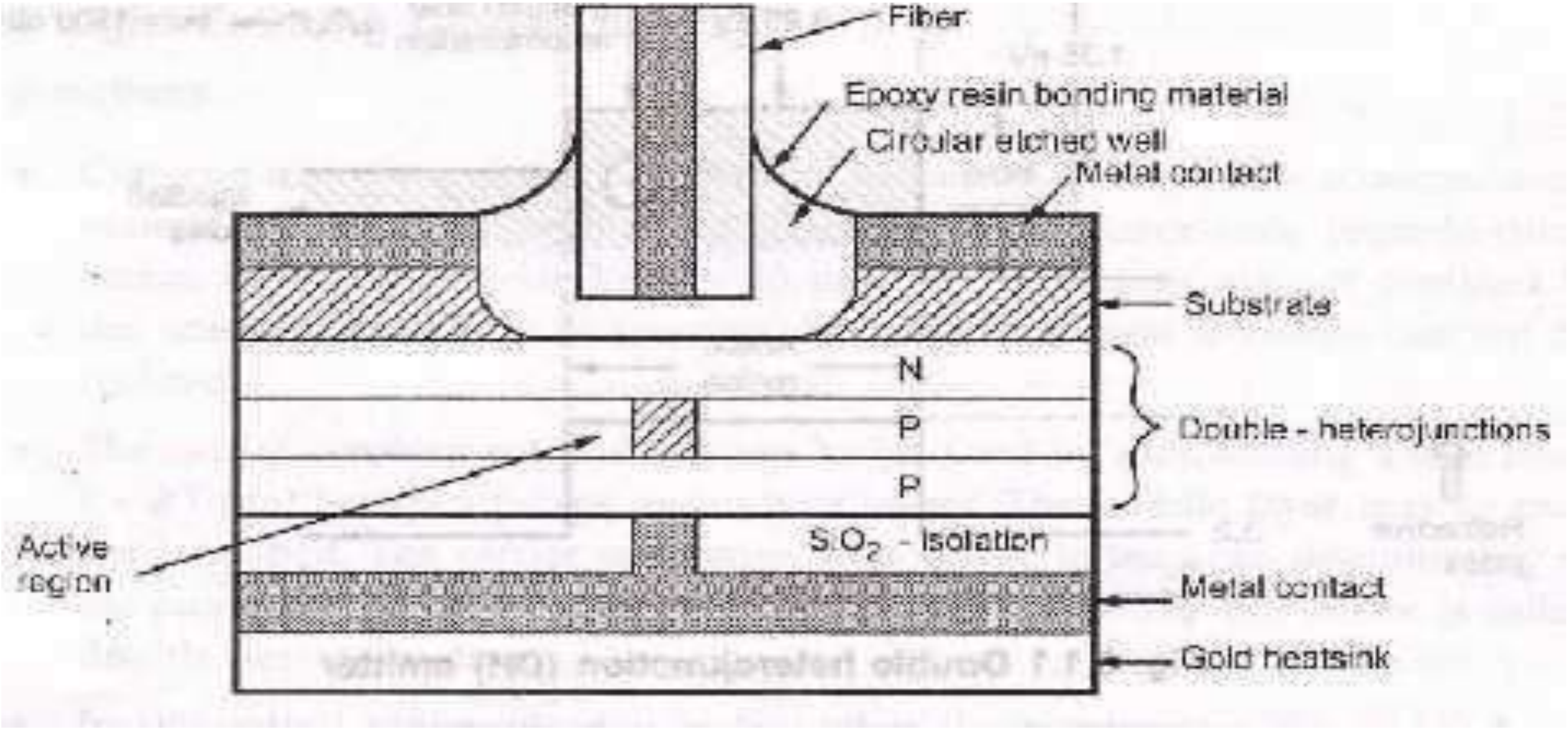
- **Intramodal Dispersion:**

- It is the pulse spreading that occurs within a single mode.

Material Dispersion

- Waveguide Dispersion

LIGHT EMITTING DIODE



LIGHT EMITTING DIODE

- A **Light Emitting Diode (LED)** works on the principle of **electroluminescence**, which is the emission of light when an electric current passes through a semiconductor material.
- **Construction**
- **Type of junction**: **p-n junction diode**
- **Materials**: Gallium arsenide (GaAs), Gallium phosphide (GaP), Gallium arsenide phosphide (GaAsP)

LIGHT EMITTING DIODE

- Conventional p-n junction is called as homojunction as same semiconductor material is used on both sides junction. The electron-hole recombination occurs in relatively layer = 10 μm. As the carriers are not confined to the immediate vicinity of junction, hence high current densities cannot be realized. The carrier confinement problem can be resolved by sandwiching a thin layer (= 0.1 μm) between p-type and n-type layers. The middle layer may or may not be doped. The carrier confinement occurs due to band gap discontinuity of the junction. Such a junction is called as heterojunction and the device is called double heterostructure.

LIGHT EMITTING DIODE

- **Working Principle:**
- **Forward Biasing**:
  - When the **p-n junction** is forward biased, electrons from the **n-region** and holes from the **p-region** are pushed toward the junction.
- **Recombination**:
  - At the junction, **electrons recombine with holes**.
  - During this recombination, the **electrons lose energy**.
- **Photon Emission (Electroluminescence)**:
  - The lost energy is released in the form of **photons (light)**.
  - The **wavelength** (and color) of the emitted light depends on the **energy band gap** of the semiconductor.

APPLICATIONS

- Optical fiber transmitters (short distance)
- Indicators, displays
- Remote controls
- Sensor systems

LASER

- **LASER** stands for **Light Amplification by Stimulated Emission of Radiation**. It produces a **coherent**, **monochromatic**, and **highly directional** beam of light.
- **Working Principle of LASER**
- The working of a laser is based on **three main processes**:
- **1. Absorption of Energy**
- Atoms or electrons in a **lower energy state (E_1)** absorb external energy (light, heat, or electric current) and jump to a **higher energy state (E_2)**.
- This creates an **excited state**.
- **2. Spontaneous Emission**
- After a short time, the excited electron **falls back** to a lower energy level, emitting a **photon** (light particle) randomly.

LASER

- **Stimulated Emission (Key to LASER)**
- If a photon hits an already **excited atom**, it can **stimulate** it to emit **another identical photon**.
- Both photons are **in phase**, **same frequency**, and travel in the **same direction**.
- This is the **amplification** part of LASER.

LASER

- **Condition for LASER**
- **Population Inversion**

More atoms in excited state (E_2) than in ground state (E_1), which is an unnatural condition created using a **pumping mechanism**.

- **Optical Resonator (Cavity)**
- A pair of mirrors on either side of the gain medium.
- One mirror is fully reflective, the other is partially reflective.
- Photons bounce back and forth, stimulating more emissions, and a coherent beam escapes through the partially reflective mirror.

STEP BY STEP LASER OPERATION

- **Pumping**: Energy is supplied to the active medium.
- **Excitation**: Atoms absorb energy and jump to excited state.
- **Population Inversion** is achieved.
- **Stimulated Emission** occurs as excited atoms emit photons when struck.
- **Amplification**: Photons stimulate more emissions → light multiplies.
- **Output**: A part of the amplified light escapes through the output mirror as a **narrow, powerful laser beam**.

APPLICATIONS OF LASER

- **Communication**: Optical fiber data transmission
- **Medical**: Eye surgery, skin treatment
- **Industry**: Cutting, welding, drilling
- **Military**: Range finding, target designation
- **Scientific Research**: Spectroscopy, holography
- **Electronics**: Barcode scanners, CD/DVD readers

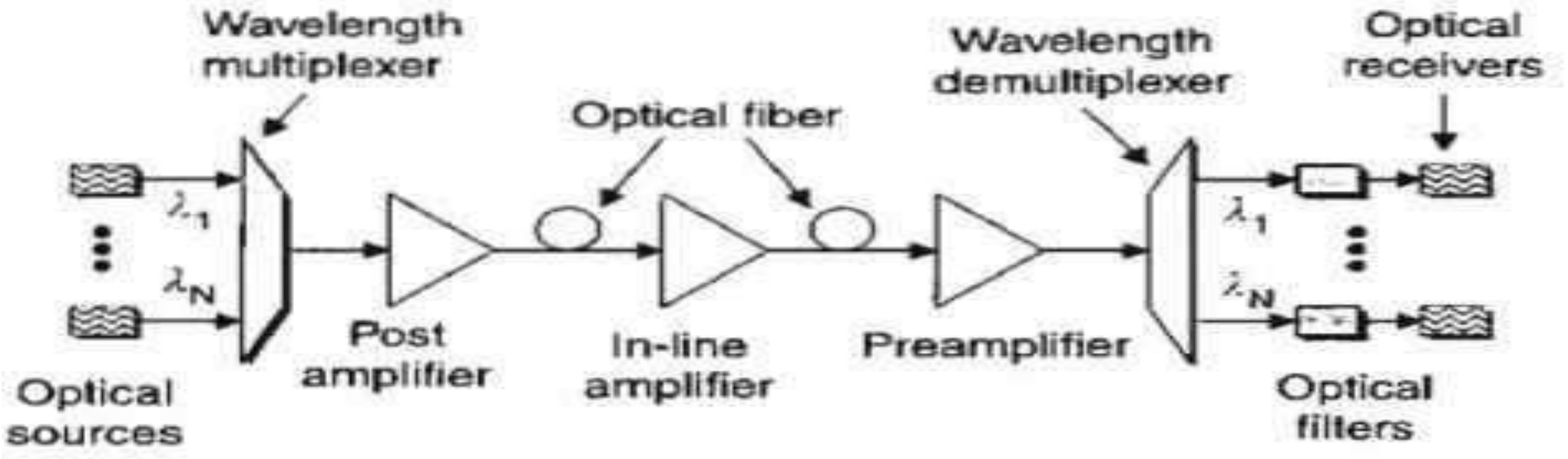
WDM

- **Wavelength Division Multiplexing (WDM)** is a technique used in **optical fiber communication** to transmit **multiple data streams simultaneously** over a **single fiber** by using **different light wavelengths (colors)**.

WDM

- Each data signal is **modulated onto a different wavelength** (λ_1, λ_2, λ_3, ...).
- These multiple wavelengths are then **combined using a multiplexer** and sent through a **single optical fiber**.
- At the receiving end, a **demultiplexer** separates them back into individual channels.

WDM LINK



Wavelength multiplexer
Optical fiber
Wavelength demultiplexer
Optical receivers
λ_1
λ_N
λ_1
λ_N
Post amplifier
In-line amplifier
Preamplifier
Optical sources
Optical filters

WDM

- Each data signal is **modulated onto a different wavelength** (λ_1, λ_2, λ_3, ...).
- These multiple wavelengths are then **combined using a multiplexer** and sent through a **single optical fiber**.
- At the receiving end, a **demultiplexer** separates them back into individual channels.

FEATURES OF WDM

- Capacity upgrade: Since each wavelength supports independent data rate in Gbps.

- Transparency: WDM can carry fast asynchronous, slow synchronous, synchronous analog and digital data.

- Wavelength routing: Link capacity and flexibility can be increased by using multiple wavelength.

ADVANTAGES OF WDM

Increases bandwidth without laying new fibers
Enables bidirectional communication on a single fiber
Scalable and flexible
Compatible with both analog and digital signals

OPTICAL FIBER LINK BUDGET

- The **optical link budget** is a calculation that determines **whether the optical power transmitted through a fiber system** is **sufficient to reach the receiver** with an acceptable signal level.

- **Purpose:**
- To ensure the **received optical power** is strong enough for reliable communication **after accounting for all losses**.

OPTICAL FIBER LINK BUDGET

- **Link Budget Formula:**
- Received Power (dBm)=Transmitted Power (dBm)−Total Losses (Db)

- Total Link Loss=(FiberAttenuation×Length)+ConnectorLosses+SpliceLosses+SystemMargin