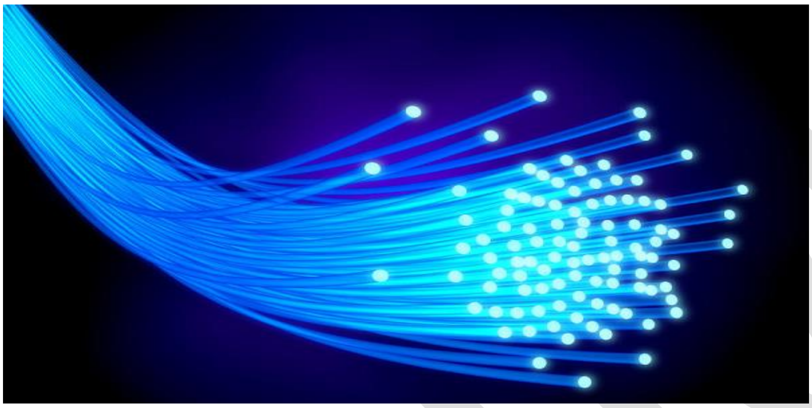
Overview of Fiber optic communication

Fiber Optics

- An optical fiber can be understood as a dielectric waveguide, which operates at optical frequencies. The device or a tube, if bent or if terminated to radiate energy, is called a **waveguide**, in general.
- The electromagnetic energy travels through it in the form of light.

Following image depicts a bunch of fiber optic cables.

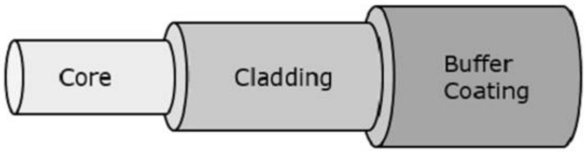


Historical development

- In the 1970s , the “optical telegraph” was invented.
- In 1880, Alexander Graham Bell created the optical telephone system called photophone.
- However, in the 1930s, Heinrich Lamm was the first person to transmit an image through a batch of optical fibers.
- In 1973, Bell Laboratories developed a modified vapor deposition process that can be mass-produced into a low-loss optical fiber.
- This process remains, to this day, the standard for fiber optic cabling manufacturing.
- In the early 1980s, telephone companies started to use fiber optics to rebuild their communication infrastructure.
- In 1986, Emmanuel Desurvire invented the erbium-doped amplifier which reduced the cost of long-distance fiber systems.
- In 1988, the first transatlantic telephone cable went into operation.
- 1991, Desurvire and Payne demonstrate amplifiers were built into the fiber optic cable itself.
- Also in 1991, the photonic crystal fiber was developed.

General System

- The most commonly used optical fiber is **single solid di-electric cylinder** of radius **a** and index of refraction n_1. The following figure explains the parts of an optical fiber.



Parts of an Optical fiber

- This cylinder is known as the **Core** of the fiber. A solid di-electric material surrounds the core, which is called as **Cladding**.
- Cladding has a refractive index n_2 which is less than n_1.

Cladding helps in −

- Reducing scattering losses.
- Adds mechanical strength to the fiber.
- Protects the core from absorbing unwanted surface contaminants.
- The major elements of an optical fiber communication system are light signal transmitter, the optical fiber and the photo detecting receiver.

Functional Advantages

- The transmission bandwidth of the fiber optic cables is higher than the metal cables.
- The amount of data transmission is higher in fiber optic cables.
- The power loss is very low and hence helpful in long-distance transmissions.
- Fiber optic cables provide high security and cannot be tapped.
- Fiber optic cables are the most secure way for data transmission.
- Fiber optic cables are immune to electromagnetic interference.
- These are not affected by electrical noise.

Physical Advantages

- The capacity of these cables is much higher than copper wire cables.
- Though the capacity is higher, the size of the cable doesn't increase like it does in copper wire cabling system.
- The space occupied by these cables is much less.

- The weight of these FOC cables is much lighter than the copper ones.
- Since these cables are di-electric, no spark hazards are present.
- These cables are more corrosion resistant than copper cables, as they are bent easily and are flexible.
- The raw material for the manufacture of fiber optic cables is glass, which is cheaper than copper.
- Fiber optic cables last longer than copper cables

Disadvantages

- Though fiber optic cables last longer, the installation cost is high.
- The number of repeaters are to be increased with distance.
- They are fragile if not enclosed in a plastic sheath. Hence, more protection is needed than copper ones.

Applications of Fiber Optics

- 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.

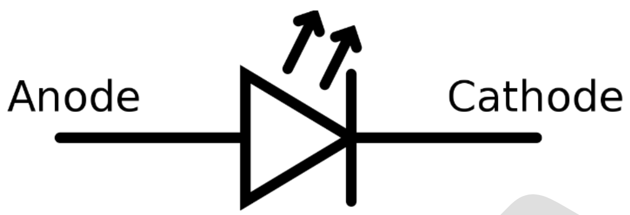
Optical Sources and Detectors

- Optical transmitter converts electrical input signal into corresponding optical signal.
- The optical signal is then launched into the fiber.
- Optical source is the major component in an optical transmitter.
- Popularly used optical transmitters are Light Emitting Diode (LED) and semiconductor Laser Diodes(LD)
- To use fiber optic cables for communications, electrical signals must be converted to light, transmitted, received and converted back from light to electrical signals.
- This requires optical sources and detectors
- There are two main categories of optical signal sources –

- Light emitting diodes
- Laser diodes

1. Light Emitting Diode

- A **light emitting diode (LED)** is a device which converts electrical energy to light energy.
- LED enables the flow of current in its forward direction whereas it blocks the flow in the reverse direction.



- We can manipulate the wavelength of the light which is generated.
- Thus, from its wavelength, the light colour and its visibility cannot be controlled.
- We can determine the colour and wavelength of the light by doping it with multiple impurities.
- We use LEDs in a lot of fields which includes optical communication, alarm and security systems.
- Further, we also use them in remote-controlled operations, robotics and more.

TV back-lighting:

- The backlight of a TV is the major power-consuming source.
- When we use LEDs, it offers an efficient power reduction.
- Using LEDs directly behind the display offers much better contrast.
- This is why CFLs and LCDs have been replaced by LEDs in TV backlighting.

Smartphone

- While the price of LED can vary as per the sizes of the display of the smartphone, the lower output voltage ensures a longer battery life.

Displays

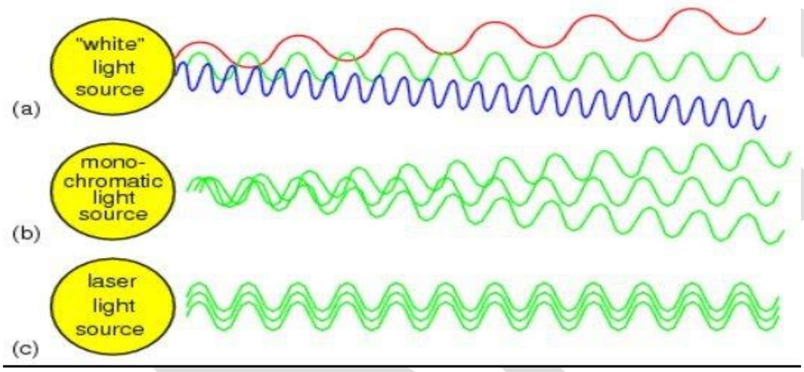
- LED display boards are common now these days and are used outdoors like storage signs, billboards, road sign etc.

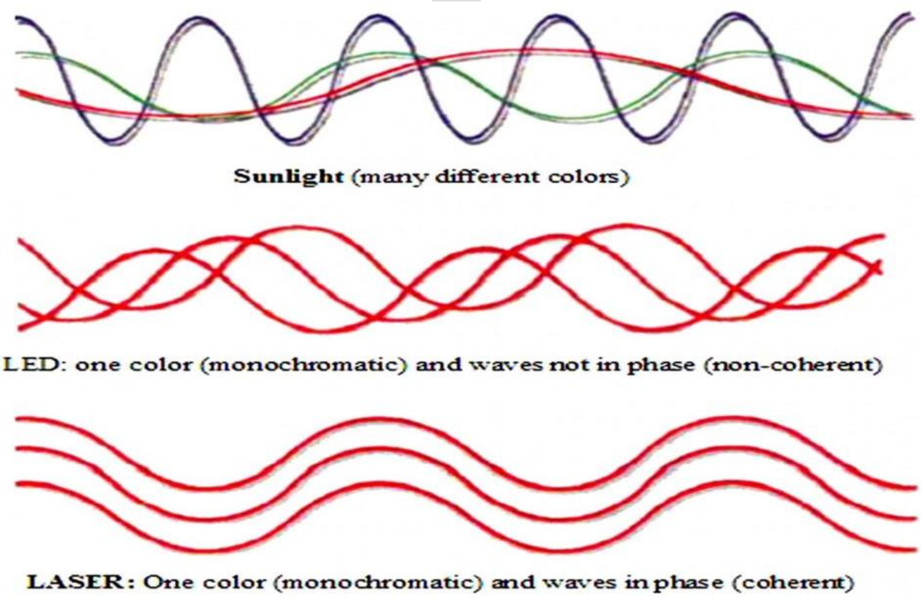
Advantages of LED

- Light in weight
- Small in size
- No complex circuitry is required
- Linearity is more
- Cost is low
- Lower operating temperature

LASER DIODE

- A Laser Diode is a semiconductor device similar to a light-emitting diode(LED)
- It used p-n junction to emit coherent light in which all the waves are at the same frequency and phase.
- This coherent light is produced by the laser diode using a process termed as “Light Amplification by Stimulated Emission of Radiation”, which is abbreviated as LASER.

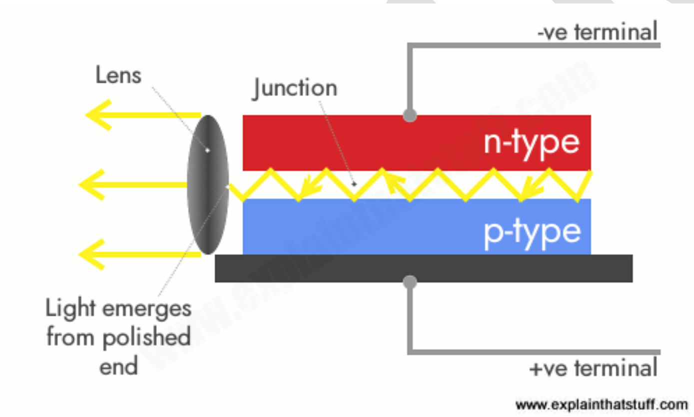




- The light from the sunlight or from most of the artificial light sources contains waves of multiple wavelengths and they are out of phase with each other.
- The light waves from monochromatic light sources like incandescent bulb also are not in phase with each other.
- In contrast to the previous light sources, laser diodes produce a narrow beam of laser light I which all the light waves have similar wavelengths and they travel together with their peaks lined up.
- This is why laser beams are very bright, and can be focused over a very tiny spot.
- Widely used in various devices like laser printers, barcode readers, security systems, Autonomous vehicles (LIDAR), Fiber optic communications etc.

Working of Laser diode takes place in three main steps:

- **1. Energy Absorption**
- **2. Spontaneous Emission**
- **3. Stimulated Emission**



Energy Absorption

- The laser diode consists of a p-n junction where holes and electrons exist(a hole means the absence of an electron).
- When a certain voltage is applied at the p-n junction, the electrons absorb energy and they transition to a higher energy level.
- Holes are formed at the original position of the excited electrons.
- The electrons stay in this excited state without recombining with holes for a very small duration of time, termed as “recombination time” or “upper-state lifetime”.
- The recombination time is about a nanosecond for most laser diodes.

Spontaneous Emission

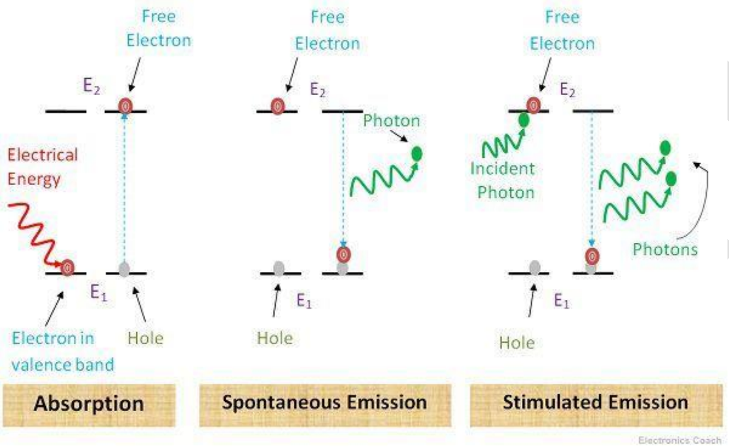
- After the upper-state lifetime of excited electrons, they recombine with holes

- As the electrons fall from higher energy level to a lower energy level, the difference in energy is converted into photons or electromagnetic radiation.
- This same process is used to produce light in LEDs.
- The energy of the emitted photon is given by the difference between the two energy levels.

Stimulated Emission

- We need more coherent photons from the laser diode than the ones emitted through the process of spontaneous emission.
- A partially reflecting mirror is used on either side of the diode so that the photons released from spontaneous emission are trapped in the p-n junction until their concentration reaches a threshold value.
- These trapped photons stimulate the excited electrons to recombine with holes.
- This result in the release of more photons.

Once the photon concentration goes above a threshold, they escape from the partially reflecting mirrors, resulting in a bright monochromatic coherent light.



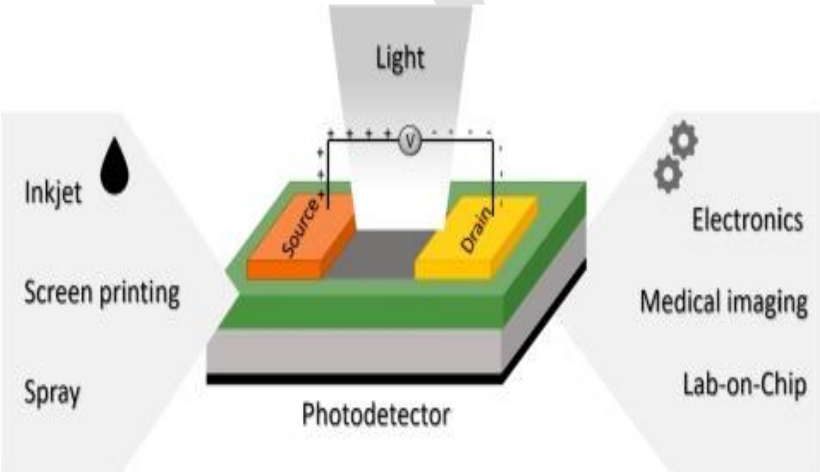
Applications of Laser Diode

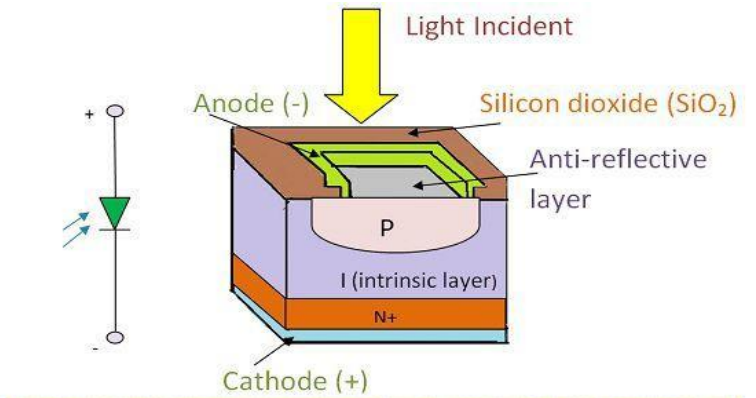
- **Consumer electronics:** This includes laser printers, CDs and DVD players, and fibre optic communication.
- **Industrial applications:** When it comes to industrial applications, laser diode is preferred as it is a source of a high-intensity laser beam and used for cutting, drilling, welding, etc.
- **Medical applications:** Laser diodes are used for the elimination of unwanted tissues and tumours and also in dental medication.

- **Scientific instrumentation:** Instruments like spectrometers, range finders, contact-less measurements can be done with the help of laser diodes.
- **The laser diode in telecom:** Laser diodes with 1.3 µm and 1.55 µm bands are used as the main source of light in telecom and as the band changes laser diodes find application in optical amplification.

Photodetectors

- At the output end of an optical transmission line there must be a receiver device which interprets the information contained in the optical signal.
- The first element of this receiver is a photodetector.
- The photodetector senses the luminescent power falling upon it and converts the variation of this optical power into a correspondingly varying electric current.
- The photodetector works on the principle of optical absorption.
- Several different types of photodetectors are in existence.
- Among these are photo multipliers, pyroelectric detectors and semiconductor-based photoconductors, phototransistors and photodiodes.
- Of the semiconductor-based photodetectors, the photodiode is used almost exclusively for fiber optic systems because of its smallsize, suitable material,high sensitivity and fast response time.
- A photodiode is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation.
- A photodiode is a p-n junction or PIN structure. When a photon of sufficient energy strikes the diode, it creates an electron, hole pair.
- This mechanism is also known as the inner photoelectric effect.



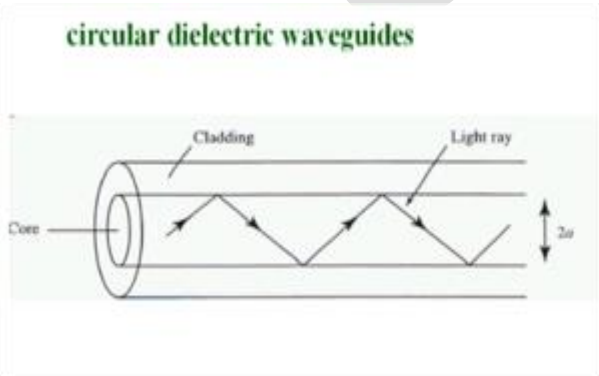


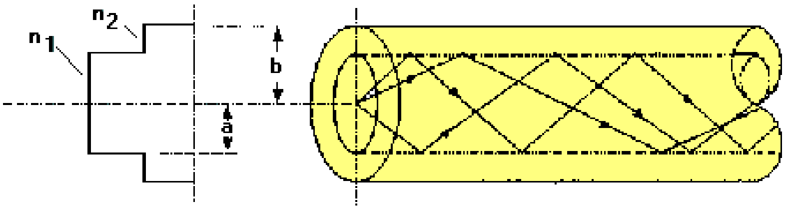
Photodiode Symbol & Construction of Photodiode

Optical fiber wave guides , optical fiber materials

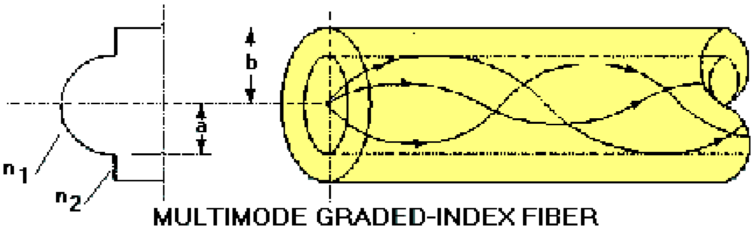
Optical Fiber Waveguides

- An Optical fiber is a flexible, transparent fiber made of extruded glass(silica) or plastic which is slightrly thicker than human hair.
- Optical fiber is mainly used in communication, power transmission, sensors and a lot of other things.
- An optical waveguide is a physical structure that guides a electromagnetic waves in the optical spectrum.
- Common types of optical waveguides include optical fiber and transparent dielectric waveguide made of plastic and glass.
- Optical waveguides are used as components in integrated optical circuits or as the transmission medium in local and long distance optical communication systems.
- Optical waveguides can be classified according to their geometry(planar, strip or fiber waveguides), mode structure (single mode, multimode), refractive index distribution(step or gradient index) and material (glass, polymer, semiconductor).





MULTIMODE STEP-INDEX FIBER



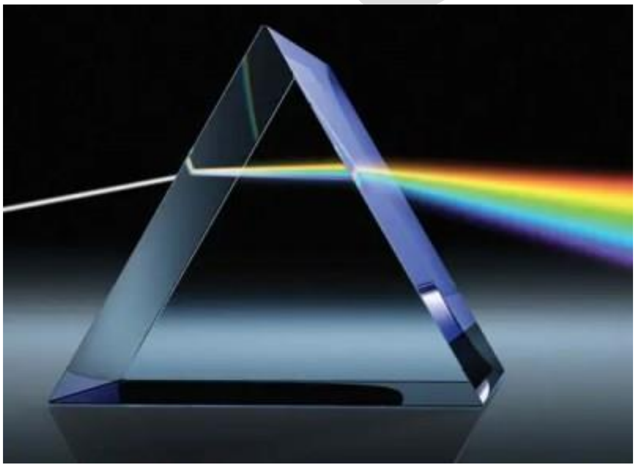
MULTIMODE GRADED-INDEX FIBER

Optical fiber materials

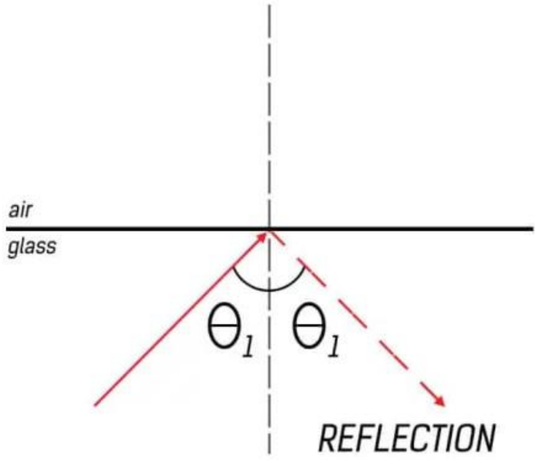
- The fundamentals for making optical fiber need materials which are transparent.
- To make thin, uniform fiber the approach is to heat up a material until it softens into a very thick or viscous liquid and then stretch the thick fluid into the thin ligaments.
- The most common materials for years are silica based glass and certain plastics.
- The purity of the glass used effects the degradation of the light signal being sent
- 1 km thick glass used in optic fibers will allow you to clearly see the other side.
- Therefore in optic fiber manufacturing glass purity is extremely important.

Ray theory

- The concepts of reflection and refraction of light are based on a theory known as ***Ray theory or geometric optics***, where light waves are considered as waves and represented with simple geometric lines or rays
- In a homogeneous medium , light rays are straight lines.
- Light may be absorbed or reflected

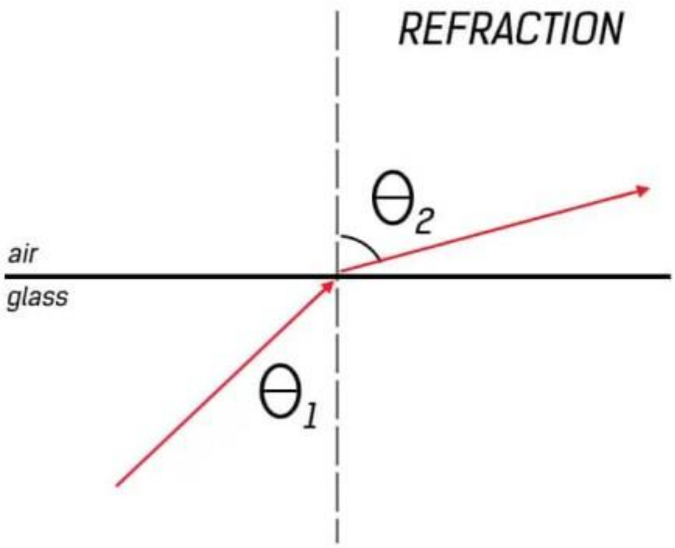


Reflection of light



- The Law of Reflection states that the angle of incidence must be equal to the angle of reflection.
- Reflection depends on the type of surface on which light is incident
- The *images* produced from this reflection have different properties according to the shape of the surface. For example, for a flat mirror, the image produced is upright, has the same size as that of the object, and is equally distanced from the surface of the mirror as the real object.

Refraction of light



- Refraction is the bending of light in a particular medium due to the speed of light in that medium.
- The speed of light in any medium can be given by v= c/ n
- Here n is the **refractive index** of that medium
- When a ray of light is incident at the interface of two media with different refractive indices, it will bend either towards or away from the normal depending on the refractive indices of the media.

According to **Snell's law**, refraction can be represented as

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

n1 and ***n2*** are the two different mediums that will impact the refraction.θ1 is the angle of incidence; θ2 is the angle of refraction.

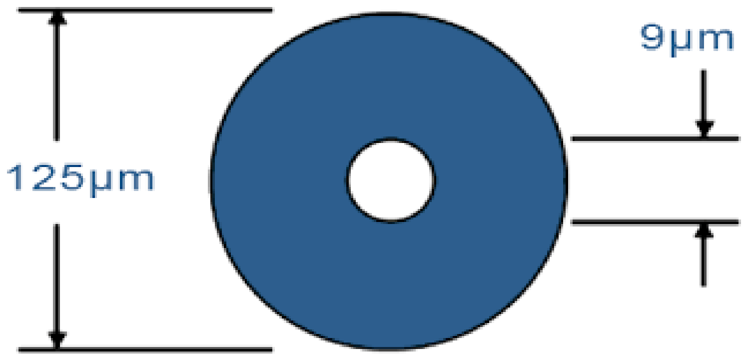
Cylindrical fiber, Single Mode fiber, Cut-off wavelength, Mode field diameter(MFD)

Cylindrical fiber

- An optical fiber is a long cylindrical dielectric waveguide, usually of circular cross-section, transparent to light over the operating wavelength.
- TE and TM modes are obtained within the dielectric cylinder.
- The cylindrical waveguide, is bounded in two dimensions rather than one. Thus two integers, *l* and *m*, are necessary in order to specify the modes.
- Where l is the circumference area and m is the radial area.
- For the cylindrical waveguide we therefore refer to TElm and TMlm modes.
- These modes correspond to meridional rays travelling within the fiber.
- Fiber optic cable has a small diametral core that allows only one mode of light to propagate.
- Because of this, the number of light reflections created as the light passes through the core decreases, lowering attenuation and creating the ability for the signal to travel further.
- This application is typically used in long distance, higher bandwidth runs by Telcos, CATV companies, and Colleges and Universities.

Single Mode Fiber

- Single mode fiber is usually 9/125 in construction. This means that the core to cladding diameter ratio is 9 microns to 125 microns.



Cut-off wavelength

- The cut-off wavelength is the wavelength at which an optical fiber becomes single-mode.
- At wavelengths shorter than cut-off several optical modes may propagate – the fiber is multi-mode.
- Using cut-off wavelength determines your choice of fiber type
- As the cut-off wavelength is approached, the fiber is then single-mode.
- At wavelengths longer than cut-off the guidance of the fundamental mode becomes progressively weaker, until eventually(usually at a wavelength several hundred nanometers above cut-off) the fiber ceases to guide – the fiber loses all optical function.
- This is often referred to as the fundamental mode cut-off or bend edge

Mode Field Diameter (MFD)

- Mode field Diameter is a measure of light intensity in a single mode fiber cross section.
- MFD is determined by the numerical aperture(NA) and cut-off wavelength of the fiber and is related to the diameter of the fiber core.
- MFD is greater than the physical diameter of the fiber core.
- In telecoms fiber operated above cut-off , the core diameter might be around 9mm, and the MFD is around 10.4 mm.
- With the high NA fiber, up around 0.2 or 0.3, the core diameter is just a few microns while MFD might be around 5 mm