Dr.Ram Manohar Lohia Awadh University, Faizabad
Institute of Engineering and Technology
Electronics and Communication Department

Optical Fiber Communications

Seventh Semester 2009/2010

Seminar Report

<u>Submitted by</u>

Shradha Pathak (6254)

<u>Submitted to</u>

- http://en.wikipedia.org/
- To Open source community
- B tech Community

Table of Content

Acknowledgements

First and foremost I offer my sincerest gratitude to my teachers who has supported me throughout my report, with his patience and knowledge. I attribute the level of my bachelor degree to his encouragement and effort and without him this report, too would not have been completed or written. One simply could not wish for a better or friendlier .

The authors also wish to thank the other faculty members , for their valuable suggestions and directions.

I am also indebted to the many countless contributors to the Internet, online optical fiber community, PDF file editors, Microsoft office for providing the numerous documents and tools I have used to produce both my report, data and figure.

Department of Electronics and Communications has provided the support I have needed to produce and complete my seminar report.

I also thanks for my batch mates for providing constant encouragement, Support and valuable suggestions during the development of the report.

Finally, I thank my parents, uncle for supporting me throughout my report through various methods.

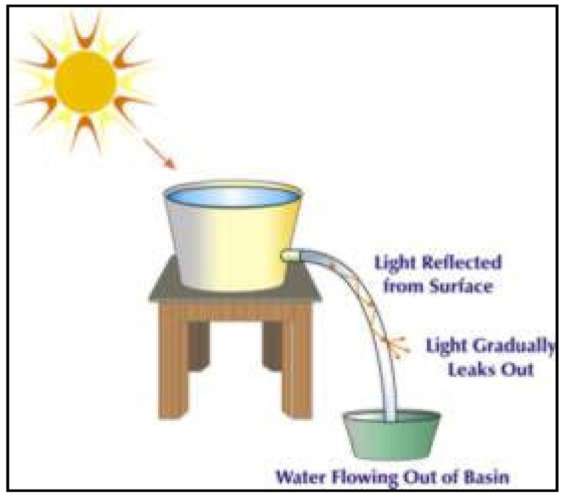
1.0 Introduction of Optical Fiber:-

Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution. Progressing from the copper wire of a century ago to today's **fiber optic cable**, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas.

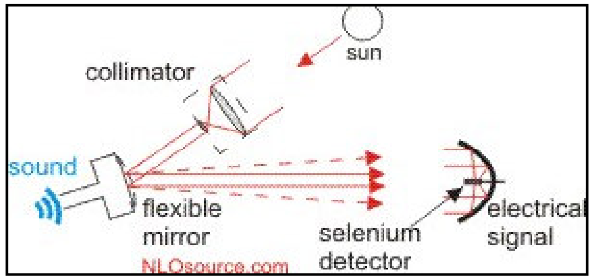
An **optical fiber** (or **fiber**) is a glass or plastic fiber that carries light along its length. **Fiber optics** is the overlap of applied science and engineering concerned with the design and application of optical fibers. Optical fibers are widely used in fiber optic communications, which permits transmission over longer distances and at **higher bandwidths** (data rates) because light has high frequency than any other form of radio signal than other forms of communications. Light is kept in the core of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide. Fibers are used instead of metal wires because signals travel along them with less loss, and they are also immune to electromagnetic interference, which is caused by thunderstorm. Fibers are also used for illumination, and are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers.

2.0 History of Fiber Optic Technology:-

In 1870**, John Tyndall,** using a jet of water that flowed from one container to another and a beam of light, demonstrated that light used internal reflection to follow a specific path. As water poured out through the spout of the first container, Tyndall directed a beam of sunlight at the path of the water. The light, as seen by the audience, followed a zigzag path inside the curved path of the water. This simple experiment, illustrated in Figure, marked the first research into guided transmission of light.

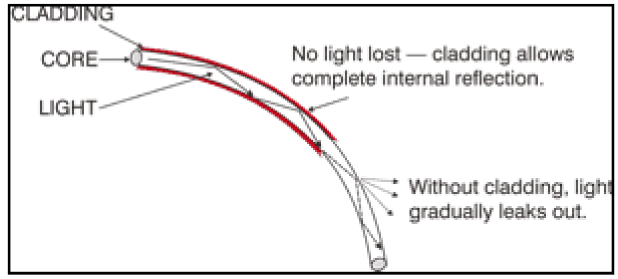


In the same year, **Alexander Graham Bell** developed an optical voice transmission system he called the **photo phone**. The photo phone used free-space light to carry the human voice 200 meters. Specially placed mirrors reflected sunlight onto a diaphragm attached within the mouthpiece of the photo phone.



At the other end, mounted within a parabolic reflector, was a light sensitive selenium resistor. This resistor was connected to a battery that was, in turn, wired to a telephone receiver. As one spoke into the photo phone, the illuminated diaphragm vibrated, casting various intensities of light onto the selenium resistor. The changing intensity of light altered the current that passed through the telephone receiver which then converted the light back into speech. Bell believed this invention was superior to the telephone because it did not need wires to connect the transmitter and receiver. Today, free-space optical links find extensive use in metropolitan applications.

The first practical all-glass fiber was devised by **Brian O'Brien** at the American Optical Company and **Narinder Kapany** (who first coined the term 'fiber optics' in 1956) and colleagues at the Imperial College of Science and Technology in London. Early all-glass fibers experienced excessive optical loss, the loss of the light signal as it traveled the fiber, limiting transmission distances.

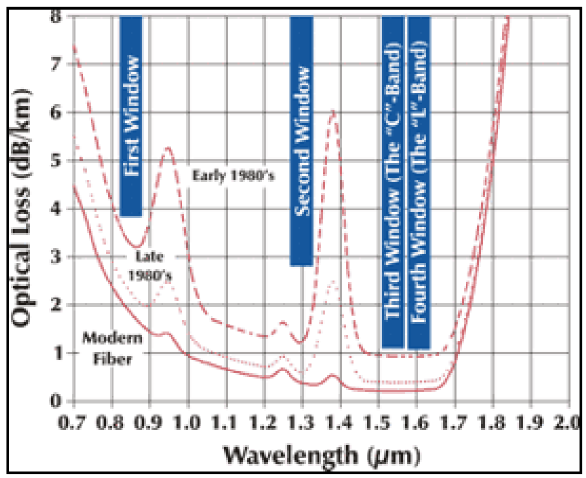


In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. The basic fiber material did not prevent the light signal from reaching the end of the fiber. These researchers believed it was possible to reduce the losses in optical fibers by removing the impurities.

Jun-ichi Nishizawa, a Japanese scientist at Tohoku University, was the first to propose the use of optical fibers for communications in 1963. Nishizawa invented other technologies that contributed to the development of optical fiber communications as well. Nishizawa invented the graded-index optical fiber in 1964 as a channel for transmitting light from semiconductor lasers over long distances with low loss.

Fiber optics developed over the years in a series of generations that can be closely tied to wavelength. Below Figure shows three curves. The top, dashed, curve corresponds to early 1980's fiber, the middle, dotted, curve corresponds to late 1980's fiber, and the bottom, solid, and curve corresponds to modern optical fiber.

The earliest fiber optic systems were developed at an operating wavelength of about 850 nm. This wavelength corresponds to the so-called 'first window' in a silica-based optical fiber. This window refers to a wavelength region that offers low optical loss. As technology progressed; the first window became less attractive because of its relatively high loss. Then companies jumped to the 'second window' at 1310 nm with lower attenuation of about 0.5 dB/km. In late 1977 the 'third window' was developed at 1550 nm. It offered the theoretical minimum optical loss for silica-based fibers. A 'fourth window,' near 1625 nm, is being developed. While it is not lower loss than the 1550 nm window, the loss is comparable, and it might simplify some of the complexities of long-length, multiple-wavelength.



3.0 Construction of Optical Fiber Cable:-

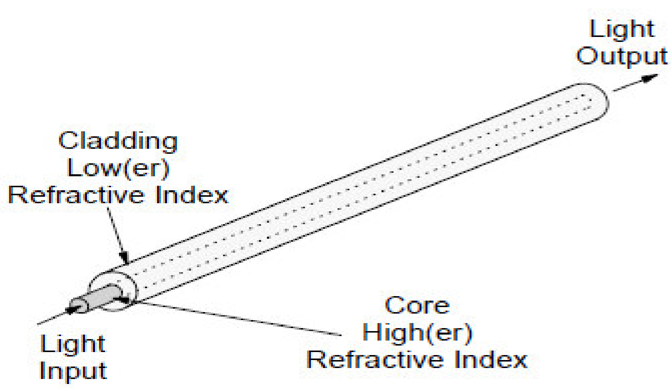


Figure:-Construction of Fiber

An optical fiber is a very thin strand of silica glass in geometry quite like a human hair. In reality it is a very narrow, very long glass cylinder with special characteristics. When light enters one end of the fiber it travels (confined within the fiber) until it leaves the fiber at the other end.

An optical fiber consists of two parts: the **core** and the **cladding**. The core is a narrow cylindrical strand of glass and the cladding is a tubular **jacket** surrounding it. The core has a (slightly) higher refractive index than the cladding. Light travelling along the core is confined by the mirror to stay within it even when the fiber bends around a corner.

A fiber optic cable has an additional coating around the cladding called the **jacket**. The **jacket** usually consists of one or more layers of polymer. Its role is to protect the core and cladding from shocks that might affect their optical or physical properties. It acts as a shock absorber. The jacket also provides protection from abrasions, solvents and other contaminants. The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable.

4.0 Guiding Mechanism in optical fiber:-

Light ray is injected into the fiber optic cable on the right. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than an entity called the critical angle then it is reflected back

into the core. Since the angle of incidence is always equal to the angle of reflection the reflected light will again be reflected. The light ray will then continue this bouncing path down the length of the fiber optic cable. If the light ray strikes the core-to-cladding interface at an angle less than the critical angle then it passes into the cladding where it is attenuated very rapidly with propagation distance.
Light can be guided down the fiber optic cable if it enters at less than the critical angle. This angle is fixed by the indices of refraction of the core and cladding and is given by the formula:

$$\boxed{\theta_c = \arcsin\left(\frac{n_2}{n_1}\right)},$$

The critical angle is measured from the cylindrical axis of the core. By way of example, if $n_1 = 1.446$ and $n_2 = 1.430$ then a quick computation will show that the critical angle is 8.53 degrees, a fairly small angle.

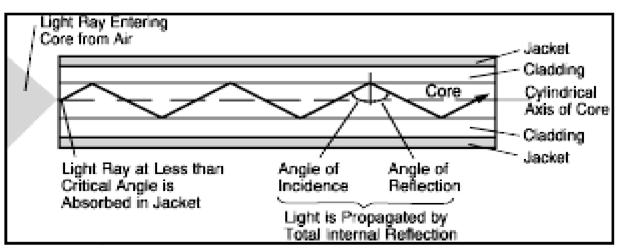


Figure:-Mechanism of Light wave guide in Fiber

Of course, it be noted that a light ray enters the core from the air outside, to the left of Figure. The refractive index of the air must be taken into account in order to assure that a light ray in the core will be at an angle less than the critical angle. This can be done fairly simply. Suppose a light ray enters the core from the air at an angle less than an entity called the external acceptance angle It will be guided down the core.

5.0 Basic Component of Optical Fiber Communication:-

5.1 Transmitters: -

Fiber optic transmitters are devices that include an LED or laser source, and signal conditioning electronics, to inject a signal into fiber. The modulated light may be turned on or off, or may be linearly varied in intensity between two predetermined levels.

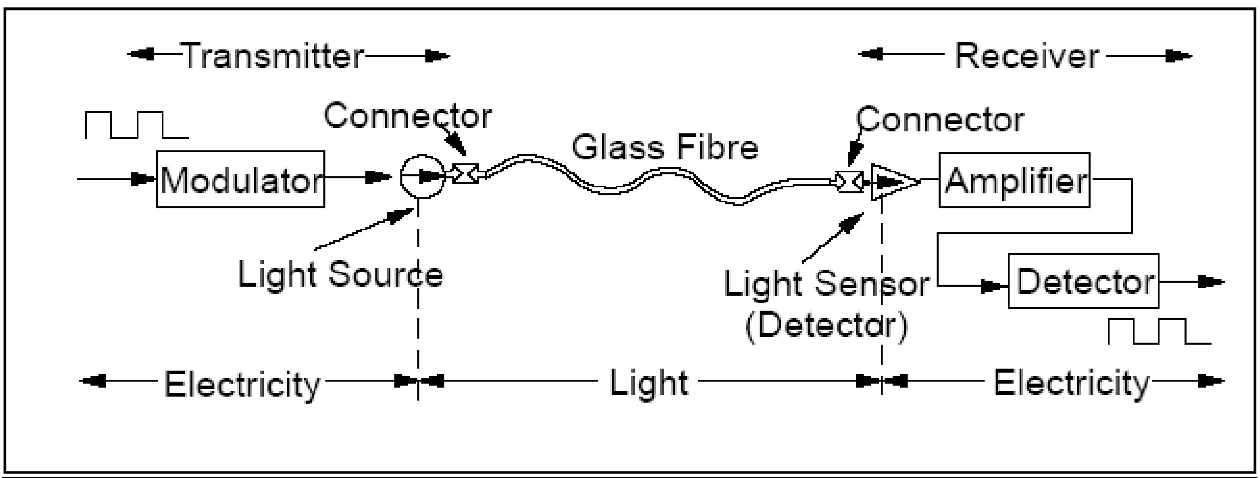


Figure:-The basic components of an optical fiber communication

5.2 Fiber:-

It is the medium to guide the light form the transmitter to the receiver.

5.3 Receivers:- Fiber optic receivers are instruments that convert light into electrical signals. They contain a photodiode semiconductor, signal conditioning circuitry, and an amplifier at the receiver end.

5.4 Process of Optical Fiber Communication:-

A serial bit stream in electrical form is presented to a modulator, which encodes the data appropriately for fiber transmission.

- A light source (laser or Light Emitting Diode - LED) is driven by the modulator and the light focused into the fiber.
- The light travels down the fiber (during which time it may experience dispersion and loss of strength).
- At the receiver end the light is fed to a detector and converted to electrical form.
- The signal is then amplified and fed to another detector, which isolates the individual state changes and their timing. It then decodes the sequence of state changes and reconstructs the original bit stream.
- The timed bit stream so received may then be fed to a using device

6.0 Principle of optical transmission

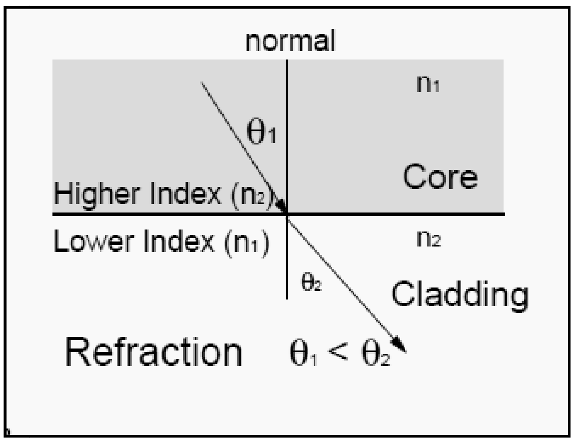
6.1 Index of refraction:-

This is the measuring speed of light in respective medium. it is calculated by dividing speed of light in vacuum to the speed of light in material. The RI for vacuum is 1, for the cladding material of optical fiber it is 1.46, the core value of RI is 1.48(core RI must be more than cladding material RI for transmission. it means signal will travel around 200 million meters per second. it will 12000 km in only 60 seconds.

other delay in communication will be due to communication equipment switching and decoding, encoding the voice of the fiber.

6.2 Snell's Law:-

In order to understand ray propagation in a fiber. We need one more law from high school physics. This is Snell's law.



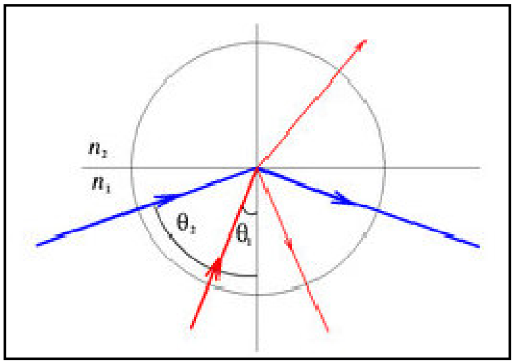
n1 sin .01 = n2 sin .02

Where n denotes the refractive index of the material.01/02 are angles in respective medium. Higher Refractive Index means denser medium.

1) When light enters in lighter medium from denser it inclines towards normal.
2) When light enters in denser medium from lighter it inclines away to normal

6.3 Critical Angle:-

If we consider we notice above that as the angle 01 becomes larger and larger so does the angle 02. Because of the refraction effect 02.



becomes larger more quickly than 01 .At some point 02 will reach 90° while 01 is still well less than that. This is called the **"critical angle".** When 01is increased further then refraction ceases and the light starts to be reflected rather than refracted. Thus light is perfectly reflected at an interface between two materials of different refractive index if:

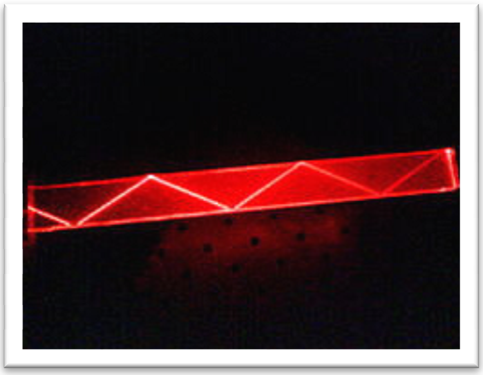
$$\boxed{\theta_c = \arcsin\left(\frac{n_2}{n_1}\right),}$$

1. The light is incident on the interface from the side of higher refractive index.
2. The angle is greater than a specific value called the "critical angle".

Glass refractive index is 1.50 (critical angle is 41.8), Diamond critical angle is 24.4 degree.

6.4Total Internal reflection (TIR):-

When light traveling in a dense medium hits a boundary at a steep angle (larger than the "critical angle "for the boundary), the light will be completely reflected. This phenomenon is called **total internal reflection**. This effect is used in optical fibers to confine light in the core. Light travels along the fiber bouncing back and forth off of the boundary; because the light must strike the boundary with an angle greater than the critical angle, only light that enters the fiber within a certain range of angles can travel down the fiber without leaking out. Total internal reflection occurs when light enters from higher refractive index to lower refractive index material, i.e from glass to air total internal reflection is possible but it is not possible in air to glass.



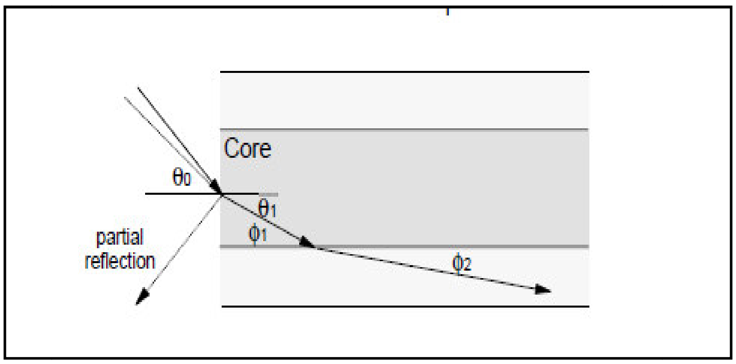


Figure-1(optical rays leaks out from core i.e. is loss)

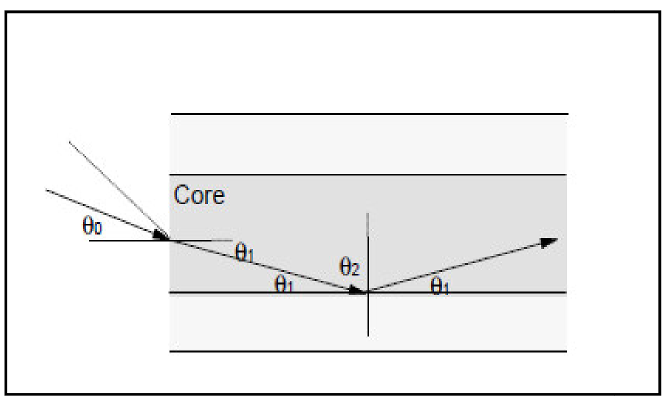


Fig-2 (Optical rays reflected back due to TIR)

If we now consider above Figures we can see the effect of the critical angle within the fiber. In Figure 2 we see that for rays where angle01 is less than a Critical value then the ray will propagate along the fiber and will be "bound" within the fiber. In Figure 1 we see that where the angle 01 is greater than the critical value the ray is refracted into the cladding and will ultimately be lost outside the fiber. This is loss.

6.5 Acceptance Cone:-

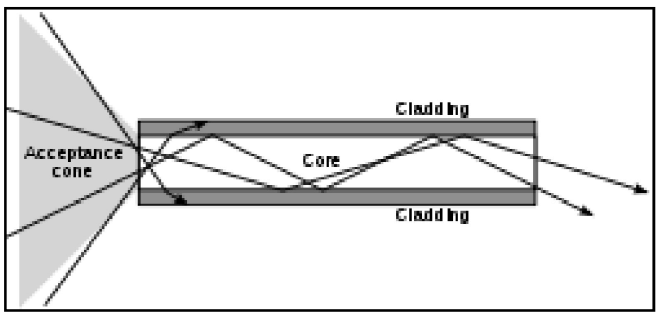


Figure 3: Acceptance cone

When we consider rays entering the fiber from the outside (into the end face of the Fiber) we see that there is a further complication. The refractive index difference between the fiber core and the air will cause any arriving ray to be refracted. This means that there is a maximum angle for a ray arriving at the fiber end face at which the ray will propagate. Rays arriving at an angle less than this angle will propagate but rays arriving at a greater angle will not. This angle is not a "critical angle" as that term is reserved for the case where light arrives from a material of higher RI to one of lower RI. (In this case, the critical angle is the angle within the fiber.) Thus there is a "**cone of acceptance**" at the end face of a fiber. Rays arriving within the cone will propagate and ones arriving outside of it will not. The size of acceptance cone is function of difference of RI of core and cladding.

6.6 Numerical aperture (NA):-

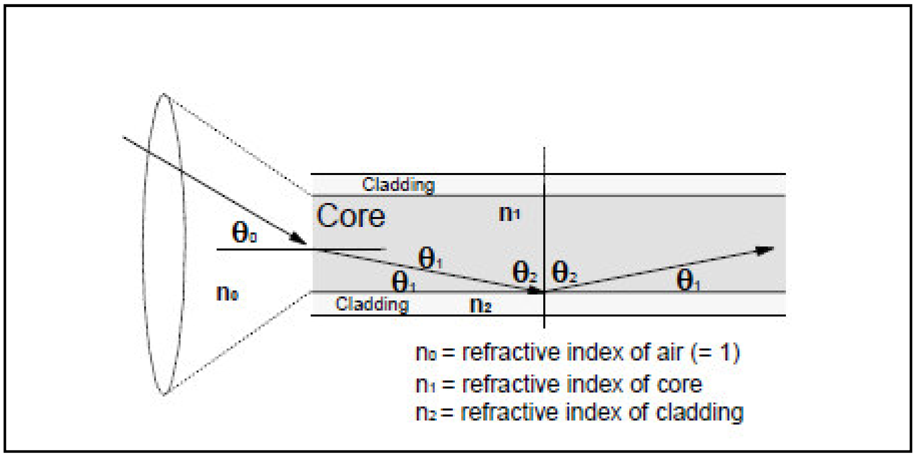


Figure: - 4 (Numerical aperture)

One of the most often quoted characteristics of an optical fiber is its "**Numerical Aperture**". The NA is intended as a measure of the light capturing ability of the fiber. However, it is used for many other purposes. For example it may be used as a measure of the amount of loss that we might expect on a bend of a particular radius etc.

Figure 2 on shows a ray entering the fiber at an angle close to its axis.

This ray will be refracted and will later encounter the core-cladding interface at an angle such that it will be reflected. This is because the angle 02 will be greater than the critical angle. The angle is greater because we are measuring angles from a normal to the core-cladding boundary not a tangent to it.

Figure 1 on shows a ray entering at a wider angle to the fiber axis. This

One will reach the core-cladding interface at an angle smaller than the critical angle and it will pass into the cladding. This ray will eventually be lost. It is clear that there is a "cone" of acceptance (illustrated in Figure 3). If a ray enters the fiber at an angle within the cone then it will be captured and propagate as a bound mode. If a ray enters the fiber at an angle outside the cone then it will leave the core and eventually leave the fiber itself.

*The **Numerical Aperture** is the sine of the largest angle contained within the cone of acceptance. In figure 4 it is* *SINE* $\underline{0_o}$

We know that sin 02 =n2/n1

Because 02 is the critical angle

And $n_0 \sin 0_0 = n1 \sin 0_1$ from Snell's Law

Now, $\cos 0_1 = \sin 0_2 = n_2/n_1$

We know that $\sin x = (1 - \cos 2x)^{1/2}$(Rule)

Therefore $\sin 0_1 = (1 - n2^2/n1^2)^{1/2}$

Since $n_0 = 1$ then $\sin 0_0 = n1\,(1 - n2^2/n1^2)^{1/2}$

Therefore $\underline{NA = (n1^2 - n2^2)^{1/2}}$

Where n1 = refractive index of the core

n2 = refractive index of the cladding

Typical NA for single-mode fiber is 0.1. For multimode, NA is between 0.2 and 0.3(usually closer to 0.2)

6.6.1 Significance of NA with fiber characteristics:-

- It is a measure of the ability of the fiber to gather light at the input end.
- Because it is a measure of the contrast in RI between the core and the cladding. It is a good measure of the light guiding properties of the fiber. The higher the NA the tighter (smaller radius) we can have bends in the fiber before loss of light becomes a problem.
- The higher the NA the more modes we have rays can bounce at greater angles and therefore there are more of them. This means that the higher the NA the greater will be the dispersion of this fiber (in the case of Multi Mode fiber).
- In Single Mode(SM) fiber a high RI contrast usually implies a high level of dopant in the cladding. Since a significant proportion of optical power in SM travels in the cladding we get a significantly increased amount of attenuation due to the higher level of dopant. Thus (as a rule of thumb) the higher the NA of SM fiber the higher will be the attenuation of the fiber.

7.0 Advantage of Optical fiber:-

Fiber optic transmission systems a fiber optic transmitter and receiver, Connected by fiber optic cable offer a wide range of benefits not offered by traditional copper wire or coaxial cable. These include:

- *Less Expensive*. First, fiber optics are less expensive than copper wire. This is because many miles of optical cable are easier and less expensive to install than the same amount of copper wire or cable.
- *Thinner*. Fiber optics is thinner than copper wire cables, so they will fit in smaller, more crowded places. This is important for underground cable systems, like in cities, where space needs to be shared with sewer pipes, power wires, and subway systems.
- *Higher Carrying Capacity*. More information can also be carried over fiber optic systems. This can be especially important for computers, since a computer has to send so much information at one time. Also, more phone lines can be in one optical fiber. Many people use the same optical cable for phone conversations at the same time.
- *Less signal degradation*. Information gets lost over distances an any kind of wire. But, fiber optic cables don't lose as much signal (information) as other kinds of wires and cables.
- *Use Light Signals*. Because fiber optics use light signals instead of electricity, the signals don't interfere with each other. This makes the signals clearer and easier to understand.
- *Low Power*. Optical fiber signals are created using low-power transmitters because the signal degrades less (instead of high-

power electric transmitters used for copper wires). Lower power use saves money for users and providers.

- *Digital Signals*. Computer networks need digital information, since fiber optic cables send information digitally; they are the best thing to use for computer networks.
- *Non-flammable***.** Since fiber optics send light instead of electricity, fiber optics are non-flammable. This means there is not a fire hazard. Fiber optics also does not cause electric shocks, because they do not carry electricity.
- *Light weight***.** Fiber optics is easier to install and transport than copper wires. That is good news for technicians
- *Flexible*. Since fiber optics is more flexible, they can go around corners and into tighter places than traditional cable. This is important in computer and very big office networks.

Other benefits are:-

- The fiber is totally immune to virtually all kinds of interference, including lightning, and will not conduct electricity. It can there- fore come in direct contact with high voltage electrical equipment and power lines. It will also not create ground loops of any kind.
- As the basic fiber is made of glass, it will not corrode and is unaffected by most chemicals. It can be buried directly in

most kinds of soil or exposed to most corrosive atmospheres in chemical plants without significant concern.

- Fiber optic cables are virtually unaffected by outdoor atmospheric conditions, allowing them to be lashed directly to telephone poles or existing electrical cables without concern for extraneous signal pickup.

- Fiber optic cable is ideal for secure communications systems because it is very difficult to tap but very easy to monitor. In addition, there is absolutely no electrical radiation from a fiber.

7.1 Advantage of optical fiber communication:-

- *Wider bandwidth*: The information carrying capacity of a transmission system is directly proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the range 10^{13} to 10^{15} Hz while the radio wave frequency is about 10^{6} Hz and the microwave frequency is about 10^{10} Hz. Thus the optical fiber yields greater transmission bandwidth than the conventional communication systems and the data rate or number of bits per second is increased to a greater extent in the optical fiber communication system. Further the wavelength division multiplexing operation by the data rate or information carrying capacity of optical fibers is enhanced to many orders of magnitude.

- *Low transmission loss*: Due to the usage of the ultra low loss fibers and the erbium doped silica fibers as optical amplifiers, one can achieve almost lossless transmission. In the modern optical fiber telecommunication systems, the fibers having a transmission loss Of 0.002 dB/km are used. Further, using erbium doped silica fibers over a short length in the transmission path at selective points; appropriate optical amplification can be achieved. Thus the repeater spacing is more than 100 km. Since the amplification is done in the optical domain itself, the distortion produced during the strengthening of the signal is almost negligible.
- *Dielectric waveguide*: Optical fibers are made from silica which is an electrical insulator. Therefore they do not pickup any electromagnetic wave or any high current lightning. It is also suitable in explosive environments. Further the optical fibers are not affected by any interference originating from power cables, railway power lines and radio waves. There is no cross talk between the fibers even though there are so many fibers in a cable because of the absence of optical interference between the fibers.
- *Signal security*: The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a fiber in an easy manner. Therefore optical fiber communication provides hundred per cent signal security.

➢ *Small size and weight*: Fiber optic cables are developed with small radii, and they are flexible, compact and lightweight. The fiber cables can be bent or twisted without damage. Further, the optical fiber cables are superior to the copper cables in terms of storage, handling, installation and transportation, maintaining comparable strength and durability.

8.0 Dispersion:-

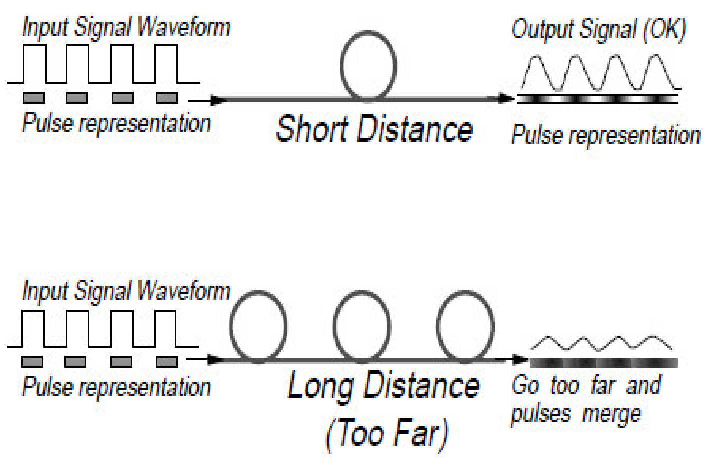


Figure:-5 Effect of Dispersion

Dispersion occurs when a pulse of light is spread out during transmission on the fiber. A short pulse becomes longer and ultimately joins with the pulse behind, making recovery of a reliable bit stream impossible. (In most communications systems bits of information are sent as pulses of light. 1 = light, 0 = dark. But even in analogue transmission systems where information is sent as a continuous series of changes in the signal, dispersion causes distortion.)

There are many kinds of dispersion, each of which works in a different way, but the most important three are discussed below:

8.1Material dispersion (chromatic dispersion):-

Both lasers and LEDs produce a range of optical wavelengths (a band Of light) rather than a single narrow wavelength. The fiber has different refractive index characteristics at different wavelengths and therefore each wavelength will travel at a different speed in the fiber. Thus, some wavelengths arrive before others and a signal pulse disperses (or smears out).

8.2 Intermodal dispersion (Mode Dispersion):-

When using multimode fiber, the light is able to take many different paths or “modes” as it travels within the fiber. The distance traveled by light in each mode is different from the distance travelled in other modes. When a pulse is sent, parts of that pulse (rays or quanta) take many different modes (usually all available modes). Therefore, some components of the pulse will arrive before others. The difference between the arrival times of light taking the fastest mode versus the slowest obviously gets greater as the distance gets greater.

8.3 Waveguide dispersion:-

Waveguide dispersion is a very complex effect and is caused by the shape and index profile of the fiber core. However, this can be controlled by careful design and, in fact, waveguide dispersion can be used to counteract material dispersion.

Dispersion in different fibers:

Mode dispersion > .material dispersion > waveguide dispersion.

9.0Attenuation:-

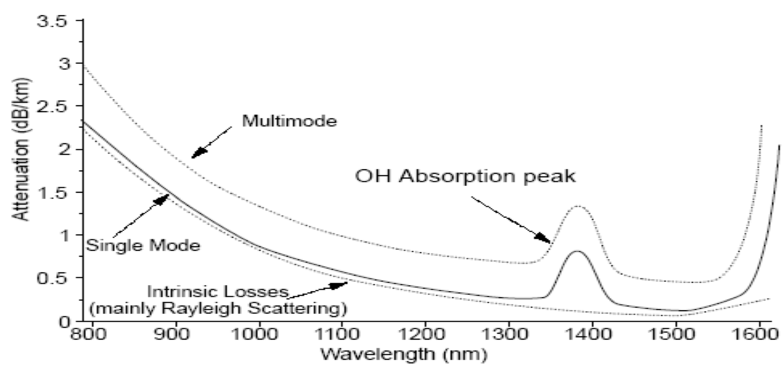


Figure:-6. Fiber Infrared Absorption Spectrum. The lower curve shows the characteristics of a single-mode fiber made from a glass containing about 4% of germanium dioxide (GeO2) dopant in the core. The upper curve is for modern graded index multimodefibre. Attenuation in multimode fiber is higher than in single-mode because higher levels of dopant are used. The peak at around 1400 nm is due to the effects of traces of water in the glass.

Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam with respect to distance travelled through a transmission medium. Attenuation coefficients in fiber optics usually use **units of dB/km** through the medium due to the relatively high quality of transparency of modern optical transmission media.

Attenuation in an optical fiber is caused by absorption, scattering, and bending losses. **Attenuation** is the loss of optical power as light travels along the fiber. Signal attenuation is defined as the ratio of optical input power (P_i) to the optical output power (P_o). Optical input power is the power injected into the fiber from an optical source. Optical output power is the power received at the fiber end or optical detector.

$$\text{attenuation} = \left(\frac{10}{L}\right)\log_{10}\left(\frac{P_i}{P_o}\right)$$

Each mechanism of loss is influenced by fiber-material properties and fiber structure. However, loss is also present at fiber connections i.e. connector, splice, and coupler losses.

9.1 Absorption loss:-

Absorption in optical fibers is explained by three factors:

- Imperfections in the atomic structure of the fiber material
- The intrinsic or basic fiber-material properties
- The extrinsic (presence of impurities) fiber-material properties

Imperfections in the atomic structure induce absorption by the presence of missing molecules or oxygen defects. Absorption is also induced by the diffusion of hydrogen molecules into the glass fiber.

9.1.1 Intrinsic Absorption. - Intrinsic absorption is caused by basic fiber-material properties. If an optical fiber were absolutely pure, with no imperfections or impurities, then all absorption would be intrinsic. Intrinsic absorption sets the minimal level of absorption.

9.1.2Extrinsic Absorption. - Extrinsic absorption is caused by impurities introduced into the fiber material. Trace metal impurities, such as iron, nickel, and chromium, OH ions are introduced into the fiber during fabrication. Extrinsic absorption is caused by the electronic transition of these metal ions from one energy level to another.

9.2 Light scattering:-

Basically, scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured. During manufacturing, regions of higher and lower molecular density areas, relative to the average density of the fiber, are created. Light traveling through the fiber interacts with the density areas as shown in Light is then partially scattered in all direction.

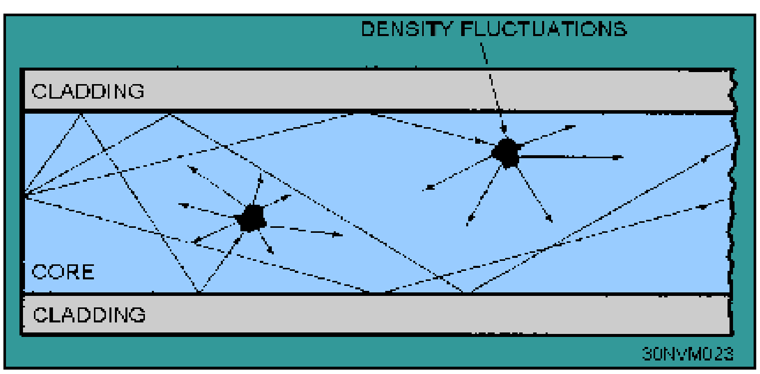


Figure: - 7(Scattering process)

In commercial fibers operating between 700-nm and 1600-nm wavelength, the main source of loss is called **Rayleigh scattering**.. As the wavelength increases, the loss caused by Rayleigh scattering decreases. If the size of the defect is greater than one-tenth of the wavelength of light, the scattering mechanism is called **Mie scattering**.

9.3 Bending loss:-

As light travels along the fiber, it is reflected from the interface between the core and cladding whenever it strays from the path straight down the Center. When the fiber is bent, the light only stays in the fiber because of this reflection. But the reflection only works if the angle of incidence is relatively low. If you bend the fiber too much the light escapes.

The amount of allowable bending is specific to particular cables because it depends on the difference in refractive index, between core and cladding. The bigger the difference in refractive index, the tighter the allowable bend radius. There is a tradeoff here because there are many other reasons that we would like to keep this difference as small as possible. Two types of losses are there.<u>microbend loss or macro bend loss.</u>

Micro bends losses are small microscopic bends of the fiber axis that occur mainly when a fiber is cabled. **Micro bend losses** are caused by small discontinuities or imperfections in the fiber. External forces are also a source of micro bends.

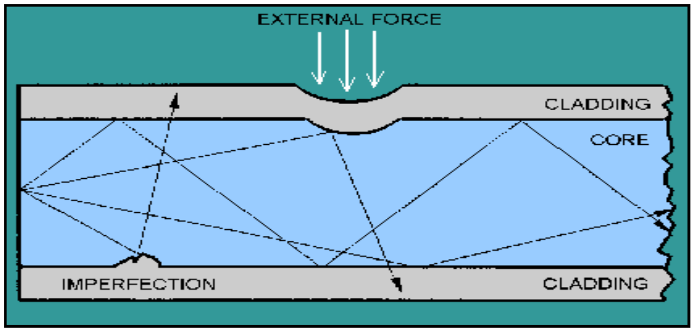


Figure:-8 Bending loss

<u>10.0 Fiber:-</u>

Fiber is the medium to guide the light form the transmitter to the receiver. It is classified into two types depending on the way the light is transmitted: <u>multimode fiber and single-mode fiber.</u>

<u>10.1 Multimode Fiber:-</u>

Multimode fiber designed to transmit more than one light at a time. Fiber diameter ranges from 50-to-100 micron. Multimode fibers can be divided in to two categories <u>Multimode Step-index Fiber and Multimode Graded-index Fiber</u>.

In <u>**Multimode Step-index Fiber**</u> the lights are sent at angles lower than the critical angle or straight (or simply the angle is zero). Any light angle exceed the critical angle will cause it to penetrate through cladding (refracted) and being lost as shown in Figure 9. Obviously light with lower angle which has less number of reflection, reach the end faster than those with larger angle and this will result in unstable wave light. To avoid this problem there should be spacing between the light pulses, but this will limit the bandwidth and because of that it is used for very short distance.

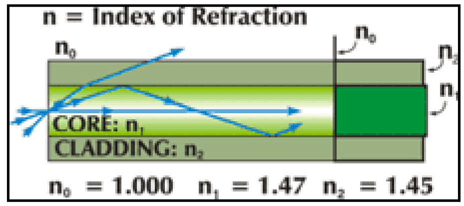


Figure 9 :- Multimode Step-index Fiber

The **Multimode Graded-index** Fiber designed to reduce the problem in Multimode Step-Index fiber by making all the beams reaching the receiver at the same time. This can be done by slowing down the ones with shorter distance and increasing the speed for ones with longer distance, see Figure 10. This is done in fiber implementation by increasing its refractive index at the center and gradually decreases it toward the edges. In the Figure 10 we can see the light near the edges is curved until it is reflected, this is due to the refraction caused by the change in density.

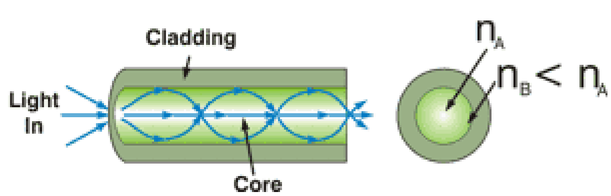


Figure 10:- Multimode Graded-Index Fiber

10.2 Single-Mode Fiber:-

In single-mode, only one light is transmitted in the fiber which diameter ranges from 8.3 to 10 microns, see Figure 11. Since there is only one light the problem associated with the multimode fiber does not exist and by this we can have a higher transmission rate and also it can be used for longer distance.

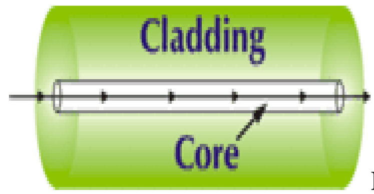


Figure 11:- Single-Mode Fiber

11.0 Optical Sources:-

There are two kinds of devices that are used as light sources: **Lasers** and **LEDs.**

11.1 LED: - LED is just a forward biased p-n junction. There is a recombination of holes and electrons. This recombination requires energy possessed is the unbound free electron is transferred to another state. In all semiconductor p-n junctions some of this energy will be given off as heat and some in the form of photons .In silicon and germanium greater percentage is given up in the form of heat and the emitted light is insufficient. In other material, such as gallium arsenide phosphide (GaAsP) or gallium phosphide (GaP) , the number of photos of light energy emitted is sufficient to create a very visible light source.

*The process of giving off light by applying an electrical source of energy is called **electroluminescence**.*

11.1.1 Operation of LEDs:-

The wavelength of light emitted by the LED is inversely proportional to the band gap energy. The higher the energy the shorter the wavelength. The formula relating electron energy to wavelength is given below.

$$\lambda = \frac{h\,c}{\varepsilon_{ph}} = \frac{1.24}{\varepsilon_{ph}\,(Ev)}$$

Where: λ = Wavelength in microns
h = Plancks constant = 6.63×10^{-34} = 4.14×10^{-15} $eV.s$
c = Speed of light = 3×10^{8} $metres.sec$
ε_{ph} = Photon energy in eV

The materials of which the LED is made determine the wavelength of light emitted. The following table shows energies and wavelengths for commonly used materials in semiconductor LEDs and lasers.

Table 1. Bandgap Energy and Possible Wavelength Ranges in Various Materials

Material	Formula	Wavelength Range λ (μm)	Bandgap Energy W_g (eV)
Indium Phosphide	InP	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AlAs	0.59	2.09
Gallium Indium Phosphide	GaInP	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AlGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

11.1.2 Heterojunctions (Practical LEDs):- Heterojunction means that a *p-n* junction is formed by a single crystal such that the material on one side of the junction differs from that on the other side of the junction. In the modern GaAs diode lasers, a hetero junction is formed between GaAs and GaAlAs. This type of *p-n* junction diode laser or LED is used at 800 m wavelength. At longer wavelengths, InP-InGaAsP heterojunction

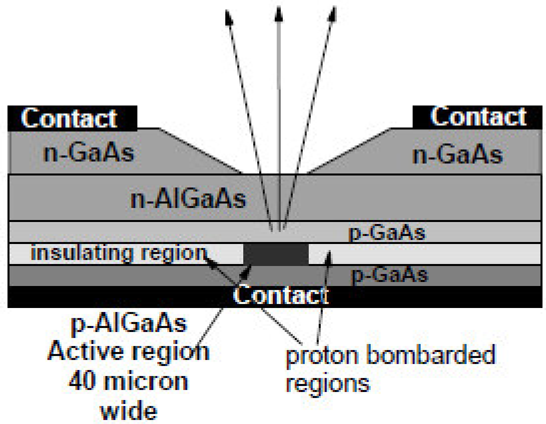


Figure: Hetrojunction LED

diodes are used. Generally heterojunction LEDs have minimum threshold current density (10 A/mm2), high output power (10 mW) even with low operating current (<500 mA) high coherence and high monochromaticity, high stability and longer life.

Characteristics of LEDs:-

- Low Cost
- Low Power
- Relatively Wide Spectrum Produced
- Incoherent Light
- Digital Modulation
- Analogue Modulation

11.2 Lasers:- LASER is an acronym for "*Light Amplification by the Stimulated Emission of Radiation*". Lasers produce far and away the best kind of light for optical communication. Ideal laser light is single-wavelength only. This is related to the molecular characteristics of the material being used in the laser. It is formed in parallel beams and is in a single phase. That is, it is “coherent”.

- Lasers can be modulated (controlled) very precisely (the record is a pulse length of 0.5 femto seconds.
- Lasers can produce relatively high power. Indeed some types of laser can produce kilowatts of power. In communication applications, semiconductor lasers of power up to about 20 mill watts are available. This is many times greater power than LEDs can generate. Other semiconductor lasers (such as those used in “pumps” for optical amplifiers) have outputs of up to 250 mill watts.
- Because laser light is produced in parallel beams, a high percentage (50% to 80%) can be transferred into the fiber.

11.2.1 Principle of the LASER:-

1.An electron within an atom (or a molecule or an ion) starts in a low energy stable state often called the “ground” state.

2. Energy is supplied from outside and is absorbed by the atomic structure whereupon the electron enters an excited (higher energy) state.

3. A photon arrives with energy close to the same amount of energy as the electron needs to give up reaching a stable state. (This is just another way of saying that the wavelength of the arriving photon is very close to the wavelength at which the excited electron will emit its own photon.)

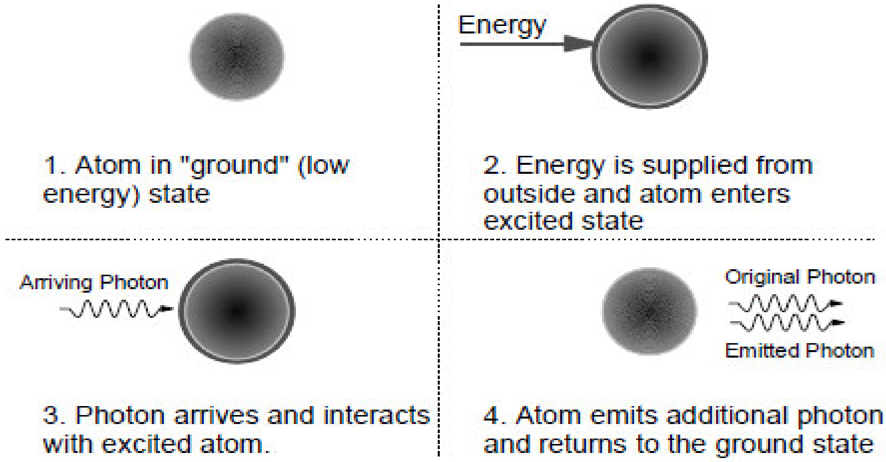


Figure:-Principle of operation of laser

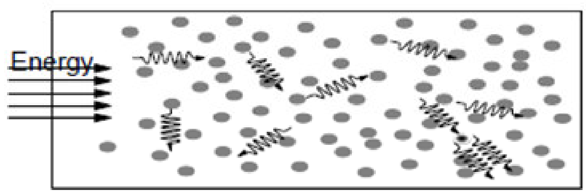


Figure: Spontaneous Emission

4. The arriving photon triggers a resonance with the excited atom. As a result the excited electron leaves its excited state and transitions to a more stable state giving up the energy difference in the form of a photon.

The critical characteristic here is that when a new photon is emitted it has identical wavelength, phase and direction characteristics as the exciting photon.

Note: The photon that triggered (stimulated) the emission itself is not absorbed and continues along its original path accompanied by the newly emitted photon.

12.0 Optical Detectors:-

The predominant types of light detector used in communications systems rely on the principle of ionization in a semiconductor material. When discussing photo detectors there are four important parameters:

Detector Responsivity:-This is the ratio of output current to input optical power. Hence this is the efficiency of the device.

Spectral Response Range:-This is the range of wavelengths over which the device will operate.

Response Time:-This is a measure of how quickly the detector can respond to variations in the input light intensity.

Noise Characteristics:-

12.1 Photoconductors:-

Photoconductors are the simplest conceivable optical detector. The device consists of a piece of (undoped) semiconductor material with electrical contacts attached. A voltage is applied across the contacts. When a photon arrives in the semiconductor it is absorbed and an electron/hole pair is created. Under the influence of the electric field between the two contacts the electron and the hole each migrate toward one of the contacts. Wave length depends on amount of light falling .

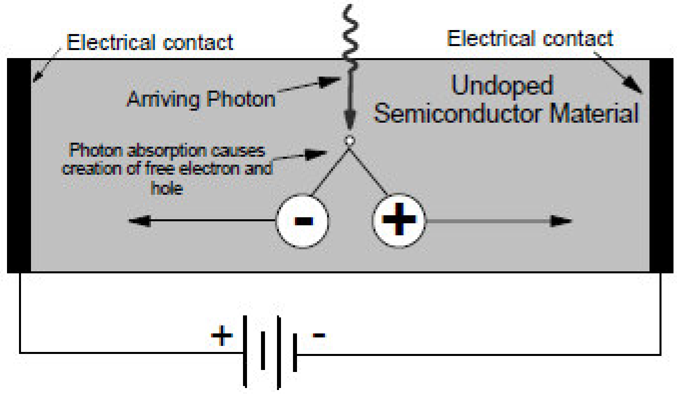


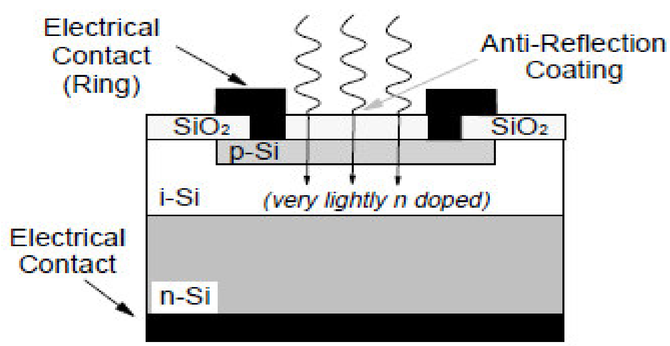
Figure: Photoconductor detector

12.2 Photodiodes:-

Photodiodes convert light directly to electric current. An ideal (p-i-n) diode can convert one photon to one electron of current

12.2.1 P-N Diodes:-

The principle involved in a PIN diode is simply the principle of the LED in reverse. That is, light is absorbed at a p-n junction rather than emitted. The big problem here is that the depletion zone in a p-n junction is extremely thin. But current produced is insufficient and devices are not fast enough for current communications.



12.2.2 P-I-N Diodes:-

Figure:- Silicon P-I-N Diode Schematic

The answer to the problem created by the extreme thinness of a p-n junction is to make it thicker! The junction is extended by the addition of a very lightly doped layer called the intrinsic zone between the p and n doped zones. Thus the device is called a p-i-n diode rather than a p-n diode. The wide intrinsic (i) layer has only a very small amount of dopant and acts as a very wide depletion layer. There are a number of improvements here:

- It increases the chances of an entering photon being absorbed because the volume of absorbent material is significantly increased.
- Because it makes the junction wider it reduces the capacitance across the junction. The lower the capacitance of the junction the faster the device response. Increasing the width of the depletion layer favors current carriage by the drift process which is faster than the diffusion process. The result is that the

  Addition of the "i" layer increases the responsivity and decreases the response time of the detector to around a few tens of picoseconds.

12.3 Avalanche Photodiodes (APDs):-

APDs amplify the signal during the detection process. They use a similar principle to that of "photomultiplier" tubes used in nuclear radiation detection.

Methodology of Conduction in APDs:-

1. A single photon acting on the device releases a single electron.

2. This electron is accelerated through an electric field until it strikes a target material.

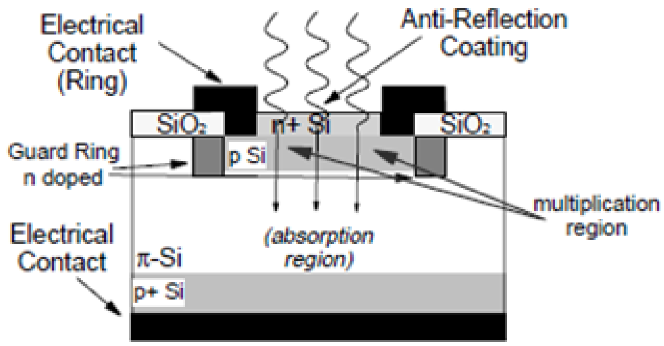


Figure:- Avalanche Photodiode (APD)

3. This collision with the target causes "impact ionization" which releases multiple electrons.

4. These electrons are then themselves accelerated through the field until they strike another target.

5. This releases more electrons and the process is repeated until the electrons finally hit a collector element.

APDs develop a very high electric field in the intrinsic region as well as to impart more energy to photoelectrons to produce new electron-hole pairs by impact ionization. This impact ionization leads to avalanche breakdown in the reverse biased diode. *So the APDs have high sensitivity and high responsivity over p-i-n diodes due to the avalanche multiplication.*

13.0 Limitations of Optical Fiber:-

1. The terminating equipment is still costly as compared to copper wire.
2. Delicate so has to be handled carefully.
3. Communication is not totally in optical domain, so repeated electric to optical to electrical conversion is needed.
4. Optical amplifiers, splitters, MUX-DEMUX are still in development stages.
5. Tapping is not possible. Specialized equipment is needed to tap a fiber.
6. Optical fiber splicing is a specialized technique and needs expertly trained manpower.
7. The splicing and testing equipments are very expensive as compared to copper equipments.
8. Bending Cables
9. Gamma Radiation
10. Electrical Fields
11. Sharks Eat the Cable
12. Gophers (and Termites) Really Do Eat the Cable

14.0 Applications of Optical Fiber:-

Due to the advantages of fiber optic over the traditional connectivity networks, networks are being changed to the new technology of fiber optic. Here is some applications use fiber optics for the communication:

- Long Haul telecommunication systems on land and at sea to carry many simultaneous telephone calls (or other signals) over long distances. These include ocean spanning submarine cables and national backbone networks for telephone and computer data transmission.
- Interoffice trunks that carry many telephone conversations simultaneously between local and regional switching facilities.
- Connections between the telephone N/W and antennas for mobile telephone service.
- Links among computers and high resolution video-terminals used for such purposes as computer aided design.
- Transmission of signals within ships and aircraft.
- Local area Networks operating at high speeds or over large areas, and backbone systems connecting slower local area Networks.
- High speed interconnections between computer and peripherals devices, or between computers, or even within segments of single large
- Cable TV,CCTV ,Optical Fiber Sensors, X-ray Imaging ,Night Vision

Other uses of optical fibers

- Fibers are widely used in illumination applications. They are used as light guides in medical and other applications where bright light Some buildings, optical fibers are used to route sunlight from the roof to other parts of the building .
- Optical fiber ***illumination*** is also used for decorative applications, including signs, art, and artificial Christmas trees.
- Optical fiber is also used in imaging optics i.e. an ***endoscope***, which is used to view objects through a small hole. Medical endoscopes are used for minimally invasive exploratory or surgical procedures (endoscopy). Industrial endoscopes are used for inspecting anything hard to reach, such as jet engine interiors.
- In ***spectroscopy***, optical fiber bundles are used to transmit light from a spectrometer to a substance which cannot be placed inside the spectrometer itself, in order to analyze its composition.
- A ***spectrometer analyzes*** substances by bouncing light off of and through them. By using fibers, a spectrometer can be used to study objects that are too large to fit inside, or gasses, or reactions which occur in pressure vessels.

Future Applications of Optical Fiber Communication:-

Today, however, lower costs and higher production volumes mean that fiber optics can now make sense in areas where it didn't before, including relatively short distances.

Advancement in Communications: -

- Fiber technologies provide higher bandwidth, higher speed, and increased reliability over existing DSL technology, which uses Copper wires for communication.
- In future it will be possible to have Wave length Band in Radio compare to FM band (where synchronizing is done through frequency).In Wavelength band Channels will have Different wavelengths (earlier, it was once just one wavelength of light traveling through the fiber, today it is more like 160 wavelengths traveling at once.).So as research is going on number of wavelength per fiber is increasing.
- *In cars, fiber optics is replacing copper as a lighter alternative for entertainment systems, CD players, and global positioning systems.*
- Research is going on to integrate semiconductor devices, including a transistor, inside micro structured optical fibers. Then it will be possible to manipulate signals inside optical fibers. After these developments there will be not any need of electronic switching

devices at both ends of fiber. So signal will never leave fiber. This results in faster cheaper and more efficient operation.

- INTEL has developed new technology to connect PC USB to Optical Fiber. So direct communication can be achieved between users through Optical Fiber

Advancement in Fiber Optics: -

- In the research world, fiber is enabling the creation of clocks that are more accurate than ever before, By combining a laser with an optical fiber, these clocks allow scientists to measure time more accurately than they've been able to previously, enabling better, more precise.
- By using Fiber optics it is possible to prepare more reflective and shining cloths.
- Room Lighting may improve. Now you can imagine a home with cheerful splashes of natural sunlight in every room at once. Lighting Colour wili be changed. So, by using some almost invisible optical fibers to an outside light source, they could bring natural, outside light to a space that needs.
- This is new way to get sunlight into a place that wouldn't otherwise have it. Such as a dark, interior room.
- Fiber-optic light bulbs have already been developed, and may be an additional way to tap into fiber optics for household lighting.

Conclusion:-

- The age of optical communications is a new era. In several ways fiber optics is a pivotal breakthrough from the electric communication we have been accustomed to. Instead of electrons moving back and forth over a regular copper or metallic wire to carry signals, light waves navigate tiny fibres of glass or plastic to accomplish the same purpose.
- With a bandwidth and information capacity a thousand times greater than that of copper circuits, fiber optics may soon provide us with all the communication technology we could want in a lifetime, at a cost efficient price.
- At present there are many optical fiber communication links throughout the world without using optical solutions. When we introduce optical solutions as light pulses through the fibers, we can achieve high quality telecommunication at a lower cost. We can expect a great revolution in optical fiber communication within a few years by means of solutions.

References:-

- From paper written by *Harry J. R. Dutton for* International Technical Support Organization titled as Understanding Optical Communications by IBM.
- http://en.wikipedia.org/wiki/Optical_fiber
- http://www.fiber-optics.info/articles/wdm.htm
- http://www.arcelect.com/fibercable.htm
- From paper Optical fiber communication—An overview by M ARUMUGAM (Department of Physics), Anna University.
- An educational resource published by Communications Specialties, Inc.paper titled Introduction to Fiber Optics