Fibre optics

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History of all great works in to witness that no great work was ever done without either active or passive support of a person ‘ surrounding and one’s close quarters. Thus is it not hard to conclude how active assistance from senior could positively impact the execution of a project . I am highly thankful to our learned faculty for her active guidance throughout the completion of project.

Last but not least, I would also want to extend my appreciation to those who could not be mentioned here but have well played their role to inspire me behind the certain……………………………..

History:-

1. Daniel Colladon first described this “ light fountain” or “ light pipe” in an 1842 article entitled On the reflections of a ray of light inside a parabolic liquid stream. This particular illustration comes from a later article by Colladon, in 1884.

The principle that makes fiber optics possible, was first demonstrated by Daniel Colladon and Jacques Babinet in Paris in the early 1840s.

John Tyndall wrote about the property of total internal reflection in an introductory book about the nature of light in 1870:

“ When the light passes from air into water, the refracted ray is bent towards the perpendicular… When the ray passes from water to air it is bent from the perpendicular… If the angle which the ray in water encloses with the perpendicular to the surface be greater than 48 degrees, the ray will not quit the water at all: it will be totally reflected at the surface…. The angle which marks the limit where total reflection begins is called the limiting angle of the medium. For water this angle is 48°27′, for flint glass it is 38°41′, while for diamond it is 23°42′.”

0. The groundbreaking event happened in around 1965, Charles K. Kao and George A. Hockham of the British company Standard Telephones and Cables (STC) were the first to promote the idea that the attenuation in optical fibers could be reduced below 20 decibels per kilometer (dB/km), allowing fibers to be a practical medium for communication. They proposed that the attenuation in fibers available at the time was caused by impurities, which could be removed, rather than fundamental physical effects such as scattering. They correctly and systematically theorized the light-loss properties for optical fiber, and pointed out the right material to manufacture such fibers – silica glass with high purity. This discovery led to Kao being awarded the Nobel Prize in Physics in 2009.

0. NASA used fiber optics in the television cameras that were sent to the moon. At the time its use in the cameras was ‘ classified confidential’ and only those with the right security clearance or those accompanied by someone with the right security clearence were permitted to handle the cameras.

0. In 1991, the emerging field of photonic crystals led to the development of photonic-crystal fiber which guides light by means of diffraction from a periodic structure, rather than total internal reflection. The first photonic crystal fibers became commercially available in 2000.

Photonic crystal fibers can be designed to carry higher power than conventional fiber, and their wavelength dependent properties can be manipulated to improve their performance in certain applications.

PROCESS OF MANUFACTURING OF FIBRE OPTICS :-

Illustration of the modified chemical vapor deposition (inside) process

Standard optical fibers are made by first constructing a large-diameter preform, with a carefully controlled refractive index profile, and then pulling the preform to form the long, thin optical fiber. The preform is commonly made by three chemical vapor deposition methods: inside vapor deposition, outside vapor deposition, and vapor axial deposition.

With inside vapor deposition, the preform starts as a hollow glass tube approximately 40centimeters (16in) long, which is placed horizontally and rotated slowly on a lathe. Gases such as silicon tetrachloride ($SiCl_4$) or germanium tetrachloride ($GeCl_4$) are injected with oxygen in the end of the tube. The gases are then heated by means of an external hydrogen burner, bringing the temperature of the gas up to 1900K (1600°C, 3000°F), where the tetrachlorides react with oxygen to produce silica or germania (germanium dioxide) particles. When the reaction conditions are chosen to allow this reaction to occur in the gas phase throughout the tube volume, in contrast to earlier techniques where the reaction occurred only on the glass surface, this technique is called modified chemical vapor deposition.

The oxide particles then agglomerate to form large particle chains, which subsequently deposit on the walls of the tube as soot. The deposition is due to the large difference in temperature between the gas core and the wall causing the gas to push the particles outwards (this is known as thermophoresis). The torch is then traversed up and down the length of the tube to deposit the material evenly. After the torch has reached the end of the tube, it is then brought back to the beginning of the tube and the deposited particles are then melted to form a solid layer. This process is repeated until a sufficient amount of material has been deposited. For each layer the composition can be modified by varying the gas composition, resulting in precise control of the finished fiber's optical properties.

In outside vapor deposition or vapor axial deposition, the glass is formed by flame hydrolysis, a reaction in which silicon tetrachloride and germanium tetrachloride are oxidized by reaction with water (H2O) in an oxyhydrogen flame. In outside vapor deposition the glass is deposited onto a solid rod, which is removed before further processing. In vapor axial deposition, a short seed rod is used, and a porous preform, whose length is not limited by the size of the source rod, is built up on its end. The porous preform is consolidated into a transparent, solid preform by heating to about 1800K (1500°C, 2800°F).

The preform, however constructed, is then placed in a device known as a drawing tower, where the preform tip is heated and the optic fiber is pulled out as a string. By measuring the resultant fiber width, the tension on the fiber can be controlled to maintain the fiber thickness.

Principle of operation:-

An optical fiber is a cylindrical dielectric waveguide (nonconducting waveguide) that transmits light along its axis, by the process of total internal reflection. The fiber consists of a core surrounded by a cladding layer, both of which are made of dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding. The boundary between the core and cladding may either be abrupt, in step-index fiber, or gradual, in graded-index fiber.

Index of refraction:

The index of refraction is a way of measuring the speed of light in a material. Light travels fastest in a vacuum, such as outer space. The actual speed of light in a vacuum is about 300, 000 kilometres (186 thousand miles) per second. Index of refraction is calculated by dividing the speed of light in a vacuum by the speed of light in some other medium. The index of refraction of a vacuum is therefore 1, by definition. The typical value for the cladding of an optical fiber is 1. 46. The core value is typically 1. 48. The larger the index of refraction, the slower light travels in that medium. From this information, a good rule of thumb is that signal using optical fiber for communication will travel at around 200 million meters per second. Or to put it another way, to travel 1000 kilometers in fiber, the signal will take 5 milliseconds to propagate. Thus a phone call carried by fiber between Sydney and New York, a 12000 kilometer distance, means that there is an absolute minimum delay of 60 milliseconds (or around 1/16th of a second) between when one caller speaks to when the other hears. (Of course the fiber in this case will probably travel a longer route, and there will be additional delays due to communication equipment switching and the process of encoding and decoding the voice onto the fiber).

Total internal reflection: –

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 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. This range of angles is called the acceptance cone of the fiber. The size of this acceptance cone is a function of the refractive index difference between the fiber’s core and cladding.

In simpler terms, there is a maximum angle from the fiber axis at which light may enter the fiber so that it will propagate, or travel, in the core of the fiber. The sine of this maximum angle is the numerical aperture (NA) of the fiber. Fiber with a larger NA requires less precision to splice and work with than fiber with a smaller NA. Single-mode fiber has a small NA.

TYPES OF FIBRE OPTICS:-

Multi-mode fiber:-

Fibers which support many propagation paths or transverse modes are called multi-mode fibers (MMF). Multi-mode fibers generally have a larger core diameter, and are used for short-distance communication links and for applications where high power must be transmitted.

“ Fiber with large core diameter may be analyzed by geometrical optics. Such fiber is called multi-mode fiber”. from the electromagnetic analysis . In a step-index multi-mode fiber, rays of light are guided along the fiber core by total internal reflection. Rays that meet the core-cladding boundary at a high angle , greater than the critical angle for this boundary, are completely reflected. The critical angle (minimum angle for total internal reflection) is determined by the difference in index of refraction between the core and cladding materials. Rays that meet the boundary at a low angle are refracted from the core into the cladding, and do not convey light and hence information along the fiber. The critical angle determines the acceptance angle of the fiber, often reported as a numerical aperture. A high numerical aperture allows light to propagate down the fiber in rays both close to the axis and at various angles, allowing efficient coupling of light into the fiber. However, this high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber.

Single-mode fiber:-

Those which can only support a single mode are called single-mode fibers (SMF). Single-mode fibers are used for most communication links longer than 550meters (1, 800ft).

The structure of a typical single-mode fiber.

1. Core: 8µm diameter
2. Cladding: 125µm dia.
3. Buffer: 250µm dia.
4. Jacket: 400µm dia.

Fiber with a core diameter less than about ten times the wavelength of the propagating light cannot be modeled using geometric optics. Instead, it must be analyzed as an electromagnetic structure, by solution of Maxwell's equations as reduced to the electromagnetic wave equation. The electromagnetic analysis may also be required to understand behaviors such as speckle that occur when coherent light propagates in multi-mode fiber. As an optical waveguide, the fiber supports one or more confined transverse modes by which light can propagate along the fiber. " Fiber supporting only one mode is called single-mode or mono-mode fiber."

The most common type of single-mode fiber has a core diameter of 8-10 micrometers and is designed for use in the near infrared. The mode structure depends on the wavelength of the light used, so that this fiber actually supports a small number of additional modes at visible wavelengths. Multi-mode fiber, by comparison, is manufactured with core diameters as small as 50 micrometers and as large as hundreds of micrometers. The normalized frequency V for this fiber should be less than the first zero of the Bessel function J0 (approximately 2. 405).

Special-purpose fiber: –

Some special-purpose optical fiber is constructed with a non-cylindrical core and/or cladding layer, usually with an elliptical or rectangular cross-section. These include polarization-maintaining fiber and fiber designed to suppress whispering gallery mode propagation.

Photonic-crystal fiber is made with a regular pattern of index variation (often in the form of cylindrical holes that run along the length of the fiber). Such fiber uses diffraction effects instead of or in addition to total internal reflection, to confine light to the fiber's core. The properties of the fiber can be tailored to a wide variety of applications.

APPLICATIONS OF FIBRE OPTICS:-

1. Optical fiber communication:

1. Optical fiber can be used as a medium for telecommunication and networking because it is flexible and can be bundled as cables. It is especially advantageous for long-distance communications, because light propagates through the fiber with little attenuation compared to electrical cables. This allows long distances to be spanned with few repeaters.
2. Additionally, the per-channel light signals propagating in the fiber have been modulated at rates as high as 111 gigabits per second by NTT, although 10 or 40Gb/s is typical in deployed systems. Each fiber can carry many independent channels, each using a different wavelength of light (wavelength-division multiplexing (WDM)). The net data rate (data rate without overhead bytes) per fiber is the per-channel data rate reduced by the FEC overhead, multiplied by the number of channels.
3. For short distance applications, such as creating a network within an office building, fiber-optic cabling can be used to save space in cable ducts. This is because a single fiber can often carry much more data than many electrical cables, such as 4 pair Cat-5 Ethernet cabling. Fiber is also immune to electrical interference; there is no cross-talk between signals in different cables and no pickup of environmental

noise. Non-armored fiber cables do not conduct electricity, which makes fiber a good solution for protecting communications equipment located in high voltage environments such as power generation facilities, or metal communication structures prone to lightning strikes.

4. They can also be used in environments where explosive fumes are present, without danger of ignition. Wiretapping is more difficult compared to electrical connections, and there are concentric dual core fibers that are said to be tap-proof.

0. Fiber optic sensors :-

1. Fibers have many uses in remote sensing. In some applications, the sensor is itself an optical fiber. In other cases, fiber is used to connect a non-fiberoptic sensor to a measurement system. Depending on the application, fiber may be used because of its small size, or the fact that no electrical power is needed at the remote location, or because many sensors can be multiplexed along the length of a fiber by using different wavelengths of light for each sensor, or by sensing the time delay as light passes along the fiber through each sensor. Time delay can be determined using a device such as an optical time-domain reflectometer.
2. Optical fibers can be used as sensors to measure strain, temperature, pressure and other quantities by modifying a fiber so that the quantity to be measured modulates the intensity, phase, polarization, wavelength or transit time of light in the fiber. Sensors that vary the intensity of light are the simplest, since only a simple source and detector are required. A particularly useful feature of such fiber optic

sensors is that they can, if required, provide distributed sensing over distances of up to one meter.

3. Extrinsic fiber optic sensors use an optical fiber cable, normally a multi-mode one, to transmit modulated light from either a non-fiber optical sensor, or an electronic sensor connected to an optical transmitter. A major benefit of extrinsic sensors is their ability to reach places which are otherwise inaccessible. An example is the measurement of temperature inside aircraft jet engines by using a fiber to transmit radiation into a radiation pyrometer located outside the engine. Extrinsic sensors can also be used in the same way to measure the internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement techniques impossible. Extrinsic sensors are used to measure vibration, rotation, displacement, velocity, acceleration, torque, and twisting.

0. Other uses of optical fibers:-

Light reflected from optical fiber illuminates exhibited model

1. Fibers are widely used in illumination applications. They are used as light guides in medical and other applications where bright light needs to be shone on a target without a clear line-of-sight path. In 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. Swarovski boutiques use optical fibers to illuminate their crystal showcases from many different angles while only employing one light

source. Optical fiber is an intrinsic part of the light-transmitting concrete building product, LiTraCon.

2. Optical fiber is also used in imaging optics. A coherent bundle of fibers is used, sometimes along with lenses, for a long, thin imaging device called 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 used for inspecting anything hard to reach, such as jet engine interiors.
3. 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.
4. An optical fiber doped with certain rare earth elements such as erbium can be used as the gain medium of a laser or optical amplifier. Rare-earth doped optical fibers can be used to provide signal amplification by splicing a short section of doped fiber into a regular (undoped) optical fiber line. The doped fiber is optically pumped with a second laser wavelength that is coupled into the line in addition to the signal wave. Both wavelengths of light are transmitted through the doped fiber, which transfers energy from the second pump wavelength to the signal wave. The process that causes the amplification is stimulated emission.

5. Optical fibers doped with a wavelength shifter are used to collect scintillation light in physics experiments
6. Optical fiber can be used to supply a low level of power (around one watt) to electronics situated in a difficult electrical environment. Examples of this are electronics in high-powered antenna elements and measurement devices used in high voltage transmission equipment.

USES:-

1. Optical fibers are widely used in fiber-optic communications, which permits

   transmission over longer distances and at higher bandwidths (data rates) than

   other forms of communications.

2. Fibers are used instead of metal wires because signals travel along them with

   less loss, and they are also immune to electromagnetic interference.

3. 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.

Light is kept in the core of the optical fiber by total internal reflection. This causes the fiber to act as a waveguide.

ADVANTAGES OF FIBRE OPTICS:

We knowthe electrical signals travel pretty well in metal cables but nothing compares to light inoptical fibre. If we have to list the most outstanding advantages of using light as a

carrier and optical fibres as transmission channels these may be some of them:

1. Great bandwidth available to transmit information. You can easily use many GHz of

   bandwidth limitations being mostly related to electronics in the transmitters and the

   receivers.

2. Low attenuation of the light travelling through optical fibres. Light can travel many

   kilometres in an optical fibre with little attenuation and without using

   amplifiers/repeaters or having them spaced a lot more than amplifiers in coaxial cables

   for example.

3. Immunity to interference's. Optical fibres are made of glass not of any metal which

   makes them immune to any kind of electromagnetic interference.

4. Galvanic isolation. Since they are not metallic they don't establish electrical contactbetween emitter and receiver nor create any capacitance along the length of the cable.

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