# Optical Fibers: From Communication to Medicine

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## Abstract

This paper presents a formal review of physics of optical fibers and their applications. Mechanisms on various physical phenomenon involed in optical fibers have been discussed in detail. Specifically the mechanisms of various losses in optical fibers have been discussed. From application point of view emphasis is put on medical diagnosis and treatment related applications.

## 1. Introduction

The quantity of information that can be carried by a transmission channel, for example a pair of telephone wires or a microwave radio beam, depends on the frequency of the signal; the higher the frequency, the greater the amount of information. Since the frequency of light is roughly 1,000 times the frequency of the shortest radio waves, communication engineers have always dreamed of using light as a means of transmitting information [1]. However, light from ordinary sources cannot be modulated rapidly enough to carry large amounts of information. Coherent light from the first practical laser in 1960 eliminated this major hurdle of this light wave communication and gave people a hope that light might one day replace electrical signals as the common carrier for information exchange.

But the next question for optical communication was "what kind of channel could be used to transmit the modulated light signal"? Today the leading candidate for that function is the optical fiber.

## 2. Optical Fiber

The fiber consists of two concentric cylinders: the core and the cladding.

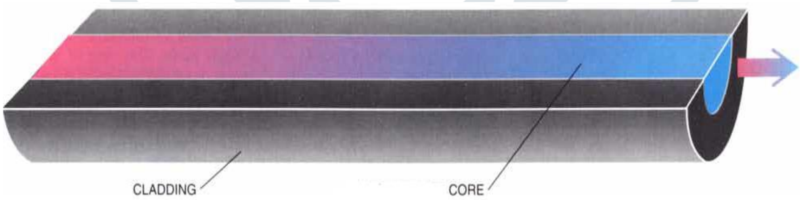


**Fig: Structure of Optical Fiber.**

Light from the source illuminates the core. Some of this light will pass straight along the axis of the core, while the remainder will enter at an angle and will eventually hit the core cladding interface. Light striking the interface at steep angles will breach the interface and cladding and will then be absorbed typically by a plastic coating meant to protect the fiber from mechanical damage. Light striking the interface at shallow angles will be totally reflected back into the core. This total reflection process occurs repeatedly, guiding light rays along the length of the fiber.

### 2.1 Total Internal Reflection

Although a curved rod of glass or other transparent material appears to bend light rays passing through it, it does not actually do so. Instead the light follows a zigzag path down the rod, travelling always in straight lines and caroming repeatedly off the surface. Since the surface is transparent, the rays might be expected to cross it and escape from the conductor. The reason they do not is to be found in the phenomenon known as total internal reflection.

When light falls obliquely on the dividing surface, or interface, between two transparent media, part of it is invariably reflected back through the medium in which it was travelling. Another part may pass into the second medium, the rays being bent or refracted at the surface (This is the effect that accounts for the familiar illusion that a stick thrust into the water is bent.) The amount of the refraction depends on the difference between the speeds of light in the two media; its direction depends on whether the speed is greater in the first or the second medium. When a ray travels from the medium of lower velocity to that of higher, it bends away from the perpendicular to the surface.

If the angle between the incident ray, and the perpendicular is great enough, the refracted ray bends 90 degrees from the perpendicular, or along the interface. The angle of incidence at which this happens is called the critical angle. It depends, obviously, on the ratio of the speeds, or to put it another way, on the ratio of the indexes of refraction of the two media. (A higher refractive index means a lower speed, and vice versa.)

At angles of incidence greater than the critical angle no light passes into the second medium; it is entirely reflected back through the first. If the interface is very smooth and is protected from contaminating influences, virtually no light is lost in this total internal reflection. The process is thus much more efficient than reflection from an ordinary opaque mirror, where considerable energy is absorbed at the surface.

Transparent rods operate as light conductors by means of total internal reflection. They can contain a ray, bouncing it from one side to the other, as long as it always strikes their surface at an angle greater than the critical one. In a straight rod the angle of incidence is the same from one reflection to the next.

This angle is determined by the angle at which the light enters the end of the rod. Hence the smaller the critical angle, the wider the external cone of rays that can be trapped and transported by the conductor. Furthermore, bending a rod decreases the angles of incidence of the shuttling ray. Hence the degree of curvature allowable also depends on the smallness of the critical angle.

## 2.2 Step Index Fiber

Simplest optical fiber is one whose core are cladding have constant values of index of refraction as shown belo.

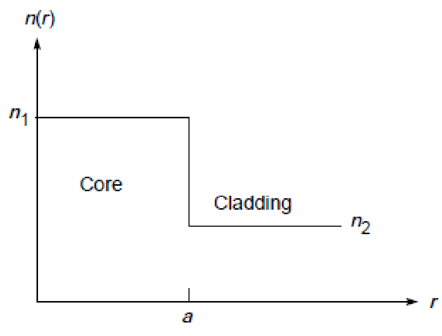


**Fig. Refractive Index profile of step index fiber.**

## 2.3 Parabolic Index Fiber

Stretching the concept of core and cladding, the parabolic index fiber consists of a single material "loaded" with another material in such a way that the refractive index decreases with increasing rapidity away from the axis of the fiber. In this fiber light rays cross and recross the axis repeatedly, travelling not in straight lines but along snakelike sinusoidal paths. The fiber has the remarkable characteristic of speeding up the light rays that travel the longer distance, that is, the ones that make the greatest excursion from the axis, so that all the rays travel at nearly the same net axial velocity. Refractive index profile of parabolic index fiber is shown in figure below:

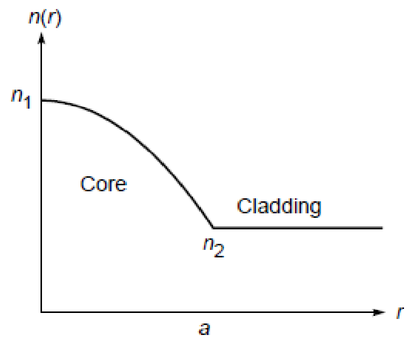


**Fig. Refractive Index profile parabolic index fiber.**

## 3. Differential Delay in Optical Fiber

The basic components for long distance communication are:

1. An oscillator: to generate a high frequency carrier wave.
2. Modulator: to put information on the carrier.
3. Transmitter: to convey the modulated wave (information+carrier) to the destination.
4. Detector: to receive the modulated wave.
5. Demodulator: to separate information from the modulated wave.

Information is sent by varying the intensity of the source either continuously (analogue modulation) or impulsively (digital modulation). The medium carries the modulated signal to the receiver, which reconstructs the original information from the modulated pattern it receives. It is the task of the medium (in this case the fiber) to deliver the modulated signal to the receiver not perfectly, but with enough fidelity so that a reasonably well-designed receiver can tell how the signal source was modulated.

The receiver's function is best seen with digital signals. Assume that the information consists simply of the pattern of light impulses generated in a continuous series of uniform time slots, some of which contain light flashes and some of which do not. To determine what the sent message was the receiver, which is designed to step along exactly in time with the transmitter (the source of the modulated light), must simply discover in which time slots the light source was flashed. Because the receiver "knows" how to interpret the on-off pattern, it can then reconstruct the original message.

A problem confronting the receiver is that the medium (in the current example the optical fiber) degrades the pulses of light in two ways as they travel along it: it attenuates, or dims, them and also makes them less impulsive, or broader in time. If the pulses become too dim, the ubiquitous noise in the receiver masks them. If they become too broad, they begin to spread into the adjacent time slots. Eventually they are washed out over so many slots, some of which were flashed and some of which were not, that the receiver can no longer tell what the transmitter was doing.

Light’s journey through an optical fiber starts at a source that generally is a laser or a light-emitting diode. Some of the light rays entering into the fiber from the light source travel parallel to the axis of the fiber, but other rays enter at an angle to the axis and thus reflect back and forth down the core. It is apparent that the coaxial rays will travel more rapidly than the reflecting ones because they do not travel as far.

If the difference in arrival time between the slowest rays and the fastest ones is comparable to the interval between impulses, the received signal pulses begin to overlap. The farther the signal travels, of course, the larger the differences in arrival time are and the more dispersed in time the pulses become. Moreover, the faster the light is modulated-the closer together the time slots are-the less the pulse-broadening needs to be to cause signal confusion [2-4].

### 3.1 Controlling Differential Delay

The reflection at the interface of core and cladding depends on the fact that the two materials possess slightly different indexes of refraction. The situation is analogous to what a skin diver sees from below the surface of a quiet body of clear water: the surface is either a mirror or a window, depending on the angle from which it is viewed. Directly overhead it is a bright window to the upper world, whereas some distance away from the diver it is a mirror, reflecting only the light from underwater objects.

The reason is that light rays that strike the air-water interface from inside the higher-index water at a shallow angle are reflected back from the surface, whereas the rays that strike the surface more nearly perpendicularly to it go on through. The angle at which the surface becomes transmitting or transparent rather than reflecting depends on the difference in the refractive indexes of the two materials at the interface. If the difference is small, which is not the case with air and water, the critical angle is small too. Hence a solution to the differential-delay problem is to maintain the indexes of refraction of the core and cladding materials close together, so that the light rays that travel down the core all proceed almost axially. Rays that travel at slightly larger angles simply pass through the interface and are lost in the surrounding medium.

Indeed, it is possible to avoid the differential-delay problem altogether. As with other kinds of transmission line, such as a wave guide or a coaxial cable, the dimension of the guide-in this case the diameter of the fiber core-can be chosen in such a way as to eliminate the propagation of all but one electromagnetic mode. The strategy results in the capturing by the fiber core of only the axial rays. Such fibers have been made; the core in this case is typically a few microns in diameter.

A third way to improve upon differential delay is to use parabolic index fibers. Parabolic index fiber has the remarkable characteristic of speeding up the light rays that travel the longer distance, that is, the ones that make the greatest excursion from the axis, so that all the rays travel at nearly the same net axial velocity.

## 4. Dispersion in Optical Fibers

In addition to differential delay another reason for pulses to increase their width as they travel along the fiber is the phenomenon termed material dispersion[5-7]. The index of refraction of the known low-loss fibers is slightly different for different wavelengths of light, that is, different colors. The result is that light of one color travels in the fiber at a velocity different from that of light of a slightly different color.

All optical sources radiate light at more than one frequency at a time, which is to say that the light is multicolored. The different colors from the source enter the fiber together in a single impulsive flash, but they arrive at the far end in a sequence of colors spread out in time. A detector there, being color-blind, simply "sees" a wider (more time-dispersed) pulse than the one sent by the source. A laser radiates nearly monochromatic light, so that typically the variation of the fiber's refractive index over the spectrum of the laser is too small to be a problem. For some sources of light, however, spectral width can be important.

## 5. Attenuation in Optical Fibers

Even if light has entered the fiber and is guided along the core, internal scattering and absorption effects can impede propagation and attenuate the signal[8-10]. In solid transparent materials the attenuation of light results from three independent mechanisms:

1. Electronic absorption,
2. Light scattering
3. Vibrational absorption

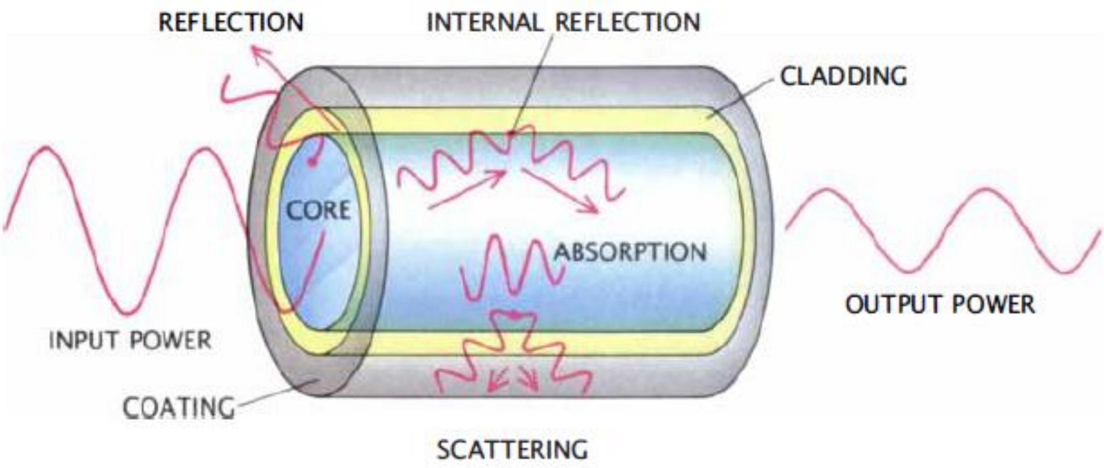


**Fig: Attenutaion in Optical Fibers.**

Although their magnitude may vary with the material, these three phenomena are indigenous to all transparent solids.

**5.1 Electronic Absorption:** Electronic absorption governs attenuation at short wavelengths. A fiber is, after all, composed of atoms joined together by the electrons that form their chemical bond. If a light wave of appropriate energy enters the fiber, it may be absorbed by the bonding electrons and subsequently dissipated as heat. Since short wavelengths correspond to high energies of chemical bonds, short-wavelength light will be absorbed more strongly by this method than long-wavelength light.

**5.2 Scattering:** Light scattering governs attenuation at longer wavelengths. One common form of intrinsic light scattering is Rayleigh scattering, which occurs in liquids, gases and many solids including glasses. The scattering arises from localized variations in the index of refraction of the material caused by changes in density and composition. The intensity of the scattering decreases rapidly with increasing wavelength; its magnitude depends on the material. Experiments carried out on many silica-based glasses suggest that among the more important parameters for determining the attenuation due to Rayleigh scattering are the index of refraction and the glass-transition temperature. This temperature marks the point at which molten glass solidifies, freezing in localized variations in the refractive index. Materials that have low glass-transition temperatures and low indexes of refraction should exhibit low Rayleigh scattering. There are two other scattering processes also that results attenuation of light in optical fibers. These are: (1) Raman scattering and (2) Brillouin scattering.

Raman scattering of light occurs as a consequence of its interaction with vibrational modes of the molecules of the material constituting the fiber. Equivalently it is the scattering of light due to spontaneously generated optical phonons. Brillouin scattering of light occurs as a consequence of its interaction with thermally produced acoustical phonons.

**5.3 Vibrational Absorption:** Vibrational absorption governs attenuation at the longest wavelengths. It is a complicated function of the effective charges, masses and sizes of the atoms that compose a solid. A bond between atoms in a crystal or a glass can be thought of as an attraction between positively charged ions (cations) and negatively charged ions (anions). Two ions joined by a chemical bond vibrate continuously like two weights connected by a stiff spring. If the weights are displaced by a periodic force that matches their vibrational period, energy will be efficiently transferred to the weights and will increase the amplitude of the vibration. The effect is known as resonance. If the atomic bonds are displaced by light at certain resonant wavelengths, the light energy is transformed into the vibrational energy of the ions. Signal strength declines because energy is absorbed. As the wavelength becomes shorter than the resonant wavelength, vibrational absorption decreases and the material become more transparent.

The resonant wavelength is determined by bond strength and ion mass. The resonant wavelength tends to be short when the mass of the ionic pair is small and the inter atomic bond is strong. In silicon dioxide, for example, each silicon cation is surrounded by four oxygen anions. The silicon is bonded strongly to the oxygen, and the combined mass of the two ions is light compared with the ions in other infrared optical fibers. Therefore significant absorption occurs at short wavelengths in the infrared region, and silicon dioxide can transmit light only to about 2. 5 microns.

In the disordered atomic arrangement that is characteristic of glasses and even in the well-ordered lattice of crystals, the onset of vibrational absorption occurs gradually as the resonant wavelength is approached. This gives rise to what is called the vibrational- absorption edge of the material. In this region the intensity of absorption in many substances is found to decrease exponentially with decreasing wavelength.

Electronic absorption, Rayleigh scattering and vibrational absorption are all regarded as intrinsic forms of loss because they are inherent in the material. Knowledge of the intrinsic properties allows one to predict the maximum transparency that can be achieved in a particular solid. Also to be considered in choosing materials are the extrinsic losses, which are the result of contamination and improper processing. Extrinsic factors that result in absorption of light in optical fiber are: presence of impurities in the material, scattering of light due to large sized particulates or bubbles, non uniformity of the fiber cross section and localized deviations from the desired index of refraction.

The total power loss from intrinsic and extrinsic sources is represented by an attenuation coefficient. The coefficient is defined in dB/Km. If a fiber has an attenuation of one dB/Km, then 10 W of optical energy injected into a fiber one Km long will emerge as 7.9 W. Normal window glasses have an attenuation of several thousand dB/Km. Optical communication systems require that losses be held to a level of one dB/Km in a fiber 50 Km long; still longer links require reduction of the loss to .01 dB/Km. If windows were produced with that transparency, one could peer through a pane 200 Km thick.

In addition to low optical attenuation, other characteristics of a fiber material must be considered. The ideal fiber material should be strong, flexible, simple to fabricate and immune to chemical attack. Unfortunately low attenuation and good structural characteristics tend to be incompatible. Many of the same properties that favour long-wavelength transparency such as low glass-transition temperature, weak inter atomic bonds and an ions heavier than oxygen-often produce materials that have undesirable physical, chemical and mechanical behaviour. Nevertheless, there exist a number of crystals and glasses with improved long-wavelength transparency for which these tradeoffs are acceptable. Such materials can transmit infrared wavelengths with little Rayleigh scattering and electronic absorption. Therefore their transparency can in theory be enhanced to levels beyond those found in silica fibers.

The lowest attenuation yet achieved in silica fibers is .2 dB/Km at a wavelength of 1. 5 $\mu m$. This agrees very closely with the intrinsic transparency limit predicted for silica-based glasses on the basis of their Rayleigh scattering, electronic absorption and the vibrational-absorption edge associated with the silicon- oxygen bond. The low attenuation was achieved by careful processing of the glass and fiber so that all sources of extrinsic losses were virtually eliminated.

## 6. Obtaining Transparencies Higher than Silica Based Fibers

To obtain transparencies higher than those available in silica based fibers, new materials chosen on the basis of their intrinsic attenuation properties-must be refined to minimize extrinsic attenuation factors. These new materials will operate in the infrared beyond 2 $\mu m$. There are three classes of materials for this purpose:

**6.1 Crystalline materials:** Crystalline materials form the first class of substances that may be effective as infrared optical fibers. In theory many two-component crystals-silver bromide, zinc selenide, sapphire and even sodium chloride-have low intrinsic attenuations. In practice, however, the use of single crystals as long length optical fibers presents several problems. The growth rates of single crystal fibers are quite low, often only a few centimeters per minute. This low growth rate increases the chance that the fiber diameter will vary. The simultaneous fabrication of a true optical- fiber structure, with a high-index core and lower-index cladding, has also proved difficult.

Much more promising are the polycrystalline materials, principally those based on thallium or silver halides. A composite fiber of thallium, bromine and iodine has been studied intensively. To be sure, the high refractive index (about 2.7) of the thallium halide crystal

suggests that it might exhibit significant Rayleigh scattering. A vibrational edge in the far-infrared region, however, allows use of light at a wavelength where Rayleigh scattering is less significant. Theoretically thallium halide single crystals could be made that would have an attenuation factor of less than .01 decibel per kilometre near seven microns. Yet in the fabrication= process the material develops a granular, polycrystalline microstructure, which scatters light. Such extrinsic scattering effects, coupled with impurity- related absorption, have limited the attenuation of polycrystalline thallium halide fibers to between 150 and 400 dB/Km. This moderate level of attenuation, however, is retained over a broad range of wavelengths extending from about six to 15 $\mu m$.

The related polycrystalline material, silver halide, consists of silver, bromine and chlorine. Like the thallium halides, silver halide fibers can transmit the light from a carbon dioxide laser at a wavelength of 10.6 microns. The material is therefore effective for laser power-transmission applications such as laser-assisted surgery.

**6.2 Chalcogenide Glasses:** The chalcogenide glasses, the second class of infrared-transparent fiber materials, are fabricated by combining metals with chalcogens (the heavier elements in the oxygen family): sulfur, selenium and tellurium. Arsenic trisulfide and arsenic triselenide epitomize the properties of the chalcogenide glasses. The electronic absorption of arsenic trisulfide lies in the middle of the visible spectrum and that of arsenic triselenide is in the near infrared. Consequently arsenic trisulfide glass is red in color and arsenic triselenide glass is an opaque black. These materials have high refractive indexes (between 2.4 and 2.7) and low glass-transition temperatures (between about 150 and 175 degrees Celsius); as a result they exhibit low Rayleigh scattering. Arsenic trisulfide is transparent to about 10$\mu m$, whereas the glass based on selenium, which has more than twice the atomic weight of sulfur, transmits to a wavelength of about 14 $\mu m$.

In contrast to single or polycrystalline materials, chalcogenide glasses can be easily fabricated into optical fibers possessing the proper core, cladding and diameter that can stretch for many kilometers. Much of the loss is a result of contamination from water molecules and other hydrogen containing impurities. A more serious problem affecting chalcogenide fibers is the possible existence of a strong intrinsic electronic absorption in the infrared due to defects in the glass structure that may limit the minimum attainable attenuation to 10 dB/Km.

**6.3 Heavy Metal Fluoride Glasses:** Virtually any metal in the periodic table can be incorporated into a heavy metal fluoride glass. From the standpoint of infrared transparency and ease of glass fabrication, however, only a limited number of compositional types have warranted intensive study: the fluorozirconate, fluorohafnate and barium-thorium glasses.

Measurements on the transmission characteristics of heavy-metal fluoride glass indicate the existence of high transparencies over a broad spectrum of wavelengths that range from .3-8 $\mu m$.The materials have moderate glass-transition temperatures and silica like refractive indexes (=1.5). A long-wavelength infrared vibrational edge and low Rayleigh scattering suggest that intrinsic attenuations of .01 dB/Kmare possible in heavy-metal fluoride glasses.

## 7. Optical Fibers in Medicine

In addition to communication, optical fibers are finding applications in medical diagnosis and treatment. These ultrathin, flexible cables have enabled to see happenings inside the living tissues of the human body. Physicians can now peer into the airways of the lungs, the folds of the intestine, the chambers of the heart and many other areas of the body by inserting optical fibers through natural openings or small incisions and threading them along the body's established pathways. Before optical fibers such area of body were completely inaccessible. By placing fiber-optic sensors in the bloodstream, physicians can do rapid and reliable chemical analyses at the bedside, in the examining room or in the operating room-analyses that otherwise involve taking blood samples from patients for examination in laboratories. By directing a beam of laser light down an optical fiber, physicians can even perform surgery inside the body without giving any cut to any healthy tissue to reach the site of disease.

By delivering laser light through optical fibers, for example, gastroenterologists have cauterized vessels to stop intestinal bleeding, vascular surgeons have begun to vaporize plaque and blood clots in peripheral arteries, and neurosurgeons may soon bond nerves together in the brain and spinal cord. Fiber-optic devices may soon combine diagnosis and treatment for instance by incorporating both a means of detecting cancer cells and a means of destroying the cancer without damaging nearby healthy tissue.

Many fiber-optic procedures for diagnosis and treatment do not require anesthesia and can be performed safely in a physician's office; the continued development of fiber-optic techniques should therefore reduce the risk and cost of medical care. Fiber-optic procedures may also be applied in cases where invasive surgery is dangerous or impossible, as it sometimes is in the young or the elderly.

**7.1 Fiberscopes:** The first medical applications of optical fibers were imaging systems, called fiberscopes those are meant for viewing the stomach and esophagus. Now these devices are so refined that they can be used to inspect virtually every organ system of the body. Indeed, most of the optical fibers used in medicine are incorporated into fiberscopes. The modern fiberscope consists of two bundles of optical fibers. One, the illuminating bundle, carries light to the tissues, and the other, the imaging bundle, transmits the image to the observer.

The illuminating bundle is coupled to a high-intensity light source such as a xenon arc lamp. Light enters the cores of the fibers, which are made of high-purity silica glass. A lens collects the light that is reflected off tissue and focuses it onto the receiving end of the imaging bundle. Each optical fiber in this bundle admits only the reflected light that is aligned with its axis, and so each fiber transmits only a small fraction of the total image. The fibers are glued together just at the ends to allow flexibility and yet avoid scrambling the image. The reconstructed image can be viewed through an eyepiece, recorded by a camera or displayed on a television screen. Since thousands of fibers can be combined in a single bundle with a diameter of less than a millimeter, a fiberscope can carry images that have high spatial resolution and virtually perfect chromaticity.

The illuminating and imaging bundles can easily fit in a catheter a few millimeters in diameter. This fiberscope can then be inserted through orifices in the body and brought to focus on tissues at distances of from five to 100 millimeters (mm) from the tip.

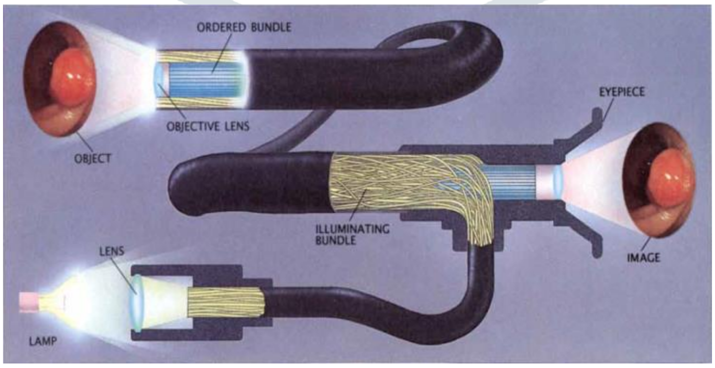


**Fig: Fiberscope**

Fiberscopes are often part of larger instruments, called endoscopes, that include ancillary channels through which physicians can perform other tasks. Through one channel, for example, fluids can be drawn or water or air injected to clear debris away, thereby improving visibility. Another channel may contain fine wires that can be manipulated to angle the endoscope's tip. A third may make it possible to insert tiny scalpels for cutting tissue or snares for removing it or needles for injecting drugs. Most endoscopes on the market are from .3 to 1.2m in length and from 2.5 to 15mm in diameter.

With these devices physicians can gain intimate views of the digestive, reproductive, circulatory and respiratory systems. They can remove small samples of tissue for laboratory analysis and even perform surgery. Peering through fiberscopes, physicians can detect a polyp in the colon, a foreign object in the lungs or a tumor in the esophagus and then remove it with miniature surgical instruments.

During the past five years the fabrication of ultrathin fibers has led to a reduction in fiberscope diameter and an increase in the number of fibers within the imaging bundle, which in turn has increased resolution. The newest fiberscopes incorporate 10,000 fibers in a bundle less than one mm in diameter and can resolve objects 70 $\mu m$ across. These fiberscopes, inserted through an artery in the arm, can convey images of heart valves as well as obstructions in the coronary arteries, the vessels that carry blood to the heart.

**7.2 Chemical and Physical Analysis of Human Physiology**

In addition to providing images optical fiber systems can offer direct and immediate chemical and physical analysis of the blood and other aspects of human physiology. The basic sensing system consists of an optical fiber inserted through a catheter into the body. The external end of the fiber is coupled to a light source and an optical processor, a device for analyzing the reflected light. The other end of the fiber sends light directly into the body or to a miniature sensor called an optode. The reflected light is carried back through the fiber to the processor, which extracts information about physiological conditions from the wavelength and intensity of the reflected light.

In many cases these fiber systems may be more sensitive, reliable and cost-effective than traditional methods, in which fluids are drawn from the body and tested in the laboratory. The fiber systems eliminate delays and reduce the chance of error. Furthermore, the fiber-optic sensors are compatible with body chemistry (for example, they will not provoke a response from the immune system), and in principle the optical fiber itself may be disposable. Fiber systems also appear to be more durable, flexible and potentially safer than the microelectronic devices that have also been developed to collect data from within the body. Some of the fiber optic devices are already available on the market, whereas many other devices are being tested in clinical trials.

Fiber-optic measurements of blood flow rely on light reflected from blood cells. A fiber is inserted through a catheter into an artery. Low-intensity laser light sent through the fiber strikes red blood cells. When the light scatters off the moving cells, its wavelength changes because of a phenomenon known as the Doppler effect. The faster the cell is moving toward the tip of the fiber, the shorter the wavelength of the scattered light will be. Some of this light will be transmitted back through the fiber. The processor at the other end of the fiber then will determine the difference in wavelength between the laser light and the scattered light and will compute the velocity of the blood in the region of the tip.

**7.3 Oxygen Content of Blood:** Optical fibers also make it possible to determine directly the oxygen content of the blood. Hemoglobin (the chemical responsible for oxygen transport in the blood) reflects much more red light when the compound carries oxygen than when it does not. Infrared light, however, is reflected equally from all hemoglobin regardless of its oxygen content. If red and infrared light are transmitted into the blood through optical fibers, the intensity of reflected red light reveals the amount of oxygen-carrying hemoglobin, whereas the intensity of infrared light measures the total amount of hemoglobin. This technique, now applied routinely, helps to reveal the capacity of a patient's blood to carry oxygen or the ability of the heart and lungs to supply oxygen.

**7.4 Pressures in the Arteries:** An optical fiber based sensor that can measure pressure in arteries sensor consists of a small tube at the end of an optical fiber, the far end of the tube sealed by a thin reflective membrane. If the pressures inside and outside the tube are equal, the membrane will stay flat, and light conveyed through the fiber will be reflected straight back. If the pressure is greater outside the tube than inside, the membrane bends inward, creating a convex mirror that reflects less light back through the fiber. If the pressure is lower outside the tube than inside it, the membrane bends outward, and the concave surface focuses more light onto the fiber.

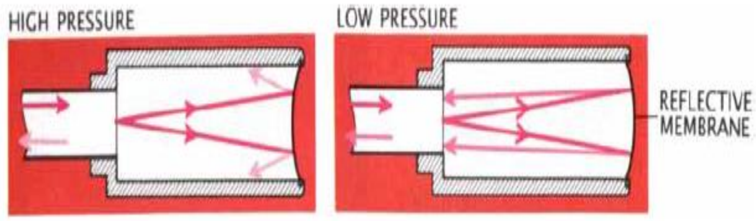


**Fig: Optical Fiber based sensor to measure pressure in arteries.**

**7.5 Laser Surgery: I**n past few decades a significant application of optical fibers in medicine has been the delivery of laser energy inside the body for surgery and therapy. How laser radiation interacts with human tissue depends on the wavelength and intensity of the radiation. Although a particular laser emits light of a single wavelength, or color, a variety of lasers are now available that generate light throughout the visible, infrared and ultraviolet spectrum. Light is absorbed by tissue to a degree that varies depending on the wavelength and on the tissue's chromophores-coloring agents such as hemoglobin, melanin and keratin. Therefore, a laser of a particular wavelength targets specific tissues and produces specific photochemical reactions.

In general low-power lasers cause a gentle, local heating that coagulates blood and causes proteins to congeal. In this way laser light can bond soft tissues together and thereby seal wounds or join blood vessels. High power lasers ablate tissue, in most cases by boiling water away. Such a beam also cauterizes incisions, so that a minimum amount of blood is lost during operations. Surgical applications of lasers require from 10 to 100 watts of continuous laser power or pulsed laser power that reaches peaks of 10,000 to one million watts. Since this power is discharged onto areas smaller than a square millimeter, the power densities achieved are even high.

**7.6 Removal of Arterial Obstructions:** Many of the most devastating diseases of the cardiovascular system occur when arteries become blocked by calcified, fibrous fat deposits, known as atherosclerotic plaque, and by blood clots. If these obstructions cut off circulation, they cause strokes, heart attacks and gangrene in the limbs. To treat a patient with obstructions in the coronary arteries, a physician today might first resort to a method called percutaneous trans luminal coronary angioplasty. This technique relies on a special catheter that has a tiny balloon attached to its end. If an artery is only partially occluded, the tip of the catheter can be inserted through the constricted region. The balloon is inflated so that it compresses and reduces the occlusion. This method is not applicable for treating complete occlusions, and beneficial results may only be temporary. A physician might then recommend a more radical surgical procedure known as a coronary artery bypass: a vein is removed from the leg, the chest cavity is opened to expose the heart and the vein is implanted to carry blood around the blocked artery. Al though the bypass operation usually re establishes blood flow to the heart, it is a traumatic procedure, which involves a lengthy recovery period and great expense.

The development of optical fibers capable of delivering significant laser energy has now made available several new techniques for removing arterial obstructions, known as laser angioplasty. In one set of techniques the end of a fiber is covered with a small metal tip. If the fiber is inserted into an obstructed artery and laser light sent through the fiber, the metal tip will heat up and melt the obstruction. Very careful control of treatment is needed in this technique. Otherwise the hot tip can stick to the arterial wall or even perforate it. Several successful laser-angioplasty instruments are now in use. An alternative that is potentially more effective but technically more complex is a system in which laser light ablates the plaque directly.

**7.7 Fiber Optic Biosensor:** It consists of a cell bounded by a semi permeable membrane, reagents inside the membrane or bound to its inner surface, a fiber to illuminate the cell and detectors to measure the change in optical properties. In most cases, a single fiber both carries light into the cell and collects transmitted or reflected light for analysis.

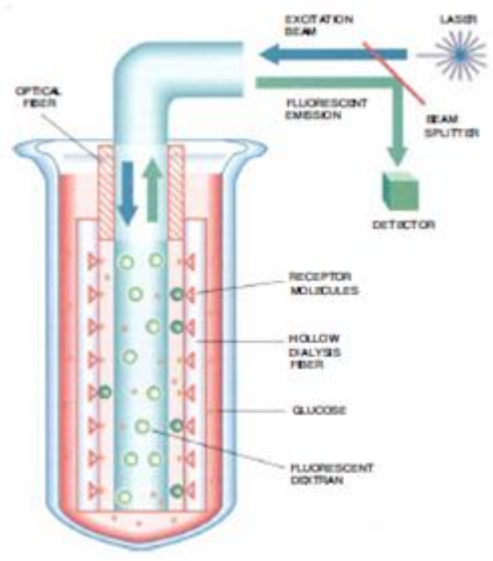


**Fig: Fiber optic biosensor.**

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