Fiber Optics

By: Ashley Malik

Lab Section: M001

Justin Mitchell

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Fiber optics involves the transmission of light through transparent glass or plastic fibers. There are many types of optical fibers that are widely used in the fields of communication, lighting and medicine. However, the fibers can all be explained by the same concepts of physics such as the properties of light. The study of light and its "bending" capabilities provides a breakthrough in understanding the many abilities and advantages optical fibers have over previously used methods and materials.

Even though optical fiber technology is more prominent in modern times, the theory behind it is associated with research performed involving light. In the early 1840s, Daniel Colladon and Jacques Babinet were the first to demonstrate that light used internal reflection to follow a specific path, the principle that makes fiber optics possible. Years later, John Tyndall included a demonstration of this concept during his lectures in London around 1870. The demonstration involved a jet of water that flowed from one container to another and a beam of light. As water poured out the first container's spout, Tyndall directed a beam of sunlight at the path of the water. The light, as seen by the audience, followed a zigzag path within the curved path of the water. This signified the first research into the guided transmission of light. In 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, 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. The crucial attenuation level of 20 dB/km was first achieved in 1970, by researchers Robert D. Maurer, Donald Keck, Peter C. Schultz, and Frank Zimar

(Twentieth Century 1). By analyzing and eventually understanding the properties of light and fibers, crucial discoveries were made that continue to have an effect on society.

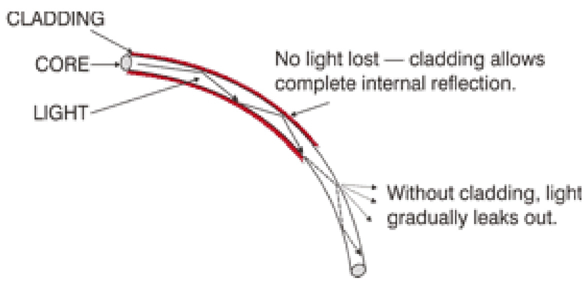


Figure 1: Structure of Optical Fiber

Figure 1 Source: "The Twentieth Century." 5 Dec. 2008. 10 Apr. 2009 <http://www.fiber-optics.info/history/P2/>.

The structure of an optical fiber is composed of two types of glass placed in a concentric arrangement to allow a hollow middle section as shown in Figure 1. The innermost of the fiber, the core, contains a higher index of refraction (1.5) than the outside circle (1.47). The outer coating, also known as the optical cladding, is not involved in carrying light. The core is used to transmit the light, while the glass coating prevents the light from leaking out of the core by reflecting the light within the boundaries of the core. As light travels in a transparent material and meets the surface of another transparent material, two things are possible: some of the light is reflected or some of the light is transmitted into the second transparent material. The transmitted light usually changes direction, or “bends,” when it enters the second material. This bending of light is called refraction. The basis for refraction relies on the principle that light traveling at one speed in one material and will travel at another speed in a different material. Each material then has its own refractive index which determines the amount of bending that takes place. Snell's Law states that “the angle at which light is reflected is dependent on the refractive indices of the two materials" (Twentieth Century 1). The lower refractive index of the cladding causes the light to be angled back into the core as illustrated in Figure 1. Refractive index is defined as: $\mathbf{n = c / c_n}$ where **n** is the refractive index, **c** is the speed of light in a vacuum, and $\mathbf{c_n}$ is the speed of light in the material. Light can travel from a material with a low refractive index to one with a high refractive index or vice versa.

Figures 2 and 3 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009 <http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

Figure 2: $n_1 < n_2$

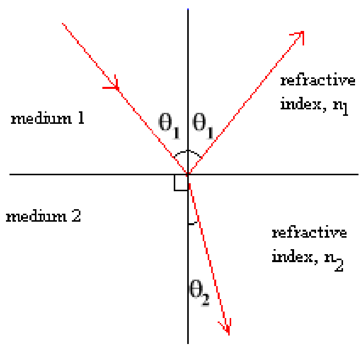
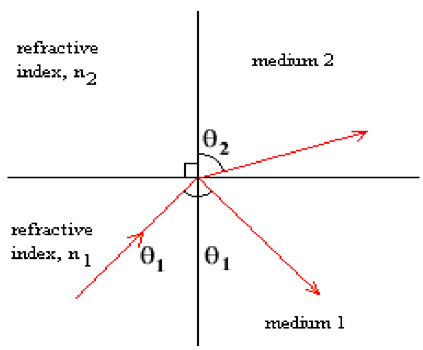


Figure 3: $n_1 > n_2$



In the second case above, angle 2 is always greater than angle 1. Increasing angle 1 will cause angle 2 to reach 90^o before angle 1 does. Once the light is bent to a 90^o angle with the surface normal, the light cannot escape from the material. This is known as total internal reflection. The angle where this occurs first, the critical angle, depends on the index of refraction of the materials (Critical angle 1). Total internal reflection is demonstrated in Figure 4.

Figure 4: Total Internal Reflection

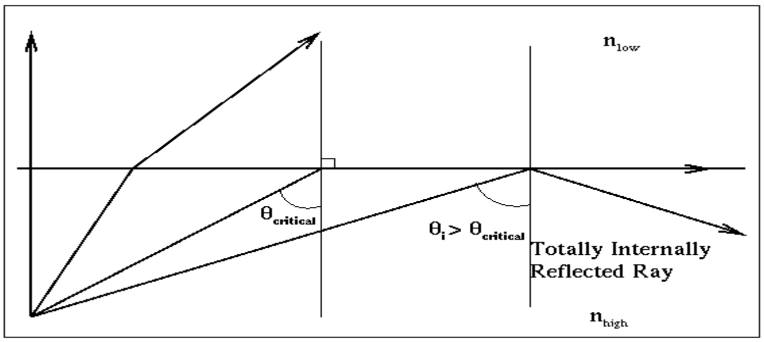


Figure 4 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009 <http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

In order for total internal reflection to occur the refractive index of the first medium must be greater than the refractive index of the second medium. The minimum angle of incidence must be equal to the critical angle. Total internal reflection causes 100% reflection. Since 100% reflection does not occur in any situation in nature, where light is reflected, total internal reflection is beneficial to optical fiber technology.

Figure 5: Propagation of Light in Optical Fibers

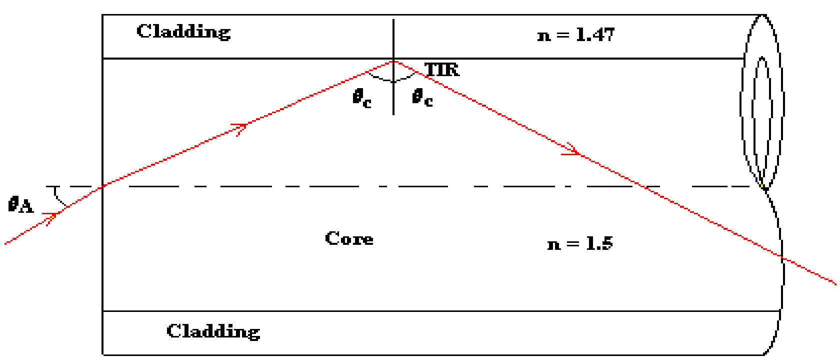


Figure 5 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009 <http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

The angle *A* in Figure 5 is called the Acceptance Angle. Light that enters the fiber at an angle less than the acceptance angle will encounter the cladding at an angle greater than the critical angle. As stated previously, total internal reflection occurs if light meets the core at an angle greater than or equal to the critical angle. None of the energy from the light enters the cladding because it is reflected back into the core. A beam of light enters the fiber and crosses to the other side of the core meeting the cladding on the other side at an angle and causing total internal reflection. The light ray is then reflected back across the core again and the same thing happens continuously as the light is transmitted through the fiber. A pulse of light traveling along the core of the fiber is a bundle of these rays.

Light moves in the same direction as a fiber once it enters that fiber. Light can be bent around corners by using optical fibers due to the fibers' abilities to also be bent. There are two main fiber types: 1. Step index (multimode, single mode) 2. Graded index (multimode) (Industrial Glass 1). In Step index fiber, the refractive index of the fiber "steps" upon moving from the cladding to the core of the fiber. The refractive index is constant within the cladding and constant within the core. Due to its narrow core, a Single Mode Step Index Fibers can support only one mode as shown in Figure 6. This is known as the "Lowest Order Mode".

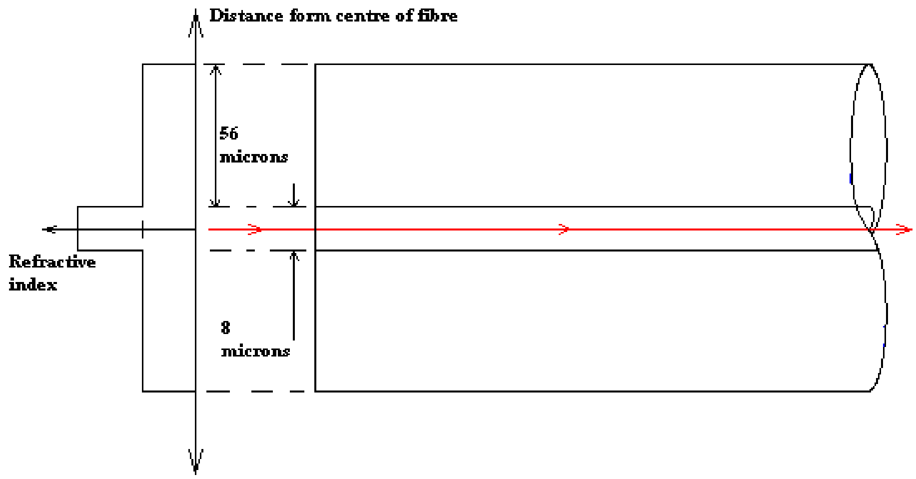


Figure 6: Single mode Step Index Fiber

Figure 6 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009

<http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

Due to the wave nature of light, only certain directions of light rays can travel down the fiber. These are called the "Fiber Mode". In a multimode fiber, many different modes are supported by the fiber as shown below in Figure 7.

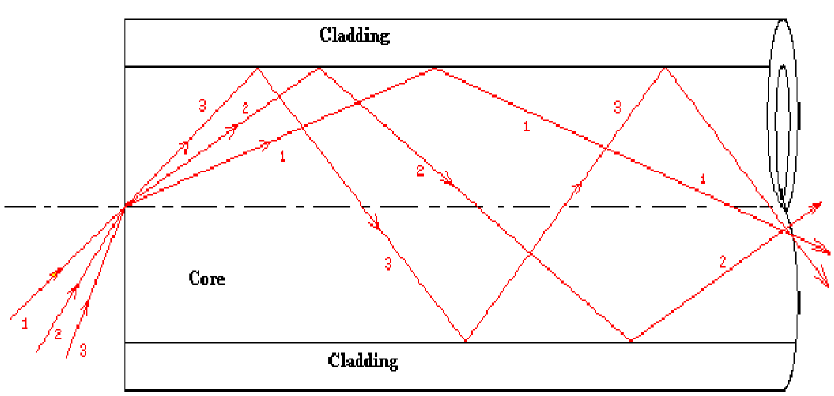


Figure 7: Multimode Step Index Fiber

Figure 7 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009 <http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

Graded Index Fiber possesses a different core structure from single mode and multimode step index fibers. Unlike a step-index fiber where the refractive index of the core is constant throughout the core, a graded index fiber contains a refractive index that changes from the center of the core onwards. The refractive index in a graded index fiber has a Quadratic Profile. This means that the refractive index of the core is proportional to the square of the distance from the center of the fiber.

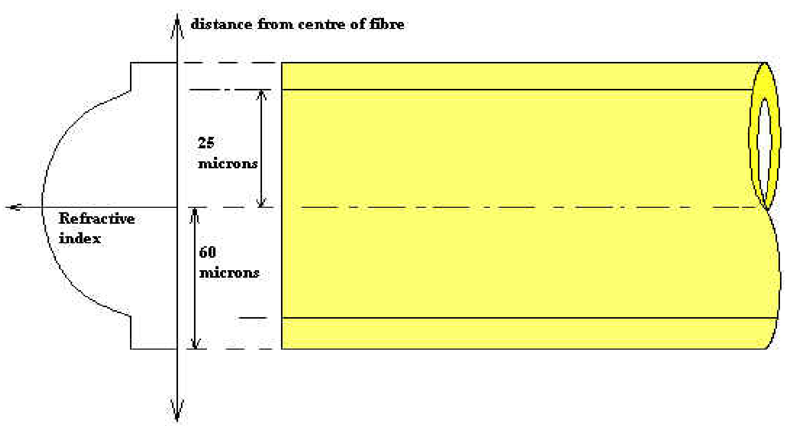


Figure 8: Graded Index Fiber

Figure 8 Source: "Optical Fibers.....Seeing the Light." 20 Feb. 2009 <http://library.thinkquest.org/C006694F/Optical%20Fibres/Homepage.htm>.

Telephone calls were mainly sent as electrical signals along copper wire cables. Eventually, simple copper wires did not have the capacity, or bandwidth, to carry the increasing amount of information required. Systems reverted to using coaxial cables like TV aerial leads. However, the need for more bandwidth continued to intensify making it increasingly expensive to maintain these systems and expand them over long distances when more signal regenerators were required. Since these copper systems could not handle the increasing demand for communication, the door was opened to optical fibers (Fibre optics 1). Optical fibers offer a greater capacity for expanding communication than copper wire cables. In optical fibers, a single fiber can carry the conversations of every person, at the same time, twice over.

The use of optical fibers in the area of communication has many advantages. As compared to a copper cable, a greater amount of information can be carried on an optical fiber. Also, when a signal travels down a cable, a portion of energy is lost thus requiring the signal to be boosted by regenerators. For copper cable systems this process is needed every 2 to 3km but with optical fiber systems it is required every 50km (Optical Fibers.....Seeing the Light 1). Another advantage for optical fibers is that they do not experience any electrical interference unlike copper cables. Optical fibers do not cause sparks therefore they can be used in explosive environments such as gas pumping stations or oil refineries.

The development of optical fibers has led to much advancement in medical technology. Optical engineering and imaging technology have played a major role in the minimally invasive surgery by making it possible to visualize the manipulation of tissue at remote internal sites (Boppart, Deutsch, & Rattner 1). Optical fibers involved in this type of laparoscopic surgery, also known as keyhole surgery, are usually used during an operation performed in the stomach area such as appendectomies. Keyhole surgery utilizes two or three bundles of optical fibers where each bundle is composed of thousands of individual fibers. To perform this surgery, a number of small incisions are created in the target area. Air can then be used to fill the area and provide more room for the surgeon. A bundle of optical fibers can act to illuminate the area. Finally, another bundle can provide a way for information to be brought back to the surgeon. Performing this surgery in addition to laser surgery, utilizes yet another optical fiber that carries a laser beam to the relevant spot. The beam would then proceed to cut the tissue or affect it in some way. In this way, optical fibers can serve many purposes in just one surgery.

Another important application of optical fibers is in sensors. A small but measurable change in light transmission can be detected if a fiber is subjected to a change of environment. A sensor can be made from optical fibers and placed in areas such as in a tank of acid or close to an explosion and then connected back to a central point so the effects can be measured. Distributed fiber optic sensors make it possible to collect the data at different points along the fiber and to know how the different measurements relate. Research is currently being done on developing a compact ring-shaped tunable fiber laser suitable for fiber-optic sensing applications (Fu, Yang, et al. 392). This successful test demonstrates the potential capability of such a fiber laser system in specific sensing applications. Optical fibers can also be used as simple light guides. Under the hood of at least one car is a single high intensity lamp that utilizes optical fibers as a way of carrying the light to a series of mini-headlamps at the front of the car. Less complex versions of this system carry light from bulbs to the glove compartment. Since light is not clearly affected by electromagnetic fields, it also does not obstruct other instruments that operate using electricity.

Researchers are discovering ways in which the fibers become the active elements of the circuit, such as in amplifiers or filters. This would entail that the information remain in light form from one end of a link to the other. This removes the limitations of the electronics in circuits and permits more of the theoretical information carrying capacity to be employed. Future engineers could eventually have the ability to design and use telecommunications systems that have infinite bandwidth, no loss of energy and high reliability. New services for customers, such as 3D high definition TV, could become more easily available and could provide the customers with the benefits of lower costs and greater flexibility (The Twenty-First Century and Beyond 1).

Although now the physics behind optical fibers may not seem difficult to understand, the concepts behind its discovery proved elusive for many years. By finally understanding how to manipulate the properties of light traveling through materials, researchers were then able to, and continue to be able to, construct optical fibers for various purposes. The development of optical fibers has been beneficial to many areas of society, most importantly communication and medicine. Without the advancement of optical fibers to replace outdated methods, society as seen today would not exist.

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