

# Optical Fiber-Past, Present and Future: A Review

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## Abstract

During the second half of the twentieth century there were several technological revolutions around the world, one of the most important being the supplanting of telecommunication over copper wires by optical transmission over glass fibers. Advances in optical fiber technology have been spectacular in the past 30 years but still there is more to come. Photonic fiber structures will create a radically new era of fiber optic communication. In this paper the rapid growth of optical fiber technology is reviewed and its possible new directions in communication are discussed.

**Key words:** Optical fiber , Optical Communication, Optical Amplifier, Erbium Fiber, Photonic Bandgap

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## Introduction

Optical fibers are thin (like a human hair) cylindrical filaments of glass or polymer consisting of highly transparent core surrounded by a cladding. The core has higher refractive index than the clad. Light is passed longitudinally into the core and it propagates by total internal reflection through the fiber. In silica based glass fiber, light of a suitable wavelength can be transmitted over tens of kilometers and if a few meters of amplifying fiber are inserted after every few tens of kilometers the light propagation can continue for thousands of kilometers. The input light is digitally modulated by a signal, and the signal can be carried for hundreds, to thousands, of kilometers through the fiber. The main raw material to produce optical fiber is nothing but normal sand and this is why it is cheaper compare to the copper cable in telecommunication. The advantages of optical fibers as compared to electrical transmission media are: extremely low

transmission loss, very high bandwidth (BW), smaller size and much lighter in weight (Pal, 1986). Now a days optical fibers, therefore, form the basis of local, national and international telecommunication networks. Optical fiber technology is also fast and almost error free. A hair like fiber can transmit an unbelievable amount of information. Such attractive features of optical fiber transmission influenced the people to do massive R&D efforts on the field of the technology development that became operational around two and a half decades ago. Since 1974 optical fibers have rapidly replaced copper wire in optical communication systems and now carry most of the world's telephone, data, video traffic, indeed a wide variety of information, more cheaply and reliably (Gambling, 2001).

Using an erbium fiber amplifier with the optical fiber the improvement is about by a factor of 50,000 than copper cable in a period of about 10 years in the transmission of signal in telecommunication. This makes all types of communication very easy and cheap using a fiber. Advances in optical fiber technology have been spectacular in the past 30 years but it is not all and still there is more to come. Photonic fiber structures will create a radically new era of fiber optic communication.

### **What is an optical fiber?**

Optical fiber is a long, thin (like a hair) material which is made of normal glass. Its diameter may be at any value ranging from 1 mm to 1  $\mu\text{m}$  which is controlled in the production process. Optical fiber is a highly transparent material and the light of a definite wavelength can be transmitted through it. The main raw material to produce it is normal sand and this is why it is cheaper compared to the copper cable in telecommunication. The mechanism of the light propagation through the fiber is quite

simple, namely total internal reflection. Figure 1 shows a typical structure of an optical fiber which is made of basically two parts.

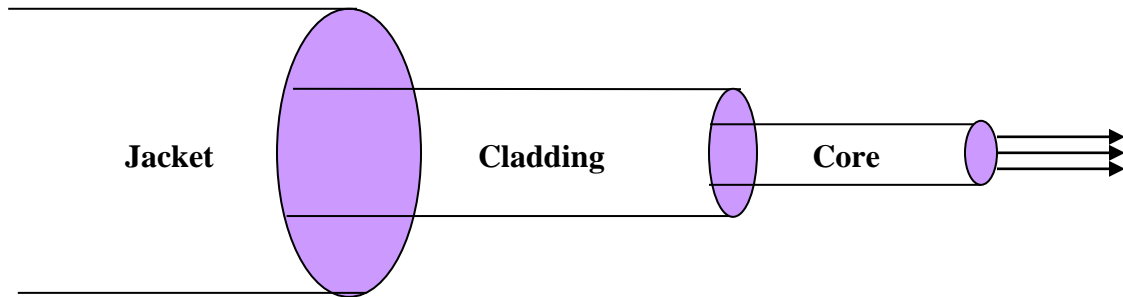


Fig.1. Typical structure of an optical fiber

The inner parts having higher refractive index is called the core and the outer part having lower refractive index is called the clad. The core and clad are enclosed in an opaque jacket as shown in the figure 1.

Usually some small amount of oxides (e.g.  $P_2O_5$ ,  $GeO_2$ ,  $B_2O_3$ , F etc.) are added with normal sand at a very high temperature (about  $2000\text{ }^\circ\text{C}$ ) to fabricate the fiber (Acharya, 2001). When an input light is digitally modulated by a signal, that signal can be carried to thousands of kilometer distance without any significant loss. Optical fiber technology is very cheap, fast and almost error free. A hair like fiber can carry a very wide BW and can transmit easily a lot of information from one place to another.

Figure 2 shows the mechanism of the light transmission within the fiber. At point A, the core-cladding interface, total internal reflections occurs. This ray confined to the fiber core as shown in the figure. For convenience we assume that the angle of incidence at core-cladding interface is the critical angle  $\theta_c$ . Hence from Snell's Law one can write  $\theta_c = \sin^{-1}(n_1/n_2)$ , where  $n_1$  and  $n_2$  are the refractive index of the clad and core, respectively

(Ghatak, 1999). All rays with an incident angles larger than the critical angle  $\theta_c$  will propagate in the fiber. According to the electromagnetic theory, these rays propagate at distinct angle in the fiber.

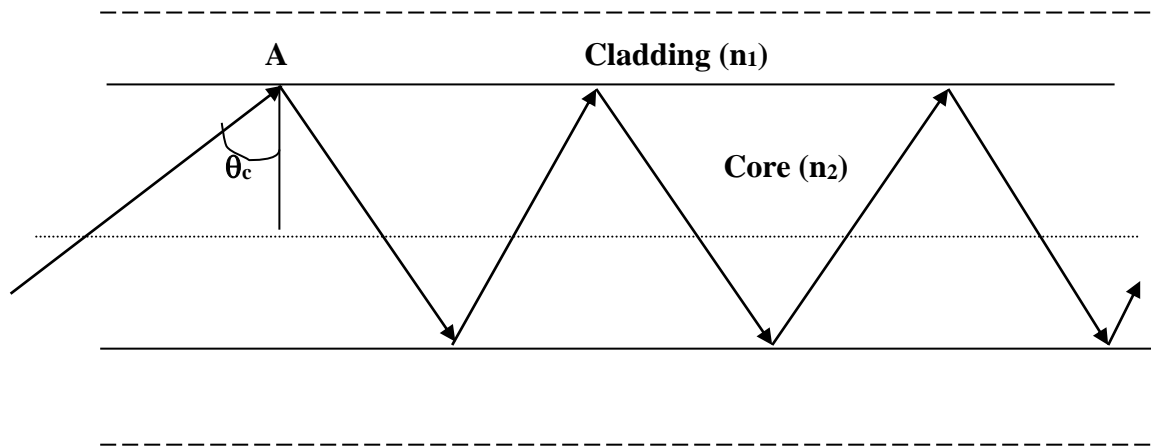


Fig. 2. Total internal reflection in optical fiber

The light loss in optical fiber is expressed in decibel and it is defined as

$$\text{Loss(in dB)}=10 \times \log (P_{\text{out}}/P_{\text{in}})$$

where  $P_{\text{in}}$  and  $P_{\text{out}}$  are the input and output powers in the fiber, respectively. The three main causes of light loss in the fiber are material loss, scattering loss and bend loss. The loss due to the atomic structure of the material itself is relatively small. For example in Ge-Si glass this loss is less than 0.1 dB/Km with a light of wavelength ranging from 0.8  $\mu\text{m}$  to 1.6  $\mu\text{m}$  (Mallick, 2001). These losses due to impurities in the glass can be reduced by better manufacturing process. When light is scattered by an obstacle due to Rayleigh scattering some power is lost. Rayleigh scattering varies with wavelength ( $\lambda$ ) as  $1/\lambda^4$ . That means the longer the wavelength the lower the loss. For example, at 1.8  $\mu\text{m}$  wavelength for typical glass fiber the loss is about 0.1 dB/Km. This type of loss cannot be eliminated by the manufacturing process of the fiber. Bending of the fiber causes

radiation of light away from the fiber. This bending loss can be minimized by careful handling.

The BW of a fiber or system is the range of frequencies that it can handle with minimum amplitude distortion. The BW of a system is directly related to the rate (bits/sec) that the system can handle. The dispersion in an optical fiber affects the BW. Dispersion causes a broadening of the transmitted pulse i.e. the output pulse width is larger than the input pulse width. The BW is length dependent and longer fiber results in more pulse spreading which leads to lower BW. As a result the fiber BW is often given in terms of the BW times length (kilometer) product.

### **History of Optical fiber and Communication by light**

Question may arise why peoples are interested in communicating with light waves instead of the electrical wave. The answer is quite simple. Around in the middle of the 20<sup>th</sup> century the demand of telecommunication was increasing so rapidly that the copper wire and electric current could not fulfil the requirements of the people. In addition to the telephone system to carry data, video and other services was just beginning at that time. The existing network was having great difficulty in coping even with the telephone demand and alternatives to copper wire and electric current were being considered. These included microwave cables, satellites and overmoded millimeter waveguides.

The possibility of using an optical fiber carrier wave for telecommunication began soon after the invention of the Laser in 1960. It was found that the amount of information that can be modulated onto a carrier wave is roughly proportional to its frequency. Therefore a shift from microwaves to light waves could increase the carrier frequency by a factor of  $10^6$  and even if the BW could only be increased in practice by 100 or 1000 times, the

improvement was enormous compared to the existing system at that time. At that time many laboratories around the world began research on optical communication by using the Laser as a possible source of carrier waves. Also the necessities of a suitable transmission medium was considered from that time. It was considered that this transmission was possible using a pipe lining with a smooth, highly reflecting material (Eaglesfield, 1962). Also some peoples (Goubau and Schwering, 1961) considered to use a converging lens in such a pipe to protect the spreading of light. Another idea (Karbowiak, 1964) was to guide light on a thin polymer tape. All of these ideas had some technical problems, costly, bulky and were inflexible systems.

At the end of 1966 Charles Kao and George Hockhman first gave the idea of optical fiber to transmit light signal (Kao and Hockham, 1966). They found that when a light signal was send from one end of an optical fiber some parts of the signal was absent at the other end. Later in 1970 Kapron and his colleagues at Corning Glass Works, USA, reported the fabrication of a single mode fiber with a comparatively low transmission loss (20 dB/km) (Kapron, Keck and Maurer, 1970). This discovery was a surprise and many laboratories around the world started research on optical fiber. It was later discovered that a thin layer of titania had been deposited on the internal surface of a silica tube which had been collapsed and drawn into a fiber (Gambling, 2001). During the drawing process the tatania would have diffused into the silica surface to produce a  $\text{TiO}_2/\text{SiO}_2$  central core having a higher refractive index than the surrounding silica cladding. The fiber produced by this method was too brittle for any practical use. But now that problem is over. Now some oxides are added with silica to control the refractive index of core and clad (Acharya, 2001). The oxides  $\text{TiO}_2$ ,  $\text{GeO}_2$ ,  $\text{P}_2\text{O}_5$  and  $\text{Al}_2\text{O}_3$  increase the refractive index whilst  $\text{B}_2\text{O}_3$  and F lower it. At present there are two steps to produce optical fiber commercially. During the first step the preform is made from silica with the addition of

some oxides as mentioned above. In the second step the fiber is drawn from the perform at high temperature (2000 °C). During the preparation of the perform the refractive index for the core and clad is maintained as one requires. Usually a perform is about one meter long having a diameter of a few centimeters.

From the point of view of system engineering the three major components of any optical fiber communication system are shown in Fig.3. It consists of the electrooptic transmitter (e.g. LED/Laser), the optical transmission medium (fiber) and the optoelectronic receiver (PIN/APD-photodetector) (Pal, Thyagarajan and Kumar, 1988).

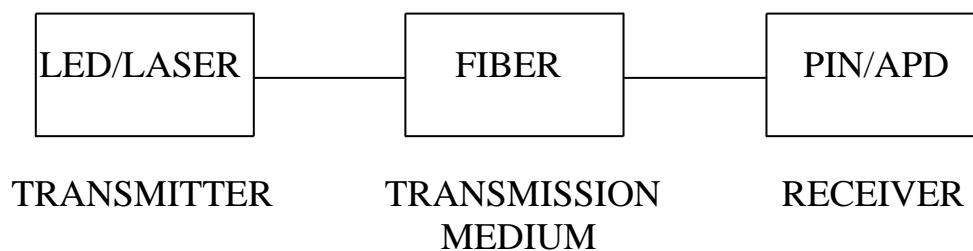


Fig.3. Basic components of an optical fiber telecommunication system

### **Present and Future of Optical fiber Communication**

The signal level in a passive optical fiber decreases steadily with increasing distance due to several types of losses in the fiber. Therefore people introduced repeaters to detect and amplify the weak signal. Such types of repeaters were used after a particular length in the fiber to transmit signal from one place to another. However these repeaters are expensive, bulky, totally inflexible and inefficient, especially for under water applications. Scientists were able quickly to solve this problems of using the complicated techniques of repeaters just after the discovery of erbium fiber amplifier in 1987. The erbium fiber repeater consists of about 10 meters of normal single-mode fiber in which the core contains a

small quantity of erbium. The erbium-doped fiber amplifier (EDFA) is capable of providing an enormous optical bandwidth of 4600GHz

The effectiveness of EDFA was experimentally demonstrated in 1992. It was found that a 45ps soliton pulses were transmitted at a rate of 10 Gb/s over a distance of  $10^6$  km with zero error. As a practical application transatlantic and transpacific cables with a capacity of 600,000 telephone circuit and a capital cost per circuit of only US\$500 are coming into operation (Gambling, 2001). The effectiveness of the erbium fiber can easily be understood by comparing with the first transatlantic fiber cable laid in 1986 which had an equivalent capacity of 8,000 circuit at a cost of US\$30,000 per circuit.

It has been found that the frequency of a wave is proportional to the BW and from the bandwidth  $\times$  length product of  $\sim 100\text{MHz.km}$  with copper cable an electromagnetic wave we have now reached something like 5,000GHz.km with fiber and light wave. That means using an optical fiber and erbium fiber amplifier the improvement is about by a factor of 50,000 in a period of about 10 years. But still we do need more. Fibers, microelectronics and software have created the information society, -the web, the internet, home banking and shopping, video and almost everything else on demand, working from home or anywhere else – and the demand seems to be insatiable. This is why the improvement of the fiber design will continue. Finally, a new chapter may be underway with the discovery of the phenomenon of photonic bandgaps. Photonic crystal devices could possibly be used to bend light around very sharp corners, which normal waveguide can not do without causing attenuation, to construct micron-size optical benches, add/drop filters and provide high-resolution spectral filtering. The new phenomena will likely spawn a new technology which will have widespread application (Gambling, 2001).

## **Summary**

Optical fibers have swept away copper in nearly all but the local network and largely taken over from satellites which introduce an annoying, very noticeable, delay into a telephone conversation. Optical fibers are created from a very common material, silica and this is why it is very cheap. Fibers also have other advantages of low cost, small size, great flexibility and freedom from electromagnetic interference. Using an optical fiber and erbium fiber amplifier the improvement is about by a factor of 50,000 than copper cable in a period of about 10 years in the transmission of signal. This makes all types of communication very easy and cheap. Advances in optical fiber technology have been spectacular in the past 30 years but still there is more to come. Photonic fiber structures will create a radically new era of fiber optic communication.

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## **References**

- Acharya, H.N., 2001. Fiber Optics Basics. *Lecture Notes of UNESCO Regional Training Course in Fibre Optics for College University Teachers at IIT Kharagpur, India*, Vol.1: 44-68.
- Eaglesfield, C.C., 1962. Optical pipeline: a tentative assessment. *Proceedings I.E.E.*, 109B: 26-32.

- Gambling, W.A., 2001. The rise, and rise, of optical fibers. *Lecture Notes of UNESCO Regional Training Course in Fibre Optics for College University Teachers at IIT Kharagpur, India*, Vol.2: 303-317.
- Ghatak, A.K., 1999. Basics of Fiber Optics. *Proceedings of Indo-US Workshop on Fiber and Integrated Optics at IIT Kharagpur, India*, Part-A: 1-62.
- Goubau, G. and Schwering, F., 1961. On the guided propagation of electromagnetic wavebeams. *IRE Transection*, AP9: 248-256
- Kao, K.C. and Hockham, G.A., 1966. Dielectric-fibre surface wave-guides for optical frequencies *Proceedings. I.E.E.*, 133: 1151-1158.
- Kapron, F.P., Keck, D.B. and Maurer, R.D., 1970. Radiation losses in glass optical waveguides. *Applied Physics Letter* 17: 423-425.
- Karbowiak, A.E., 1964. Guided propagation at optical frequencies. *Proc. Conference on Lasers and their applications, I.E.E.*, pp. 33.1-33.7.
- Mallick, A.K., 2001. Fiber Optics Basics. *Lecture Notes of UNESCO Regional Training Course in Fibre Optics for College University Teachers at IIT Kharagpur, India*, Vol.1: 1-34.
- Pal, B.P., 1986. Fundamental Characteristics of Telecommunication Optical Fibers: A Review. *IETE Tech. Rev. (India)*, 3:347-372.
- Pal, B.P., Thyagarajan, K. and Kumar, A., 1988. Characterization of Optical Fibers for Telecommunication and Sensors. *International Journal of Optoelectronics (UK)*, 3: 45-71.