Principles of Optical Fibers

Simon Kwan

In partial fulfillment of course requirement for MatE 115, Fall 2002

Instructor: Prof. G. Selvaduray

San Jose State University

TABLE OF CONTENTS

I. INTRODUCTION

The idea of using light to send messages has been developed since the eighth century B.C., when the Greeks used fire signals for sending alarms or calls for help[1]. Thus before optical fibers was developed such techniques used for communication needed to be prearranged between both the sender and receiver[2]. It was only in the mid 1960s did Charles K. Kao determined that glass had a loss of 20db/km, which spurred researchers into exploring methods for making glass more pure[3]. This discovery sparked a revolution in the telecommunication industry as a new industry of processing optical fibers becomes commercially important.

A typical optical fiber can be either made out of glass (otherwise known as silicon dioxide) or plastic (typically a polysterene or polymethyl methacrylate). Because of the fibers lightness and small size with the ability to have greater information carrying capacities than metallic wires they are more suitable for many different applications[4]. With so many beneficial factors in using an optical fiber it is no surprise that many companies have applied this technology into developing new installations and applications making them commercially viable.

This paper will discuss the basic principles of how optical fibers work by explaining it through light theory. As well it will discuss the different modes that a fiber can have along with the import roles that attenuation plays when designing a fiber. Also, the construction methods used in the fabrication of optical fibers such as *Flame Hydrolysis* will be discussed. Lastly, a general description of how an optical fiber is integrated into a system and used to send large amounts of data.

II. LIGHT THEORY

When light is directed into an optical fiber the effectiveness of the wire depends on its ability to guide the light ray far distances with little scattering or absorption of the light as possible. Doing so means that the optical fiber must exhibit total internal reflection within the wire. Thus when considering the propagation of light for an optical fiber the refractive index of the dielectric medium needs to be accounted for. As light rays become incident on an interface between two dielectrics with different index of refractions, refraction occurs between the two mediums. This can be best described by using Snell's Law of Refraction which states:

$$n_1 \sin \phi_1 = n_2 \sin \phi_2$$

This equation shows that at certain angles partial internal reflection will arise, as well at other angles total internal reflection will occur as shown in figure #1.

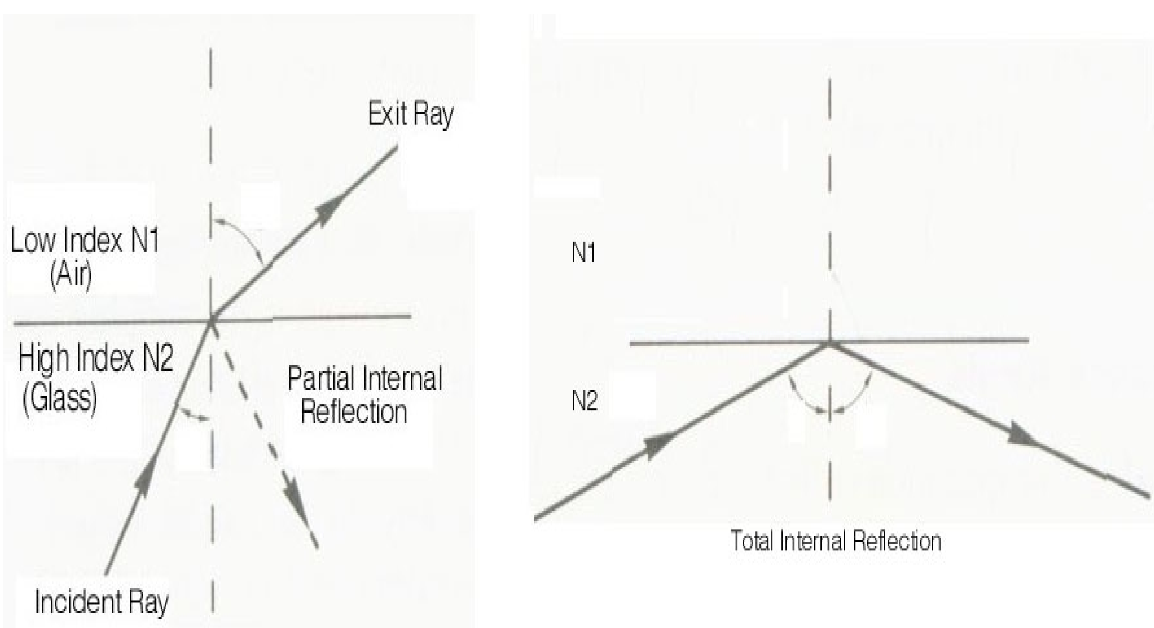

Figure #1 Light Ray Diagrams [5]

This relationship can then be used to find the critical angle ϕ_c which serves as the limiting case of refraction and the angle of incidence[5]. By launching the light ray at an angle $\phi > \phi_c$ as seen in figure #2, it is reflected at the same angle to the normal, leading to total internal reflection within the optical fiber. A typical optical fiber with two dielectric mediums is shown in figure #2, with the silica core having the index refraction of n_1 and the silica cladding with a lower index of refraction of n_2 . With this setup it is possible to send packets of information through light rays which can propagate through an optical fiber with very little loss or distortion. However other factors will influence the effectiveness of the optical fiber due such things like impurities but this will be discussed in detail in later sections of this paper.

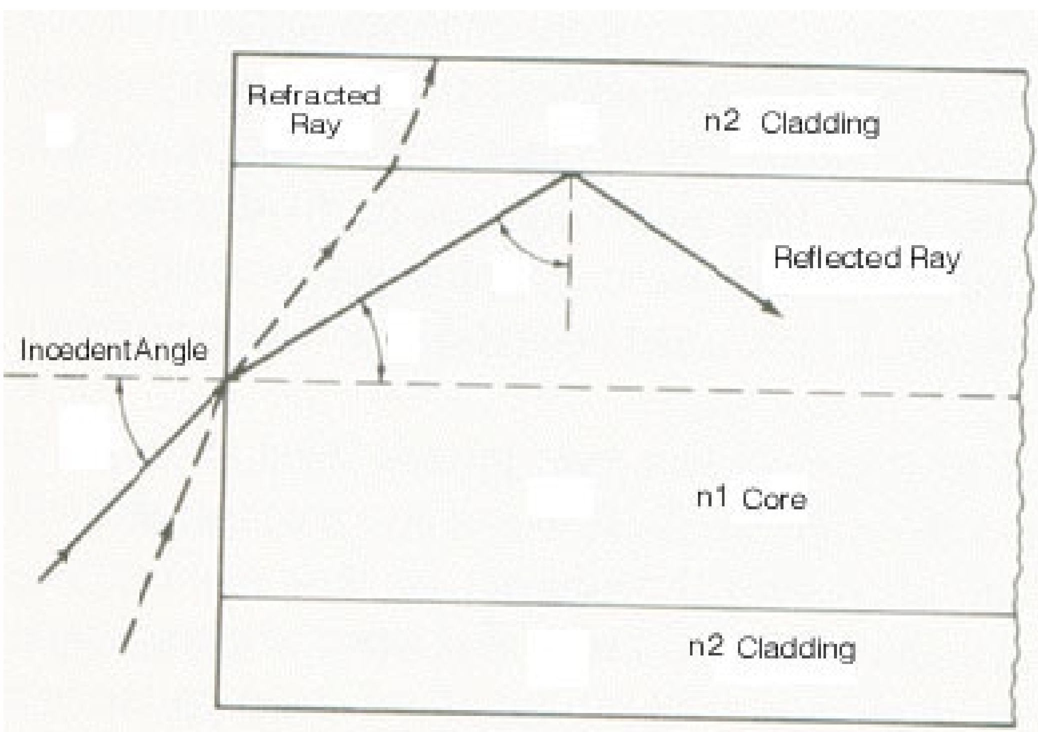

Figure #2 Total internal reflection between two dielectric mediums[6]

III. THE OPTICAL FIBER

The typical fibers today are made out of glass or plastic since it is possible to make them thin and long. Also both glass and plastic are transparent at particular wavelengths, which allow the fibber to guide light efficiently [7].

The fiber is constructed with a core with a high index surrounded by a layer of cladding at a lower index. The core and the cladding can be made out of both plastic and glass. For plastics, the core can be polystyrene or polymethylmethacrylate and the cladding is generally silicone or Teflon [8]. For glasses both the cladding and the core are made out of Silica with small amounts of dopants such as boron, germanium to change its index [9].

Major differences exist between the two materials when it comes to making the optical fiber. In plastic core fibers they are more flexible and inexpensive compared to glass fibers. They are easier to install and can withstand greater stresses and weight 60% less than glass fibers [10]. However, they transmit light less efficiently leading to high losses, giving them very limited use in communication applications. Such plastic fibers are practical for short runs such as within buildings. Therefore, due to their restrictive nature glass core fibers are much more widely used because they are capable of transmitting light effectively over large distances[11].

A. OPTICAL FIBER TYPES

There are 3 basic types of optical fibers: multimode graded-index fiber, multimode step-index fiber and single-mode step-index fibers.

A multimode fiber can propagate hundreds of light modes at one time while single-mode fibers only propagate one mode [12] as shown in figure #3.

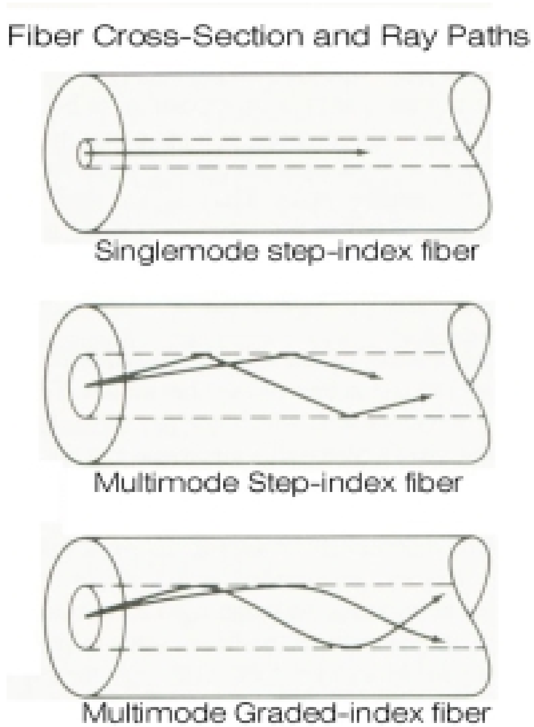

Figure #3 Optical Fiber Modes[13]

The difference between graded-index and step-index fibers is that in a graded-index fiber it has a core whose refractive index varies with the distance from the fiber axis, while the step-index has core with the same refractive index throughout the fiber[14].

Since the single-mode fibers propagate light in one clearly defined path, intermodal dispersion effects is not present, allowing the fiber to operate at larger bandwidths than a multimode fiber[15]. On the other hand, multimode fibers have large intermodal dispersion effects due to the many light modes of propagations it handles at one time. Because of this multimode fibers operate at lower bandwidths, however they are typically used for enterprise systems such as offices, buildings, universities since they are more cost effective than single mode ones.

B. FIBER ATTENUATION

The maximum transmission distance between a transmitter and a receiver of an optical fiber is known as the attenuation of the fiber[16]. The attenuation is usually expressed in decibels per unit length (dB km^{-1}) and can be determined by:

$$\alpha_{db} L = 10 \log_{10} (P_i / P_o)$$

Where α_{db} is the signal attenuations per unit length in decibels, L is the fiber length, P_i is the input (transmitted) optical power into the fiber and P_o is the output (received) optical power[17]. Such transmission losses in typical fibers used today are less than 5 dB km^{-1} verses the metallic wires used in the past with transmissions losses with significantly higher losses.

In reducing the attenuation of the fiber, it cuts down on the costs since fewer repeaters are required to restore the signal[18]. With this in mind two very important techniques are considered when manufacturing an optical fiber with a specific attenuation. The first technique involves purifying the material composition, which reduces material absorption and Rayleigh scattering of the light rays within the fiber[19]. The second is the preparation method of the fiber that must be done in a controlled manner such as fiber drawing otherwise microscopic variation in the material density and compositional fluctuations will result in light scattering in an optical fiber [20].

IV. FIBER CONSTRUCTION (FLAME HYDROLYSIS)

There are many different variations of vapor phase deposition that have been used to produce low loss optical fibers. In general such vapor phase techniques used today fall into two categories: *Flame hydrolysis* and *Chemical Vapor Deposition (CVD)*, however this paper will only focus on *Flame hydrolysis* techniques such as Vapor Axial Deposition (VAD) and Outside Vapor Phase Oxidation (OVPO).

The VAD method uses glass particles such as $SiCl_4$, $GeCl_4$, BCl_3 and synthesizes them by hydrolysis with a torch forming silica soot[21]. The soot is then deposited onto a solid porous glass perform in the shape of a boule as it is continuously rotated[22]. This resultant perform is then drawn into a fiber by heating it in a furnace.

The OVPO involves using hydrolysis to form silica soot like the VAD process. Then the soot is deposited onto a silica mandrel, this allows the preparation of a continuously shaped refractive index profiles[23]. After the soot body is dehydrated in a chlorine-based atmosphere at high temperatures (1400 °C ~ 1600 °C) creating a dense glass, the silica mandrel is removed and a clear perform is formed as shown in figure #4a[24]. The perform is then mounted in a fiber drawing tower as shown in figure #4b[25].

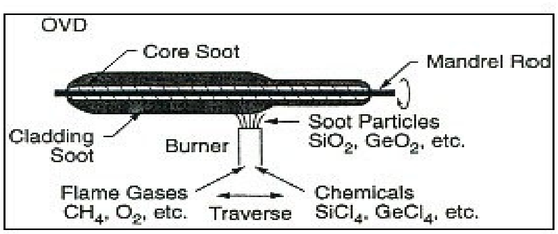

Figure #4a OVPO Process[26]

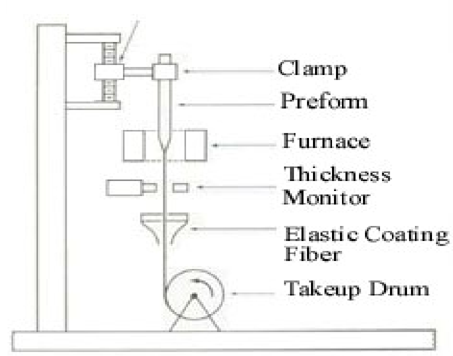

Figure #4b Fiber Drawing Tower[27]

V. FIBER APPLICATION

The three major parts that make up the fiber optical system is: a light source, the optical fiber and a light detector. This system first uses and encoder and takes the electrical input signal and converts it to an infrared light signal. A light source such as a semiconductor laser diode or a light-emitting diode (LED) will launch this light signal through an optical fiber. The light detector on the other end will then capture the signal and a digital decoder converts the signal back into and electrical this set up can be seen in figure #5[28].

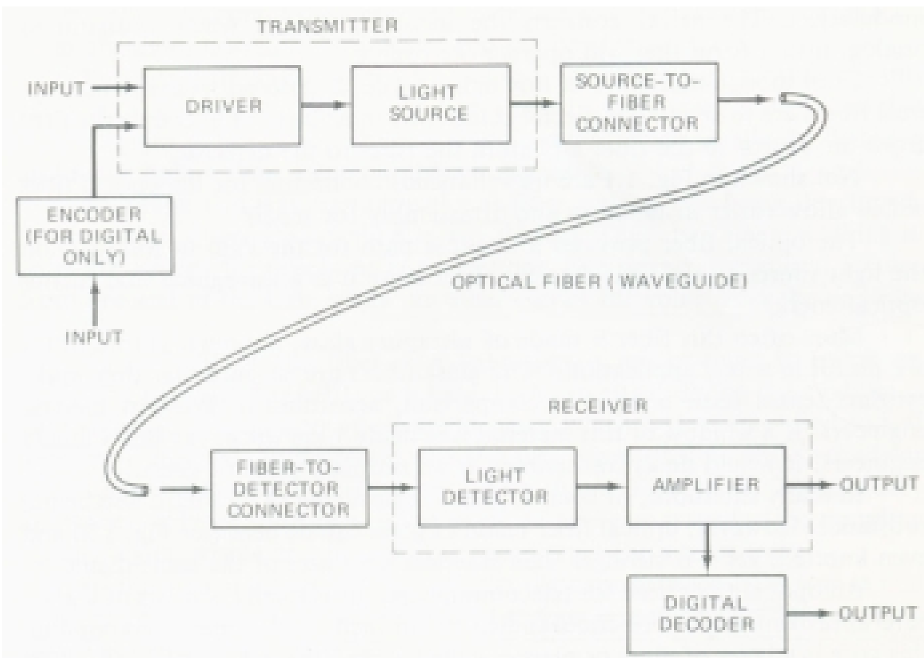

Figure #5 Optical Fiber communication system set-up[29]

VI. CONCLUSION

The understanding of light theory was used as the fundamental building block for the development of the optical fibers that are used today. By using Snell’s law, it was possible to send light signals over any distance using optical fibers. Different fiber types are better suited for different applications depending on what is required. Attenuation plays an important role on how effective the fiber can transmit the signal with low loss. In perfecting the purification and production process it will reduce the number of flaws that may arise during these processes. With the ideal optical fiber readily available it can be applied to a working optical fiber system.

VII. REFERENCES

1. G. Keiser, Optical Fiber Communications, (McGraw Hill, New York, NY, 1983), pp.2.

2. lbid, p19-21.

3. V. Hostrands's Scientific Encyclopedia, 9th ed. (John Wiley & Son Inc., NY, 2002), pp2564.

4. J. Palais, Fiber Optic Communication, (Prentice-Hall, Englewood Cliffs, New Jersey, 1984), pp 20

5. J. Senior, Optical Fiber Communications Principles and Practice, (Prentice-Hall, Englewood Cliffs, New Jersey, 1985), pp 11.

6. G. Keiser, op cit, p19-21.

7. G. Keiser, op cit, p 48.

8. E. Lacy, Fiber Optics, (Prentice-Hall, Englewood Cliffs, New Jersey, 1982), pp 69.

9. G. Keiser, op cit, p 50.

10. E. Lacy, op cit, p 70.

11. J. Senior, op cit, p 15.

12. V. Hostrands's, op cit, p 2565.

13. G. Keiser, op cit, p 51

14. J. Palais, op cit, p 20.

15. E. Lacy,op cit, p 70.

16. G. Keiser, op cit, p 54.

17. J. Senior, op cit, p 63.

18. G. Keiser, op cit, p 54.

19. T. Shin-ichi, S. Shigeki, S. Kiyomasa, "Evaluation of optical glasses for low loss fibers: optical attenuation and fiber drawing ability" Japanese Journal of Applied Physics, **34**, 3128-3133 (1995).

20. K. Yoshida, T. Morikawa, "*O*ptical fibers with polygonal cladding" Optical Fiber Technology, **3**, 273-277 (1997).

21. http://yaman.hypermart.net/optical-fiber.htm, (2002).

22. http://web.umr.edu/~jlowry/fiber.htm, (2002).

23. K. Ralf, O. Jueegen, L. Volker, "Thick coatness of doped synthic silica glass by plasma impulse CVD" Journal of the Ceramic Society, **99**, 894-902 (1991).

24. J. Senior, op cit, p 119.

25. G. Keiser, op cit, p 277.

26. http://web.umr.edu/~jlowry/fiber.htm, (2002).

27. G. Keiser, op cit, p 278

28. E. Lacy,op cit, p 78.

29. E. Lacy,op cit, p 78.