Chapter

# Introductory Chapter: Optical Fibers

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## 1. Optical fibers

The optical fibers invented by Kapany [1], based on the observations that John Tyndall made a few years before, have become the object of research, technological development, and applications to this day.

The optical fibers have the ability to transport a large amount of information between two points (emitter-receiver). Unlike the conductive cables that are commonly used for sending information, fiber-optic cables offer the advantage of being very light [2]. As for its physical characteristics, an optical fiber is commonly compared to a human hair whose diameter is around 120 μm [3]. In terms of capacity for sending information, they can carry up to 20 billion light pulses per second [3]. Nowadays, due to the high transmission capacity and low absorption losses in an optical fiber, it is possible to send information over distances of more than 100 km without the need for repeaters. To carry out the sending of information from one point to another by means of a fiber-optic system, three basic elements should be considered as mentioned in **Figure 1**:

- A transmitter, which generates the wave signal to be transmitted, which is fed with the information to be sent
- Fiber-optic cable, which corresponds to the medium in which the information moves from the sender to the receiver
- Receiving system, which receives the information sent

In order to have mechanical support and total reflection of the light traveling in the fiber [4], avoiding absorption, the optical fiber is composed of three main elements (**Figure 2**):

- The core of the fiber, which is the fiber-optic glass where the light to be transmitted moves
- The cladding, which consists of a thin layer of material whose purpose is to achieve light reflection in the fiber and prevent it from escaping, based on the principle of total internal reflection
- The coating, made of plastic, similar to that used on copper cables, which provides protection to the fiber against climatic factors, corrosion, or external damage

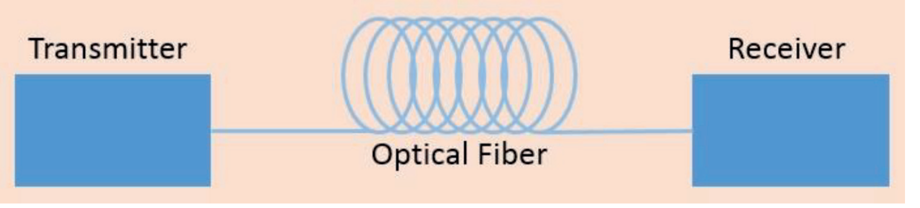


**Figure 1.**
*Basic schema of an optical communication system.*

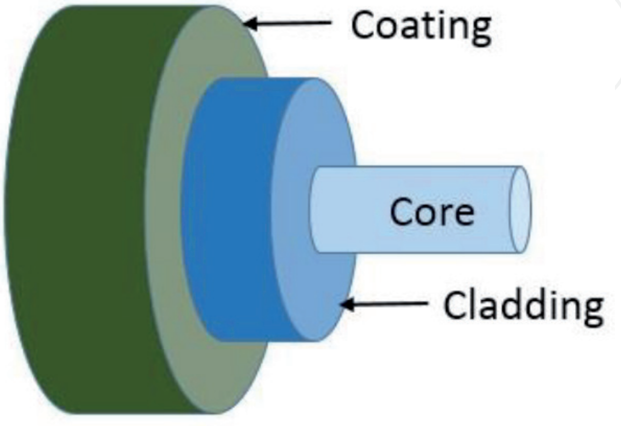


**Figure 2.**
*Principal elements of an optical fiber.*

Due to their ease of manufacturing, the optical fibers are made of glass and plastic; however due to their performance, the optical glass fibers are the most used due to the transmission length and their efficiencies. Basically there are two types of optical fibers, and they are defined by their ability to transmit information, which implies the type of application [4]. Those fiber types are mentioned next:

1. Single-mode fibers: they have a smaller diameter than multimode fibers. In this type of fibers, the light travels parallel to the axis which creates a small dispersion. In these fibers the modes of transmission are many, and therefore the distances that these fibers can cover can be more than 50 times those of multimodal fibers. These types of fibers are the most used by communications companies.

2. Multimode fibers: they can send different data transmissions simultaneously on a single fiber. Its diameter is slightly larger than that of single-mode fibers, and it can be 50 and 62.5 μm, which allows light to enter at different angles.

**Figure 3** shows a graphic comparison of the expected behavior in the two types of the mentioned fibers; the way of sending information between the fibers can be noted.

When the copper transmission capacity comparison is made, which allows a few million pulses per second, versus more than 20 million pulses that can be sent in an optical fiber, it is possible to appreciate the great efficiency advantage. It is understandable that communications companies can work with large amounts of information that would be limited with the use of conductive cables. Therefore, the great increase in the transmission of information that we can see on the Internet and the Word Wide Web has been achieved [5].

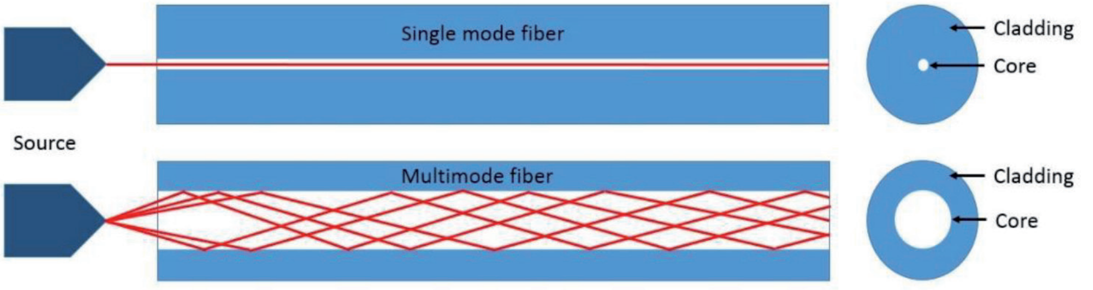


**Figure 3.**
*Simple graphical comparison between single-mode and multimode optical fibers.*

## 2. Optical fiber transmission

From the invention of optical fibers to the present day, research and technological development on optical fibers has been carried out [6]. The use of semiconductor devices coupled to fiber-optics in technological development for the transmission of information has evolved over time since 1980. Five generations of technological development have been implemented where fiber-optic technology coupled to semiconductor materials has increased the amount of information as well as the distance between repeaters (**Table 1**).

| Generation | Type | Year | Bit rate | Repeater spacing | Operating wavelength |
|---|---|---|---|---|---|
| First | Graded-index fibers | 1980 | 45 Mb/s | 10 km | 0.8 μm |
| Second | Single-mode fibers | 1985 | 100 Mb/s to 1.7 Gb/s | 50 km | 1.3 μm |
| Third | Single-mode lasers | 1990 | 10 Gb/s | 100 km | 1.55 μm |
| Fourth | Optical amplifiers | 1996 | 10 Tb/s | >10,000 | 1.45–1.62 μm |
| Fifth | Raman amplification | 2002 | 40–160 Gb/s | 24,000–35,000 km | 1.53–1.57 μm |

**Table 1.**
*Evolution of different generations of light wave systems.*

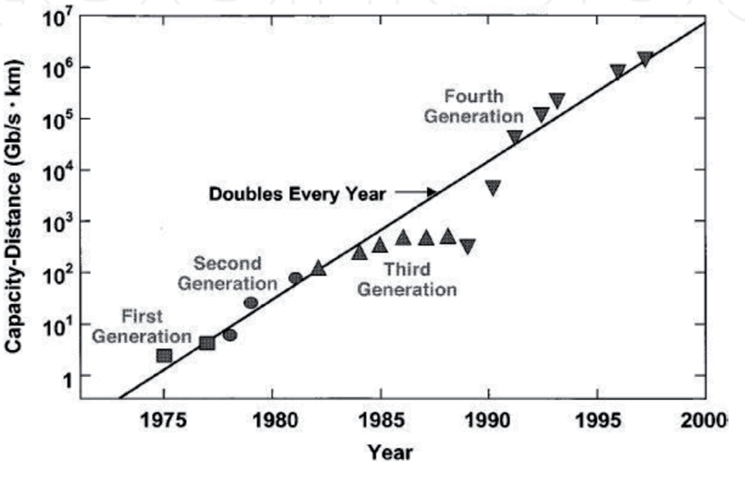


**Figure 4.**
*Increase in the BL product from 1975 to 2000 through four generations of light wave systems. Different symbols are used for successive generations [4].*

**Figure 4** shows the evolution of the first four generations of optical fiber coupled with laser devices as an emission source. Two mechanisms can be mentioned about the fourth generation to amplify the information that reaches a system; these are the rare earth-doped amplifiers and semiconductor amplifiers [7, 8]. Additionally as mentioned in the fifth generation, there are Raman amplifiers [9].

Among the amplifiers doped with rare earths, those made with fiber-optic doped with erbium and doped with ytterbium can be mentioned [10–12]. The optical fibers doped with erbium are the most used for the construction of this type of amplifiers, among other sensors and other applications [13–16]. The above due to its low cost compared to the ytterbium and because its amplification window coincides with the third transmission window of silica-based optical fibers [17].

## 3. Optical fiber applications

Regarding the advantages of optical fibers for the transmission of information and their multiple applications over existing methods such as those based on conductors such as copper, the following can be mentioned:

1. Perhaps the most outstanding feature of optical fibers is that they are capable of transmitting at the speed of light, which greatly increases the ability to send information.

2. Optical fibers are not affected by electrical signals that distort information, as is the case with conductive cables.

3. Due to the absence of intermittency due to electromagnetic fields, a fiber-optic cable cannot be detected remotely since it can only be accessed by entering the fiber. This is very attractive as a security measure for the government, banks, and other companies that need to protect their information.

4. Unlike metallic conductors, optical fibers are not capable of producing sparks with the information they carry; therefore, there is no risk of fire due to such events.

5. The signal absorption in the optical fiber is much lower than in a copper cable, in addition to the fact that cladding allows a very efficient internal reflection. With this, in applications where information is transmitted over several channels, there is no possibility of mixing data between fibers as can occur in cable communications.

6. The cost of installing several kilometers of fiber-optic is cheaper than the installation of copper cables. In this way, communication services such as the Internet are cheaper because with low-power intensity, information can be transmitted over long distances.

7. The bandwidth that can be had, as well as the data capacity of an optical fiber, allows to have a lot of information in a very thin cable. This is the reason for the continuous research and technological innovation for its increase.

8. Fiber-optic cable installations are less expensive than copper or coaxial cable installations, as well as the installation equipment.

9. It is well known that the distances for transmission through the use of optical fiber are very long, more than 100 km without active or passive elements intervening, in addition to the obtained low attenuation.

Additionally, some disadvantages could have been found; perhaps one of the main ones is that optoelectronic devices that can be connected are expensive.

Comparing the emitting and receiving devices of electrical systems against those used with fiber-optic technology, this difference can be understood. That is why some companies still use electrical devices.

Considering the advantages, simplicity of manufacturing, as well as its versatility and growth in popularity, multiple technological applications and practical uses for optical fibers have been developed.

Some of the optical fiber applications which are not sensitive to electrical or magnetic interference make them highly recommended for military applications [18–20]. In addition there are different applications in industrial areas, such as sensing an ambient temperature, pressure, and gases or even wiring of automotive systems [21–24].

In the area of medicine, optical fibers are the modifications for laser surgery, such as light guides and tools for the transmission of images [25–28]. In the area of sciences, fiber-optic applications are very useful [21, 25]. In the manipulation of particles by means of optical tweezers, the optical fibers provide a great advantage [29].

In the subject of communications, the use of optical amplifiers has been outstanding over other applications. These optical amplifiers have been developed by manufacturing doped optical fibers with rare earth ions to have light amplification by stimulated emission [4, 30, 31]. **Table 2** shows some of the most common dopants, as well as the glass used as the host for their application.

In addition, systems with nonlinear behavior have been found. Among the results observed with the said nonlinear behavior in fiber doped with erbium ($Er^{3+}$), there are behaviors with multistability, phenomenological dynamics, different sensors, and masking in communications, among others [14, 16, 23, 33–35].

As mentioned above, to improve all the possible applications in a fiber-optic system, the process of integration with optoelectronic devices is necessary.

This book offers a comprehensive review about the design, manufacturing, and performance obtained from the integration of fiber-optics with optoelectronic devices. In particular, it analyzes some of the advances in light-emitting diodes (LEDs), lasers, photodetectors, as well as applications in communication systems, sensors, interferometric, and holographic methods, which with the use of optical fiber strengthens the capacity and applications.

| Dopant | Common host glasses | Important emission wavelengths |
|---|---|---|
| Erbium ($Er^{3+}$) | Silicate and phosphate glasses, fluoride glasses | 1.51.6 μm, 2.7 μm, 0.55 μm |
| Holmium ($Ho^{3+}$) | Silicate glasses, fluorozirconate glasses | 2.1 μm, 2.9 μm |
| Neodymium ($Nd^{3+}$) | Silicate and phosphate glasses | 1.031.1 μm, 0.90.95 μm, 1.321.35 μm |
| Praseodymium ($Pr^{3+}$) | Silicate and fluoride glasses | 0.3 μm, 0.635 μm, 0.6 μm, 0.52 μm, 0.49 μm |
| Thulium ($Tm^{3+}$) | Silicate and germanate glasses, fluoride glasses | 1.72.1 μm, 1.451.53 μm, 0.48 μm, 0.8 μm |
| Ytterbium ($Yb^{3+}$) | Silicate glass | 1.01.1 μm |

**Table 2.**
*Common laser-active ions, host glasses, and important emission wavelength [32].*

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