Component of Optical Fiber: A Comprehensive Review

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ABSTRACT: This article looks at how optical communication technologies have evolved through time, as well as some of its early failures. The features of different generations of optical fiber communication are next studied. Total internal reflection, as well as different types of fibers, their diameters and refractive index profiles, dispersion, and loss mechanisms, are all addressed. Finally, the entire system of optical fiber communication, as well as its advantages and limitations, are briefly addressed. Future soliton-based optical fiber connection is also highlighted. Optical fiber is a data transmission technique that use light pulses that pass through a long fiber made of plastic or glass. For optical fiber communication transmission, metal wires are used because signals travel more safely. Optical fibers are unaffected by electromagnetic interference. The fiber optical cable uses full internal reflection of light. Depending on the power and transmission distance requirements, the fibers are designed to assist in the propagation of light in conjunction with the optical fiber. Single-mode fiber is used for long-distance transmission, whereas multimode fiber is used for shorter distances. The outer coating of these fibers requires greater protection than the outer coating of metal wires.

KEYWORDS: Amplifiers, Coupler, Component, Detectors, Optical Fiber.

1. INTRODUCTION

Fiber optic sensor technology has been under development for over 40 years, resulting in the creation of a variety of devices such as fiber optic gyroscopes, temperature, pressure, and vibration sensors, and chemical probes. Fiber optic sensors provide a variety of benefits over traditional sensors, including greater sensitivity and geometric flexibility, which allows for the creation of any forms. Fiber optic sensors may be utilized in high voltage, high temperature, and corrosive environments since they are dielectric devices. Furthermore, these sensors are compatible with communications networks and are capable of remote sensing. The discovery of novel materials with non-linear optical characteristics for significant prospective applications in photonics has recently been the focus of research in the area. Conjugated semiconducting polymers, which combine optical and electrical characteristics of semiconductors, are an example of these materials. These conducting polymers also exhibit photo luminescent and electroluminescent characteristics, making them ideal for optoelectronic applications [1], [2].

Fiber optic sensors and their applications are discussed in this chapter. It also goes over novel optical materials that are being researched for use in chemical optical sensors. To offer a clear and logical flow of subjects, the chapter is divided into five parts (including conclusions). The first part goes through the basics of optical fibers, such as basic principles, optical fiber structure, and general features. Snell's law, the critical angle, and total internal reflection are all addressed in relation to light propagation in optical fibers. The second part covers fiber optic sensors in depth, including their properties, functional categorization, modulation techniques, and main applications. The third part covers rare-earth-doped fibers used in fluorescence optical sensors, such as erbium (Er^{3+}), neodymium (Nd^{3+}), ytterbium (Yb^{3+}), praseodymium (Pr^{3+}), samarium (Sm^{3+}), europium (Eu^{3+}), holmium (Ho^{3+}), and erbium/ytterbium (Er/Yb A review of the performance of rare-earth-doped fiber sensors and their applications in remote temperature monitoring, taking into consideration the sensing material, temperature range, and temperature sensitivity, is also given. The next section gives an overview of novel optical materials and assesses their potential as optical fiber sensors. Because of their intriguing electrical, chemical, and optical characteristics, conducting polymers such as polypyrrole (PPy), polyaniline (PANI), polythiophene (PTh), and its derivatives are considered as possible optical sensors. Because of its ability to transport enormous amounts of data, including video and data, the optical fiber has marked a revolution in the world of telecommunications. To increase the transmission distance, erbium-doped fibers may be utilized as optical amplifiers. The research in this area has allowed the spectrum of optical fiber applications to expand, resulting in the creation of novel devices such as fiber lasers and optical fiber sensors, which are the focus of this article [3], [4].

An optical fiber is a filament-shaped optical waveguide that is usually constructed of glass (although it can also be made of plastic materials). The core, cladding, and coating or buffer are the three components of an optical fiber. Fibers come in a variety of diameters; the cladding diameter is usually 125 m, while the core diameter is typically 10 to 50 m. Figure 1 depicts the fundamental construction of an optical fiber. The core is usually composed of glass and is a cylindrical rod of dielectric material. The fiber's core is where light propagates the most. The cladding layer is composed of a dielectric substance having a lower n2 index of refraction than the core material, n1. Typically, the cladding is composed of glass or plastic. The cladding reduces light loss from the core into the atmosphere, reduces scattering loss at the core's surface, shields the fiber from absorbing surface impurities, and provides mechanical strength. The coating, also known as a buffer, is a layer of plastic that protects the optical fiber from damage. The core and cladding create the essential conditions for an optical signal to travel down the optical fiber [5], [6].

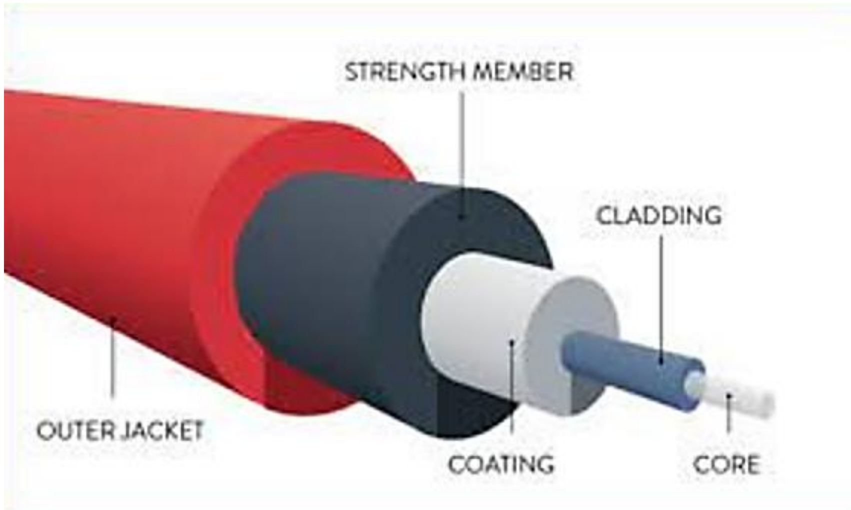

Figure 1: Diagrammatic Representation of Optical Fiber [BASE64].

1.1 Component Of Optical Fiber:

1.1.1. Optical sources:

In optical fibers, heterojunction LEDs and lasers are often employed as optical sources communication. A p-n connection created by a single crystal is known as a heterojunction. such that the material on one side of the junction is different from the material on the other junction. A hetero junction is created between GaAs and silicon in contemporary GaAs diode lasers. GaAlAs. At a wavelength of 0.8 m, this kind of p-n junction diode laser or LED is employed. At InP-InGaAsP heterojunction laser diodes are utilized for longer wavelengths. Heterojunction lasers or LEDs outperform homojunction lasers or LEDs. LEDs. In general, heterojunction lasers and LEDs have a low current density threshold. (10 A/mm2), high output power (10 mW) despite low working current (500 mA), etc. High coherence and monochromaticity, as well as stability and longevity.The active junction area of a double hetero structure stripe laser, for example, is just a few microns long. As a result, the current density at the threshold is substantially decreased. The striation The diode's lifespan is extended due to the diode's steadiness. As a result, it provides a lot of power output, continuous wave operation, high efficiency, high coherence, and high directionality are all desirable characteristics. Both the carriers and the receivers benefit from the heterojunction produced by two distinct materials. The core active layer confines the optical field. Differences in bandgap between neighboring layers contain charge carriers, while a step change in the indices of refraction of neighboring layers limits the optical field to the core active layer, resulting in an effective optical field confinement structure of a waveguide Due to the twofold confinement, both efficiency and power are increased [7], [8].

1.1.2. Optical amplifiers:

The repeaters in long-distance optical fiber communication networks are spaced at a distance of 100 kilometers apart. These receive and amplify the sent signal to its original strength before passing it on to the main cable. It was formerly done by converting optical energy into electrical energy, amplifying it using electrical amplifiers, and then converting electrical energy back into optical energy. Such techniques not only raise the cost and complexity of an optical communication system, but they also decrease the system's operating bandwidth. However, it is now done in an elegant way using erbium doped optical fiber amplifiers by inserting a length of 10 m fiber amplifier for every 100 km length of primary fiber. Due to optical domain operation alone, the signal to noise ratio is significantly enhanced. Due to its basic design, which is in the form of a fiber coupler, and cheap manufacturing, the cost of laying and maintaining the optical amplifier is significantly reduced. Optical amplifiers have been discovered to be capable of concurrently amplification of several wavelength division multiplexed optical signals.

Initially, stimulated Raman scattering and Brillouin scattering were used to build optical amplifiers. The laser action is accomplished via the nonlinear effects generated inside the fiber and may offer optical amplification by injecting a high power laser beam as pumping radiation into an undoped relatively long length fiber (10 km) or a doped short length fiber (10 m). In general, Raman gain is negligible. Large length fibers, extremely low loss fibers, and tiny diameter fibers are observed to have greater Raman gain. The limited gain-bandwidth of Raman or Brillouin amplifiers is not suited for high-speed communications. Furthermore, these amplifiers have no way of increasing their bandwidth or strength. Meanwhile, Mollenauer developed a silica fiber laser amplifier with erbium doping. Even in a short length fiber, it has a significant gain. The concentration of erbium ions in erbium doped silica fiber is about 1025 ions/m3 [9], [10].

An InGaAsP laser diode operating at a wavelength of 1.48 m is utilized as a pumping source for optical signal amplification at 1.55 m. The erbium ions in the ground level 'E1' absorb this radiation and are stimulated to the expanded higher level E2. Due to the electric field of neighboring ions (i.e. energy level splitting via Stark effect) and the amorphous structure of silica glass, the energy level E2 is expanded into a band. Only the transition between E2 and E1 is 100 percent radiative in erbium doped silica fiber; all other transitions are non-radiative. Even though the absorption wavelength of E3+ r ions in the energy band E2 is 1.48 m, the emission wavelength is 1.55 m from the bottom of the energy band E2. This is due to the fast thermalization of E3+ r ions in the energy band E2. Despite the fact that the erbium ions are stimulated to the E2 level at low pump powers, population inversion does not occur owing to dominating spontaneous emission. The optical signal at 1.55 m will be attenuated in this instance. The rate of excitation rises as the pump power increases. As a result, population inversion may occur at a certain pump power threshold. The incoming signal photons stimulate the erbium ions in the energy level E2, resulting in laser activity with the output photon and stimulating photon having the same energy and phase. As a result, the signal is boosted. Because the signal is amplified and reabsorbed as it goes down the optical fiber amplifier, the pump power may progressively be reduced there is a maximum gain length for the fiber amplifier. When the starting pump power is 5 mW, the fiber amplifier's optimal length is about 7m [11].

1.1.3. Fiber coupler:

A coupler is a device that divides light into one or more branch fibers from a primary fiber. Surface interaction type couplers and core interaction type couplers are the two types of interaction couplers. The light energy is transferred via the core cross-section in core interaction type couplers. via butt-joining the fibers or employing imaging optics between the fibers (e.g. A spherical lens was utilized to photograph the core utilizing lensing techniques such as rounded end fiber. a taper-ended fiber and a fiber with a core region of one fiber on the core area of the other fiber). At first glance Light energy is transferred via the fiber surface and normal to the fiber surface in this interaction type. By converting guided core modes to cladding and refracted modes, the fiber's axis may be changed.

1.1.4. Optical detectors:

In optical fiber communication systems, photodiodes based on semiconductors are employed as optical detectors. They are tiny in size, have a great sensitivity, and respond quickly. Photodiodes are divided into two categories: p-i-n photodiodes and Avalanche photodiodes are two types of photodiodes (APD)

- P-I-N photodiodes: The p and n areas are separated by a very weakly doped intrinsic region in a positive-intrinsic-negative (p-i-n) photodiode. Silicon p-i-n photodiodes with a wavelength of 0.8 m are utilized, whereas InGaAs p-i-n photodiodes with wavelengths of 1.3 m and 1.55 m are employed. The p-i-n photodiode is normally operated with a high reverse bias voltage. As a result, the diode's intrinsic area is completely devoid of carriers. The absorption of a photon with energy higher than or equal to the bandgap energy of the photodiode material results in the formation of an electron-hole pair. The strong electric field present in the depletion area separates such photongenerated carriers in the depleted intrinsic region, where most of the incoming light photons are absorbed, and they are collected across the reverse biased junction.

In the external circuit, this results in a photocurrent flow. The p-i-n photodiode behaves as a linear device, with I = RP, where I = photo current, P = incident optical power, and R = photodiode responsivity.

- Avalanche photodiodes (APDs): It consists of four regions p + i p n+ in order to develop a very high electric field in the intrinsic region as well as to impart more energy to photoelectrons to produce new electron-hole pairs by impact ionization. This impact ionization leads to avalanche breakdown in the reverse biased diode. So the APDs have high sensitivity and high responsivity over p-i-n diodes due to the avalanche multiplication. The responsivity of APD is given by R = ηq hν M where M is called avalanche multiplication which is greater than 50. APDs are made from silicon or germanium having operating wavelength 0.8 µm and from InGaAs having operating wavelength 1.55.

- Multiplexers: Multiple optical signals (channels) sent over the same fiber is a simple method to enhance the fiber's transmission capacity against fiber dispersion, fiber nonlinearity, and the speed of electronic components that restrict the bit rate. As a result, multiplexing methods are used. Multiplexing refers to the simultaneous transmission of several signals. Assume that each channel has a bit rate of 100 Gb/s, and that by multiplexing 100 channels, the total bit rate via a single fiber may be raised to 10 Tb/s (1 Tera = 1012): The multiplexing method thereby increases the information carrying capacity of a fiber.

1.2 Advantages Of Optical Fiber :

- Increased bandwidth: A transmission system's information carrying capacity is directly proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the region of 1013 to 1015 Hz, whereas radio waves are about 106 Hz and microwaves are around 1010 Hz. As a result, the optical fiber communication system has a larger transmission bandwidth than traditional communication systems, and the data rate or number of bits per second is raised to a greater degree. Furthermore, the wavelength division multiplexing operation is improved by several orders of magnitude by the data rate or information carrying capacity of optical fibers.
- Transmission loss is minimal: It is possible to obtain nearly lossless transmission by using extremely low loss fibers and erbium doped silica fibers as optical amplifiers. Fibers with a transmission loss of 0.002 dB/km are utilized in contemporary optical fiber communications networks. Furthermore, suitable optical amplification may be accomplished by employing erbium doped silica fibers in the transmission channel for a short distance at certain locations. As a result, the repeater separation is more than 100 kilometers. Because the signal is amplified in the optical domain, the distortion caused by the signal strengthening is virtually non-existent.
- Dielectric waveguide: Optical fibers are composed of the electrical insulator silica. As a result, they are immune to electromagnetic waves and high-current lightning. It's also safe to use in potentially explosive situations. Furthermore, interference from power cables, railway power lines, and radio waves has little effect on optical fibers. Because there is no optical interference between the fibers, even if there are many fibers in a cable, there is no cross talk between them.
- Signal security: The sent signal does not propagate via the fibers. Furthermore, the signal cannot be easily tapped from a fiber. As a result, optical fiber connection ensures complete signal security.
- Tiny size and weight: Fiber optic cables are flexible, compact, and lightweight, and they have small radii. The fiber cables may be twisted or bent without causing harm. In addition, optical fiber cables outperform copper cables in terms of storage, handling, installation, and transportation while retaining similar strength and longevity.

2. DISCUSSION

Optical fibers are used to transmit light between two ends of a fiber and are extensively used in fiber-optic communication, where they enable transmission over longer distances and at higher bandwidths (data transfer rates) than electrical lines. Signals go via fibers with less loss than through metal wires, and fibers are immune to electromagnetic interference, which is a problem with metal wires. Fibers are also used for lighting and imaging, and they are often bundled in bundles to carry light or images into or out of limited areas, such as a fiberscope. Fiber optic sensors and fiber lasers are two examples of applications that use specifically designed fibers. In optical fibers, a core is typically covered by a transparent cladding material with a lower index of refraction. Light is kept in the core by the phenomenon of full internal reflection, which causes the fiber to act as a waveguide. Single-mode fibers enable just one mode, while multi-mode fibers allow several propagation pathways or transversal mode (SMF).

3. CONCLUSION

To summarize, the following are the main advantages of the optical sensor system proposed for monitoring ammonia with PANI films: its sensitivity to intensity variations of the optical source signal, which helps to avoid measurement errors; its simple signal detection system with ammonia information; and the possibility of using a light emitting diode (LED) as the optical. As a result, the possibility of using polyaniline polymers to create intrinsic optical fiber sensors for distant ammonia detection. Optical fiber sensors have seen considerable upsurge in research and commercialization in recent years. Optical fiber sensors have a broad range of uses today, and their expansion into sensor systems optoelectronics has led to a wide range of applications in a variety of areas. However, as technology advances in a variety of areas, new difficulties emerge for the development and instrumentation of high-performance optical fiber sensor systems and devices. The study and development of novel materials having electrical and optical characteristics, such as conductive polymers, paves the way for new optoelectronic devices, such as sensor systems, to be developed.

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