Fiber Optics And Its Types For Sensing Applications In Various Fields

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ABSTRACT

In recent years, fiber optic sensors have been deployed successfully in the supervision of structures. Mainly due to their small size they are enable to be widely used in structural elements. In facts, advances in the production of optical fibers made possible the recent development of innovative sensing systems. The current state of the art of optical fiber sensors is reviewed.The principles of operation are detailed and the various types of fiber sensors are outlined. Numerous researches have been conducted in past decades using fiber optic sensors with different techniques. Intensity, phase, and wavelength based fiber optic sensors are the most widely used sensor types. In this paper, an overview of fiber optic sensors and their applications are presented.

Keywords: Fiber optics, optical fiber sensing, interferometry.

1. INTRODUCTION

With the invention of the laser in 1960’s, a great interest in optical systems for data communications began. The invention of laser, motivated researchers to study the potential of fiber optics for data communications, sensing, and other applications. Laser systems could send a much larger amount of data than microwave, and other electrical systems. The first experiment with the laser involved the free transmission of the laser beam in the air. Researchers also conducted experiments by transmitting the laser beam through different types of waveguides. Glass fibers soon became the preferred medium for transmission of light. Initially, the existence of large losses in optical fibers prevented coaxial cables from being replaced by optical fibers. Early fibers had losses around 1000 dB/km making them impractical for communications use [1]. OPTICAL fiber sensor development has matured to the point where the impact of this new technology is now evident. Fiber sensors offer a number of advantages: increased sensitivity over existing techniques, geometric versatility in that fiber sensors can be configured in arbitrary shapes, a common technology base from which devices to sense various physical perturbations (acoustic, magnetic, temperature, rotation, etc.) can be constructed, dielectric construction so that it can be used in high voltage, electrically noisy, high temperature, corrosive, or other stressing environments, and inherent compatibility with optical fiber telemetry technology. Progress in demonstrating these advantages has been substantial in the past few years with over 60 different sensor types being developed.This large number of individual devices is usually categorized into amplitude or phase (interferometric) sensors. In the former case the physical perturbation interacts with the fiber or some device attached to the fiber to directly modulate the intensity of the light in the fiber. The advantages of intensity sensors, which are described in detail in the body of this paper, are the simplicity of construction and the compatibility with multimode fiber technology. In some cases, sensitivity is traded off in order to realize these advantages. In view of the fact that extreme sensitivity is not required for most applications and that these devices are competitive with existing devices, a large market appears to exist for this class of sensor. The phase (or interferometric) sensor, whether for magnetic, acoustic, rotation, etc., sensing, theoretically offers orders of magnitude increased sensitivity over existing technologies. In the case of the acoustic sensor constructed utilizing optical fiber interferometers, these theoretical predictions have been verified to the limit of state of the art in acoustic measurementsRecent advances in fiber optic technology have significantly changed the telecommunications industry. The ability to carry gigabits of information at the speed of light increased the research potential in optical fibers. Simultaneous improvements and cost reductions in optoelectronic components led to similar emergence of new product areas. Last revolution emerged as designers to combine the product outgrowths of fiber optic telecommunications with optoelectronic devices to create fiber optic sensors. Soon it was discovered that, with material loss almost disappearing, and the sensitivity for detection of the losses increasing, one could sense changes in phase, intensity, and wavelength from outside perturbations on the fiber itself. Hence fiber optic sensing was born [2]. In parallel with these developments, fiber optic sensor technology has been a significant user of technology related with the optoelectronic and fiber optic communication industry [3-7]. To date, fiber optic sensors have been widely used to monitor a wide range of environmental parameters such as position, vibration, strain, temperature, humidity, viscosity, chemicals, pressure, current, electric field and several other environmental factors [8-13].

2. STRUCTURE OF AN OPTICAL FIBER.

An optical fiber is composed of three parts;

1. Core
2. Cladding
3. Coating

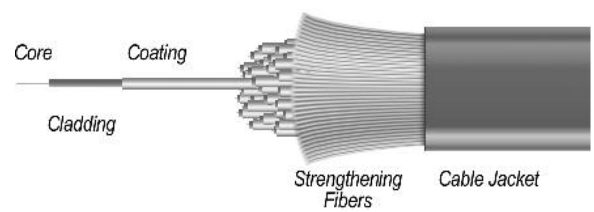

Figure 1. Basic structure of an optical fiber.

1. The core is a cylindrical rod of dielectric material and is generally made of glass. Light propagates mainly along the core of the fiber [1].
2. The cladding layer is made of a dielectric material with an index of refraction. The cladding executes such functions as decreasing loss of light from core into the surrounding air, decreasing scattering loss at the surface of the core, protecting the fiber from absorbing the surface

contaminants and adding mechanical strength [1].

3. The coating or buffer is a layer of material used to protect an optical fiber from physical damage. The material used for a buffer is a type of plastic. The buffer is elastic in nature and prevents abrasions [1].

3. PRINCIPLE:

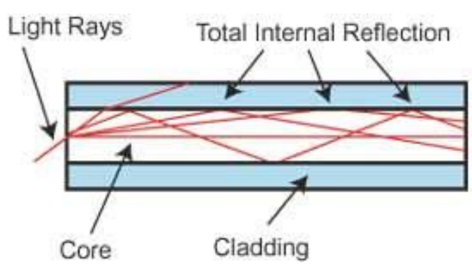

Figure 2. Basic Geometry of Optical Fiber Sensor

It consists of an optical source (Laser, LED, Laser diode etc), optical fiber, sensing or modulator element (which transduces the measurand to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc).

Fiber optic sensors can be classified under three categories: The sensing location, the operating principle, and the application. Based on the sensing location, a fiber optic sensor can be classified as extrinsic or intrinsic. In an extrinsic fiber optic sensor (see Figure 3), the fiber is simply used to carry light to and from an external optical device where the sensing takes place. In these cases, the fiber just acts as a means of getting the light to the sensing location.

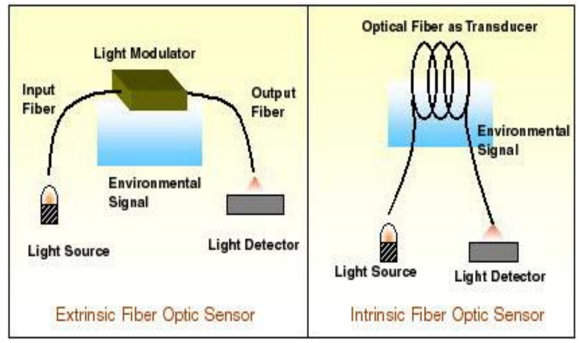

Figure 3. Extrinsic and intrinsic types of fiber optic sensors.

On the other hand, in an intrinsic fiber optic sensor one or more of the physical properties of the fiber undergo a change (see Figure 3).

4. FIBER OPTIC SENSOR TYPES: (For signal purpose)

1. Intensity Based Fiber Optic Sensors:
Intensity-based fiber optic sensors rely on signal undergoing some loss. They are made by using an apparatus to convert what is being measured into a force that bends the fiber and causes attenuation of the signal. Other ways to attenuate the signal is through absorption or scattering of a target. The intensity-based sensor requires more light and therefore usually uses multimode large core fibers [5].

***Advantages & Disadvantages:**
The advantages ofthese sensors are: Simplicity of implementation, low cost, possibility of being multiplexed, and ability to perform as real distributed sensors. The drawbacks are: Relative measurements and variations in the intensity of the light source may lead to false readings, unless a referencing system is used [14].
Type of intensity based fiber optic sensor is the evanescent wave sensor (see Figure 4)

that utilizes the light energy which leaks from the core into the cladding. These sensors are widely used as chemical sensors. The sensing is accomplished by stripping the cladding from a section of the fiber and using a light source having a wavelength that can be absorbed by the chemical that is to be detected. The resulting change in light intensity is a measure of the chemical concentration. Measurements can also be performed in a similar method by replacing the cladding with a material such as an organic dye whose optical properties can be changed by the chemical under investigation [15].

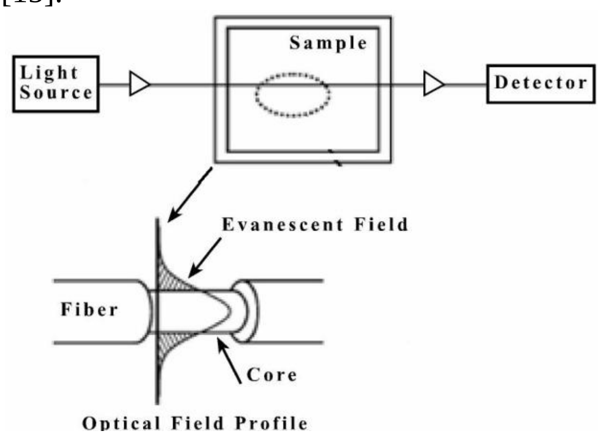

Figure 4. Evanescent wave fiber optic chemical sensor.

2. Wavelength Modulated Fiber Optic Sensors:

Wavelength modulated sensors use changes in the wavelength of light for detection. Bragg grating sensors are examples of wavelength-modulated sensors.

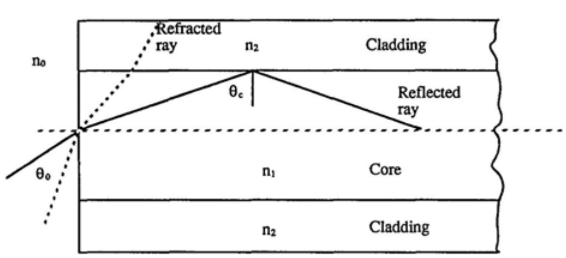

Figure 5. Basic Geometry of Optical Fiber Sensor

The Bragg grating sensor relies on the reflection of light from a region in the index of refraction of the optic fiber core. Longitudinal strain in the fiber changes the spacing of these periodic variations, thereby varying the wavelength of reflected light. (Figure 5) The most widely used wavelength based sensor is the Bragg grating sensor. Fiber Bragg gratings (FBGs) are formed by constructing periodic changes in index of refraction in the core of a single mode optical fiber. This periodic change in index of refraction is normally created by exposing the fiber core to an intense interference pattern of UV energy. The variation in refractive index so produced, forms an interference pattern which acts as a grating.

OPERATION:

Light from a broadband source (LED) whose center wavelength is close to the Bragg wavelength is launched into the fiber. The light propagates through the grating, and part of the signal is reflected at the Bragg wavelength. The complimentary part of the process shows a small sliver of signal removed from the total transmitted signal. This obviously shows the Bragg grating to be an effective optical filter [13].

3. Phase Modulated Fiber Optic Sensors:

Phase modulated sensors use changes in the phase of light for detection. The optical phase of the light passing through the fiber is modulated by the field to be detected. This phase modulation is then detected interferometerically, by comparing the phase of the light in the signal fiber to that in a reference fiber. In an interferometer, the light is split into two beams, where one beam is exposed to the sensing environment and undergoes a phase shift and the other is isolated from the sensing environment and is used for as a reference. Once the beams are recombined, they interfere with each other

[5]. Examples: Mach-Zehnder, Michelson, Fabry-Perot, Sagnac, Polarimetric etc.

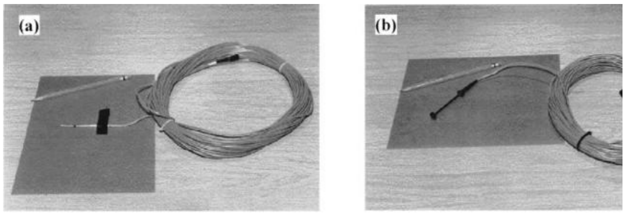

Figure 6. Two Types of Fabry-Perot Fiber Optic Sensors

Another commonly used interferometer based sensor is the Fabry-Perot interferometric sensor (FFPI) and is classified into two categories: Extrinsic Fabry-Perot interferometer (EFPI) sensor and intrinsic Fabry-Perot interferometer (IFPI) sensor. In an EFPI sensor, the Fabry-Perot cavity is outside the fiber. Fiber guides the incident light into to the FFPI sensor and then collects and the reflected light signal from the sensor. In an IFPI sensor, the mirrors are constructed within the fiber. The cavity between two mirrors acts both as sensing element and waveguide. In this case, the light never leaves the fiber [16].

4. POLARIZATION MODULATED FIBER OPTIC SENSORS:

The direction of the electric field portion of the light field is defined as the polarization state of the light field. Different types of polarization states of the light field are linear, elliptical, and circular polarization states. For the linear polarization state, the direction of the electric field always keeps in the same line during the light propagation. For the elliptical polarization state, the direction of the electric field changes during the light propagation. The end of the electric field vector forms an elliptical shape; hence, it is called ‘‘elliptical polarized light”. The refractive index of a fiber changes when it undergoes stress or strain. Thus, there is an induced phase difference between different polarization directions. This phenomenon is called photo elastic effect. Moreover, the refractive index of a fiber undergoing a certain stress or strain is called induced refractive index. The induced refractive index changes with the direction of applied stress or strain. Thus, there is an induced phase difference between different polarization directions. In other words, under the external perturbation, such as stress or strain, the optical fiber works like a linear retarder. Therefore, by detecting the change in the output polarization state, the external perturbation can be sensed [10]. The polarized light is launched at 45 degrees to the preferred axes of a length of bi-refrigent polarization-preserving fiber. This section of fiber is served as sensing fiber. Under external perturbation such as stress or strain, the phase difference between two polarization states is changed. Then, the output polarization state is changed according to the perturbation. Hence, by analyzing the output polarization state at the exit end of the fiber, the external perturbation can be detected [10].

(For civil purpose)

1. Intension-metric:

An intension-metric sensor relies on variations of the radiant power transmitted through an optical fiber. External forces (such as compressive stress) can introduce small bends in an optical fiber which couples light out of the fiber, thereby varying the intensity of light transmitted through the fiber. A micro-bend sensor is a common intension-metric sensor.

2. Interfero-metric:

An interfero-metric sensor relies on measured induced phase change in light propagating through the optical fiber. Two interfero-metric type sensors are Fabry-Perot and Bragg grating. The Fabry-Perot sensor consists of two mirrors placed in line with the optical fiber. Strain induced changes in the longitudinal mirror spacing produces a measurable phase change in the light frequency. Two samples of these sensors are shown in Figure 6.

(For artificial technology purpose)

1. PHYSICAL SENSORS:

Physical optic sensors measure physical parameters such as temperature, curvature, displacement, torsion, pressure, refractive index, electric field, and vibration. The measurement, monitoring, and control of these parameters are of vast interest for several applications. Physical sensors that assess strain/displacement, curvature/bend, transversal load, torsion, and temperature are of immense interest for structural health monitoring. Civil structures like buildings, piles, bridges, pipelines, tunnels, and dams need continuous monitoring with the purpose of controlling and preventing abnormal states or accidents at an early stage, in order to avoid casualties as well as giving maintenance and rehabilitation advice [17]. Physical fiber sensors are perfect for this purpose, since they provide *in situ*, continuous measurement and analysis of key structural and environmental parameters under operating conditions [18, 19]. Other physical sensors like pressure and refractive index find applications in fields such as medicine and bio chemistry, while electric and magnetic field fiber sensors are of enormous benefit for sensing at high voltages, since they provide an insulating link to high-voltage areas (not offered by conventional electric sensors) [20].

According to various applications the following types of sensors are used:

1. *Curvature/Bend Sensors.*
2. *Displacement/Strain Sensors*
3. *Electric and Magnetic Field Sensors.*
4. *Pressures Sensors.*
5. *Temperature Sensors.*
6. *Torsion/Twist Sensors.*
7. *Transversal Loading Sensors.*
8. *Refractive Index Sensors.*
9. *Vibration Sensors.*
10. *Multiparameter Sensing.*

2. BIO CHEMICAL SENSORS:

Optical fibers can be used for sensing of chemical and biological samples. OF-based sensors are advantageous for chemical and bio sensing due to their miniaturization, small size, flexibility, and remote capability, making fibers suitable for *in vivo* experiments, due to the fact that these waveguides are electrically passive, not representing a risk to patients, since there are no electrical connections to their body, and due to the ability for real-time measurement and the possibility to simultaneously measure several parameters. One approach for chemical/bio sensing is to provide the fiber end with a suitable indicator or a material that responds to the parameter of interest. Chemically sensitive thin films deposited on selected areas of optical fibers can influence the propagation of light in such fibers depending on the presence or absence of chemical/biological molecules in the surrounding environment. A wide range of optical sensors has been developed for selective bimolecular detection. Most of them have reliability issues as they employ very fragile antibodies as sensing elements [21].

5. Applications of Fiber Optic Sensors:

Fiber optic sensors are used in several areas. Specifically:

- Measurement of physical properties such as strain, displacement, temperature, pressure, velocity, and acceleration in structures of any shape or size.

- Monitoring the physical health of structures in real time.
- Buildings and Bridges: Concrete monitoring during setting, crack (length, propagation speed) monitoring, prestressing monitoring, spatial displacement measurement, neutral axis evolution, long-term deformation (creep and shrinkage) monitoring, concrete-steel interaction, and post-seismic damage evaluation.
- Tunnels: Multipoint optical extensometers, convergence monitoring, shotcrete / prefabricated vaults evaluation, and joints monitoring damage detection.
- Dams: Foundation monitoring, joint expansion monitoring, spatial displacement measurement, leakage monitoring, and distributed temperature monitoring.
- Heritage structures: Displacement monitoring, crack opening analysis, post-seismic damage evaluation, restoration monitoring, and old-new interaction.

6. CONCLUSION:

An overview of fiber optics sensors and their applications has been presented. The major types of sensors discussed included micro bending sensors, evanescent wave sensors, FBGs, optical fiber interferometers, and polarization modulated fiber optic sensors. it can be concluded that the fiber optic sensors can be successfully used for accuracy of structures and determination of quantity of parameters.

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