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CLASSIFICATION OF FIBER OPTIC SENSORS AND THEIR APPLICATIONS

Physics

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ABSTRACT

Beside advantages; recent advances, and cost reductionshas stimulated interest in fiber optical sensing. So, researchers combined the product outgrowths of fiber optic telecommunications with optoelectronic devices to emerge fiber optic sensors. 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.

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]. In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. By removing these impurities, construction of low-loss optical fibers was possible. In 1970, Corning Glass Works made a multimode fiber with losses under 20 dB/km. The same company, in 1972, made a high silica-core multimode optical fiber with a 4 dB/km loss [1]. Recent 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]. Many of the components associated with these industries were often developed for fiber optic sensor applications. Fiber optic sensor technology in turn has often been driven by the development and subsequent mass production of components to support these industries. As component prices have decreased and quality improvements have been made, the ability of fiber optic sensors to replace traditional sensors have also increased.

Fiber optic sensors are excellent candidates for monitoring environmental changes and they offer many advantages over conventional electronic sensors as listed below:

- Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry.
- Inability to conduct electric current.
- Immune to electromagnetic interference and radio frequency interference.
- Lightweight.
- Robust, more resistant to harsh environments.
- High sensitivity.
- Multiplexing capability to form sensing networks.
- Remote sensing capability.
- Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature and acoustic signals.

Fiber Optic Sensor Principles

The general structure of an optical fiber sensor system is shown in Figure 1. It consists of an optical source (Laser, LED, Laser diode etc), optical fiber, sensing or modulator element (which transduces the measure and to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc).

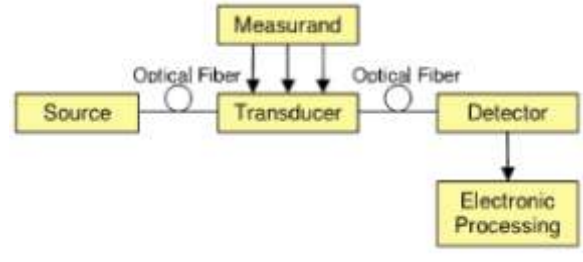

Figure 1. Basic components of an optical fiber sensor system.

Fiber optics sensors can be classified under three categories: the sensing location, the operating principal and the applications. Depending on location of sensor, a fiber sensor can be classified in intrinsic or extrinsic. Based on the operating principal and demodulation technique, a fiber optic sensor can be further divided into intensity, phase, frequency or polarization sensor. Based on application, fiber sensors can be classified in physical, chemical, biochemical sensors. Next section will explain these classification types deeply.

CLASSIFICATION OF FIBER OPTICS SENSOR SYSTEMS

The above classification of fiber optics sensor system can be explained in following manner:

A.Based on Sensor location
i. Intrinsic
ii. Extrinsic
B. Based on operating Principle.
i. Based on intensity
ii. Based on phase
iii. Based on frequency
iv. Based on polarization
C. According to application
i. Physical sensor

ii. Chemical sensor
iii. Bio-medical sensor

Intrinsic type optical sensor

In intrinsic sensing, the internal property of optical fiber itself converts the environmental changes into a modulation of light signal. This modulation of light signal may be in form of intensity, phase and frequency or may be polarization [13]. The following figure shows the basic concept of intrinsic optical sensor.

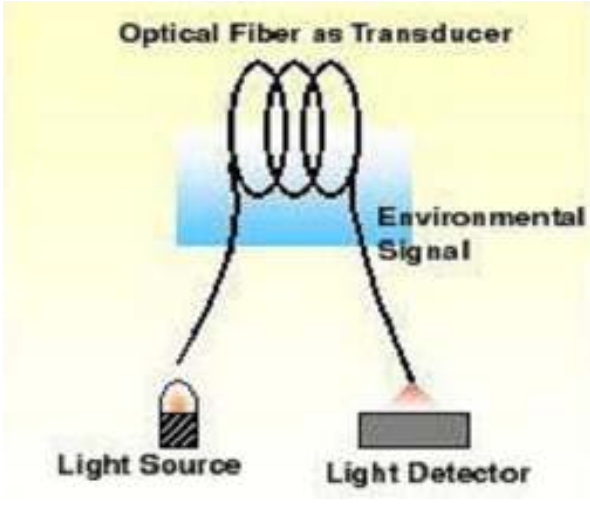

Figure 2 Intrinsic fiber optic sensor

Extrinsic optical fiber sensor

In contrast to intrinsic sensing, in extrinsic sensing, the fiber may be used as information carriers that lead to a black box and that will generate a light signal depending on the information arrived at black box. This black box may be made of mirrors, gas, liquid cell, or many other mechanisms that will proceed to generate an optical signal [12]. The following figure shows the block diagram explain function of external optical fiber sensing.

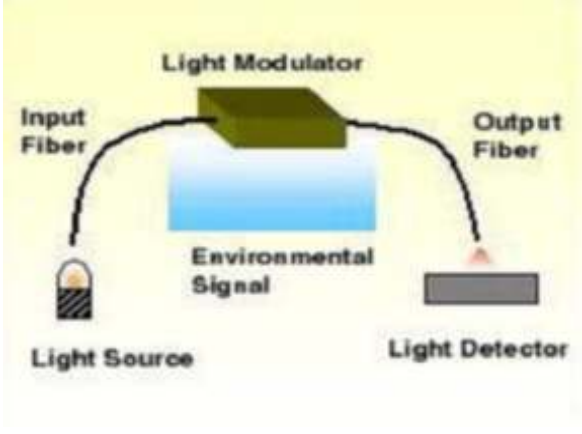

Figure 3 Extrinsic Fiber Optic Sensor

Intensity Based Fiber Optic Sensors

When extrinsic sensor is used, generally it uses intensity based modulation. The figure 4 gives the idea about how a light intensity will be work as sensing parameter. This figure also explains how this arrangement makes the fiber to work as a vibration sensor. As there is a vibration, there will be a change in light injected from one end to another and this will make the intelligence for measuring vibration amplitude [8].

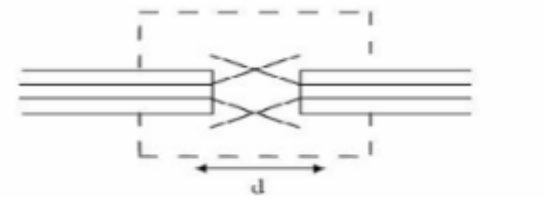

Figure 4 Closer and vibration fiber optics sensor depending on light intensity in later part.

Intensity based optical fiber has lot of limitations due to variable losses in the system that are not occurring in environment. These losses are mainly due to connections at joints, splices, micro bending loss, macro bending loss, mechanical creep and many other factors [4]. There are many other transducers available which may result in light intensity change when a light ray passes through optical fiber.

Wavelength Modulated Fiber Optic Sensors

Wavelength modulated sensors use changes in the wavelength of light for detection. Fluorescence sensors, black body sensors, and the Bragg grating sensor are examples of wavelength-modulated sensors. Fluorescent based fiber sensors are being widely used for medical applications, chemical sensing and physical parameter measurements such as temperature, viscosity and humidity. Different configurations are used for these sensors where two of the most common ones are shown in Figure 5. In the case of the end tip sensor, light propagates down the fiber to a probe of fluorescent material. The resultant fluorescent signal is captured by the same fiber and directed back to an output demodulator [18].

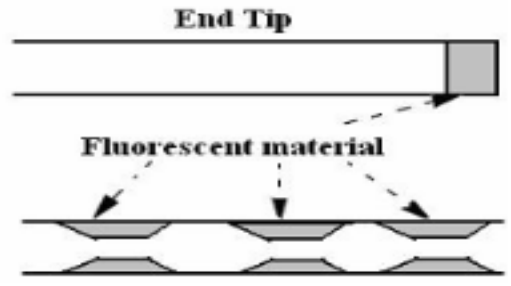

Figure 5. Fluorescent fiber optic sensor probe.

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. The Bragg grating sensor operation is shown in Figure 6 where 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].

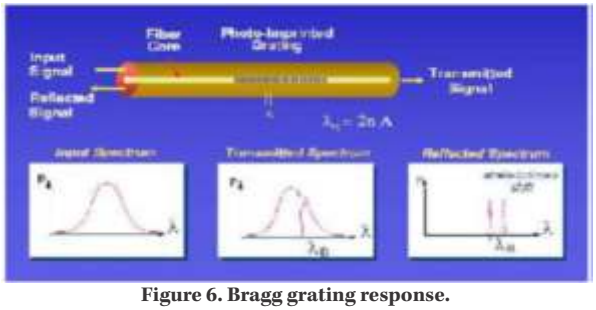

Figure 6. Bragg grating response.

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].

Mach-Zehnder, Michelson, Fabry-Perot, Sagnac, polarimetric, and grating interferometers are the most commonly used intereferometers. The Michelson and Mach-Zehnder interferometers are shown in Figures 7 (a) and 7 (b), respectively.

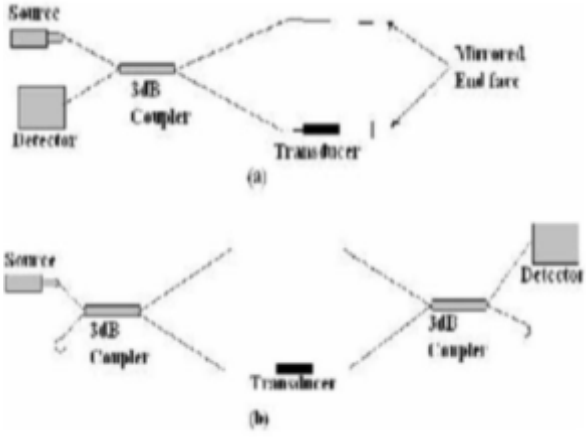

Figure 7. Shematic diagrams of (a) Michelson, and (b) Mach-Zehnder interferometers

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 photoelastic 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]. Figure 8 shows the optical setup for the polarizationbased fiber optic sensor. It is formed by polarizing the light from a light source via a polarizer that could be a length of polarization-preserving fiber. 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].

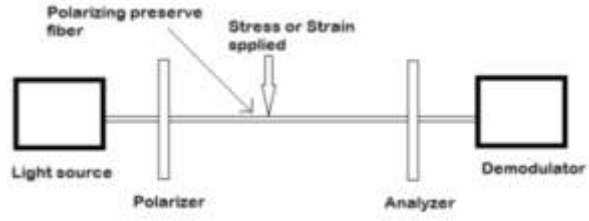

Figure 8. Polarization-based fiber optic sensor.

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.
- Night Vision Camera: This sensor enables low light imagining TV frame rates and above without the limitation of vacuum tube based system. This is most widely used in military and law enforcement.
- Biometrics: Detection of finger prints, face, eyes using optical sensors. Basic steps involved in this procedure are image capturing, image processing, feature extraction and feature comparison.
- Partial Discharge detection: Optical fiber sensors are being tested for use in detecting partial discharge in electrical transformation. Such discharge is essential for preventing insulation breakdown and catastrophic failures.
- Measuring wheel loads of vehicles: The fiber used has a unique design with two concentric light guiding regions of different effective optical path lights, which has the potential to enable direct measure ment of magnitude as well as locations of forces acting at multiple points along single fiber.

CONCLUSION

There are inherent advantages of fiber optic sensors which include their ability to be light in weight, very compact and small in size. Easy to launch light, low ISI, resistance to electromagnetic interference, high sensitivity, wide bandwidth and environmental ruggedness make them widely used in different fields. All these mentioned characteristics make best use of optical fiber as sensor and the networks which are made up of optical fiber are very advantageous in industry for long time investment.

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