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Research Article

Optical Sensors-A Study

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Abstract

Sensors are widely used in engineering applications for accurate operational monitoring and measurement. With the advancement of technology, the need of more sophisticated and precise sensor is always sought. A sensor is characterized by range of operation, accuracy, resolution, repeatability, response time and settling time. Now days, fiber optic sensors have been developed as these provide advantages of being less expensive, higher transmission capacity, less signal degradation, immunity to electromagnetic interference and environmental variations. Considering the measurement accuracy and ease of implementation, the paper describes various variants of fiber optic sensors.

Keywords: *Fabry perot interferometer, fiber bragg grating, hydrophone, polarimetric, sensor.*

Introduction

A sensor is a transducer that converts energy from one form to another so that it could be measured or observed. The output of detector may generate measured value of quantity or it may produce some signal which is further processed further for the measurement. Considering the advantages associated with optical fiber sensors, these are widely used for the measurement of various physical quantities. Broadly, optical sensors are classified into two categories named as extrinsic optical sensor or intrinsic optical sensor. In an extrinsic fiber optic sensor, the modulation of light takes place out of the fiber. In this case, separate module impresses the information onto the light beam. The information could be impressed in terms of intensity, phase, frequency, polarization, or other methods. Another optical fiber then carries the light with the environmentally impressed information. Schematically it is as represented in fig.1.

In an intrinsic fiber optic sensor light is being modulated by the environmental effect within the fiber. In this case the modulation is either directly or through environmentally induced optical path length changes within the fiber. [1]

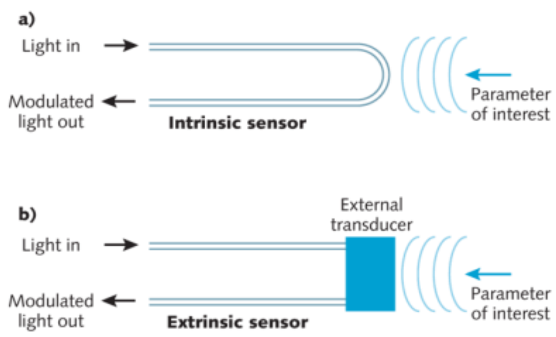

Fig.1: Intrinsic and Extrinsic optical sensor

I. Fabry – Perot Interferometric Sensors

The Fabry–Perot interferometer (FPI), consists of two mirrors of reflectance R_1 and R_2 separated by a cavity of length L, as shown in fig.2.

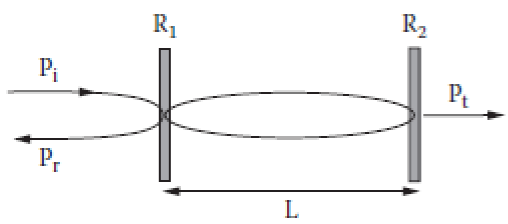

Fig.2: Fabry Perot Interferometric

The individual mirrors in the Fabry Perot Interferometer can be characterized by transmittance and reflectance such that $R_i + T_i = 1$. The excess loss, which is due to the portion of the incident power absorbed or scattered out of the beam by the mirror, is not considered in this analysis. The FP reflectance R_{FP} and transmittance T_{FP} are calculated as

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$$R_{FP} = \frac{R_1 + R_2 + 2\sqrt{R_1 R_2}\cos\phi}{1 + R_1 R_2 + 2\sqrt{R_1 R_2}\cos\phi}$$

$$T_{FP} = \frac{T_1 T_2}{1 + R_1 R_2 + 2\sqrt{R_1 R_2}\cos\phi}$$

where R_{FP} represents the ratio of the power reflected to the incident power, T_{FP} is the ratio of the transmitted power P_t to the incident power, and the round-trip propagation phase shift in the interferometer, is expressed as

$$\phi = \frac{4\pi n L}{\lambda}$$

Where 'n' is the refractive index of the region between the mirrors and λ the free space optical wavelength. [2]

Fiber Fabry–Perot interferometers are extremely sensitive to perturbations that affect the optical path length between the two mirrors. Various fiber Fabry-Perot Interferometer sensors are as shown in fig.3.

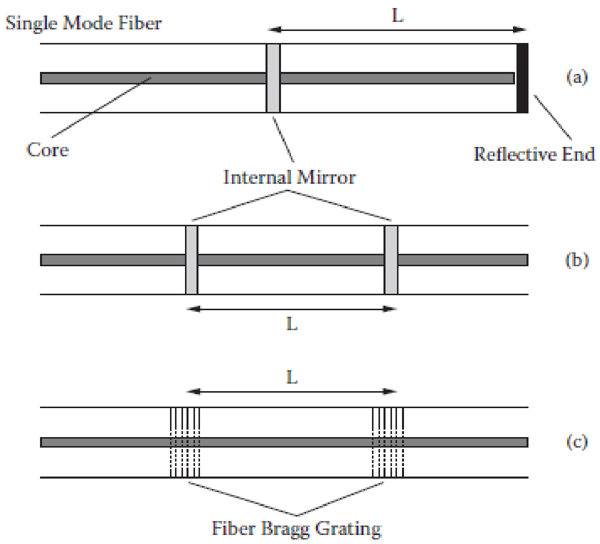

Fig.3: Intrinsic Fabry Perot Interferometer Sensors

In fig 3(a) a cleaved or polished end of the fiber forms one mirror and the second mirror is internal to the fiber. The intrinsic version most widely studied and used has two internal mirrors followed by a "nonreflecting" fiber end, as shown in fig. 3(b). Finally, the interferometer cavity can be formed by fiber Bragg reflectors, shown in fig.3(c).

External Fiber Perot Interferometer (as shown in fig.4) makes use of a diaphragm positioned near the cleaved or polished end of a fiber. The air-gap cavity is bounded by the reflecting surfaces of the diaphragm and the end of the fiber. After the fiber is positioned to achieve the desired cavity length, it is permanently bonded to the supporting structure. Such short cavity lengths make it possible to operate these sensors with multimode fiber and low-coherence LED light sources. Another configuration (fig. 4(b)) makes use of a film of a transparent solid material on the end of the fiber, such that the cavity is in the film, bounded by the fiber–film and film–air interfaces. Another EFPI configuration (fig.4(c)) makes use of an air-gap cavity formed between two cleaved or polished fiber surfaces, where the fibers are aligned end to end in a hollow tube. Finally, an EFPI termed the "in-line fiber etalon" (ILFE) (Figure (d)) makes use of an air-gap cavity in a section of hollow-core fiber spliced between two single-mode fibers.

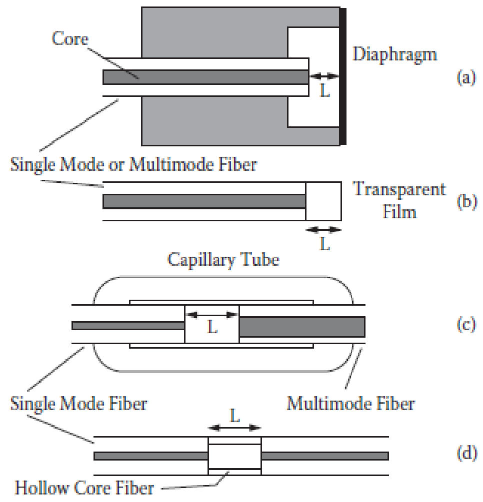

Fig. 4: Extrinsic Fabry Perot Interferometer Sensors

Applications

i) Temperature Measurement

The sensitivity of an interferometric fiber optic sensor to temperature is determined by the rate of change of optical path length nL with temperature. For an intrinsic sensor in a fused silica fiber, the optical path length change is dominated by the temperature coefficient of refractive index. An FFPI was used to measure temperature over the range from 20°C to 800°C.

ii) Strain Measurement

Surface-mounted transducers are generally used for monitoring parameters such as strain, temperature, and acoustic pressure in structural materials. Although embedding is the ultimate goal in some smart materials development efforts, externally mounted fiber sensors can also be very useful in this field. The surface-mounted sensor can be readily repositioned or replaced. Furthermore, surface-mounted sensors can be used with materials that must be processed at such high temperatures that embedding may be difficult or impossible. [3]

iii) Pressure Measurement

A diaphragm-based FFPI pressure sensor, in which the end of a fiber containing the FFPI is bonded to a thin (≈50 μm) stainless-steel diaphragm is also in use. The fiber is bonded under tension so that pressure-induced deflection of the diaphragm acts to reduce the strain on the FFPI, as shown in fig5. A sensitivity of 0.4 torr over the range 0 to 100 torr was reported.

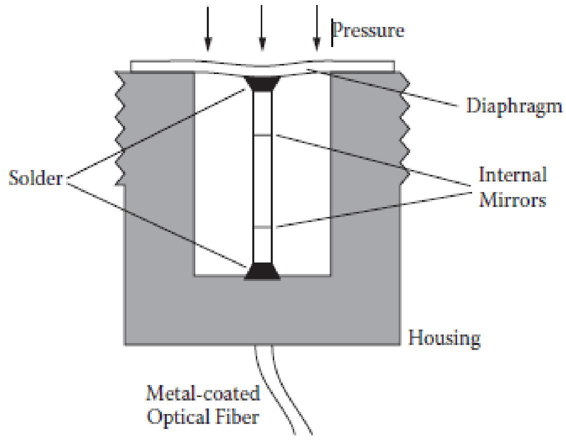

Fig.5: Diaphragm-mounted FFPI pressure sensor

II. Polarimetric Optical Fiber Sensor

Polarimetric sensors involve the use of optical retarders. Optical retarders are components made of birefringent materials. Here, light travelling through one of the principal axes of the retarder is delayed with respect to the light traveling in the orthogonal axis. After exiting from the retarder, there is a relative phase difference between two components from with respect to their initial phase.

The relative phase difference or retardance ΔΦ between the two constituent components' ordinary and extraordinary waves (or components along the fast and slow axes of birefringent material) is given by

$$\Delta\varphi = (2\pi/\lambda)\, d(|n_o - n_e|)$$

where d is the thickness of the material, λ is the wavelength of the propagating light, and n_o and n_e are the refractive indices of the ordinary and extraordinary wave components, respectively. The thickness of the birefringent material d is chosen so as to introduce the required relative phase difference between the two components.

A. Birefringent Optical Fiber

A range of optical fibers has been devised for measurement applications where it is essential to ensure that the polarization state of the propagating wave is preserved. Generally, these fibers offer the two distinct refractive indices. The two orthogonal principal axes of these birefringent fibers are described as the fast and slow axes, referring to the phase velocity of the light traveling within them. A beam guided in the axis with the higher index will have a lower velocity than a beam at the orthogonal axis. The birefringence of the fiber is calculated as the difference in the refractive index of the two optic axes as

$$B = n_s - n_f$$

where n_s and n_f are the indices of refraction of the slow axis and the fast axis, respectively. Birefringence is usually defined in terms of the fiber beat length, LB, The beat is defined as the length of fiber over which the difference in phase shift between the orthogonal polarizations amounts to 2π:

$$L_B = \lambda / B$$

B. High-Birefringence Fibers and Their Applications

There are two principal methods for introducing birefringence into optical fibers. The first of these relies on modifying the waveguiding characteristics of the core region by altering its geometry such that the circular symmetry is lost and two axes with different refractive indices are produced. These so-called geometrical birefringent fibers, have beat lengths in the order of a few millimeters. [4]

In an alternative design, linear birefringence can be introduced into the fiber by applying asymmetric stress to the core, which modifies the refractive index profile of the core. This is accomplished either by introducing highly doped regions around the core or by making the area surrounding the core noncircular. Birefringence is induced elasto-optically due to the different thermal expansion coefficients of the material surrounding the core combined with the asymmetric fiber cross-section.

C. Applications

i) Measurement of current

Polarization rotation property of optical fibers can be used to monitor the current variations in the electric supply industry and in the transmission networks. The optical current transducer (OCT) determines the current flow in an electrical conductor by measuring the magnetic flux density within the vicinity of the conductor. The magnetic flux density is determined by the polarization rotation induced as the light propagates through the optical fiber. This change in polarization state is a function of the magnetic flux density, the interaction length, and the Verdet constant of the material used to construct the device. The angular rotation θ (measured in degrees) experienced by the light passing through the sensor is described as

$$\theta = VBl$$

where B is the magnetic field strength (tesla), a function of the applied current and the geometry of the conductor and *l* is the length of the sensor exposed to the magnetic field. Similarly, voltages can also be measured using polarimetric measurement. [5]

II. Fiber Bragg Grating Sensor

The elementary fiber bragg grating comprises a short section of single-mode optical fiber in which the core refractive index is modulated periodically. The structure acts as a highly wavelength-selective reflection filter with the wavelength of the peak reflectivity, λ_B, determined by the phase matching condition:

$$\lambda_B = 2\eta_{eff} \Lambda$$

where η_{eff} is the effective refractive index of the guided mode in the fiber, and Λ is the period of the refractive index.

This periodical index-modulated structure enables the light to be coupled from the forward-propagating core mode into the backward-propagating core mode by generating a reflection response.

Applications

i) Strain and Temperature Sensing

The sensing function of an FBG derives from the sensitivity of both the refractive index and grating period to externally apply mechanical or thermal variations. The strain varies the response of an FBG by the compaction and expansion of grating pitch size and through the starin induced modifications of the refractive index so called strain-optic effect. The sensitivity of bragg grating sensor is due to the change in refractive index with measurand. [6]

ii) FBGs with Different Fiber Diameters

In this approach two fiber Bragg gratings are written on either side of a splice between two fibers with different diameters, as shown in fig.6. It is considered that the strain the fiber experiences can be related to the size of its cross-section. The fiber with a larger diameter experiences smaller strain than that with a smaller diameter. Therefore, in such a configuration, a change in temperature will shift the center wavelengths of the two gratings by similar amounts, maintaining their wavelength spacing, while a change in strain results in the center wavelengths moving by different amounts, changing the wavelength spacing.

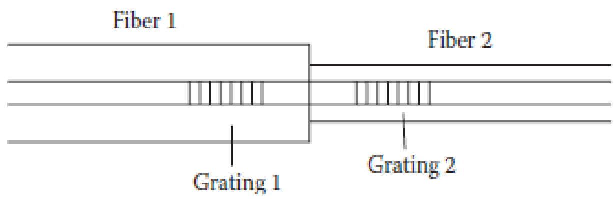

Fig.6: Two FBGs inscribed on the fibers with different diameters

III. Distributing Sensor

A distributed sensor describes a single sensor that has sensing capability at multiple locations.

Optical fiber distributed sensors consist of a single optical fiber sensitive over all its length. [7] A single distributed fiber optic sensor could therefore replace thousands of discrete sensors. The low fiber attenuation allows a monitoring over extremely long distances, which represent an impressive number of measuring points. Broadly, there are two types of distributed fiber optic sensors: intrinsic distributed fiber optic sensors and quasidistributed fiber optic sensors. For the intrinsic distributed fiber optic sensors, a single measurand can be monitored continuously over the path of the fiber. However, in some cases truly distributed sensing is difficult to realize, and so the quasidistributed fiber optic sensors are used. In this case, the measurand is not monitored continuously along the fiber path, but at a finite number of locations by multiplexing point fiber optic sensors. In particular, in many cases, quasi-distributed fiber optic sensors can be simply realized by integrating many point fiber optic sensors. Both intrinsic and quasi-distributed fiber optic sensors are based on monitoring the change of optical signals propagating along the fiber.

Conclusion

Fiber optic sensors are gaining popularity over conventional sensors due to higher sensitivity and trouble free operation along with high data carrying capacity. This paper presents the systematic preview of various optical sensors and their applications. It is anticipated that commercial deployment of fiber based sensors will result in precise observation in diverse engineering applications.

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