Chapter

Introductory Chapter: Application of Optical Fiber for Sensing

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1. Introduction

The history of the use of optical fiber for sensing applications began with two different, but interrelated, discoveries: laser light and optical fibers. The first laser was built in 1960 by T. H. Maiman at Hughes Research Laboratories, based on the theoretical work by C. H. Townes and A. L. Schawlow. A laser provides a source of an intense coherent light, highly collimated, and quasi-monochromatic; its potential for data transfer was immediately envisaged. Naturally, first experiments involved the transmission of the laser beam through the air. However, a communication channel cannot be practically sustained propagating freely through the air, owing to atmospheric attenuation and weather influence. Researchers also conducted experiments by transmitting the laser beam through glass fibers, which soon became the preferred medium for transmission of light. First, optical fibers were not practical to sustain a communication channel mainly due to the presence of impurities in the fiber material, resulting in very high transmission losses (>1000 dB/km), until Corning presented at the beginning of the 1970s optical fibers with (in comparison) very lower transmission losses, with only a few dB/km. Today, typical transmission losses are below 0.2 dB/km. This represents an extraordinary improvement as compared with electrical signal transmission through coaxial cables, not to mention the wider bandwidth available, which is several orders of magnitudes higher.

These developments paved the way to a plethora of different works on fiber optic sensing. But, what is an optical fiber sensor? **Figure 1** shows a block diagram of a typical optical fiber sensor. It is composed of a light source (which not only can be a laser, but also a broad band light source like a light emitting diode, etc.), the optical fiber itself transmits the light from the light source to the sensing area

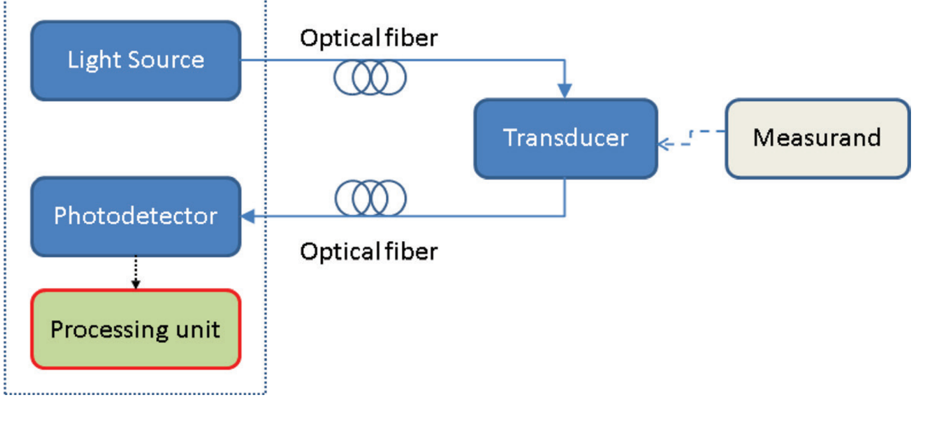

Figure 1.
General block diagram for an optical fiber sensor.

(forward optical fiber), the sensing element (which can be the same optical fiber, or another specially designed optical fiber, or not fiber at all, see below the differences between intrinsic and extrinsic optical fiber detectors), another optical fiber, which carry the light with the information of the measurand of interest (in some case, backward or return optical fiber; in this case, forward and backward fibers are the same fiber; it typically used some additional optical fiber element like an optical circulator), a photo-detector, which converts light in an electrical signal, and an end-processing device or processing unit (which converts this electric signal, eventually digitized in the measurand of interest; in a research laboratory environment, it would be an optical-spectrum analyzer, oscilloscope, etc.; and in a final user environment, the processing unit is simplified in order to provide more easy access to the measurand information, and of course, in order to reduce costs).

Compared with other types of sensors, fiber optic sensors exhibit a number of advantages, among them are the following:

- Possibility of use in high-voltage environments, since an optical fiber is made fundamentally of silica, which is an electrically insulating material.
- Possibility of use in explosive environments, since electricity is not present, there is no risk at all of electrical sparks.
- Optical fibers are chemically passive (the object to be measured can hardly be contaminated).
- Immunity to corrosion.
- Immunity to electromagnetic interference, no matter how much intense they were. Because an optical fiber is electrically nonconductive, it becomes impossible to act as an antenna.
- Very wide operating temperature range.
- Easy integration into a wide variety of structures, including composite materials, with little interference due to their small size and cylindrical geometry.
- Lightweight, which is fundamental in aero spatial applications.
- Robust and resistant to harsh environments.
- Material cost is relatively low, which in turn prevents theft (as compared with copper wires).
- Security of information passed down the cable.
- Highly sensitive sensing capabilities.
- Multiplexing capability to form sensing networks, multiple sensors in a single fiber can be simultaneously interrogated.
- Remote sensing capability.
- Multifunctional sensing capabilities such as strain, pressure, corrosion, temperature, and acoustic signals.

- No need for power amplifiers in a broad length range, since the attenuation losses can be very low, even over long distances.

Optical fiber sensor can be divided into intrinsic or extrinsic. In the first, intrinsic, the measurand of interest interacts itself with the optical fiber; that is, the optical fiber structure is modified under the influence of the measurand and the fiber itself plays an active role in the sensing function. As a consequence, there is some kind of modulation of light inside the fiber (this modulation can affect the intensity, wavelength, phase, or polarization), which carries the information of the performed measurement. Thus, by detecting these parameters and their changes, the external perturbations can be sensed. This is the reason why they are also called all-fiber sensors. A typical example of this kind of sensors is a fiber Bragg grating working as a strain sensor; under different strains, the Bragg reflection shifts to a different wavelength. On the other hand, in an extrinsic sensor, the measurand does not act on the fiber itself, it acts outside the fiber. In this case, the optical fiber merely acts as a transmission medium, and of course light collection. Some fiber optic Fabry-Perot interferometers are good examples of this kind.

The aforementioned division is not unique, and optical fiber sensors can be divided according to other characteristics. One especially useful is according to the point of measurement. Therefore, we can distinguish single-point sensing, quasi-distributed sensing, and continuous distributed sensing. In the former, there is one single point of measurement; for example, a LPG measuring the concentration of some organic compound at a specific place. On the contrary, in quasi-distributed sensing, there are integer numbers of point sensors along the optical fiber; for example, when several fiber Bragg gratings are employed as sensing elements distant some length between them (in this case, some kind of multiplexing is necessary). Finally, in continuous distributed sensing, there is

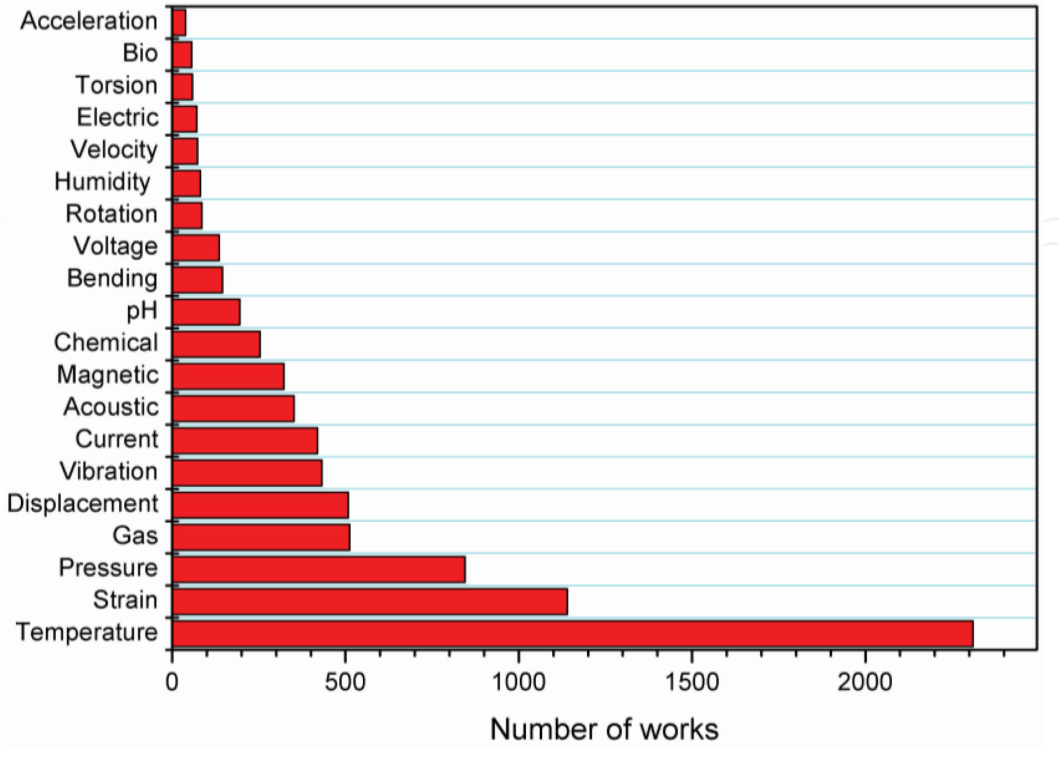

Figure 2.
Published works along all years distributed according to the nature of the measurands. Patents are not included. In those cases, where the work deals with more than one measurand; for example, temperature and strain, the work counts for both.

a continuous, real-time measurement along the entire length of an optical fiber cable; not only there are theoretically infinite numbers of measurement points, but also the optical fiber itself is the sensing element (as an example in Raman distributed optical sensing).

Optical fiber sensors have attracted the attention of several research groups around the world along all these years. **Figure 2** shows the result of a rapid search of those published works with the simultaneous presence in their titles of three words: fiber + sensor + measurand of interest (i.e., temperature, strain, pressure, gas concentration, etc.). Temperature and strain are the most frequent physical quantities measured through optical fiber sensors, which is not surprising at all, since first efforts were focused in this direction.

The optical fiber sensors in turn, can be constructively performed in several ways, either by using: short (Bragg) or long period gratings, interferometers (Fabry-Perot, Mach-Zehnder, etc.), by detecting different scattered light signals (Raman, Brillouin, and Rayleigh), photonic crystal fibers, surface plasmon resonance (SPR) etc. **Figure 3** shows the number of those published works with the simultaneous presence in their titles of three words: fiber + sensor + operation principle (i.e., Bragg grating, photonic crystal fiber, Fabry-Perot, etc.). It should not be surprising that the most used fiber optic sensor is the fiber Bragg grating, which is motivated firstly by its versatility.

To resume, the optical fiber sensing technology is today a successful and mature technology after a half-century of development [1–5], with a year-to-year increasing market participation. It is expected that in the near future arose new emerging applications offering new opportunities for research and exploitation.

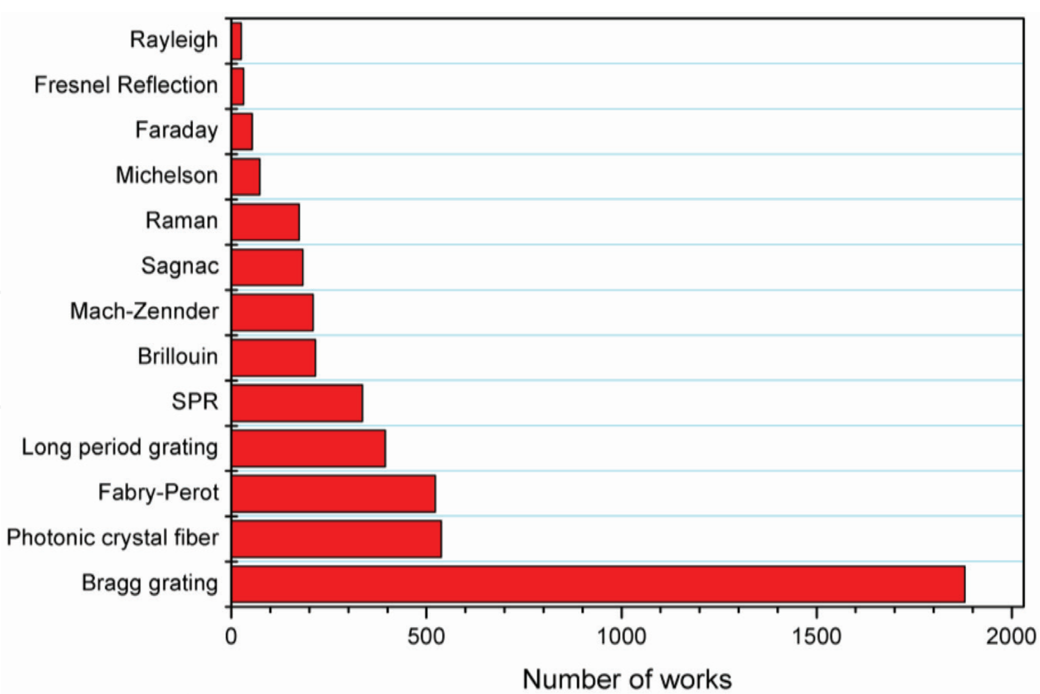

Figure 3.
Published works along all years distributed according to the operation principle. Patents are not included. In those cases, where the work deals with more than one operation principle (e.g., fiber Bragg grating and long-period grating), the work counts for both.

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