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Hybrid FBG–LPG sensor for surrounding refractive index and temperature simultaneous discrimination

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ABSTRACT

In this work, we propose a configuration of a hybrid fiber Bragg grating together with a long period grating sensor used for simultaneously detect surrounding refractive index and temperature to be applied in aqueous environment and to reveal pollution. We present the simulation of such sensor and analyze the reflected wavelength and amplitude variations of the fiber Bragg grating spectrum to obtain the temperature and the external refractive index variations, respectively. The results show that the fiber Bragg grating reflected amplitude change depends on the variation of the long period grating transmission spectrum with the surrounding refractive index modification and the reflected wavelength shift depends on the temperature of the aqueous solution.

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1. Introduction

Optical fiber sensors are found in a series of applications in civil, industrial and military fields [1]. There are several advantages to use optical fiber sensors [2]. Due to its low attenuation, the optical fiber is capable of transmitting information over long distances. That property provides the use of optical fiber sensors in remote sensing, where the sensor head can be located several kilometers away from the analysis unit and still offering reliability [3]. In addition, it is also possible to make a distributed measurement along the fiber, if the necessity relies on an extensive data acquisition. The information amount that can be transmitted in an optical fiber is much higher than the one from the electrical technologies, thus, several parameters of light, such as wavelength, intensity, polarization and phase can be used for a single measurement by increasing the sensitivity of the sensor [3]. On the other hand, multiplexing allows the use of a large number of sensors in the same fiber. In some cases, the number of fiber sensors used to support a structural monitoring system could be quite large, perhaps involving thousands of fiber Bragg grating sensors [4]. Compared to conventional sensors, optical fiber sensors have potentially greater sensitivity, dynamic range and resolution when detecting small parameter variations [5].

In conventional fiber Bragg gratings (FBGs), for refractive-index sensing, etching of the cladding is required for the evanescent field of the guided mode to be accessed [6]. This reduces the strength and durability of the sensor and makes it susceptible to damage under harsh environmental conditions. Long period grating (LPG) refractive index sensors retain their endurance, as the integrity of the fiber is not violated. Although long period gratings have larger temperature, strain and refractive index coefficients than fiber Bragg gratings, the former have a number of limitations. Long period gratings are highly bend sensitive, and strain and refractive index sensors can be expected to suffer from temperature cross sensitivities. Moreover, for a demodulation system that detects a wavelength shift that is a fixed fraction of the grating bandwidth, fiber Bragg gratings can present a higher sensitivity [7].

When pollution is concerned, simultaneous measurement of the temperature and the refractive index of the environment is a good way to predict any degradation. There are some works in the literature which show the possibility of measuring two different parameters simultaneously. In [8], Patrick et al. presented a hybrid configuration to discriminate simultaneously strain and temperature using a LPG along with two FBGs. The sensor [8] uses the difference in strain and temperature response of fiber Bragg gratings and a long period grating to discriminate between strain and temperature induced wavelength shifts. It is a simple and elegant configuration although it needs two FBGs to interrogate the LPG. Eggleton et al. [9] proposed, in the 1990s, a procedure to fabricate gratings with a periodically varying envelope to be used as sensors. The reflection spectrum of such superstructure gratings shows a series of regularly spaced peaks. The authors [9] demonstrated how a periodic superstructure can be fabricated in an optical fiber by translating an ultraviolet beam along a fiber and phase mask assembly while the intensity of the beam is modulated. Guan et al. [10] then used the superstructure fiber Bragg grating (SFBG) proposed by Eggleton et al. [9], to simultaneously discriminate

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strain and temperature. Since the SFBG is a special type of fiber Bragg grating fabricated using periodically modulated exposure over the length of a phase mask [9,10], it functions like a periodically modulated FBG and also like a long period grating. Guan [10] used this SFBG feature to measure strain and temperature, simultaneously. It is a straightforward way to simultaneously measure strain and temperature but it needs such a special device like the SFBG. In [11], Shu et al. reported a scheme for simultaneous measurement of temperature and refractive index using the same SFBG device. Since the SFBG possesses both fiber Bragg grating and long-period grating spectral responses the authors showed that the temperature effect was measured solely from the fiber Bragg grating response, whereas the refractive index information was extracted from the long period grating response. The authors [11] demonstrated the dependence on temperature of the refractive index of sucrose solution. The idea is a well-designed way to simultaneously measure temperature and refractive index. However, it uses a transmission configuration which complicates remote sensing.

In this work, it will be proposed and demonstrated by simulation a very simple configuration of a hybrid sensor which uses only one FBG together with a LPG to discriminate simultaneously surrounding refractive index (SRI) and temperature. The device is suggested to be applied to aqueous environment and to reveal pollution. It will be analyzed the amplitude change and the wavelength shift in the fiber Bragg grating reflected spectrum for the discrimination of the surrounding refractive index and the temperature of the solution, respectively. The results show that the fiber Bragg grating reflected amplitude variation depends on the long period grating transmission spectrum change with the surrounding refractive index variation and the reflected wavelength shift depends on the temperature of the aqueous solution. Since the proposed configuration is used in a reflection configuration, the hybrid sensor can also be used in a remote sensing arrangement which is a relevant aspect to be considered when pollution is taken into account.

In Section 2, the hybrid sensor principle of operation and description will be presented. The results will be analyzed and discussed in Section 3. This paper ends with the conclusion of the work in Section 4.

2. Hybrid FBG–LPG sensor principle of operation

Fiber Bragg gratings are based on counter-propagating mode coupling. In the case of a single-mode fiber, the core propagating mode is reflected into an identical core mode propagating in the opposite direction [3]. The FBG sensitivity is related to the changes in refractive index and/or in the period of the grating. Strain and temperature directly changes the fiber refractive index, causing a shift in the reflection peak and increasing the value of the resonance wavelength [4].

FBGs are sensitive to several physical parameters just as the silica matrix. It was conceived that the spectral properties of fiber Bragg gratings rest on some factors like temperature and mechanical stress. The temperature sensitivity of a FBG sensor occurs mainly through the effect of the induced refractive index change and, to a lesser extent, on the thermal expansion coefficient of the fiber [3].

The LPG promotes coupling between the core mode and the co-propagating cladding modes. The sensitivity of LPGs to environmental parameters is influenced by the period of the LPG, by the order of the cladding mode to which coupling takes place and by the composition of the optical fiber [12,13].

Any modulation of the core and cladding guiding properties modifies the spectral response of long period gratings, and this phenomenon can be utilized for sensing purposes. Since the cladding modes interact with the fiber jacket or any other material surrounding the cladding, changes in the properties of these materials can also be detected. The sensitivity of long period gratings to external perturbations is a function of the differential propagation constant between the guided and cladding modes [7].

In this work, a very simple hybrid configuration used to simultaneously measure the temperature and the refractive index of aqueous solutions in order to detect pollution is proposed and demonstrated by simulation. The suggested setup should consist of an ASE broadband source, an optical circulator, a LPG, a FBG and the OSA, as shown in Fig. 1. The LPG would be centered at 1563 nm in air and at room temperature. It should be placed into a recipient with the aqueous solution together with the FBG. The fiber Bragg grating, designed to be spectrally located on one edge of the LPG

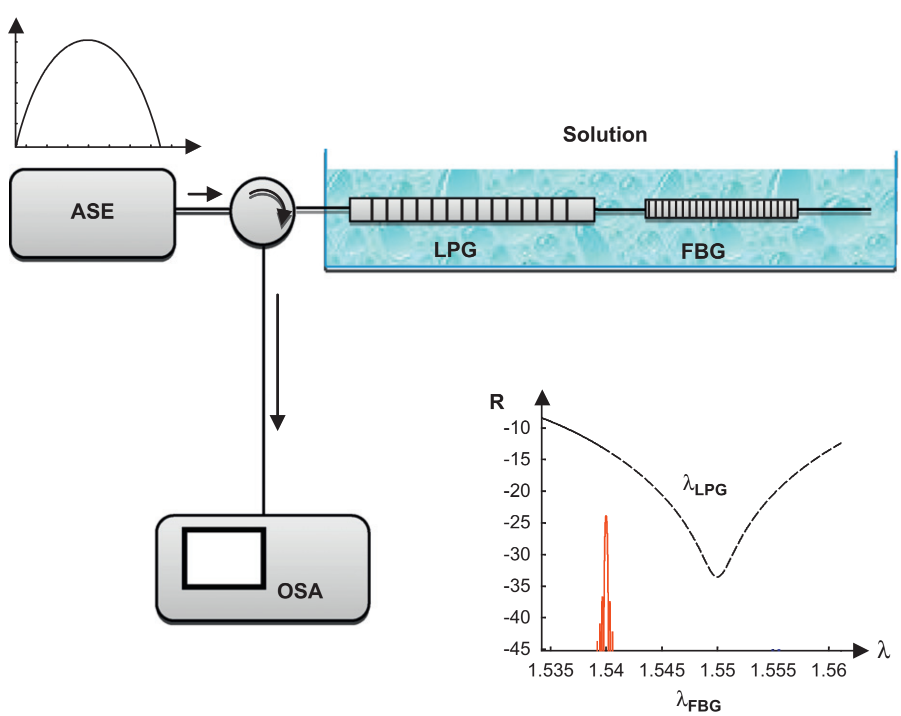

Fig. 1. Proposed and simulated experimental setup.

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