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Simultaneous measurement of strain and temperature based on a long-period grating with a polarization maintaining fiber in a loop mirror

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ABSTRACT

Simultaneous measurement of strain and temperature using a long-period grating (LPG) and a polarization maintaining fiber (PMF) in a fiber loop mirror (FLM) is presented. The sensing head is formed by an LPG. The transmitted optical intensity from the FLM is linear with the variation of the strain. And the interference resonant dip has a blue shift with the increasing of the temperature. Experimental results show that the proposed sensor has the sensitivities of 0.0346 nm/°C and 1.82×10^{-3} dB/με within the strain range of 0–1300 με, respectively.

1. Introduction

Long-period fiber grating (LPG) has received considerable attentions in various fiber-optic sensor applications for the advantages of low back-reflection, high sensitivity and possibility of mass production. The resonance wavelengths of the attenuation bands have been shown to be sensitive to the local environment. Therefore, LPGs have been proposed as sensors for strain, temperature, bend curvature, and the refractive index of the surrounding material [1,2]. However, the cross-sensitivity of strain and temperature is still a problem and need to be solved [2].

Fiber loop mirror (FLM) acts like a multi-centre band-pass filter, and the characteristic of the filter is similar to an unbalanced Mach–Zehnder [3]. And it has been demonstrated for numerous applications on temperature [4], strain [5–7], pressure, liquid level, curvature [8], and refractive index [9], and multi-parameters [10–13] detections. However, most of these FLM sensors are based on the monitoring of the resonant wavelength variations. Therefore, an expensive optical spectrum analyzer (OSA) is needed.

In this paper, a strain and temperature measurement without cross-sensitivity by using a polarization maintaining fiber in a fiber loop mirror (PMF-FLM) concatenated with an LPG was presented. A band-pass filter was used as a demodulator. And the LPG was used as the sensor head for the strain measurement.

2. Experiment

The schematic diagram of the proposed sensor for temperature and strain measurement is shown in Fig. 1. The LPG is attached to a micrometric translation stage for strain measurement. The FLM configuration consists of a 3-dB (2×2) optical coupler with low insertion loss, an LPG and a section of PMF with a length of 24.3 cm. The birefringence index of PMF is 7.7024×10^{-6}. A broad band source (BBS) with a wavelength ranging from 1450 to 1650 nm is used as the light source. An optical power meter (OPM) is used to monitor the output light intensity of the sensor. An OSA (YOKOGAWA735301) with a spectral resolution of 0.02 nm is used for monitoring the interference spectra of the FLM. A polarization controller (PC) is used to adjust the polarization states of the input lights in order to obtain a high fringe visibility.

LPG couples light from the fundamental guided mode into forward-propagating cladding modes, where the cladding modes are quickly attenuated due to absorption and scattering. The coupling from the guide mode to cladding modes is wavelength dependent. The effective indices of the guided mode and the cladding modes as well as the grating period determine the cladding modes to which can be coupled. This results in a series of loss bands in the interference spectrum corresponding to resonances with various cladding modes [2]. In experiment, the period and length of the LPG are 561 μm and 22.44 mm, respectively. And as shown in Fig. 2a, the resonance wavelength of the LPG is 1579.2 nm.

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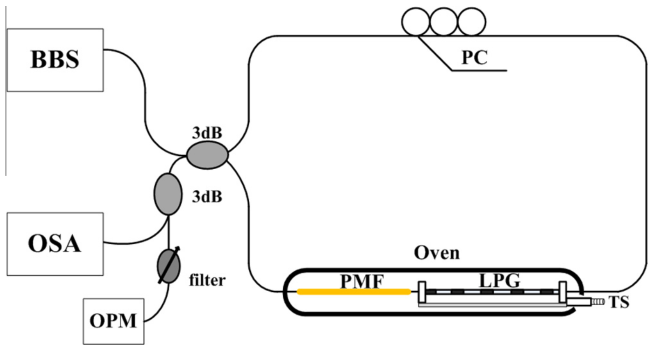

Fig. 1. Experimental setup of the sensor.

As a broadband light transmits through this system, it is equally split into two counter-propagating light by the 3-dB coupler. Subsequently, they recombine at the coupler after clockwise and anticlockwise light beams propagating around the loop. The counter-propagating light beams introduce a relative phase difference due to the birefringence property of the inserted PMF. Therefore, the interference patterns appeared as shown in Fig. 2b.

The transmission optical intensity I_t in terms of the phase difference can be described as,

$$I_t = [1 - \cos\phi]/2 \tag{1}$$

with

$$\phi = 2\pi LB/\lambda \tag{2}$$

where ϕ is the phase difference. λ is the center wavelength of the light source. L is the length of the PMF. $B = n_s - n_f$ is the modal birefringence index of the PMF. n_s and n_f are the effective refractive indices on the slow and fast axis of the PMF, respectively. The resonant wavelength satisfies the expression of $\phi = 2k\pi$, where k is a random integer.

Therefore, the resonant wavelength can be described as

$$\lambda = BL/k \tag{3}$$

The wavelength spacing S between the adjacent interference fringes can be expressed as,

$$S = \lambda^2/BL \tag{4}$$

In our design, the S has the value of 12.8 nm.

The periodic interference spectrum of FLM is modulated by the transmission spectrum of LPG. As shown in Fig. 3, the interference patterns of FLM have a large attenuation around 1580 nm resulting from the resonant dip of the LPG.

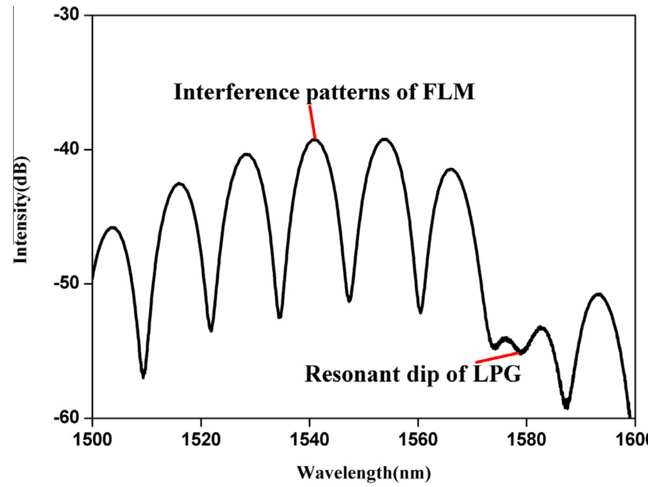

Fig. 3. Interference patterns of FLM and LPG.

3. Results and discussions

The LPG is used as the sensing head for strain measurement, and the PMF-FLM is used for temperature sensing. The LPG is attached to a micrometric translation stage with a resolution of 1 μm. The LPG and PMF are placed into a tubular oven. The temperature of the oven is set to increase from 20 °C to 90 °C with a step of 10 °C.

In strain measurement experiment, one end of the LPG is fixed, and the other end of the LPG is stretched by a translation stage. Fig. 4 shows the interference spectra response to the strain variation. It can be seen that the intensity of the resonant dip of the LPG increased with the increasing of the strain, and it almost has no wavelength shifting for the resonant dip. The patterns of the FLM are relatively stable. The partial enlarged drawing of spectra variation of the LPG is shown in the inset.

The intensity of interference wavelength of 1582.4 nm is chosen to measure the strain variation. The band-pass filter is used to ensure that the intensity of a narrow band around 1582.4 nm is detected by the OPM. Fig. 5 shows the linear relationship between the intensity and strain variation. The sensitivity of 1.82×10^{-3} dB/με and a linear fit with a high value of 0.9983 are obtained, respectively.

Fig. 6 shows the wavelength shifts of the PMF-FLM and LPG response to temperature increasing. The measured shifting dip wavelength in interference spectrum is 1579 nm. It can be seen that the interference spectrum has a blue shift with the increasing of the temperature, which is different with that of Frazão [10,14].

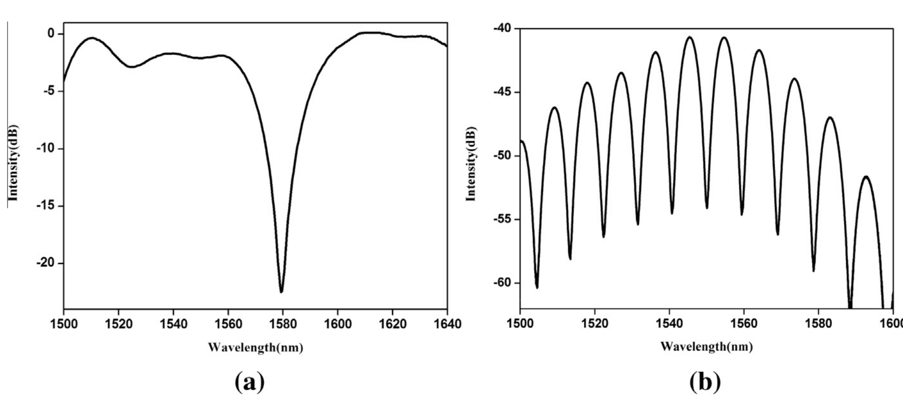

Fig. 2. (a) The transmission spectrum of the LPG. (b) The interference spectrum of the FLM.