Simultaneous and quasi-independent strain and temperature sensor based on microstructured optical fiber

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ABSTRACT

In this paper, a new sensor system for simultaneous and quasi-independent strain and temperature measurements is presented. The interrogation of the sensing head has been carried out by monitoring the FFT phase variations of two of the microstructured optical fiber (MOF) cavity interference frequencies. This method is independent of the signal amplitude and also avoids the need to track the wavelength evolution in the spectrum, which can be a handicap when there are multiple interference frequency components with different sensitivities. The sensor is operated within a range of temperature of 30ºC-75ºC, and 380με of maximum strain were applied; being the sensitivities achieved of 127.5pm/ºC and -19.1pm/με respectively. Because the system uses an optical interrogator as unique active element, the system presents a cost-effective feature.

Keywords: microstructured optical fiber, fiber sensor, temperature sensing, strain sensing, simultaneous sensing.

1. INTRODUCTION

Sensors based in optical fibers have proven to be very useful measuring different parameters such as strain, temperature, curvature, displacement, pressure, refractive index, electric field and gases, among others. Since the first experiments with microstructured optical fibers (MOFs), they have shown some improved characteristics over conventional optical fibers, which offer a great potential for sensing applications [1]. Different geometries have been proposed for this kind of special fibers. Among them, suspended-core MOFs present relatively large air holes surrounding a small core (typically few µm in diameter) resembling to be suspended along the fiber length maintained by small width silica bridges. Different pure silica suspended-core fibers have been applied for instance in temperature [2], curvature [3], and gas sensing [4].

Moreover, there are PCF sensors for simultaneous strain and temperature measurements based on the wavelength tracking of different sensing cavities with different sensitivities: a multimodal PCF interferometer with a fiber Bragg grating (FBG) [5], with resolutions of 0.27ºC and 9.1με , or another PCF in combination with a long period grating (LPG) [6], with resolutions of 1.5ºC and 5.2με. Other sensors were based on the detection of different interference patterns in a single sensing structure, which had different sensitivities to strain and temperature. In [7] a new design based on clover geometry PCF in a Sagnac configuration was used showing resolutions of 2ºC and 11με. Also in [8] a Hi-Bi PCF was used, in a Sagnac configuration too, achieving resolutions of 1.5ºC and 4.7με.

In this work a simultaneous strain and temperature sensor based on a microstructured suspended core fiber is characterized. The sensor comprises a suspended core PCF with its end cleaved spliced to a single mode fiber (SMF) and is based on the combination of a multimodal and a birefringent interferences with different fringe patterns. Resolutions of 0.039ºC and 0.262με were achieved.

2. EXPERIMENTAL SETUP AND OPERATING PRINCIPLE

The sensing head was fabricated by splicing a commercial SMF to 23cm of a four-bridge MOF with its end cleaved. The fiber is composed by four big air holes divided by four thin silica bridges, approximately 900 nm thick, and presents a non-circular core of 3.2µm by 1.07µm, exhibiting a double Y shape. This specific shape provides unprecedented

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possibilities for interferometric sensing. The cross-section of the four-bridge MOF and its core details are presented in Figure 1.

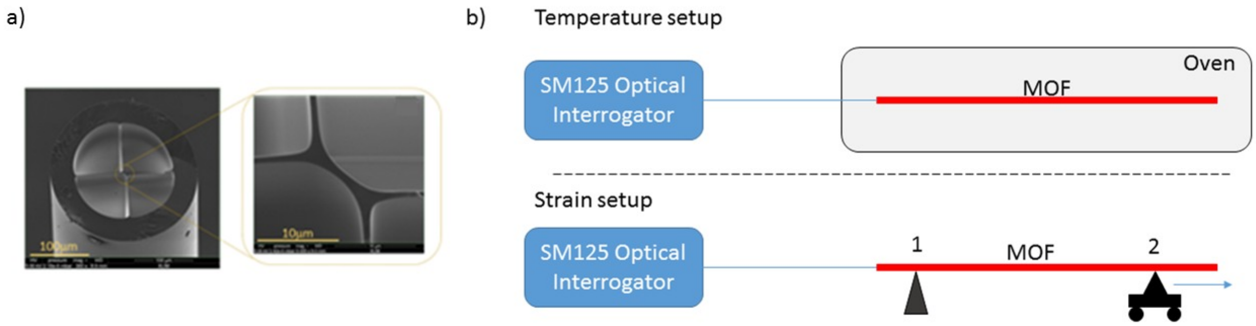

Figure 1: a) Cross-section of the four-bridge MOF and close-up on the double Y shape core and b) schematic representations of the two experimental set-ups used here.

Figure 1.b shows the two different experimental set-ups used to characterize the four-bridge MOF Fabry-Perot interferometer. In the first set-up (top of the Figure 1.b), the sensing head was inserted into an oven where temperature changes going from 30ºC to 75ºC by steps of 5ºC were applied. Figure 1.b (bottom) shows the strain testing set-up. In this set-up, point 1 of the fiber was fixed, and a maximum longitudinal strain of 380με was applied to point 2, having the length of the MOF fiber equal to 14.5cm.

A commercial interrogator of optical fiber sensors (Smartec SM125) was used to illuminate the network and also to analyze the spectra signal guided through the MOF sensor. It should be noticed that this equipment was originally commercialized for FBG sensors´ monitoring and allows to interrogate sensors with a scan frequency of 1Hz [9] and a 5pm resolution. The FFT is computed in MATLAB also every second, providing real-time information of the sensor system.

3. EXPERIMENTAL RESULTS

Typical interferometric sensors are based on tracking the spectrum displacement with the measured parameter. However, the presence of many interference frequencies and their different sensitivities is a challenge for this kind of sensing systems. Alternatively, by monitoring the FFT phase change of each interference, more stable and accurate measurements can be carried out.

The MOF sensor is based on the combination of two interferences. Due to the multimodal and birefringent behaviors of the fiber, multiple interference combinations are present in the sensors' transfer function, as it is shown in Figure 2 a). Each interference leads to a sinusoidal contribution. In this manner, the FFT module spectrum of the transfer function is represented in the spatial frequency domain by a combination of peaks where each one represents a frequency contribution. When a phase change occurs to a spatial frequency component, it will be reflected as a change in the FFT phase spectrum at that component´s spatial frequency.

Figure 2 b) shows the FFT module of the sensors' transfer function. It can be easily noticed the presence of multiple spatial frequency interference contributions. Those who present the best sensing features are component f_1 and component f_2 located at $0.476nm^{-1}$ and $0.574nm^{-1}$ respectively. Other strong components, such as the one located at $0.687nm^{-1}$ ($2*f_2-f_1$), are intermodulation products of the main spatial frequency components.

The spatial frequency peak located at $0.149nm^{-1}$ is produced by the cavity formed between the MOF fiber interfaces: SMF-MOF and MOF (cleaved)-air.

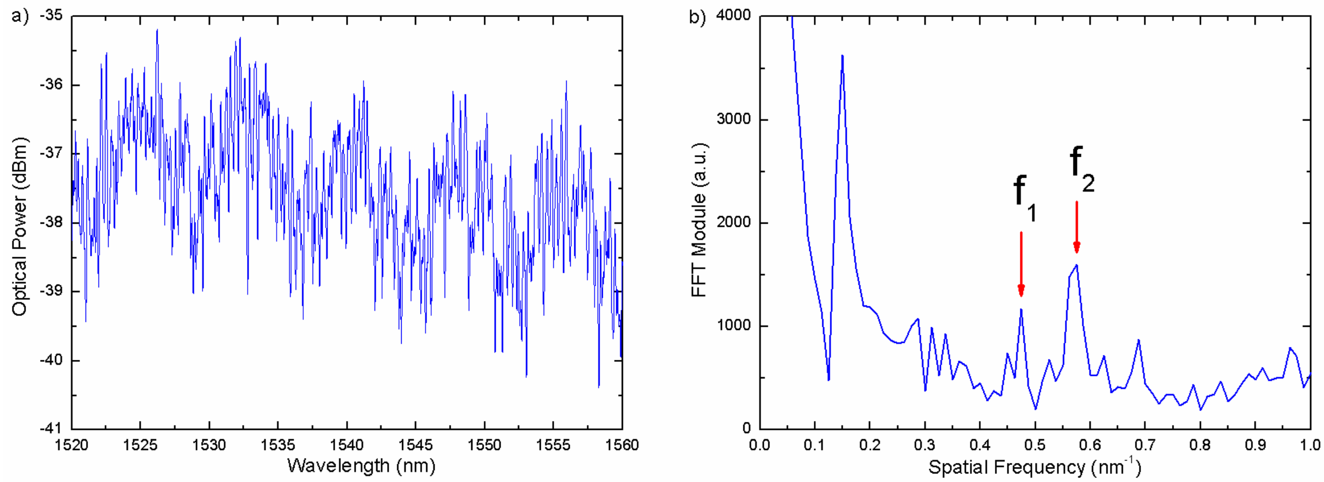

Figure 2. (a) Optical transmission spectra of the sensor at 25ºC and 20% humidity, and (b) its fast Fourier transform.

In order to verify the operation of the sensing head, the strain and temperature performances of the MOF sensing head were experimentally carried out.

On the one hand, the temperature characterization was carried out by using an oven in the temperature range going from 30ºC to 75ºC with 5ºC per step. On the other hand, strain characterization was performed using two translation stages, one remaining fixed (point 1 in Figure 1.b) while the other moves applying strain to the fiber (point 2 in Figure 1.b). Both spatial frequencies f_1 and f_2 were simultaneously monitored to ensure the independence of the both measurements.

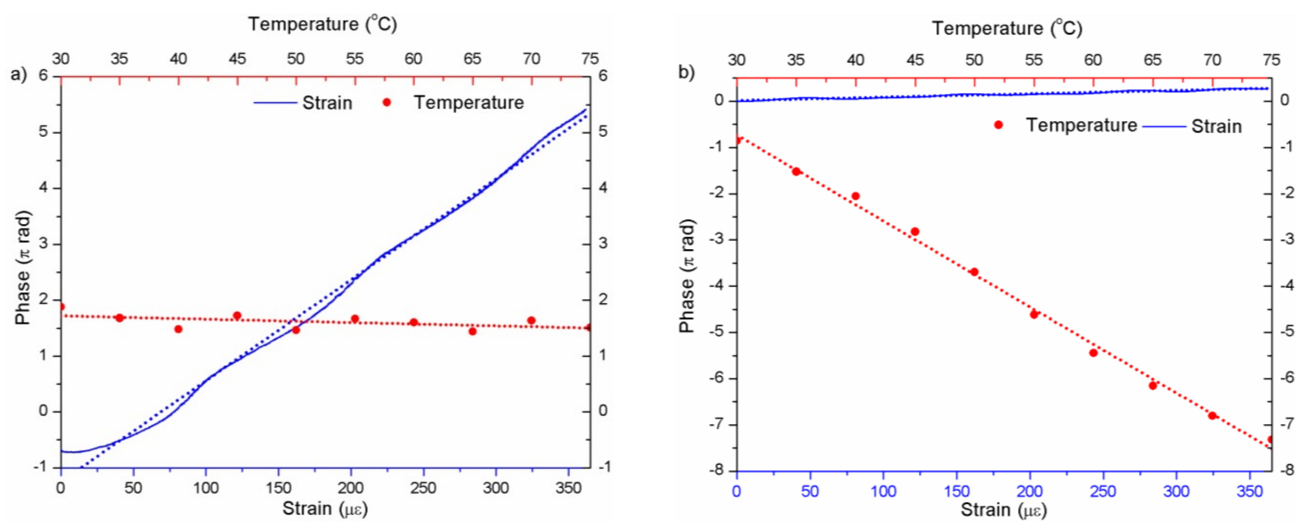

Figure 3. Performance of the spatial frequencies versus temperature and strain variations: a) component f_1 and b) component f_2.

Figure 3 a) illustrates the response of the FFT phase at the spatial frequency f_1 to strain and temperature variations. As it can be noticed the phase presents linear response to strain variations (due to the lack of tightness in the fiber during the strain measurements in the range located from 0 to 50με, the measured results show a slight deviation from the linear fit) and almost non sensitivity to temperature variations. This is due to the multimodal character of the interference related to the f_1 spatial frequency, showing sensitivities to strain and temperature of 0.018π rad/με and -0.00058π rad/ºC respectively and resolution of 0.262με. Overhanging these results to the optical domain (spatial frequency f_1 gives an optical interference spectrum pattern of 2.1nm) sensitivities to strain and temperature are -19.1pm/με and 0.615pm/ºC respectively.

Figure 3 b) describing the component f_2 shows similar results. As for f_1, it presents a linear response to temperature variations and very low sensitivity to strain variations, because of the birefringence of the MOF fiber. Sensitivities to strain and temperature are respectively of 0.00087π rad/με and -0.15π rad/ºC and resolution of 0.039ºC. Overhanging the results to the optical domain (spatial frequency f_2 gives an optical interference spectrum pattern of 1.7nm) sensitivities to strain and temperature are -0.74pm/με and 127.5pm/ºC respectively.

As a direct conclusion of the results, component f_1 can be used for temperature-quasi-independent strain measurements and f_2 for strain-quasi-independent temperature measurements.

4. CONCLUSION

To summarize, a new sensor system for simultaneous and quasi-independent strain and temperature measurements has been proposed and experimentally demonstrated. The sensing head is based on a microstructured optical fiber used to create a cavity in reflection configuration. The interrogation of the sensing head has been carried out by monitoring the FFT phase variations of two of the MOF cavity interference frequencies. This method is independent from the signal amplitude and also avoids the need to track the wavelength evolution of the spectrum, which can be a handicap when there are multiple interference frequency components with different sensitivities. The sensor presents linear response to strain and temperature variations with sensitivities of -19.1pm/με and 127.5pm/ºC and resolutions of 0.262με and 0.039ºC respectively with very low crosstalk (3.87% for strain measurements and 0.48% for temperature measurements).

5. ACKNOWLEDGMENTS

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