SnO_2-MOF-Fabry-Pérot humidity optical sensor system based on Fast Fourier Transform technique

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ABSTRACT

In this paper, a new sensor system for relative humidity measurements based on a SnO_2 sputtering deposition on a microstructured optical fiber (MOF) low-finesse Fabry-Pérot (FP) sensing head is presented and characterized. The interrogation of the sensing head is carried out by monitoring the Fast Fourier Transform phase variations of the FP interference frequency. This method is low-sensitive to signal amplitude variations and also avoids the necessity of tracking the evolution of peaks and valleys in the spectrum. The sensor is operated within a wide humidity range (20%–90% relative humidity) with a maximum sensitivity achieved of 0.14rad/%. The measurement method uses a commercial optical interrogator as the only active element, this compact solution allows real time analysis of the data.

Keywords: Photonic crystal fiber, microstructured optical fiber, fiber sensor, humidity sensing, Fast Fourier Transform.

1. INTRODUCTION

Optical fiber based sensors have shown relevant capabilities to measure different parameters such as temperature, curvature, displacement, pressure, refractive index, electric field, relative humidity and gases, among others. Since the first experiments with microstructured optical fibers (MOFs), they have shown improved characteristics over conventional optical fibers and great potential for sensing applications [1]. Several geometries have been proposed for this kind of fibers. Among them, suspended-core MOFs present relatively large air holes surrounding a small core (typically few μm of diameter) that seems to be suspended along the fiber length and maintained by small width silica bridges. Different pure silica suspended-core fibers have been applied for instance in temperature and curvature sensing [2] and in gas sensing [3].

Fiber based optical Fabry-Pérot (FP) interferometers are a quite popular sensor configuration due to their compactness, simple configuration, flexibility in tuning sensitivity and dynamic range. A fiber based FP sensor is most of the times fabricated by splicing a section of a waveguide, which acts as the cavity, to a standard optical fiber, providing the potential for low insertion-loss and multiplexing capability. The FP cavity output signal presents an interference pattern that is a function of the length and of the refractive index of the cavity, or more precisely, the effective indices of the different modes supported by the fiber sample. FP cavities composed by MOFs are an even more common structure: a hybrid structure that used a MOF as the guiding fiber and cascade it with a hollow-core fiber and a single mode fiber (SMF), for high-temperature sensing, was demonstrated [4]. Other fiber based sensors were accomplished by fusing a small length of PCF to the end of a cleaved SMF for relative humidity ranged 40%-95% RH [5] or by chemical deposition of PSP and PAH [6].

Among optical fiber sensors, those based on nanocoatings have recently experienced a remarkable development [7]. Furthermore, new techniques in chemical deposition, such as sputtering [8], allow the morphology of the deposited coatings to be controlled with high accuracy, and as a consequence, the final features (sensitivity, kinetics) of the sensor.

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In this paper, a SnO_2 hybrid-Fabry-Pérot interferometer based on a novel four-bridge dual highly coupled cores microstructured optical fiber is presented and characterized. By monitoring the Fast Fourier Transform (FFT) phase variations of the FP interference frequency, an experimental study of this cavity's response with relative humidity changes is presented. This measuring method is independent of the signal amplitude and avoids the necessity of tracking the wavelength evolution in the spectrum, which simplifies the measurements.

2. EXPERIMENTAL SET-UP AND OPERATION PRINCIPLE

The Fabry-Pérot interferometer was fabricated by splicing a single mode fiber to ~1mm of a novel four-bridge MOF, with its end cleaved, as shown in Figure 1 a. The fiber is composed by four big air holes divided by four thin silica bridges, approximately 900 nm thick, and presents an elongated core of 3.2µm by 1.07µm, exhibiting a double Y shape. This specific core shape can be seen as two coupled single mode guiding cores [9]. This specific shape provides unprecedented possibilities for interferometric sensing. The cross-section of the four-bridge MOF and its core details are presented in Figure 1 b and 1 c, respectively.

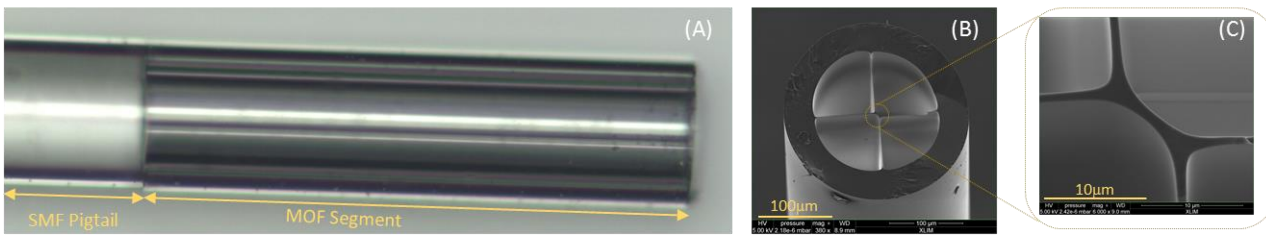

Figure 1. (a) MOF based Fabry-Perot interferometer, (b) its cross-section and (c) the four-bridge MOF core detail.

Figure 2 presents the experimental set-up used to characterize the four-bridge MOF Fabry-Pérot based sensing head and the SnO_2-FP final sensor. A commercial interrogating sensor device (Smartec SM125) was used to illuminate the network and also to analyze the spectra of the signal guided through the sensor. It should be noticed that this equipment was originally commercialized for FBG sensors´ monitoring and allows sensors to be interrogated in real time (sampling frequency of 1Hz) [10]. The SM125 is remotely controlled through a MATLAB software that also executes the FFT real time analysis. The sensing head was inserted into a climatic chamber where humidity ranges from 20% to 90% were applied at a constant temperature of 25ºC to evaluate its response to this magnitude.

Due to the use of the FFT phase as the sensing parameter, power constraints are not as limiting as in other techniques, allowing more sensors to be multiplexed.

Figure 2. Experimental setup of the proposed system.

The MOF-FP optical fiber core was used as the substrate in a DC-Sputter deposition process (Pulsed DC Sputtering System, Nadetech Innovations) with a partial pressure of argon of 6.75×10^{-2} mbar, intensity of 140 mA and voltage of 190 V. The SnO_2 target 99.99% of purity was purchased from ZhongNuo Advanced Material Technology Co. The resulting sensing layer is uniform along the crossection of the interferometer and its is thickness arround 3 µm.

SnO_2 coating is highly sensitive to changes in the refractive index of the surrounding enviroment [11], which in this case are produced by realitive humidity variations. In this manner, the refractive index of the second mirror of the interferometer varies depending on the relative humidity, and so, the intermerometric signal. Moreover, there is a section of the core laterial surface that is also deposited with SnO2, so that there is also an interaction there with the evanescent field component.

3. EXPERIMENTAL RESULTS

The output signal of the Fabry-Pérot interferometer can be seen in Figure 3. It presents an interferometric fringe pattern with a wavelength spacing of 1.6 nm (Figure 3.A). Figure 3 b) shows the FFT of the FP spectra. As a result of the periodicity of the spectra, the FFT presents a narrow set of frequencies that characterize completely the sensing head, with its main component located at 0.8375nm^{-1}. To measure the changes induced by the humidity changes, the phase variations of this frequency component were studied. This behavior in addition to the FFT analysis allows a number of different sensors to be multiplexed and simultaneously interrogated of just by setting correctly its spatial frequency, which is a result of the wavelength spacing and so of the length of the fused MOF section.

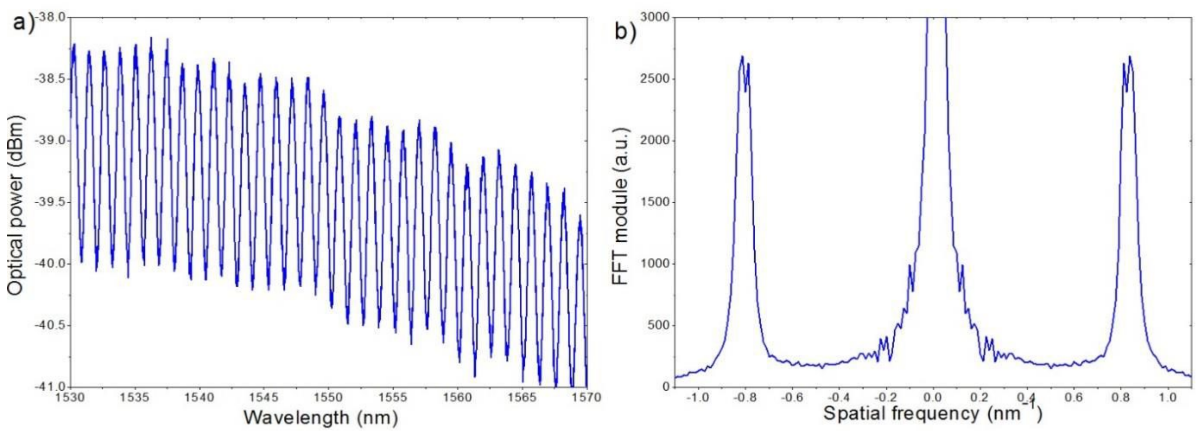

Figure 3. (a) Measured optical spectrum of the sensor before deposition at 25ºC and 40% humidity (room conditions) and (b) its Fast Fourier Transform.

In order to verify the proper operation of the SnO_2-FP sensing head, the humidity-sensing performance of the sensor with different RHs, when the temperature was set at 25ºC, was experimentally carried out. Figure 4 a) illustrates the FP performance without any chemical deposition. It can be seen that there is an unclear tendency to follow the climatic chamber variations in humidity: sensitivity is very low and the signal is too much noisy. Therefore, the interferometer is inoperative with no deposition.

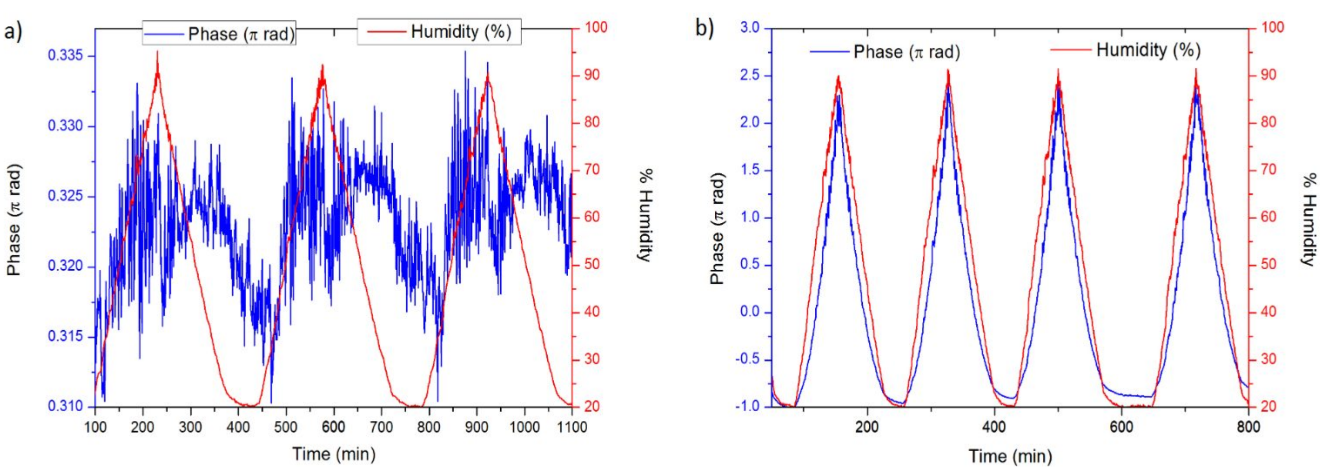

Figure 4. Sensor response to humidity: a) before deposition, and b) after SnO_2 deposition.

The sensor performance after the chemical deposition is shown in Figure 4 b). SnO_2 chemical deposition enhances its sensitivity and improves de Signal to Noise rate. Typically, the sensitivity of humidity sensors is different depending on the humidity range [5], but in our case, the sensor response shows a linear behavior in the measured humidity range (20%-90%) with a sensitivity of 0.14π rad/% RH. Two of the main characteristics of this sensing head are its speed reaction to humidity changes and its reversibility, allowing the sensor to work continuously without its replacement after saturation. Finally, in order to probe the stability of the system, the phase variations during 200 minutes for a 40% RH and 25ºC, have been tested showing an instability of around 0.007π rad.

4. CONCLUSIONS

To summarize, a new sensor system for relative humidity measurements based on its interaction with a SnO_2 chemical deposition on a MOF-Fabry-Pérot cavity has been proposed and experimentally demonstrated. The interrogation of the sensing head has been carried out by monitoring the FFT phase variations of one of the FP interference frequencies. This method is low-dependent of the signal amplitude and also avoids the necessity of tracking the wavelength evolution of maxima or minima of the spectrum, which can be a handicap when noise is present; and allows to multiplex several sensors. The sensor has been operated within a wide humidity range (20%–90% RH) with a maximum sensitivity achieved of 0.14rad/% RH and a phase standard deviation of 0.0043π rad. It presents linear and constant response along the entire RH range. The SnO_2 MOF-FP sensor presents high-speed response, reversibility, high repeatability rate, robust and compact features.

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