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Simultaneous measurement of humidity and temperature based on a partially coated optical fiber long period grating

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ABSTRACT

A humidity and temperature optical fiber sensor based on a long-period grating (LPG), which can provide simultaneous response to both magnitudes, is proposed and demonstrated via experiments. Previously, the LPG was fully coated with humidity sensitive nanostructured polymeric thin films by the Layer-by-Layer (LbL) nano assembly technique. Hence the surrounding refractive index was changed, so provoking wavelength shifts of the attenuation bands of the transmission spectrum. This fully coated LPG was exposed to relative humidity (RH) and temperature tests, varying from 20% to 80% RH and from 25 to 85 °C, respectively. Then, half of the LPG coating was chemically removed and this results in the splitting of the main attenuation band into two different contributions. When this semi-coated LPG was also exposed to RH and temperature tests, the new two attenuation bands presented different behaviors for humidity and temperature. This novel dual-wavelength based sensing method enables the simultaneous measurement of RH and temperature using only one LPG.

1. Introduction

Relative humidity (RH) and temperature are two of the most important magnitudes which must be monitored and controlled in industry, food quality, human comfort or health applications among other fields. A great variety of devices have been developed for this purpose using diverse methods [1]. Sometimes these sensors have to work in harsh environments and are affected by corrosive agents or the presence of electromagnetic interferences (EMI). To overcome these problems, optical fiber sensors are attractive due to their specific advantages such as long lifetime, corrosion free, light weight, EMI immunity, or remote sensing [2–4].

Recently, optical fiber gratings are having an important growth due to their unique sensing properties [5]. More specifically, in long-period gratings (LPGs), where the grating period written on a single-mode fiber is generally in the range of 100 μm to 1 mm, there is a coupling of light between the guided core mode and various co-propagating cladding modes. This coupling produces a series of attenuation bands in the optical fiber transmission spectrum, each one centered at a different resonant wavelength (see Fig. 1). These resonant wavelengths depend mainly on the effective index of the coupled modes and the grating pitch [6,7]. Although LPGs were initially developed as rejection-band filters [8], they also present interesting characteristics for sensing. The central wavelength of each LPG resonance depends critically on the refractive index difference between the core and the cladding, and hence any variation caused by strain, temperature, or even changes in the external refractive index may cause large wavelength shifts in the resonances [5,6,9].

In the last decades, new deposition techniques such as Layer-by-Layer (LbL) nano assembly [10], sol–gel [11], sputtering [12], or electrospinning [13] have enabled the fabrication of thin films and nanostructured sensitive coatings onto optical fiber structures. Diverse optical fiber sensors based on LPGs have been recently developed to monitor different physical and chemical magnitudes as humidity [14,15], temperature [16], pH [17], hydrogen [18,19], ethanol [20], ammonia [21], volatile organic compounds [22] and proteins [23], among others [24].

Different approaches have successfully designed sensors for two or more magnitudes thanks to the use of more than one grating along the optical fiber, as the work presented by Viegas et al. [25], where RH and temperature were simultaneously measured by the

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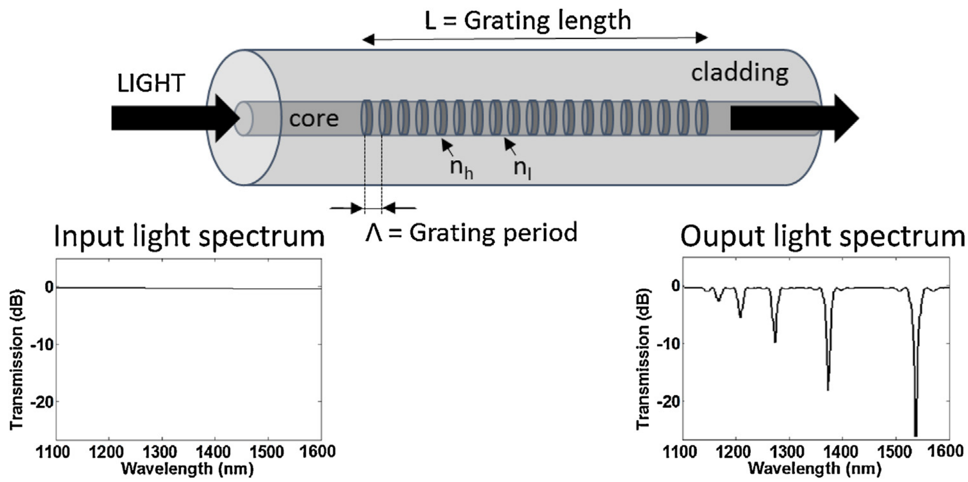

Fig. 1. Scheme of a LPG, indicating their parameters, and its characteristic spectrum when the light goes through the grating.

combination of an LPG and a fiber Bragg grating. In some reports, Mach–Zehnder interferometers based on two LPGs are able to sense temperature, external refractive index, and ammonia concentrations [26] at the same time. In other approach, one grating was combined with a Fabry–Perot interferometer [27] to sense also RH and temperature simultaneously.

Other authors have studied how some modifications in LPGs overlays can generate and tune the loss fringes in the output light spectrum [28]. Moreover, a theoretical study [29] has recently proposed the possibility of partially coated LPGs for sensing applications.

In this work, a novel approach for humidity and temperature sensing based on a half-coated LPG, is presented. To our knowledge, this is the first time that an LPG is partially coated to develop a sensing device. In addition, this new sensor provides a simultaneous response for two different external magnitudes using only one fiber grating thanks to the partial coating.

2. Material and methods

2.1. Chemical reagents and materials

Sodium hydroxide (NaOH), potassium hydroxide (1 N volumetric solution, KOH), sulphuric acid (98%, H_2SO_4), hydrogen peroxide (H_2O_2), poly(allylamine hydrochloride) (Mw ∼ 56,000, PAH), and poly(acrylic acid, sodium salt) 35 wt% solution in water (Mw ∼ 15,000, PAA) were purchased from Sigma–Aldrich. All reagents were of analytical grade and used without further purification. Ultrapure water (18.3 M cm) was obtained by reverse osmosis followed by ion exchange and filtration (Barnstead Nanopure Diamond). All solutions were prepared using ultrapure water. Both PAH and PAA solutions were prepared with a concentration of 10 mM, and adjusted to a pH 4.5.

PAH and PAA weak polyelectrolytes were chosen for the fabrication of the LbL coating because of their well-known hydrophilic nature. In particular, PAH/PAA thin films thickness is humidity-dependent due to their swelling/de-swelling behavior [30]. This swelling property produces morphological and effective refractive index variations in the resultant coating, thus provoking changes in the optical response of the LPG optical fiber sensor.

2.2. LPG fabrication

The LPG was performed using the point-by-point technique by means of an Argon-ion frequency-doubled laser at a wavelength of 244 nm and a high-precise translation stage with an accuracy of few nanometers. The laser beam, with 50 μm in diameter, was focused onto the optical fiber to modify the refractive index of the core. The exposure time in each point was constant along the total length of the grating.

The employed optical fiber was PS1250/1500 (from Fibercore Inc.), and the resultant grating parameters were 464 μm for period and 6 cm for length, respectively.

Next, LPG was connected to a broadband light source in one extreme, and to an optical spectrum analyzer (OSA) in the other to measure the transmission spectrum and observe the main attenuation band created by the grating.

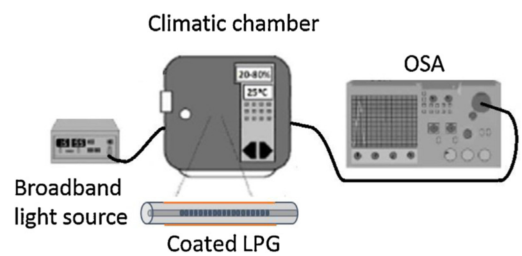

Fig. 2. Experimental setup to monitor the optical sensor response.

2.3. Experimental setup

The experimental setup shown in Fig. 2 was used to monitor the coating deposition onto the LPG, the further partial removal of the coating, and the respective RH and temperature tests. The coating deposition process will be described in the next subsection, and the partial removal of the coating is presented in Section 3.

The grating sensor was submitted to several RH cycles using a programmable climatic chamber. The humidity tests consisted of a constant slope from 80% RH to 20% RH, and next, RH variation was inverted from 20% to 80%. This cyclic up-and-down profile was repeated 3 times. Temperature was kept at 25 °C during the whole RH cycles.

Afterwards, the same setup was used to monitor the temperature. In this case, tests were performed like this: the RH was kept at a constant level of 30%RH while the temperature varied from 25 to 85 °C, and backwards.

All mentioned RH and temperature tests were previously performed with the original LPG, before coating it, thus taking these results as a reference. The same tests were also performed once