SnO_2 Based Optical Fiber Refractometers

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ABSTRACT

In this work, the fabrication and characterization of refractometers based on lossy mode resonances (LMR) is presented. Tin dioxide (SnO_2) films deposited on optical fibers are used as the LMR supporting coatings. These resonances shift to the red as a function of the external refractive index, enabling the fabrication of robust and highly reproducible wavelength-based optical fiber refractometers. The obtained SnO_2-based refractometer shows an average sensitivity of 7198 nm/refractive index unit (RIU) in the range 1.333–1.420 RIU.

Keywords: Optical fiber; LMR; Refractive index; Refractometer; Tin oxide; dip-coating

1. INTRODUCTION

Measurement of refractive index (RI) is needed in different areas. For this reason, many RI sensors have been proposed for several applications, including industrial process monitoring, quality control in the food industry, and biomedical applications. The Abbe refractometer is a well-known standard apparatus to measure RI in the visible and near-IR spectrum [1, 2]. However, some limitations of traditional refractometers, such as size and weight, have made necessary the development of novel devices. A field of research has focused on optical fibers sensors to measure RI.

Optical fiber refractometers are a promising and attractive tool in chemical and biotechnological applications due to their advantages, such as high sensitivity, immunity to electromagnetic interference, compact size and the possibility of remote sensing. In addition to this, different optical fiber architectures and techniques have been used for the fabrication of optical fiber refractometers, such as polished fibers [3], tapered fibers [4] and hetero-core [5] fibers based on surface plasmon resonances, long-period fiber gratings [6] or cladding removed multi-mode fibers (CRMMF) based on lossy mode resonances (LMRs) [7-10].

Concretely in the field of LMRs, previous works have studied the advantages of the utilization of these resonances [9] and the properties of the coatings in order to obtain the adequate conditions to produce LMRs [10]. LMRs can be produced by means of the fabrication of a metal oxide coating onto the optical fiber core core, more details about this phenomenon can be found in the literature [7-10, 14].

In this work, an optical fiber refractometer based on Lossy Mode Resonances (LMR) is presented. More specifically, this work is focused on the fabrication of LMR-based refractometers based on tin dioxide (SnO_2) coatings fabricated onto the optical fiber core. The wavelength shift of the resonances originated by SnO_2 coatings enable to monitor the coating thickness variations as well as the coating refractive index or the surrounding medium refractive index (SMRI). In particular, we will study the resonance shift as a function of the SMRI, which enhances substantially the results obtained with other devices, based in LMRs with other materials such as ITO or TiO_2, presented in previous works.

2. EXPERIMENTAL PROCEDURE

2.1 Coating Fabrication

The device developed in this work consists of a SnO_2 thin film fabricated onto a 4 cm. portion of CRMMF (FT200EMT 200/225 core/cladding diameter from Thorlabs Inc.). Firstly, the cladding of this optical fiber is removed in a portion around 10 centimeters in order to deposit a thin film. Then, the optical fiber core was used as the substrate in a sol-gel dip coating deposition process [11].

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The deposition process basically consisted of a 10-layer dip-coating fabrication process with a constant withdrawal speed of 4 cm/s. A 30 min annealing process at 500 ºC was performed after the addition of every layer. The deposition finishes with a 3 hour annealing step under nitrogen atmosphere.

2.2 Measurements

All the measurements were performed at constant temperature (25 °C) and humidity (30%) unless otherwise stated. A 4-cm portion of SnO2 coated optical fibers were cleaved perpendicularly (LCD-200, Vytran Inc.) at both ends and spliced (FITEL S176, Furukawa Co. Ltd.) to optical fiber cords. The transmission spectra were obtained using the experimental setup shown in Figure 1(a) that consisted of a halogen white light source (Ando AQ-4303B) connected at one end as the excitation source. The other end was connected to the single extreme of a bifurcated optical fiber in order to perform simultaneous measurements with two spectrometers in the visible and near-infrared spectral regions (HR4000 and NIR512, both from Oceanoptics Inc.). In this way, wavelengths between 500 and 1700 nm were monitored.

This setup was used to characterize the device when it is subjected to changes in the SMRI. In order modify the SMRI the sensitive region was immersed in different glycerol solutions in water, with a RI from 1.33 to 1.42. These values were estimated at 25 ºC and 590 nm [12].

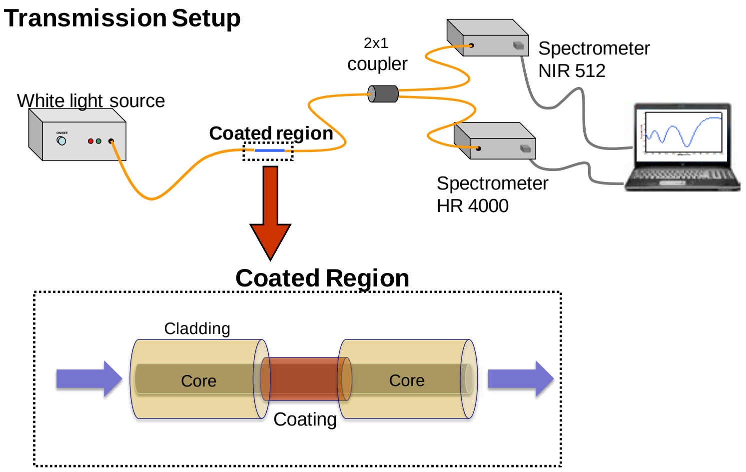

Figure 1. Optical fiber transmission setup and detail of the sensitive region.

3. RESULTS AND DISCUSSION

3.1 Characterization

SnO_2 coatings fabricated onto the optical fibers were characterized by using a scanning electron microscope (SEM) (FESEM, Carl Zeiss Inc.) and an atomic force microscope (AFM) (Innova AFM, Veeco Inc.). SEM micrographs showed a homogeneous coating with a thickness of 65 nm (Figure 2(a)). Additionally, AFM images of the coatings revealed a smooth surface (see Figure 2(b)) with a RMS roughness of 3.77 nm.

The transmission spectra of the SnO_2 coatings previously deposited on microscope glass slides have been also checked, presenting a high optical transparency [13], with a maximum (100%) around the green band. The average transmittance is around 90% in the range of 450nm – 900nm (Figure 3).

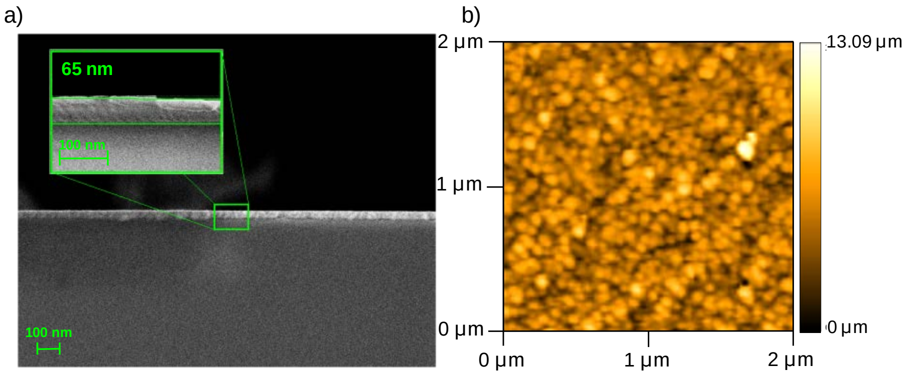

Figure 2. (a)SEM image and (b)AFM image of the SnO_2 coating.

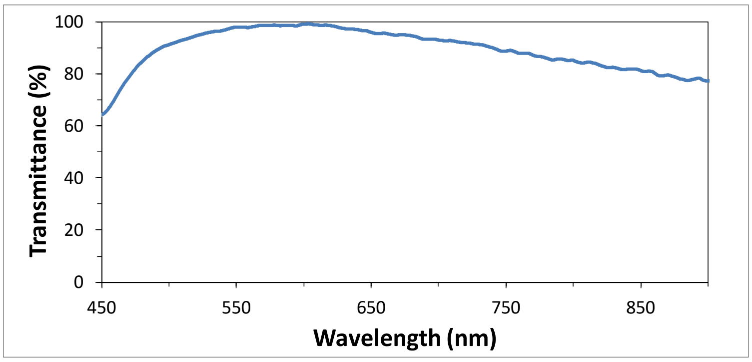

Figure 3. Optical transmission of the SnO_2 coating.

As it has been presented in previous works of this group, metal oxide coatings can produce LMRs that shift to the red as a function of the SMRI [14]. SnO_2 coated optical fiber can also generate this type of resonance as it will be detailed in the next paragraphs. The absorption spectra for different SMRI values from 1.33 to 1.42 are shown in Figure 4. In addition, the resonance wavelength variation as a function of the external refractive index is represented in the inset of Figure 4.

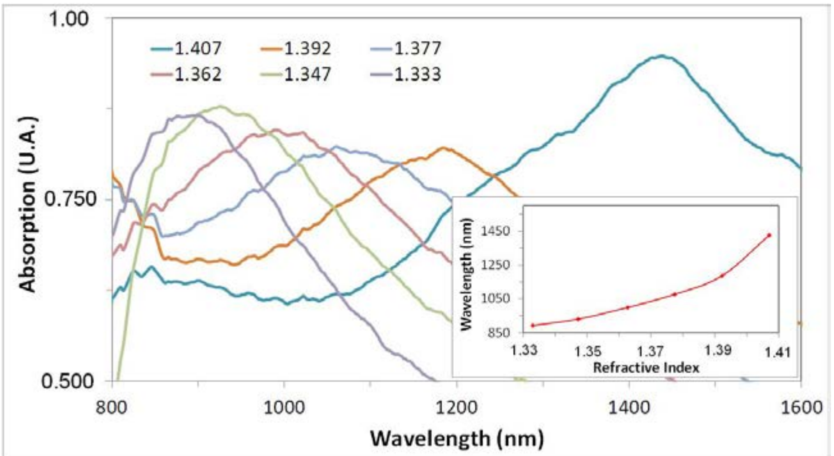

Figure 4. Spectral response of the SnO_2 refractometers. Inset: Maximum attenuation wavelength for variation of external RI.

The average sensitivity of the refractometer in the studied range from 1.321 to 1.423 of SMRI is 7198 nm/RIU. It is important to notice that, as can be appreciated in Figure 4, there are two different sensitivity regions. The first one, between SMRI values of 1.380 and 1.420, presents an average value of 16167 nm/RIU. When the SMRI value is below this interval, the average sensitivity is 4127 nm/RIU.

4. CONCLUSIONS

In this work, SnO_2 optical fiber refractometers based on LMR have been fabricated by a simple and low cost dip-coating technique. SEM and AFM analysis have shown that the coating presents a smooth and homogeneous surface. Transmission spectra have been also obtained. The absorption peaks produced by the resonance shift as a function of the SMRI, what allows the use of these devices as optical refractometers, obtaining sensitivities between 4,127 and 16,197 nm/RIU, depending on the studied region. To our knowledge, this is the first time that SnO_2-coated optical fiber refractometers based on LMR have been reported in the literature.

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