Optical Fiber Refractometers based on Sputtered Indium Tin Oxide Coatings

S. Lopez, C. R. Zamarreño[a], M. Hernaez, I. Del Villar, F. J. Arregui, I. R. Matias
Electrical and Electronic Engineering Department
Public University of Navarra
Pamplona, Spain
[a] carlos.ruiz@unavarra.es

Abstract— **This work presents the fabrication of optical fiber refractometers based on indium tin oxide (ITO) coatings deposited by sputtering with response in the visible spectral region. ITO thin-films have been sputtered by employing a rotating mechanism that enables the fabrication of smooth and homogeneous coatings onto the optical fiber core. Fabricated ITO coated optical fiber devices present several resonances in the visible and near infrared region. These resonances show high optical power attenuations (more than 10 dB) in the visible spectral region, which produces changes in the colour of the output visible light. Therefore, since these resonances shift as a function of the refractive index (RI) of the surrounding medium it is feasible to determine the RI of the outer medium in contact with the ITO coating by simply monitoring the chromatic coordinates (colour change), x and y, of the visible output light.**

Key words: Optical fiber, refractometer, indium tin oxide, resonances, sputtering, refractive index, sensor, colour.

I. INTRODUCTION

Recent works have presented the fabrication of optical fiber refractometers based on metal oxides with characteristic optical and electrical properties, such as indium tin oxide (ITO), titanium dioxide TiO_2 or indium oxide In_2O_3. [1-3]. These refractometers are based on lossy mode resonances (LMRs), which have been described in several works [4-5] and can be associated with lossy modes. LMRs, unlike the more familiar surface plasmon resonance (SPR) [6], have the advantage of being generated by both, TE and TM, light polarizations as well as allow the generation of more than one resonance without modifying the morphology of the fiber [7].

However, in most cases, the fabrication processes of these LMR supporting coatings requires an important time and it is not easy its automation. Here it is presented an alternative approach in order to solve the problems mentioned above. This approach basically consists of the application of the sputtering technique in order to produce thin and homogeneous ITO coatings around the core of optical fibers, which act as LMR supporting coatings with high attenuation bands.

II. EXPERIMENTAL PROCESS

A. Fabrication of ITO Coatings

For the fabrication of different devices shown in this study used an optical fiber (FT200EMT from Thorlabs Inc.) with diameters of 200 and 225 μm for the core and cladding respectively. Previously to the manufacture of ITO coating is necessary to prepare the fiber by the procedure described in [8]. This process basically involves the removal of the cover of plastic fiber along a length of 10 cm followed by a cleaning process using ultrasound. The process of preparation of the fiber described above will enable the manufacture of the coating directly onto the fiber core. For the manufacture of ITO coatings used a sputtering equipment (K675XD from Quorum Technologies Ltd.) with a partial pressure of Argon between $6·10^{-3}$ and $9·10^{-3}$ mbar and intensity of 150 mA which allowed to achieve deposition rates of between 0.2 and 0.4 nm/sec.

Since the sputtering technique is mainly intended to be used with planar substrates, it was necessary to implement a new mechanism in order to rotate the optical fiber during the deposition process. This mechanism should be small enough to be introduced into the sputtering chamber and capable to hold the fiber and rotate it at a constant speed.

Figure 1. Rotaion mechanism introduced into the sputtering vacuum chamber for the deposition of ITO over the optical fiber

The rotation device was based on a speed controlled DC motor and incorporates a system to hold the fiber parallel to the deposition plane as it is represented in Figure 1. After the ITO coating fabrication, the fiber was subjected to a thermal treatment at 250 °C in vacuum for two hours. This final processing step enables to adjust the properties of the coating [9].

B. Characterization of The Fiber Optic Refractometers.

After the ITO coating deposition onto the optical fiber, a portion of 4 cm approximately was cleaved (LCD-200 Vytran Inc.) and spliced (FITEL S176, Furukawa Co. Ltd.) on both ends to 200µm core diameter optical fiber pigtails. One of the ends was connected to a white light source (halogen lamp, model ASBN-W-150-H from Spectral Products) and the other one was attached to the single end of a 200 µm bifurcated optical fiber (VIS/NIR, from Oceanoptics Inc.) as shown in Figure 2. The other end of the bifurcated optical fiber was connected to two spectrometers (HR4000 and NIR-512, both from Oceanoptics Inc.) in order to cover a larger spectral range from visible to near infra-red (400 nm to 1700 nm). The light spectral data were obtained at the end of the fiber after going through the sensitive region.

The response of the device was recorded when the sensitive region (see Figure 2) was subjected to external medium refractive index (EMRI) variations. EMRI varied from air (n=1) to water (n=1.333) and 80% glycerin/water (n=1.447). Refractive indices were measured at 590 nm [10]. All the measurements were performed at room temperature (20 ºC and 30% RH).

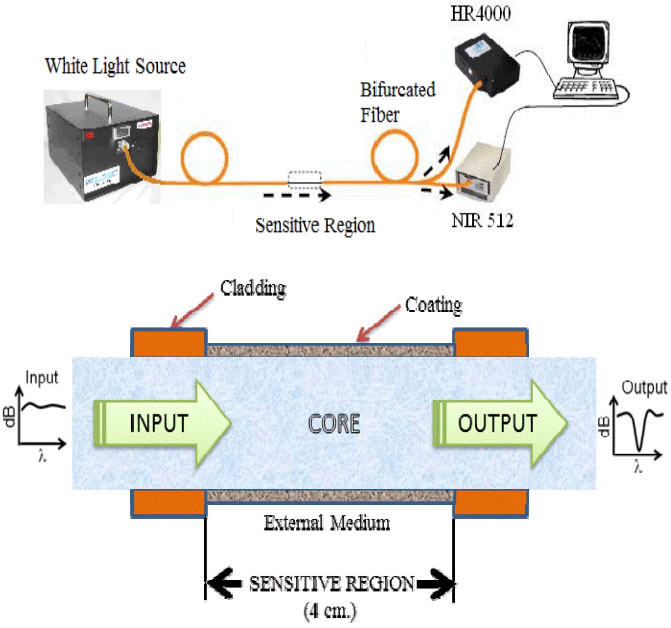

Figure 2. Top: Experimental Setup. Bottom: Section of the Sensitive Region

III. RESULTS AND DISCUSSION

A. Characterization of ITO Coatings

ITO coatings fabricated on optical fibers were characterized using a scanning electron microscope (FESEM, from Carl Zeiss Inc.) and an atomic force microscope (Innova, Veeco Inc.). Figure 3 shows the scanning electron microscope (SEM) image of a cross section of the ITO coated optical fiber. These coatings reveal an homogeneous coverage of the optical fiber core surface. In this case, the coating thickness is approximately 250 nm. Additionally, atomic force microscope (AFM) images of coatings deposited on the fiber were obtained, as it is shown in Figure 4, with an average roughness RMS of 0.34 nm.

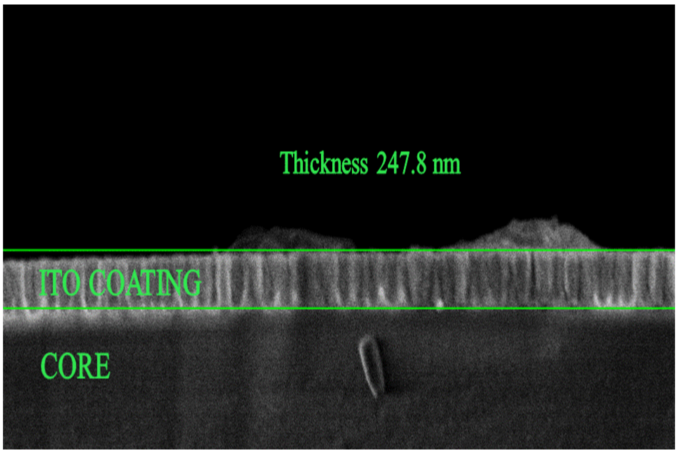

Figure 3. SEM micrograph of the ITO coating.

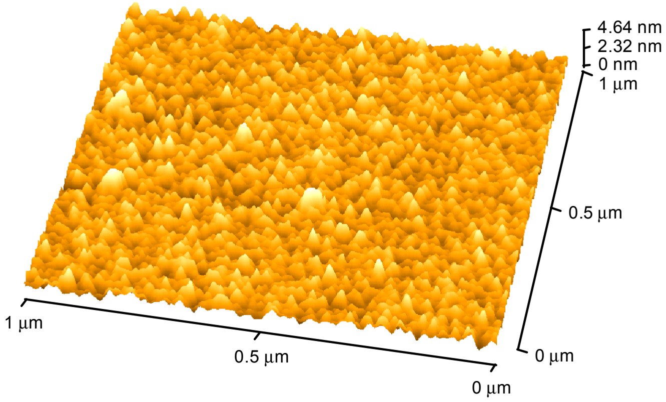

Figure 4. AFM image of the ITO coating.

B. Characterization of Fiber Optic Refractometers.

The spectral response of the refractometer was obtained for different EMRI, air (n=1), water (n=1.333) and glycerol 80% (n=1.447). Figure 5 shows the absorption spectra. The device shows several resonances in the visible and near infrared spectral region. It is also denoted that the maximum absorption wavelength shifts to the red when the EMRI is increased. Therefore, the absorption in the visible area (approximately 380-750 nm) shifts as a function of the EMRI. It is also important to remark the differences between the transmission and absorption bands (greater than 10 dB in al cases), which are denoted by the abrupt slopes. This enables to modify the color of the light at the output of the fiber.

The high attenuation bands enable to observe a change in the color of the light at the output of the optical fiber, which had not been observed in previous devices based on ITO coatings. Thus, when the external medium of sensitive region is air (see Figure 6a), the color of light at the end of the fiber is yellow; if the external medium is water the colour becomes orange (see Fig. 6b). However, if the sensitive region is immersed in a solution containing 80% glycerol, the colour of the light at the end of the fiber becomes pink (see Figure 6c).

The above results can also be expressed in terms of the chromaticity coordinates (x,y) representing the colour of the light at the output of the fiber. Thus, Figure 7 shows representation of the chromaticity coordinates within the colour chart, which corresponds to the changes in colour produced for each of the different media. In particular, the chromaticity coordinates (x, y) of the light at the output of the fiber are (0.471, 0.463) (0.507, 0.445) and (0.445, 0.392) for air, water and 80% glycerin respectively.

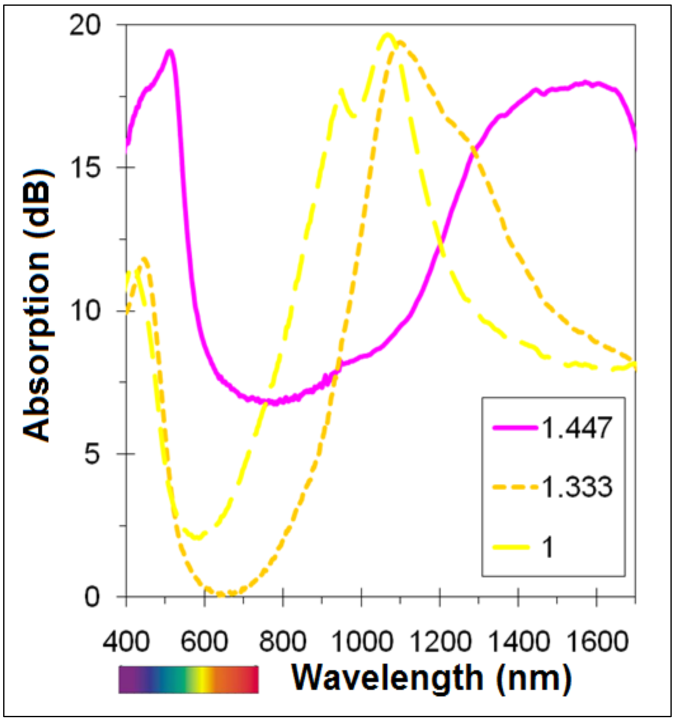

Figure 5. Spectral Response of optical fiber refractometers for different refractive indices of the external medium

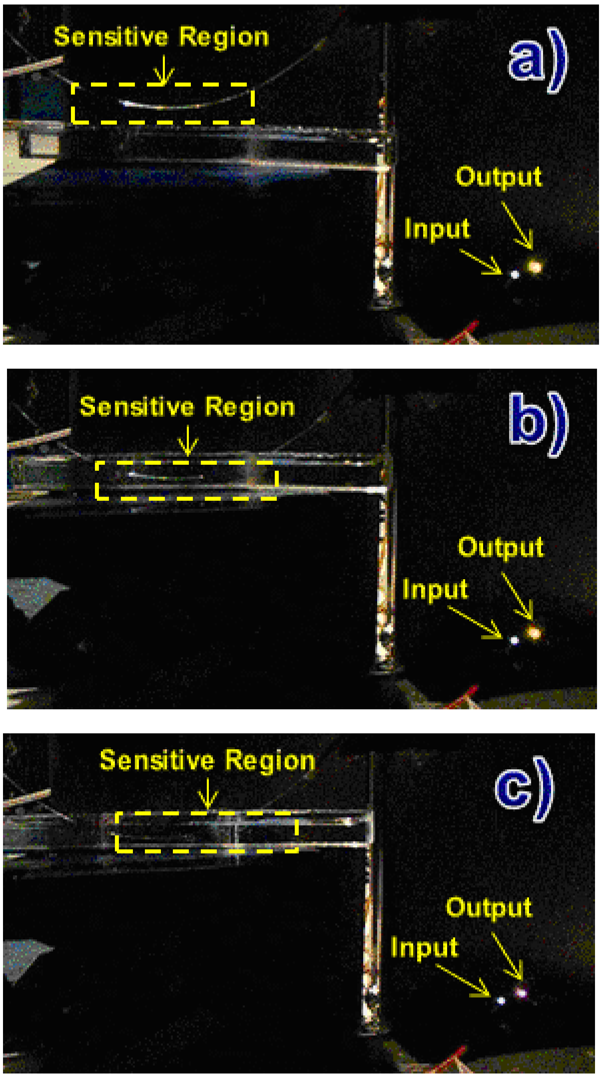

Figure 6. Colour at the fiber output when the EMRI is a) air (n=1), b) water (n=1.333) and c) 80% glycerin (n=1447).

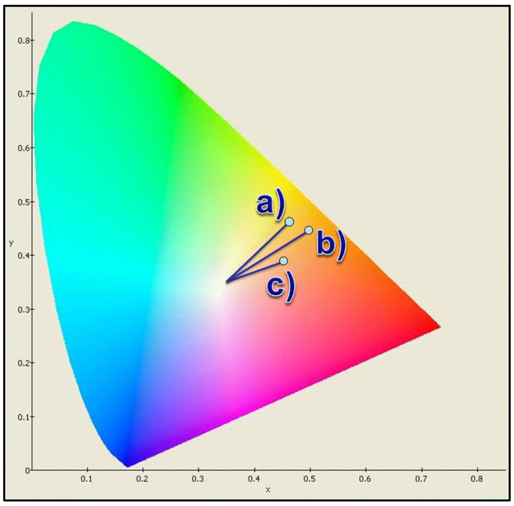

Figure 7. Chromaticity coordinates of the output signal for different external means: a) air, b) water c) 80% glycerin.

IV. CONCLUSIONS

ITO coatings have been fabricated onto the core of optical fibers using the sputtering technique. Furthermore, it has proven that ITO-coated optical fiber devices can act as refractometers in the visible and near infrared spectrum. Moreover, these resonances show high attenuation bands, which had not been seen before in previous works of our group with ITO coatings fabricated using the dip-coating technique [1]. Owing to its high absorption, these resonances enable to observe changes in the colour of the light at the output of the fiber. This also permits the utilization of these devices as optical filters in the visible spectrum modulated by the external index of refraction surrounding the filter, which is the main aim of this work.

Finally, the appropriate selection of the characteristics of the coating could make possible to tune the resonances of the device to work in the spectral range selected. Actually, other coatings based on polymers are susceptible to be used. In this regard, when over, results will be published elsewhere.

ACKNOWLEDGMENTS

This work was supported by the Spanish Ministry of Science and Innovation TEC2010-17805. The authors also thank FIDENA SA for the use of SEM.

REFERENCES

[1] C. R. Zamarreño, M. Hernaez, I. Del Villar, F. J. Arregui, and I. R. Matias, “ITO coated optical fiber refractometers based on resonances in the infrared region,” IEEE Sensors Journal vol. 10(2), pp. 365-366, 2010.

[2] M. Hernaez, I. Del Villar, C. R. Zamarreño, F. J. Arregui, and I. R. Matias, “TiO2 Optical fiber refractometers based on lossy mode resonances supported by TiO2 coatings,” App. Opt., vol. 49(20), pp. 3980-3985, 2010.

[3] C. R. Zamarreño, P. Sanchez, M. Hernaez, I. Del Villar, C. Fernandez-Valdivielso, F. J. Arregui and I. R. Matias, “Dual-Peak Resonance-Based Optical Fiber Refractometers,” Phot. Tech. Lett., vol. 22(24), pp. 1778-1780, 2010.

[4] C. R. Zamarreño, P. Sanchez, M. Hernaez, I. Del Villar, C. Fernandez-Valdivielso, F. J. Arregui and I. R. Matias, “LMR-based optical fiber refractometers based on transparent conducting and semiconducting oxide coatings: A comparative asutdy” Proceedings of SPIE- The International Society for Optical Engineering 7839, art. No. 78391E

[5] Zamarreño, C.R., Hernaez, M., Del Villar, I., Matias, I.R., Arregui, F.J., “Thin-Film resonance supportig coatings deposited onto optical wavequides towards the fabrication of sensing devices” Recent Patents on Materials Science

[6] Liu, G.Q., Tang, F.L., Li, L., Gong, L.X., YE, Z.Q: “Concentration detection of quantum dots in the visible and near-infrarred range based on surface plasmon resonance sensor” Materials Letters 65 (12), pp. 1998-2000.

[7] I. del Villar, C. R. Zamarreño, M. Hernaez, I. R. Matias, F. J. Arregui, “Lossy mode resonance generation with indium tin oxide coated optical fibers for sensing applications,” J. Lightw. Technol., vol. 28(1), pp. 111–117, Jan. 1, 2010.

[8] I. Del Villar, C. R. Zamarreño, P. Sanchez, M. Hernaez, C. Fernandez-Valdivielso, F. J. Arregui, I. R. Matias. “Generation of lossy mode resonances by deposition of high-refractive-index coatings on uncladded multimode optical fibers”. J Opt., vol. 10, 095503, 2010.

[9] I. Kasik, J. Mrazek, O. Podrazky, M. Seidl, J. Aubrecht, P. Tobiska, M. Pospisilova, V Matejec, B. Kovacs, A. Markovics, M. Szili “*Fiber-optic detection of chlorine in water*”, Sens. Actuators B, vol. 139, pp. 139–142, 2009.

[10] Y P. R. Cooper, “*Refractive index measurements of liquids used in conjunction with optical fiber,*” Applied Optics, vol. 22, pp. 3070-3072, 1983.M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.