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OPTICAL FIBER HUMIDITY SENSOR BASED ON LOSSY MODE RESONANCES

M. Hernaez, C.R. Zamarreño, I. Del Villar, F.J. Arregui, I.R. Matias
Department of Electrical and Electronic Engineering
Public University of Navarra, Campus Arrosadia S/N
31006 Pamplona, ESPAÑA
e-mail: miguel.hernaez@unavarra.es

Abstract- A novel optical fiber humidity sensor based on lossy mode resonances (LMR) has been developed. LMRs are supported here by a thin Indium Tin Oxide (ITO) coating fabricated onto an optical fiber core via a sol-gel dip coating. ITO coated optical fiber devices present a resonant maximum absorption peak in the infra-red region which is shifted to higher wavelengths when the refractive index of the medium in contact with the ITO layer is increased. A polymeric structure is deposited onto this ITO using the Layer-by-Layer (LbL) technique. The refractive index of this polymeric coating is sensitive to changes in the external relative humidity (RH), which permits the fabrication of humidity sensors based on LMRs.The wavelength based fabricated sensors showed a dynamical range of 65 nm when the RH varied in the range from 20 to 80% and it has a good linearity when the RH is higher than 40%, high stability and are highly reproducible.

Index terms*: Optical fiber sensors, lossy mode resonance, humidity sensor, spectroscopic techniques, Layer by Layer, ITO.*

I. INTRODUCTION

Humidity sensors are used in a wide range of applications, such as food preservation, air conditioning systems, agriculture, medicine, etc. These broad spectra of applications of humidity sensors have attracted the interest of many researchers in the last years, what has motivated great advance in this field [1]. Among them, the utilization of optical fiber in the design and fabrication of sensors added new and important advantages, such as simplified design, miniaturization, multiplexing capability, electromagnetic immunity, etc [2]. Different techniques have been used to develop new optical fiber sensors, such as fluorescence [3], interferometry [4], fiber Bragg gratings (FBGs) [5], long fiber gratings (LPGs) [6], photonic crystal fiber (PCB) [7] or surface plasmon resonance (SPR) [8].

Among these techniques, amplitude based techniques present some limitations, such as sensitivity to external noises and power fluctuations, which could be overcomed by wavelength based techniques. The use of these techniques has been potentiated by the development of new and less expensive wavelength interrogation systems.

In this work, a humidity sensor based on electromagnetic resonances supported by an Indium Tin Oxide (ITO) thin film coating fabricated onto the optical fiber core has been developed. A maximum in the absorption appears in the infra red region which is associated to the lossy mode resonance phenomenon [9]. This resonance peak shifts to higher wavelengths when the refractive index of the external medium rises. So, this ITO-coated optical fiber core acts as a refractometer, as shown in figure 1 [10].

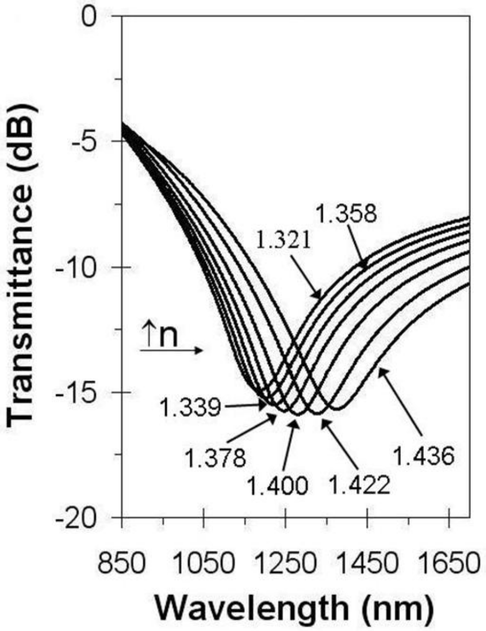

Figure 1. Variation of the LMR absorption peak with the external refractive index

In order to obtain a device sensitive to humidity changes, a polymeric structure made of poly-(allylamine hydrochloride) (PAH) and poly(acrylic acid) PAA was deposited onto the ITO coating by using the Layer by Layer (LbL) technique as it has been done in previous works

[11,12]. The refractive index of the polymeric coating varies when the relative humidity (RH) of the external medium changes, so the LMR absorption peak of the whole device shifts to higher wavelengths when the external RH rises and vice versa. This permits the fabrication of new wavelength based optical fiber sensors which exploit the LMR phenomenon originated by ITO coated optical fibers.

II. EXPERIMENTAL SECTION

All the chemicals used to perform this work were purchased from Sigma-Aldrich and used without further purification. The aqueous solutions were prepared with ultrapure deionized (DI) water (18.2MΩ•s) supplied by a Barnstead Diamond equipment. NaOH and HCl were used to adjust the pH of the different solutions. The optical fiber used to fabricate the sensors is the FT200EMT (Thorlabs Inc.), with a 200 µm core.

The fabrication of the devices was performed in a four-step process. Firstly, the cladding of a 5 cm portion of the optical fiber is chemically removed and cleaned in an ultrasonic bath with detergent, DI water and acetone, consecutively.

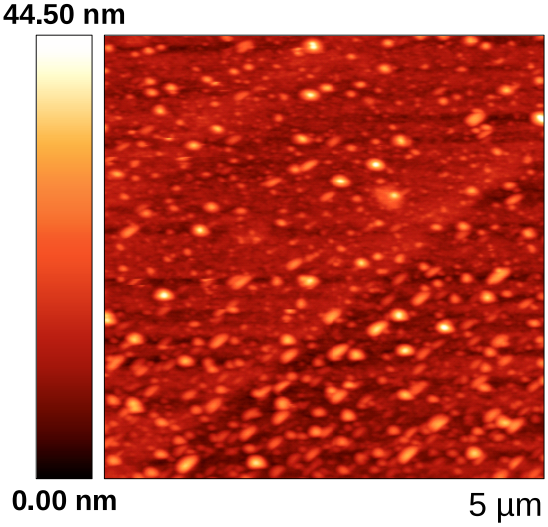

Figure 2. AFM image of the ITO-coated optical fiber core

After that, the ITO coating is deposited onto the pre-cleaned optical fiber via a sol-gel method previously described by Ota et al [13]. Ethanol, Indium(III) chloride, Tin(IV) chloride pentahydrate and TWEEN 80 were used to prepare the ITO solution. The deposition process was repeated up to 10 layers. The resulting ITO coating presented a thickness of 300 nm after the 10 layers deposition process. In figure 2, an AFM image of the ITO coating can be observed.

Once the ITO coating had been deposited, 50 bilayers of PAH and PAA were deposited onto the ITO coating using the LbL method. This method allows the control of the coating thickness with high accuracy. The polymeric coating changes its refractive index when the RH of the external medium varies. In figure 3 it is presented a SEM image of the cross section of the complete structure. The complete sensitive nanofilm onto the core of the cladding consist of a 300 nm ITO coating and a 250 nm multilayered polymeric structure onto it.

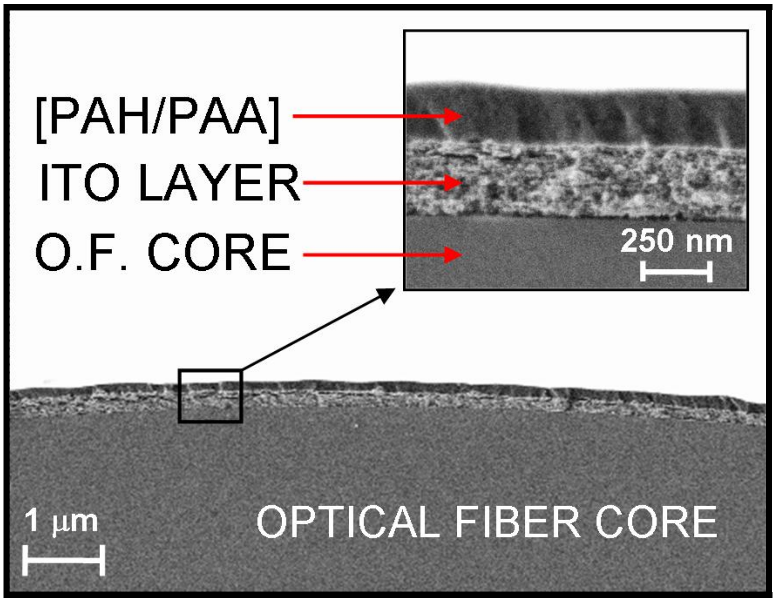

Figure 3. SEM image of the sensor cross section

Finally, the portion of optical fiber covered with the ITO coating and the PAH/PAA multilayer structure is perpendicularly cleaved and spliced in both extremes to 200 µm optical fiber pigtails.

III. RESULTS

A typical transmission setup was used to characterize the device as it is shown in Figure 4. It consists of a white light source (DH 2000, Avantes Inc.) and a NIR-512 spectrometer (Oceanoptics Inc.) connected to a PC to collect the data. The sensitive region is placed into an environmental chamber (Angelantoni Inc) in order to subject it to RH changes.

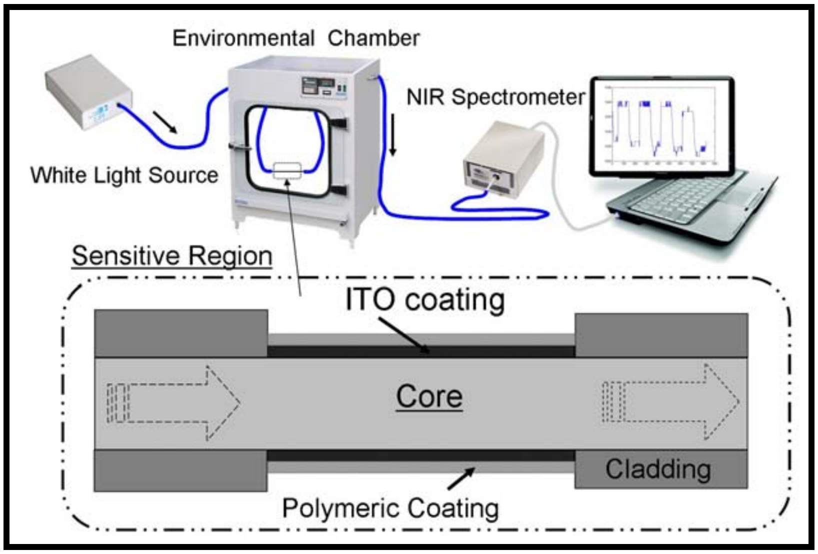

Figure 4. Experimental setup used to characterize the humidity sensor

When the RH of the external medium rises, the refractive index of the polymeric layer also varies, and thus the LMR maximum absorption peak shifts to higher wavelengths. The described effect is shown in Figure 5 when the RH varies between 20 and 80%.

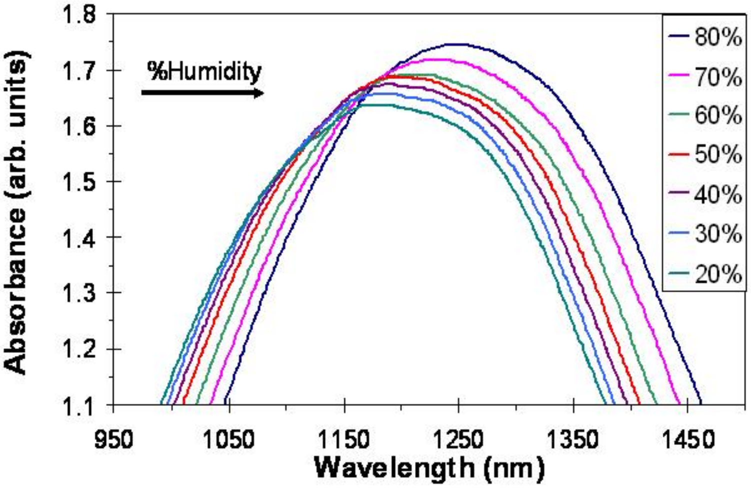

Figure 5. Absorption spectra of the device when the RH varies between 20 and 80%

The sensor shows a dynamical range of 65 nm and linearity between 40 and 80% RH. This can be better appreciated in Figure 6, where the maxima of the absorption peaks are represented for both the rising and the falling curve. The sensitivity presents two differentiated sensitive regions. For the HR range from 20% to 40% is 0.25. nm/%RH, while the sensitivity between 40%-80% is 1.5 nm/%RH, which is associated to a non-linear behavior of the PAH/PAA refractive index variation with RH, as well as to a non-linear sensitivity of the ITO coated optical fiber refractometers with the external index of refraction. Moreover, the device shows an average hysteresis of 3.29%.

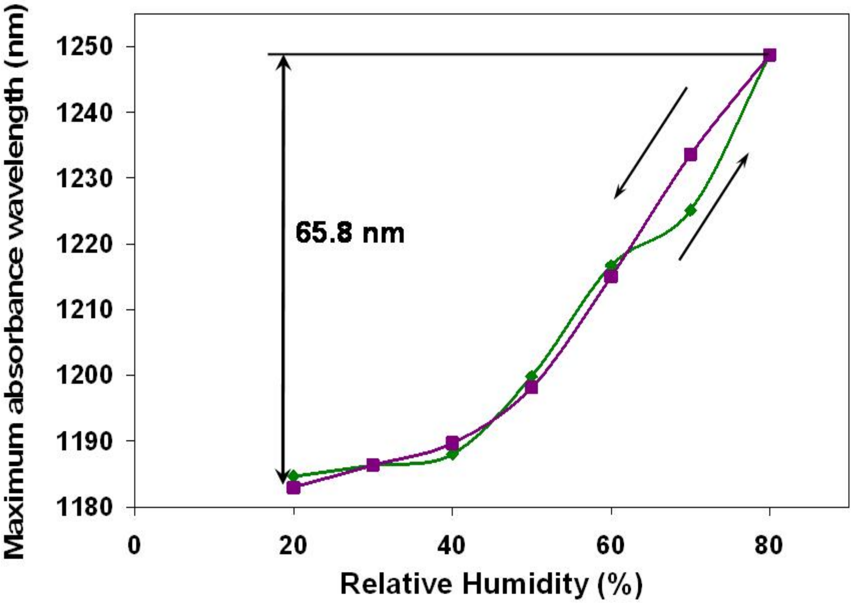

Figure 6. Transfer function of the optical fiber humidity sensor between 20% and 80% RH

IV. CONCLUSIONS

In this work, a new optical fiber humidity sensor based on LMR has been developed. A LMR supporting ITO coating has been deposited on an optical fiber core showing a resonance maximum absorption peak which shifts to higher wavelengths when the external refractive index rises.

Onto this ITO coating, a polymerical sensitive layer is deposited via the LbL method. The effective refractive index of this layer rises when the external RH rises, so a variation in the RH produces a red shift of the LMR absorption peak. The final sensor shows a dynamical range of 65 nm when the RH varies in the range from 20 to 80% and an average hysteresis of 3.29%.

But the more important thing is that a novel sensing platform to fabricate sensors based on LMR has been explained which, from our humble point of view, presents an enormous potential.

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