

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

[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 ($18.2\text{M}\Omega\cdot\text{s}$) 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 $200\ \mu\text{m}$ 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.

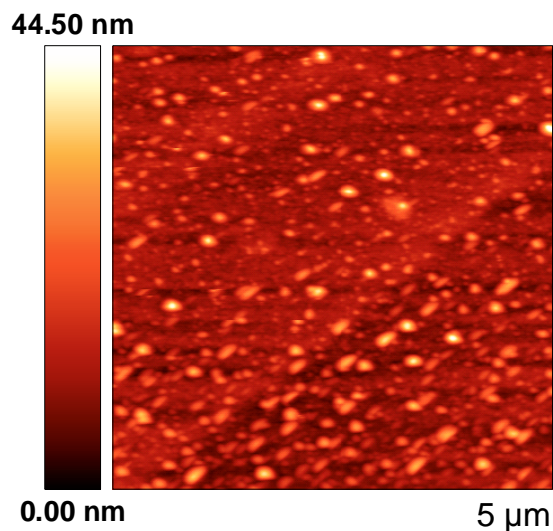


Figure 2. AFM image of the ITO-coated optical fiber core

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

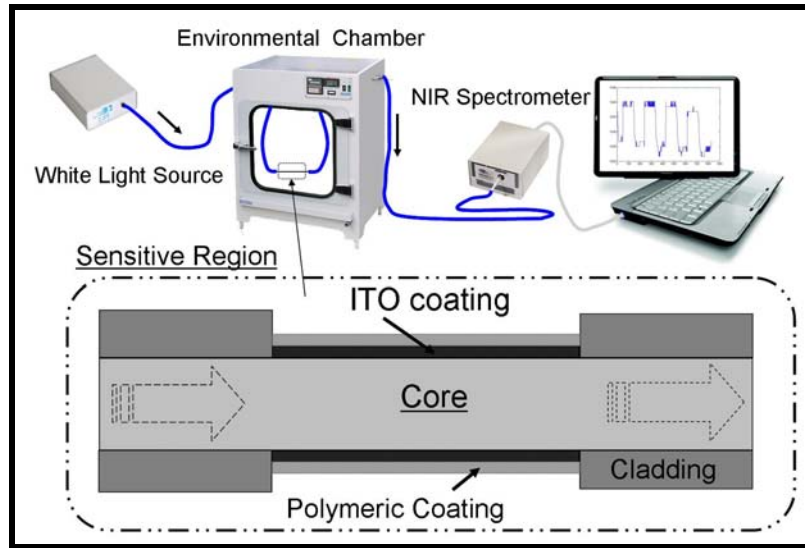


Figure 4. Experimental setup used to characterize the humidity sensor

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%.

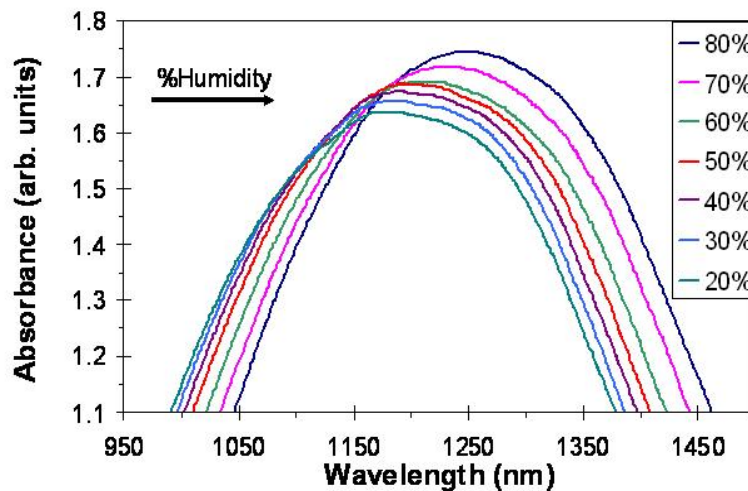


Figure 5. Absorption spectra of the device when the RH varies between 20 and 80%

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 RH 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

REFERENCES

- [1] Z. Chen, C. Lu, "Humidity sensors: a review of materials and mechanisms", *Sensor Letters*, 3, 2005, pp. 274-295.
- [2] A. Cusano, J. M. López-Higuera, I. R. Matias, B. Culshaw, "Optical fiber sensor technology and applications", *IEEE Sensors Journal*, 8, 2008, pp. 1052-1054.
- [3] J. Goicoechea, C. R. Zamarreño, I. R. Matias, F. J. Arregui, "Minimizing the photobleaching of self-assembled multilayers for sensor applications", *Sensors and Actuators B*, vol. 126, 2007, pp. 41-47.
- [4] J. M. Corres, I. R. Matias, M. Hernaez, J. Bravo, F. J. Arregui, "Optical fiber humidity sensors using nanostructured coatings of SiO₂ nanoparticles", *IEEE Sensors Journal*, vol. 8, 2008, pp. 281-285.
- [5] F. J. Arregui, I. R. Matias, K. L. Cooper, R. O. Claus, "Simultaneous measurement of humidity and temperature by combining a reflective intensity-based optical fiber sensor and a fiber bragg grating," *IEEE Sensors Journal*, vol. 2, 2002, pp. 482-487.
- [6] J. M. Corres, I. Del Villar, I. R. Matias, F. J. Arregui, "Fiber-optic pH-sensors in long-period fiber gratings using electrostatic self-assembly", *Optics Letters*, 32 (1), 2007, pp. 29-31.
- [7] B. Larrion, M. Hernaez, F. J. Arregui, J. Goicoechea, J. Bravo, I. R. Matias, "Photonic crystal fiber temperature sensor based on quantum dot nanocoatings", *Journal of Sensors*, 2009, 932471.
- [8] M. Rajarajan, T. Dar, C. Themistos, B. M. A. Rahman, K. T. V. Grattan, J. Homola, J. Irudayaraj, "Modelling and characterisation of surface plasmon based sensors for the detection of *E. coli*", *Journal of Modern Optics*, 56 (4), 2009, pp. 564-571.
- [9] I. Del Villar, C. R. Zamarreño, M. Hernández, I. R. Matías, F. J. Arregui, "Lossy Mode Resonance generation with Indium Tin Oxide coated optical fibers for sensing applications", *Journal of Lightwave Technology*, DOI:10.1109/JLT.2009.2036580 (2009).
- [10] C. R. Zamarreño, M. Hernaez, I. Del Villar, I. R. Matias, F. J. Arregui, "Optical fiber refractometers with tunable sensitivity based on Indium Tin Oxide coatings", *IEEE Sensors Journal*, DOI 10.1109/JSEN.2009.2034628 (2009).
- [11] G. Decher, "Fuzzy nanoassemblies: Toward layered polymeric multicomposites", *Science*, vol. 277, no. 5330, 1997, pp. 1232-1237.

