MMI Fiber Optic Refractometer with Universal pH Indicator Coating

Adolfo Rodríguez-Rodríguez[1], René Domínguez-Cruz[2], Daniel May-Arrioja[3], Ignacio Matías-Maestro[4], Carlos Ruíz-Zamarreño[4] and Francisco Arregui[4]

[1]*Department of Computer Systems Engineering, Autonomous University of Tamaulipas, Apdo. Postal 1460, Col. Arcoiris, Reynosa, Tamaulipas, Mexico*

[2]*Electrical and Electronics Department, Autonomous University of Tamaulipas, Apdo. Postal 1460, Col. Arcoiris, Reynosa, Tamaulipas, Mexico*

[3]*Centro de Investigaciones en Óptica, Unidad Aguascalientes, Prol. Constitución 607, Fracc. Reserva Loma Bonita, Aguascalientes, Ags, Mexico*

[4]*Departamento de Ingeniería Eléctrica y Electrónica, Universidad Pública de Navarra, Edif. Los Tejos, Campus Arrosadía-31006, Pamplona, Spain*

Keywords: Fiber Optic, Refractometer, Multimodal Effect, Universal pH Indicator.

Abstract: In this paper we show the preliminary results about fabrication of an optical fiber refractometer based on multimode interference effects (MMI) provided with Universal pH Indicator coating. The layer, deposited by coating dip-coating technique, allows increase the refractometer sensitivity which is around 344.5054 nm/RIU in a range of 1.333 to 1.4223. Highly repetitive and reversible refractometer have been achieved using a simple fabrication process. The device shown offers the possibility to be used as instrument to identify substances included aggressive liquids as gasoline.

1 INTRODUCTION

The refractometer is an interesting and useful tool to analize the compounds and concentrations. This is due to many applications as in biology, medical science, environment control and process engineering area. In this sense, optical fiber based in refraction index (RI) sensors have been studied broadly due to the advantages they offer such as immunity to electromagnetic interference, compact size, remote operation, high sensitivity and the wavelength signals multiplexing. Some techniques to implement RI sensing incorporate a fiber Bragg gratings FBG (Han et al, 2010), long period gratings LPG (Allsop et al, 2002), macro-bend single mode fiber (Wang et al, 2009), surface plasmon resonance (Liang et al, 2010), a Fabry-Perot interferometer (Frazao et al 2009), or multi-D-shaped optical fiber (Chen et al, 2010). However, an alternative, attractive, low cost and simple technique for RI measurements is based in multimodal interference effects (MMI). MMI effect in optical fiber is obtained by splicing a segment of Multimode Fiber (MMF) between two segments of single mode Fiber (SMF) as is showed in Figure 1. The MMI effect relies on the fact that when the light field coming from the input SMF enters the MMF, will excite several modes, propagating along the MMF section, thus causing interference between them. This means that the optical power coupled to the output SMF will depend on the amplitudes and relative phases of the various modes at the exit end of the MMF. Also, the MMI fiber structure can act as a bandpass filter or edge filter depending on the length of the MMF used. Thus, the operating principle of sensors based on MMI structures relies in the interference between excited modes that are propagating in MMF section, which can be influenced by external perturbation (Wang and Farell, 2006). Additionally, the MMI devices has been proposed as sensors for micro-displacement measurements (Antonio-Lopez et al, 2013), level sensor (Antonio-Lopez et al, 2011) and temperature sensor (Ruiz-Perez et al, 2012).

Rodríguez-Rodríguez, A., Domínguez-Cruz, R., May-Arrioja, D., Matías-Maestro, I., Ruiz-Zamarreño, C. and Arregui, F.
MMI Fiber Optic Refractometer with Universal pH Indicator Coating.
DOI: 10.5220/0005821702730276
In *Proceedings of the 4th International Conference on Photonics, Optics and Laser Technology (PHOTOPTICS 2016)*, pages 275-278
ISBN: 978-989-758-174-8

Figure 1: Structure of MMI element built in optical fiber. (SMF, single mode fiber; MMF, multimode fiber).

In other hands, a universal indicator is collectively a mixture of indicators which show a colour change in a solution, which interprets how the acidity or alkalinity of solutions is. Typically, a universal indicator can be in paper form or present in a form of a solution (Walker, 2007). Novel uses for Universal pH Indicator have been proposed in optical fiber sensors, such as ammonia detection (Rodríguez et al, 2014) and in medicine field for physiological processes in the patient's body (Zajíc et al, 2015). In this work we show a simple MMI structure for RI measurements using No-core Multimode fiber spliced between two Single Mode fibers covered with a Universal pH Indicator coating to increase the sensitivity. The MMI sensor is able to detect different liquids such as water, ethanol anhydrous and other liquid substances more aggressive as gasoline.

2 EXPERIMENTAL SET-UP

2.1 MMI Refractometer Fabrication

To fabricate the refractometer based on the MMI effect shown in this paper, we used two SMF segments (with diameter of 8.2 µm for the core and 125 µm for coating) and No-core Multimode fiber segment, NC-MMF (with diameter of 125 µm). For a 58.13 mm segment of NC-MMF, their polymer jacket was removed using acetone and it is spliced between two SMF segments using a FSM Fujikura® 60S splicer. Lately, the NC-MMF section was coated with the pH sensitive solution using a standard dip-coating technique by deposition system from Nadetech, Inc.® (Pamplona, Spain). The NC-MMF fiber was inserted and pulled out of the solution at a rate of 150 mm/min while the temperature was maintained at 100 °C during the whole process. The coated MMF element sensor was kept at room temperature during 20 min, and then placed into an oven for thermally curing at 85 °C for 15 min. To avoid losses for bending, we fixed the MMI element on the surface of a chamber and we perform all our measurement at room temperature.

To prepare pH sensitive solution, we use Universal pH Indicator provided by the company (PANREAC), which is made of a mixture of various indicators such as methyl red (40 mg), p-dimethylaminoazobenzene (60 mg), bromothymol blue (80 mg), thymol blue (100 mg) and phenolphthalein (20 mg) (Indicator Universal de pH, 2013). In order to immobilize the indicator on the surface of the MMF fiber, the polymer is incorporated into a thermoplastic host that allow simple coating of the optical fiber. The pH sensitive solution was prepared by mixing 120 mL of ethanol, 120 mL of pH universal indicator, and 4.32 g of thermoplastic polyurethane (TPU), Tecoflex® provided by the company Thermedics (Newton, NJ, USA).

2.2 Experimental Array

Once upon fabricated the MMI refractometer and fixed into a chamber, the ends of the SMF segments are fused to single mode optical fiber provided with FC/PC connectors. One of these connectors is plugged to a Super-luminescent laser diode source (SLD). The optical signal is propagating into the MMI structure and is detected by an Optical Spectrum Analyzer (OSA) ANRITSU MS9780. The full experimental system is shown in Figure 2.

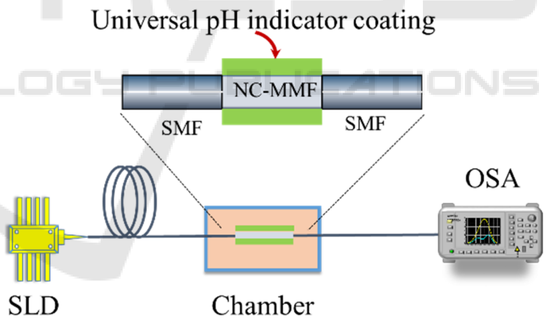

Figure 2: Experimental set-up.

To determine the operating parameters of the MMI structure, we used the self-image distance *L*, given as (Wang and Farell, 2006):

$$L = p\left[\frac{n_{MMF}^{2} D_{MMF}^{2}}{\lambda_o}\right]; \quad p=0, 1, 2, 3\ldots \qquad (1)$$

where D_{MMF} = 125 µm and n_{MMF} = 1.444 are the diameter and refraction index of the NC-MMF respectively, λ_o is the wavelength in free space and p is the number of the input field image that replicates at the end of the MMF segment. However, due to the nature of the MMI effect, the true images of the input field are given at every fourth image (p=4).

The images formed at other positions are known as pseudo-images, and although they resemble the input field they exhibit higher losses. Thus, all our experiments were operated at the fourth image of MMI refractometer. To obtain tuning in 1560 nm in air, the length of the NC-MMF must be L_{π}=58.13 mm. A good approximation of the Equation (1) was experimentally confirmed by the response of the MMI structure shown in Figure 3.

Figure 3: Spectral response in air of MMI refractometer without coating.

2.3 Results and Discussion

The MMI refractometer was initially characterized without Indicator pH Universal coating with some liquids such as water (n= 1.333), anhydrous ethanol (n~1.3611), and commercial gasoline with 98 octanes and gasoline with 95 octanes (n ~ 1.4223). The refractometer response to the different refractive indexes is shown in Figure 4.

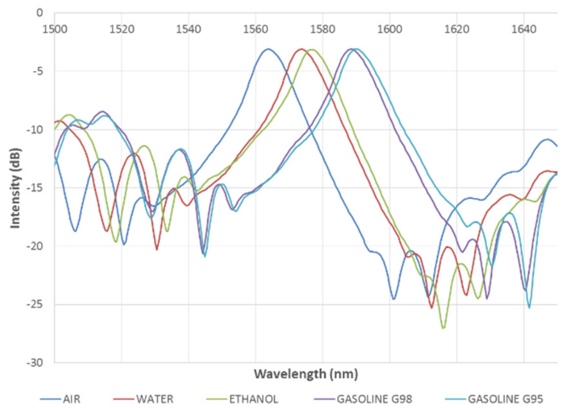

Figure 4: Spectral response of MMI refractometer without coating for several liquid substances surrounding.

When we cover the NC-MMF segment with water, anhydrous ethanol or gasoline, the condition of self-image in the structure of MMI is modify and we estimate a sensitivity around 290.1098 nm/RIU (refractive index units).

The variation in humidity and temperature do not significantly affect the behavior of MMI refractometer when the measurements is performed. Additionally, the recovery time of the device is less than 15 seconds after a washing with acetone.

Due to the sensitivity of the MMI sensor is directly related to the effective diameter (i.e. the diameter of the NC-MMF and the surrounding environment), we decided to fix on the NC- MMF a coat of Universal pH Indicator coating thickness as we explain in Section 2.1. The response of this new refractometer shown in Figure 5. In this case, we can estimate a sensitivity around 344.5054 nm/RIU.

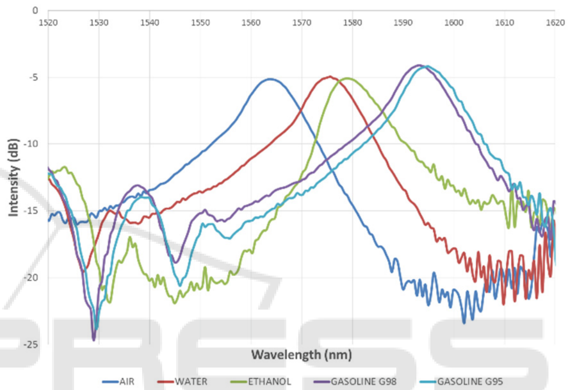

Figure 5: Spectral response of MMI refractometer provided with a Universal pH Indicator coating for several liquid substances surrounding.

In Figure 6 we shows the shift of wavelength peak for both MMI refractometers fabricated. In this curve, we observe the increase in the sensitivity when NC-MMF is provide with a Universal pH Indicator coating. As consequence, this MMI device offers a better resolution for the substances used.

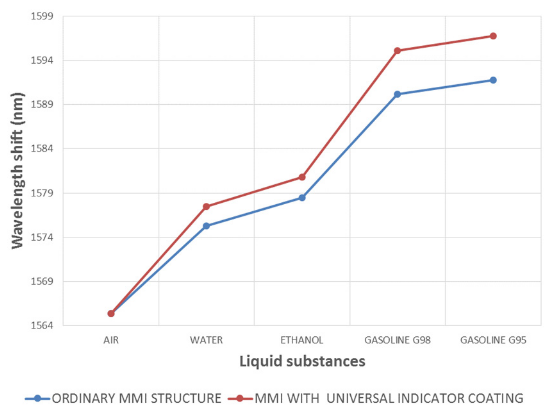

Figure 6: Comparison of the wavelength shifts for different MMI refractometers designed.

As we explained before, a MMI structure is fabricated by splicing a segment of MMF between two SMF segments. In our device the MMI structure is able to see the liquid surrounding the fiber because the MMF does not have a cladding. A simple way to enhance the sensitivity of the MMI structure is to cover the MMF with a high RI thin film. One aspect to consider is the control of the coating thickness. If the film is too thick, it will start guiding and all light from the MMF will be coupled into the high RI film. When the MMI device with high RI film is covered with a liquid, the effective diameter of the fundamental mode is increased as compared to a MMI structure without film under the presence of the same liquid. As shown in Figure 6, the MMI structure without film exhibits the typical wavelength shift for the RI liquids (blue line). Nevertheless, when the MMI structure is provided with Universal Indicator coating, the MMI device exhibit a larger wavelength shift and hence a higher sensitivity (red line).

3 CONCLUSIONS

This paper we shown a fiber optic refractometer based on the effect of multimodal interference (MMI) provided with a Universal pH Indicator coating on NC-MMF fiber and it was tested to detect different liquids. The MMI device has a high reproducibility and reversibility, no significant interference against temperature or humidity.

The fabricated devices provide a simple and inexpensive solution (based in a segment of NC-MMF with specified length spliced between two segments of SMF). The sensitivity of the structure is increased when a layer of Universal pH indicator is deposited on NC-MMF, which is 344.5054 nm/RIU. The device can be a tool in the detection or identification of substances included aggressive liquids as gasoline, where the measured variable depends of refractive index.

ACKNOWLEDGEMENTS

A.R.R. and R.D.C. thank the UAT for the support to achieve this work. This paper was also supported by the Spanish Economy and Competitivity Ministry-TEC2013-43679-R.

REFERENCES

Han, M., Guo F., W., Lu, Y.(2010). *Optical fiber refractometer based on cladding-mode Bragg grating.* Opt. Lett, vol. 35, No. 3, pp. 399-401.

Allsop, T., Reeves, R., Webb, D. J., Bennion, I., Neal, R. (2002). *A high sensitivity refractometer based upon a long period grating Mach-Zehnder interferometer*. Review of Scientific Instruments, vol. 73, no. 4, pp. 1702-1705, 2002.

Wang, P., Semenova, Y., Wu, Q., Farrell, G., Ti, Y., Zheng, J. (2009). *Macrobending single-mode fiber-based refractometer*. Applied Optics, vol. 48, no. 31, pp. 6044-6049.

Liang, H. M., Miranto, H., Granqvist, N., Sadowski, J. W., T. Viitala, Wang, B. C., Yliperttula, M. (2010). *Surface plasmon resonance instrument as a refractometer for liquids and ultrathin films*. Sensors and Actuators B Chemical. Vol. 149, no. 1, pp. 212-220,

Frazao, O., Caldas, P., Santos, J. L., Marques, P. V. S., Turck, C., Lougnot, D. J., Soppera, O. (2009). *Fabry-Perot refractometer based on an end-of-fiber polymer tip.* Optics Letters, vol. 34, no. 16, pp. 2474-2476.

Chen, C. H., Tsao, T. C., Tang, J. L. and Wu, W. T., (2010). *A multi-D-shaped optical fiber for refractive index sensing*. Sensors, vol. 10, no. 5, pp. 4794-4804,

Wang, Q. and Farrell G. (2006). *All fiber multimode interference based refractometer sensor: proposal and design.* Optics Letters, vol. 31, no. 3, pp. 317-319.

Antonio-Lopez, J. E., LiKamWa, P., Sanchez-Mondragon, J. J., and May-Arrioja, D. A. (2013). *All-fiber multimode interference micro-displacement sensor*. Measurement Science and Technology, vol. 24, 055104.

Antonio-Lopez J. E., May-Arrioja D. A. and LiKamWa P. (2011). *Fiber Optic Liquid Level Sensor*. Photonics Technology Letters, vol. 23, no. 23, pp. 1826-1828.

Ruiz-Perez V. I., Lopez-Cortes D., Sanchez-Mondragon J. J. and May-Arrioja D. A. (2012). *MMI Fiber Optic Temperature Sensor*. Procc. Latin American Optics and Photonics Conference LAOP 2012, Paper LS3B.4.

Walker, D. (2007). Acids and Alkalis (1st Ed.). London: Evans. p. 13. ISBN 0-237-53002-3. Retrieved 4 June 2015.

Rodríguez, A. J., Zamarreño, C., Matías-Maestro, I., Arregui, F. May-Arrioja, D.A. Domínguez-Cruz, R.F. (2014), *A Fiber Optic Ammonia Sensor Using a Universal pH Indicator*, Sensors, vol. 14, no. 3, pp. 4060-4073.

Zajíc, J., Traplová,L., Matjjec, V., Pospíšilová,M. and Barto, I. (2015). *Optical pH Detection with U-Shaped Fiber-Optic Probes and Absorption Transducers*. Conference Papers in Science. Meeting on Materials and Their Applications for Devices and Sensors. Volume 2015, Article ID 513621.

PANREAC. Indicador Universal de pH. Available on: <http://www.patacake.net/panreac/spanish/catalogo/fichastec/281370ES.HTM> [Accessed on 09 November 2015].