Iraqi J. Laser, issue 2, vol., 21, pp. 33-40 (2022)

IRAQI JOURNAL OF LASER

S and U shape offset studying of the refractive index sensor based on coreless fiber

Aya R. Mejble*   Hanan J.Taher

Corresponding author:* ***Aya.riadh1201a@ilps.uobaghdad.edu.iq*

Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

(Received 13/8/2022; accepted 21/11/2022)

Abstract: Two different shapes of offset optical fiber was studied based on coreless fiber for refractive index (RI)/concentration (con.) measurement, and compare them. These shapes are U and S-shapes, both shapes structures were formed by one segment of coreless fiber (CF) was joined between two single mode (SMF) lead in /lead out with the same displacement (12.268µm) at both sides, the results shows the high sensitive was achieved in a novel S-shape equal 98.768nm/RIU, to our knowledge, no one has ever mentioned or experienced it, it's the best shape rather than the U-shape which equal 85.628nm/RIU. In this research, it was proved that the offset form has a significant effect on the sensitivity of the sensor. Additionally, the sensor is produced using a low-cost fabrication technique. Therefore, the suggested structure is advantageous for RI/ (con.) sensing applications.

Keywords: offset, RI sensor, concentration, S-shape, U-shape.

1. Introduction

Liquid refractive index (RI) assessment is crucial for a variety of applications, including environmental monitoring [1], food safety [2], and medical diagnostics [3]. The benefits of optical fiber-based RI sensors are resistance to electromagnetic interference, small size, high sensitivity, quick response, corrosion resistance, and availability for remote sensing [4].Numerous optical fiber-based RI sensor types have been proposed up to this point, such as the Plasmon resonance at the optical fiber surface [5], the optical fiber Bragg grating [6] , photonic crystal fiber [7-8].But to fabricate this kind of sensors mentioned requires a high cost and time consuming. In recent times, Mach-Zehnder interferometers (MZIs) in-line fibers have gained more and more attention due to their ease of fabrication. Different configurations of fiber-based MZIs have been claimed such as the two tapered fiber structure [9], long-period grating pairs [10], the two peanut fiber structure [11], double cladding [12] (PCF)[13-14], femtosecond laser-assisted partial fiber ablation[15].However, these RI sensors based on these structures do not have sufficient sensitivity. Even though increasing the sensitivity by chemically etching or decreasing the fiber diameter [16]. As a result, the sensor loses a lot of its mechanical strength and becomes brittle. Coreless offset fiber is one quick and easy way to create optical fiber RI sensors that have good mechanical strength and high sensitivity. A number of offset fiber RI/(con.) sensors have recently been introduced based on: fiber types spliced such as single mode fiber (SMFs),multimode fiber (MMF), photonic crystal fiber(PCF) and coreless fiber(CF), based on shape offset including U-shape and S-shape , and based on side offset, this displacement site means in one or two sides. In this research, the RI sensor was studied based on offset shape and the (CF) with both sides' displacements. In this paper, the effect of the displacement shape on the sensitivity of the refractive index sensor was studied to find out which one is better; S-shape or U-shape, the results showed that the S-Shape has a higher sensitivity than the U –shape. The suggested sensor has the benefits of high sensitivity, straightforward design, straightforward production, and inexpensive cost.

2. Fabrication Principle and Sensing Structure

The configuration of the sensor was consist of one segment of CF (the coreless fiber is a special type of multimode fiber with uniform refractive index 1.46 (thorlabs)) was spliced between two SMFs lead in /lead out to be the (SCS) structure with fixed offset at both sides and two different shapes (U and S-shape) of sensor at the same best length which at CF 6 cm according to our previous work [17]. In this research the CF will be act as sensing segment and will be considered as a core and the environment as the cladding. To configure the U and S-shaped sensor, a fusion splicer with manual mode was used with some steps in fusion splicer as follows, a step one chose the splice mode for offset, in step two the set button was pressed (manual align) to choose motor x to control the amount of the offset, step three after the displacement amount has been determined, the button arc was pressed. With regard to the shape of the U when the ends of the fibers in the V-groove in the fusion splicing machine were precisely aligned x-direction , which represents the first part of the splicing (SMF – CF) with offset 12.268μm by displacing the CF (to down) and fixing the SMFs/lead in and this part (SMF-CF) was spliced with SMFs/lead out at the same offset with the first part(SMF-CF) remaining on the same side(left side) of the Fusion splicing(displacing SMF-CF, and fixed SMF/lead out to create the second part of the sensor and complete the U-shape, as for the shape of the S, the same steps as the U-shape but SMFs/lead out displacing to up with the same offset. An approximately Gaussian-shaped field intensity distribution is carried by light that enters the CF and moves along the lead-in SMF, at the first joint fiber (first offset) the light is, three optically pathways are created from the optical signal I_1: along the cladding of CF , and the other in the surrounding area near the surface of CF , At the second splice joint, they are then rejoined into the core at the SMFs lead out so as to create interfering fringe, which can be identified by measuring I_{out} .Given that light is passing through the sensor, as the RI of the environment varies with variations in the concentration of the solution used, it is evident that the optimum propagate constant of the cladding modes could change, so that we may measure the phase shift of the interference fringe and use the MZI fiber as a RI/(con.) sensor. When the following condition is met, the interference signal is at its lowest phase difference between cladding and core modes [18].

$$2\pi\left[n_{eff}^{co} - n_{eff}^{cl,j}\right]\frac{L}{\lambda D} = (2k+1)\pi \qquad (1)$$

Where λ_D denotes the interference spectrum dip's wavelength, n_{eff}^{co} is the core mode's effective RI, $n_{eff}^{cl,j}$ is the effective RI of the j'th order cladding mode, L is the interferometer length, and k is an integer. Consequently, the sensitivity can be stated as follows [9]:

$$\frac{d\lambda D}{dnext} = \frac{-\lambda D}{\Delta neff}\frac{\partial n_{eff}^{cl;j}}{\partial next} / \left[1 - \frac{\lambda D}{\Delta neff}\left(\frac{\partial n_{eff}^{co}}{\partial \lambda} - \frac{\partial n_{eff}^{cl,j}}{\partial \lambda}\right)\right] \quad (2)$$

Where next is the RI of the surrounding medium, and Δneff is the distinction between

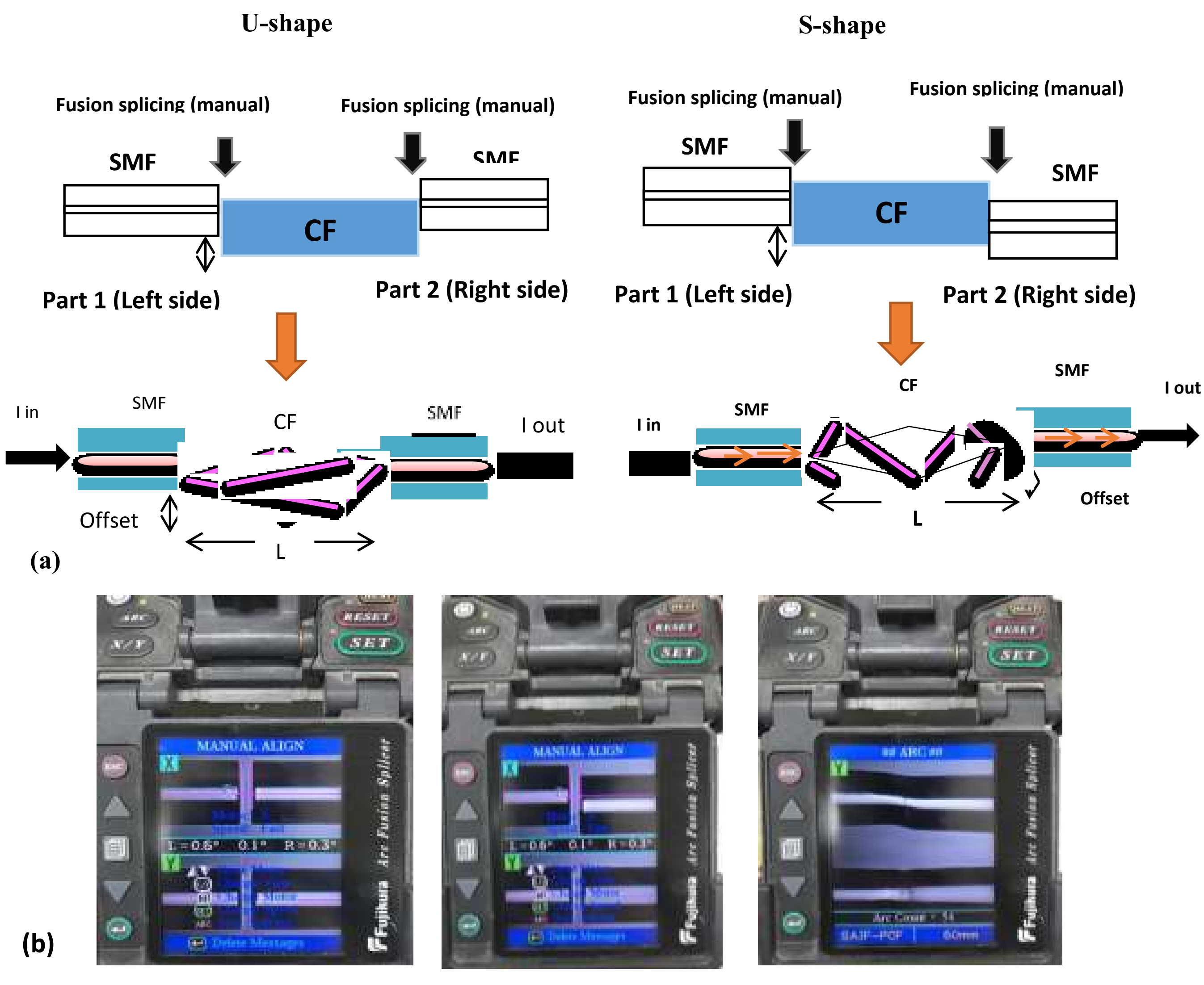


**Figure (2) (a): the steps that go into fabrication the suggested sensor.
(b): picture captured from a splicing machine demonstrating an offset splicing.**

3. Experimental Setup The experimental setup for the suggested RI/ (con.) sensor based on the offset SCS fiber structure shows the conceptual framework Fig.2, one end of the structure was linked to the cores and the claddings effective RIs.Fig.1 depicts graphically the suggested sensor structure. A broadband light source (B.B.S), the other end was spectrum of the sensors in different concentration of sodium chloride (NACL) (5%, 10%, 15%, 20%, 25%). The structure was placed in u-groove, and fixed the sensor by two holders as shown in Fig. 2.to kept the sensor from any bending and strain during the experiment.

Few drops of the NACL solution were distilled along the SCS structure until it was completely submerged, this process was repeat with each concentration of the NACL, and same experience for both sensors U, S-shape to study the effect shape offset sensor on sensitivity and compare them.

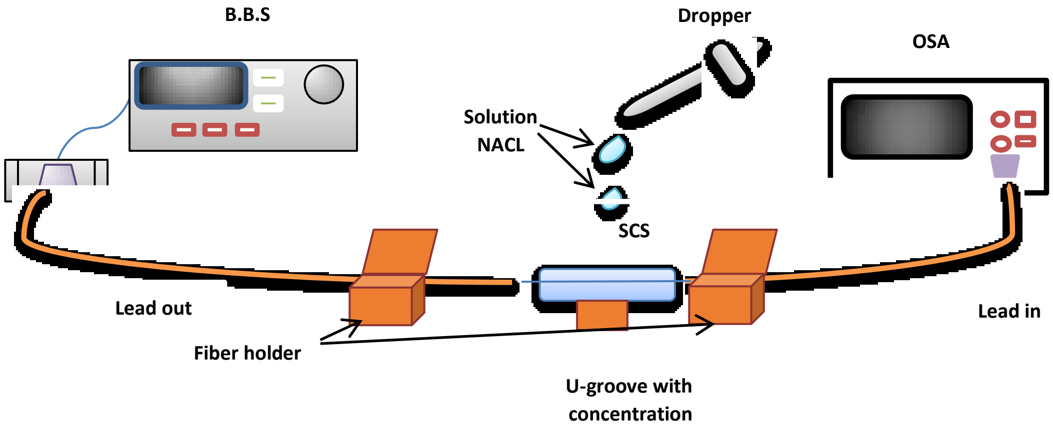
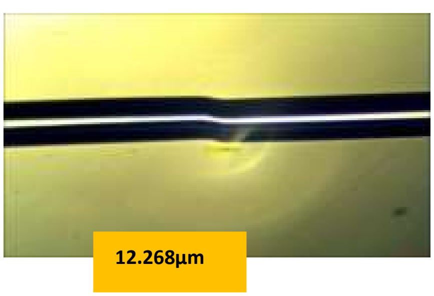
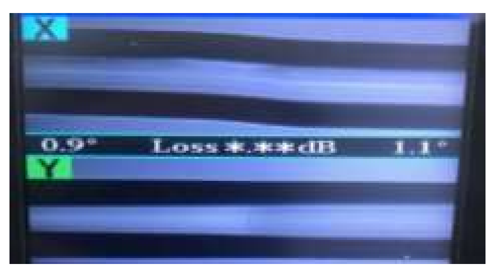


Figure (2): The schematic of the experiment setup

4- Experimental Results and Discussion

The RI/ (con.) response of the SCS (U, S-shapes) fiber structure (with offset in both sides at the same displacement 12.268 µm as shown Fig.3, and the same length of the CF 6 cm) toward the ambient RI/ (con.) was investigated. The RI was increased from 1.33 to 1.38 with increasing the (con.) of the NACL from (0% to 25%), It was made by weighing different NaCl powder concentrations (5, 10, 15, 20 and 25 gm) using an electrical scale to achieve greater accuracy. Each of these concentrations was dissolved in 100 ml of deionized water by a magnetic stirrer at room temperature (25 °C). The RI of each concentration of NACL solution is shown in table1 [19]. Fig.4 was shown the change of NACL conc. with refractive index of each con. . The transmutations spectra of each sensor (U, S-shapes) were recorded as shown as Fig. 3, where there was a clear indication of the spectral red shift. The shift in wavelengths was from 1604.455 to 1617.037 nm as shown in Fig. 4, the transmission spectra response shifted toward the longer wavelength (red shift) as the RI/(con.) of the surrounding was increased.

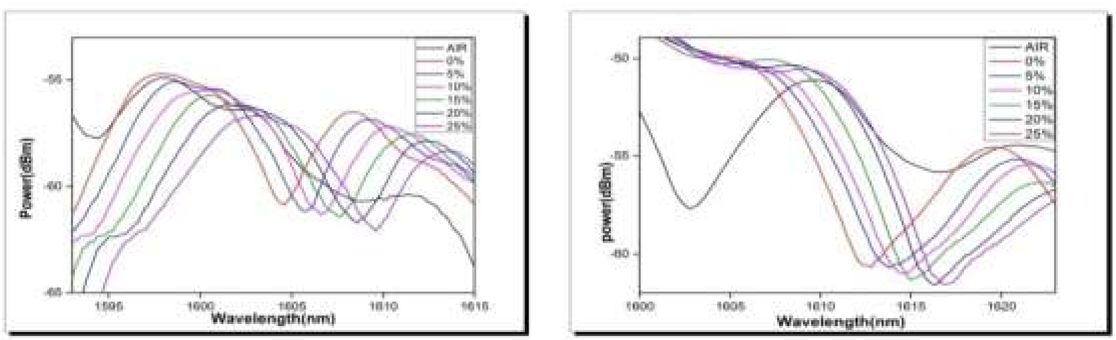




Figurer(3): (a) image the offset rejoin under the microscope (b) Image captured by a splicing device demonstrating an offset splice between SMF and CF coming from the x-direction (up) and the y-

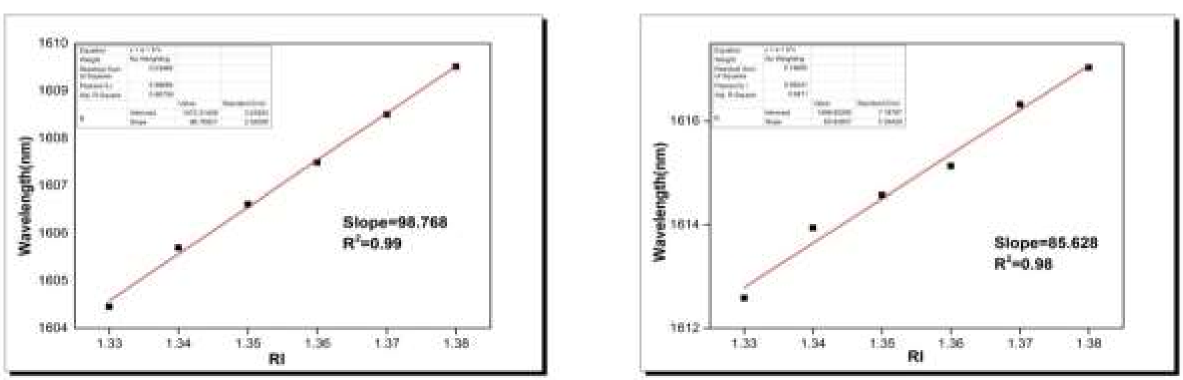
Table 1: The refractive indices of the NaCl concentrations

The NaCl concentrations (%)	RI (RIU)
0%	1.33
5%	1.34
10%	1.35
15%	1.36
20%	1.37
25%	1.38



(a) **(b)**

Figure (4): Transmission spectra of two different offset shape (a) S-shape (b) U-shape



(a) **(b)**

Figure (5): The fitting linear of two offset shapes (a) s-shape (b) u-shape

The sensitivity of each sensor was calculated. Where the S-shaped sensor was more sensitive than the U-shape sensor as shown in Fig.5 which represented the fitting linear of these sensors The experiment results shows the high sensitive was achieved in a novel S-shape equal 98.768nm/RIU, to our knowledge, no one has ever mentioned or experienced it. It's the best shape rather than the U-shape which equal to 85.628nm/RIU, The reason for the high sensitivity of the S-shape sensor is due to more evanescent wave could be interact where there were more high order mode can be interference at two splicing area when the refractive index was increased from 1.33 to 1.38 [20]. Table 2 compares prior fiber MZI approaches in terms of length and RI sensitivity.

Table2 Comparison of the length and RI sensitivity of the various fiber MZI sensor approaches

Techniques	MZI length	RI sensitivitynm/RIU
Small offset(5µm)with tapered MZI[10]	**30 mm**	**78.7**
Small offset 6µm	**100mm**	**43.97**
Large offset 40 µm[21]	**70mm**	**123.40**
Small offset8.1 µm[22]38	**36mm**	**13.76**
This work	**6cm**	**98.76**

5. Conclusion

In this research, it was demonstrated that the shape of the sensor by using offset affects the sensitivity of the sensor, two shapes was studied (S and U-shapes), where it turns out that the S-shape is better than the U-shape, where the sensitivity of the S-shape is 98.786nm/RIU, while the U-shape is 85.628nm/RIU . The sensor was made in an easy and inexpensive way by attaching a piece of CF between two SMF lead in/lead out with displacement of 12.268µm at both sides.

Reference

[1] Joe, H. E., Yun, H., Jo, S. H., Jun, M. B., & Min, B. K. *"A review on optical fiber sensors for environmental monitoring"*. International journal of precision engineering and manufacturing-green technology, *5*(1), 173-191(2018)

[2] Patel, P. D. " *(Bio) sensors for measurement of analytes implicated in food safety: a review*". TrAC Trends in Analytical Chemistry, 21(2), 96-115(2002).

[3]Ahmed, K., Ahmed, F., Roy, S., Paul, B. K., Aktar, M. N., Vigneswaran, D., & Islam, M. S. *"Refractive index-based blood components sensing in terahertz spectrum" . IEEE Sensors Journal*, *19*(9), 3368-3375(2019).

[4] Bhardwaj, V., Kishor, K., & Singh, V. K. *"Experimental and theoretical analysis of connector offset optical fiber refractive index sensor"*. *Plasmonics*, *12*(6), 1999-2004(2017)

[5] Slavík, R., Homola, J., & Čtyroký, J. *"Single-mode optical fiber surface plasmon*

resonance sensor". Sensors and Actuators B: Chemical, *54*(1-2),74-79 (1999).

[6] Iadicicco, A., Cusano, A., Cutolo, A., Bernini, R., & Giordano, M. *"Thinned fiber Bragg gratings as high sensitivity refractive index sensor". IEEE Photonics Technology Letters*, *16*(4), 1149-1151(2004).

[7] Wu, D. K., Kuhlmey, B. T., & Eggleton, B. J. *"Ultrasensitive photonic crystal fiber refractive index sensor". Optics letters*, *34*(3), 322-324(2009).

[8]Gangwar R, Singh VK *"Refractive index sensor based on selectively liquid fluid infiltrated dual core photonic crystal fiber"* .Photon Nano Str 15:46–52(2015).

[9] Zhang, Q., Zhou, J., Chen, J., & Tan, X. *"Single-mode fiber refractive index sensor with large lateral offset fusion splicing between two abrupt tapers". Optical Engineering*, *51*(9), 090502(2012)

[10] Chong, J. H., Shum, P., Haryono, H., Yohana, A., Rao, M. K., Lu, C., & Zhu, Y. *"Measurements of refractive index sensitivity using long-period grating refractometer". Optics communications*, *229* (1-6), 65-69(2004).

[11] Huang, R., Ni, K., Ma, Q., & Wu, X. *"Refractometer based on a tapered Mach–Zehnder interferometer with Peanut-Shape structure". Optics and Lasers in Engineering*, *83*, 80-82(2016) .

[12] Lvanov O, *Chertoriyskiy "Fiber-optic bend sensor based on double cladding fiber"*. J Sens. 726793–6(2015).

[13] H. Gong, C. Chan, F. Zhang, C. Wong, X. Dong, *"Miniature refractometer based on modal interference in a hollow-core photonic crystal fiber with collapsed splicing"*, J. Biomed. Opt. 16, 2–5(2011).

[14] C. Li, S. Qiu, Y. Chen, F. Xu, Y. Lu *"Ultra-sensitive refractive index sensor with slightly tapered photonic crystal fiber"*, IEEE Photon. Technol. Lett. 24, 1771–1774(2012).

[15] L. Zhao, L. Jiang, S. Wang, H. Xiao, Y. LuA *"high-quality Mach-Zehnder interferometer fiber sensor by femtosecond laser one-step processing"*, Sensors.11 , 54–61(2011).

[16] Coradin, F. K., Possetti, G. R., Kamikawachi, R. C., Muller, M., & Fabris, J. L. *"Etched fiber Bragg gratings sensors for water-ethanol mixtures: a comparative study". Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, *9*, 131-143 (2010).

[17] A.R. mejbel and H. J.Taher *"Coreless fiber length influence for refractive index measurements based on lateral offset structure"*. Neuro Quantology 2022; 20(7):2337-2342(2022).

[18] Xia, T. H., Zhang, A. P., Gu, B., & Zhu, J. J. *"Fiber-optic refractive-index sensors based on transmissive and reflective thin-core fiber modal interferometers". Optics Communications*, *283*(10), 2136-2139(2010)

[19] Zhao, Y., Li, X. G., & Cai, L." *A highly sensitive Mach–Zehnder interferometric refractive index sensor based on core-offset single mode fiber". Sensors and Actuators A: Physical*, *223*, 119-124(2015).

[20] Hamza, N. *Enhanced Refractive Index Sensor Based on Etched Coreless Fiber*. Authorea Preprints (2020).

[21] Yu, F., Xue, P., & Zheng, J. *Study of a large lateral core-offset in-line fiber modal interferometer for refractive index sensing*. *Optical Fiber Technology*, *47*, 107-112 (2019).

[22] Yao, Q., Meng, H., Wang, W., Xue, H., Xiong, R., Huang, B., & Huang, X. *Simultaneous measurement of refractive index and temperature based on a core-offset Mach–Zehnder interferometer combined with a fiber Bragg grating. Sensors and Actuators A: Physical*, *209*, 73-77(2014).

دراسة تأثير شكل الاوفسيت (S and U) على حساسية متحسس معامل الانكسار المعتمد على الليف البصري منزوع القلب

ايه رياض مجبل حنان جعفر طاهر

معهد الليزر للدراسات العليا / جامعة بغداد – بغداد، العراق

الخلاصه : تمت دراسة شكلين مختلفين من المتحسسات بناءا على شكل الاوفسيت (الازاحه الجانبيه) هما ال S و ال U وتأثيرها على متحسس معامل الانكسار المصنوع من ليف بصري منزوع القلب ذو طول 6سم تم لحامه بين ليفين بصريين احادي الطول الموجي بازاحه متساويه في كلا الطرفين وقدرها 12.268مايكرومتر بشكليين مختلفيين .لمعرفة مدى تاثير شكل الاوفسيت ع حساسية المتحسس , حيث اضهرت النتائج ان الحساسية الاعلى قد حققت في الشكل الجديد ال S الذي لم يسبق لاحد تجربته او صناعته على حد علمي , حيث كانت 98.768نانومتر/وحدات معامل الانكسار بينما حساسية ال U كانت تساوي 85.628نانومتر/وحدات معامل الانكسار.في هذا البحث تم اثبات ان شكل الاوفسيت يؤثر على حساسية المتحسس .بالاضافة الى ذلك ، يتم إنتاج المستشعر باستخدام تقنية تصنيع منخفضة التكلفة. لذلك ، فإن الهيكل المقترح مفيد لتطبيقات استشعار معامل الانكسار.