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Surface Plasmon Plastic Optical Fiber Resonance with Multi-Layer as Chemical Sensor

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Abstract

A chemical optical fiber sensor based on surface plasmon resonance (SPR) was developed and implemented using multimode plastic optical fiber. The sensor is used to detect and measure the refractive index and concentration of various chemical materials (Urea, Ammonia, Formaldehyde and Sulfuric acid) as well as to evaluate the performance parameters such as sensitivity, signal to noise ratio, resolution and figure of merit. It was noticed that the value of the sensitivity of the optical fiber-based SPR sensor, with 60nm and 10 mm long, Aluminum(Al) and Gold (Au) metals film exposed sensing region, was 4.4 µm, while the SNR was 0.20, figure of merit was 20 and resolution 0.00045. In this work a multimode plastic optical fiber with a core diameter of 980 µm, fluorinated polymer cladding of 20 µm and a numerical aperture of 0.51 was used.

Article Info.

Keywords:
Plastic optical fiber, surface Plasmon resonance, multi- layer metal, chemical sensor.

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1. Introduction

The surface Plasmon sensor is a highly effective tool for evaluating very minor changes in the refractive index (RI) at an interface between a metal substrate and a dielectric medium [1] . Surface Plasmon resonance optical fiber is commonly used as a detection concept with a lot of sensors in various areas, as in the case of bio and chemistry monitoring [2-4]. Plasmonic sensor based fiber optic device sensing device is based on the guidance of light through optical fiber via total internal reflection (TIR) [5]. The optical fiber used is usually either a glass or plastic [6]. Plastic optical fiber are especially beneficial to be used in sensors. Because of their excellent durability, simple handling, large numerical aperture, large diameter and smaller bending radii [7] . Most fiber-optic SPR sensors are covered with gold metals that were applied to the measurement in most situations depending on the refractive index change [8]. For this work, the deposition of metal is rendered, using multimode plastic optical fiber bent forming a D- shape on the polished surface in contact with core.

Jorgenson et al. was the first to utilize the SPR sensors in optical fiber without prism [3]. SPR is based on the interaction of free electrons of a metallic layer with light [9]. Resonance occurs when the oscillation frequency of the metal electrons are equal to the incident light frequency, thus, light intensity reflected from the metallic film is significantly, and a Plasmon surface wave is formed by the transfer of photon energy to the metal layer [10]. Optical components such a high refractive index prism, optical fiber, and diffraction grating are used to excite the surface Plasmon [11]. The optical fiber sensors that have been reported increased in the research lines and possibilities for the manufacture of new sensors were applied with the use of nano-coating deposition techniques [12].

2. The performance parameters SPR

The parameters of the SPR sensors include, sensitivity, signal to noise ratio, figure of merit and resolution. In the Case of spectral interrogation, Sensitivity can be defined as the change in the wavelength of the resonance per unit change in the refractive index of the sensing medium and can be written as [7]:

$$S=\frac{\Delta\lambda res}{\Delta ns} \qquad \frac{nm}{RIU} \tag{1}$$

where $\Delta\lambda_{res}$ and Δn_s are the change of the resonance wavelength and the change of refractive index respectively. The minimum change of the refractive index detectable by the sensor can be defines the resolution and is given as [13]:

$$R=\frac{\Delta ns}{\Delta\lambda res}\,\Delta\lambda_{DR} \tag{2}$$

where (λ_{DR}) is the spectral resolution of the spectrometer. The signal, it is specified as SNR which is highly dimensionless parameter dependent on the RI shift [7].

$$SNR\ (n) = [\frac{\Delta\lambda res}{\Delta\lambda 0.5}] \tag{3}$$

where $\Delta\lambda_{0.5}$ is the width of the spectral curve.

$$FOM=\frac{S}{\Delta 0.5} \tag{4}$$

FOM is a figure of merit which is one of the essential parameters for the signal to noise ratio (SNR) to determine the output of plastic optical fiber sensor by adding the spectral width [14].

3. Experimental work (multi- layer based optical fiber chemical sensor)

3.1. Experimental setup

Using an experimental low cost and easy to use setup with highlight`1 the multi-layer metal efficiency in this very useful experimental set up. The experimental setup consisted of a light source (halogen torch), an optical spectrum analyzer (OSA) from Thorlabs Company, and the plastic optical fiber from Thorlabs Company as well. The OSA is connected to a computer. The bends of SPR along with the data are seen online and saved as shown in Figs.1 and 2.

Figure 1: Experimental process.

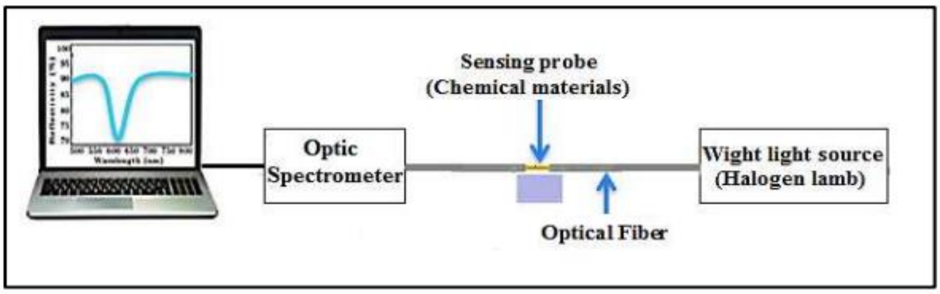


Figure 2: The diagram of the experimental setup for the optical fiber chemical sensor based on SPR.

3.2. Sensors by SPR. POF

The multimode optical plastic fiber has the following dimension: diameter 100µm, core diameter of 980 µm, cladding of 20µm and numerical aperture of 0.51. The plastic optical fiber was embedded in a resin block, the optical fiber plastic unit was it rendered by disable the plastic fiber padding along half the diameter, giving the D- shape wave guide, polishing method used. The method of polishing was done with 5 µm polishing paper to remove the core and the cladding components. Following a Figure of "8", after 20 full strikes as shown in Fig.3. Thereafter, the polishing process was performed. The removed clad part was cleaned with distilled water, and then it was deposited about 30 nm thickness of aluminum and 30 nm thickness of gold metal by using ION- COATER. The thickness of the metal layer was determined as shown in Fig.4. The used machine was of the Model KIC-1A from COXEM Company, Korea. To deposit aluminum and 30 nm gold requires an approved condition, were 7 mA current and 300 sec time of deposition for both metals.

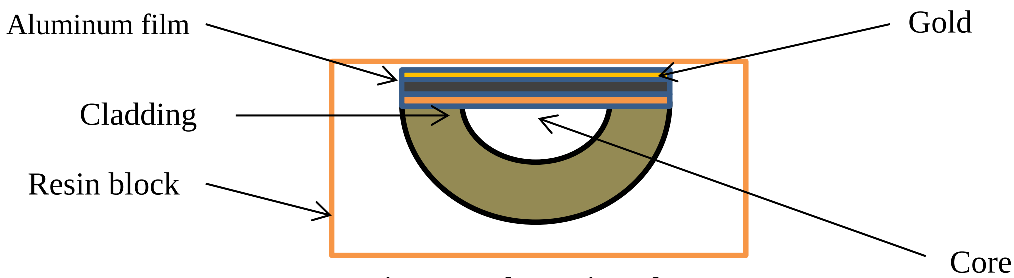


Figure 3: The section of sensor.

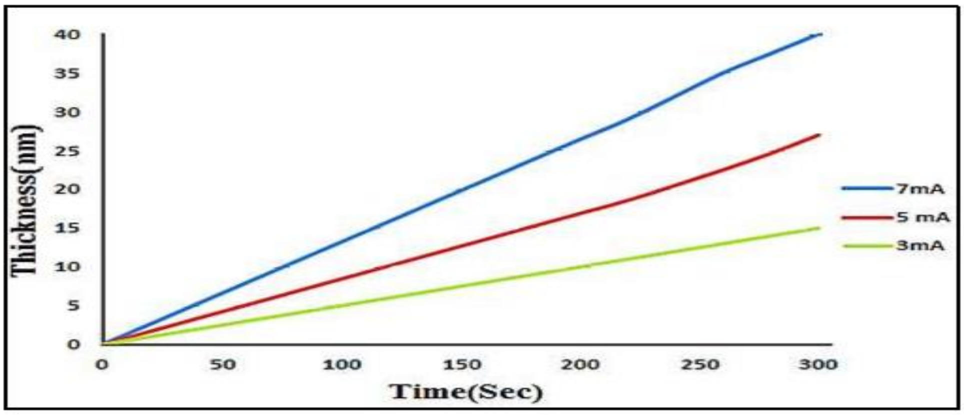


Figure 4: The thickness of the gold layer as a function of deposition time in sec.

3.3. Preparation of testing solutions

The sensitive area of the sensor is protected by diverse solution of sucrose/ water with different concentration and then different (n_s) refractive indices. To measure the refractive index of the solution the (Abbe), refractometer was used. Fig.5 shows the relationship between the refractive index and the solution concentration.

4. Results and discussion

The parameters values used in the experimental analysis of numerical included numerical fiber optic aperture (NA) = 0.51, core fiber diameter (D) = 980 µm, longitude detection (L) = 10 mm, thickness of metal stratum (d) = 60 nm, (30 nm aluminum/30nm gold), and different values (1.34, 1.351, 1.354, 1.361 and 1.37), a refractive index of the sucrose-water solution.

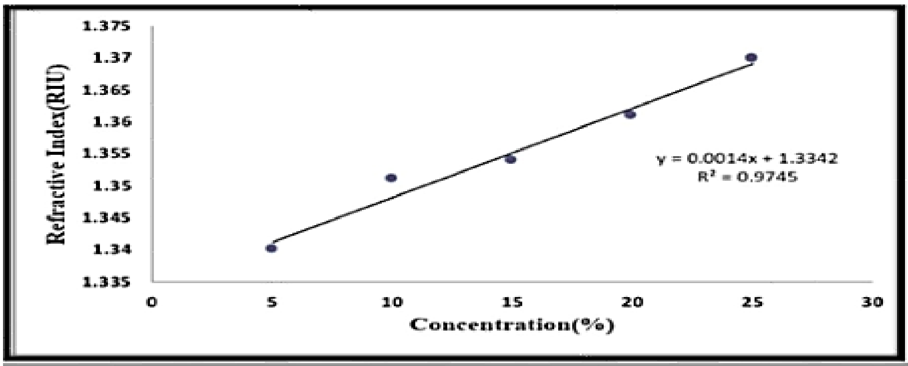


Figure 5: Refractive index of sucrose solution in water as a function of solution concentration.

The spectra were obtained by recording the propagation curves T (transmission), of light using an optical fiber based on the ratio of the intensity I measured while a sample was present and the amplitude of the optical signal I_o measured with air. The transmission (T) is a function of wavelength in (nm). The SPR curve is called the wavelength curve and, at a particular wavelength, at a given wavelength called resonance wavelength. A clear sharp dip happens in T because the energy of light at incident is transferred to the electron of the metal and thus lessens the reflected light intensity. This dip position depends on the refractive index (n) of the sensing medium. The resonance wavelength increases as the refractive index of the solution increases. This takes place because the energy decreases and thus the sharp dip of the sensor wavelength will be shifted to the longer wavelength side (redshift), that shown in Fig.6.

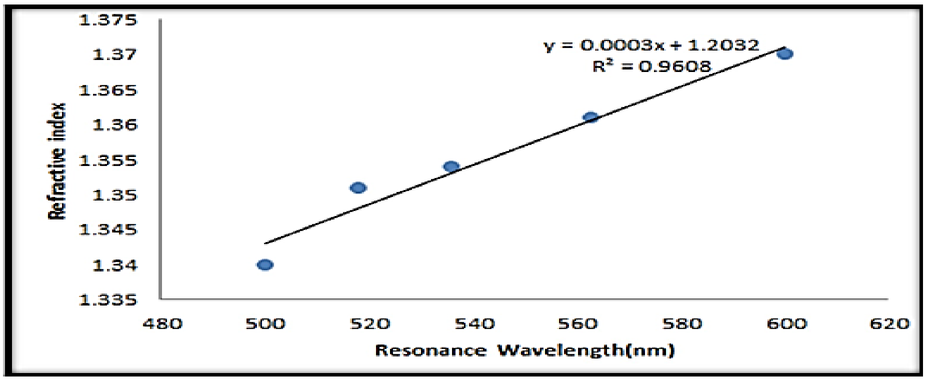


Figure 6: Refractive index in light of the wavelength of resonance.

Fig.7 shows the surface Plasmon resonance of multi-layer combined Aluminum (Al) and Gold (Au), at specific refractive index values of the sensing devices of chemical samples. It is obvious that the width and dip position of each SPR response curve is changed to the sensor, with each sample having a different refractive index. Also, the magnitude of shifting of the dip position increases as the surface Plasmon resonance (SPR) curve width, the value of the shifting, and the position of dip, change with changing the resonance wavelength and refractive index of the sensing medium, these changes occur because the parameters performance depend on the change in the resonance wavelength, the refractive index and the width of the spectral curve.

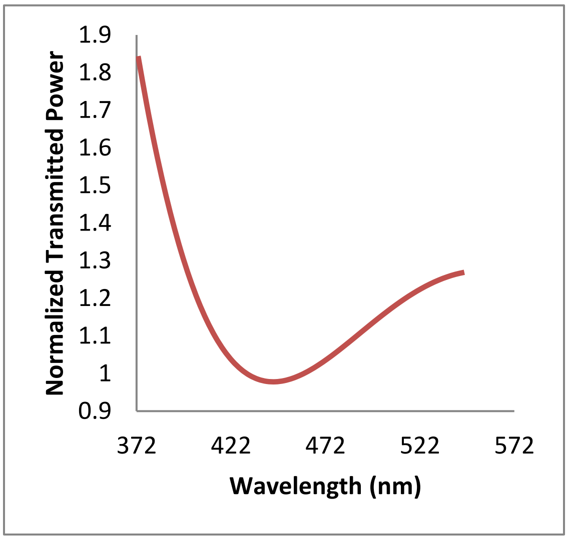
Table 1 display experimental performance parameters for multi-layer (aluminum/gold) simulated and manufactured sensor. Table 2 demonstrates the values of the refractive index and the concentration for each sample of chemical at different resonance wavelength. The refractive index increases as the concentration of the solution increases and thus the resonance occurs with longer wavelength.

Table 1: Experimental performance parameters of the multi-layer based sensor.

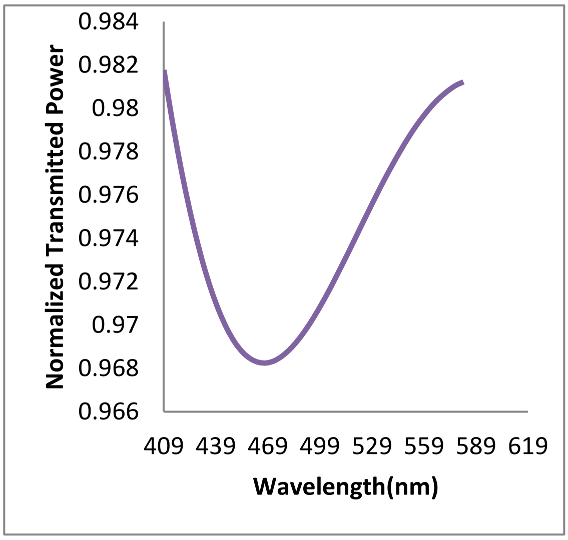
Metal	**Sensitivity(sn) [µm/RIU]**	**Signal to noise ratio (SNR)**	**Figure of merit (FOM)**	**Resolution [15]**
Gold	4.4	0.20	20	0.00045

Table 2: Resonance wavelengths of different values of concentration and refractive index.

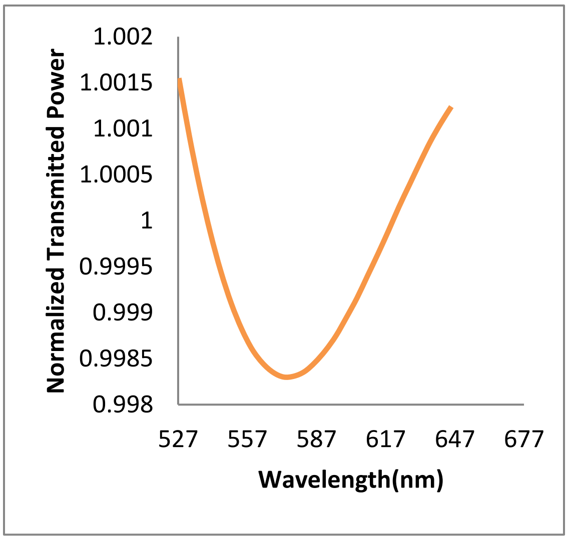
Samples	**Resonance wavelength (λ_{res})(nm)**	**Refractive index(n).(RIU)**	**Concentration (c)(%)**
Urea	445	1.3367	1.9572
Ammonia	468	1.3436	1.9894
Formaldehyde	568	1.3736	2.1294
Sulfuric acid	604	1.3844	1.9222



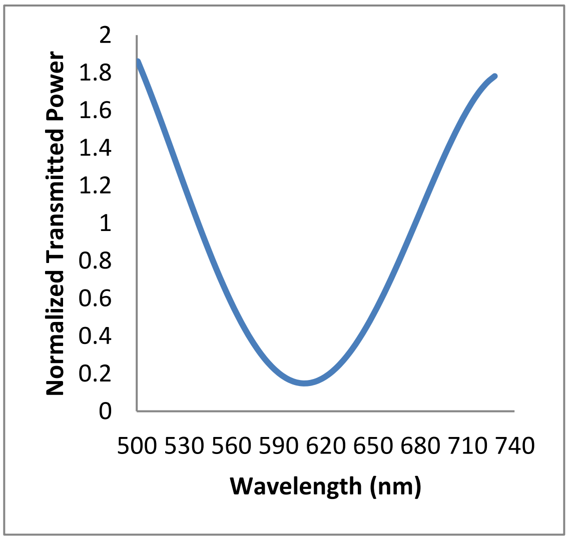
(a) Urea λ_{res}=445



(b) Ammonia λ_{res}=468



(c) Formaldehyde λ_{res}=568



(d) Sulfuric acid λ_{res}=604

Figure 7: SPR curve of the optical fiber sensor with multi-layer metal (aluminum/gold) for different samples of chemical: (a) Urea, (b) Ammonia, (c) formaldehyde, and (d) Sulfuric acid.

5. Conclusions

In this work we have reported the ability of a low cost (SPR-POF) sensor to be exploited in chemical applications. The systems of (SPR_POF) sensor are easy to use, of small size and of low cost. The change in the SPR response curves for each sample was reported which showed a dip in the resonance position. For each increase in the refractive index and thus for various values of the concentration of chemical solution a variation in the resonance wave occurs. This dip shift occurs for different type of solutions. The sensitivity of the resonance of plastic optic fiber-based surface Plasmon, with the 60 nm thick Al/Au multi- layer of metal film exposed sensing region, had value of 4.4 µm/RIU, while the signal to noise ratio was 0.20.

Acknowledgements

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Conflict of interest

Authors declare that they have no conflict of interest.

References

1. Zeni L., Cennamo N., and Pesavento M. *Chemical sensors in plastic optical fibers*. in *Proceedings of the Ninth International Conference on Sensor Device Technologies and Applications, Venice, Italy*. 2018.
2. Homola J., *Present and future of surface plasmon resonance biosensors.* Analytical and bioanalytical chemistry, 2003. **377**(3): pp. 528-539.
3. Jorgenson R.C. and Yee S.S., *A fiber-optic chemical sensor based on surface plasmon resonance.* Sensors and Actuators B: Chemical, 1993. **12**(3): pp. 213-220.
4. Latifi H., Zibaii M.I., Hosseini S.M., and Jorge P., *Nonadiabatic tapered optical fiber for biosensor applications.* Photonic Sensors, 2012. **2**(4): pp. 340-356.
5. Pospíšilová M., Kuncová G., and Trögl J., *Fiber-optic chemical sensors and fiber-optic bio-sensors.* Sensors, 2015. **15**(10): pp. 25208-25259.
6. Cennamo N., Varriale A., Pennacchio A., Staiano M., Massarotti D., Zeni L., and D'Auria S., *An innovative plastic optical fiber-based biosensor for new bio/applications. The case of celiac disease.* Sensors and Actuators B: Chemical, 2013. **176**: pp. 1008-1014.
7. Cennamo N., Massarotti D., Conte L., and Zeni L., *Low cost sensors based on SPR in a plastic optical fiber for biosensor implementation.* Sensors, 2011. **11**(12): pp. 11752-11760.
8. Sharma A. and Mohr G., *Theoretical understanding of an alternating dielectric multilayer-based fiber optic SPR sensor and its application to gas sensing.* New Journal of Physics, 2008. **10**(2): pp. 023039.
9. Nesterenko D.V. and Sekkat Z., *Resolution Estimation of the Au, Ag, Cu, and Al Single- and Double-Layer Surface Plasmon Sensors in the Ultraviolet, Visible, and Infrared Regions.* Plasmonics, 2013. **8**(4): pp. 1585-1595.
10. Hottin J., Wijaya E., Hay L., Maricot S., Bouazaoui M., and Vilcot J.-P., *Comparison of Gold and Silver/Gold Bimetallic Surface for Highly Sensitive Near-infrared SPR Sensor at 1550 nm.* Plasmonics, 2013. **8**(2): pp. 619-624.
11. Murtadha Faaiz S., Ali A.A.-Z., and Shehab A.K., *Surface Plasmon Resonance Based Fiber Optic Sensor: Theoretical Simulation and Experimental Realization.* Al-Nahrain Journal of Science, 2018. **21**(1): pp. 65-70.

12. Jassam G.M. and Al –Bassam S.S., *Acetic acid concentration estimation using plastic optical fiber sensor based surface plasmon resonance.* Iraqi Journal of Physics (IJP), 2019. **17**(43): pp. 11-17.
13. Srivastava S.K. and Gupta B.D., *Influence of ions on the surface plasmon resonance spectrum of a fiber optic refractive index sensor.* Sensors and Actuators B: Chemical, 2011. **156**(2): pp. 559-562.
14. Chu S., Nakkeeran K., Abobaker A.M., Aphale S.S., Babu P.R., and Senthilnathan K., *Design and analysis of surface-plasmon-resonance-based photonic quasi-crystal fiber biosensor for high-refractive-index liquid analytes.* IEEE Journal of Selected Topics in Quantum Electronics, 2018. **25**(2): pp. 1-9.
15. Mishchenko A., Vonlanthen D., Meded V., Burkle M., Li C., Pobelov I.V., Bagrets A., Viljas J.K., Pauly F., and Evers F., *Influence of conformation on conductance of biphenyl-dithiol single-molecule contacts.* Nano letters, 2010. **10**(1): pp. 156-163.

رنين بلازمون السطح لليف بصري متعدد الطبقات كمتحسس كيمياوي

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الخلاصة

تم تطوير وتنفيذ متحسس الالياف الضوئية الكيميائية المعتمدة على اساس رنين البلازمون السطحي باستخدام الالياف الضوئية البلاستيكية متعددة الانماط. يستخدم المستشعر لأكتشاف وقياس معامل الأنكسار وتركيز المواد الكيميائية المختلفة وكذلك لتقيم معلمات الأداء مثل التحسسية، نسبة الاشارة الى الضوضاء، قيمة الكفاءة، وقدرة الفصل للمتحسس المصنع. لقد وجد أن تحسسية متحسس الألياف البصرية المعتمدة على رنين بلازمون السطح لسمك المعدنيين 60 nm وطول الغشاء 10 mm لمنطقة المتحسس المكشوفة هي 4 µm/RIU. بينما نسبة الاشارة الى الضوضاء 0.20، قيمه الكفاءة 20، وقدرة التحليل 0.00045. نوع الالياف البصرية المستخدمة في هذا العمل هو الالياف البلاستيكية متعددة الانماط قطرها الاساسي 980µm، والكسوة 20µm، والفتحة العددية 0.51.