Optimum Design to Get the Best Sensitivity of U shape Localize Surface Plasmon Resonance Sensor

Saffana Z. Maseer[1],Bushra R. Mahdi[2]

ABSTRACT:

In this study, three sensors were synthesized in U shape by using plastic optical fiber and tested in two steps. Firstly, three sensors were tested without coating. They were manufactured using a plastic optical fiber, this optical fiber was bent in a U-shape, and then a part of the fiber clad was removed by polishing at the sensor head to become a D-shape. These sensors were bent with three different bending diameters (1, 0.7, and 0.5) cm to study the effect of bending diameter on the sensitivity of the sensor. These sensors were tested with sodium chloride solution with refractive indices ranging from 1.333 to 1.363, and it was noted that there was decreasing in Intensity of output light with increase concentration of solutions. Secondly, these three sensors were coated with 20nm layer of gold nanoparticles thickness. These sensors were tested with a solution of sodium chloride salt, and it was noted that there was a shift in wavelengths, and the largest shift in wavelengths was achieved by the sensor with a curvature diameter of 0.5 cm, where the shift in wavelength was 5.37nm and the sensitivity was 179nm/RIU. Thus, the sensor with bending diameter of 0.5 cm achieves the highest sensitivity, so it was chosen as an optimum bending diameter. 7574

Keywords: plastic optical fiber, localize surface Plasmon Resonance, U bent fiber sensor.
DOI Number:10.14704/nq.2022.20.8.NQ44781 **NeuroQuantology 2022; 20(8): 7574-7582**

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

INTRODUCTION:

Surface Plasmon Resonance (SPR) sensors, a family of optical sensors, have been extensively employed for sensing applications in chemistry, biology, environmental monitoring, the food industry, and clinical diagnostics due to its high sensitivity, stability, and dependability(Ariadny da S Arcas *et al.*, 2018).When the wave vector of the incident light matches the resonance parameters, the Local Surface Plasmon Resonance (LSPR) sensing operates on the fundamental tenet of the excitation of charge density oscillations propagating along the metal nanoparticle/dielectric interface(Kadhim, Wu and Wang, 2022).The electromagnetic fields linked to the aforementioned oscillations are extremely responsive to changes in the medium(Lee *et al.*, 2021). For metallic coating on fiber usually gold is used(Khaleel and Tawfeeq, 2021).Gold nanoparticles (GNPs), a sensitive coating among Nano sized metallic materials, are commonly used in optical sensing applications due to their remarkable optical characteristics(Al-Hayali, Salman and Al-Janabi, 2021).Gold Nano Particles (GNPs) demonstrates a higher shift of resonance parameter to change in sensing layer and is chemically stable(Gupta and Verma, 2009).Because it outperforms silica fiber in terms of machinability, resilience, optical coupling, and handling, plastic optical fiber (POF) has attracted more attention in recent years(Christopher, Subrahmanyam and Sai, 2018).In recent years, various SPR sensor constructions, including tapered fiber, side-polished fiber, hetero-core structured fiber, and U-shaped fiber, have been developed to boost the fiber SPR's sensitivity sensor's sensitivity(Xie *et al.*, 2021).In comparison to straight fiber optic sensors, the U-bent sensor structure has shown promising performance in terms of sensitivity, with one of its most notable advantages being its applicability for point sensing applications(Ariadny da S. Arcas *et al.*, 2018).The bend diameter of a U-bent sensor is an important factor in the best design for efficient achieving mode conversion, and smaller bending diameters may provide greater response due to improved evanescent wave interactions inside the active sensing zone(Tan *et al.*, 2020).There is a critical radius of curvature below which the fiber no longer transmits light because coupling of evanescent field between two fiber arms with less than the optimum bend radius. Since plastic fibers have larger NA than glass fibers, they can be bent with a smaller bend radius without significant loss of light given the same wavelength of light(Tan *et al.*, 2022). Refractive index (RI) sensors, pH sensors, strain sensors(Hasan and Taher, 2021), temperature sensors, curvature sensors, and humidity sensors are just a few of the sensing applications where optical fiber sensors have received significant attention(Khashin and Taher, 2021).

Although U-shaped fiber sensors significantly increases sensitivity, there are other ways to do so according to the research, These techniques entail further modifying the existing U-shaped fiber probes, producing a hybrid structure and even higher sensitivity(Wang *et al.*, 2020). In most cases, structural modification techniques like tapering by polishing are employed to increase the sensitivity of optical fiber sensors(Wang *et al.*, 2020). When the U-shaped outer curvature is removed by polishing, the evanescent field's power and penetration depth increase because when the outer curvature of the U-shaped is removed by polishing; the RI difference between the analytic and the inner curvature of fiber will decrease, leading to the increase of evanescent wave power, as well as its penetration depth. These structural modifications are used to improve the sensitivity better sensing performance is made possible by these structural changes. In this work U bent plastic optical fiber sensor with polishing the head sensor with optimum bending diameter was designed. This sensor based on local surface Plasmon resonance phenomena by coating the head sensor with Gold Nano particles as a Plasmon metal.

MATERIAL AND METHOD:

In this investigation, a semiconductor laser operating at 650 nm and 5 mW was used as the source, an Ocean 2000 spectrometer was employed, and plastic optical fiber POF with a diameter of 980 µm was bent in the shape of a U to create the sensors illustrated in figure 1.

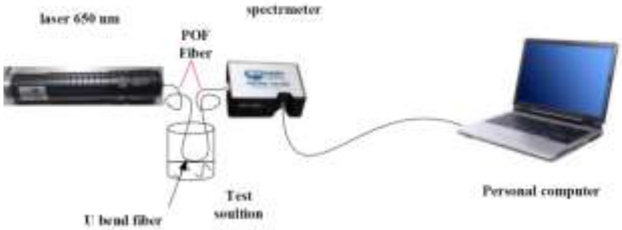


Figure1: Experimental setup.

Firstly,Plastic Optical Fiber (POF) was made of PMMA with refractive indices 1.49 and 1.41 for core and cladding respectivelywas bent in U shape with three different bending diameters as shown in figure 2

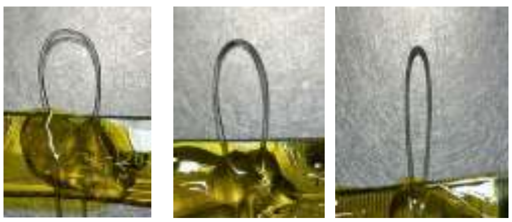


Figure2: three POF bent in U shape with three different bending diameters (1, 0.7 and 0.5) cm respectively.

Then, partial from head sensor was removed by polishing the POF by using very smooth emery paper as shown in figure 3

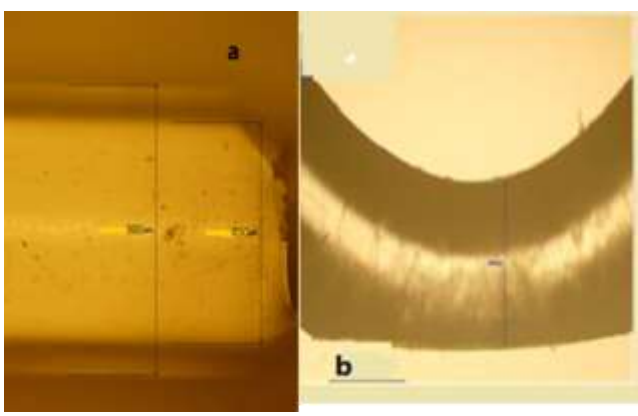


Figure3: Microscope image of (a) straight POF and (b) bent POF in U shape with polished head sensor.

Finally, these three sensors were sputtered with Gold Nano Particles (GNPs) by using DC Plasma coating device as shown in figure 4

Figure 4: Dc Plasma coating device.

The U shape POF head sensor was put into the vacuum chamber as shown in the figure 4, the chamber is supplied with a load lock system and diffusion pumps with DC power suppliers and also provided with a standard stage in which the head sensor could be hold as shown in figure 4. The gold target with a thickness of (1 mm) a diameter of (5 cm), and a purity of (99.9%) was utilized to sputter deposited GNP thin films upon the head sensor. The Scanning Electron Microscope (SEM) image for the GNPs was shown in figure 5.

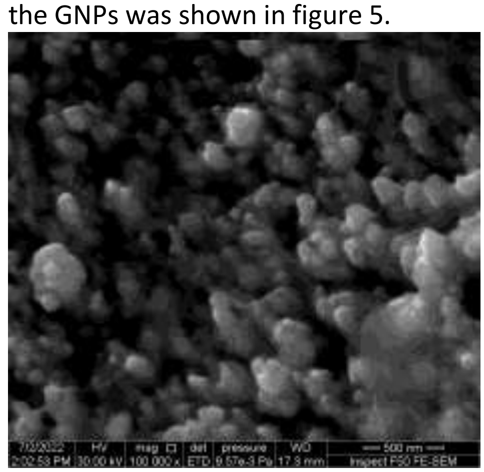


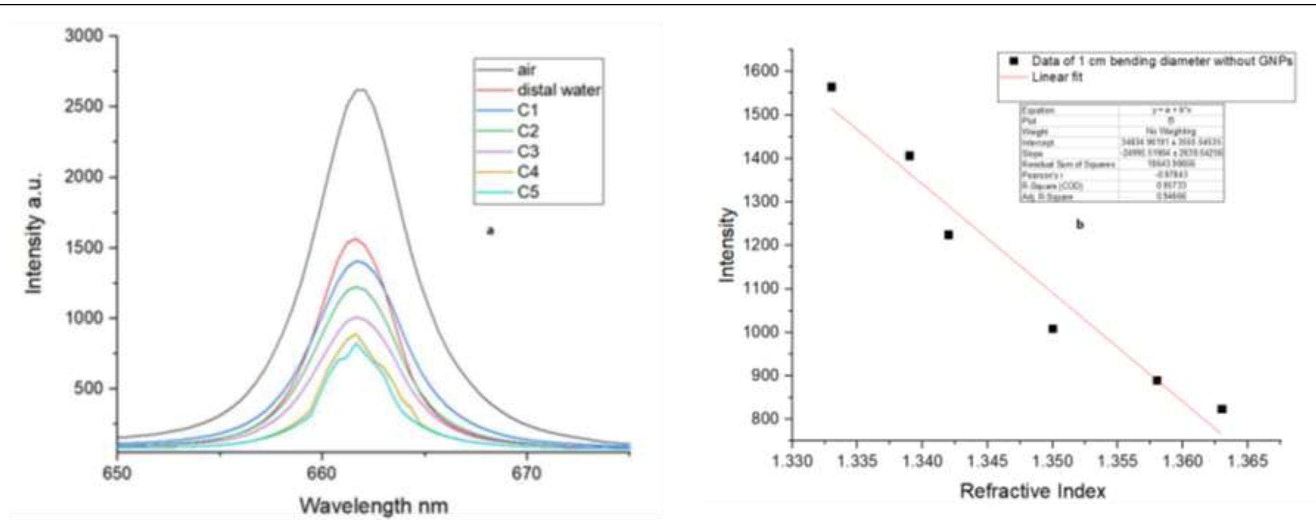
Figure 5: SEM image to show Gold Nano Particles (GNPs) in scale 500nm.

These sensors were tested by usingSodium chloride solutions as a tester solution. Sodium chloride (NaCl) solutions with different concentrations are used as samples with different refractive indices. NaCl solutions were prepared by taken different concentration values of the Salt powder dissolved in distal water at room temperature. Abbe refractometer measured the refractive index (RI) of the solutions with ranges (1.333-1.363). The testing process is done by immersing the manufactured sensor in the prepared saline solution and before each test process the sensor is washed with distilled water

RESULTS AND DISCUSSION:

In this work, the effectiveness of the bending diameter on the sensor sensitivity was studied by using three pieces of POF bent in U shape with different bending diameter (1, 0.7, and 0.5) cm with polishing head sensor as D-shape. The first end of each sensor connected to the laser source and the second end connected to the Ocean spectrometer. In the first step the spectra for these sensors were recorded with peak intensities (2618, 2294 and 2084) for sensorswithout coating with bending diameters (1, 0.7 and 0.5) cm respectively. The senor with 0.5 cm bending diameter shows lower peak intensity than peak intensities of sensors with 0.7cm and 1 cm because as bending diameter decrease the power of evanescent wave increase as shown in figures 6, 7 and 8

The U bent POF sensors with (1, 0.7 and 0.5) cm bending diameters were subjected to Sodium Chloride solution with RI varying from 1.333 to 1.363. The intensity curves were recorded for Sodium Chloride solutions at room temperature as shown in figures6, figure7 and figure8 for U bent sensors with (1, 0.7 and 0.5) cm respectively.



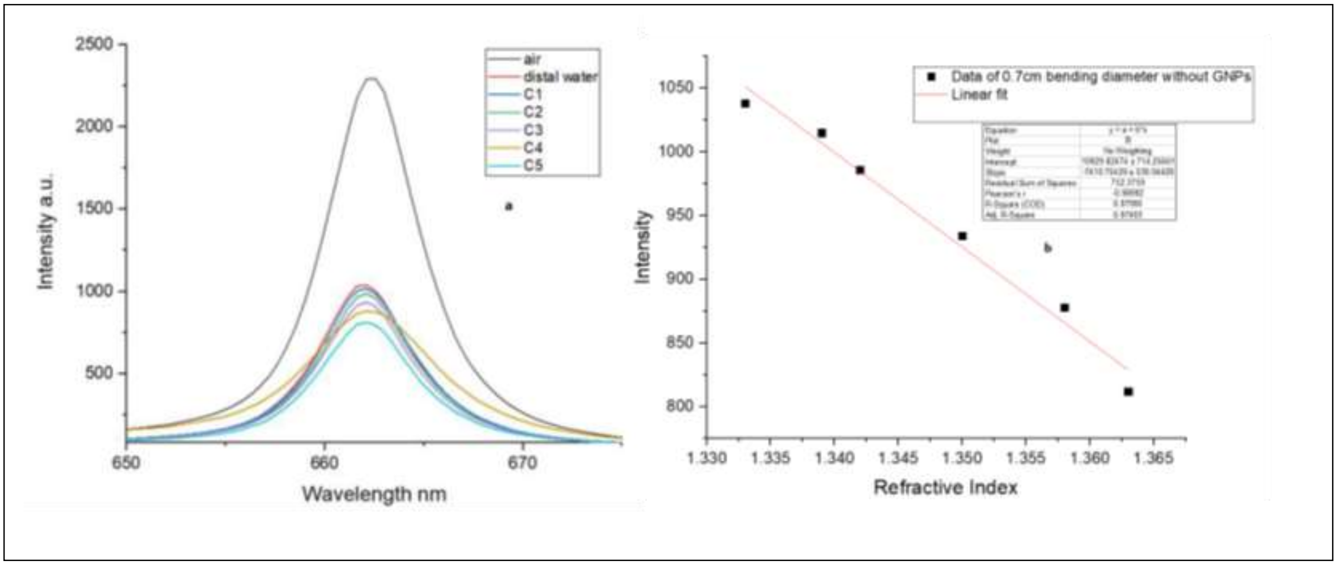


Figure 7: (a) the Intensity spectra response of U bent POF sensor with 0.7cm bending diameter without coating (b) Linear fitting curve.

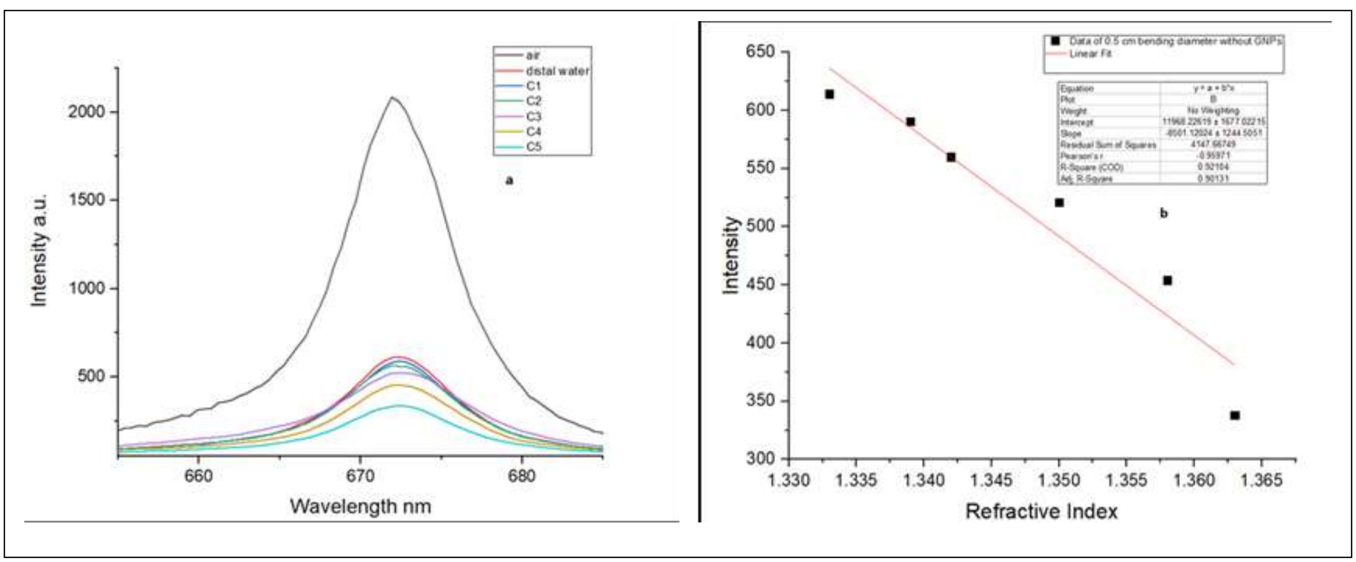


Figure 8: the intensity response of U bent POF sensors with 0.5 cm bending diameter without coating. (b) Linear fitting curve.

It is evident from figures (6a, 7a and 8a) that as the concentration of Sodium Chloride solutions increase the intensity decrease this occurs because the increased in concentration of Sodium Chloride solution increases absorption of light power by the solution resulting in decreasing the intensity of light. Generally, the bend loss is equivalent to the intensity modulation which is easily influenced by the light source and the outside environment and consequently limited the sensor resolution[15]. Therefore, as the refractive index changes/ increases, then the signal intensity also changes/decrease. The fit calibration curves were plotted for these three sensors as shown in figures (6b, 7b and 8b). The calibration curves of intensities and the coefficient of determination for three sensors (1, 0.7 and 0.5) cm are -24995 ΔI/RIU ($R2=0.95$), -7410 ΔI/RIU ($R2=0.97$) and -8501 ΔI/RIU ($R2=0.92$) respectively**.**

Then in step two LSPR curves were recorded for Sodium Chloride solutions at room temperature as shown in figure9, figure10 and figure11.U bent POF LSPR sensors with (1, 0.7 and 0.5) cm bending diameters coated with 20nm of GNPs thickness were subjected to Sodium Chloride solution with RI varying from 1.33 to 1.363.

It is evident from the three figures (9, 10 and 11)that as the concentration of Sodium Chloride solution increase the LSPR curve gradually moves to longer wavelengths with peak intensity decreasing this occur because the increased concentration of Sodium Chloride solution increases absorption of light power by the solution resulting in decreasing the intensity of light. The change in resonance wave length with change in refractive index of sensing media can explained by the operating principle of SPR sensor is based on the interaction of evanescent field with the surface electron emitted from the Plasmon metal and the shift of the resonance curve depends on the real part of the dielectric constant ofthe metal. The real part ofthe dielectric constant is large in the case of gold than other metal and hence gold demonstrates a higher shift of resonance parameter to change in refractive index of sensing layer.

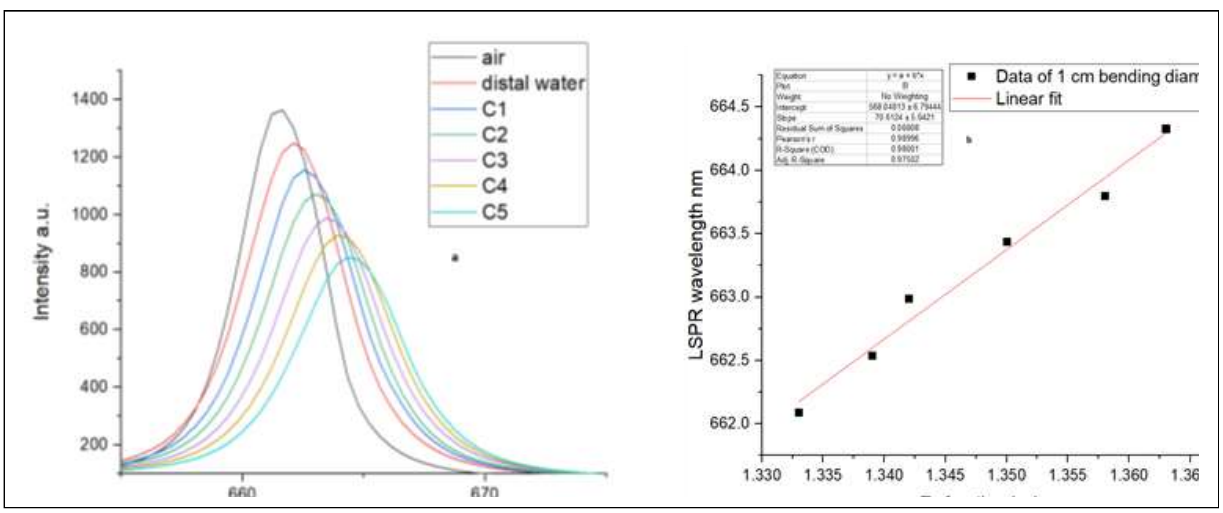


Figure 9 :U POF LSPR sensor with 1cm bending diameter. (a) Intensity spectrum. (b) Linear fitting curve.

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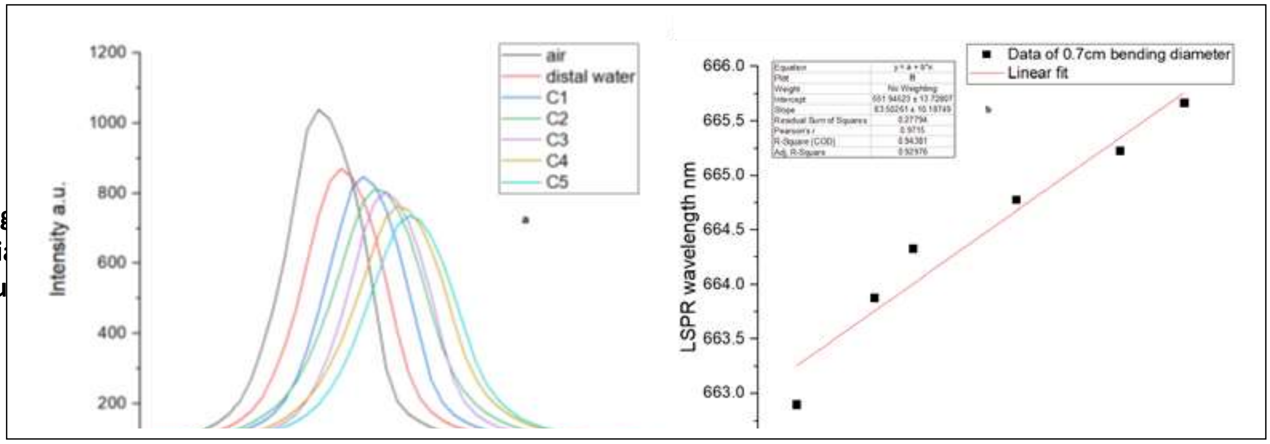

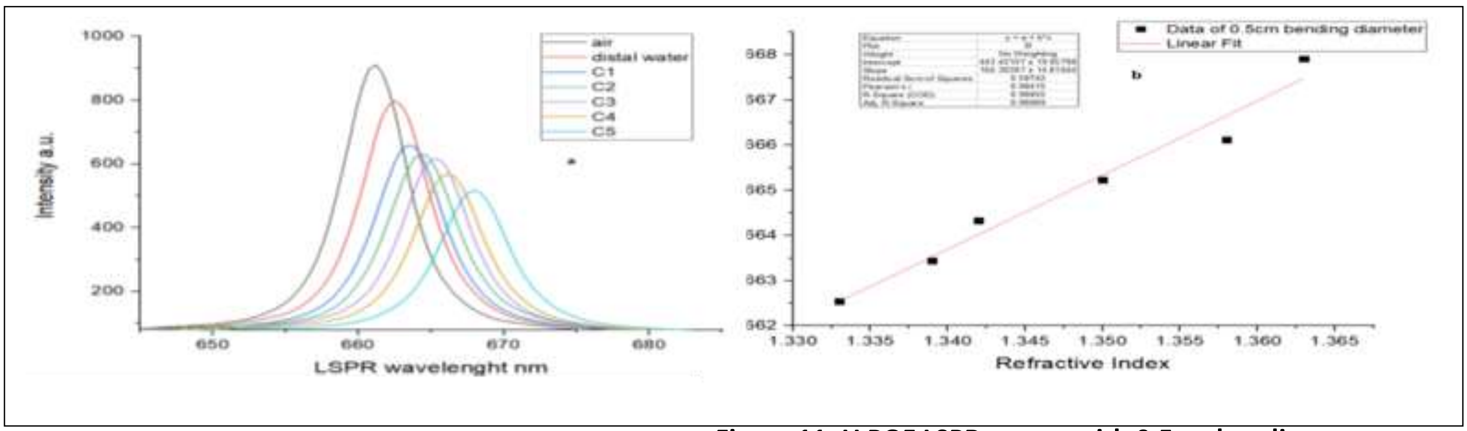

Figure 11: U POF LSPR sensor with 0.5cm bending diameter. (a) Intensity spectrum (b) linear fitting curve.

Resonance wavelengths are determined for LSPR spectra from figures (9, 10 and 11and 8), the resonance wavelength shift from 662.09 to 664.33 to get shift in wavelength (Δλ=2.24 nm) and sensitivity=74.66 nm/RIU with change in refractive index Δn=0.03 for U LSPR sensor with 1cm bending diameter. This sensor exhibits a good linear regression coefficient (R^2=0.97)

It is evident from figure 10 the resonance wavelength shift from 662.9 to 665.67 to get Δλ=2.77 nm and sensitivity=92.3 nm/RIU with Δn=0.03 for sensor with 0.7cm. This sensor has a linear regression coefficient (R^2=0.92).

It is evident from figure 11 the resonance wavelength shift from 662.54 to 667.91 to get Δλ=5.37 nm and sensitivity=179 nm/RIU with Δn=0.03 for sensor with 0.5cm. This sensor exhibits a good linear regression coefficient (R^2=0.96). Where sensitivity $S = \frac{\Delta\lambda}{\Delta n}$(Feng *et al.*, 2022)

Finally,the varying of the bending diameter of U bent LSPR sensor affected on the sensitivity of the sensor, RI sensitivity decreases with the bending diameter increases. For the proposed sensor maximum sensitivity (179nm/RIU) was obtained when the bending diameter was 0.5 cm. These findings are agreement with the earlier reported results(Satija *et al.*, 2014)(Xie *et al.*, 2021)(Wang *et al.*, 2021). The U bent POF LSPR sensor with 0.5cm bending diameter was chosen asthe optimum bending diameter because it has the highest sensitivity.

CONCLUSION:

Through the research and after its completion, the following conclusions were obtained:

1-Using a plastic optical fiber to manufacture U-shaped sensors was much easier than using the silica optical fiber because the latter is subjected to rapid damage when bending occurs.

2- There is no wavelength shift, when bare plastic optical fibers were bent in U shape with different bending diameters (1, 0.7 and 0.5) cm, only a decrease in the intensity of the spectrum with increasing concentration of sodium chloride salt solution with a refractive index ranging from 1.333 to 1.363.

3- a wavelength shift was obtained when these three bare U shape POF sensors were coated with a layer of GNPs with a thickness of 20nm and the best results were obtained from bending POF with a diameter of 0.5 cm by obtaining the highest shift of the wavelength (5.37 nm) and the highest sensitivity (179nm/RIU), so this bending diameter 0.5cm was chosen as an optimum bending diameter because it has the highest sensitivity to complete the rest of the study.

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***e*ISSN**1303-5150