JOURNAL OF KUFA–PHYSICS
www.uokufa.edu.iq/journals/index.php/jkp | ISSN: 2077–5830

Comparison between one layer and bilayer surface Plasmon resonance optical fiber chemical sensor

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ARTICLE INF

Article history:
Received: 16 MAR, 2020
Revised: 18 MAY, 2020
Accepted: 07JUN, 2020
Available Online: 31 DEC, 2020

Keywords:

surface Plasmon resonance
plastic optical fiber
chemical sensor

ABSTRACT

Surface Plasmon Resonance (SPR) - based plastic optical fiber has been provided as a sensor to estimating the refractive index and then the concentration of specific chemical samples. Two configurations were suggested for a design. The first was through using a single layer of gold with a thickness of about 40nm deposited on a 10mm portion in the middle of plastic optical fiber. In the second configuration, a bilayer deposited on the fiber. This bilayer consisted of a gold layer with a thickness of about 30 nm and an aluminum layer with a thickness of about 30 nm. Both of these configurations utilized as a chemical sensor. The resonance wavelength for the bilayer-based sensor was higher than that of the single-layer sensor for all studied chemical samples. The highest resonance wavelength was for the salt-water solution with a concentration of 30%. For the salt-water solution with a concentration of 30%, the resonance wavelength with the bilayer-based sensor was 568nm while it was 540nm with the single-layer sensor.

DOI: http://dx.doi.org/10.31257/2018/JKP/2020/120205

مقارنة بين طبقة ثنائية وطبقة واحدة لرنين بلازمون السطح لليف بصري كمتحسس كيميائي

سؤدد سلمان احمد

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الـــخُـــلاصـــة

تم تقديم الألياف الضوئية البلاستيكية المستندة إلى رنين البلازمون السطحي كمتحسس لتحديد معامل الانكسار وبالتالي تركيز عينات كيميائية محددة. اقتراح تكوينين للتصميم. الأول عن طريق استخدام طبقة واحدة من الذهب بسمك حوالي ٤٠ نانومتر مرسبة على جزء ١٠ مم في منتصف الألياف الضوئية البلاستيكية. في التكوين الثاني ،تم ترسيب طبقة ثنائية على الألياف. تتكون هذه الطبقة الثنائية من طبقة ذهبية بسماكة حوالي ٣٠ نانومتر وطبقة من الألمنيوم بسماكة حوالي ٣٠ نانومتر. استخدام كل من هذه التكوينات كمتحسس كيميائي. كان الطول الموجي الرنيني للمتحسس الثنائي الطبقة أعلى منه للمتحسس أحادي الطبقة لجميع

الكلمات المفتاحية:

- رنين بلازمون السطح
- الالياف البصرية البلاستيكية
- المتحسسات الكيميائية

العينـات الكيميائيـة المدروسـة. وكـان أعلـى طـول مـوجي رنـين لمحلـول الميـاه المالحـة بتركيـز ٣٠٪. بالنسبة لمحلول الملحي بتركيز ٣٠ ٪ ، كان طول موجة الرنين مع المتحسس القائم على طبقة ثنائية ٥٦٨ نانومتر بينما كان ٥٤٠ نانومتر مع المتحسس احادي الطبقة.

1. INTRODUCTION

During the closing three decades, a splendid quantity of work has been carried out on fiber optic sensors (FOS). Due to their special capabilities like biocompatibility, remote sensing, and on-line monitoring with the opportunity of miniaturized probes for a factor of care probabilities, FOS utilized in different fields like energy, the environment, biomedicine, agriculture, the meals industry, constructions, and many others [1,2]. The most important benefits of the use of optical fiber for sensing are ease of handling, low weight, low cost, immunity to electromagnetic interference, low strength operation, withstanding harsh environment, etc[3]. On the other hand, new technology, which is a surface plasmon resonance, has emerged in the field of sensing and attracted significant attention from many researchers. The combining between the Surface plasmon resonance (SPR) and optical fiber technique in one sensor device has attracted more and more interesting in the last few years, as a result of their properties which are combined together. The new sensor has been utilized in many fields like refractive index detection of chemical and biological analytes [5-6]

The oscillations of electrons that occurs due to an external field alongside the metal-dielectric interface are known as surface plasma oscillations. The quantum of these oscillations is referred to as surface plasmon, and is, accompanied by means of a longitudinal electric field known as surface plasmon wave, which decays exponentially in metal as well as the dielectric. The field has its maximum at the metal-dielectric interface itself [7].

Surface Plasmon Resonance is a phenomenon that happens when a p-polarized light falls on a metallic film and its wave vector coupled with that of surface plasmon waves under certain conditions known as resonance conditions. To achieve a coupling point two configurations, which are Otto configuration and Kretschmann configuration, suggested. In Kretschmann configuration, the light is targeted through a glass prism onto a metal film that is deposited directly on the base of the prism. The reflected light carries the data of what happened on the surface of the metal which is observed on an optical spectrum analyzer as a dipping curve. This dipping occurs when a condition of resonance achieved. Any change in the refractive index in the vicinity of the metallic film will affect these conditions. In fact, these effects are a redshift, the higher the refractive index, the resonance will be towards higher wavelengths. Surface plasmon resonance (SPR) optical fiber sensors have attracted a good deal interest for decades, due to their benefits of high sensitivity, large accuracy, each an easy structure, and with low cost. They have been utilized for refractive index detection of chemical and biological analytes [8-9]. Comparing with different sensors based on FBG, LPFG, optical fiber interferometer (OFI) and so on, the SPR-based fiber sensors have significant performances such as ultrahigh sensitivity up to numerous microns per RIU [10]. A first fiber-optic chemical sensor based on surface plasmon resonance was presented by way of R. C. Jorgenson and S. S. Yee in 1993. The sensing component of the fiber has been fabricated through disposing of a part of the fiber cladding and symmetrically depositing a thin layer of highly reflecting metallic onto the fiber core. A white-light source is used to

introduce a wide range of wavelengths into the fiber optic. Changes in the sensing parameters (e.g., bulk refractive index, thickness and film refractive index) are decided through measuring the transmitted spectral-intensity distribution. Experimental consequences of the sensitivity and the dynamic range in the measurement of the refractive indices of aqueous solutions are in settlement with the theoretical model of the sensor [11].

2-EXPERIMENTAL WORK

The experimental setup for the manufactured chemical sensor at this work consisting of a light source (halogen lamp that was chosen in this work was once a tungsten halogen lamp of 50 watts and 12Volt). The emitted light was between about 300 and about 1000nm. To maximize the coupling between the light and the optical fiber an outfitted with "SMA 905" connectors was used. A grade plastic optical fiber with a diameter of 1000µm and numerical aperture of 0.51 provided by Thorlabs Inc. has been used in this work. The core diameter of this type of fiber was 980µm, and the cladding was 20µm. To fabricate a sensor a 30cm barring a jacket of the fiber has been used. A small portion, 10mm of fiber fixed on a resin block as shown in figure 1, has been unclad through a polishing paper. The polished section was cleaned with distilled water and then a single layer of gold with (40nm) thickness, and another one of the polished section with a bilayer metal (60nm) thickness of gold (30nm) and aluminum (30nm), has been deposited over it using (ION _COATER). The computing device of Model KIC-1A used was once from COXEM Company, Korea. The optical spectrum analyzer (CCS series 2-Thorlabs Company- Germany) with a wavelength range between 200 and 1000 nm and with spectral resolution of 1nm has been used in this work.

The surface Plasmon resonance curves alongside statistics values had been displayed on the pc and saved by means of software program Microsoft Excel. The experimental setup is shown in Figure (2).

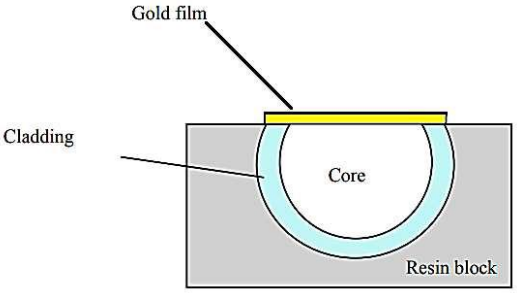


Fig. (1): The treated grade plastic optical fiber.

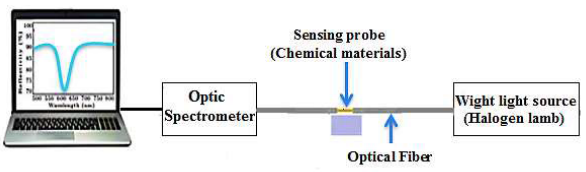


Fig. (2): The Outline of the Experimental setup of SPR based on plastic optical fiber.

3-RESULTS AND DISCUSSION:

The sensitive area of the optical fiber sensor immersed in a number of samples of sugar-water solutions with different concentrations (different refractive indices samples). Each one of the solutions has been measured using the refractometer. Figure (3) indicates the calibration curve for sucrose/water solutions. As shown in the figure the refractive index will increase as the solution concentration increase.

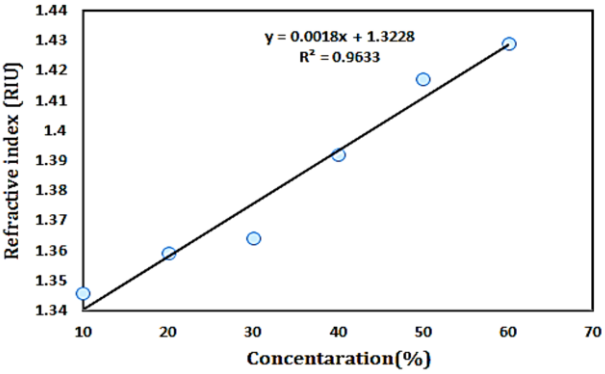


Fig. (3): Refractive index of sugar-water solutions as a function of its concentrations.

Figures (4) and (5) show the refractive index as a function of the resonance wavelength for the sensor with a single layer of gold and the sensor with a bilayer of Au and Al respectively. These figures indicate that the resonance wavelength increase as the refractive index increase. The reason for this behavior, associated with the real part of the dielectric function of the metal and then to the real part of the wave vector of the surface Plasmon wave which affects the resonance conditions. For large values of the refractive index of the sensor medium, the real part of the wave vector of the surface plasmon wave was higher.

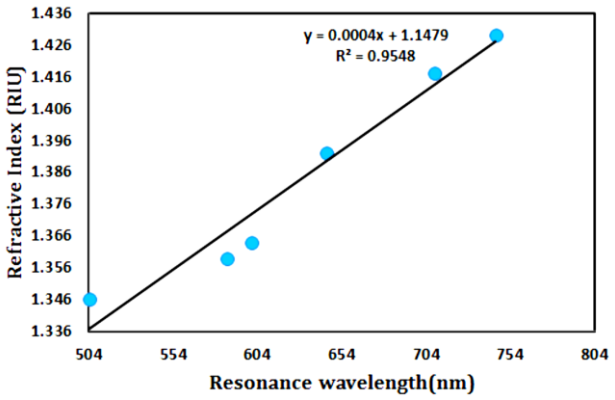


Fig. (4): The refractive index as a function of the resonance wavelength for the sensor with single layer of gold.

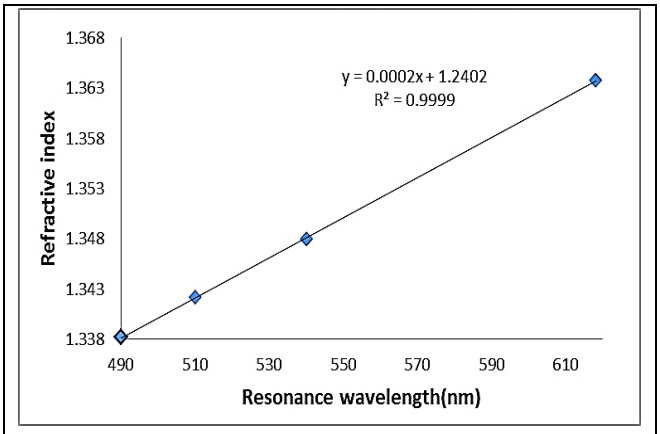


Fig. (5): The refractive index as a function of the resonance wavelength of the sensor with bilayer (Au/Al).

Figures (6)and(7) provide an explanation for the surface Plasmon resonance (SPR) for the fabricated sensor with the SPR one layer sensor and two layers SPR sensor two and two at a variety of refractive index of the chemical samples (sensing medium) .It is apparent that the width and dip position of every surface Plasmon resonance (SPR) response curve is modified to the sensor with every pattern having a distinctive refractive index and additionally the magnitude of transferring of the dip function expand as the refractive index increase. These versions make the overall performance parameters, which rely on the surface Plasmon resonance (SPR) curve width, the value of the shifting and the position of dip altering with the altering of resonance wavelength and refractive index of the sensing medium due to the fact it depends on the change of the resonance wavelength, the exchange of refractive index and the width of the spectral curve.

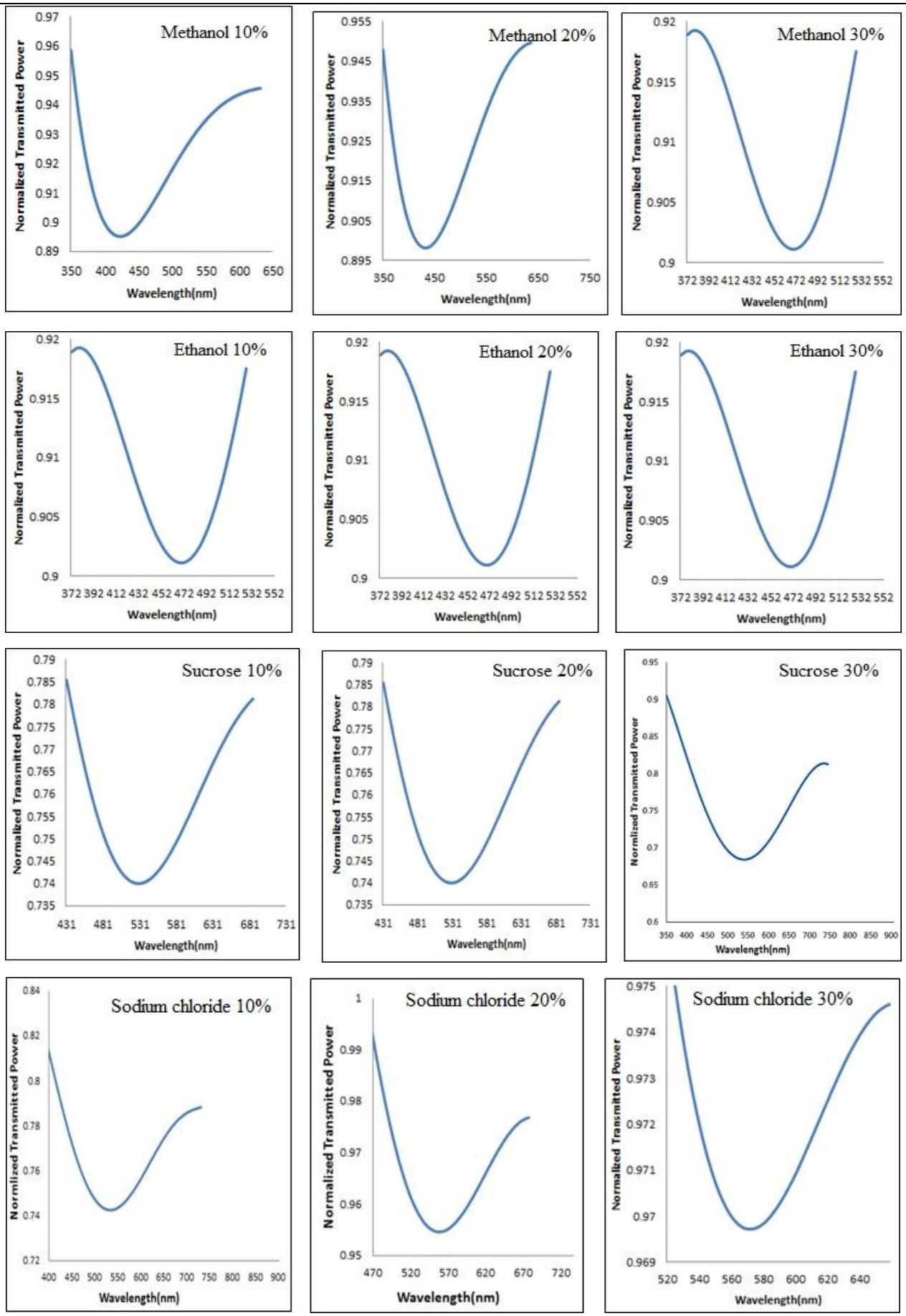
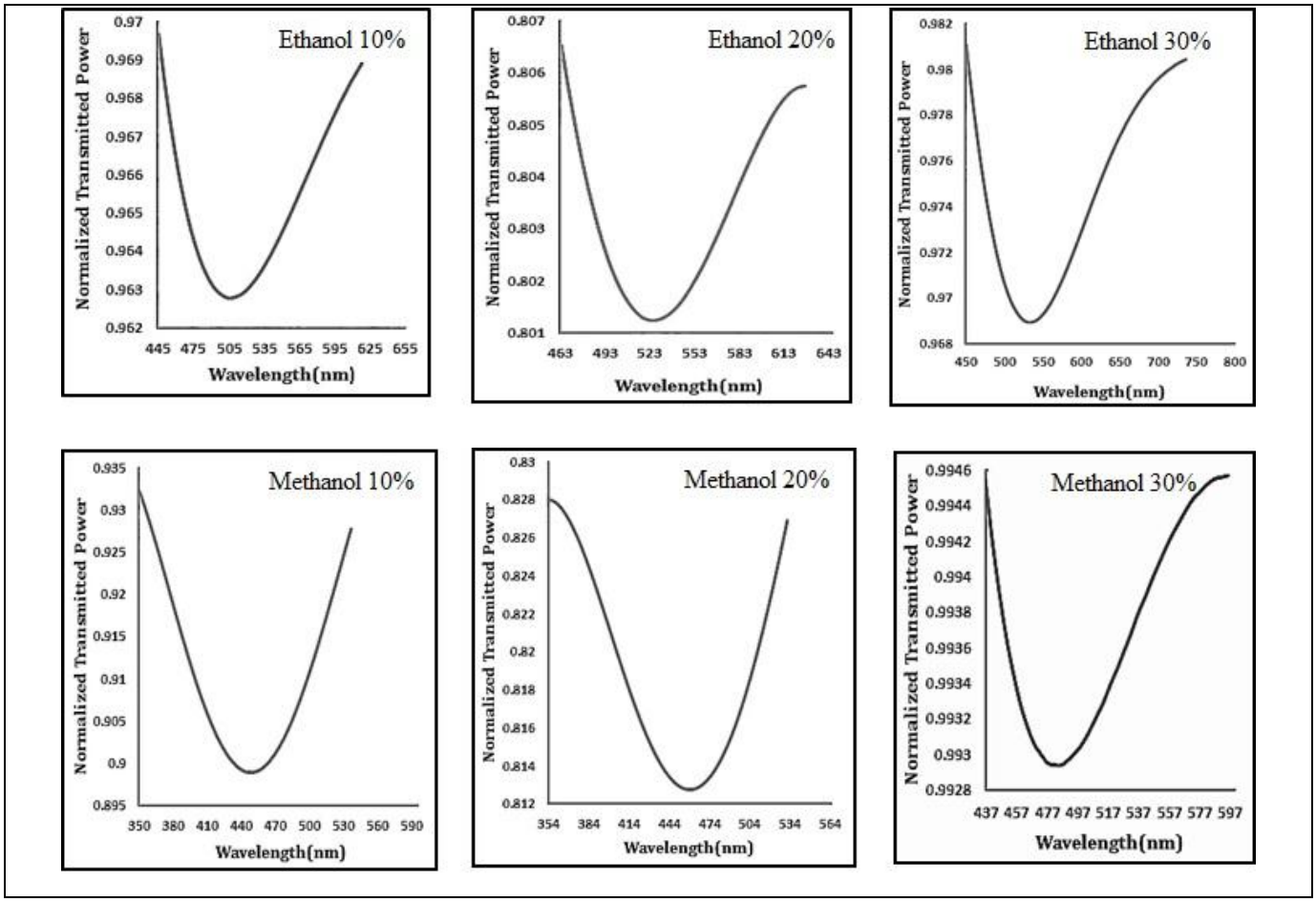


Fig. (6): SPR curves of the optical fiber sensor with the gold and aluminum metal for the different chemical sample concentrations.

Table (1): The refractive index and the concentrations of the various resonance wavelengths for gold metal

Samples	λ_{res} (nm)	Refractive index (RIU)	The values of Concentrations %
Methanol	450	1.3302	10
Methanol	459	1.332	20
Methanol	481	1.3364	30
Ethanol	504	1.341	10
Ethanol	522	1.3446	20
Ethanol	531	1.3464	30
Sucrose	500	1.3402	10
Sucrose	509	1.342	20
Sucrose	518	1.3438	30
Sodium chloride	495	1.3392	10
Sodium chloride	527	1.3456	20
Sodium chloride	540	1.3482	30



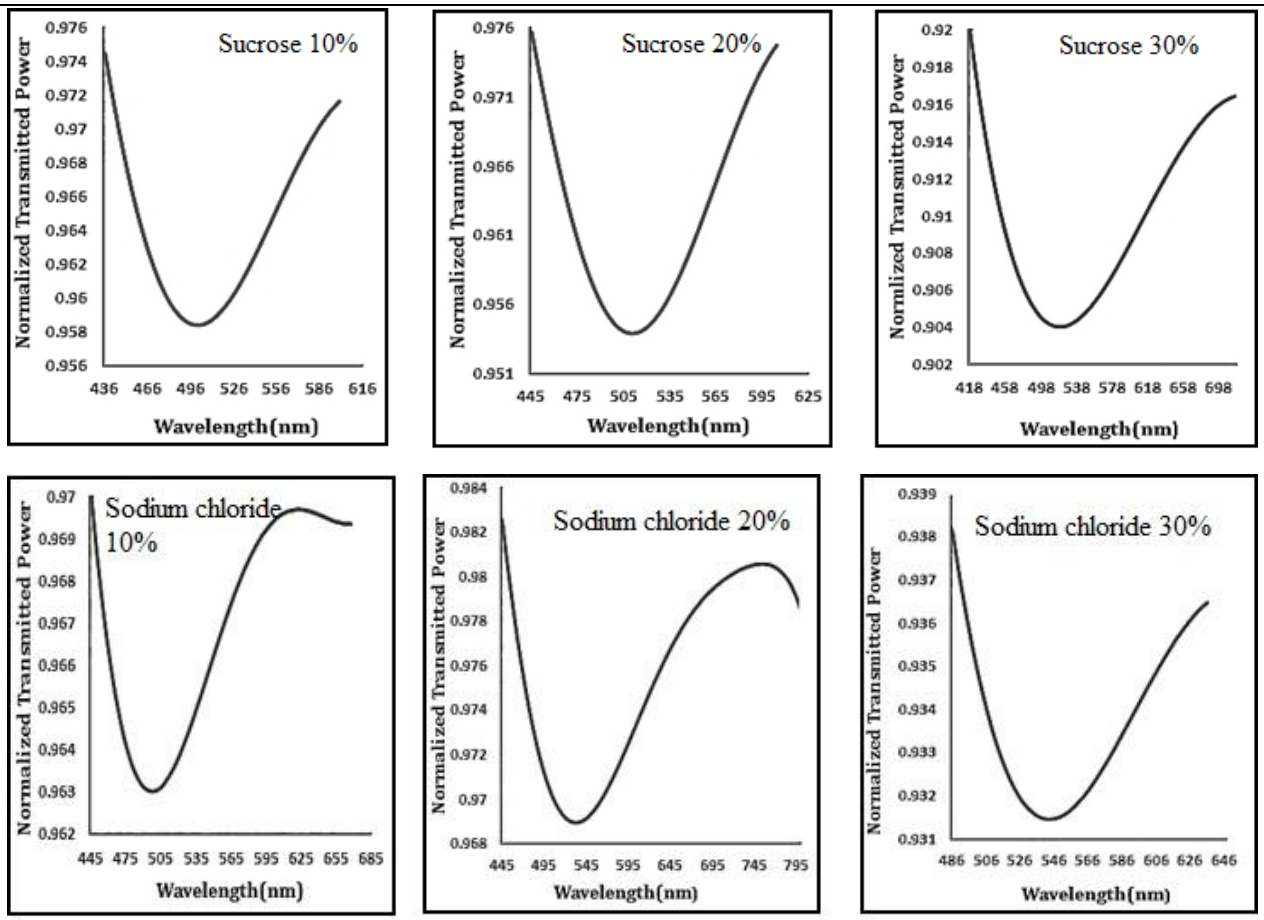


Fig. (7): SPR curves of the optical fiber sensor with the gold and aluminum metal for the different chemical sample concentrations.

Table (2): The refractive index and the concentrations of the various resonance wavelengths for gold and aluminum metal

Samples	λ_{res} (nm)	Refractive index (RIU)	The values of Concentrations %
Methanol	422	1.3246	10
Methanol	431	1.3264	20
Methanol	468	1.3338	30
Ethanol	527	1.3456	10
Ethanol	536	1.3474	20
Ethanol	572	1.3546	30
Sucrose	522	1.3446	10
Sucrose	531	1.3464	20
Sucrose	540	1.3482	30
Sodium chloride	536	1.3474	10

Sodium chloride	559	1.352	20
Sodium chloride	568	1.3538	30

Tables (1) and (2) give an explanation for the values of the refractive index and concentration for every sample of chemical at exclusive resonance wavelengths. The concentration of the samples will increase as the refractive index increases and as a result the resonance wavelengths expand this take place due to the fact the sharp dip moving to the red wavelength. We note a difference in the refractive index and the resonance wavelength of a single-layer SPR sensor and bilayer SPR sensor. Where the resonance wavelength and the refractive index of the salt and methanol samples of the bilayer SPR sensor are much less than that of the salt and methanol samples of the single-layer SPR sensor. On the other hand, the resonance wavelength and the refractive index of the sugar-ethanol samples of the single-layer SPR sensor are much less than that of sugar samples and ethanol for the bilayer SPR sensor. This can be attributed to the resonance condition of the surface plasmon wave. If the refractive index of the sample is large, then the real part of the wave vector will be large and hence the resonance condition will be satisfied at a large value of wavelength. Also if the refractive index of the sample is small, then the real part of the wave vector will be small and hence the resonance condition will be satisfied at a small value of wavelength.

4-CONCLUSION:

This work exhibits the utilizing of two configurations of a chemical optical fiber sensor based on (SPR) technique one with a single layer and one with a bilayer. Both of these configurations used to estimate the concentration and refractive index of different chemical samples. The response curve of (SPR) for various chemical samples was shown, and a dip in the resonance position was presented in this work. At each sample of chemicals, the resonance wavelength changes as its refractive index change. These changes are estimated sensitively with these highly sensitive types of sensors.

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