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

No-Core optical fibers sensor for detecting hemoglobin concentration (HB) based on the Surface Plasmon resonance(SPR).

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ARTICLE INF

Article history:
Received: 25 SEP, 2022
Revised: 24 OCT: 2022
Accepted: 03 NOV, 2022
Available Online: 06 FEB, 2023

Keywords:

Biosensor
Hemoglobin (HB)
Optical fiber
Surface Plasmon resonance
Refractive index

ABSTRACT

In this work, a fiber-optic biomedical sensor was manufactured to detect hemoglobin percentages in the blood. SPR-based coreless optical fibers were developed and implemented using single and multiple optical fibers. It was also used to calculate refractive indices and concentrations of hemoglobin in blood samples. An optical fiber, with a thickness of 40 nanometers, was deposited on gold metal for the sensing area to increase the sensitivity of the sensor. The optical fiber used in this work has a diameter of 125µm, no core, and is made up of a pure silica glass rod and an acrylate coating. The length of the fiber was 4cm removed buffer and the splicing process was done. It is found in practice that when the sensitive refractive index increases, the resonant wavelength increases due to the decrease in energy.

DOI: http://dx.doi.org/10.31257/2018/JKP/2022/140209

مستشعر الألياف الضوئية (No Core) للكشف عن تركيز الهيموجلوبين (HB) بناءً على رنين Plasmon السطحي (SPR)

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الـــخُــلاصـــة

في هذا العمل ، تم تصنيع جهاز استشعار طبي حيوي من الألياف الضوئية للكشف عن نسب الهيموجلوبين في الدم. تم تطوير وتنفيذ ألياف ضوئية عديمة النواة قائمة على *SPR* باستخدام ألياف ضوئية مفردة ومتعددة. كما تم استخدامه لحساب مؤشرات الانكسار وتركيزات الهيموجلوبين في عينات الدم. تم ترسيب ألياف بصرية بسمك ٤٠ نانومتر على معدن ذهبي لمنطقة الاستشعار لزيادة حساسية المستشعر. يبلغ قطر الألياف الضوئية المستخدمة في هذا العمل ١٢٥ ميكرومتر ، بدون نواة ، وتتكون من قضيب زجاجي سيليكا نقي وطلاء أكريليت. تمت إزالة طول الألياف بمقدار ٤ سم وتمت عملية الربط. وجد من الناحية العملية أنه عندما يزداد معامل الانكسار الحساس ، يزداد طول الموجة الرنانة بسبب انخفاض الطاقة.

الكلمات المفتاحية:

المستشعر الحيوي
الهيموجلوبين (*HB*)
الألياف الضوئية
رنين البلازمون السطحي
معامل الانكسار

1. INTRODUCTION

The most cutting-edge optical biosensing technology is based on Surface Plasmon Resonance (SPR) technology. SPR biosensors are now a crucial tool for understanding biomolecular interactions and are often used in environmental monitoring, medical diagnostics, and chemical and biological detection studies [1]. SPR sensors have come a long in the last several decades. A variety of SPR sensors and data processing techniques have been developed in order to attain excellent performance. There are several areas of interest that optical fiber-based surface plasmon resonance (SPR) can detect. For example, a flexible and improved optical structure, in situ monitoring for prism-dependent super-SPR detection, advances in remote detection, continuous screening and the detection of the polluted water [2-5]. SPR-based optical sensors are used in biomedical diagnosis, electrochemistry, life sciences and environmental safety [6,7]. An incident angle, the metal, the light wavelength, and dielectric constants of the dielectrics affect the resonance state. Every sharp dip is displayed in spectra of the signal at the resonance angle (angular interrogation) or at the resonance wavelength (spectral interrogation). Depending on the refractive index of the dielectric adjacent to the metal, the wavelength or angle of the resonant excitation of surface Plasmons can be changed substantially. So, by evaluating the angle of resonance or the resonance wavelength of the sensing medium, it is possible to identify these changes in the refractive index [8, 9, and 10]. In this work, the determination of the refractive index and hemoglobin concentration (HB) are recognized and determined utilizing a coreless fiber optic sensor spliced with multi-mode and single-mode based on surface plasmon resonance (SPR).

2. The Experimental Work

The experimental setup for sensing of the hemoglobin concentration consists of a halogen light source (for multimode fiber), laser source (for single-mode fiber), optical fibers (coreless fiber, multimode fiber, and single-mode fiber), the optical spectrum analyzer (OSA), and blood samples. Figure (1) and Figure (2) are illustrating the experimental set up of optical fiber biosensor based on SPR for single-mode and multimode fibers.

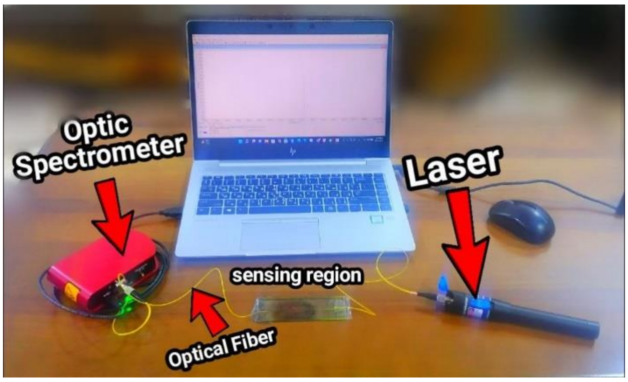


Figure (1): The experimental setup of SPR single mode fiber sensor.

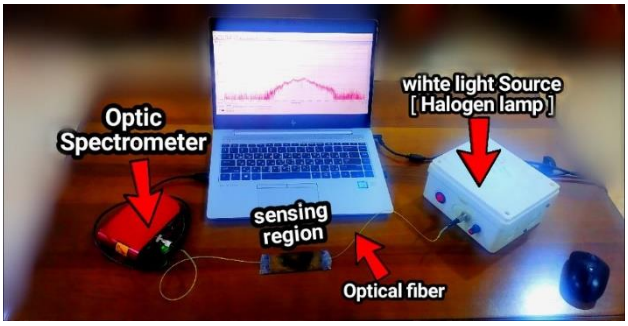


Figure (2): The experimental setup of SPR multi-mode fiber sensor.

3. Optical fiber sensor

In this work, multimode and single-mode fibers were welded to a coreless optical fiber, in which a small portion of the coreless optical fiber is sensed in the middle of the fiber. Gold was deposited onto the coreless optical fibers after being cleaned with distilled water. A coating machine was used (Sputter Coating). The machine used is called (Q150T PLUS(with a schematic diagram of the coating process as shown in Figures (3) and (4), The approved conditions for depositing gold with a thickness of 40 nm were 30 mA and a deposition time of 78 s through equation (1). The thickness of the metallic layer was determined at 40 nm and was formed on the coreless optical fibers as shown in Figure (5).

$$d = KIT \quad \text{........ (1)}$$

Where d is the thickness to be measured, I is the constant current equal to 30mA, K is the constant number (0.17) and T is the spray time in sec we made 78 for the 40 nm layer.

Figure (3): photograph of the Sputtering Coating.

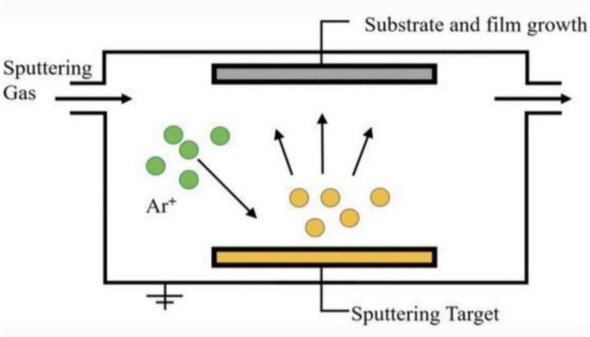


Figure (4): Schematic diagram of the gold spraying process.

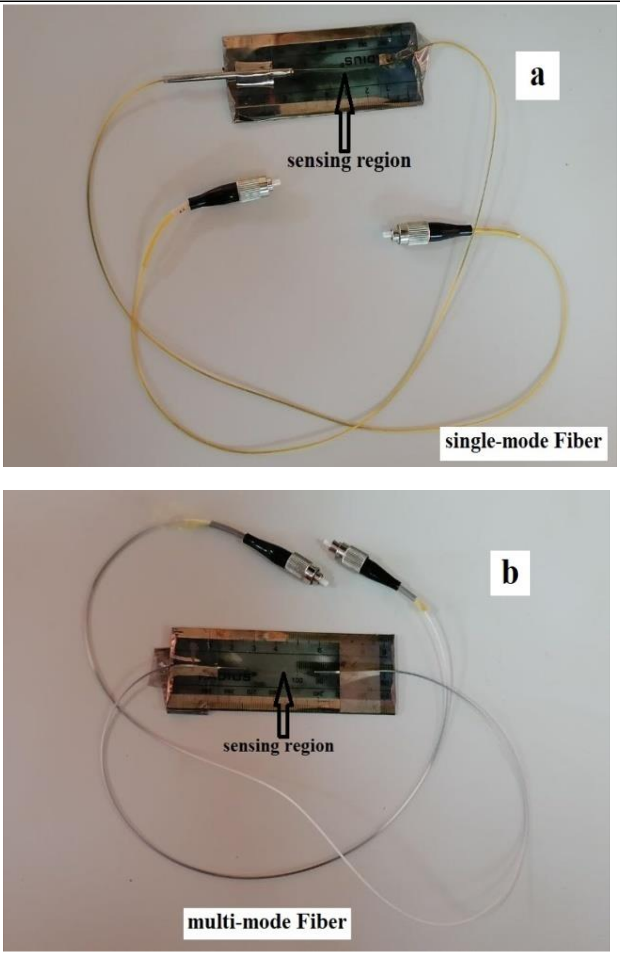


Figure (5): (a) Single-mode no core fiber sensor (b) Multi-mode no core fiber sensor.

4. Preparation of Hemoglobin blood samples:

In this work, eight blood samples were collected and then centrifuged .The natural color was red for all collected samples. Blood samples which were used for different people in term of age range (30 - 44) years to detect the hemoglobin concentration. The samples of blood are illustrated in Figure (6)

Figure (6): photograph of the samples of blood.

5. Preparation of Solutions

The sensor's sensitive region was immersed in various solutions of sucrose/water with different concentrations (1.3382, 1.3485, 1.3202,1.3640). This results in various refractive indices (ns), where the refractive indices of solutions using an Abbe refractometer were calculated. The refractive index and solution concentration had a linear relationship, as shown in Figure (7).This shape is a calibrated curve that is used to obtain the refractive indexes for different blood concentrations.

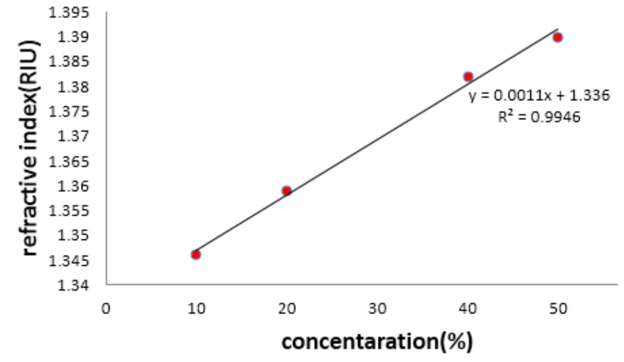


Figure (7): Sucrose /water solutions refractive index in terms of the solution concentration.

6. Results and Discussion

This work exhibited that the sensor medium's index of refraction rises as the resonance wavelength increases because the energy lowers when the acute dip switches to the red wavelength; as a result, the fast drop of the resonance wavelength will be displaced to the longer wavelength side (redshift) as illustrated in Figure (8) and (9).

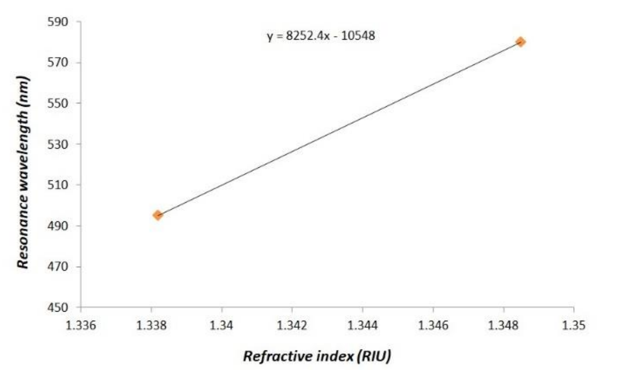


Figure (8): Refractive index (RIU) versus resonance wavelength for the sensor of a single-mode with a gold layer.

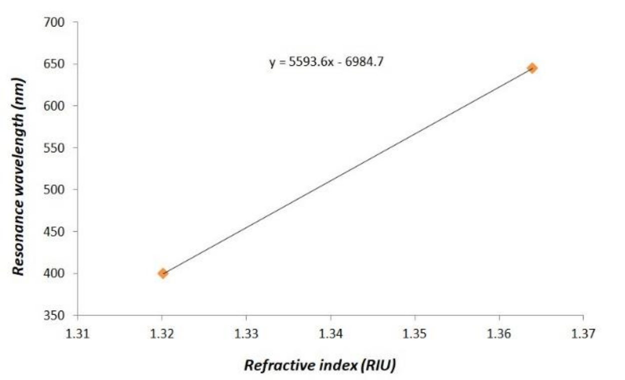
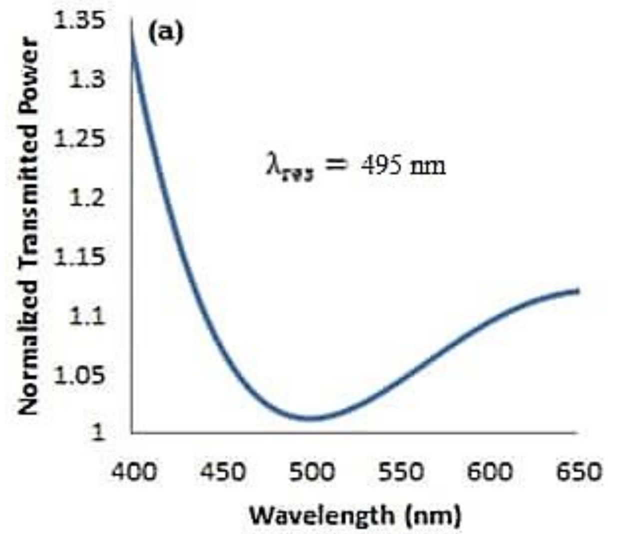


Figure (9): Refractive index (RIU) versus resonance wavelength for the sensor of a multi-mode with a gold layer.

Figures (10) and (11) show the Surface Plasmon resonance (SPR) response curve of a sensor that was made with a gold layer at various blood sample refractive index values (sensing medium). A clear shift in resonance wavelength occurred from 495nm to 580nm for single-mode fiber, as the blood sample refractive index alters between 1.3382 to 1.3485 and the resonance wavelength alters from 400nm to 645 nm for multi-mode fiber, as the blood sample refractive index varies between 1.3202 to 1.3640. A different refractive index is assigned to each sample, varying the width and dip position for each (SPR) response curve to the sensor. Moreover, when the sharp dip shifts toward the longer wavelength, the magnitude of the shift is increased as the refractive index ascends. This normalized transmission is plotted as a function of the wavelength in nanometer of the incident wave. The variation in the index of the environment is measured by the shift of the minimum of the dip of the SPR curve (or of the resonance wavelength λ_{res}). The resonance appears, as shown in the SPR curves, as a dip. The dip occurs at a resonance wavelength due to the maximum transfer of energy from the transmitted power of light guided through the fiber to the surface Plasmons. In the SPR curves, the position of dip on the wavelength axis depend on the real part of the dielectric function of the metal and the depth of this dip (the minimum value of normalized transmitted power) depend on the imaginary part. The justification behind the expansions in SPR resonance wavelengths with variation in refractive index of sensing medium can be clarified by resonance condition of surface Plasmon waves. The real part of the wave vector of the surface Plasmon wave will be higher and hence the resonance condition will be done at higher wavelength (red wavelength). Meaning that the sharp dip of the (SPR) response curve will be shifting towards high wavelengths. For a small value of a refractive index, the real part of the wave vector of the surface Plasmon wave will be lower and hence the resonance condition will be done at smaller wavelengths. Table (1) explains the magnitudes of the refractive indices and concentration of blood samples at different resonance wavelengths for single and multi-mode fiber and Table (2) represents the values the performance parameter of the sensor with the gold layer. The materials used to prepare the samples include (HF) acid, Distilled Water, and ethanol alcohol. These materials are described in Table (3).



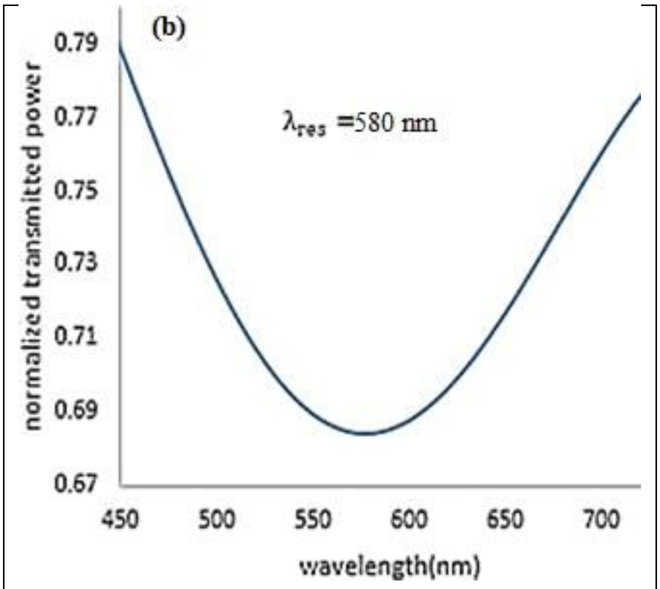
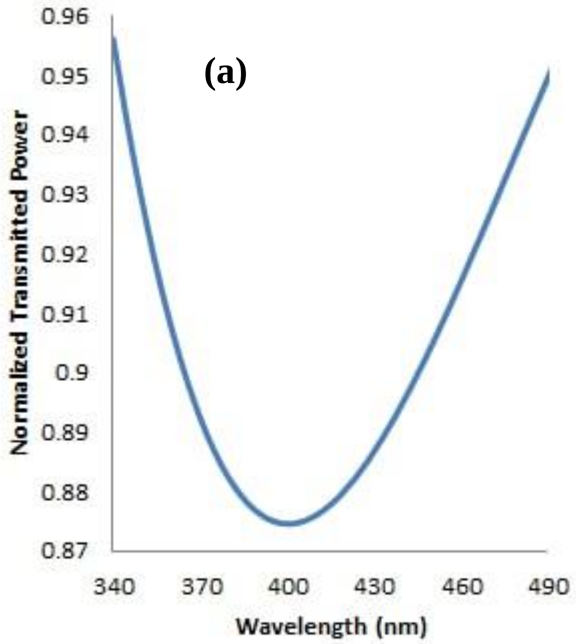


Figure (10): (a) and (b) SPR curve of the single-mode fiber sensor with a gold metal of different blood samples on the optical fiber.



$\lambda_{res} = 400$

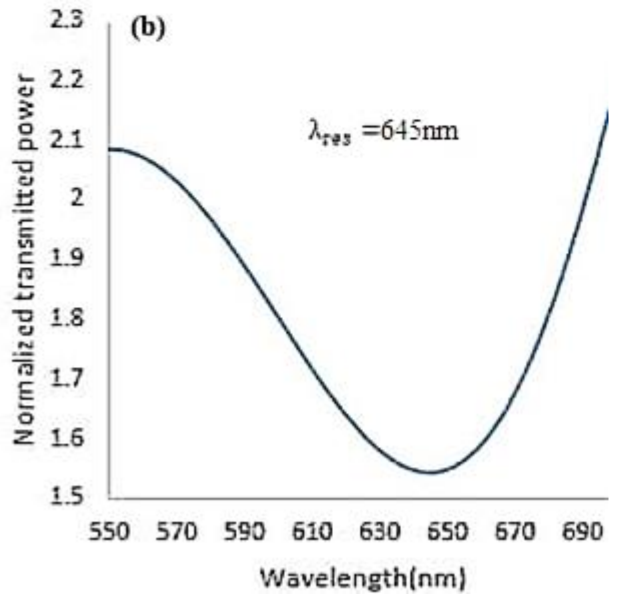


Figure (11): (a) and (b) SPR curve of the multi-mode fiber sensor with a gold metal of different blood samples on the optical fiber

Table1: Refractive index and concentration values for different resonance wavelengths

Type of fiber	Samples	λ_{res} (nm)	Refractive index (RIU)	Hemoglobin in (HB)	P.C.R
Single mode fiber	a	495	1.3382	12.1	37
	b	580	1.3485	10.3	32
Multi-mode fiber	a	400	1.3202	12.1	37
	b	645	1.3640	10.3	32

Table2: The experimental performance parameters of the sensor with gold.

Metal	Sensitivity (S_n) [µm/RIU]	Signal to noise ratio (SNR)	Figure of merit (FOM)	Resolution [RIU]
Gold	2	7.6	66.6	$1.47*10^{-6}$

Table (3): The materials used to prepare the samples.

Materials	weight gm/mol
Ethanol alcohol	46.069 g/mol
Hydrofluoric acid	20.0036 g/mol

7. Conclusion:

1. Surface Plasmon Resonance (SPR) response curves for different samples of the blood were recorded in this work and exhibited a dip in the position of resonance. A change in the value of the resonance wavelength occurs for each change in the refractive index and hence for each change in the concentration hemoglobin of in blood samples. The change in the refractive index of the sensing medium regardless of the type of material led to the change in the wavelength in the (SPR) response curve and these change appears as a sharp dip called resonance wavelength (λ_{res}). So any slight change in the refractive index will cause a change in the values of the resonance wavelength. The resonance wavelength increase as the refractive index increase and thus leading to an increase in the concentration hemoglobin of in blood samples. The cause for this is due to the large values of the refractive index of the sensing medium, the real part of the wave vector of surface Plasmon wave will be higher and hence the resonance condition will be provided at a higher wavelength.

2. From the results, it is clear that for the optical fiber based on (SPR) sensor with 40nm thick film of gold layar and 4cm of exposed sensing region, success to get performance parameters of the sensitivity approach 2 µm/RIU, signal to noise ratio 7.6, resolution $1.4 \times \mathbf{10^{-6}}$ RIU and figure of merit 66.6.

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