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Optical fiber biomedical sensor based on surface Plasmon resonance for Candida detection

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ABSTRACT

In this work, optical fibers were designed and implemented as a medical sensor based on surface Plasmon resonance (SPR) to estimate different refractive indices and (Candida) concentrations and improve the endoscope's performance. Using multi-mode and single-mode optical fibers deposited by 40 nm thickness gold metal deposition for the sensing area, In practice, it was found that when the refractive index of the sensitive medium increases, the length of the resonant wave increases due to the decrease in energy.

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الكشف عن (Candida) بأستخدام مستشعر طبي حيوي للالياف الضوئية بالإعتماد على رنين البلازمون السطحي

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الكلمات المفتاحية:

Candida – المستشعر الحيوي
رنين البلازمون السطحي
الألياف الضوئية
معامل الانكسار

الــــخُــــلاصـــة

في هذا العمل ، تم تصميم الألياف الضوئية وتنفيذها كمستشعر طبي يعتمد على رنين البلازمون السطحي (*SPR*) لتقدير مؤشرات الانكسار المختلفة وتركيزات (*Candida*) وتحسين أداء المنظار الداخلي. باستخدام الألياف الضوئية متعددة الأوضاع والوضع الأحادي المودعة بواسطة ترسيب طبقة من الذهب بسمك ٤٠ نانومتر لمنطقة الاستشعار ، من الناحية العملية ، وجد أنه عندما يزداد معامل الانكسار للوسط الحساس ، يزداد طول الموجة الرنانة بسبب انخفاض في الطاقة.

1. INTRODUCTION

Candida is an imperfect yeast that co-exists with many different of animals [1, 2]. Infections with Candida or closely related species, such as Candida tropical, can be a major medical issue in people who have compromised immunity [3,4,5]،Optical fiber sensors have many uses in the field of remote sensing, science, environmental monitoring, and communications technology because they are small in size, immune to electromagnetic interference, do not require electrical power, and have broad bandwidth and high sensitivity[6,7]. And for the first time in 1982, the SPR method was used for gas detection [8]. Plasmons are used for surface stimulation, as well as optical equipment such as optical fibers, high refractive index prisms, and diffraction networks [9]. By applying nano-coating deposition processes, optical fiber sensors have been developed in wide fields of study and practical possibilities. Many optical fiber structures have been encapsulated with nanostructured thin films and Nano-layers to create new sensors [10,11]. Temperature, pressure, current, voltage, gas, chemical pollutants, rotation, vibration, acceleration, bending, torsion, displacement, and biomolecules were measured using fiber-optic sensors. [12]. SPR-based optical sensors are used in a variety of fields including chemical sciences, electrochemistry, life sciences, environmental safety, and biomedical diagnostics [13]. In this work, design and fabrication of optical fiber medical sensor based on surface plasmon resonance is presented. The sensor is used to detect and measure the refractive index and concentration of the (Candida). The sensor can be used in medical fields to improve the performance of endoscopic sensing based on surface plasmon resonance.

2. The Experimental setup

The experimental setup for measuring the transferred light spectrum in case of multimode fiber consists of a halogen light source, optical fiber, and the optical analyzer (OSA) shown as a photographic plate in Figure (1). While in case of single mode fiber consists of laser source, optical fiber, and a spectrophotometer shown in Figure (2)

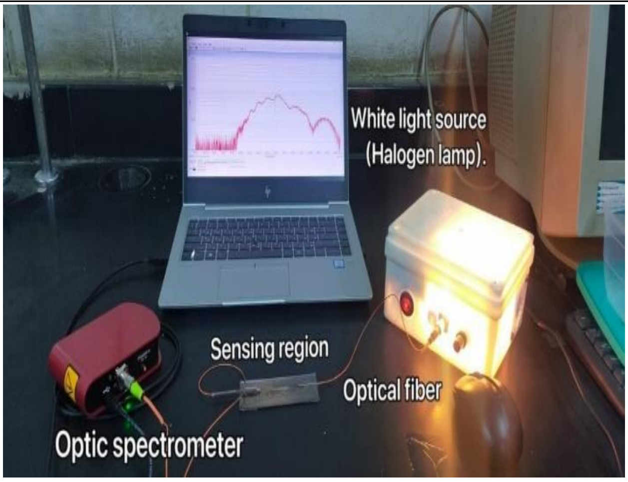


Figure (1): SPR multi-mode fiber sensor experimental setup.

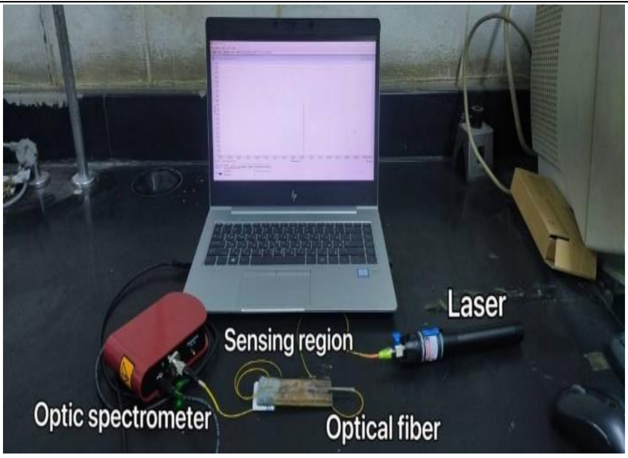


Figure (2): SPR single mode fiber sensor experimental setup.

3. Optical fiber sensor

In this work, multi-mode and single-mode optical fibers were used where a small portion of the optical fiber represents the sensing portion in the middle of the fiber. The sensing portion was cleaned with distilled water, then about 40 nm thick gold metal was deposited using the spray technique. The approved conditions for depositing gold with a thickness of 40 nm were 30 mA current and 78 s deposition time. The thickness of the metallic layer was determined as shown in Figures 3(a) and (b).

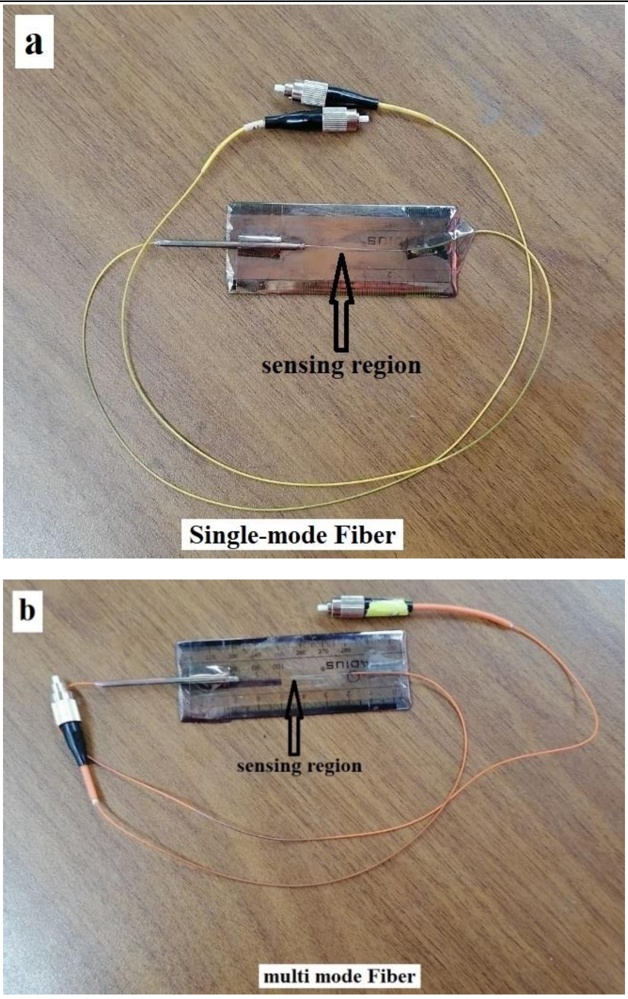


Figure (3): (a) Single-mode fiber sensor.

(b) Multi-mode fiber sensor

4. Fungal Preparation (Candida)

Candida was cultured on optical fibers consisting of the sensing part deposited with a 40 nm layer of gold metal - containing antifungal (clotrimazole cream) as shown in Figure 4. It was left for 24 hours in the incubator. Then, it was found that the Candida did not grow on the optical fiber coated with gold which means that this part of the sensor can kill the Candida.

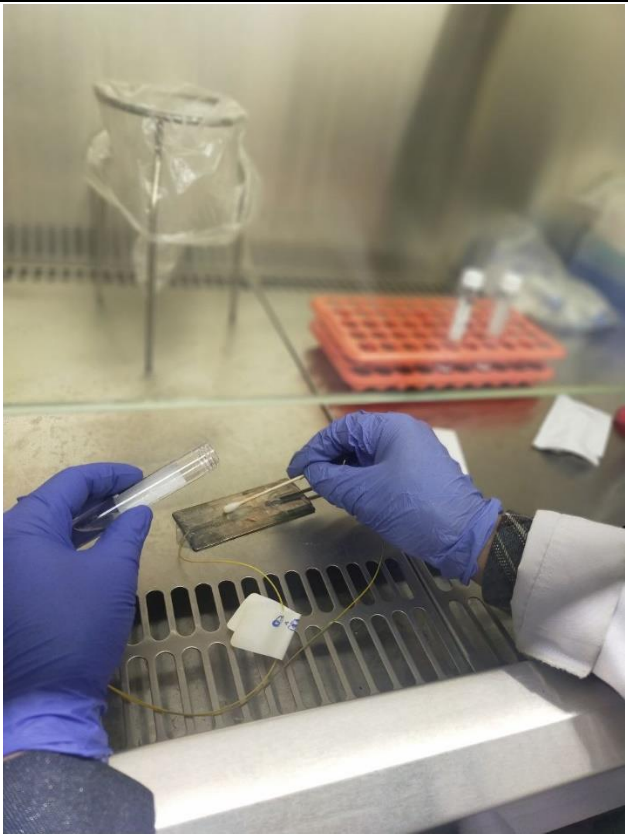


Figure (4): The Fungal Preparation.

5. Preparation of Solutions

The sensor's sensitive region was immersed in various solutions of sucrose / water with different concentrations, This resulted in various refractive indices(n_s), The refractive indices of solutions using an Abbe refractometer were calculated. Figure (5) shows the linear relationship between the refractive index and the concentration of the solution.

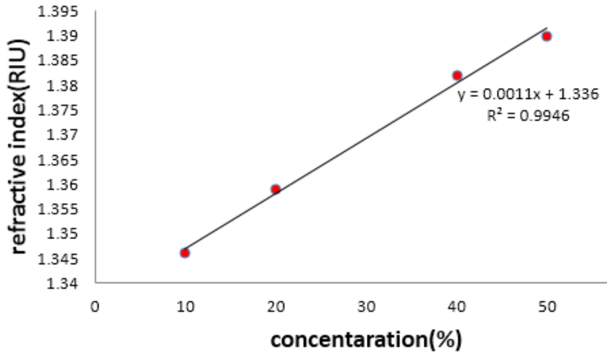


Figure (5) : Sucrose /water solutions refractive index in terms of the solution concentration.

6. Results and Discussion

In the present work, multiple parameters involving multi-mode and single-mode fibers with varying refractive index values (1.3502, 1.3538, 1.3394 and 1.3414) were identified in solutions of sucrose/water. Figure (6) and (7) revealed that the resonance wavelength sharp dip shifts to the greater wavelength side (redshift) when the sensor medium's refractive index augments as result of energy reduction. Figures (8) and (9) illustrates the SPR response curve of the fabricated sensor that has a gold layer at variable refractive indexes for the Candida (sensing medium). For multi-mode fiber, it is obvious that the resonance wavelength changes from 609nm to 680nm, as the Candida refractive index alters between 1.3502 to 1.3538 and the resonance wavelength shift from 420 nm to 570 nm for single-mode fiber, as the Candida refractive index alters between 1.3394 to 1.3414. With each sample having a different refractive index, the dip position and width of the (SPR) response curve to the sensor changes. Due to a decrease in energy with increasing index of refraction, the amount of shifting of the dip location ascends with an increase in refractive index, and the resonance wavelength's sharp dip shifts to the longer wavelength side (red shift). Table (1) shows the index of refraction magnitudes and the Candida concentration at numerous resonant wavelengths. The materials used to prepare the samples include (HF) acid, Distilled Water, and ethanol alcohol. These materials are described in table (2). Sensitivity was also calculated using the following equation:

$$\boldsymbol{S} = \frac{\Delta\lambda}{\Delta n_s} \quad \ldots\ldots\ldots (1)$$

Where $\boldsymbol{\Delta\lambda}$ and $\boldsymbol{\Delta n_s}$ are the change of the resonance wavelength and the change of refractive index respectively. From this equation, the unit of sensitivity is nanometers per refractive index unit (nm/RIU).

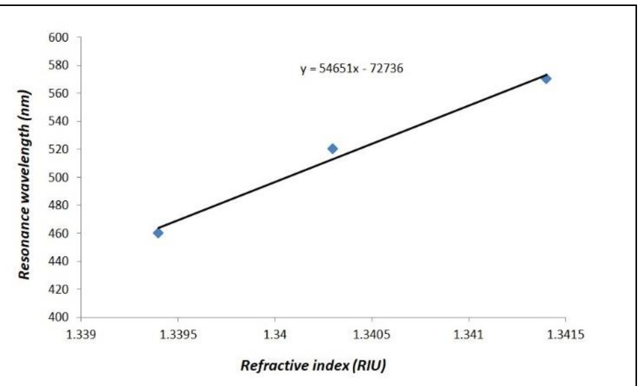


Figure (6): Refractive index versus resonance wavelength for the sensor with a gold layer for single-mode fiber.

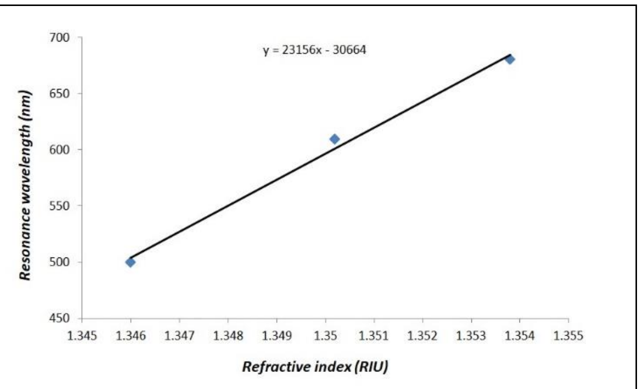
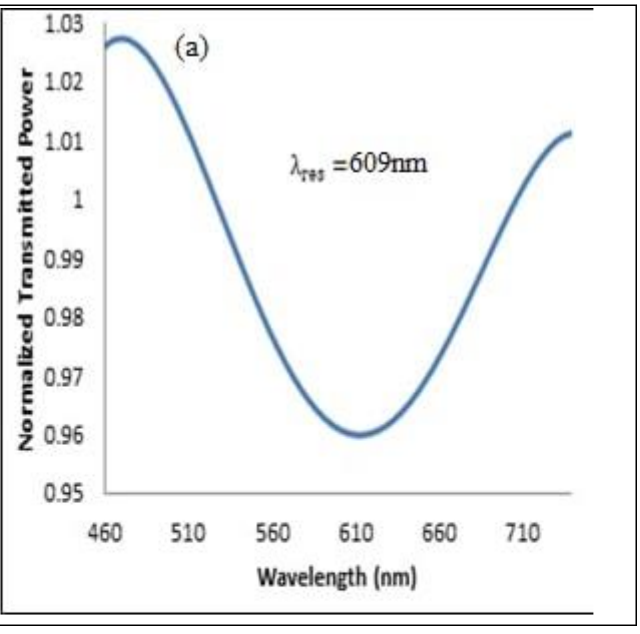


Figure (7): Refractive index versus resonance wavelength for the sensor with a gold layer for multi-mode fiber.



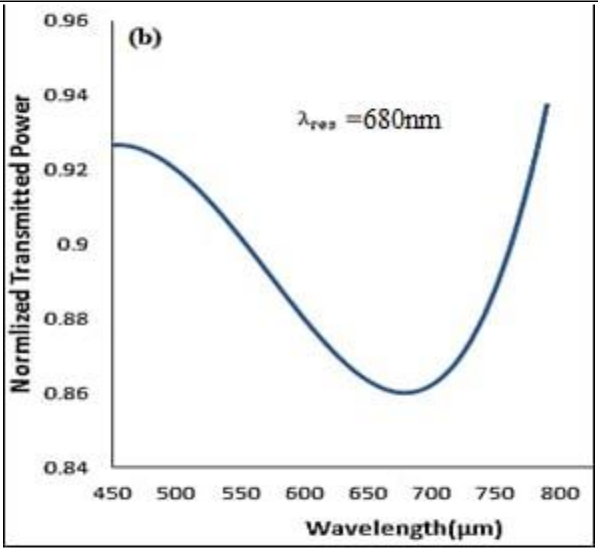


Figure (8): (a) SPR curve of the multi-mode fiber sensor with a gold metal of multi-mode samples before Candida was grown on the optical fiber.

(b) SPR curve of the multi-mode fiber sensor with a gold metal of multi-mode samples after Candida was grown on the optical fiber.

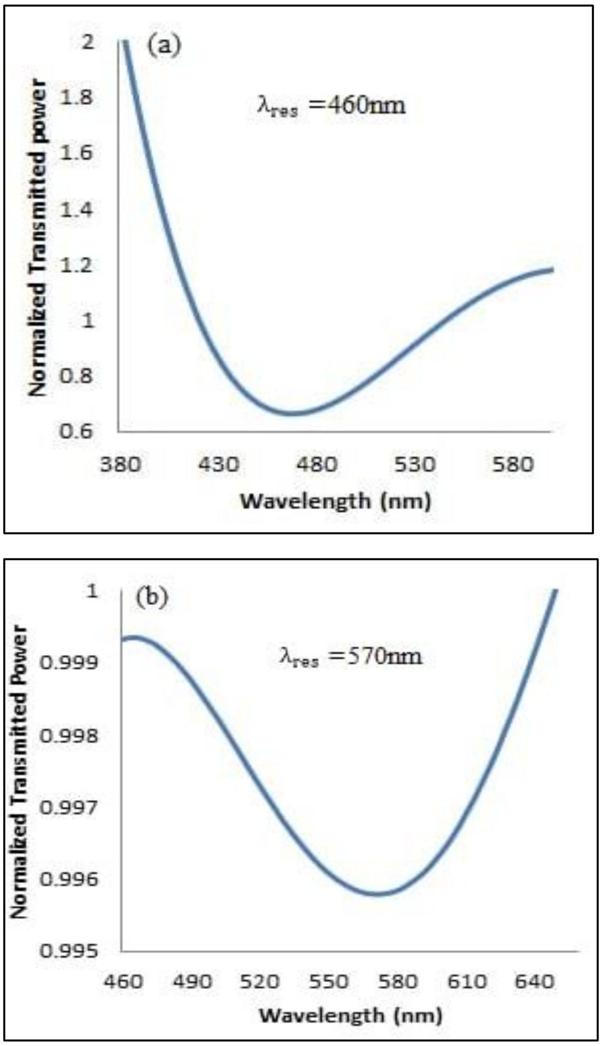


Figure (9): (a) SPR curve of the single-mode fiber sensor with a gold metal of multi-mode samples before Candida was grown on the optical fiber.

(b) SPR curve of the single-mode fiber sensor with a gold metal of multi-mode samples after Candida was grown on the optical fiber.

Table 1: Refractive index values and concentration for numerous resonance wavelengths.

Type of Fiber	Samples	λ_{res} (nm)	Refractive index (RIU)
Multi fiber	a	609	1.3502
	b	680	1.3538
Single fiber	a	460	1.3394
	b	570	1.3414

Table 2: The materials used to prepare the samples

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

7. Conclusions:

This research exhibits the application of optical fiber as a biomedical sensor based on (the SPR) technique for estimating the concentration and refractive index of Fungal (Candida). The response curve of (SPR) for various samples of Fungal (Candida) was shown, and a dip in the resonance position was presented in this work. At each sample of Fungal (Candida), the resonance wavelength change. Changing the index of refraction and then the Candida concentration will change the resonance wavelength value. From the results, it is clear that for the optical fiber based on surface Plasmon resonance (SPR) sensor with 40nm thick film of gold metal 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 1.47×10^{-6} RIU and figure of merit 66.6.

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