



ISSN: 0067-2904

Optical Fiber Biomedical Sensor Based on Surface Plasmon Resonance

Namaa Salem Rahim¹, Sudad S. Ahmed¹, Murtadha Faaiz Sultan²

¹Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

²Department of Physics, College of Science, Mustansiriyah, Iraq

Received: 31/7/2019

Accepted: 19/11/2019

Abstract

Optical fiber biomedical sensor based on surface plasmon resonance for measuring and sensing the concentration and the refractive index of sugar in blood serum is designed and implemented during this work. Performance properties such as signal to noise ratio (SNR), sensitivity, resolution and the figure of merit were evaluated for the fabricated sensor. It was found that the sensitivity of the optical fiber-based SPR sensor with 40 nm thick and 10 mm long Au metal film of the exposed sensing region is $7.5\mu\text{m}/\text{RIU}$, SNR is 0.697, figure of merit is 87.2 and resolution is 0.00026. The sort of optical fiber utilized in this work is plastic optical fiber with a core diameter of $980\mu\text{m}$, a cladding of $20\mu\text{m}$, and a numerical aperture of 0.51.

Keywords: blood serum, optical fiber sensor, surface plasmon resonance, blood serum.

متحسس الألياف البصرية الطبية الحيوية المعتمدة على رنين بلازمون السطح

نماء سالم رحيم¹ , سؤدد سلمان احمد^{1*} , مرتضى فائز سلطان²

¹قسم الفيزياء، كلية العلوم، جامعة بغداد، بغداد، العراق

²قسم الفيزياء، كلية العلوم، جامعه المستنصرية، بغداد، العراق

الخلاصة

متحسس الألياف البصرية الطبية الحيوية المعتمدة على رنين بلازمون السطح لقياس وتحسس تركيز ومعامل انكسار السكر في مصل الدم تم تصميمها وتنفيذها خلال هذا العمل . تم تقييم معاملات الأداء مثل نسبة الإشارة إلى الضوضاء، تحسسية، قدرة الفصل، وقيمة الكفاءة للمتحسس المصنع. لمنطقة $7.5\mu\text{m}/\text{RI}$ لقد وجد ان تحسسية لمتحسس الالياف البصرية المعتمدة على رنين بلازمون السطح بسمك 40 nm وطول فلم معدن الذهب 10 mm التحسس المتعرضه هي نسبة الإشارة إلى الضوضاء هي 0.697، قيمة الكفاءة هي 87.2 و قدرة الفصل هي 0.00026. نوع الالياف البصرية المستخدمة في هذا العمل هو الالياف البصرية البلاستيكية التي يبلغ قطرها و الفتحة العددية الأساسي $980\mu\text{m}$ ، اللب $0.5120\mu\text{m}$.

1. Introduction

Several developments within the field of sensing have been achieved in many areas of science, including biomedicine, biology, chemistry, biochemistry and physics. These developments have provided solutions to various problems associated with the sensors. The difficulties which can face the sensors are

*Email:soudadbassam@gmail.com

linked with the cost, the amount of the sample to be sensitive, the sensor size, and its performance properties such as the signal to noise ratio, sensitivity, and resolution etc.[1-3]. The optical fiber-based Surface Plasmon Resonance (SPR) detects numerous points of interest; for example, improved and flexible optical structure, advancement of remote detecting, ceaseless examination, and the in situ observation of superior prism-based SPR detection [4-7]. Optical excitation of surface plasmon waves (SPW's) has been used for several decades to build up various sensors. The SPR method was used for the first time in 1982 for gas sensing [8]. SPR-based optical sensors are employed for different applications in life sciences, environmental safety, electrochemistry and biomedical diagnostics [9, 10] . Surface plasmon is the oscillations of electron density whenever the associated transverse magnetic (TM) polarized waves are controlled parallel to the interface between the dielectric and metal. At the point when the momentum and energy of the incident light are equal to that of the surface plasmon wave, SPR takes place in the metal-dielectric interface. The energy is conveyed by photons transfer to the electrons in a metal to accomplish an obvious dip into the light intensity [11]. The resonance condition relies upon the dielectric constant of each the dielectric and the metal, as well as the wavelength of light and the incident angle. Each sharp dip is shown within the spectrum of the producing signal at the resonance wavelength (spectral interrogation) or the resonance angle (angular interrogation). The wavelength or the angle about which the resonant excitations of surface plasmon take place is extremely delicate to changes in the refractive index of the dielectric adjacent to the metal. Therefore, these changes in the refractive index of the sensing medium can be identified by estimating the resonance angle or the resonance wavelength [10, 12, 13]. To excite the surface plasmons, optical elements such as optical fiber, high refractive index prism, and diffraction grating are used [14, 15]. In 1993, the utilization of optical fibers for surface plasmon resonance sensing was first presented [16]. In this work, an optical fiber sensor based on surface plasmon resonance was designed and implemented for sensing and measuring the refractive index and concentration of sugar in blood serum.

2- Surface Plasmon Resonance

The resonant oscillation of the conduction electrons at the interface between the dielectric and metal, stimulated by an electromagnetic wave, is known as SPR. SPR can be excited by the photons or electrons. When the propagation constant of an incident light is equal to that of the collective oscillation of surface electrons in the metal, their momenta can be matched, and hence resonance occurs. Thus, SPR is highly sensitive to variations in the refractive index (RI) [17].

3- Performance properties

Performance characteristics to be studied are sensitivity, signal to noise ratio, figure of merit, and resolution. In the case of spectral interrogation, sensitivity can be defined as the change in resonance wavelength per unit change in refractive index of the sensing medium, and it can be written as [18]:

$$S = \frac{\Delta\lambda_{res}}{\Delta n_s} \dots\dots\dots (1)$$

Signal to noise ratio (SNR) and figure of merit (FOM) are inversely proportional to the width of SPR spectral curve, and can be written as [18] :

$$SNR (n) = \left[\frac{\Delta\lambda_{res}}{\Delta\lambda_{0.5}} \right] \dots\dots\dots (2)$$

$$FOM = \frac{S}{\Delta\lambda_{0.5}} \dots\dots\dots (3)$$

The resolution of the sensor can be defined as the minimum of change in refractive index detectable by the sensor, and is given as [15]:

$$R = \frac{\Delta n_s}{\Delta\lambda_{res}} \Delta\lambda_{DR} \dots\dots\dots (4)$$

2. The experimental work and devices

The experimental setup for measuring the transferred light spectrum consists of the light source (halogen lamp), plastic optical fiber from Thorlabs, the optical spectrum analyzer (OSA) from Thorlabs, and blood serum. The scheme illustrating the components of the SPR based optical fiber biomedical sensor setup is shown in Figure-1).

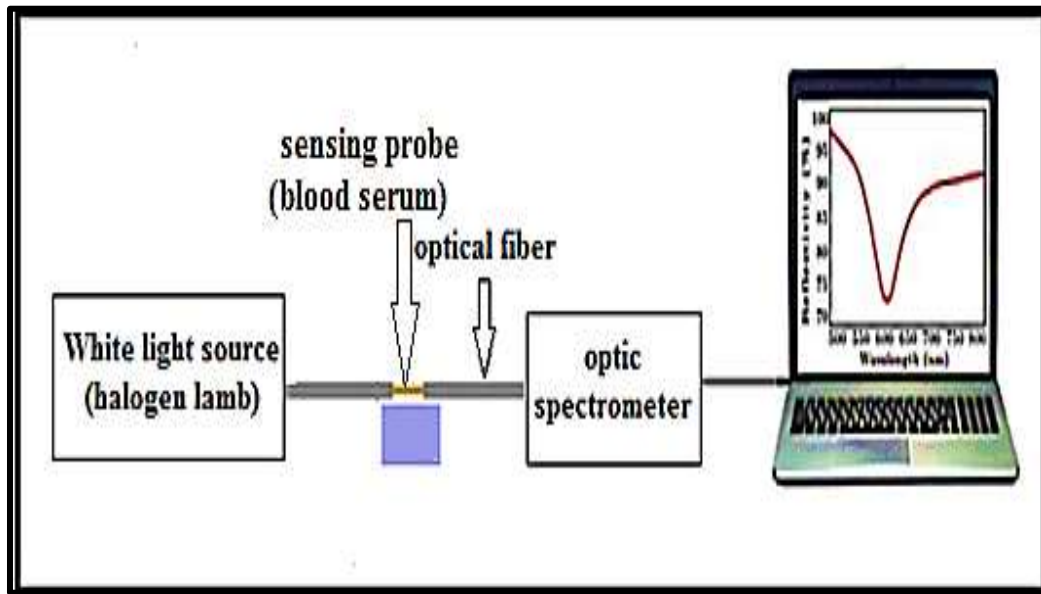


Figure 1-The outlines of the experimental setup of SPR based on plastic optical fiber.

2.1. Optical Sensor Systems

An optical-grade plastic optical fiber with a core diameter of 980 μm a numerical aperture of 0.51, without a jacket, and a small part (10mm) of optical fiber in the middle, was embedded in a resin block, then the polishing process was performed. The unclad part was cleaned with distilled water and deposited with about 40nm thickness of gold metal using ION_COATER (COXEM Company, Korea).

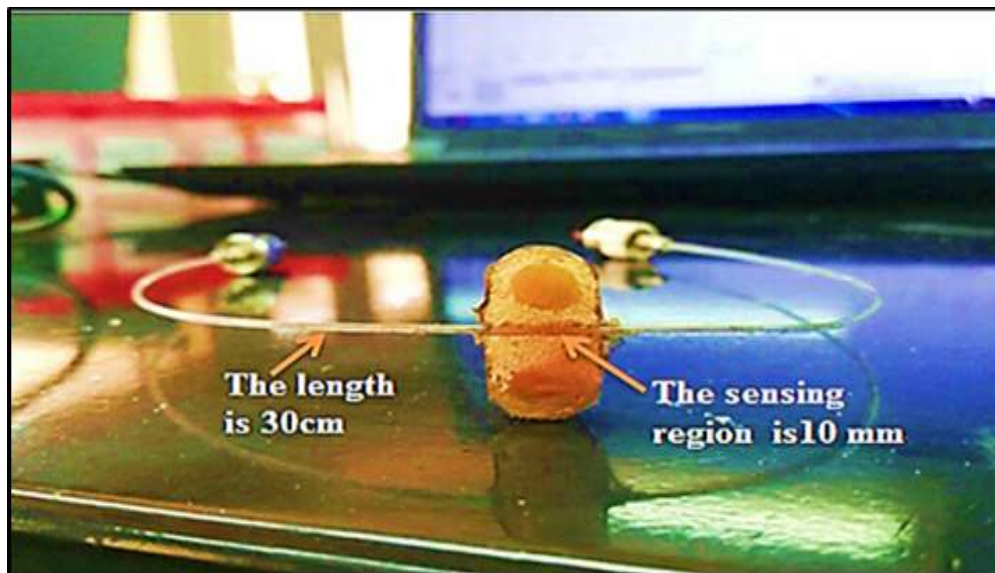


Figure 2-A photograph of the plastic optical fiber.

2.2. Preparation of Solutions with different refractive indices

The sensitive region of the sensor was covered in sucrose /water solutions with various concentrations and, thereby, different n_s refractive indices. We measured the refractive indices of the solutions using an

Abbe refractometer. Figure-3 demonstrates the linear relationship between the refractive index values and the solution concentrations.

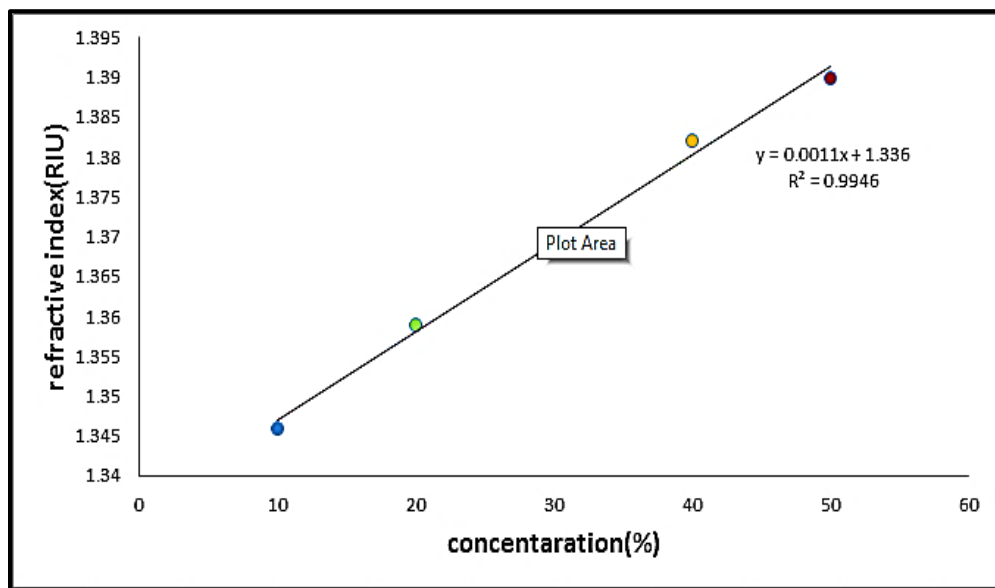


Figure 3-Refractive index of sucrose /water solutions as a function of the solution concentration.

3. Results and Discussion

In this work, several parameters including fiber core diameter =980 μ m, fiber optic numerical aperture (NA) =0.51, gold layer thickness (d) =40nm, sensing length (L) =10mm and various values (1.346, 1.359, 1.382 and 1.39) of refractive index from sucrose /water solutions were found.

The spectra are obtained by recording the transition curves (T) of light through optical fiber. T is calculated from the ratio of the intensity (I) measured in the presence of a sample (sensing medium) and the intensity of the optical signal (I_0) that is evaluated in the absence of the sample.

The transmission (T) is a function of the wavelength in nm. The T-wavelength curve is called SPR curve and, at a special wavelength, named resonance wavelength. A sharp dip happens within T because the energy of incident light transfer into the electrons of the metal and thus reduces the reflected light intensity. The location of this dip depends on the refractive index (n) of the sensing medium. As the refractive index of the sensing medium increases, the resonance wavelength increases because of the sharp dip shifting to the red wavelength, as shown in Figure-4.

Figure-5 shows the SPR response curve of the fabricated sensor with a gold layer at various refractive index values of blood serum (sensing medium). It is clear that the resonance wavelength shifts from 495nm to 531nm for the gold metal, as the refractive index of the blood serum varies from 1.3392 to 1.3464. The width and dip position of each (SPR) response curve to the sensor is changed with each sample having a different refractive index. Also, the magnitude of shifting of the dip position increase as the refractive index increases. These variations make the performance parameters, which depend on the SPR curve width, the value of the shifting and the position of dip, change with the changing of resonance wavelength and refractive index of the sensing medium. This occurs because they depend upon the change of the resonance wavelength, the change of refractive index, and the width of the spectral curve. Table-1 shows the experimental performance parameters of the sensor with gold.

Table-2 demonstrates the values of the refractive index and concentration of sugar for each sample of blood serum at different resonance wavelengths. The resonance wavelengths were determined from SPR curves for various samples of blood serum (Figure-5), while concentration and refractive index values were calculated from slope equations, as shown in Figures-(3, 4), respectively.

The concentration of the samples increased as the refractive index increased and the resonance wavelengths increased. This occurs because of the sharp dip shifting to the high wavelength (red wavelength).

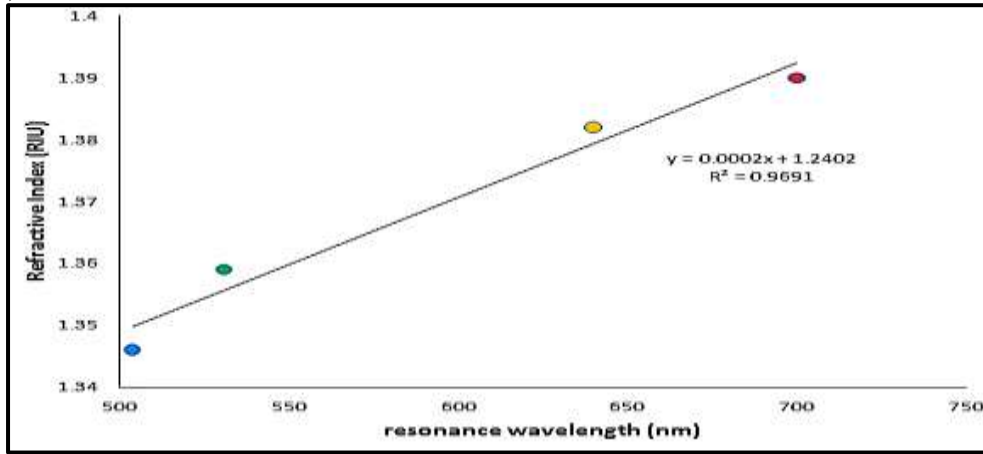


Figure 4-Refractive index as a function of resonance wavelength for the sensor with a gold layer.

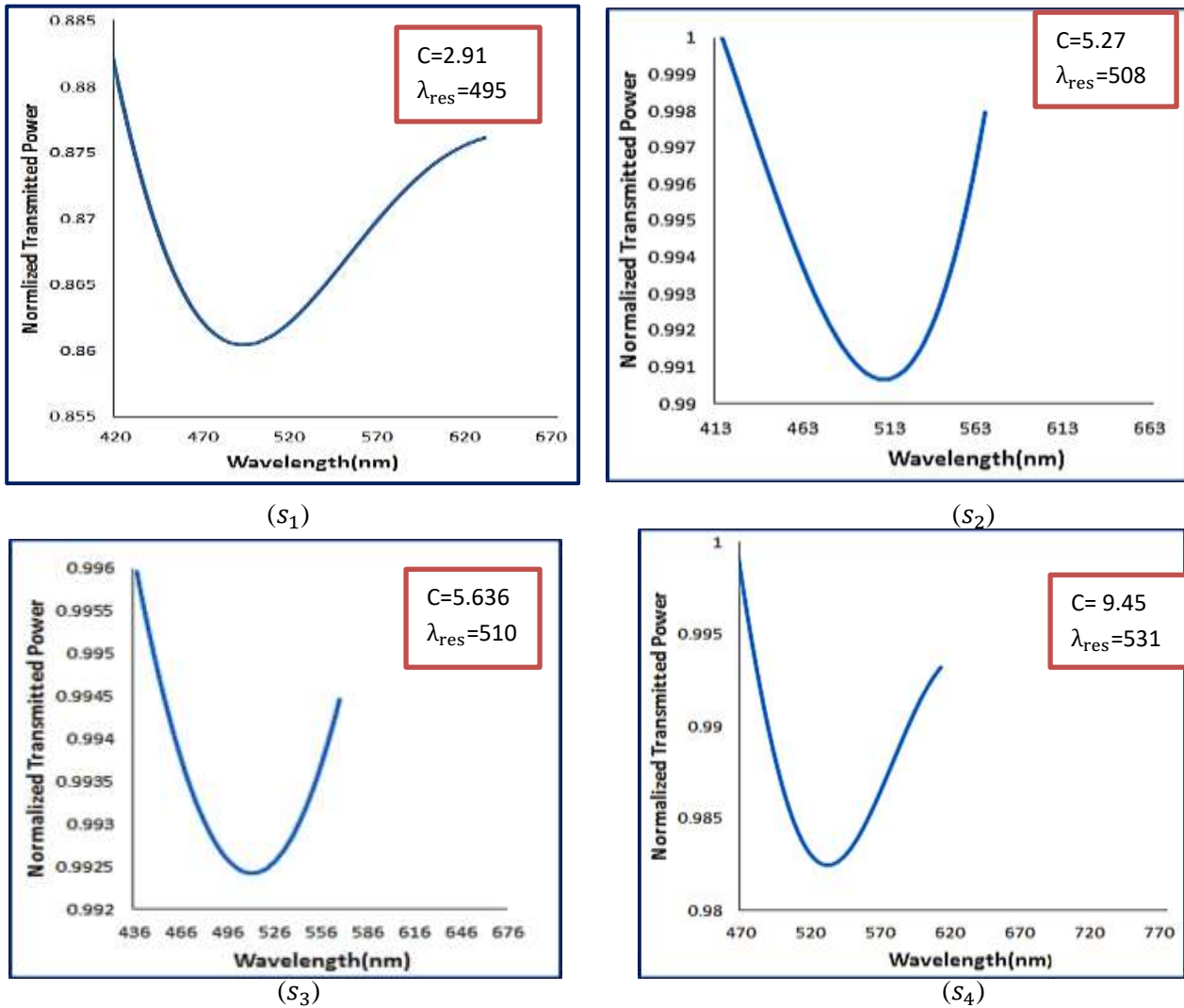


Figure 5-SPR curve of the optical fiber sensor with a gold metal of different samples of blood serum.

Table 1-Experimental performance parameters of the sensor with gold

Metal	Sensitivity (S_n) [$\mu\text{m}/\text{RIU}$]	Signal to noise ratio (SNR)	Figure of merit (FOM)	Resolution [RIU]
Gold	7.5	0.697	87.2	0.00026

Table 2-Values of the refractive index and concentration for various resonance wavelengths

Samples of blood serum	$\lambda_{res}(\text{nm})$	Refractive index (RIU)	Concentration(C)
S_1	495	1.3392	2.91
S_2	508	1.3418	5.27
S_3	510	1.3422	5.636
S_4	531	1.3464	9.45

4. Conclusions

This paper presents the usage of the plastic optical fiber as a sensor of sugar concentration in the serum of human blood as a biomedical sample. SPR response curves for different samples of blood serum were recorded 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 of sugar in the blood serum. The sensitivity of the plastic optical fiber- based SPR sensor with 40nm thick Au metal film of the exposed sensing region was 7.5 $\mu\text{m}/\text{RIU}$ and the signal to noise ratio was 0.697.

References

- Ligler, F.S. and C.R. Taitt, C.R. **2002**. *Optical biosensors: present & future*: Gulf Professional Publishing.
- Homola, J., S.S. Yee, and G. Gauglitz, G. **1999**. Surface plasmon resonance sensors. *Sensors and Actuators B: Chemical*, **54**(1-2): 3-15.
- Sultan, M.F. **2018**. Performance Parameters Evaluation of Surface Plasmon Resonance Based Fiber Optic Sensor with Different Bilayer Metals: Theoretical Study. *Al-Mustansiriyah Journal of Science*, **29**(1): 195-203.
- Homola, J. **1995**. Optical fiber sensor based on surface plasmon excitation. *Sensors and actuators B: chemical*, **29**(1-3): 401-405.
- Lin, W.B. **2000**. The effects of polarization of the incident light-modeling and analysis of a SPR multimode optical fiber sensor. *Sensors and Actuators A: Physical*, **84**(3): 198-204.
- Sharma, A.K. and B. Gupta, B. **2004**. Absorption-based fiber optic surface plasmon resonance sensor: a theoretical evaluation. *Sensors and Actuators B: Chemical*, **100**(3): 423-431.
- Sultan, M.F., A.A. Al-Zuky, and Kadhim, S.A. **2018**. Surface Plasmon Resonance Based Fiber Optic Sensor: Theoretical Simulation and Experimental Realization. *Al-Nahrain Journal of Science*, **21**(1): 65-70.
- Nylander, C., Liedberg, B. and Lind, T. **1982**. Gas detection by means of surface plasmon resonance. *Sensors and Actuators*, **3**: 79-88.
- Venditti, I. **2017**. Gold nanoparticles in photonic crystals applications: A review. *Materials*, **10**(2): 97.
- Kretschmann, E. and Raether, H. **1968**. Radiative decay of non radiative surface plasmons excited by light. *Zeitschrift für Naturforschung A*, **23**(12): 2135-2136.

11. Homola, J. **2008**. Surface plasmon resonance sensors for detection of chemical and biological species. *Chemical reviews*, **108**(2): 462-493.
12. Otto, A. **1968**. Excitation of nonradiative surface plasma waves in silver by the method of frustrated total reflection. *Zeitschrift für Physik A Hadrons and nuclei*, **216**(4): 398-410.
13. Kretschmann, E. **1971**. Die bestimmung optischer konstanten von metallen durch anregung von oberflächenplasmaschwingungen. *Zeitschrift für Physik A Hadrons and nuclei*, **241**(4): 313-324.
14. Lin, W.B. **2001**. Development of a fiber-optic sensor based on surface plasmon resonance on silver film for monitoring aqueous media. *Sensors and Actuators B: Chemical*, **75**(3): 203-209.
15. Srivastava, S.K. and Gupta, B.D. **2011**. Influence of ions on the surface plasmon resonance spectrum of a fiber optic refractive index sensor. *Sensors and Actuators B: Chemical*, **156**(2): 559-562.
16. Jorgenson, R. and Yee, S. **1993**. A fiber-optic chemical sensor based on surface plasmon resonance. *Sensors and Actuators B: Chemical*, **12**(3): 213-220.
17. Gandhi, M. **2019**. Recent advances in plasmonic sensor-based fiber optic probes for biological applications. *Applied Sciences*, **9**(5): 949.
18. Cennamo, N. **2011**. Low cost sensors based on SPR in a plastic optical fiber for biosensor implementation. *Sensors*, **11**(12): 11752-11760.