

Fabrication and Characterization of SPR Based Fiber Optic Probe Using e beam Deposition

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Abstract: A surface plasmon resonance based fiber optic probe has been fabricated using electron beam deposition. The fabricated probe has been characterized using sucrose solution. It has been observed that the resonance wavelength i.e. SPR wavelength increases with increasing concentration of sucrose solution. The experimental results so obtained have been compared with theoretically simulated model results and are found to be in good agreement qualitatively. This study will found applications in fabrication of biochemical sensors. Copyright © 2014 IFSA Publishing, S. L.

Keywords: Surface plasmons, Fiber optics, Evanescent wave, Plasmons, e beam deposition, Biosensors.

1. Introduction

Surface plasmons in conjunction with optical fibers have revolutionized the area of imaging, plasmonic devices, terahertz optics and also in sensing [1-10]. It is a most reliable tool for sensing various biochemical species, gases and liquid media [3-4]. Researchers from all over the world are exploring various other applications of this upcoming area [10-20]. Recently many theoretical models have been proposed for the better sensing mechanisms such as localized surface plasmon resonance based fiber optic sensors [3] use of conducting metal oxides is also an important study [10-12]. In the last year people have fabricated and characterized the fiber optic sensing probes for pH sensing [9] and H₂S gas sensing [10]. Sensing of Phenolic compounds and Ammonia gas sensing has also been proposed [11-12]. Fiber optic grating is also being used in conjunction with SPR to make a miniaturized fiber optic probe for sensing the refractive indices [13-14]. Most recently people are also proposing certain models on optical waveguides which involves artificially structured materials such as metamaterials

as a SPR active material [15]. In the present study we have fabricated the fiber optic probe by depositing a thin layer of silver on to the core of the fiber using electron beam deposition technique. The probe so fabricated is characterized for sensing the sugar solution. Apart from the experimental study theoretical simulation for the fiber optic SPR probe has also been carried out. A comparative study has been carried in terms of the theoretical model and experimental results so obtained.

2. Experimental

2.1. Materials

The sugar cubes for laboratory purpose were purchased from the Scientific Supplier India. The silver wire with 99.99 percent purity was purchased from Advanced Scientific Delhi, India. The distilled water required was available in Chemistry Department. The multimoded PCS fiber was purchased from Fiberguide (USA).

2.2. Deposition of Silver on Fiber Core

A plastic clad silca fiber of 600 micrometer core diameter and 0.40 numerical aperture and 15 cm in length was taken. Around 1 cm of the cladding was removed from the middle portion of the fiber using a Tungsten blade. After cleaning with acetone, it was mounted on to specially designed plate so that only 1 cm piled core is exposed for coating. This plate was then kept in an e beam evaporation chamber. The rotary pump was started to make the pressure in the chamber around $5 \cdot 10^{-2}$ mBar. Then using the diffusion pump the pressure inside the chamber was made around $5 \cdot 10^{-6}$ mBar. At this pressure the e beam gun supply was made on and slowly the current in the e beam supply was increased around 25 mA. The silver kept in crucible inside the chamber starts evaporating. At the same time the thickness monitor was switched on and the shutter to deposit the evaporated silver on to the core of the fiber was opened. In around 5 minutes of electron beam bombardment on to the silver we get the 50 nm of the coating on to the fiber. Since the fiber possess the cylindrical symmetry therefore to make uniform coating on to the whole circular region the fiber was rotated by 120 degree and then deposited the silver again and further round was completed by further rotating the fiber by 120 degrees. In this way by 120 degree rotation three times we get a uniform deposition of the silver film of around 50 nm thickness on to the exposed core of the fiber.

2.3. Experimental Setup

The schematic diagram of the experimental set up is shown in the Fig. 1. After fabricating the SPR fiber optic probe it was kept in flow cell with inlet and outlet facilities. Polychromatic light from tungsten halogen lamp was launched in to the one end of the fiber with proper optics and was collected from the other end of the fiber. The light received from this end was sent to the spectrometer. The output of the spectrometer was sent to the computer loaded with avasoft 8.0 package. The computer shows the variation of the transmitted power with the wavelength in the form of an SPR dip. The minima of the SPR dip corresponds to the resonance wavelength which was determined by data converted in excel format.

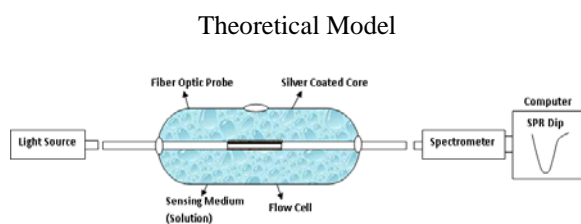


Fig. 1. A typical Schematic diagram of experimental set up.

3. Theoretical

The theoretical model is based on the principle of attenuated total reflection (ATR) with Kretschmann configuration. Various mathematical formulae to calculate the transmitted power were taken from our previous work [5]. The light is launched into the one end of the fiber through a broadband light source with proper optics. The other end is connected to a detection system to record the output signal. Consider the propagation of all the guided rays launched in the fiber using a collimated source and a microscope objective. The objective focuses the beam at the end-face of the fiber at axial point. The angular power distribution of rays guided in the fiber with θ as the angle of the ray with the normal to the core-cladding interface is given by [5]

$$dP \propto \frac{n_1^2 \sin \theta \cos \theta}{(1 - n_1^2 \cos^2 \theta)^2} d\theta \quad (1)$$

To determine the effective transmitted power, the reflectance (R_p) was calculated using N-layer model and a single reflection is raised to the power of the number of reflections the specific propagating angle undergoes with the sensor interface [5]. The effective formula to calculate the transmitted power at the output end of the fiber is given in eq.

$$P_{trans} = \frac{\int_{\theta_c}^{\pi/2} R_p^{N_{ref}(\theta)} \frac{n_1^2 \sin \theta \cos \theta}{(1 - n_1^2 \cos^2 \theta)^2} d\theta}{\int_{\theta_c}^{\pi/2} \frac{n_1^2 \sin \theta \cos \theta}{(1 - n_1^2 \cos^2 \theta)^2} d\theta}, \quad (2)$$

where θ_c is the critical angle for the core cladding interface. The variation of the refractive index of the fiber core and of the metal layer and with wavelength was taken in to consideration using Sellmeier and Drude relations [5].

4. Results and Discussions

To study the response of the SPR fiber optic probe SPR spectrums were recorded for different concentrations of sugar solutions. The solutions were made by taking 8.1752 gm of sugar cubes in 100 mL of distilled water. The solution was kept on a magnetic stirrer for 15 minutes. Then the half of the solution was kept as concentration 1. Remaining half solution was diluted by adding the equal amount of water and again kept on a magnetic stirrer for about 15 minutes. Half of the solution thus obtained was kept as solution with concentration 0.5. Again this process was repeated and a solution with concentration 0.25 was made. The experimental set up was arranged as shown in the Fig. 1. First of all pure water was poured in to the flow cell and the SPR spectrum was recorded. The

transmitted power was recorded at the output end. This transmitted power shows a minimum in the visible range of the spectrum. The resonance wavelength (SPR wavelength) comes out around 606.797 nm. Then the water from the flow cell was taken out using a syringe. The empty flow cell then was dried with a dryer. Similarly the solution with one fourth concentrations was poured in to the flow cell and the SPR spectrum was recorded. The minimum wavelength was found to be 607.128 nm. In this way the solutions with increasing concentrations were poured one by one and SPR spectrums were recorded. The recorded SPR spectrums with increasing concentrations are shown in the Fig. 2.

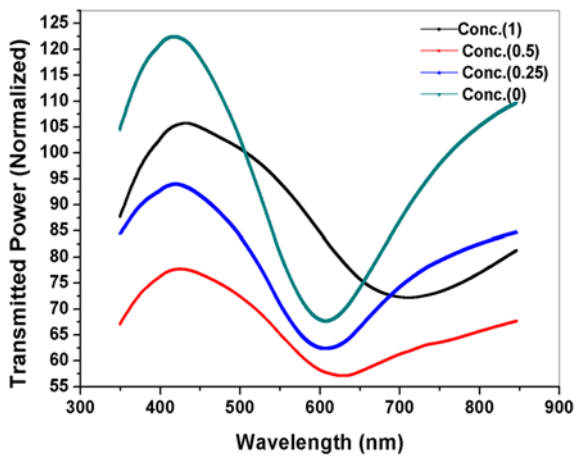


Fig. 2. Typical SPR spectrum with increasing concentration of sugar solution.

Also the variation of resonance wavelength with concentration is plotted and is shown in Fig. 3. The data corresponding to the concentration and wavelength are given in the Table 1. It is found that as the concentration of the sugar solution increases the resonance wavelength also increases.

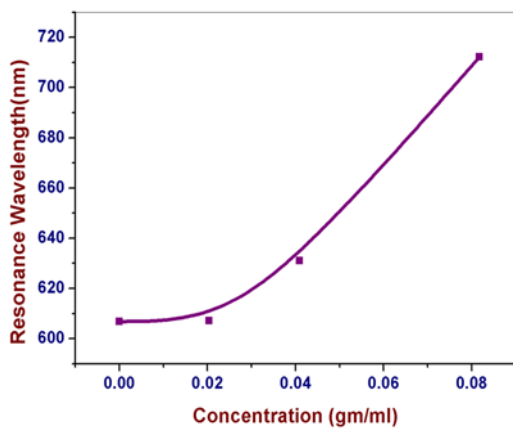


Fig. 3. Variation of resonance wavelength with concentration.

It appears that as we increase the concentration of the solution its refractive index also increases. Due to the increased refractive index the resonance condition (matching of the SPR wave vector and evanescent wave vector) is satisfied at higher value of the wavelength thereby increasing the resonance wavelength.

Table 1. Data for resonance wavelength with concentration.

Concentration (gm/ml)	Resonance wavelength (nm)
0.0818	712.262
0.0409	630.969
0.0405	607.128
0.0000	606.797

The theoretical SPR curves with increasing concentrations are also shown in the Fig. 4 and the corresponding variation of resonance wavelength with refractive index has also been plotted in Fig. 5.

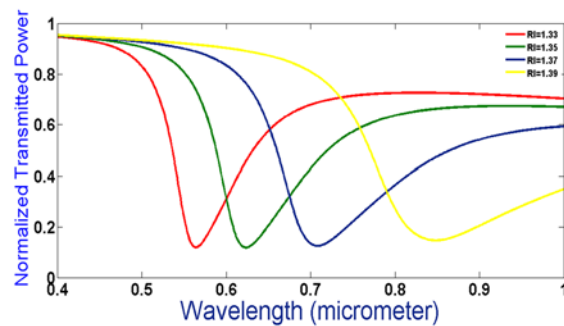


Fig. 4. Typical SPR spectrum with increasing Refractive indices (theory).

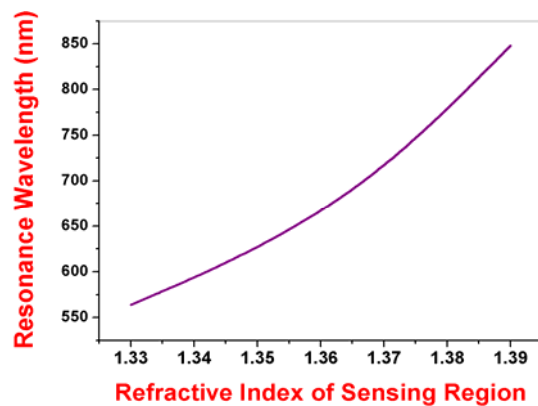


Fig. 5. Variation of resonance wavelength with refractive index of sensing region (theory).

Therefore it confirms that the theoretical and experimental results match qualitatively.

5. Conclusions

In summary, a comparative study between theory and experiment for an SPR based fiber optic fabricated by electron beam deposition has been carried out. It is found that on increasing the concentration of the sugar solution the resonance wavelength increases. The results obtained from theory and experiment matches qualitatively.

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