Chapter- 12

Biochemical Sensitivity of Surface Plasmon Resonance Sensors

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Abstract

Biochemical sensors based on surface plasmon resonance (SPR) are highly efficient tools for label free chemical detection and for the investigation of real time biomolecular interactions. This flexible, powerful and highly sensitive technique is widely used for rapid detection in medical and biological fields. The current research work focus on the surface plasmon resonance of the metal's gold and copper through simulation analysis. The theoretical analysis was based on Fresnel's equations of electromagnetic waves that describe the behaviour of light waves when they encounter an interface between two media with different refractive indices. The propagating surface plasmon waves are analysed on the planar structure on prism based Kretschmann Raether configuration. The angular scanning method of SPR detection was employed in this process. The reflected light intensity was measured for an angular range of 0^o to 90^o. Also, SPR bio sensitivity was studied by employing a simulated sugar solution environment to the metal surface. The detection sensitivity of SPR based sensors are revealed through this work.

Key words: Surface plasmon resonance, biochemical sensor, simulation analysis, angular scanning method

1. Introduction

In the current era of modern technology, both scientific research and commercial applications demand sensors for rapid and exact

ISBN: 9789348505767

analysis. Surface plasmon resonance (SPR) [1-5] biosensors are sophisticated detection and analysis tool with multiple applications in biotechnology, health care diagnosis, drug detection, preservation of the environment, food security and hygiene biological field and fluorescence-based correlated emissions [6-12]. Relative to traditional sensing techniques, plasmonic sensing technology's affordable manufacturing costs and versatility have made them the industry frontrunner in commercial sensors.

Surface plasmon resonance (SPR) occurs when plane-polarized light impacts a thin, semi-transparent metal sheet (such as silver or gold) placed at the bottom of a high-RI prism. When incoming light photons reach a certain critical angle of incidence, the metal surface absorbs them and transfers the energy to electrons, which transform into surface plasmons. A decrease in the intensity of reflected light indicates the production of surface plasmons. These circumstances are particularly sensitive to any changes occurring near to the metal-dielectric interface, such as the formation of molecular layers and the adsorption of molecules onto the metal surface. This optical approach analyses changes in the refractive index (RI) of a medium in close proximity to a metallic surface as a result of surface binding events. The composition of the metal and the wavelength of the incoming radiation play important roles in the generation of surface plasmons.

SPR sensing techniques can use phase, angular, intensity, and wavelength interrogation methods [13-19]. The angular scanning method provides a large dynamic window for a wide range of practical applications. This method of SPR detection is a prism based set up on Kretschmann Raether configuration [20-22]. It involves a thin metal film on top of a high-refractive-index prism, typically made of glass. When light is incident on the prism at a specific angle, an evanescent wave is generated at the metal-dielectric interface. When the angle of incidence matches the SPR angle, the evanescent wave couples with the surface plasmons, leading to a sharp decrease in reflected light intensity.

The present research works the SPR studies were conducted on the metal thin film in the nanometre range. Gold and copper are used for the simulation analysis of SPR response from the planar structures. Theoretical analysis was carried out on the basis of Fresnel's equations

ISBN: 9789348505767

for light waves. The SPR reflection dip was analysed and the studies were continued for biochemical sensitivity of these metals. Simulated sugar solution environment was used for the study of biochemical sensitivity of surface plasmons. The study shows the shift in the reflection dip in the presence of foreign particles on the metal surface.

2. Experimental Methods

Simulation analysis was carried out for the theoretical study of SPR response and its biochemical sensitivity from the metal's gold and copper. WinSpall Software is used to carry out the simulation operations. This is based on Fresnels equations of electromagnetic radiations. These equations describe how light waves behave when they pass across an interface between two mediums with distinct refractive indices. By modifying the parameters such as the extinction coefficient, thickness, and refractive index, different SPR curves may be produced. Additionally, it offers a configuration for producing various curves for various incident light wavelengths, and appropriate prisms may be chosen.

SPR became apparent when light was incident on a thin metal layer via a prism with a sufficient refractive index. For incidence angles greater than the critical angle, light experiences entire internal reflection. However, due to evanescent waves, free electrons within the metal vibrate, resulting in surface plasmons. At the plasmon resonance angle, incident light is absorbed due to the phase matching condition between the incident light and the surface plasmon at the metal dielectric interface. The incident wave vector's in-plane component needed to be matched. This criterion results from solving Maxwell's equation for the boundary conditions, which states that the in-plane component of the electric field has to be continuous across the interface. The wave vectors, of the incident light in-plane of the interface (k_x) and the surface plasmon (k_{sp}), are given by

$$k_x = k_o n_p \sin\theta_I \; and \; k_{sp} = k_o \left(\frac{\varepsilon_m \varepsilon_s}{\varepsilon_m + \varepsilon_s} \right)^{1/2} \qquad (1)$$

Where ε_m is the dielectric constant of the metal (m) and ε_s is the effective dielectric constant at the metal dielectric interface. For SPR

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absorption to occur, the light wave vector must equal the surface plasmon wave vector, as provided by:

$$k_{sp} = k_x = k_o n_p \sin\theta_{sp} \qquad (2)$$

The most used method for excitation of surface plasmons is the attenuated total internal reflection method or prism coupling method. Kretschmann Raether configuration for the study of surface plasmons were shown in the figure-1.

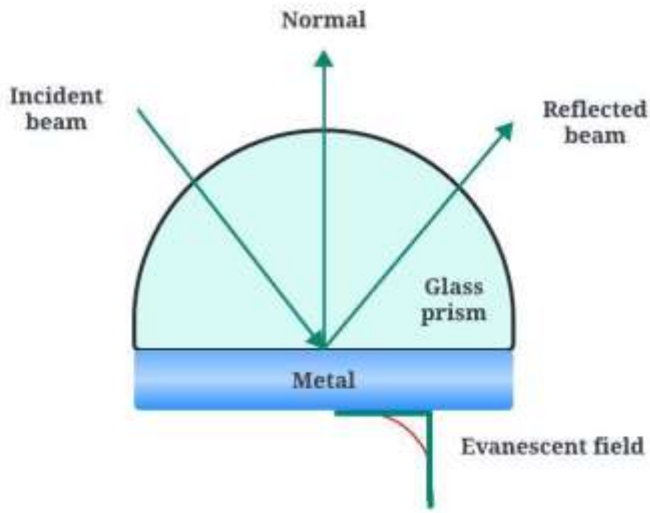

Figure-1: SPR setup in the Kretschmann configuration

In this setup the samples composed of metallic films on a glass substrate in air is attached to the glass prism. Light from below, at an angle relative to the film's normal, strikes the metal film from the glass side through prism. SPPs on the metal/air side may be triggered if the specified momentum matching conditions are achieved.

3. Results and Discussion

Surface plasmon resonance reflection curves were generated for an excitation wavelength of 500 nm. The thin metal planar films in the nanometer range were used for the analysis of the creation of surface plasmons theoretically. For gold films in the 50 nm thickness the Winspall generated SPR curve is shown in the figure-2(a) and for copper film is given in figure-2(c).

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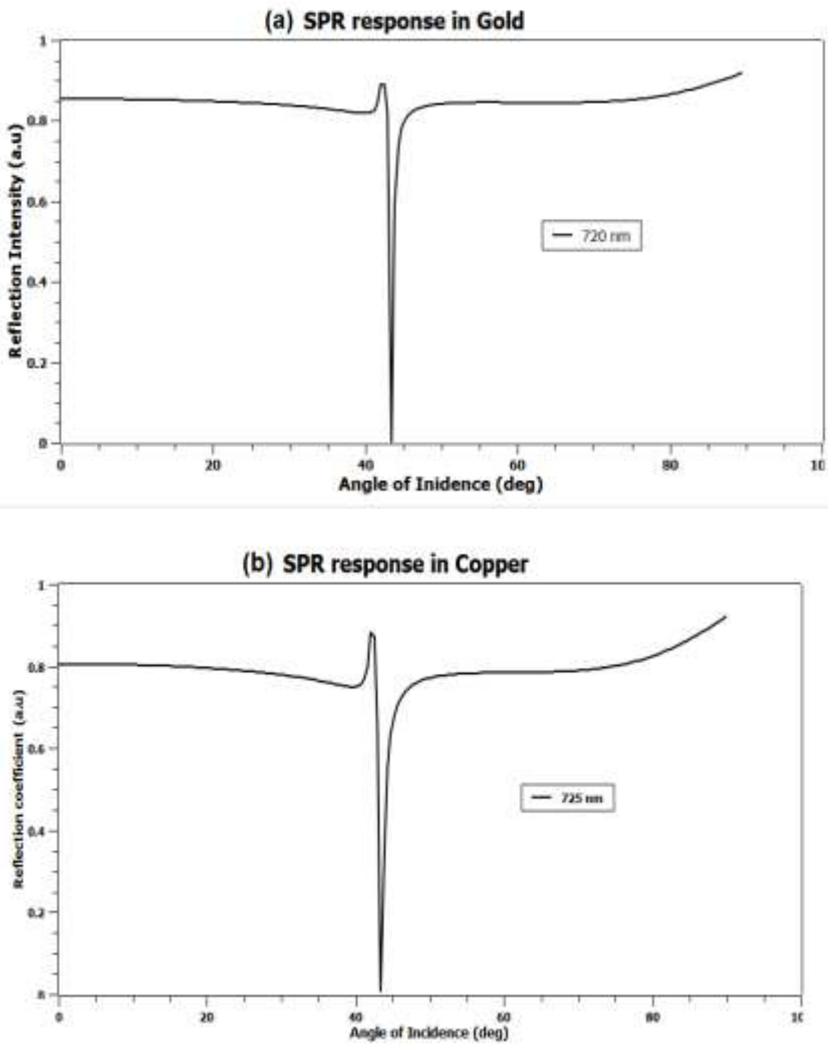

Figure-2: (a) Simulated SPR response from gold thin film (b) Simulated SPR response from copper thin film

Planar gold films in the nanometre range (50 nm) were excited with radiations of 720 nm wavelength. The generations of surface plasmons are detected by a sharp dip in the reflection curve in this angle scanning method of SPR detection. For gold film the dip was at 43.5^{o}. The fullwidth at half maximum (FWHM) of the curve is 0.59. For thin copper film in the nanometer range (40 nm) (figure-2 (c)), the reflection dip shown in the curve is at 43.4^{o}. The FWHM of this reflection dip is 0.96. It is higher than gold film but almost similar to an ideal SPR curve.

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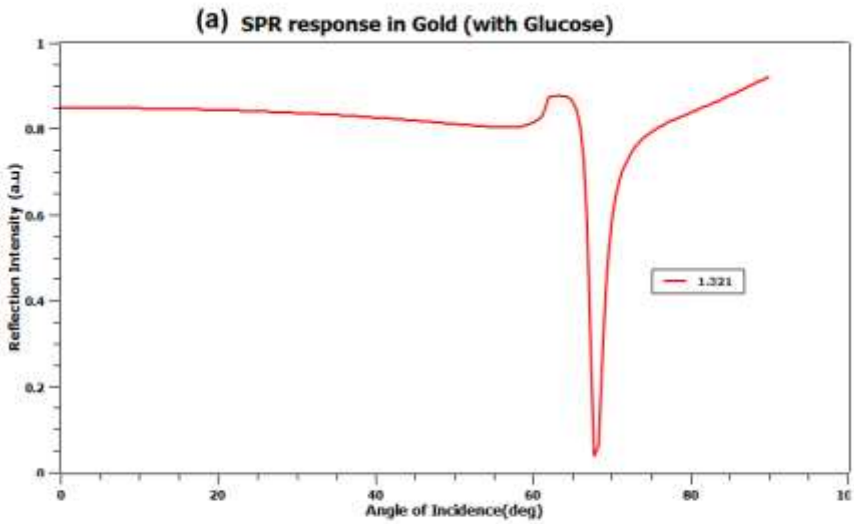

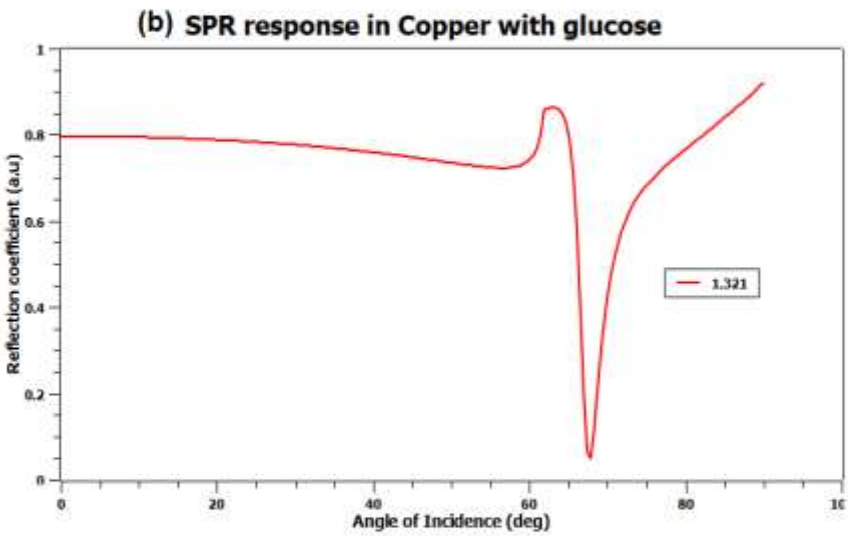

Figure-3: (a) Simulated SPR response from gold thin film with glucose (b) Simulated SPR response from copper thin film with glucose

To understand the chemical sensitivity of these metal SPR active structures, the simulation analysis was continued with glucose as the chemically active substance. By providing the refractive index corresponding to the glucose solution, the angle scanning process was done so as to find the change in the SPR curve. A drastic shift was

ISBN: 9789348505767

observed in the SPR curve of gold film, shown in the figure-3(a). The new SPR angle was at 67.9^{o}, a shift of 24.4^{o} was obtained for the gold metal planar system with glucose solution. For copper metal planar system, the presence of glucose shows a shift in the SPR curve with reflection angle at 67.6^{o}. A shift of 24.1^{o} was obtained in the presence of glucose. Thus, these two metal planar thin film systems are found to be highly sensitive to the biochemical environment that can be determined via angle scanning method of SPR detection.

4. Conclusion

By employing the simulation analysis using WinSpall software, the SPR studies were conducted on metal planar thin films of gold and copper in the nanometre range. The study continued for the biochemical sensitivity of these materials by employing a glucose solution. A large shift in the reflection curve was obtained from the normal dip of gold and copper films. This reflects the high sensitivity of these metals for the glucose molecule. Thus, the angular scanning method of SPR detection is a reliable and highly sensitive pathway for biochemical sensing.

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ISBN: 9789348505767