Performance Optimization of Surface Plasmon Resonance based Sensors from the First Principle

Himanshu Kushwah[1], Jagneet Kaur Anand[1]
[1]*Department of Electronics, Keshav Mahavidyalaya, University of Delhi, Delhi-110034*
Author e-mail address: himanshu.kushwah@keshav.du.ac.in

Abstract: Performance optimization of surface plasmon resonance (SPR) based sensors due to improvement in input optical coupling is theoretically investigated from the first principle. Various design parameters are optimized in a typical prism coupling Kretschmann configuration.

1. Introduction

SPR based optical devices are finding a lot of sensing-applications, including gas and chemical sensors to be used in chemically hazardous environments and as bio-sensors to be used for detecting various bio-molecules [1]–[3]. In this article, we consider an SPR sensor consisting of prism-gold-silica-analyte regions in Kretschmann configuration and angular interrogation set-up. We discuss its design methodology to obtain enhanced transverse electric field component in the input electromagnetic wave which is incident on the prism base and excites the surface plasmon (SP) mode in the SPR sensor. An enhanced transverse component of the input electric field increases the real part of the effective index of the SP mode which is responsible for the improvement in the sensitivity of the sensor.

2. Basic Physics

Figure 1 shows a typical SPR sensor in the Kretschmann configuration. Here n_p, n_m, n_d, and n_a are the refractive indices of the prism, metal, affinity layer, and the aqueous medium (analyte containing biomolecules to be sensed) respectively. An incident light of wavelength λ falls on the prism base at an input angle θ_i. The SP modes are excited at metal-affinity layer interface at the incident angle $\theta_i = \theta_R$ known as the resonance angle. From the figure, $|E_x| = E_{in}\, Sin\theta_i$, hence to increase E_x, the value of θ_i at which the SP mode gets excited should be large. We define the input optical coupling as the percentage of the electric field intensity present in the input optical electric field getting coupled into the SP mode, *i.e.* $\frac{E_x}{E_{in}} = \sin\theta_i$. The real part of the effective index of the SP mode can be directly calculated as $n_p . \sin\theta_i$ [4].

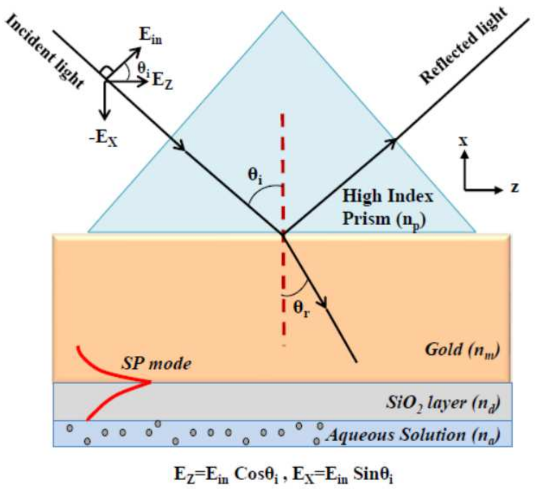

Figure 1: Prism-coupled SPR sensor in the Kretschmann configuration to excite SP modes at the Metal-Dielectric interface.

3. Results

Instantaneous electric flux lines appearing in the form of dis-continuous loops, are generated using Maxwell's equations for an SPR sensor configuration considered here (refer Figure 1). SiO_2 is used as an affinity layer in SPR sensors for the detection of bacteria like E-Coli present in the aqueous solution. Figure 2 shows the instantaneous electric field lines appearing in the form of loops in the xz-plane of the sensor at the gold-silica interface. Figure 2(a) gives a detailed view of the electric field lines over a propagation length of 1 μm (zoom-in); and Figure 2(b) shows the attenuation of the field lines due to absorption at the metal-affinity layer interface, for $30\ \mu m < z < 40.6\ \mu m$. The field is completely absorbed after a distance $z = 40.6\ \mu m$ which is the range of the symmetric mode (TM_0) excited in the sensor, calculated using Muller's method [5]. A tangent drawn at any point (see point *k*) gives the slope of the electric field $\frac{E_x}{E_z}$ at that point. A large slope of the tangent at the metal-dielectric interface signifies that the electric field lines are predominantly transverse at the interface. In this article, we have studied various design parameters for the enhancement of the slope at the interface and hence, corresponding improvement in the input coupling efficiency and the sensitivity of the SPR sensor. We have computed the improvement in the input coupling efficiency and the sensitivity by varying the index of prism (flint glass) and affinity layer (Silica), the thickness of the gold film and the wavelength of the input light.

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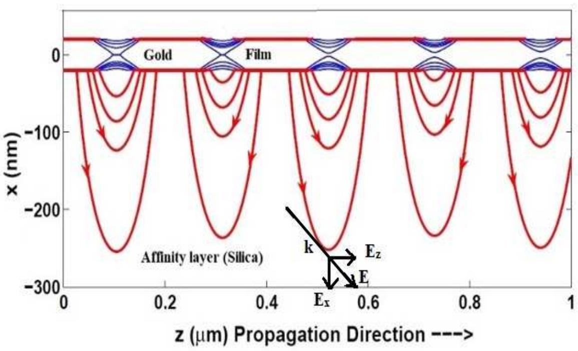
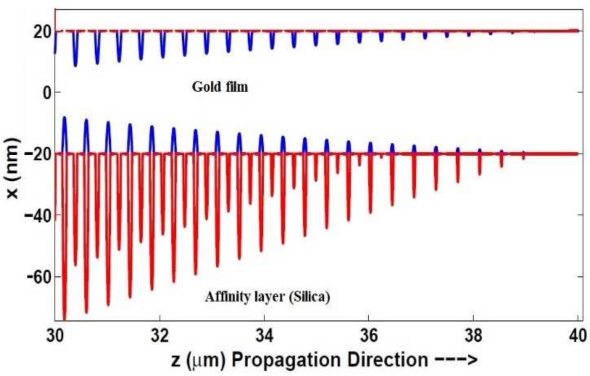
We report improvement of 6.8 (°/RIU), 0.6 (°/RIU), 7.5 (°/RIU), and 47.2 (°/RUI) in the sensitivity when prism index varies from 1.65-1.62, affinity layer index changes from 1.4570-1.4630, gold thickness changes from 35nm-70nm, and wavelength of input optical wave changes from 900nm-633nm respectively. The corresponding enhancement in the input coupling efficiency is 64.33 %/RIU, 58.787 %/RIU, 45.855 %/μm, and 20.90 μm^{-1} respectively, which influences the real part of the effective index of the SP mode participating in the sensing application. The improvement in the sensitivity is a direct consequence of the increased real part of the effective index. With increase in the thickness of the gold film, the real part of the effective index increases, whereas the imaginary part first reduces and then increases, with a minima at around gold thickness of 45 nm which is in the range of the skin depth of most of the metals at optical wavelengths. The propagation length depends inversely on the imaginary part, with the result that the propagation length of the SP mode is the maximum at gold thickness of 45 nm. This results in a maximum reflectivity dip and maximum sharpness (implying small value of full width at half maxima, *i.e.*, FWHM) of the reflectivity curve of the sensor, leading to the maximum value of the signal to noise ratio (SNR = reflectivity dip/FWHM) for the SPR sensor configuration of Figure 1.



2(a)



2 (b)

Figure 2: Electric field lines for the TM_0 mode at the metal-affinity interface in the xz-plane. The vertical axis *x (nm)* is the transverse direction of the SPR sensor.

4. Conclusion

Enhancement in the input coupling efficiency as a function of various design parameters of an SPR sensor is investigated and corresponding improvement in the sensitivity is calculated. A decrease in the prism index improves the sensitivity to a greater extent as compared to a corresponding increase in the affinity layer index. The sensitivity improves with reducing wavelength of the input light, hence a He-Ne laser at 632.8 nm is a preferred choice as an input monochromatic light source. The optimum thickness of the gold film for optimum sensitivity and maximum SNR is around 45 nm.

5. References

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