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Investigation on the Performance of the Prism Based SPR Sensor with Composite of Indium Nitrate and Gold

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Abstract

The performance of the SPR sensor is analysed numerically by employing three prisms of different refractive indices coated with a composite of Indium Nitrate (InN) and gold of different film thickness. The reflection spectra are studied under the angular interrogation mode and the effects of low- and high-refractive-index prisms on the performance of the sensors are discussed. It is observed that composite of gold metal with 10% of InN has given maximum shift of resonance angle (8.25˚) and smaller FWHM of resonance curve (6.19˚) for the film thickness of 45nm when changing the refractive index of the sensing medium from 1.33 to 1.36 for the prism with refractive index of 1.456.

Keywords: *Surface plasmon resonance; Reflectivity; Indium Nitrate; Kretschmann configuration and Refractive Index.*

1. INTRODUCTION

Surface Plasmon Resonance (SPR) is a phenomenon associated with the coupling of light and collective oscillations of electrons at a metal-dielectric interface (Raether et al. 1988). These oscillations are referred to as Surface Plasmon (SP) waves and their confined electromagnetic fields make them excellently suited to the characterization of binding interactions of biomolecules on metallic surfaces. The phenomenon of SPR is exploited for numerous applications mainly in the fields of chemical (Kurihara et al. 2002, Matsubara et al. 1998) and biochemical sciences (Knoll et al. 1998, Lras et al. 1992, Salamon et al. 1997). The SPR sensor structures are in general based on Kretschmann's attenuated total reflection (ATR) configuration (Kretchmann et al. 1968). Au-based sensor is more sensitive but lesser accurate than a Ag-based sensor. However, Au layer is chemically very stable. Keeping these limitations in mind, some work started on the idea of bimetallic structures but was not applied for sensing purposes. (Ehler et al. 1995) In order to take the benefit of high sensitivity, a SPR sensor based on resonant bimetallic layers was proposed a few years back(Zynio et al. 2002).In this paper we investigated the variation of angular sensitivity for different prism materials with refractive index (1.456, 1.51391 and 1.597) coated with gold (Au) with varying volume fractions embedded in host metal matrices of InN.

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2. THEORY

The SPR sensing is based on the principle of attenuated total reflection (ATR) with Kretschmann's configuration. For the Kretchmann's configuration of the three-layer system as shown in Fig. 1. The surface plasmons are excited when θ equals the resonant angle θsp, the wave vectors of the incident light and the SPW in the metallic films are expressed as

$$k_x = \frac{2\pi}{\lambda} n_p \sin(\theta) \tag{1}$$

$$k_{sp} = \frac{2\pi}{\lambda} \sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}} \tag{2}$$

where ε_d, ε_m, and n_p represent a complex dielectric constant of dielectrics, a complex dielectric constant of metal, and a refractive index of the prism, respectively, and λ denotes the wavelength of incident light. When the wave vector of the incident TM polarized electromagnetic wave parallel to the prism–metal interface matches with that of the surface plasmon, a strong surface plasmon wave (SPW) is generated at the metal–dielectric interface. This matching of propagation constants is known as resonance condition.

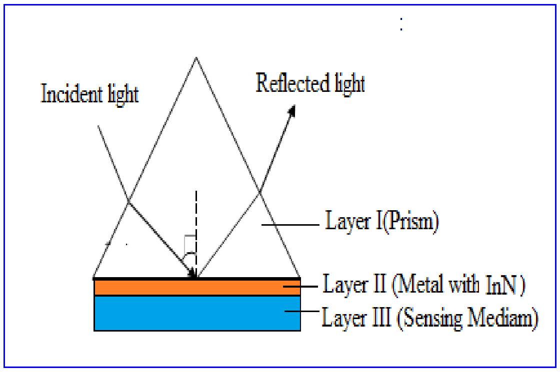

Fig. 1: Schematic diagram of prism based SPR sensor

In the proposed system three types of prism will be used to analyse the performance names as S-TIM5 prism, BK7 prism and synthesized quartz. The refractive index value (n_p) for S-TIM5 prism, BK7 prism and synthesized quartz are 1.597, 1.51391 and 1.456 respectively at λ=670nm. According to the Drude formula, the dielectric function (ε_m) of any metal can be written as

$$\varepsilon_m(\lambda) = \varepsilon_{mr} + i\varepsilon_{mi} = 1 - \frac{\lambda^2 \lambda_c}{\lambda_p^2(\lambda_c + i\lambda)} \qquad (3)$$

Where λ_p(=1.6826 x10^{-7}m) and λ_c(=8.9342 x 10^{-6}m) denote the plasma wavelength and the collision wavelength for gold respectively. If ε_{m1} is the dielectric constant of metal/metal oxide particles of component 1 and ε_{m2} is the dielectric constant of host dielectric matrix of component 2, the effective dielectric constant of composite is given by (Roy et al. 2003)

$$\varepsilon_A(\mathrm{x}, \lambda) = \mathrm{x}\,\varepsilon_{m1}(\lambda) + (1-\mathrm{x})\varepsilon_{m2}(\lambda) \qquad (4)$$

where x is the volume fraction of the nano particles of the first metal.

The dielectric constant of host dielectric matrix InN is written according to the Drude model as (Thakur et al. 2002)

$$\varepsilon_2 = \varepsilon_\infty \left[1 + \frac{(\omega_{L0}^2 - \omega_{T0}^2)}{(\omega_{L0}^2 - \omega^2 - \mathrm{i}\,\omega\gamma)} - \frac{\omega_p^2}{(\omega^2 + \mathrm{i}\,\omega\Gamma)} \right] (5)$$

Here, ε_∞ is the high frequency dielectric constant, ω_{LO} and ω_{TO} are LO and TO frequencies of phonon mode, ω_p is the plasma frequency, γ and Γ are the two corresponding damping constants. For InN $\varepsilon_\infty = 7.5$ $\omega_p = 4100$ cm^{-1}, $\Gamma = 1382$ cm^{-1}, $\omega_{LO} = 590$ cm^{-1}, $\omega_{TO} = 450$ cm^{-1} and $\gamma = 120$ cm^{-1}.

The dielectric constant of the sensing medium is ε_s .If ns is the refractive index of the sensing medium, then $\varepsilon_s = n_s^2$.Here the refractive index value for the sensing medium is taken as 1.33. We have used the matrix method for N-layer model (Yamamoto et al. 2002) in order to obtain the intensity of reflected light (reflectivity) because the matrix method is very accurate as it contains no approximations.

3. RESULTS AND DISCUSSION

Fig.2 shows the performance of SPR sensor with Au and InN compositions of different film thickness coated on the prism of refractive index n_p=1.456, 1.51391 and 1.597 respectively. It is observed from Fig.2(a), the lower refractive index prism (n_p=1.456) gives maximum shift in resonance angle (8.25˚) for the film thickness of 45nm and percentage composition of 10% of InN hosted in the metal matrix of Au. The corresponding FWHM of the resonance curve is measured as 6.19˚ and shown in Fig.2(b).Thus the above configuration is desirable for devising SPR Sensor which needs higher sensitivity. However, it is also observed from Fig.2(b) that the FWHM of the resonance curve is minimum for the film thickness of 60nm. Hence the film thickness of 60nm is desirable for making SPR sensor which needs higher noise to signal ratio. It is observed from Fig.2(a), for the film thickness of 60nm, the volume fraction of 10% of InN gives maximum shift in resonance angle as 6.24˚ and the calculated FWHM of the resonance curve as 4.87˚.Thus the above configuration is suitable for SPR sensor where high signal to noise ratio is desirable.

Fig.2(c and d) shows that for the prism with n_p=1.51391 maximum shift in resonance curve is obtained for the film thickness of 50nm and volume fraction of 30% of InN. The calculated shift in resonance curve is 7.01˚ and the corresponding FWHM is 9.45˚ and is measured from Fig.2(d). However to obtained large SNR film thickness of 60nm is desirable since FWHM of the resonance curve is minimum for all fraction of InN at this thickness.

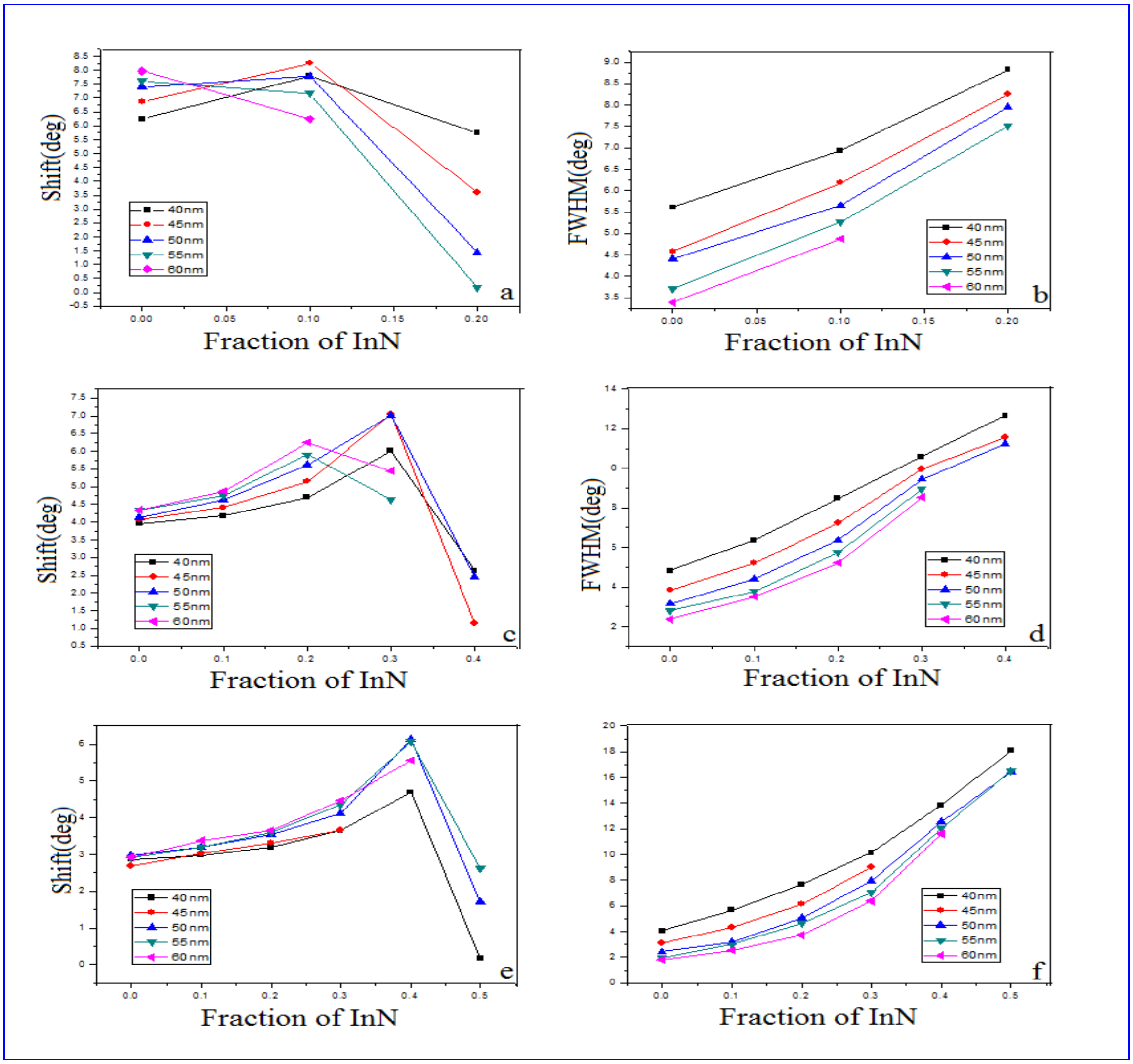

Fig. 2: Variations of the shift in resonance angle and FWHM of prism based SPR sensor for InN hosted on the dielectric metal gold (a)and(b) for the prism of n_p=1.456 (c)and(d)for the prism of n_p =1.51391 (e)and(f) for the prism of n_p =1.597

The maximum shift obtained for film thickness of 60nm is for the volume fraction of 20% of InN and is calculated as 6.24˚. The corresponding FWHM is 5.21˚.

Fig.2(e and f) shows the performance of Au and InN composite for the prism of n_p=1.597. It is observed that volume fraction of 40% of InN in pure Au gives maximum shift to all the film thickness and are shown in Fig.2(e). The maximum shift (6.07°) is obtained for film thickness of 55nm and 40% of InN. The corresponding FWHM is 12.03˚. Hence from the above analysis we have optimised the film thickness and volume fraction of InN for the prism of three different refractive index to observe higher sensitivity and large SNR values. It is observed prism with low refractive index (n_p =1.597) shows better performance than the other two prism.

4. CONCLUSION

In this paper, the effects of low- and high-refractive-index prisms on the performance of the sensor were discussed, and it is concluded from the investigations that the choice of prism material can enhance the sensor performance depending on the working requirements. Because of adding Indium Nitrate with gold, the performance of the SPR sensor is highly sensitive. 10% of InN with gold has given the best value of shift (8.25˚) in resonance and FWHM (6.19˚) for the thickness of 45nm for the change in refractive index of the sensing medium from 1.33 to 1.36. We expect that the present study will open a new window for chemical and biosensing applications by riding on the advantage of latest fabrication and characterization techniques to design a highly sensitive and accurate biosensor.

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