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An Analysis on the Performance of the Prism Based SPR Sensor with Composite of Indium Tin Oxide and Gold

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Abstract

In this paper, we theoretically studied the role of the prism material in sensor design of SPR-based sensor. We analysed the performance of three prisms of different refractive indices coated with composites of Indium tin oxide and gold with different thickness values. We studied the reflection spectra under the angular interrogation mode and the performance are evaluated by employing two main parameters such as sensitivity and Full width Half Maximum (FWHM) of resonance curve. It is found that 10% of ITO hosted in metal matrix of gold gives the highest shift (8.14˚) in resonance angle and least FWHM (5.15˚) of the resonance curve for the film thickness of 50nm for the prism of n_p=1.456.

Keywords: *Indium tin oxide; Kretschmann configuration; N-layer model; Refractive Index; Reflectance Surface Plasmon Resonance.*

1. INTRODUCTION

Surface plasmon resonance (SPR) is a simple and direct optical sensing technique that is used to probe refractive index changes that occur in the very near vicinity of a thin metal film. In SPR based sensors, the Kretschmann configuration (Kretchmann, *et al*. 1968; Kretchmann, 1971) is most commonly used, in which a thin metallic layer is deposited directly on the base of a coupling prism. The dielectric whose refractive index is to be determined is kept in contact with the metallic layer. Surface plasmon waves are excited by evanescent wave from a high refractive index prism at the total reflection condition. For any SPR-based sensor, the width of the SPR curve determines how precisely a sensor can detect the resonance wavelength for a given refractive index of sensing layer, and therefore the width should be determined with utmost accuracy. Au demonstrates a higher shift and is chemically stable.It has become possible to achieve surface plasmon resonance by using transparent conducting metal oxide thin films. Further, highest accessible transmissivity for visible light, lowest electrical resistivity, reflection spectra in infrared region and wide band gap semiconductor, makes indium tin oxide (ITO) (Navneet K. Sharman *et al*. 2014) as one of the most extensively used transparent conducting metal oxides. Besides, ITO thin films are continuous (i.e. no agglomeration as islands) and no involvement of band to band transitions. In recent times, utilization of ITO thin films in SPR based fiber optic sensing is studied theoretically as well as experimentally in many research explorations (Vermaand Gupta, 2010; Mishra and Gupta, 2012; Rani *et al*. 2013; Sharma *et al*. 2013).

In the present work, we have theoretically studied the performance of SPR-based sensor with prism of three different refractive index 1.456, 1.51391 and 1.597 and numerous innovative composites comprising of gold (Au) with their varying volume fractions embedded in host dielectric matrices of indium Tin Oxide (ITO) are considered. SPR based optic sensor with each composite layer (one at a time) coated on the prism is theoretically analyzed. Performance of the sensor is validated in terms of its shift in resonance angle, FWHM, sensitivity and accuracy.

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2. THEORY

The SPR sensing is based on the principle of attenuated total reflection (ATR) with Kretschmann's configuration. In the proposed prism based SPR sensor, the sensing system comprising of a prism-composite of metal with ITO-sensing medium is considered as shown in Fig.1. 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 resonance phenomenon can be mathematically expressed by equating the x-component of the input wave vector, k_x, with the real part of the wave vector of the SPW, k_{sp}, as shown in the following equations.

$$k_x = k_0 n_p \sin\theta_1 \quad (1)$$

$$k_{sp} = k_0 \sqrt{\frac{\varepsilon_m n_s^2}{\varepsilon_m + n_s^2}} \quad (2)$$

$k_0=2\Pi/\lambda_0$ is the wave vector in free space, λ_0 the free space wavelength, n_p the refractive index of the prism, n_s the refractive index of the dielectric sample, and ε_m the complex dielectric constant of the metal.

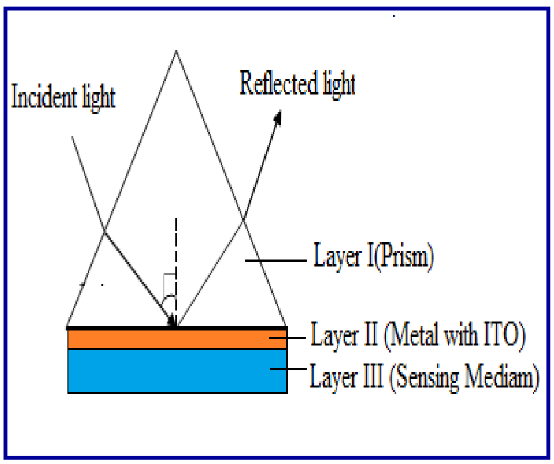

Fig.1: Schematic diagram of prism based SPR sensor

2.1 Layer I

Layer I is made of prism. The performance of the SPR sensor is investigated by three types of prisms which is having the refractive index of n_p=1.456, 1.51391 and 1.597.

2.2 Layer II

Layer II is made of composite. In a composite material, particles of one component material are embedded in a continuous host dielectric matrix of other component (Singh and Gupta,2010).According to the Drude formula, the dielectric function (ε_m) of any metal can be written as

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

The dielectric constant of host dielectric matrix ITO is written according to the Drude model as

$$\varepsilon_m(\lambda) = \varepsilon_{mr} + i\varepsilon_{mi} = 3.8 - \frac{\lambda^2\lambda_c}{\lambda_p^2(\lambda_c + i\lambda)} \quad (4)$$

Where $\lambda_{p(=}1.6826 \times 10^{-7}$m) and $\lambda_{c(=}8.9342 \times 10^{-6}$ 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)

$$\varepsilon_A(\mathrm{x},\lambda) = \mathrm{x}\,\varepsilon_{m1}(\lambda) + (1-\mathrm{x})\varepsilon_{m2}(\lambda) \quad (5)$$

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

2.3Layer III

Layer III is made of sensing medium. The dielectric constant of the sensing medium is ε_s .If n_s is the refractive index of the sensing medium, then $\varepsilon_s=n_s^2$.

2.4 Reflectivity

We have used the matrix method for N-layer model in order to obtain the intensity of reflected light (reflectivity) because the matrix method is very accurate as it contains no approximations. The expression for the reflection coefficient (reflectance) of p-polarized incident light can be obtained by using the matrix method for N-layer model (Rhodes *et al*. 2008; Hecht, 2002; Ghatak and Thyagarajan, 1999).The layers are assumed to be stacked along the z-axis.

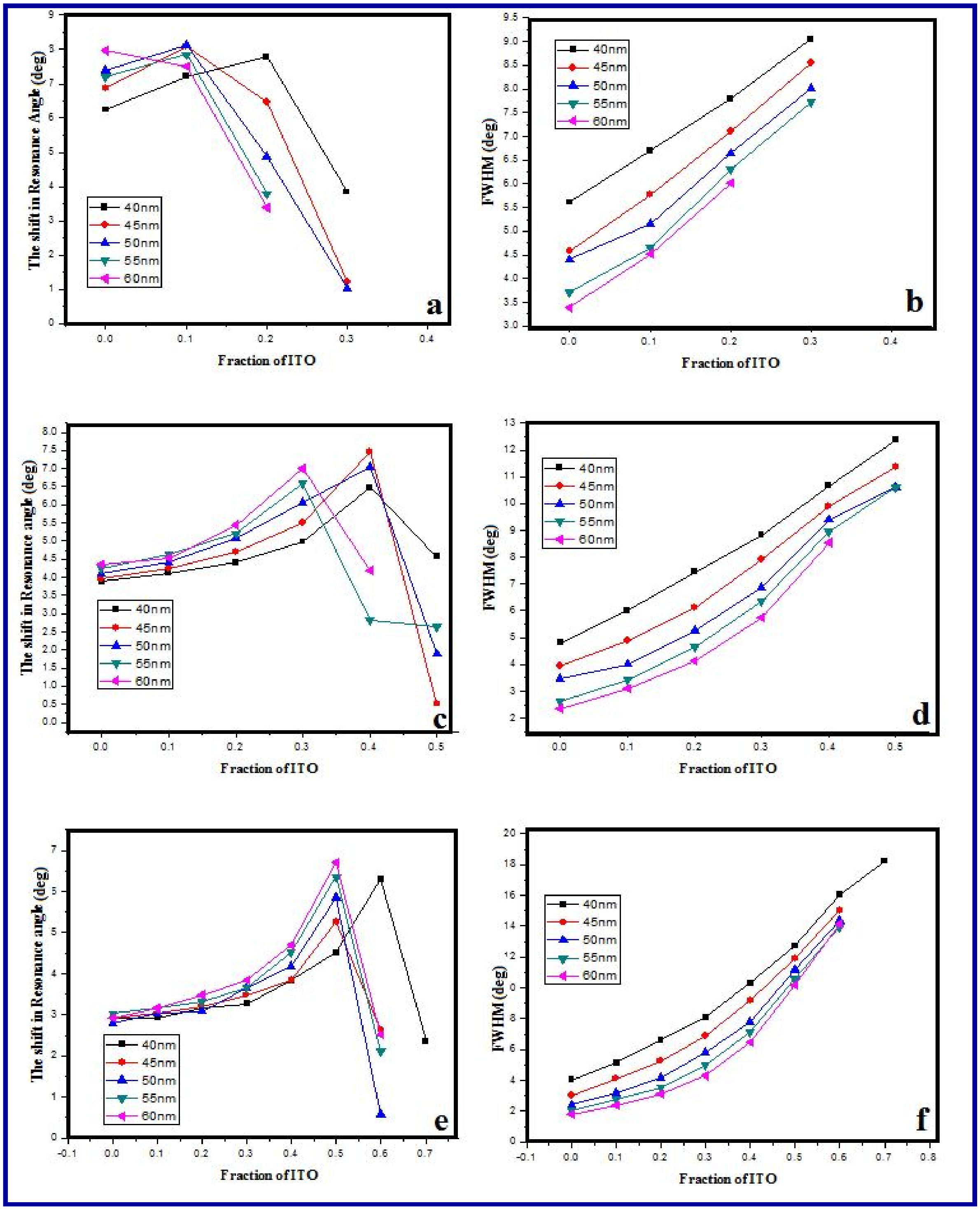

Fig.2: Variations of the shift in resonance angle and FWHM of prism based SPR sensor for ITO hosted on the dielectric metal gold (a)and(b) for the prism of n_p=1.456 (c)and(d)for the prism of n_p =1.51391 (e)and(f) for the prism of n_p =1.597

3. RESULTS & DISCUSSION

Fig.2 (a) shows the measured value of shift in the resonance curve corresponding to various thicknesses and compositional percentage of ITO embedded in the host metal matrix of pure gold for the change in refractive index of the sensing medium from 1.33 to 1.36. It is observed from Fig.2 (a), the shift in resonance angle is found to be greater for the composite having 10 % of ITO in pure gold for all the film thickness considered above 40 nm for the prism of n_p =1.456. However for film thickness of 40 nm, the larger shift is obtained for the volume fraction of 20 % of ITO in pure gold. The maximum shift 8.14˚ is observed for the film thickness of 50 nm having 10 % volume fraction of ITO. Fig.2 (b) shows the measured value of FWHM of the resonance curve corresponding to various thickness and compositional percentage of ITO. It is observed from the figure, the increase in FWHM value of the resonance curve is found to be minimum for the film thickness of 50 nm.The FWHM value obtained for the ITO fraction volume of 10% is observed as 5.15˚ corresponding to the film thickness of 50nm. Hence by choosing a composite of 10 % ITO in the host metal matrix of pure gold and film thickness of 50 nm one can get maximum shift and minimum increase in FWHM value of resonance curve. The shift in resonance angle and FWHM of the resonance curve are 7.39˚ and 4.4˚ respectively for the pure gold film of thickness 50 nm.

However for the prism with n_p =1.51391, the volume fraction of 40 % of ITO gives maximum shift corresponding to the film thickness of 40 nm, 45 nm and 50 nm and are shown in Fig.2(c). It is also found greater shift is obtained for the fraction of 30 % of ITO corresponding to the film thickness of 55 nm and 60 nm. It is also observed that maximum shift of 7.45˚ is obtained for the film thickness of 45nm having volume fraction of 40 % of ITO. Fig.2(d) shows the calculated value of the FWHM of the resonance curve for different volume fraction of ITO and for different film thickness. It is observed from the figure, the increase in FWHM is found to be smaller for the film thickness of 60 nm.Thus by using a 30 % volume fraction of ITO and film thickness of 60nm, one can obtain better shift in resonance angle about 6.99 with FWHM of the resonance curve 5.73˚. However, the shift in resonance angle and FWHM of the resonance curve are measured as 4.35˚ and 2.35˚ respectively for the pure gold of thickness 60 nm.

Fig. 2(e and f) shows the performance of Au and ITO composite for the prism of n_p =1.597. It is observed from Fig.2(e), the shift in resonance angle is found to be larger for the volume fraction of 50 % of ITO for all thickness consider above 40 nm. It is observed the film thickness of 60nm corresponding to the volume fraction 50 % of ITO gives maximum shift of 6.7˚ with minimum increase of FWHM of 10.2˚. However, the shift in resonance angle and FWHM of the resonance curve are measured as 2.92˚ and 1.77˚ respectively for the pure gold of thickness 60nm. Thus when using the prism of n_p =1.597, a film thickness of 60 nm and having a composite of ITO with volume fraction of 50 % gives maximum performance the resonance curves obtained for the change in refractive index of sensing medium from 1.33 to 1.36 for the above optimized condition of 60 nm thick and 50 % volume fraction ITO in pure gold.

4. CONCLUSION

We analysed the performance of three prisms of different refractive indices coated with composites of Indium tin oxide and gold with different thickness values. It is observed that by selecting the suitable composite combinations, one can able to tune the position as well as the width of the SPR curve depending upon the prism and which metal is coupled with ITO. It is observed that by using prism with refractive index 1.456, the film thickness of 50 nm with 10% volume fraction of ITO gives shift of 8.14˚ and FWHM of 5.15˚.Thus as far is the gold is considered, prism with low refractive index shows the higher performance when compared to the prism with higher refractive index. On a whole, the choice of prism material and a suitable composite of metal – ITO and film thickness proves to be a vital design parameter and is significant for tuning and optimizing the sensor's performance.

REFERENCES

Ghatak, A. and Thyagarajan, K., An Introduction to Fiber Optics, *Cambridge University Press, Cambridge* (1999).

Hecht, E., *Optics, fourth ed.,* Pearson Education Inc. 431–436(2002).

Kretchmann, E. and Reather, H. Naturforsch., Radiative decay of non radiative surface plasmons excited by light, 23, 2135-2136(1968).

Kretchmann, E., The determination of the Optical Constants of Metals by Excitation of Surface Plasmons, *Z. Phys.,* 241, 313-324(1971).

Mishra, S. K. and Gupta, B. D., Surface plasmon resonance based fiber optic hydrogen gas sensor utilizing indium-tin oxide (ITO) thin films, *Plasmon.*, 7, 627-632(2012). doi:10.1007/s11468-012-9351-7

Navneet K. Sharman, Swati Yadav. And VivekSajal, Theoretical analysis of highly sensitive prism based surface Plasmon resonance sensor with indium tin oxide, *Opt. commun.,* 318, 74–78(2014).
doi:10.1016/j.optcom.2013.12.049

Rani, M., Sharma, N. K. and Sajal, V., Surface plasmon resonance based fiber optic sensor with nanoparticles, *Opt. Commun.,* 292, 92-100(2013).
doi:10.1016/j.optcom.2012.11.087

Rhodes, C., Cerruti, M., Efremenko, A., Losego, M., Aspnes, D. E., Maria, J. P. and Franzen, S., Dependence of plasmonpolaritons on the thickness of indium tin oxide thin films, *J. Appl. Phys.,* 103, 093108(2008).
doi:10.1063/1.2908862

Roy, R. K., Mandal, S. K. and Pal, A. K., Effect of interfacial alloying on the surface plasmon resonance of nanocrystalline Au–Ag multilayer thin films, *Eur. Phys. J. B.,* 33, 109–14(2003).
doi:10.1140/epjb/e2003-00147-x

Sharma, N. K. Rani, M. and Sajal, V., Surface plasmon resonance based fiber optic sensor with double resonance dips, *Sens. Actuat. B.,* 188, 326-333(2013).
doi:10.1016/j.snb.2013.07.007

Singh, S. and Gupta, B. D., Simulation of a surface plasmon resonance-based fiber-optic sensor for gas sensing in visible range using films of nano composites, *Meas. Sci. Technol.,* 21, 115202(2010).
doi:10.1088/0957-0233/21/11/115202

Verma, R. K. and Gupta, B. D., Surface plasmon resonance based fiber optic sensor for the IR region using conducting metal oxide film, *J. Opt. Soc. Am. A.,* 27, 846-851(2010).
doi:10.1364/JOSAA.27.000846