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Simulation of Cobalt Based Fiber Optic Surface Plasmon Resonance Sensor

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Abstract

In these days, a large number of theoretical and experimental research investigations have been carried out to improve the performance of the surface plasmon resonance based fiber optic sensor. Now a days, some new types of fiber optic sensors such as micro and nano structured fiber sensors are attracting a number of researchers due to outstanding progress in the fields of surface plasmon resonance and photonic crystal fiber technology. In continuation to this, a surface plasmon resonance basedfiber optic sensor with nanolayer of Cobalt metal coated on the core of the optical fiber utilizing Kretschmann's configuration is proposed and theoretically analyzed. The sensor's performance is taken into consideration, measuring the change in sensitivity according to the change in design parameters such as operating wavelength, sensing medium. The sensitivity of the sensor has been found to increase with increase in cobalt layer thickness.

Keywords: *Optical fiber, cobalt, surface plasmon resonance, sensor.*

1. Introduction

Surface plasmon resonance (SPR) is a phenomenon, which has brought a new revolution in the field of opto-electronics since last 2 decades. Researchers have found fascinating results via experimental and theoretical works based on this SPR study [1-3]. Plasmons are the collective excitation of electrons on the metal-dielectric surface. A transverse electromagnetic wave propagating parallel to the metal-dielectric interface gives rise to the phenomena of surface plasmon resonance (SPR) [4]. Being transverse in nature, plasmons can be excited by exponentially decaying evanescent field of the p-polarized light [5]. The excitation takes place when the wave vector of the evanescent wave of some frequency matches with surface plasmon of the same frequency at any particular angle of incidence. Kretschmann's configuration based on attenuated total internal reflection (ATR) has been used to fabricate the optical fiber sensor [6]. The configuration works on removing the cladding from a smaller portion of the optical fiber and coating that unclad portion by a metal. The sensing medium comprises the outermost layer of the whole configuration adhering the metal coating. When the wave vectors of the two waves matches, an abrupt decrease in the transmitted light is observed. Performance of an optical fiber sensor can be measured by sensitivity parameter. [7].

Metals and their optical properties have been a very exciting research area over past few decades. Along with optical behavior their magnetic properties with super magnetic behavior has revolutionized the research era. Credit to this motivation leads to Surface plasmon resonance which is basically the collective oscillation of free electrons on a metal-dielectric interface. A lot of research has been focused on SPR curve and its blue and red shift with special concern to particle size [8-10]. Such interesting properties of surface plasmons are mostly valid for optically active materials. Cobalt being magnetic is a material which is well known for its attractive applications in data storage, optoelectronics and telecommunications. Cobalt particles are interesting because of their non linear, magneto-optical and magnetic

properties [11-15]. Optical properties of gold and silver are more considerable in the field of optical sensors. Cobalt does not show those exciting optical properties but it is well known for its magnetic properties. Other than magnetic properties it is used for coloring glasses and for photothermal conversion of solar energy.
Our study is based on a fiber optic sensor using this cobalt material as an active metal layer. Resonance minima are calculated at various thicknesses using wavelength interrogation method. Further sensitivity has been calculated numerically for various thicknesses and different refractive indices. It has been found that the sensitivity of the proposed SPR sensor increases with increase of Co layer thickness.

2. Theory

The phenomena surface plasmon resonance is achieved by attenuated total internal reflection utilizing Kretschmann's configuration. In this configuration, a high refractive index prism is coated with metal layer touching the unknown sample. In a prism based SPR sensor, light of some fixed wavelength (angular interrogation) is incident at various angles on the metal coating. And at some θ_{SPR} there is transfer of energy of evanescent waves to surface plasmons resulting in a decrease in the reflected light .Presently this high refractive index prism is replaced with an optical fiber because of its simplified optical design, small size and potential in remote sensing areas. In the fiber optic SPR sensor, metal layer is coated at the core-cladding interface of the fiber as shown in Fig. 1.

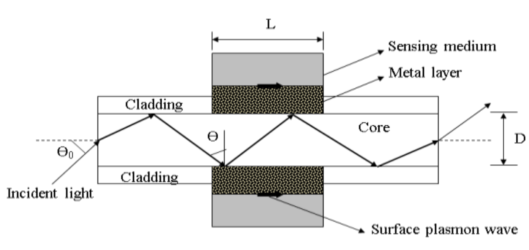

Fig. 1 Schematic diagram of SPR based fiber optic sensor with metal layer

The LSPR sensing technique of wavelength interrogation (fixed incidence angle) has been opted because the angular intensity distribution of light gets impossible to differentiate due to mode mixing as a result of intrinsic bending of the multimode optical fiber in sensing areas.

In the proposed SPR based fiber optic sensor, the plastic cladding around the core from the middle portion of a step index multimode PCS fiber is removed and is then coated with a thin Co layer, which is then finally surrounded by the sensing medium. The dielectric constant of the sensing medium is ε_s. If n_s is the refractive index of the sensing medium, then $\varepsilon_s = n_s^2$. The resonance condition for excitation of surface plasmon wave is given as,

$$\frac{2\pi}{\lambda} = n_1 \sin\theta = \mathrm{Re}\{K_{sp}\} \qquad (1)$$

Where,

$K_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_m \varepsilon_s}{\varepsilon_m + \varepsilon_s}} = \frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon_m n_s^2}{\varepsilon_m + n_s^2}}$ is the propagation constant of the surface plasmon wave and *c* is the speed of light in vacuum. The left hand side of Eq. (1) denotes the propagation constant of the light incident at an angle θ and the right hand side shows the real part of the propagation constant of the surface plasmon wave.Resonance wavelength (λ_{res}) is determined corresponding to the refractive index of the sensing medium (n_s) in the SPR sensor based on wavelength interrogation. If the refractive index of the sensing medium is altered by δn_s, the resonance wavelength shifts by $\delta\lambda_{res}$. The sensitivity (S_n) of a SPR sensor with wavelength interrogation is defined as[16],

$$S_n = \frac{\delta\lambda_{res}}{\delta n_s} \qquad (2)$$

When light from a polychromatic source enters in the fiber, then for a fixed value of refractive index of sensing medium, at resonance wavelength, the output spectrum has minimum transmitted power .When the refractive index of sensing sample changes, then there is a corresponding change in resonance wavelength. This is because, the negative real part of the dielectric constant increase with the increasing wavelength for the metallic layer, resulting in a red shift of LSPR band. Now in the present simulations, following mathematical relations have been used.

3. Results and discussion

For theoretical calculations, the refractive index of the sensing medium is assumed to be changed from 1.30 to 1.37 and following values of the parameters have been used: Numerical aperture of the fiber = 0.24, fiber core diameter D = 600 µm, length of the exposed sensing region L = 15 mm. The transmitted output power of SPR based fiber optic sensor has been calculated for different thickness values (10 nm to 50 nm) of Co layer and corresponding resonance wavelengths are determined.To obtain the maximum sensitivity of the SPR sensor, it will be essential to identify the optimized thickness of Co layer. The sensitivity of the SPR based fiber optic sensor for various thicknesses of Co layer are compared in table 1.

It can be seen from table 1, that the sensitivity of 50 nm thick Co layer based SPR sensor is maximum (4875 nm/RIU) and it is minimum (882 nm/RIU) for 10 nm thick Co layer based SPR sensor. Though, the sensitivities of SPR sensor for other thicknesses (20 nm, 30 nm, and 40 nm) of Co layer are intermediate between those of 10 nm and 50 nm thick Co layers. The variations of sensitivity of the SPR sensor with thickness of Co layer have been plotted in Fig. 2.

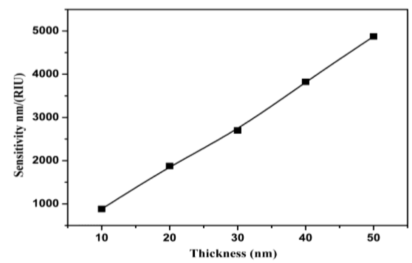

Fig. 2Variations of sensitivity of the SPR based fiber optic sensor with thickness of Co layer

Table 1

Thickness of Co layer (nm)	**Sensitivity(S_n) (nm/RIU)**
10	882
20	1875
30	2700
40	3825
50	4875

Fig.2 depicts the variation of sensitivity of the SPR sensor with thickness of Co layer. It is noticeable that the sensitivity of the SPR sensor decreases with the decrease in the thickness of Co layer. This happens because the thin Co layer permits less interaction between surface plasmon mode and the fiber mode, resulting in small absorption of light power by the sensing medium around resonance wavelength. This causes increased normalized transmitted power and hence decreases the sensitivity of the sensor. Further, it can be observed from Fig.2 and table 1 that 50 nm thick Co layer based SPR sensor has the highest sensitivity (4875 nm/RIU). Therefore, in designing SPR based fiber optic sensor with high sensitivity, the proper thickness of Co layer should be chosen. However, the optimized thickness of Co layer of the SPR based fiber optic sensor is found to be 50 nm. So, taking all these facts in to consideration, it is concluded that 50 nm thick Co layer based fiber optic SPR sensor demonstrates high sensitivity of 4875 nm/RIU.

4. Conclusions

The simulation of a SPR based fiber optic sensor with Co layer has been presented. The sensitivity of SPR sensor for various thicknesses (10 nm to 50 nm) of Co layer is studied theoretically. The proposed Co layer based SPR sensor possesses high sensitivity with resonance dip in near infrared region of spectrum allowing the sensing in infrared spectral region, which needs attention to many environmental and security applications. In addition, the sensitivity of the SPR sensor increases with increase in thickness of Co layer. 50 nm thick Co layer based fiber optic SPR sensor displays high sensitivity of 4875 nm/RIU.

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