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Metamaterial Based Optical Surface Plasmon Resonance Sensor

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Abstract: *This paper deals with a comparative study of Surface Plasmon resonance (SPR) sensor using metamaterial and conventional surface Plasmon resonance (SPR) sensor. This comparative study results better understanding of novel property of metamaterials which can be used in the field of sensing. Reflectance is evaluated for the p-polarized light launched in the fiber. Contrary to the conventional case, in which surface polaritions with positive phase velocity appears at a boundary of metallic guide, where as in this case, surface polaritons propagate along the boundary of a metamaterial guide with negative refractive index.*

Indexterms: *Optical fiber, Surface Plasmon resonance (SPR), Reflectance.*

1. INTRODUCTION

The phenomenon of surface Plasmon resonance has been known for a long time and has been used for chemical sensors and remote sensing [1]. It makes use of a prism and a thin metal layer deposited upon the prism. Traditionally, SPR is measured using the Kretschman configuration, with a prism and a thin highly reflecting metal layer (silver or gold) deposited upon the prism base [2]. The reflection spectrum (reflected light intensity versus angle of incidence with respect to the normal of the metal) is measured by coupling transverse magnetically (TM) polarized monochromatic light in to the prism and measuring the reflected light intensity of the ray exciting the prism versus the angle of incidence. Fresnel equations [3] are used to predict reflected and transmitted light intensity from multilayered structures. Resonance condition is established when the frequency of light photons matches the natural frequency of surface electrons oscillating against the restoring force of positive nuclei. This paper explores the use metamaterials to produce the surface Plasmon resonance at microwave frequencies. Metamaterials are materials with negative permittivity and permeability. Metamaterials have attracted considerable attention in recent years [4-8]. These are artificial materials engineered to provide properties which may not be readily available in Nature. These materials usually gain their properties from structure rather than composition, using the inclusion of small inhomogeneties to enact effective macroscopic behavior [9]. Apart from sensing field metamaterial can be used in other applications such as perfect lens, various filter applications, phase shifter, and MRI .By using metamaterial in surface Plasmon resonance (SPR) sensor, it increases refractive index sensitivity by generating the resonance condition at longer wavelength and reduces the value of reflectance.

2. FORMULATIONS FOR A GENERALIZED SURFACE PLASMON RESONANCE SENSOR

Considering the layered structure shown in Fig.1.A Plane wave is incident from the medium 1 with ε_1 and μ_1 on the layer with ε_2 and μ_2 bounded by the medium 3 with ε_3 and μ_3.Here ε and μ are relative permittivity and relative permeability normalized to free space ε_0 and μ_0.The reflection coefficient R is well know [10].

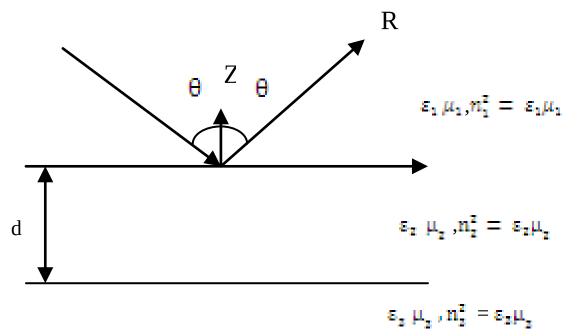

Fig.1 Geometry of three layered Structure

$$R = \frac{A + \frac{B}{Z_3} - Z_1\left(C + \frac{D}{Z_3}\right)}{A + \frac{B}{Z_3} + Z_1\left(C + \frac{D}{Z_3}\right)} \quad (1)$$

Where

$A = D = \cos k_{z2} d$, $B = jZ_2 \sin k_{z2} d$, $C = \frac{j \sin k_{z2} d}{Z_2}$

$k_{zi} = \sqrt{k_i^2 - (k_i \sin\theta_1)^2}$, i = 1, 2, 3, $k_i = k_0 n_i$

$k_0 = \frac{\omega}{c}$ is the free space wave number

$$Z_i = \begin{Bmatrix} \frac{k_{zi}}{\omega \varepsilon_0 i} \text{ for p} - \text{polarization } (E_x, E_z, H_y) \\ \frac{\omega \mu_0 \mu_i}{k_{zi}} \text{ for s} - \text{polarization } (H_x, H_z, E_y) \end{Bmatrix}$$

In this formulation, both ε_i and μ_i are complex. However for a passive medium , we require, using exp($j\omega t$) time dependence,

Im (ε_i) < 0
Im (μ_i) < 0
Im (n_i) < 0
Im (k_{zi}) < 0
Re $\sqrt{\frac{\mu_i}{\varepsilon_i}} > 0$

In this paper we examine equation (1) for metamaterials and discuss its physical meanings.

3. CONVENTIONAL SURFACE PLASMON RESONANCE SENSOR

Before we discuss metamaterial surface plasmon resonance sensor, firstly we see the conventional optical sensor making use of the surface Plasmon resonance.

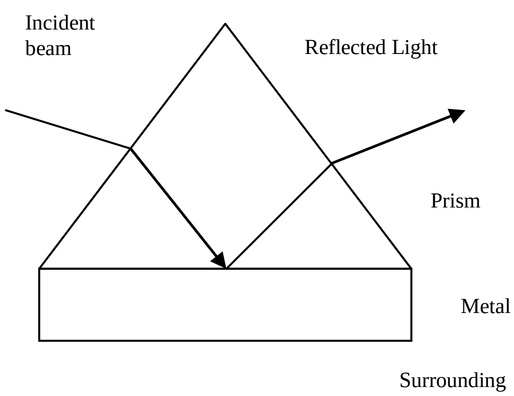

Fig 2.Schematic geometry of the conventional surface plas mon resonance sensor strucuture

Fig. 2 illustrates the model geometry of the three layered surface Plasmon resonance (SPR) presented here. The model structures consist of a high index prism (SF10 with refractive index n = 1.723), Ag metal layer, and a water buffer (n = 1.332) for a p-polarized incident light of 632.8 nm to have sharp resonance curves and minimum reflectivity dips.

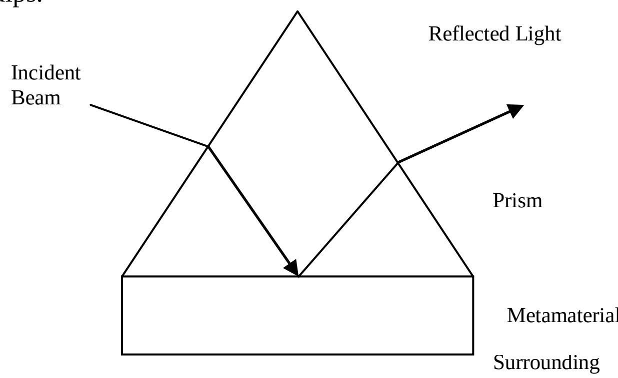

Fig 3.Schematic geometry of the metamaterial based surface plasmon resonance sensor structure

4. SURAFCE PLASMON FOR META MATERIALS

We now generalize the conventional Plasmon sensor discussed in above section to include the metamterials with arbitrary ε and μ .Fig. 3. Illustrates the model geometry of the three layered SPR structure using metamaterial in the place of Ag metal layer in conventional SPR sensor. All considerations are same as made for conventional structure only Ag metal layer is replaced by metamaterial layer. This layer of metamaterial, which is having the value of ε is -0.66-0.001*i and the value of μ is -2.All values of the index for the prism and water buffer layer are kept same as taken for the conventional plasmon resonance sensor .

5. RESULTS AND CONCLUSION

This paper has presented the use of metamaterials for Plasmon resonance sensors (SPR) at microwave frequencies and also deals with the comparison of conventional surface Plasmon resonance sensor using Ag metal layer and surface plasmon resonance sensor using metamaterial. Fig.4 shows the reflectance curve for the conventional surface plasmon resonance sensor as a function of incident angle θ, in the incident medium of the SF10 prism. The optimum thickness of Ag metal layer is determined to be 131 nm. The complex refractive index of Ag used is 0.082 + 4.1563 * i. Fig 5 shows the reflectance curve for the metamaterial based sensor as a function of incident angle θ.Thickness of Metamaterial layer is same as Ag metal layer.

From the above discussion, it can be said that on the same thickness of the layer, metamaterial based surface plasmon resonance sensor gets the lower value of reflectance in comparison to the reflectance of the Ag metal layer (conventional surface plasmon resonance sensor). Numerical values of minimum reflectance of silver- metal layer and metamaterial based surface plasmon resonance sensor are 0.95537 and 0.00090 respectively and incident angles for the silver- metal layer and metamaterial based surface plasmon resonance sensor are 54.74612. and 32.80183 respectively.

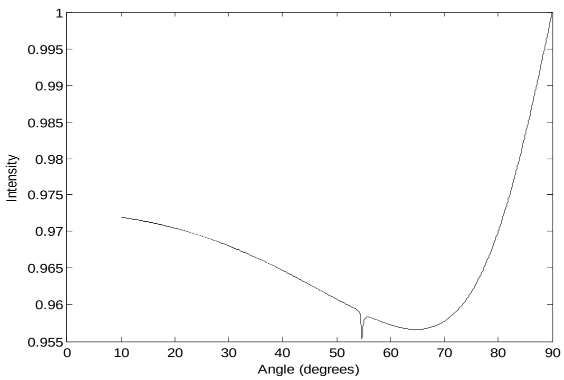

Fig. 4 Reflectance curve for conventional surface plasmon resonance sensor as a function of incident angle.

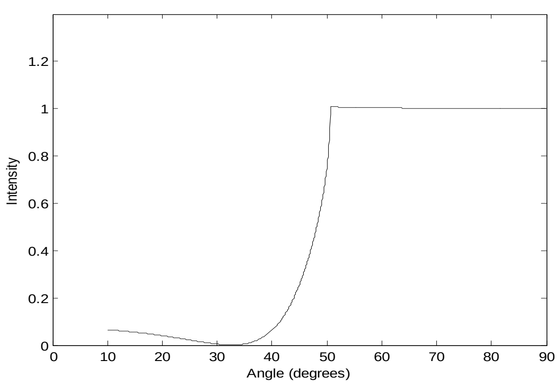

Fig. 5 Reflectance curve for metamaterial based surface plasmon resonance sensor as a function of incident angle.

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