Sensitive Surface Plasmon Resonance Biosensor Based on a Photonic Crystal and Bimetallic Configuration

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Abstract—**In this paper, we present and numerically demonstrate a highly sensitive photonic crystal (PC) Surface Plasmon Resonance (SPR) sensor. This proposed sensor consists of an Ag-Au bimetallic configuration that integrates the better evanescent field enhancement of silver, the higher resolution in the reflectivity minimum of silver, and the high chemical of gold. In comparison to most convenient SPR sensors which use single gold films, this PC-bimetallic configuration is shown theoretically to possess a narrower resonance width, smaller minimum reflectance and higher sensitivity, which makes it a much better choice to be employed for SPR biosensing applications.**

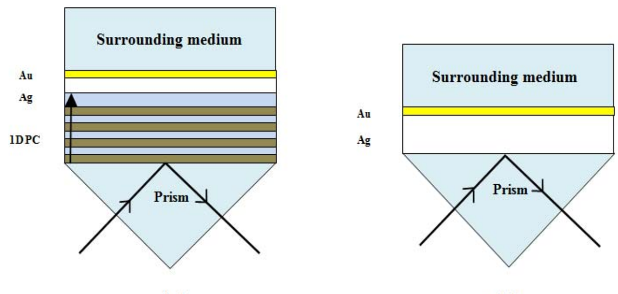
Keywords—Surface Plasmon Resonance, photonic crystal, bimetallic configuration, Refractive index, reflectance, full-width at half-maximum, FOM

I. INTRODUCTION

Surface Plasmon Resonance (SPR) is a simple, direct and label free optical technique that is used to probe refractive index changes which occur in the near vicinity of a thin metal film. This phenomenon can be observed when a p-polarized light is incident on a metal surface whose wave vector is same as the Surface Plasmons (SPs). The three important factors that affect the performance of SPR sensors are detection sensitivity, minimum reflectance and narrower full-width at half-maximum (FWHM). Generally, as for the choice of metal for use in SPR devices, gold is considered inert in aqueous environments but produces a broader SPR spectrum and has higher losses when compared to silver. Even though silver produces a sharper SPR spectrum, it is very reactive and often requires a protective over layer. Therefore a bimetallic layer of gold and silver can get the best out of both metals [2-3]. In addition, in order to improve the resolution of refractive index, it's essential to narrower the FWHM. A one-dimensional (1-D) photonic crystal (PC) structure is investigated and often employed to narrow the spectral width [1]. In this photonic crystal metallic configuration, because the excited plasmon mode has to satisfy the conditions both the existence of the resonance mode in the Fabry-Perot cavity and the Plasmon mode in the metallic structure and its width can be narrowed. In this paper, a photonic crystal surface plasmon resonance biosensor based on a bimetallic configuration of Silver and Gold is proposed and numerically simulated. Detailed calculations show this new structure can improve the mentioned limitation that exists in the traditional SPR sensor, which opens a new window for ultra-stable high performance SPR sensors.

II. SIMULATION MODEL

The proposed theoretical structure based on prism coupling technique is as follows: substrate/TiO_2/$(SiO_2/TiO_2)^3$/X/Ag/Au. For a desired resonance wavelength of 632.8 nm, the construction is made of alternating an 87-nm TiO_2 layer and a 286.5-nm SiO_2 layer, the "defect" layer X is composed of another 390-nm SiO_2layer, and the metallic structure is a 20-nm Ag layer, 5-nm Au on the top. The refractive indices of the substrate, TiO_2, SiO_2, Ag, Au and DI water at λ=632.8nm, were n_0=1.515, n_{TiO2}=2.232, n_{SiO2}=1.451, n_{Ag}=0.059+4.279i, n_{Au}=0.1726+3.4218i and n_t=1.333, respectively. In order to compare the results, PC-Au structure and conventional surface plasmon resonance biosensor geometry are also come up with. In Fig. 1(b), the metal is taken as Ag film with thickness 47nm, Au film 5nm. The remaining parameters are same as those of proposed configuration (Fig. 1(a)).



(a) (b)

Fig.1(a) Schematic diagram of PC-Ag-Au configuration and (b) conventional surface Plasmon resonance (Ag-Au) biosensor.

To numerically obtain the optical characteristics of the sensor, we use the transfer-matrix method TMM [4]. Here the reflectance R is represented by 2 x 2 matrix,

$$R = \left[\frac{M_{12}}{M_{22}}\right]^2 \quad (1)$$

$$M = \begin{vmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{vmatrix} = I_{01}L_1 \cdots L_{10}I_{1011} \quad (2)$$

$$I_{jk} = \begin{bmatrix} 1 & r_{jk} \\ r_{jk} & 1 \end{bmatrix} \text{ and } L_j = \begin{bmatrix} e^{ik_{zj}d_j} & 0 \\ 0 & e^{-ik_{zj}d_j} \end{bmatrix} \quad (3)$$

$$r_{jk} = \frac{\left[\frac{k_{zj}}{\varepsilon_j} - \frac{k_{zk}}{\varepsilon_k}\right]}{\left[\frac{k_{zj}}{\varepsilon_j} + \frac{k_{zk}}{\varepsilon_k}\right]} \quad k_{zj} = \sqrt{\varepsilon_j\left(\frac{\omega}{c}\right)^2 - k_x^{\,2}}\ , \ k_x = \sqrt{\varepsilon_0}\frac{\omega}{c}\sin\theta \quad (4)$$

Where ω is the angular frequency, and ε_j is the optical constant of j-th layer. Besides, the sensitivity S can be characterized by the figure of merit (FOM) [5],

$$FOM = \frac{S_{sol}}{\Delta\theta} \quad (5)$$

Where Δθ is the full-width of the resonant dip at half-maximum(FWHM), S_{sol} is the bulk solvent refractive index sensitivity using a angle modulation which is the radio of the resonance angle shift θ_R to the change of the bulk solvent refractive index n_t:

$$S_{sol} = \frac{d\theta_R}{dn_t} \quad (6)$$

III. Results And Discussions

A. Reflectance spectra of the PC-Ag-Au, PC-Au, the conventional (Ag-Au) structure.

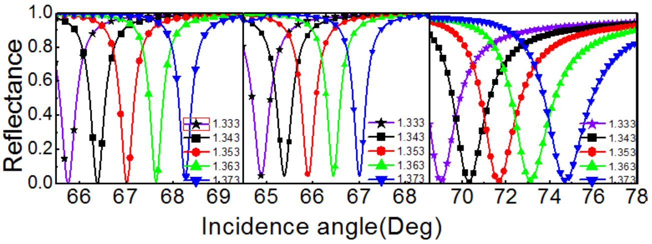


Fig.2 (a-c) The reflectance spectra of the PC-Ag-Au (Ag20nm, Au5nm), PC-Au (Au16.75nm), conventional SPR (Ag47nm, Au5nm) for refractive indices of the sensing region ranging from1.333 to 1.373.

Figure 2 shows the reflectance spectra of the above three kinds of structures when the surrounding medium is ranging from 1.333 to 1.393, the optimized results show the small minimum reflectance respectively are 0.0005, 0.0456, 0.0114.

B. Overall comparison of resonance angle, FWHM among the above three kinds of structures.

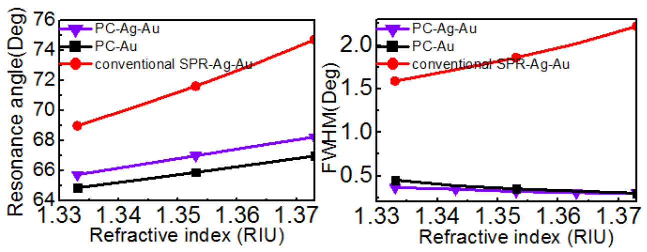


Fig.3(a-c) The resonance angle, FWHM comparison of those three kinds of constructions when the refractive index is changed from 1.333 to 1.373

As can be seen from the Figure 3(a) the average S_{sol} of PC-Ag-Au is 67.008°/RIU, PC-Au is about to 66.634°/RIU, while conventional SPR is 71.748°/RIU. (b) shows that the average FWHM of conventional SPR is 1.882°which is around 5.2 times larger than PC-Au(0.3622°), 5.76 times wider than PC-Ag-Au(0.327°).

C. The figure of merit (FOM).

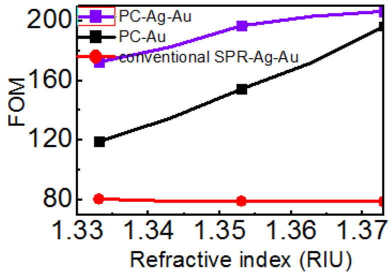


Fig.4 The FOM of these three structures shift with refractive indices

Therefore, we can get the average FOM comparison from figure 4: PC-Ag-Au (192.4066) > PC-Au (155.5044) > the conventional SPR (79.3284).

IV. Conclusions

In a word, simulations results for the PC-Ag-Au, PC-Au, the conventional SPR Ag-Au structures show that this novel PC-Ag-Au bimetallic can achieve much narrower resonance width, which is 1.12 times narrower than PC-Au, 5.76 times of the traditional Ag-Au set-up. In addition, it can obtain smaller minimum reflectance (0.000535) and higher sensitivity, which is 1.24 times higher than PC-Au, 2.43 times of Ag-Au structure. Finally, it is demonstrated this configuration put forward an innovative idea to use a PC-metallic structure to excite Plasmon modes in a TIR configuration ,at the same time, because of the higher stability and better biomolecules adhesion characters, it will be a much better option to be employed in biosensing application as compared to the conventional SPR sensor.

V. Acknowledgment

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