Surface Plasmon Resonance Fiber Optical Sensor Based on Photonic Crystal and Graphene

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***Abstract*-In this paper, a theoretical analysis of figure of merit (FOM) of a surface plasmon resonance (SPR) sensor with a one dimensional (1D) Photonic Crystal (PC)and an anti-oxidizing layer of the graphene has been carried out. The numerical simulation is based on side polished multi mode fiber SPR sensor with the 75 μm residual fiber thickness and 20nm silver film thickness. Meanwhile, the comparisons for traditional SPR sensor and SPR sensor with only one anti-oxidizing layer have also been studied. The studies show that the SPR sensor with PC structure and graphene layer has higher FOM than other SPR sensors mentioned. This design is expected to be a better choice on chemical and biological sensing.**

Keywords—Surface Plasmon Resonance; Side Polished Fiber; Photonic Crystal; Graphene

I. INTRODUCTION

Since the last few decades, surface plasmon resonance (SPR) sensing technology has become a great conceptual tool for chemical and biological sensing [1]. The resonance appears in the form of a sharp dip of output optical signal either with incident angle (angular interrogation) or wavelength (spectral interrogation). The three important factors that affect the performance of SPR sensors are detection sensitivity, resonance depth and full-width at half-maximum (FWHM). The SPR sensor based on side polished fiber (SPF) configuration in which the metallic layer is deposited directly on the base of a side polished fiber has significant advantages, such as small size and remote sensing, over other SPR sensors. There are more studies of gold film on the previous studies, but in fact, the silver film SPR sensor can provide higher accuracy of spectral analysis and narrower FWHM than the gold film [2]. Considering the silver film can be easily oxidized in the air, an anti-oxidizing layer of the graphene has been proposed to be deposited directly on the silver film. Besides, the graphene can bring many other merits such as large surface area, rich functional groups, excellent biological compatibility, and strong π bonds. However, it also causes some negative effects such as increasing non-resonance absorption, broadening resonance width, and degrading resonance depth [3]. So, it is important to inserting an optical configuration layer between the side polished fiber and the silver film to decrease the negative effects caused by the graphene and to improve the performance of the SPR sensor.

II. SIMULATION MODEL

The meridional cross section of SPR sensor based on the side polished fiber is showed in Figure 1.

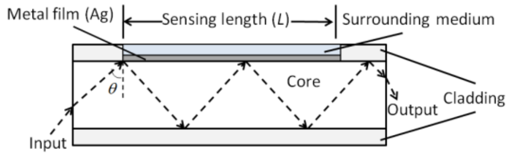


Fig. 1. The meridional cross section of SPR sensor based on side polished fiber

A conventional configuration consists of side polished fiber, monolayer silver film and surrounding medium. The diameters of the core and the cladding are 105 μm and 125 μm, respectively. Three configurations based on SPF are SPF-Ag, SPF-Ag-graphene, and SPF-PC-Ag-graphene, respectively, as showed in figure 2. The PC structure is made of an alternating 87 nm TiO_2 layer and 286.5 nm SiO_2 layer, a "defect" layer X of a 390 nm SiO_2 layer, a Ag film of 20nm, and a graphene stacks. Each monolayer of graphene is 0.34 nm.

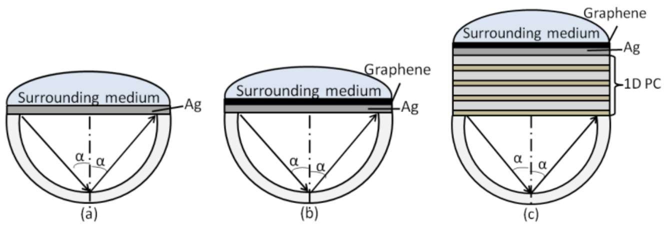


Fig. 1. Schematic diagram of (a) SPF-Ag, (b) SPF-Ag-graphene, and (c) SPF-PC-Ag-graphene configurations.

The transfer-matrix method TMM has been used in the studies. Here the reflectance R is represented by a 2x2 matrix, where ω is the angular frequency, and ε_j is the optical constant of *j*th layer. The normalized transmitted power can be calculated by equations (1)-(5). L and h denote the sensing area length and the residual fiber thickness, as shown in figure 1. Besides, the sensitivity *S* and the figure of merit (FOM) can be calculated by S=Δλ/Δn and FOM=S/FWHM, respectively.

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

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

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

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

$$P_{trans} = \frac{\int_0^{\partial_{max}} \int_{\theta_{cr}}^{\pi/2} R^{N_{ref}(\theta)} \frac{n_1^2 \sin\theta\cos\theta}{(1-n_1^2\cos^2\theta)^2} d\theta d\partial}{\int_0^{\partial_{max}} \int_{\theta_{cr}}^{\pi/2} \frac{n_1^2 \sin\theta\cos\theta}{(1-n_1^2\cos^2\theta)^2} d\theta d\partial} \quad N_{ref}(\theta) = \frac{L\cos\partial}{2(h-10)\tan\theta} \quad \theta_{cr} = \sin^{-1}\left(\frac{n_{cl}}{n_1}\right) \quad (5)$$

III. RESULTS AND DISCUSSIONS

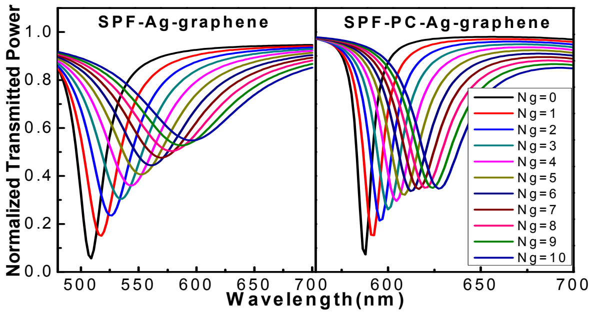


Fig.3. (Left) The normalized transmitted power spectra of SPF-Ag-graphene and (Right) SPF-PC-Ag-graphene for the RI of 1.333 for the surrounding area where the number of graphene layers rangeing from 0 to 10.

Figure 3 shows the transmission spectra for the corresponding modes shown in Fig. 2. The left graph shows the transmitted spectra in SPF-Ag-graphene configuration, and the right one shows the transmitted spectra in SPF-PC-Ag-graphene configuration. The refractive index of the surrounding medium is 1.333 RIU. The number of graphene layers ranges from 0 (without graphene) to 10. It can be observed that, the resonance spectra depth becomes smaller quickly with the increasing of graphene layers when the SPR sensor without the PC configuration. In the configuration SPF-PC-Ag-graphene, the resonance depth becomes declines more slowly with the increasing of graphene layers. Meanwhile, it can be observed that the resonance depth keeps relatively stable at 0.35 when the graphene is more than 5 layers.

Figure 4 shows the resonance spectra in the three structures respectively while the refractive index of the surrounding medium changes 1.33 RIU and 1.34 RIU. It can be observed that the FWHM in SPF-PC-Ag-graphene configuration is narrower than that without the PC configuration.

Figure 5 shows the sensitivity, FWHM and FOM in these three configurations. The sensitivity in the SPF-PC-Ag-graphene configuration is the highest (2333.3nm/RIU) and the FWHM is the smallest (11.5nm) among these three configurations. The highest FOM of 203 RIU^{-1} and the lowest FOM of 66.1 RIU^{-1} are obtained in the SPF-PC-Ag-graphene and SPF-Ag-graphene configuration, respectively. The highest FOM is more than 3 times as the lowest one, which means a 3 fold enhanced is achieved by using the PC structure.

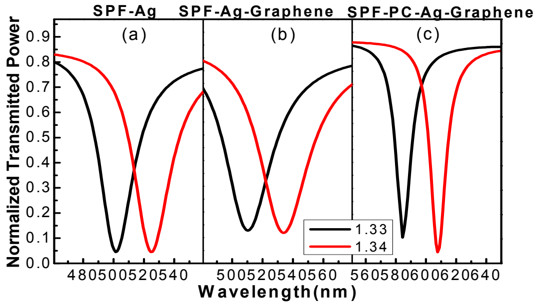
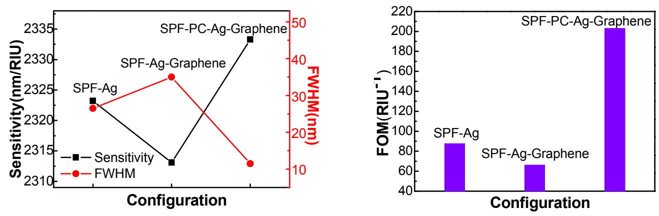


Fig. 4. The normalized transmitted power spectra of (a) SPF-Ag, (b) SPF-Ag-graphene and (c) SPF-PC-Ag-graphene configuration respectively while the RI of the surrounding medium are 1.33 and 1.34.



(a) (b)

Fig. 5. (a) is The sensitivity and FWHM in SPF-Ag, SPF-Ag-graphene, and SPF-PC-Ag-graphene configurations respectively. (b) is the FOM in SPF-Ag, SPF-Ag-graphene, and SPF-PC-Ag-graphene configurations respectively.

IV. CONCLUSIONS

In summary, we have established the numerical models for three SPR configurations, and have performed simulations on their transmission spectra. The simulation results show that the SPF-PC-Ag-graphene configuration can achieve much narrower resonance width (11.5 nm) and higher sensitivity (2333.3 nm/RIU) than the other structures. A 3 fold enhancement of FOM is achieved in the SPF-PC-Ag-graphene configuration. This novel SPR sensor is expected to be a good candidate for chemical and biological sensing.

V. ACKNOWLEDGMENT

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