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# Sensitivity analysis of graphene coated surface plasmon resonance biosensors for biosensing applications

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ABSTRACT

This paper describes the effect of adding graphene layers in prism and planar waveguide based surface plasmon resonance biosensors using angular interrogation mode. The proposed sensors are designed based on graphene material as biomolecular recognition elements (BRE) and the sharp SPR curve of gold (Au)·Our calculations show that the proposed graphene in prism and planar waveguide based SPR biosensors have 1 + 0.40L and 1 + 0.45L; (where L is the number of graphene layers) times more sensitivity than the conventional SPR biosensor respectively. The enhanced sensitivity is due to increased SPR angle change about 40L% and 45L% by adding graphene layer and using the optical property of graphene. We also investigate the performance of proposed biosensors in terms of sensitivity using graphene sublayers.

## 1. Introduction

Surface plasmon resonance (SPR) sensors are the most advantageous sensors due to the ability of enabling bio-molecular detection with high speed and sensitivity, which is mainly because they eliminate time-consuming labeling process and reduce molecular binding disturbance [1].They have played an important role in monitoring and sensing various biomolecular interactions like protein bindings and DNA hybridization [2].In case of SPR based biosensors, surface plasmon wave (SPW), a schematic representation of an electron density wave propagation or plasma oscillation is generated along metal-dielectric interface with resonant frequency simulated by incident light. That means, when light rays incident on the interface and matches with the wave vector of surface plasmon (SP), resonance occurs at the surface [3].

Prism coupling is the most common technique used for excitation of SPs. Prism coupling can be obtained by two configuration i.e. Otto configuration and Kretschmann's–Raether configuration [4,5]. Both configurations are based on attenuated total internal reflection. For the observation of SPR technique, Kretschmann's configuration is most widely used. In the conventional SPR sensor structure, a thin surface of metals such as gold (Au) and silver (Ag) etc. is coated on side of the prism, separating the sensing medium and the prism [6], which support the propagation of SPs. In this case, deviation of reflected angle helps to detect the nature of biochemical substance which needs to be kept on biosensor. But this type of biosensor would face complexity monitoring remote and distant species. Besides, large systems with costly projects can only suit this type of SPR based biosensor. Therefore, it would be only suitable working at laboratory [7].

On the other hand, waveguide based SPR can handle remote sensing and cost reduction compared to prism based biosensor [8–10]. It ensures the fabrication of multisensor devices with monolithic. In this type of sensors, beam of light is thrown into a waveguide core and falls into accession between a fundamental core mode and a plasmon which spreads over a metal film deposited over waveguide [7].Then resonance occurs at their interface.

It is a matter of fact that improvement of performance of SPR based biosensor is a burning question. Experimental study reveals that performance of SPR based biosensor can be enhanced if graphene layer is added. Graphene aids a good resort for absorption of biomolecule as they have huge surface area and such structure containing π-configuration for which an excellent dielectric top layer is ensured [11]. A research shows that, graphene layer on gold layer gives a good platform for absorbing biomolecule, thus providing a large refractive index change at graphene-gold interface. Introduction of graphene layer promotes the sensitivity of SPR sensing [12].

One of the most important constituents of any sensing device is the binding/adsorbing material with large surface area, and the recently developed 2D nanomaterials such as graphene have attracted a considerable amount of attention [13].Graphene is emerging as an attractive material candidate for future electronics and optoelectronics due to its unique combination of several important characteristics, including

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high carrier mobility, high optical transparency, exceptional mechanical flexibility and strength. Recent studies have demonstrated the exciting potential of exploiting graphene for diverse optoelectronic devices including solar cells, touch panels, photodetectors, ultra-fast lasers, polarizers and optical modulators [14,15].The wideband absorption, high carrier mobility and short carrier lifetime make graphene an ideal material for wideband, high-sensitive biosensors. Graphene and graphene oxide provide good support for biomolecule adsorption due to their large surface area and rich π conjugation structure, making them suitable dielectric top layers for SPR sensing [16]. However, graphene produces more damping in SPs due to large imaginary dielectric constant for higher graphene layers, and hence results in decreased detection accuracy [17].

In this paper, we investigate the numerical modeling of graphene coated SPR biosensors. Since graphene has prominent properties, a monolayer of graphene is sandwiched between metal films and sensing medium as biomolecular recognition elements (BRE). Numerical results show that compared to graphene in prism based SPR biosensor, graphene in planar waveguide based SPR biosensor offers 25% more sensitivity for five layers of graphene.

## 2. Design of the proposed biosensors

We introduce a numerical model of prism based biosensor whose configuration is shown in Fig. 1(a). Here, the first layer is a SF10 glass prism having RI $??_p = 1.723$ [18], the second layer is formed of gold film having thickness and RI are $??_{Au} = 50$ nm and $??_{Au} = 0.1726 + ??3.4218$, respectively [19]. Third layer is graphene having thickness and RI are $d_G = 0.34$ nm and $n_G = 3 + ??1.149106$, respectively [20]. Lastly, the final layer is water as a sensing medium whose RI is $??_S = 1.33$ [21].

Again, the cross-section view of the proposed waveguide based SPR biosensor [9] has been illustrated in Fig.1(b). Total design has been divided into two distinct areas. Among them, region (i) covers a lossless single-moded single-layer input and output waveguide. The function of this part is to allow light engage into and out of the multilayer region. The other area (region (ii)) sets as multilayer metal-clad. This area interacts with the test sample whose existence is to be found. To design this type of sensor, operating wavelength is one of the key problems. The accurate choice of substrate material and picking up exact metal forming sensor surface are to be properly ensured. Investigations on sensor design reveals that low refractive index substrate glass presents easiest phase matching between waveguide and surface plasmon modes at the time of occurring in water medium. The substrate glass is culled in such a way that it brings about uncomplicated waveguide fabrication and it renders low expense of unprocessed slides. Hence, the refractive index is picked as 1.46 [22]. In case of making choice of metal for using in 'bulk' SPR device has already been examined [1]. Additionally, a planar waveguide based SPR sensor put to use in the aqueous solution is accounted on the basis of stability and inertness of the metal film to the environment. If optical characteristics of film are altered, the active performance of sensor will decline. The sole cause for using gold is that it ensures chemical inertness requiring adhesive force with glass substrate. Again, gold gives forth quality electrodes for electrochemical studies.

## 3. Mathematical modeling of proposed biosensors

Light is plunged having the wavelength of 633 nm from monochromatic laser source and data is accumulated by spectrometer and computer. It has been considered, for prism based SPR biosensor light with power P is plunged over one inclined surface of prism and reflected from the other inclined surface as shown in Fig.1 (a). On the other hand, same light is passed into one end of the waveguide; whereas comes out of other end of the waveguide as shown in Fig. 1(b). If dP is the power acquired at one end of both sensor between incident angles θ and θ + dθ then P can be outlined as [12],

$$dP \propto P(\theta)d\theta \tag{1}$$

Here P(θ) is the modal power in connection to incident angle θ can be shown as [2,8],

$$P(\theta) = \frac{n_c^2 \sin\theta \cos\theta}{(1 - n_c^2 \cos^2\theta)^2} \tag{2}$$

Here $n_c$ is the higher refractive index for both core and prism. Considering the value of reflectance for a single reflection at both prism-metal and core-metal interface, the normalized transmitted power is thus as follows [12],

$$P_{trans} = \frac{\int_{\theta_{cr}}^{\pi/2} R_p^{Nref(\theta)} P(\theta)d\theta}{\int_{\theta_{cr}}^{\pi/2} P(\theta)d\theta} \tag{3}$$

Here, $Nref(\theta) = \frac{L}{D\tan\theta}$ is the total number of light reflections in the SPR sensor by a ray whose incident angle is θ with the normal to the core metal layer interface in the sensing region, L is the length of sensing region, D is the diameter of the fiber core and $\theta_{cr}$ is the critical angle of the optical fiber expressed as $\theta_{cr} = \sin^{-1}(n_{cl}/n_c)$, $n_{cl}$ is the refractive index of the cladding. $R_p$ is the reflectivity, can be found by employing the four layer (prism or optical waveguide/metal/sensing layers/sensing medium) model analysis.

### 3.1. Mathematical modeling for reflectivity

The matrix method for N-layer model is applied for the calculation of reflectivity of the reflected light. The relation between tangential field at first boundary and those at final boundary can be shown by [23];

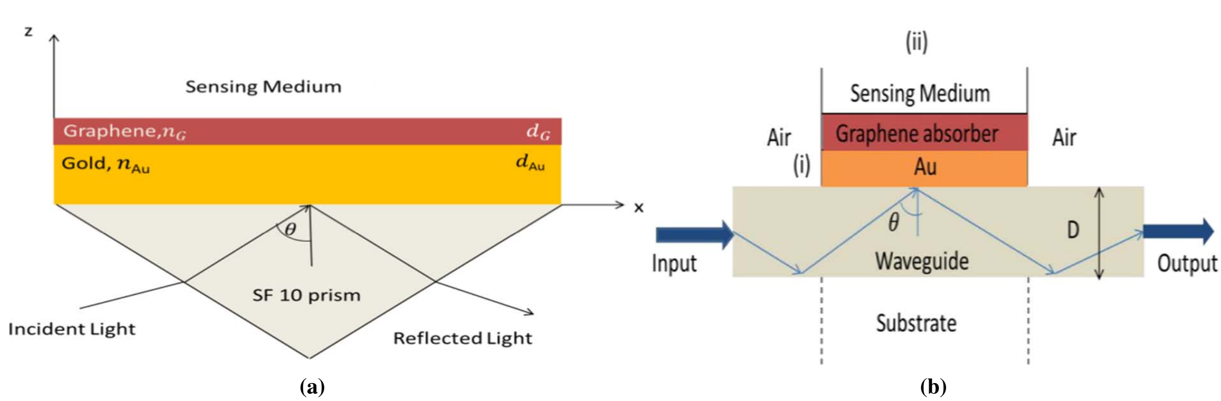


**Fig. 1.** Schematic diagram of proposed SPR biosensor based on Kretschman configuration (a) prism based SPR biosensor (b) PW based SPR biosensor.