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# Sensitivity improvement of graphene based surface plasmon resonance biosensors with chaclogenide prism

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ABSTRACT

Graphene and chalcogenide prism based surface plasmon resonance (SPR) biosensor used for the detection of Pseudomonas and Pseudomonas-like bacteria is presented in this paper. Angular responses, sensitivity, detection accuracy and quality parameter of SPR biosensor is investigated. This biosensor comprises of chalcogenide prism which is coated with gold layer and graphene layers. The proposed biosensor uses Kretschmann configuration to detect the change in refractive index near the sensor surface. By comparing these results with the conventional surface plasmon resonance biosensor coated with gold layer and chalcogenide prism, it is observed that the proposed SPR biosensor has sensitivity 6.47 times greater than that of chalcogenide prism based conventional SPR sensor. Also, the dependence of sensitivity, detection accuracy and quality parameter on the number of graphene layers for the proposed sensor is plotted and analyzed.



## 1. Introduction

Surface plasmon resonance (SPR) biosensor was first demonstrated for bio-sensing in 1983 by Liedberg et al. [1]. The principle, development, and applications of SPR biosensors have been well described in several excellent review papers [2–5]. Presence of free electrons at the interface of two materials is essential for the generation of surface plasmons (SPs). In practice this always implies that one of these materials is a metal where free conduction electrons are abundant. When the incident light illuminates the interface between the metal and dielectric layer, an electron density oscillation occurs and as a result, SPs are excited and the evanescent wave is generated, which is exponentially decayed along the normal direction. This phenomenon is known as surface plasmon resonance and it is only possible by the coincidence of the wave vectors of the incident light and the SPs. These wave vectors are functions of refractive indices of the dielectric, metal and analyte i.e. sensing medium. In sensing medium, a change in concentration of analyte will produce a local change in the refractive index (RI) near the metal surface. The change in RI will in turn lead to a change in the propagation constant of SPs and angle of incidence in order to satisfy the resonance condition. The resonance condition depends on the incident angle, wavelength of the light and the dielectric constants of both the metal and the silica based prism [6]. Thus, the resonance condition determines the performance of the bio-sensor in terms of sensitivity, detection accuracy or resolution and quality factor. One of the parameters that determine the performance of the sensor is resolution. Resolution is limited by the noise of the bio-sensor. Resolution of the bio-sensor can be improved by reducing the full width at half maximum (FWHM). Narrower FWHM helps us for accurate detection (resolution) of resonance angle. Generally, SPR bio-sensor used silica based prism. However, the SPR technique with silica based prism does not allow accurate detection in the infrared region, which requires attention due to its many environmental and security applications [7,8]. In this context, chalcogenide glass is a potential candidate for design of SPR based biosensor in visible and near infrared region because of its large wavelength range. Also, high refractive index of chalcogenide prism enhanced the resolution of bio-sensor [9]. For observing SPR, Kretschmann's configuration is most widely used over the other SPR sensing structures [10].

In most SPR sensor applications the plasmon supporting material is gold or silver, as they readily support plasmon modes at visible light frequencies. But, gold is usually preferred because it is resistant to oxidation and corrosion in different environments [6,11]. But, the main drawback is biomolecules adsorb poorly on gold, which limits the sensitivity of the conventional SPR biosensor. However, there are several methods to improve the adsorption such as using nanoparticles and nanoholes, metallic nanoslits [12,13].

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Recently, some new materials such as metamaterials and negative index materials are also promising option to enhance the performance of these sensors [14] but, it is very difficult to fabricate negative index materials and metamaterials with small feature size (300 nm), operating at optical wavelength. Thus, fabrication of optical negative index materials is challenging [15].

Very recently, an alternative approach to improve the performance of biosensor, researchers have proposed and fabricated SPR based fiber optic sensor coated with graphene layers [16–18]. Fabrication of graphene material is much simpler than metamaterials and negative index materials. Graphene is a single-atom thin planar sheet of $sp_2$ carbon atoms perfectly arranged in a honeycomb lattice. Graphene and graphene oxide have large surface area and rich $\pi$ conjugation structure, making them suitable dielectric top layers for SPR sensing [19,20]. Thus, graphene is suitable material to enhance the performance of optical sensors. Thus, for high performance of any bio-sensor, the sensitivity and detection accuracy should be as high as possible.

Despite these advances much more work needs to be done before SPR biosensors become commercially viable option for sensing. Moreover the attachment of marine Pseudomonas spices to variety of surfaces was investigated and it was found that these bacteria are attached not only on special carbon sources (nicotine, toluene etc.) but also on some hydrophobic plastic (Teflon, polyethylene) with little or no surface charge [21–23].

In this paper, making use of excellent properties of graphene and chalcogenide materials, an SPR biosensor has been proposed in which graphene is coated on the gold surface with chalcogenide prism for the detection of Pseudomonas and Pseudomonas-like bacteria. The attachment of bacteria to affinity surfaces is an important phenomenon in this SPR sensor. Also, these obtained results with those obtained by conventional SPR biosensor with chalcogenide prism have been compared. The paper is organized as follows: Section 2 contains the necessary formula along with theoretical background of the proposed sensor. In Section 3, the obtained results are discussed and compared. A conclusion is drawn in Section 4.

## 2. Theoretical background

Fig. 1(a) shows the schematic diagram of proposed SPR biosensor configuration. The $k$th layer ($k$ is from 2 to $N-1$) has thickness $d_k$ and refractive index $n$ ($\lambda$). The wavelength ($\lambda$) of the excitation light source is taken as 633 nm. Here, the first layer is prism with the wavelength dependence refractive index $n_s$ of the chalcogenide prism is given by $n_s(\lambda) = 2.24047 + \frac{2.693\times10^{-2}}{\lambda^2} + \frac{8.08\times10^{-3}}{\lambda^4}$ [24]. The wavelength dependence refractive index of gold metal layer using Drude Lorentz model is given by $n_m(\lambda) = \sqrt{1 - \frac{\lambda^2\lambda_c}{\lambda_p^2(\lambda_c + i\lambda)}}$, where $\lambda_c$ is collision wavelength ($8.9342 \times 10^{-6}$ m) and $\lambda p$ plasma wavelength ($1.6826 \times 10^{-7}$ m) respectively [2] and thickness of $d_m = 50$ nm is attached on the top of chalcogenide prism. The refractive index of graphene ($n_g$) calculated at 633 nm wavelength is given by $n_g = 3 + i$ 1.149106 and thickness of layer is given by $d_g = L \times 0.34$ nm, where $L$ is the number of graphene layers [25]. For the detection of Pseudomonas, consider three different affinity layers each layer having refractive index $n_a = 1.4370$, and thickness $d_a = 3$ nm when submerged in water, and produce a local increase in the refractive index $\Delta n$ at the graphene surface. In order to compare the results of proposed configuration, with that of conventional sensor with chalcogenide prism, conventional SPR biosensor with chalcogenide prism configuration is also investigated as shown in Fig. 1(b). All parameters are same in both the configurations except for graphene layer present in proposed SPR biosensor. It is clearly shown in Fig. 1(a).

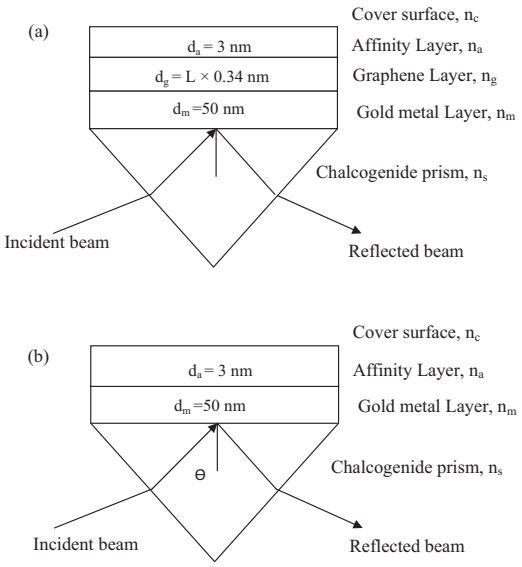


**Fig. 1.** Schematic diagram of (a) proposed graphene layer and chalcogenide prism based SPR biosensor with their thickness and refractive indices. (b) Chalcogenide prism based conventional SPR biosensor configuration with their thickness and refractive indices.

A light of wavelength ($\lambda$) passes through the prism and is totally reflected at the prism-metal interface, generating an evanescent wave. This evanescent wave penetrates through the gold layer and propagates along the $x$ direction with propagation constant $k_x = n_{\text{prism}}\left(\frac{2\pi}{\lambda}\right)\sin\theta$. The propagation constant $k_x$ can be adjusted in to order match to that of the SPs by controlling the angle of incidence $\theta$. The interaction between the light wave and surface Plasmon in the ATR method can be calculated using the Fresnel multilayer reflection theory for $p$-wave (transverse magnetic wave) [26]. The plot of total reflected intensity ($R$) versus angle of incidence ($\theta$) is called the SPR curve.

Proposed structure is a multilayer (prism, metal, graphene and affinity layer), the reflection coefficient for $p$-polarized incident light is obtained using transfer matrix method. For transfer matrix consider a generalized $N$-layer model as shown in Fig. 1. The tangential fields at the first boundary are related to those at the final boundary by

$$\begin{bmatrix} U_1 \\ V_1 \end{bmatrix} = M_2M_3M_4\ldots\ldots\ldots M_{N-1}\begin{bmatrix} U_{N-1} \\ V_{N-1} \end{bmatrix} = M\begin{bmatrix} U_{N-1} \\ V_{N-1} \end{bmatrix} \quad (1)$$

For $p$-wave at boundary $k$,

$$U_k = H_y^T + H_y^R$$
$$V_k = E_y^T + E_y^R \quad (2)$$

and

$$M_k = \begin{bmatrix} \cos\ \beta_k & -i\sin(\beta_k/q_k) \\ -iq_k sin\,\beta_k & \cos\ \beta_k \end{bmatrix} \quad (3)$$

where

$$q_k = (\mu_k/\varepsilon_k)^{1/2}\cos\theta_k$$

$$\beta_k = \frac{2\pi}{\lambda}n_k\cos\theta_k(d_k)$$