Highly Sensitive Bimetallic Graphene-Based SPR Biosensor for Blood Plasma Detection

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***Abstract*—This research proposes a highly sensitive biosensor utilizing bimetallic surface plasmon resonance (SPR) technology for detecting blood plasma concentration which consist of a BK-7 prism, Au (25 nm), Ag (20nm), $BatiO_3$ (5 nm), Graphene (3L*0.34nm) and a biosample. To increase the sensitivity a dielectric material $BaTiO_3$ is introduced between bimetal and graphene layer. With optimized layer parameters the proposed sensor shows enhanced sensitivity of 220◦/RIU as compare to the single metal structure.**

*Keywords— **SPR sensor, Barium titanate ($BaTiO_3$), graphene, reflectance, sensitivity.***

I. Introduction

Over the last few decades, surface plasmon resonance (SPR) sensing has grown significantly due to its label-free, real-time monitoring of chemical and biological elements in gases and liquids. Surface plasmons (SPs) are free electrons at the metal-dielectric interface, triggered by various coupling methods like prism coupling, where a prism matches the momentum of the surface plasmon wave (SPW) to incident transverse magnetic (TM) light. This process transfers maximum energy to the SPW, producing a strong evanescent field at the boundary. The reflectance curve exhibits a sharp decline when the dielectric and metal surface properties are in resonance. Since SPW excitation depends on the refractive index (RI) of the metal-dielectric interface, even minor changes in the dielectric medium's refractive index cause significant resonance angle shifts, making SPR widely used for detecting chemical and biological parameters.

In the Kretschmann configuration for SPR sensors, plasmonic materials like gold (Au) and silver (Ag) are mounted on a prism. Gold is favored for its corrosion and oxidation resistance, high sensitivity, and chemical stability, though it shows a broader curve area, reducing detection accuracy. Silver offers better resolution but is more prone to corrosion and oxidation. Adding a Barium titanate ($BaTiO_3$) layer, significantly enhances the integral of the electric field in the analyte region which leads to enhanced sensitivity [1]. Additionally, graphene has been found to possess high charge carrier mobility and revealed that incorporating graphene enhances the sensitivity of metal-based SPR biosensors [1-2].

A. Almawgani et al. theoretically analysed a SPR- black phosphorous (BP) based biosensor to enhance sensor performance for detecting blood plasma concentration and shown the highest sensitivity of 123 deg./RIU is achieved [3]. A. Yadav et al. proposed a bimetallic surface plasmon resonance (SPR) biosensor utilizing metal nitride to achieve high sensitivity in detecting urine glucose [4].

This study presents a highly sensitive bimetallic SPR based biosensor for detecting blood plasma concentration. The proposed structure consist of Bk7/Au-Ag/$BaTiO_3$/Graphene/Sensing medium. The proposed design bestows improved sensitivity and figure of merit (FoM) with bimetallic and optimized layer parameters.

II. Structure Analysis and Mathematical Modelling

The proposed kretschmann configuration biosensor is illustrated in Fig.1, showcasing the optimized thickness and number of graphene layers. A BK7 prism with a refractive index of 1.520 is used to align the momentum of the incident light with the surface plasmon wave. Above the prism, layers of Au and Ag are placed, and their refractive indices are determined through the Drude-Lorentz model. The fourth layer is composed of $BaTiO_3$ with a refractive index of 2.4042, positioned on top of the Ag layer. A graphene 2D-material with a refractive index value of 3+1.19i serves as the sensing layer over the $BaTiO_3$.

The simulation was conducted using COMSOL Multiphysics utilizes the finite element method (FEM) for simulation and analysis. The wave optics module, specifically the electromagnetic waves in the frequency domain interface, was utilized. A user-controlled mesh was created, with a maximum element size set at 0.833nm and a minimum element size defined as 0.5nm, calibrated for general physics. A port was included to introduce light of wavelength (λ) 632.8nm at one interface and terminate it at the other.

III. Results and Discussions

The thickness of the plasmonic metal is a critical characteristic that needs to be carefully tuned to obtain the maximum performance of the sensor. In our Au-Ag bimetallic configuration, we maintain a total thickness of 45 nm. The thickness ratios of the layers are varied, with two configuration: 30nm Au / 15nm Ag and 25nm Au / 20nm Ag.

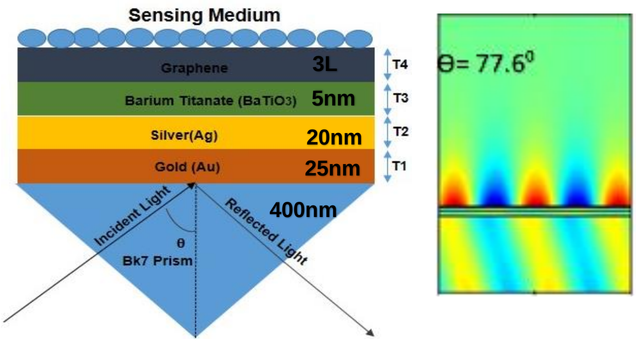

Fig.1 Simulated proposed structure and plasmonic excitation state at resonance angle of Θ=77.6^{O}.

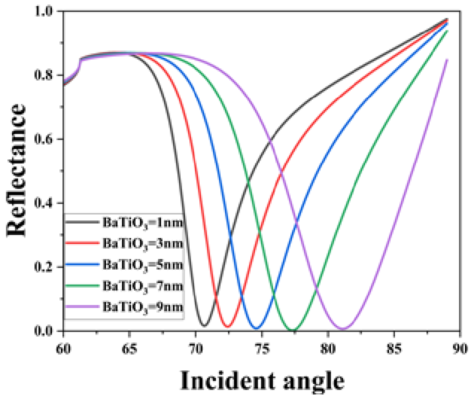

Fig. 2. SPR reflectance curve for different thickness of BaTiO3 at λ= 632.8nm

We determined the sensitivity and full width half maximum (FWHM) in each configuration by varying the analyte RI value by 0.01. The 25 nm Au / 20 nm Ag configuration yielded the best results with sensitivity of 130 Deg /RIU and FWHM of 4.42 nm. Thus, we choose this as the optimized thickness for our bimetallic configuration.

Fig. 2 shows the variation in reflectivity and resonance angle for different $BaTiO_3$ layer thicknesses. Increasing the $BaTiO_3$ thickness shifts the SPR angle to higher resonance angles with minimum reflectivity close to zero. The inclusion of $BaTiO_3$ enhances the electric field intensity near the metal-dielectric interface to 18.638×10^4 V/m, increasing sensitivity proportionally. We selected 5 nm as the optimum $BaTiO_3$ thickness because it offers higher sensitivity and lower minimum reflectance compared to 1 nm and 3 nm. Although 7 nm and 9 nm provide higher sensitivity, they result in a larger FWHM, reducing detection accuracy. Therefore, 5 nm strikes the best balance between sensitivity and FWHM.

Fig.3 shows reflectance curve for the variation of the graphene layers. It is clearly visible that as number of graphene layer increases, the minimum reflectance increases which is undesirable. So we analysed the sensitivity verses the number of graphene layers and determined that three layers (3L) of graphene provide the maximum sensitivity of 190 Deg/RIU with each layer having an optimized thickness of 0.34 nm.

With the optimized layer parameters, the sensor's performance was assessed for different blood plasma concentrations. Fig. 4 shows the performance parameters of the proposed sensor, including sensitivity, quality factor (QF), detection accuracy (DA) and FWHM. It was found that when the blood plasma concentration changed from 15 g/L to 20 g/L, corresponding to a refractive index change from 1.35 to 1.36, the sensor achieved the highest sensitivity of 220 Deg/RIU. With a single metal optimized structure of BK7/Au (45nm)/$BaTiO_3$ (5 nm)/Graphene (3 layers)/Sensing medium and a bimetallic optimized structure of BK7/Ag (25 nm)-Au (20 nm)/$BaTiO_3$ (5 nm)/Graphene (3 layers)/Sensing medium, highest sensitivity of 130 Deg/RIU and 200 Deg/RIU respectively was observed. Therefore, our structure demonstrates superior performance in terms of sensitivity.

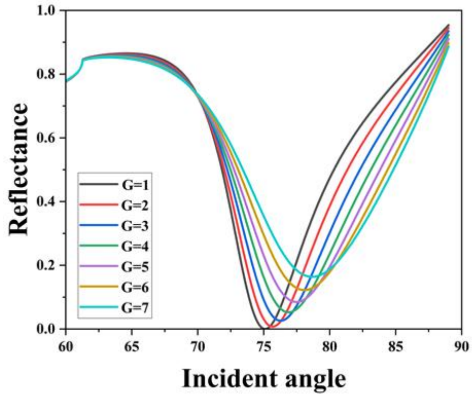

Fig. 3. Shift in SPR curves corresponding to different numbers of graphene layers.

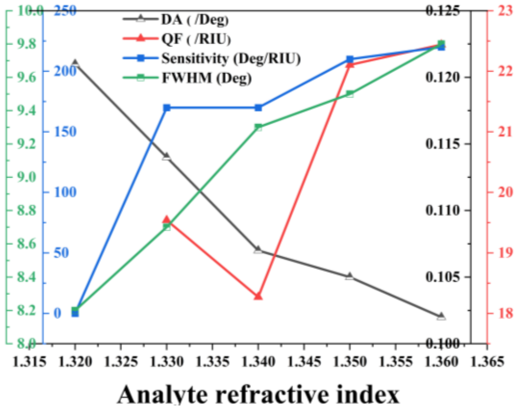

Fig. 4: Sensitivity, FWHM, QF, and DA versus RI of blood plasma.

IV. Conclusions

In this study, a SPR based bimetallic biosensor is proposed for detection of blood plasma. The simulation and optimization is done in COMSOL Multiphysics using FEM method to get the accurate result. We observed enhanced electric field intensity along the Graphene-sensing medium interface with the inclusion of $BaTiO_3$. The highest sensitivity of 220Deg/RIU is achieved for plasma concentration of 20g/L. Also we compare the result with bimetallic (Ag 25nm/Au 20nm) configuration and single metal Au layer and found that our proposed sensor is giving better performance in terms of sensitivity, and Quality factor.

Acknowledgements

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