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RESEARCH ARTICLE

Sensitivity Enhancement of Surface Plasmon Resonance (SPR) Sensor Assisted by BlueP/MoS_2 Based Composite Heterostructure

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ABSTRACT This paper addresses a very high sensitivity of surface plasmon resonance (SPR) sensor assisted by novel BlueP/MoS_2 based composite heterostructure based on angular interrogation technique. Research on SPR techniques based on angular interrogation system is attracted a lot in recent years due to ease of implementation, robust, reliable and compatibility. These SPR sensors have wide applications in the field of biosensing, biochemical, gas detection, and biological science to mention a few. By these SPR techniques, performance parameters like figure of merit (F.O.M.), detection accuracy (D.A.), and most importantly sensitivity have been tremendously increased. In recent past 2D materials have attracted a massive response in SPR biosensors. Hence in this paper, 2D material like blue Phosphorene/molybdenum disulfide (i.e., BlueP/MoS_2) hybrid nanostructure as an integrating layer with the analyte is suggested to improve the sensitivity substantially of SPR sensor. In this connection performance of multilayer structure in conjunction with CaF_2 prism, Ag metal layer, Black Phosphorus, BlueP/MoS_2 has been analyzed in this paper. The maximum sensitivity of the order of 458°/RIU has been obtained in this proposed scheme attributed to BlueP/MoS_2 based composite heterostructure at the visible wavelength of 662 nm. The proposed design analysis results in a significant improvement in sensitivity compared to traditional and graphene-based SPR sensors.

INDEX TERMS Blue phosphorene, surface plasmon resonance, chemical sensor, angular interrogation, sensitivity, transfer matrix method.

I. INTRODUCTION

Over the past few decades, in the field of gas sensing, biochemical sensing, and chemical sensing surface plasmon resonance (SPR) sensors have been broadly used [1], [2], [3]. To fabricate SPR sensors, metals like gold (Au)/silver (Ag) are mainly used with Kretschmann configuration [4], [28]. In the proposed structure, we have used Blue Phosphorene/MoS_2 heterostructure with silver and black phosphorus (BP) layer. The advent of graphene applications in numerous optoelectronics systems prompted researchers to investigate other two-dimensional (2D) materials, shown their significant contribution to ongoing technologies. Due to the quantum confinement effect, 2D materials exhibit unique physical, chemical, and optical properties as compared to their bulk counterparts. A novel 2D materials have been used to make this SPR biosensor structure while the effect of each layer has been analyzed. In the proposed SPR biosensor different prism comparison and BP and BlueP/MoS_2 layers has been theoretically investigated before deciding the proposed

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topology. The sensitivity properties of the adapted structure were simulated using Transfer matrix method based on angular interrogation technique, and it was discovered that the sensitivity can be significantly increased with this new structure. Recently 2D materials for applications in optoelectronic devices have been explored recently [5], [6], [7], [8], [31]. Conventional single metal film SPR biosensors have always had a limited sensitivity. Since 2014, BP has been a new promising 2D material, attracting substantial attention for its broadly tunable and direct bandgap, high carrier mobility, and outstanding electrical, optical, and photonic properties [9], [10], [11], [12]. Also, the heterostructure of BlueP and 2D materials have been used to enhance the sensitivity. BlueP is as stable as black phosphorene, and its narrow band gap makes it ideal for sensing applications [13]. However, when number of layers of 2D materials increased the difference in resonance angle get reduced due to angle range limitations, by this sensitivity continuous drop [14]. Angular sensitivity does not affect the metal thickness, and it can be summarized expressively (from 32 nm to 55 nm) though increasing the sensitivity [15]. Higher sensitivity can be achieved with the optimized parameters with the MoS$_2$ enhanced structure [2]. Exquisite efficiency can be obtained by precisely adjusting the gold film thickness and the number of BP interlayers [16], [17]. To achieve high sensitivity in the proposed configuration, we used Caf$_2$ as the coupling prism due to its lower refractive index (R.I.) value [18]. It has been studied that by using an optimized number of the layer of MoS$_2$, we will get higher detection accuracy for the system [16]. In this structure, the Blue Phosphorene/MoS$_2$ heterostructure with a silver metal layer and the BP layer has been taken. The sensitivity properties of the adapted structure were simulated using angular interrogation, and it was discovered that the sensitivity can be significantly increased with this new structure. The proposed SPR biosensor performance realized theoretically through MATLAB software. We assumed in the simulation that prism is uniform in transverse direction and has infinite thickness.

Moreover, the number of Blue Phosphorene/MoS$_2$ layers for best simulation results are also clarified [19], [20]. Ag possesses remarkable optical features, including a low optical damping, the absence of interband transmission at visible light frequencies, a more prominent resonance peak, and a narrower SPR curve, amongst other attributes. For this reason, it has the potential to be an advantageous material choice when developing SPR sensors. Therefore, a higher level of sensitivity is attainable with the utilisation of silver as a plasmonic material [26], [29], [30]. Also, BP used another material that helped the proposed SPR sensor be more sensitive. This material was phosphorus, which has a single pair on each atom, which makes it very reactive to air. This arrangement of atoms make two different directions in the black phosphorus lattice: the zigzag, which runs parallel to the atomic ridges, and the armchair, which runs perpendicular to the atomic ridges (perpendicular to the ridges) [27]. This strong structural anisotropy is what gives it its unique electrical and optical properties in the same plane. MoS$_2$ monolayer and BlueP have hexagonal lattice structures, so stacking BlueP on top of MoS$_2$ can readily create a heterostructure. Covalent bonds ensure in-plane stability. This heterostructure prevents external phosphorene degradation. Direct contact between heterostructure and sensor layer increases adsorption and enhances the interface field. This work explores improving sensitivity with heterostructure layers over Ag. BlueP/MoS$_2$ prevents Ag layer oxidation. BlueP/MoS$_2$ heterostructure is the analyte-contacting fourth layer [2]. In the proposed SPR biosensor different prism comparison and BP and BlueP/MoS$_2$ layers selection has been theoretically investigated for achieving the maximum sensitivity.

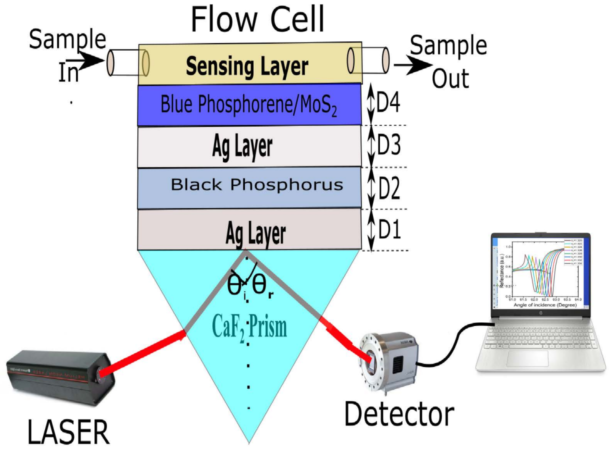

FIGURE 1. Schematic diagram of a proposed 6-layers (Ag/BP/Ag/ Blue Phosphorene/MoS$_2$) SPR sensor configuration.

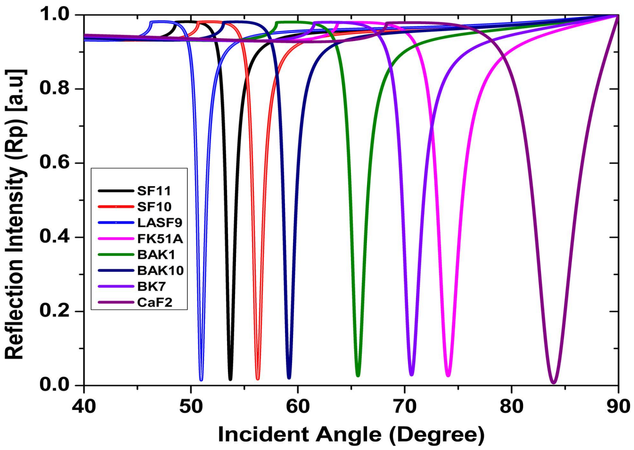

FIGURE 2. Reflectance intensity with incident angle comparison of different prisms.

II. DESIGN CONSIDERATION OF PROPOSED SPR SENSOR AND ITS IMPLEMENTATION

The proposed structure of the SPR sensor is considered with the Kretschmann configuration. The proposed sensor is a six-layer (BK7/Ag/BP/Ag/BlueP/Sensing medium) structure as shown in Figure 1. At one face of the prism, TM polarized light from the source with an operating wavelength (λ) of 662 nm is applied, and the reflected light is obtained using appropriate photodetector arrays instruments. The SPR sensor is used of a Caf_2 prism [18] with a silver-metal coating (refractive index $n_\circ = 1.43286$ at $\lambda = 662$ nm). The refractive index taken for the metal film (Ag) $n_{Ag} = 0.04944 + i \times 4.5027$, for BP $n_{BP} = 3.8337 + i \times 0.015215$. The refractive index of Blue Phosphorene/MoS_2 heterostructure is considered as $n_{BlueP/MoS_2} = 2.7915 + i \times 0.335$. Sensing layer refractive index was chosen as $n_S = 1.33$ at the wavelength of 662 nm. The BP layer is sandwiched between two layers of Ag films in this proposed arrangement. The Ag first and third layer thickness are considered to be 40 nm and 8 nm respectively. The width of the BP has been determined to be $D_s = M \times 0.65$ nm. The thickness of Blue Phosphorene/MoS_2 has been calculated as Blue Phosphorene/MoS_2 $= N \times 0.75$ nm, where M and N are the number of BP and Blue Phosphorene/MoS_2 layers respectively [16].

The reflectivity of proposed multi-layered structure is calculating using the expression:

$$r_{pm_1d_1m_2d_2} = \frac{r_{pm_1} + r_{m_1d_1m_2d_2} e^{2iK_{m_1x}d_{m_1}}}{1 + r_{pm_1} r_{m_1d_1m_2d_2} e^{2iK_{m_1x}d_{m_1}}} \tag{1}$$

where:

$$K_{ix} = \sqrt{\left(\frac{2\pi}{\lambda}\right)^2 \varepsilon_i - K_z^2}; \quad i = p, m_1, d_1, m_2, d_2, \tag{2}$$

$$r_{pm} = \frac{(\varepsilon_m K_{px} - \varepsilon_p K_{mx})}{(\varepsilon_m K_{px} + \varepsilon_p K_{mx})}; \quad r_{md} = \frac{(\varepsilon_d K_{mx} - \varepsilon_m K_{dx})}{(\varepsilon_d K_{mx} + \varepsilon_m K_{dx})} \tag{3}$$

p, *m* and *d* denoted as the prism, metal and dielectric respectively. As in the above process when the resonance condition is satisfied then the resonance dip in the reflectance curve is achieved as per Eq. (1). Thus, as seen in Eq. (1), the coupling equation for incident light and SPs at the metal-dielectric interface is as follows:

$$k_z = k_{sp} = \frac{2\pi}{\lambda} n_p \, sin \, \theta_{spr} = real\left(\frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon_m \varepsilon_s}{\varepsilon_m + \varepsilon_s}}\right) \tag{4}$$

In above Eq. (4), n_p refers as a refractive index of the substrate medium (glass/prism), λ is the wavelength of light. Here ε_m and ε_s are the dielectric constants of the metal layer and the sensing (analyte) layers respectively, also signifies the coupling of incident light and SPs at the metal-dielectric interface. The angle at which the SPR curve has dipped (R_{min}), that angle is referred to as the resonance angle (SPR angle), for a transition in the R.I. of the analyte, the SPR dip shifts. In Figure 2, a comparative analysis of several prisms in terms of their reflectance curves indicates that Caf_2 prisms have the largest SPR angle for the proposed structure, and thus Caf_2 prisms are chosen as a light coupling glass at 662 nm wavelength. The proposed structure having Ag, BP and BlueP/MoS_2 on the top of the coupling prism, out of them Ag is used as an SPR-active metal layer. BlueP/MoS_2 heterostructure has been considered as the last layer, which interacts with the analyte directly. The dielectric constants of BlueP/MoS_2, Ag, Caf_2, and BP at 662 nm wavelength are extracted from [18], [21] and [22] respectively. The sensitivity (S) and detection accuracy (D.A.) of the sensor have been investigated [16] and calculated as:

TABLE 1. **Parameters of the proposed sensor's design.**

Layers	Material used	Refractive Index (λ=662 nm) (n + i x k)	Thickness (nm)
I	Prism (CaF_2)	1.43286	-
II	Metal (Ag)	0.04944+ i x 4.5027	40
III	2D material (BP)	3.8337+ i x 0.015215	0.65
IV	Metal (Ag)	0.04944+ i x 4.5027	8
V	Hetrostructure (BlueP/MoS_2)	2.7915+ i x 0.335	0.75
VI	Analyte	1.331 to 1.336	-

$$S = \frac{\Delta\theta_{SPR}}{\Delta n_S} \tag{5}$$

$$D.A. = \frac{1}{FWHM} \tag{6}$$

Sensitivity is defined as the change in resonance angle proportional to the change (n_s) in analyte R.I. and calculated mathematically as per Eq. (5). The D.A. defined in Eq. (6) as the inverse of the SPR curve's angular FWHM (full width at half maximum) [19]. The six layer design parameters for the proposed sensor at a wavelength of 662 nm are shown in Table 1, along with the layer thicknesses and refractive indexes. The SPR requirement is met by a metal-dielectric contact satisfying the following equations. Tranfer matrix method (TMM) has been used to quantify the reflectance of the data. In TMM method a N-layer approximation method has been devised to theoretical analyze of reflectance data. The schematic of a six-layer structure is shown in Figure 1, where n_k represents the complex values of the refractive index, ϵ_k represents as permittivity of the k^{th} layer with thickness d_k. As shown in Eq. (7), the N-layer structure can be represented using the characteristic matrix [23]:

$$M = \prod_{K=2}^{N} M_K = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix} \tag{7}$$

$$M = \begin{bmatrix} cos(\beta_k) & -isin(\beta_k)/q_k \\ -iq_k sin(\beta_k) & cos(\beta_k) \end{bmatrix} \tag{8}$$

where:

$$\beta_k = \left(\frac{2\pi d_k}{\lambda}\right)\sqrt{\epsilon_k - n_1^2 sin^2\theta_1}$$

$$q_k = \sqrt{\epsilon_k - n_1^2 sin^2\theta_1/\epsilon_k}$$

The reflection coefficient (r_p) and transmission coefficient (t_p) of the incident TM polarized (p-polarized) light is given

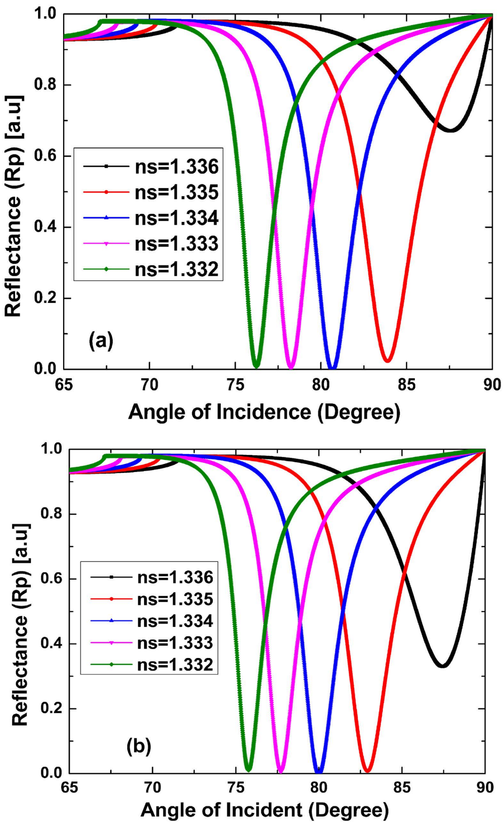

FIGURE 3. (a) Variation of reflectance with respect to the incident angle for refractive index ranges 1.332 to 1.336 with BP layer and (b) without BP layers.

by Eq. (9):

$$r_p = \frac{{H_y}^{ref}}{{H_y}^{inc}} = \frac{(M_{11}+M_{12}q_N)q_1-(M_{21}+M_{22}q_N)}{(M_{11}+M_{12}q_N)q_1+(M_{21}+M_{22}q_N)} \tag{9}$$

and Eq. (10):

$$t_p = \frac{{H_{yN}}^0}{{H^0}_y} = \frac{2q_1}{(M_{11}+M_{12}q_N)q_1+(M_{21}+M_{22}q_N)} \tag{10}$$

and then the reflectance (R_P) for p-polarized light is calculated as:

$$R_P = \left|r_p\right|^2 \tag{11}$$

Eq. (9) and Eq. (10) have been used to estimate the reflection coefficient and transmission coefficient respectively of this paper.

III. RESULTS AND DISCUSSION

In the proposed novel structure the refractive index sensor characteristic has been simulated assisted by BlueP/MoS$_2$ heterostructure, silver metal and BP layers by the Kretschmann configuration. The proposed refractive index sensor has revealed a better sensitivity to capable enough for the detection of biofluids dissolved in water, biochemicals dissolved with water molecules, hard water detection, softwater detection to mention a few. In this connection, reflectance graph of the proposed structure as a function of an incident angle has been studied to precisely estimate the sensitivity improvement. The parameters in the proposed SPR sensor have been extracted from the literature and optimized thickness of the layers D$_1$, D$_2$, D$_3$ and D$_4$ have been considered layer by layer basis followed by simulation results to achieved the maximum sensitivity of the proposed SPR structure. In the proposed sensor the thickness of the Ag = 40 nm and 8 nm for first and third layer respectively, BlueP/MoS$_2$ = 0.75 nm and BP = 0.65 nm is considered at

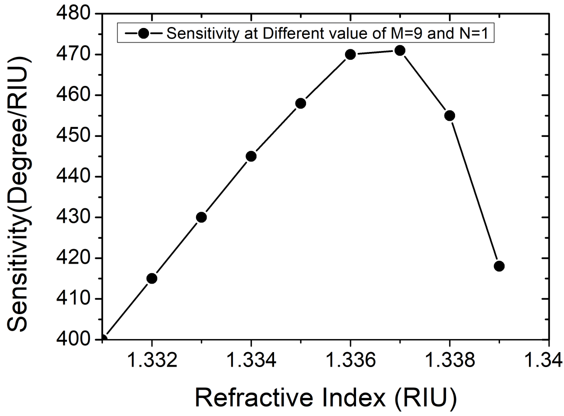

FIGURE 4. Sensitivity (o/RIU) graph for the number of BP layers (M) with constant N = 1.

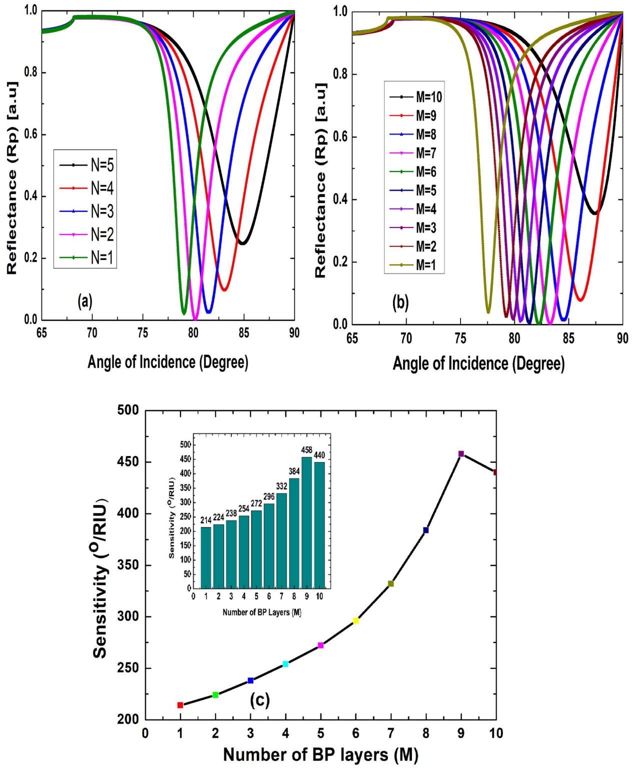

FIGURE 5. (a) Variation of Reflectance with respect to incident angle for different number of BlueP/MoS$_2$ (N) heterostructure layers in the condition of constant BP layer (M), (b) Reflectance graph for different numbers of BP layers (M) and single BlueP/MoS$_2$ (N) heterostructure layer, (c) Sensitivity of the 9 layers of BP and single layer of BlueP/MoS$_2$ heterostructure layers.

visible 662 nm wavelength. Due to the excitation of SPR, it has been observed a sharp dip in reflectance graph at a certain angle due to the excitation of SPR wave energy which is adsorbed by the sensing layer or substance. Despite of a small shifts in SPR angle due to slight change in the sensing layer's refractive index, still the resonance dip has a significant excursion of about $\delta\theta = 2.29°$. Apparently this is due to insignificant molecular interaction on sensing head. The sensitivity parameter can be consistently calculated with the help of Eq. (5). It has been found that sensitivity parameter enhanced upto 458°/RIU of the proposed structure while properly optimization of the number of layers and thickness of each layer. In all the calculations of this paper the range of refractive index taken for the simulation is between 1.331 to 1.336. Since the prism and gold layer are traditionally used in past SPR structures, hence similar prism-based structure in conjunction with novel 2D material has been chosen to achieve the optimum refractive index sensor's sensitivity. Structure has been improved over previous structures with the considering the BP and a BlueP/MoS_2 heterostructure layer with Ag as the metal layer. The refractive index of the sensing layer can be used to monitor the sensitivity of the proposed refractive sensor study.

Figure 3 illustrates the relationship between the chemical sensor's sensitivity and the refractive index of the sensing layer in the proposed BP and BlueP/MoS_2 heterostructure. Figure 3(a) shows the reflectance versus incidence angle curve for the R.I. range from 1.332 to 1.336 with the Ag + BP + Ag + BlueP/MoS_2 heterostructure. Infact as the refractive index value of the substance changed, SPR dip changed, and FWHM (full width at half maximum) value increased, leading to decreased detection accuracy. Figure 3(a) reveals the responses for two layers of BlueP/MoS_2 heterostructure and single BP layers along with change of analyte R.I. Figure 3(b) reveals the results when two BlueP/MoS_2 heterostructure and without BP layers are incorporated. The effect of thickness for the layers on the sensing properties when considering the evanescent fields in a typical SPR sensor is that if number of layer will increase the value of RI will increase as well as in complex Ri (real part of refractive index) term and k (imaginary part of refractive index) term will increase hence maximum light will absorb and high penetration depth will appear in evanescent wave but at the same time due to enhancement in damping evanescent field will drop very earlier. So first the SPR angle will get wide and R_{min} value will reduce so FWHM will hard to calculate. Sensitivity has been tremendously increased with every increment of BlueP/MoS_2 heterostructure layers. Sensitivity is significantly increased with incorporating few numbers of BlueP/MoS_2 heterostructure layers upto some limit however on the account of increment of FWHM parameter. Hence there is a trade off between the sensitivity and FWHM parameters in connection with the increment of BlueP/MoS_2 heterostructure layers. It has been found that sensitivity enhanced with BP layers too with stable FWHM values while keeping fix BlueP/MoS_2 heterostructure layers. Apparently one can not increase or decrease the number of BP and BlueP/MoS_2 heterostructure layers blindly on account of compromised values of D.A. and sensitivity. Furthermore the computation has been carried out with varying number of BP layer and BlueP/MoS_2 hetero-structure layers to exactly know the effect on various performance parameters of the proposed SPR sensor design parameters in the R.I. range of analyte 1.331 to 1.336. Table 2 shows the sensitivity comparison of the final structure with the conventional and the bimetallic structure at wavelength $\lambda = 662$ nm and obtained the highest sensitivity around 214 (°/RIU) for the change of analyte R.I. $\Delta n_s = 0.001$. However with the changing of analyte R.I. Range from 1.331 to 1.336 RIU, the change in resonance angle $\Delta\theta_{SPR} = 1.07°$ is achieved with the Caf_2 + Ag + BP + Ag + BlueP/MoS_2 heterostructure configuration.

TABLE 2. **Comparison of sensing performance at $\lambda = 662$ nm.**

Configuration (CaF2+)	$\Delta\theta_{SPR}$ (Degree)	Sensitivity (°/RIU)	Analyte R.I. range (n=0.005)
Ag	0.93	186	1.331 to 1.336
Ag+BP	0.99	198	1.331 to 1.336
Ag+BP+Ag	1.00	200	1.331 to 1.336
Ag+BP+Ag +BlueP/MoS_2 hetrostructure	1.07	214	1.331 to 1.336

TABLE 3. **Variation of the BP layer (M) and a constant BlueP/MoS_2 heterostructure has an impact on the output parameter.**

No. of BP Layers (Fixed BlueP/MoS_2 Layer=1)	F.W.H.M. (Degree)	Sensitivity (°/RIU)	F.O.M. (nm)
1	2.07	214	103.38
2	2.25	224	99.55
3	2.45	238	97.14
4	2.69	254	94.42
5	2.96	272	91.89
6	3.29	296	89.96
7	3.68	332	90.21
8	4.13	384	92.97
9	4.45	**458**	102.92
10	3.02	440	145.69

Table 3 shows the effect on the performance parameter by changing the number of BP layer (M) while keeping constant BlueP/MoS_2 heterostructure (N = 1) layer. It has been found that sensitivity increased to maximum value 458°/RIU for the 9 number of BP layers there after it start decreasing with further increasing of BP layers. It has been found that at $\Delta n_s \approx 0.007$ the maximum sensitivity touched down to a value of 471.42°/RIU, which opens a new era to the researcher for the several applications. Figure 4 shows the sensitivity (o/RIU) graph for different BP layers with constant BlueP/MoS_2. Figure 5 (a) shows the schematic diagram of reflectance with incidence angle for the different number of BlueP/MoS_2 heterostructure layers with the condition of constant BP layer (M). Figure 5(b) shows the reflectance graph for different numbers

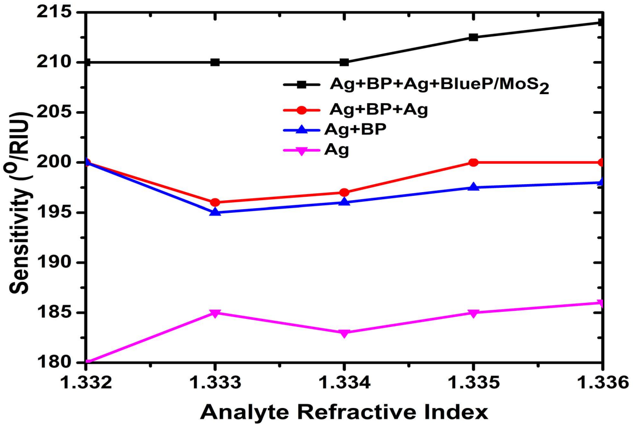

FIGURE 6. Optimization of sensitivity for different configuration of layers structures for R.I. range 1.332 to 1.336 RIU.

TABLE 4. Sensitivity comparison table with some recent papers works.

References	Operating Wavelength (nm)	n$_s$ ($\Delta n_s \approx 0.005$)	Max. Sensitivity (°/RIU)
[24]	633	1.33	190.83
[15]	633	1.33	279
[25]	633	1.33	187
[16]	633	1.33	230.66
[2]	662	1.33	355.525
		1.33	432.15
Proposed work	662	1.331 to 1.336	**458**
		1.331 to 1.338 ($\Delta ns \approx 0.007$)	471.42

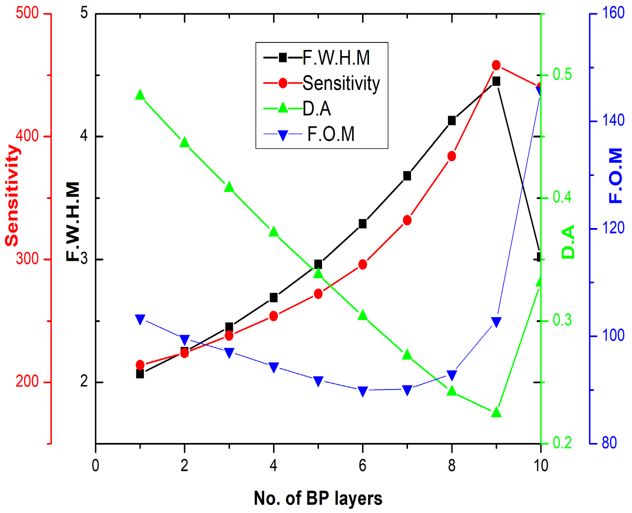

FIGURE 7. Performance parameters (F.O.M., D.A., FWHM, Sensitivity) of the proposed six layer structure.

of BP layers and single BlueP/MoS$_2$ heterostructure layer. Figure 5(c) shows the sensitivity of 458 °/RIU by the 9 layers of BP and single layer of BlueP/MoS$_2$ heterostructure layers. Figure 5(a) shows the simulated results for increasing BlueP/MoS$_2$ heterostructure (N) layers and single BP layer for fixed refractive index media. It is observed that BlueP/MoS$_2$ heterostructure layers increasing the sensitivity improved layer by layer. At the same time, its detection accuracy is decreasing because FWHM of reflectance wave rises with a growing BlueP/MoS$_2$ heterostructure layer. It cannot randomly increase the BlueP/MoS$_2$ heterostructure layers because when FWHM increases sensitivity decreases. Apparently large FWHM and less reflectance dip more than 0.5 (a.u.) are not suitable for sensing application. Figure 5(b) shows the simulated results for only single layer of BlueP/MoS$_2$ heterostructure with varying BP layers up to 10 layers. It has been observed that up to 9 layers of BP the FWHM value is not less than 0.5 and also very sharp reflectance dip is obtained while after 9 layers of BP the FWHM increases and so as sensitivity starts decreases. Due to this observation optimum 9 layers of BP has been considered in the proposed structure for achieving highest sensitivity (458 °/RIU) parameter. Sensitivity at different R.I. has been shown in Figure 6 by the theoretical analysis for the proposed structure layer by layer of Ag + BP + Ag + BlueP/MoS$_2$ heterostructure. The maximum sensitivity is obtained 214 °/RIU at R.I. = 1.336 of analyte when single layer of BP and BlueP/MoS$_2$ heterostructure has been introduced. In Figure 6 the layer-by-layer analysis has been done for the R.I. range of 1.332 to 1.336. In this analysis firstly at 1.332 R.I., with only Ag layer SPR performance has been seen and similarly added a single layer of BP and BlueP/MoS$_2$ layer sensitivity calculated. Table 4 shows the sensitivity comparison with some recent paper works with the proposed work. It has been investigated that by the proposed configuration sensitivity enhancement achieved to be 471.42 °/RIU for a small change of analyte refractive index $\Delta n_s \approx 0.007$.

Figure 7 shows the performance parameters of the proposed SPR sensor, at 9 layers of BP the FWHM achieved 4.45°, sensitivity 458 °/RIU, D.A. = 0.22472 and F.O.M. 102.9 RIU^{-1}. After layer number 09 (9 x 0.65 nm thickness), the evanescent filed penetration depth decreases to the outer medium due to noncompliance of the SPR condition hence in the proposed SPR sensor sensitivity would decreased after layer number 09.

IV. FABRICATION PROSPECT

The proposed sensing chip is developed with different deposition materials on top of a multi-layered structure made of high-refractive-index glass. The Ag layer will be deposited on top of the prism or glass substrate by the e-beam deposition machine. Then, the index-matching gel is used to stick the SPR chip (glass substrate) to the flat side of the prism. After the deposition of the Ag layer other materials will be deposited layer by layer. On the top of the sensing chip, the sensing analyte was moved to the flow cell. Light can be launched on one side of the prism, and on the other side reflected light can be collected through a spectrophotometer and the spectrophotometer is connected to the PC/laptop by the help of the ASPIRE-SPECTRA- 21 (compatible with the Windows) software where absorbance, reflectance, and transmittance spectrum can be obtained. Given all of these options and the current state of material technology, we are optimistic that the suggested SPR sensor for testing can be used in real life. The prism needs to be put between the source and detector of the spectrophotometer. A spectrophotometer has two light sources: white light (tungsten halogen) and LED light (wavelength range 200-1100 nm). After that, there is a need to set a reference value in a dark room so that the lab environment can be done in natural light. After getting the reference value from the surrounding environment, the LED light source on one side of the prism was used to send light through the prism must land on the top of the prism, where the sensing material is positioned. In the coating process, we can use field emission scanning electron microscopy (FESEM) to look at the deposition of layers on a glass substrate from a cross-sectional view, and this is done to make sure that the layers are deposited correctly as per the required thickness of the layers.

V. CONCLUSION

A BlueP/MoS$_2$ heterostructure has been suggested for use in an SPR-based sensor. In comparison to conventional SPR sensor schemes and graphene-based SPR sensor schemes, it is demonstrated that the proposed system with this structure will achieve enhanced sensitivity. The maximum sensitivity is obtained when a 9-layer BP (black phosphorous) heterostructure and a single-layer BlueP/MoS$_2$ heterostructure are used. Additionally, the identification accuracy is within reasonable limits. We analyzed the sensor's performance by considering the cumulative effect of the wavelength and the varying BP and heterostructure layers. Owing to the extremely sensitive nature of the proposed scheme, it could be a competitor to graphene-based SPR sensors.

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