Performance of graphene-on-gold SPR biosensor using wurtzite nitrides

Goutam Mohanty
Department of Physics
National Institute of Technology
Raipur, G. E. Road,
Raipur-492010 (C.G), India
gmohanty.phd2012.phy@nitrr.ac.in

Bijay Ku. Sahoo
Department of Physics
National Institute of Technology
Raipur, G. E. Road,
Raipur-492010 (C.G), India
bksahoo.phy@nitrr.ac.in

Jamil Akhtar
Sensors and Nano-Technology Group
CSIR-Central Electronic Engineering Research Institute
Pilani-333031 (Raj), India
jamil@ceeri.ernet.in

***Abstract*—The effect of wurtzite nitride semiconductor on performance of a graphene-on-gold surface plasmon resonance (SPR) biosensor has been explored theoretically. Wurtzite nitrides (i.e. Aluminium Nitride, Gallium Nitride and Indium Nitride) have been introduced in between active metal gold and graphene layers. All performance parameters of the proposed SPR configuration has been computed for with and without semiconductors. It is found that wurtzite nitrides demonstrate high sensitivity and improved performance in comparison to Si and Ge due to its superior optical and electronic properties. The enhancement of evanescent electric field due to wurtzite nitrides as well as Si and Ge have been computed and found highest enhancement for InN. This is due to higher refractive index of InN than GaN and AlN. Analysis shows that for a high sensitive imaging biosensor the requisite optimal thickness of InN, graphene and gold are respectively 11 nm, 0.34 nm and 49 nm for light of wavelength 632.8 nm. This study suggests that addition of InN-layer would be a better choice for fabrication of high sensitive and high precision imaging SPR sensor for biomedical application.**

Keywords*— *SPR biosensor, wurtzite nitrides, sensitivity, FOM, evanescent field, performance.

I. Introduction

Surface plasmon resonance (SPR) is an important optical phenomenon that occurs at the interface of a metal and a dielectric medium. This phenomenon measures the refractive index changes in the vicinity of thin metal layers (i.e. Au, Ag, Cu or Al) in response to biomolecular interactions [1]. It is widely used in the healthcare industry to monitor molecular interaction at the interface and allows the real-time analysis of reactions without the use of labels [2], [3]. The first application of SPR for gas molecule detection was demonstrated by Nylander *et al.* [4]. Then after, research in the field of SPR sensing grew in a very successive rates. Finally, it significantly contribute to study the interactions between different types of bio-molecules like protein, lipids, antigens, nucleic acids, and viruses etc. [3], [5]. Many of the research groups has been involved in the development of SPR sensor. To improve the overall performance of these sensors, one should focus on the number of parameters such as sensitivity, evanescent field, full-width-half-maximum (FWHM), figure of merit (FOM) and stability of the metal [6]. A number of metals like Ag, Au, Cu or Al has been used as active metal layer in the SPR sensor. It is to be pointed out that a silver film yields higher sensitivity than gold but the potential drawback is that it is highly vulnerable to oxidation. However, the gold film is highly stable and reliable but it adsorbs bio-molecules very poorly and hence sensitivity of gold based SPR sensor is low. [7], [8].

In order to get better sensitivity of gold based SPR sensor, a sheet of graphene can be functionalized on the surface of metal film [9]. The main advantages of graphene is that it efficiently adsorbs bio-molecules and protects underlying metal layer from oxidation [10]. For further enhancement of sensitivity, high-index dielectric material like silicon is being used in between gold and graphene [11]-[13]. The high index of refraction boosts the intensity of evanescent field leading to higher imaging sensitivity. Recently, few research groups reported that the performance of SPR biosensor is affected by elevated temperatures [14]-[16]. Thus, to improve imaging sensitivity, a dielectric material that possesses superior optical properties, high evanescent field and high resistance to temperature rise is required to be investigated. In these circumstances, wurtzite nitride semiconductors are most promising candidates. They possess a number of superior properties like high refractive index, high electron concentration, high temperature resistance, more reliability and long term stability [17]. Also, they are basic materials for fabrication of thin film optoelectronic devices. In the molecular research point of view, these materials are chemically stable, non-toxic, bio-friendly and can be easily attached with graphene surface due to hexagonal structure. In practical point of view, wurzite nitride can be grown on metal surface and also, graphene can be grown directly over the wurtzite nitrides [18]-[20]. Recently, Jewett *et al.* demonstrated that gallium nitride (GaN) can be used for the detection of hexylamine and peptide [21]. In our earlier work, it has been reported that aluminium nitride (AlN) exhibits higher performance for a graphene-on-silver SPR biosensor

[22]. Also, author reported that Indium nitride (InN) shows higher performance for a graphene-on-copper SPR biosensor [23].

To our knowledge, the potential of wurtzite nitrides for graphene-on-gold SPR biosensor for high sensitivity and performance at ambient temperatures and high evanescent field enhancement has not been investigated. In this work the superior optical, electronic and thermal properties of wurtzite nitrides have been exploited to improve the sensitivity and overall performance of a graphene-on-gold SPR biosensor.

II. Theory and Principle of SPR Biosensor

Surface plasmon polariton (SPP) is the two dimensional electromagnetic evanescent wave propagating at the flat interface between a conductor and a dielectric. This concept was verified experimentally by Otto and then it was modified by Kretschmann in 1968 [24], [25]. Later on, Kretschmann configuration was more popular in the whole scientific community. The SPP can be excited at the interface by allowing TM-polarized light at an angle α $(\alpha > \alpha_c)$ through another high-index dielectric medium (e.g. glass prism). Here α_c is the critical angle of glass prism. At resonance condition wave vectors of both incident light and SPs present on the metal surface becomes equal which can be written as [3]:

$$k_x = k_{sp} \Leftrightarrow \frac{2\pi}{\lambda} n_1 \sin\alpha = \frac{\omega}{c}\sqrt{\frac{n_m^2 n_d^2}{n_m^2 + n_d^2}} \tag{1}$$

Where λ is wavelength of incident light (= 632.8 nm), α is resonance angle (deg.), ω is plasma frequency (Hz), c is the velocity of light (m/s). n_1, n_m and n_d are refractive index of prism, metal and dielectric medium respectively. The angle at which resonance occurs called resonance angle. At this resonance angle, intensity of reflected light is found to be minimum. The biosensor which is based on this phenomenon called as SPR biosensor. SPR based biosensor can be used to detect various biomolecules in a liquid sample (e.g. water, blood, serum and urine etc.). When sample solution flows on the sensor surface, target bio-molecules present on the sample gets adsorb on its surface and generates a layer, called binding layer, with high-index of refraction than sample solution. This will change the resonance angle. Hence the sensitivity of the sensor can be computed by using the relation i.e. Sensitivity $= \Delta\alpha / \Delta n$. Where $\Delta\alpha$ is change in resonance angle and Δn is change in refractive index.

The overall performance of the sensor depends on the efficient adsorption of the biomolecules on the sensor surface. Here graphene layer is used for efficient adsorption of biomolecules. For imaging sensors high evanescent field of excitation light at the analyte region is beneficial. This can be achieved by adding high-index dielectric layer (wurzite nitride) between gold and graphene.

III. Computational Methodology

The schematic diagram of proposed SPR biosensor is shown in Fig.1. In the present study, it has been employed generalized N-layer model, called transfer matrix method (TMM), for computing the reflectance R, where N = 6. In our simulation, we have assumed layers are stacked one after another i.e. prism| Au| semiconductor| graphene| binding layer| sample. The reflectance of the proposed configuration for p-polarized light can be computed using the expression [26]-[28]

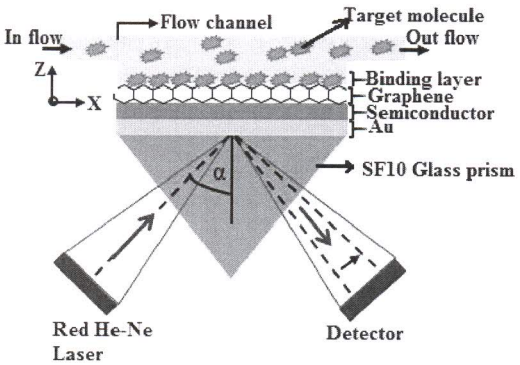

Fig. 1. Schematic diagram of SPR Biosensor.

$$R = \left|\frac{(M_{11} + M_{12}\gamma_N)\gamma_1 - (M_{21} + M_{22}\gamma_N)}{(M_{11} + M_{12}\gamma_N)\gamma_1 + (M_{21} + M_{22}\gamma_N)}\right|^2 \tag{2}$$

Where, $$M_{ij} = \left(\prod_{k=2}^{N-1} M_k\right)_{ij}; i, j = 1,2; \tag{3}$$

With $$M_k = \begin{pmatrix} \cos\delta_k & -i\sin\delta_k/\gamma_k \\ -i\gamma_k \sin\delta_k & \cos\delta_k \end{pmatrix} \tag{4}$$

and $$\gamma_k = \frac{\left(n_k^2 - n_1^2 \sin^2\alpha\right)^{1/2}}{n_k^2} \tag{5}$$

and $$\delta_k = \left(\frac{2\pi}{\lambda}\right) d_k \left(n_k^2 - n_1^2 \sin^2\alpha\right)^{1/2} \tag{6}$$

Where λ is the wavelength of incident light, n_1 is the refractive index of the prism, d_k is the thickness of k^{th} layer and n_k is the refractive index of k^{th} layer where k = 2, 3, 4,.....(N-1). The reflectance R is plotted as a function of incident angle α. From the SPR intensity curve, the angle corresponding to minimum reflectance (R_{min}) is determined and it is called as resonance angle α_{res}. This resonance angle α_{res} changes with the change in the refractive index of the binding layer. If the change in refractive index Δn induces a change in resonance angle $\Delta\alpha_{res}$ then the sensitivity of the sensor can be calculated using the expression i.e. $S = (\Delta\alpha_{res} / \Delta n)$. In this study, we have assumed that bio-molecular reaction produces a change in refractive index Δn

(≈ 0.005) but not the thickness of binding layer [11]. The binding layer thickness has been taken as 10 nm (fixed) [29]. Thus, sensitivity is directly proportional to $\Delta\alpha_{res}$. This indicates that higher $\Delta\alpha_{res}$ will imply higher sensitivity. Hereafter we write $\Delta\alpha_{res}$ as $\Delta\alpha$. For imaging sensor, maximum intensity of SPP is more beneficial. This can be achieved by improving the evanescent electric field at the interface. However, the electric field is not continuous across a metal- dielectric boundary according to Maxwell's boundary conditions. Hence, to know evanescent electric field (E), the magnetic field (H) is to be computed first using the expressions [26], [30]:

$$H = \frac{2 \times \gamma_1}{(M_{11} + M_{12}\gamma_N)\gamma_1 + (M_{21} + M_{22}\gamma_N)} \tag{7}$$

$$\text{and } E = \frac{n_1}{n_N} H \tag{8}$$

The simulation has been carried out to compute parameters i.e. reflectance (R), change in resonance angle $\Delta\alpha$, FWHM, and evanescent field intensity at wavelength 632.8 nm. The optical properties of different materials used in the computation are mentioned in the Table I. The performance parameter called figure of merit (FOM) of the proposed biosensor has also been computed. The FOM is defined as: FOM = sensitivity / FWHM.

TABLE I

OPTICAL PROPERTIES OF MATERIALS (AT λ = 633 NM)

Material	Refractive Index(n)	Extinction Co-efficient (k)	References
SF10-glass prism	1.7231	0.0000	[31]
BK7-glass prism	0.5151	0.0000	[31]
InN	2.9000	0.0000	[32]
GaN	2.3848	0.0000	[32]
AlN	2.1496	0.0000	[32]
Si	3.8827	0.0196	[33]
Ge	5.4717	0.8163	[33]
Au	0.1726	3.4218	[34]
Graphene	3.0000	1.1491	[35]
Water	1.3317	0.0000	[36]

IV. RESULTS AND DISCUSSION

The prism and active metal have been chosen as SF10-glass and gold (Au). The thickness of gold layer has been optimized for achieving minimum reflectance (R_{min}) without using graphene and semiconductors. The optimized thickness is found to be 49 nm (shown in Fig. 2). Now graphene is grown on metal surface and sample solution is allowed to flow. Let the resonance angles are α_1 and α_2 respectively before and after the formation of binding layer. The change in resonance angle is $\Delta\alpha$. This $\Delta\alpha$ has been computed for with and without presence of different semiconductor layer in between gold and graphene. The thickness of graphene and semiconductor layer has been optimized to achieve maximum change in resonance angle.

First, the effect of wurtzite nitride on performance of proposed SPR configuration has been examined. The simulation has been carried out individually after introducing InN, AlN and GaN in between Au and graphene layer in the proposed SPR configuration. *In case of InN*, the change in resonance angle $\Delta\alpha$ attains maximum value when thickness of InN-layer and graphene and are 11 nm and 0.34 nm respectively (shown in Fig. 3). In the presence of InN-layer, $\Delta\alpha$ is found to be 3.863^0 which is 3.67 times greater than the value of 1.052^0 ($\Delta\alpha$ for the absence of InN-layer). Thus it can be concluded that the addition of InN-layer, enhances the sensitivity by a factor of 3.67 because it has been assumed that change in refractive index is fixed. Also, FWHMs have been computed and found to be 4.43^0 and 14.79^0 for without and with the presence of InN-layer respectively.

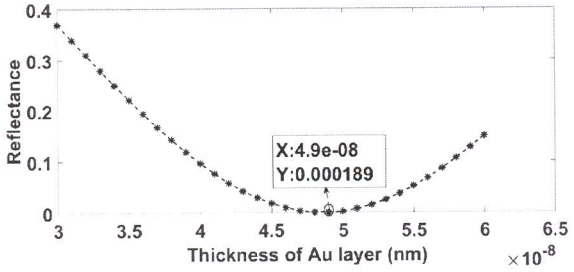

Fig. 2. Variation of minimum reflectance with the thickness of Au layer.

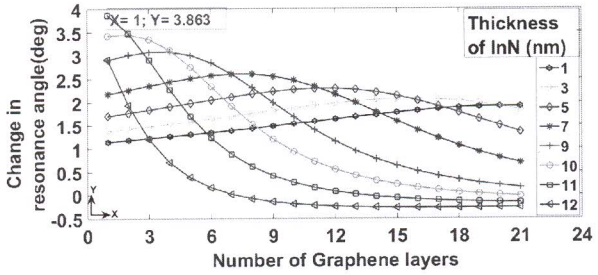

Fig. 3. Change in resonance angle as a function of thickness of graphene and InN-layers.

Similar procedure has been followed for AlN and GaN. *For AlN*, the change in resonance angle $\Delta\alpha$ attains maximum when thickness of AlN-layer and graphene are 20 nm and 0.34 nm respectively. In the presence of AlN-layer, $\Delta\alpha$ is found to be 3.610^0 which is 3.42 times greater than the value of 1.052^0. Thus it can be concluded that the addition of AlN-layer, enhances the sensitivity by a factor of 3.42. Also, FWHM has been computed and found to be 13.80^0 in presence of AlN-layer. *For GaN*, the change in resonance angle $\Delta\alpha$ attains maximum when thickness of GaN-layer and graphene are 16 nm and 0.34 nm respectively. In the presence

TABLE II

PERFORMANCE PARAMETER FOR PROPOSED SEMICONDUCTORS

Materials	Optimized thickness of Semi-Conductor (nm)	Optimized thickness of graphene (nm)	Resonance angle without binding layer α_1 (deg.)	Resonance angle with binding layer α_2 (deg.)	Change in resonance angle $\Delta\alpha$ (deg.)	FWHM (deg.)	FOM
Semiconductor	00	0.34	57.366	58.418	1.052	4.43	47.49
AlN	20	0.34	75.989	79.599	3.610	13.80	52.31
GaN	16	0.34	75.951	79.719	3.768	14.37	52.44
InN	11	0.34	74.999	78.862	3.863	14.79	52.23
Si	07	0.34	75.743	79.367	3.624	16.20	44.74
Ge	03	0.34	66.917	69.176	2.259	19.94	22.65

of GaN-layer, $\Delta\alpha$ is found to be 3.768^0 which is 3.58 times greater than the value of 1.052^0. Thus it can be concluded that the addition of GaN-layer, enhances the sensitivity by a factor of 3.58. Also, FWHM has been computed and found to be 14.37^0 in presence of GaN-layer.

In addition, simulation has been carried out for well-known semiconductors e.g. silicon (Si) and germanium (Ge). *For silicon*, it is found that $\Delta\alpha$ attains maximum value when thickness of Si-layer and graphene are 7nm and 0.34 nm respectively. The value of $\Delta\alpha$ is found to be 3.624^0 which is 3.45 times higher than 1.052^0. Thus it ca be concluded that addition of Si-layer improves the sensitivity of the proposed sensor by a factor of 3.45. The FWHM has been computed and found to be 16.20^0 in the presence of Si-layer. *For germanium*, it is observed that $\Delta\alpha$ attains maximum when thickness of Ge-layer and graphene are 3 nm and 0.34 nm respectively. The value of $\Delta\alpha$ is found to be 2.259^0 which is 2.15 times higher than 1.052^0. Thus it can be concluded that the addition of Ge-layer, enhances the sensitivity by a factor of 2.15. The FWHM has been computed and found to be 19.94^0 in the presence of Ge-layer.

From the above discussions, it is concluded that the InN based configuration has higher sensitivity in comparison to GaN, AlN, Si and Ge respectively by a factor of 1.025, 1.070, 1.060 and 1.710. Fig. 4 shows the variation of $\Delta\alpha$ with respect to graphene layers for all optimized thickness of semiconductor materials. The FWHM of InN based configuration is narrower in comparison to Si and Ge but little wider than GaN and AlN. So, detection accuracy (DA) for InN is higher than the Si and Ge but little less than GaN and AlN because DA of biosensor is determined from inverse of FWHM. The above findings are summarized in Table II. From Table II, it can be clearly seen that FOM of InN based configuration is higher than the Si and Ge but comparable to AlN and GaN. In order to determine superiority among wurtzite nitrides for active metal Au and for a specific application, the electric field intensity enhancement factor (FIEF) at the analyte interface have been examined.

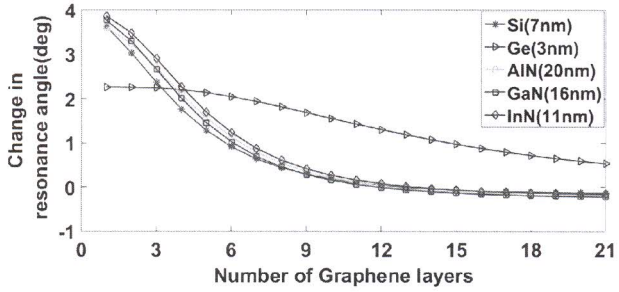

Fig. 4. Change in resonance angle as a function of thickness of graphene and Semiconductor layers.

The evanescent field produced at the analyte interface is responsible for the sensing process. Shalabney *et al.* pointed out that sensitivity can be increased by increasing the intensity of evanescent field in the analyte region [11]. A stronger evanescent field implies a larger sensing volume for monitoring biological interactions. The electric field intensity enhancement factor (FIEF) has been computed at analyte interface for each semiconductor. From Eq. (7) and (8), FIEF can be written as [37]

$$\left|\frac{E_{56}}{E_{12}}\right|^2 = \frac{n_1^2}{n_6^2}\left|\frac{H_{56}}{H_{12}}\right|^2 \tag{9}$$

E_{ij} and H_{ij} are fields at the interface of i^{th} and j^{th} layer. Fig. 5 shows the FIEF for various semiconductors as a function of angle for optimal thickness of metal and graphene layers. From Fig. 5, one can see that InN generates highest FIEF followed by GaN, AlN, Si and Ge. The propagation of electromagnetic wave in a material with complex refractive index ($n + ik$), is attenuated as a function of distance. The imaginary part (extinction co-efficient, k) is responsible for attenuation of the wave. Our simulation result shows that Si has higher FIEF than the Ge because the extinction coefficient of Si (0.0196) is smaller than the Ge (0.8162). This indicates that maximum FIEF arises for semiconductors having smaller k-value.

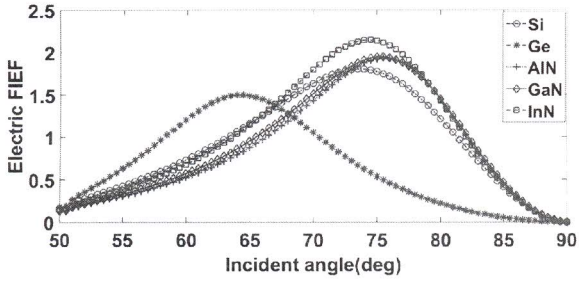

Fig. 5. Electric field intensity enhancement factor (FIEF) for different semiconductors chematic diagram of SPR Biosensor.

On the other hand, wurtzite nitrides have zero extinction co-efficient for 632.8 nm wavelength of light [34]. From Fig. 5 it can be seen that the highest FIEF is achieved for InN in comparison to AlN and GaN. This happens due to the fact that the real part of complex refractive index, n of InN (2.9000) is higher than GaN (2.3848) and AlN (2.1496) [17], [35]. Thus, for $k = 0$, higher field enhancement arises for semiconductors having higher n-value (when active layer is gold). From the Fig. 5, one can find that FIEF of InN is higher by a factor of 1.43, 1.19, 1.11 and 1.10 than Ge, Si, AlN and GaN respectively.

Again, it is pointed out that all computations have been performed for both BK7- and SF10- glass prism in this work. For BK7 glass prism, the highest change in resonance angle and highest FIEF are not found for a particular semiconductor material. However, for high refractive index SF10 glass prism, simulation result shows maximum $\Delta\alpha$ and highest FIEF for InN. Also, the current result for InN has been compared to our previous work [23]. Table III shows the comparison results.

From Table III, it is observed that the current value of $\Delta\alpha$ (i.e. 3.863^0) is 1.68 times greater than the previous reported result (i.e. $= 2.298^0$) and hence, sensitivity improves 1.68 times. The calculated FWHM, FOM and FIEF values are higher in comparison to the earlier reported [23]. Current FIEF is 1.22 times greater than the previous work [23]. On this basis, our study suggests that InN would be a better choice for active metal Au based graphene SPR biosensor for angle interrogation and imaging sensing method.

TABLE III
COMPARISON OF OPTIMIZED PARAMETERS FOR INDIUM NITRIDE BASED SPR BIOSENSOR

Parameters	Graphene-on-Au SPR configuration	Graphene-on-Cu SPR configuration [23]
Thickness of InN (nm)	11	13
Thickness of Graphene (nm)	0.34	0.34
$\Delta\alpha$ (deg.)	3.863	2.2980
FWHM (deg.)	14.79	20.770
FOM	52.23	22.128
FIEF	2.149	1.7660

V. CONCLUSION

In this work, a theoretical simulation has been performed to examine the effect of wurtzite nitride on overall performance of a graphene-on-gold SPR biosensor. The result shows that wurzite nitride enhances the sensitivity of the proposed biosensor in comparison to Si and Ge. This happens due to larger shift in resonance angle. In particular, addition of InN-layer shows highest angular shift and hence, sensitivity. Although, addition of AlN shows higher detection accuracy and GaN shows higher FOM in comparison to others. Our result shows that evanescent field enhancement factor is higher for InN followed by GaN, AlN, Si and Ge. Also, all performance parameters for InN are superior to our earlier SPR configuration [23]. This is attributed to the superior optical property of InN. This study suggests that, on the basis of high sensitivity and high FIEF, InN would be a better choice in comparison to other proposed semiconductors for a high sensitive imaging graphene-on-Au SPR biosensor. In addition, InN-layer can suppress the thermo-optic effects on sensitivity and it can be used for a variety of sensing applications. Hence, authors ensure that this study will drive the researchers to fabricate highly sensitive and accurate wurtzite nitride based SPR biosensor for biomedical applications.

ACKNOWLEDGMENT

This work was supported by the N.I.T Raipur under the fellowship scheme of Ministry of Human Research Development, India.

REFERENCES

[1] S. A. Maier, Plasmonics: Fundamental and Applications, New York: Springer, 2007.
[2] H. Reather, "Surface plasmons on smooth and rough surfaces and on gratings," Springer tracts in modern physics, vol. 111. Springer, Berlin Heidelberg, 1988.
[3] J. Homola, "Present and future of surface plasmon resonance biosensors," *Anal. Bioanal. Chem.*, vol. 377, no. 3, pp. 528 - 539, 2003.
[4] C. Nylander, C. B. Liedberg and T. Lind, "Gas detection by means of surface plasmons resonance," *Sens. Actuator*, vol. 3, pp. 79-88, 1982.
[5] H. H. Nguyen, J. Park, S. Kang, and M. Kim, "Surface plasmon resonance: a versatile technique for biosensor applications," *Sensors*, 15(5), pp.10481-10510, 2015
[6] Z. Zalevsky and I. Abdulhalim, Integrated nanophotonic devices, Second ed., Elsevier, 2014, p. 211.
[7] J. Homola, "Present and future of surface plasmon resonance biosensors," *Anal. Bioanal. Chem.* 377(3) 528 (2003)
[8] R. C. Jorgenson and S. S. Yee, "A fiber-optic chemical sensor based on surface plasmon resonance," *Sens. Actuator B: Chem.*, vol. 12, no. 3, pp. 213-220, 1993.
[9] B. Song, D. Li, W. P. Qi, M. Elstner, C. H. Fan, and H. P. Fang, "Graphene on Au(111): a highly conductive material with excellent adsorption properties for high-resolution bio/nanodetection and identification," ChemPhysChem 11(3), 585–589 (2010).
[10] S. Szunerits, N. Maalouli, E. Wijaya, J. P. Vilcot and R. Boukherroub, "Recent advances in the development of graphene-based surface plasmon resonance (SPR) interfaces," *Anal. Bioanal. Chem.*, vol. 405, no. 5, pp. 1435-1443, 2013.
[11] A. Shalabney and I. Abdulhalim, "Electromagnetic fields distribution in multilayer thin film structures and the origin of sensitivity enhancement in surface plasmon resonance sensors," *Sens. Actuator B: Chem.*, vol. 159, no. 1, pp. 24-32, 2010.

[12] O. Esteban, F. B. Naranjo, N. Diaz-Herrera, S. Valdueza-Felip, M. Navarrete and A. Gonzalez-Cano, "High-sensitive SPR sensing with indium nitride as a dielectric overlay of optical fibers," *Sens. Actuator B: Chem.,* vol. 158, no. 1, pp. 372-376, 2011.

[13] R. Verma, B. D. Gupta and R. Jha, "Sensitivity enhancement of a surface plasmon resonance based biomolecules sensor using graphene and silicon layers," *Sens. Actuator B: Chem.,* vol. 160, no. 1, pp. 623-631, 2011.

[14] L. Kai-Qun, W. Lai-Ming, Z. Dou-Guo, Z. Rong-Sheng, W. Pei, L. Yong-Hua and M. Hai, "Temperature effects on prism-based surface plasmon resonance sensor," *Chin. Phys. Lett.,* vol. 24, no. 11, p. 3081, 2007.

[15] H. P. Chiang, C. Chen, J. J. Wu, H. L. Li, T. Y. Lin, E. J. Sanchez and P. T. Leung, "Effects of temperature on the surface plasmon resonance at a metal semiconductor interface," *Thin Solid Films,* vol. 515, no. 17, pp. 6953-6961, 2007.

[16] H. P. Chiang, Y. C. Wang, P. T. Leung and W. S. Tse, "A theoretical model for the temperature-dependent sensitivity of the optical sensor based on surface plasmon resonance," *Opt. Commun.,* vol. 188, no. 5, pp. 283-289, 2001.

[17] J. Wu, "When group-III nitrides go infrared: new properties and perspectives," *J. Appl. Phys.,* vol. 106, no. 1, p. 011101, 2009.

[18] F. F. Lange, D. Kisailus, "III-V compound films using chemical deposition," U.S. Patent 6,770,131, 3 Aug 2004.

[19] Z. Yun, W. Gang, Y. Huai-Chao, A. Tie-Lei, C. Min-Jiang, Y. Fang, T. Li, Y. Jian-Kun, W. Tong-Bo, D. Rui-Fei and S. Lian-Feng, "Direct growth of graphene on gallium nitride by using chemical vapor deposition without extra catalyst," *Chin. Phys. B,* vol. 23, no. 9, p. 096802, 2014.

[20] M. Cooke, "III-V compound semiconductors from van der Waals epitaxy," *Semiconductor Today: Compounds & Advanced Silicon,* vol. 9, no. 8, pp. 94-99, 2014.

[21] S. A. Jewett, M. S. Makowski, B. Andrews, M. J. Manfra and A. Ivanisevic, "Gallium nitride is biocompatible and non-toxic before and after functionalization with peptides," *Acta. biomaterialia,* vol. 8, no. 2, pp. 728-733, 2012.

[22] G. Mohanty, J. Akhtar and B. K. Sahoo, "Effect of Semiconductor on Sensitivity of a Graphene-Based Surface Plasmon Resonance Biosensor," *Plasmonics,* vol. 11, no. 1, pp. 189-196, 2016.

[23] G. Mohanty and B. K. Sahoo, "III-V nitrides and performance of graphene on copper plasmonic biosensor," *Superlattices and Microstructures,* vol. 93, pp.226-233, 2016.

[24] A. Otto, "Excitation of nonradiative surface plasma waves in silver by the method of frustrated total reflection," *Z. Phys.,* vol. 216, p. 398, 1968.

[25] E. Kretschmann and H. Raether, "Radiative decay of non-radiative surface plasmons excited by light," *Z. Naturforsch,* vol. 23, p. 2135, 1968.

[26] W. N. Hansen, "Electric fields produced by the propagation of plane coherent electromagnetic radiation in a stratified medium," *J. Opt. Soc. Am.,* vol. 58, no. 3, pp. 380-388, 1968.

[27] M. Born and E. Wolf, Principles of optics: electromagnetic theory of propagation, interference and diffraction of light, Cambridge University Press, 2000.

[28] T. Zhan, X. Shi, Y. Dai, X. Liu and J. Zi, "Transfer matrix method for optics in graphene layers," *J. Phys. Condens. Matte,* vol. 25, no. 21, p. 215301, 2013.

[29] S. Elhadj, G. Singh and R. F. Saraf, "Optical properties of an immobilized DNA monolayer from 255 to 700 nm," *Langmuir,* vol. 20, no. 13, pp. 5539-5543, 2004.

[30] M. Yamamoto, "Surface Plasmon Resonance (SPR) Theory: Tutorial," *Rev. of Polarography*, vol. 48, pp. 209-237, 2002.

[31] A. G. Schott, "Optical glass data sheets," 2013 2016-05-04, http://refractiveindex.info.

[32] A. Zubrilov, M. E. Levinshtein, S. L. Rumyantsev and M. S. Shur, Properties of Advanced Semiconductor Materials GaN, AlN, InN, BN, SiC, SiGe, New York: John Wiley & Sons, Inc., 2001, pp. 49-66.P.

[33] D. E. Aspnes and A. A. Studna, "Dielectric functions and optical parameters of si, ge, gap, gaas, gasb, inp, inas, and insb from 1.5 to 6.0 ev.," *Phys. Rev. B,* vol. 27, no. 2, p. 985., 1983

[34] P. B. Johnson and R. W. Christy, "Optical Constants of the Noble Metals," *Phys. Rev. B,* vol. 6, pp. 4370-4379, 1972.

[35] M. Bruna and S. Borini, "Optical constants of graphene layers in the visible range," *Appl Phys. Lett.,* vol. 94, p. 031901, 2009.

[36] G. M. Hale and M. R. Querry, "Optical constants of water in the 200-nm to 200-μm wavelength region," *Appl. Opt.,* vol. 12, no. 3, pp. 555-563, 1973.

[37] B. H. Ong, X. Yuan and S. C. Tjin, "Optimised film thickness for maximum evanescent field enhancement of a bimetallic film surface plasmon resonance biosensor," *Sens. Actuator B: Chem.,* vol. 114, pp. 1028-1034, 2006.

Goutam Mohanty received his M.Sc (Physics) and M.Tech (Bioelectronics) from Sambalpur University, India and Tezpur Central University, India respectively. He is currently pursuing Ph.D degree in Physics at National Institute of Technology Raipur, India since 2012. His current research interests are focused on plasmonics, graphene biosensor, biophotonics and bioelectronics.

Bijay Ku. Sahoo received his Ph. D. degree from Utkal University, Odisha, India in 2005. He is working as an Assistant Professor in the Department of Physics at National Institute of Technology, Raipur, India since 2008. He has published more than 30 research paper in International and National Journals. He has delivered invited talks on iii-v nitrides and plasmonics in various international conferences held in Malaysia, Singapore, UK, and India His research interest includes iii-v nitride heterostructures and SPR biosensor.

Jamil Akhtar received his second Ph. D. degree from Jawaharlal Nehru University, New Delhi, India in 2008. He is currently working as Head and Chief Scientist in Sensor and Nano-Technology Group, CSIR-CEERI, Pilani, India. He is also working as a Professor in AcSIR, New Delhi, India. He has published more than 200 research papers in International and National Journals and conferences. He has delivered invited talks on sensors in various international conferences held in Abroad and India. He is expert member in various National and International bodies of S & T. His research interest includes Micro- and Nano-sensors and SPR biosensor.