Characteristics of high frequency powers through a chiral slab sandwiched between graphene layers

M. Y. NAZ[a,*], A. GHAFFAR[a], Y. KHAN[b], Q. A. NAQVI[c]
[a]*Department of Physics, University of Agriculture, Faisalabad, Pakistan*
[b]*College of Engineering, King Saud University, Saudi Arabia*
[c]*Department of Electronics, Quaid-i-Azam University, Islamabad, Pakistan*

A theoretical investigation has been carried out to find the reflection and transmission coefficient due to the interaction of electromagnetic waves with a chiral slab sandwiched between graphene layers. The reflection and transmission coefficients at graphene-chiral and chiral-graphene interfaces have been obtained analytically. Numerical results are presented to show the effect of the chirality, thickness of chiral slab and the normalized conductivity of graphene on the reflected and the transmitted powers.

(Received March 7, 2015; accepted March 19, 2015)

Keywords: Reflected power, Transmitted power, Absorbed power, Chiral, Graphene layer

1. Introduction

Considerable investigations is moving fast from many years with great pace on the microwave absorption materials due to the extended electromagnetic (EM) interference complications get up from the wide use of communication devices, such as telecommunications, local area network systems, and radar systems[1]. There are many types of metamaterial such as metallic magnetic, chiral, ferrites having specific optical properties which do not exist in natural material. One of the frontiers at which major conquests are being made is that of new materials like graphene. This material is excellent absorbing materials with extra quality of light weight and small thickness. Graphene is a single layer of carbon atoms display exceptional physical properties that make them superior candidates for microwave applications, namely high electrical conductivity, low density, and good stability.

In recent years, graphene have attained a lot of attention including electrodynamic properties [2-4]. Many researchers carried out research on frequency dependence conductivity and excitations of the graphene layer plasmons successfully [5-7]. These studies showed that both TE- and TM- polarized plasmons can exist in graphene [8]. It has also been noticed that the special spectrum of the charge carriers leads to a number of interesting transport properties such as high charge carrier mobility, electronic energy spectrum without a gap between the conduction and valence bands, and frequency dependent absorption of EM radiation. Graphene have potential applications in optoelectronics [9-11] and development of bioelectric sensory devices, to measure glucose levels, hemoglobin levels, cholesterol due to its lower resistivity and high conductivity [12, 13].

In the electrical metamaterial´s engineering it is advisable to scheme some tools for adjusting their electromagnetic features, thus achieving the tuneability [13]. These tunable metamaterials permit for endless variation of their properties through different influences. Many researchers carried out the research on electromagnetic interaction with graphene[14, 15]. Recently, the possibility of control of the hybrid surface waves in graphene placed between two dielectrics by applying an external magnetic field [16] and the waveguide properties of the sandwich structure graphene-dielectric graphene have been studied[17]. Reflection and transmission of electromagnetic waves by the graphene layer and graphene super lattice have been investigated in details [16, 18].

However, as an outcome of very concentrated researches of graphene placed in between different medium it has been found that more complex properties of graphene-based structures can find many more probable applications with more complex materials. Interaction of electromagnetic waves through chiral slab sandwiched between graphene layer to be of great interest and practical importance because this consideration may be expected to play a role in the development of diagnostic tool for remote sensing, in the design of electromagnetic shield and in the prediction of structural deformation.

In this paper we derived the reflection and transmission coefficients at graphene- chiral and graphene-chiral interfaces. We will treat the interaction of electromagnetic wave to infinite chiral slab [19-21] sandwiched in between graphene layer. The numerical computation has been carried out to reflectance, transmittance and absorption for different values of chirality parameters, thickness of the slab and normalized conductivity of graphene. The time-harmonic $(i\omega t)$ dependence is adopted and suppressed in what follows.

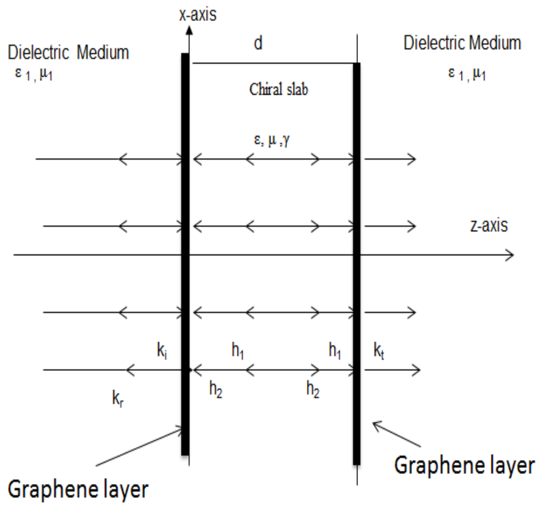

Fig. 1. Geometry of chiral slab placed between graphene layers.

2. Formulations

Consider a chiral slab of uniform thickness d sandwiched between graphene layers on both sides as shown in Fig. 1. This geometry of chiral slab is sandwiched between two graphene layer at $z = 0$ and $z = d$, and lies between two dielectric medium of the similar constitutive parameters. Suppose a monochromatic electromagnetic wave polarized in the x-axis normally incident upon interface $z = 0$ from the zone $z \leq 0$. The Constitutive relation for the EM-waves interaction with chiral medium the relations which involve the coupled nature of both electric and magnetic fields [20]

$$\boldsymbol{D} = \epsilon \boldsymbol{E} - i\gamma\sqrt{\epsilon_0\mu_0}\boldsymbol{H} \tag{1}$$

$$\boldsymbol{B} = \mu \boldsymbol{H} + i\gamma\sqrt{\epsilon_0\mu_0}\boldsymbol{E} \tag{2}$$

These relations are related to time-harmonic varying fields when EM-waves propagated in chiral medium. Where, γ is the positive chirality factor and ϵ, μ are the permittivity and permeability of the chiral medium. Two distinct waves propagate in a chiral medium a left circularly polarized wave (LCP) and right circularly polarized wave (RCP) with a wave numbers

$$h_1 = \omega\sqrt{\epsilon_0\mu_0}(\sqrt{\epsilon_r\mu_r} - \gamma) \tag{3}$$

$$h_2 = \omega\sqrt{\epsilon_0\mu_0}(\sqrt{\epsilon_r\mu_r} + \gamma) \tag{4}$$

The appropriate form to express the fields in zone $z \leq 0$ is represented by the following fields

$$\boldsymbol{E_{0i}} = E_i\hat{e}_x \exp(jk_i z) \tag{5}$$

$$\boldsymbol{H_{0i}} = \eta_1^{-1}E_i\hat{e}_y \exp(jk_i z) \tag{6}$$

where $\eta_1 = \sqrt{\mu_1/\epsilon_1}$ and the reflected electric and magnetic fields are

$$\boldsymbol{E_{0r}} = E_r\hat{e}_x \exp(-jk_i z) \tag{7}$$

$$\boldsymbol{H_{0r}} = -\eta_1^{-1}E_r\hat{e}_y \exp(-jk_i z) \tag{8}$$

There are four waves propagating into the chiral slab, two of them propagate towards the interface $z = d$ and the other two propagates towards the interface $z = 0$. The amplitudes of the electric fields linked with the right and left circularly transmitted polarized wave are E_1^+ and E_2^+ respectively. The electric and magnetic fields of the two waves that propagating towards the interface $z = d$ inside the chiral slab can be written as

$$\boldsymbol{H}^+ = -jZ^{-1}E_1^+(\hat{e}_x + j\hat{e}_y)\exp(jh_1 z) + jZ^{-1}E_2^+(\hat{e}_x - j\hat{e}_y)\exp(jh_2 z) \tag{9}$$

$$\boldsymbol{E}^+ = E_1^+(\hat{e}_x + j\hat{e}_y)\exp(jh_1 z) + E_2^+(\hat{e}_x - j\hat{e}_y)\exp(jh_2 z) \tag{10}$$

The electric and magnetic fields of the other two waves that propagating towards the interface $z = 0$ inside the can be written as

$$\boldsymbol{H}^- = jZ^{-1}E_1^-(\hat{e}_x - j\hat{e}_y)\exp(-jh_1 z) + jZ^{-1}E_2^-(-\hat{e}_x - j\hat{e}_y)\exp(-jh_2 z) \tag{11}$$

$$\boldsymbol{E_1^-} = E_1^-(-\hat{e}_x + j\hat{e}_y)\exp(-jh_1 z) + E_2^-(-\hat{e}_x - j\hat{e}_y)\exp(-jh_2 z) \tag{12}$$

where $Z = \sqrt{\frac{\mu_1\epsilon}{\mu\epsilon_1} + \frac{\mu_1}{\epsilon_1}\gamma^2}$ is the wave impedance of the chiral slab. Let the polarization, amplitude of electric field, frequency and the direction of propagation of the incident wave are known. The electric and magnetic fields of the two waves that transmitting through the chiral slab at $z = d$, total transmitted field from graphene chiral interface can be written as

$$\boldsymbol{E_{0t}} = E_t\hat{e}_x \exp(jk_t z) \tag{13}$$

$$\boldsymbol{H_{0t}} = \eta_1^{-1}E_t\hat{e}_y \exp(jk_t z) \tag{14}$$

where $k_t = k_i$. By using the boundary conditions at $x = 0$ and $z = 0$

$$(\boldsymbol{E_i} + \boldsymbol{E_r}) \times \hat{e}_z = (\boldsymbol{E}^+ + \boldsymbol{E}^-) \times \hat{e}_z \tag{15}$$

$$(\boldsymbol{H_i} + \boldsymbol{H_r}) \times \hat{e}_z = (\boldsymbol{H}^+ + \boldsymbol{H}^-) \times \hat{e}_z + \frac{4\pi\boldsymbol{J}^+}{c} + \frac{4\pi\boldsymbol{J}^-}{c} \tag{16}$$

By using the boundary conditions at $x = 0$ and $z = d$

$$(\boldsymbol{E}^+ + \boldsymbol{E}^-) \times \hat{e}_z = \boldsymbol{E_t} \times \hat{e}_z \tag{17}$$

$$(\boldsymbol{H}^+ + \boldsymbol{H}^-) \times \hat{e}_z + 4\pi\boldsymbol{J}^+/c + 4\pi\boldsymbol{J}^-/c = \boldsymbol{H_t} \times \hat{e}_z \tag{18}$$

Now the continuity equation is reads as

$$\rho = j_x(\omega)k_x/\omega \tag{19}$$

and Ohm's law is written a

$$j^{\pm}{}_x(\omega) = \sigma(\omega)E^{\pm}{}_x = \sigma_g(\omega)E^{\pm} \tag{20}$$

where σ_g is the graphene conductivity and is defined as[14]

$$\sigma_g = \sigma_1{}' + j\sigma_1{}'' + \sigma_D \tag{21}$$

Where

$$\sigma_1{}' = \sigma_0(1 + \frac{1}{\pi}\tan^{-1}\frac{\hbar\omega - 2E_F}{\hbar\Gamma} - \frac{1}{\pi}\tan^{-1}\frac{\hbar\omega + 2E_F}{\hbar\Gamma} -)$$
$$\sigma_1{}'' = \sigma_0\frac{1}{\pi}\ln\frac{(2E_F+\hbar\omega)^2+\hbar^2\Gamma^2}{(2E_F-\hbar\omega)^2+\hbar^2\Gamma^2}$$
$$\sigma_D = \sigma_0\frac{4E_F}{\pi}\ln\frac{1}{\hbar\Gamma - j\hbar\omega}$$

Where $\sigma_0 = \pi e^2/2\hbar$ the universal conductivity of graphene is, Γ is the inverse of the momentum relaxation time and $E_F > 0$ is the Fermi level position with respect to the Dirac point. By using above boundary conditions we arrive at the following result, valid for normal incidence, for the reflectivity

$$R = \frac{\left|c(-2+e^{2id}+e^{2idh2}+2g-2e^{id(h_1+h_2)}g)-8(-1+e^{id(h_1+h_2)})\pi\eta_1\sigma_g\right|^2}{\left|c(e^{2idh_1}+e^{2idh_2}+2e^{id(h_1+h_2)}g-2(1+g))+8(-1+e^{id(h_1+h_2)})\pi\eta_1\sigma_g\right|^2} \tag{22}$$

The transmitivity is also obtained for normal incidence as

$$T = \frac{\left|2e^{id\mathrm{ki}}(-e^{idh_1}-e^{idh_2}+e^{id(2h_1+h_2)}+e^{id(h_1+2h_2)})(cg-4\pi\eta_1\sigma_g)\right|^2}{\left|c(e^{2idh_1}+e^{2idh_2}+2e^{id(h_1+h_2)}g-2(1+g))+8(-1+e^{id(h_1+h_2)})\pi\eta_1\sigma_g\right|^2} \tag{23}$$

3. Numerical results and discussion

In this section, the above procedure is applied in calculating properties of reflected and transmitted powers for the fields in the chiral slab of thickness d sandwiched between graphene layers from both sides placed in dielectric medium. It is assumed that $\mu = \mu_1 = \mu_0$. The Fig. 2(a) –(c) show the reflectance, transmittance and absorption as function of the frequency at $d = 100\ \mu m$ (thick solid line) $d = 75\ \mu m$ (dashed line) $d = 50\ \mu m$ (dotted line) and $d = 25\ \mu m$ (solid line) at $\Gamma = 2.3$meV, $E_F = 10eV$, $\epsilon_r = 1.5$ and $\gamma = 0.9$. It is found from calculation that the value of reflectance and absorption increases as frequency and thickness increases. It is also observed that with the increase in the thickness of chiral slab and frequency the value of the transmittance decreases.

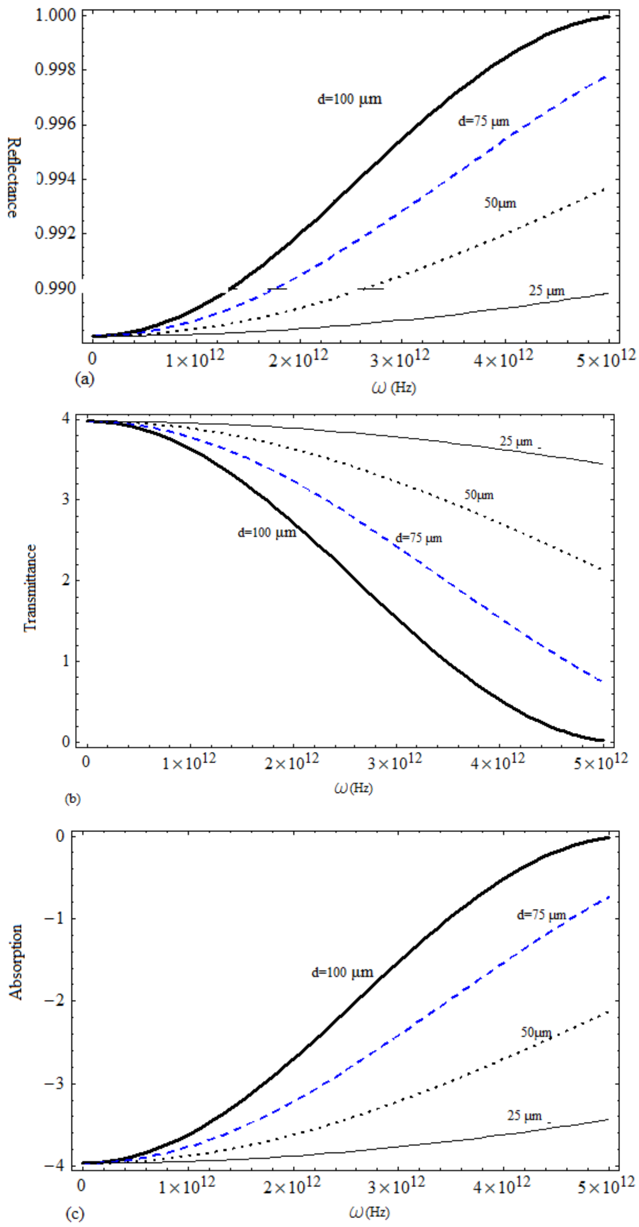

Fig. 2. The comparison of (a) reflectance (b) transmittance and (c) absorptance of chiral slab sandwiched between graphene layers versus frequency for different thickness of slab.

The Fig. 3(a) –(c) show the reflectance, transmittance and absorption as function of the frequency at $\gamma = 0.9$ (thick solid line) $\gamma = 0.8$ (dashed line) $\gamma = 0.7$ (dotted line) and $\gamma = 0.6$ solid line) at $\Gamma = 2.3$meV, $E_F = 10eV$, $\epsilon_r = 1.5$ and $d = 100\ \mu m$. It is observed from calculation that the value of reflectance and absorption increases as frequency and chirality parameter increases. It is also highly noticed that with the minor increase in value of the chirality parameter causes the transmittance power to decreases. The Fig. 4(a) –(c) show the reflectance, transmittance and absorption as function of the normalized conductivity of graphene at different values of chirality parameter $\gamma = 0.0100$ (thick solid line) $\gamma = 0.0101$ (dashed line) $\gamma = 0.0103$ (dotted line) and $\gamma =$

0.0101 solid line) at $\Gamma = 2.3\text{meV}$, $E_F = 10eV$, $\epsilon_r = 1.5$ and $d = 100\ \mu m$. It is observed from calculation that the value of transmittance increases more sharply as compare reflectance whereas absorption decreases. It is also highly noticed that with the minor increase in value of the chirality parameter transmittance increases. The effect of graphene layers on the electromagnetic properties of the structure is more evident as the conductivity of graphene decreases that lead to increase in absorptance.

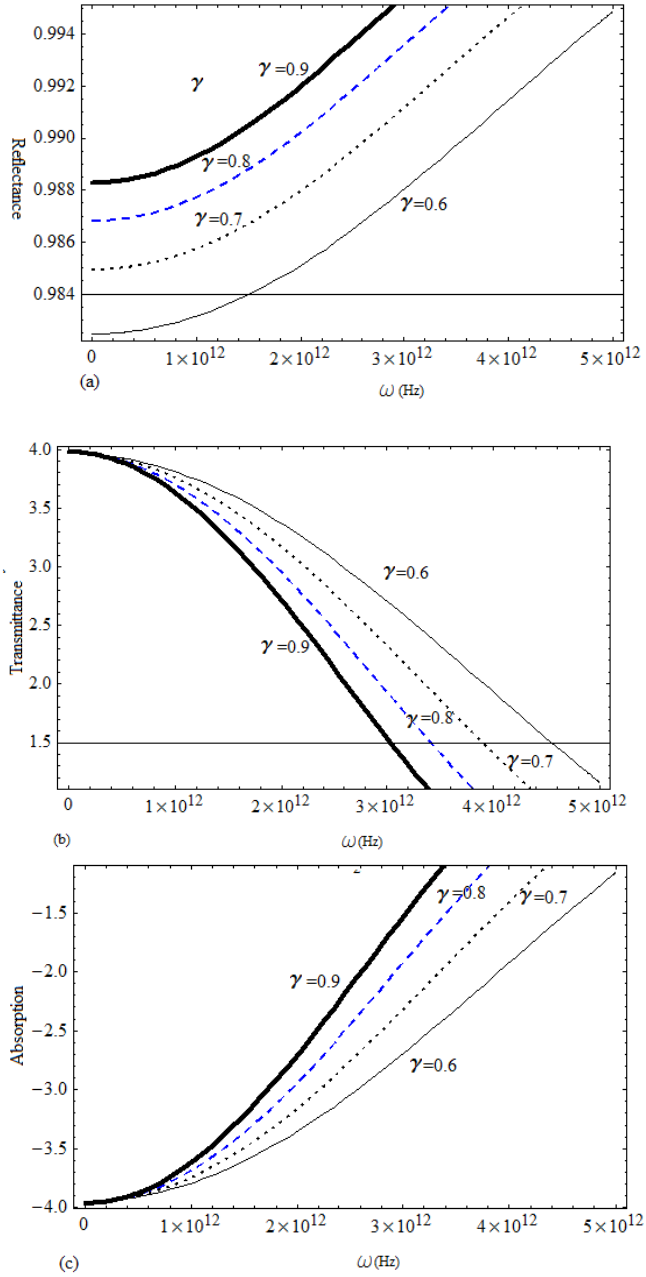

Fig. 3. The comparison of (a) reflectance (b) transmittance and (c) absorptance of chiral slab sandwiched between graphene layers versus frequency for different thickness of values of chirality.

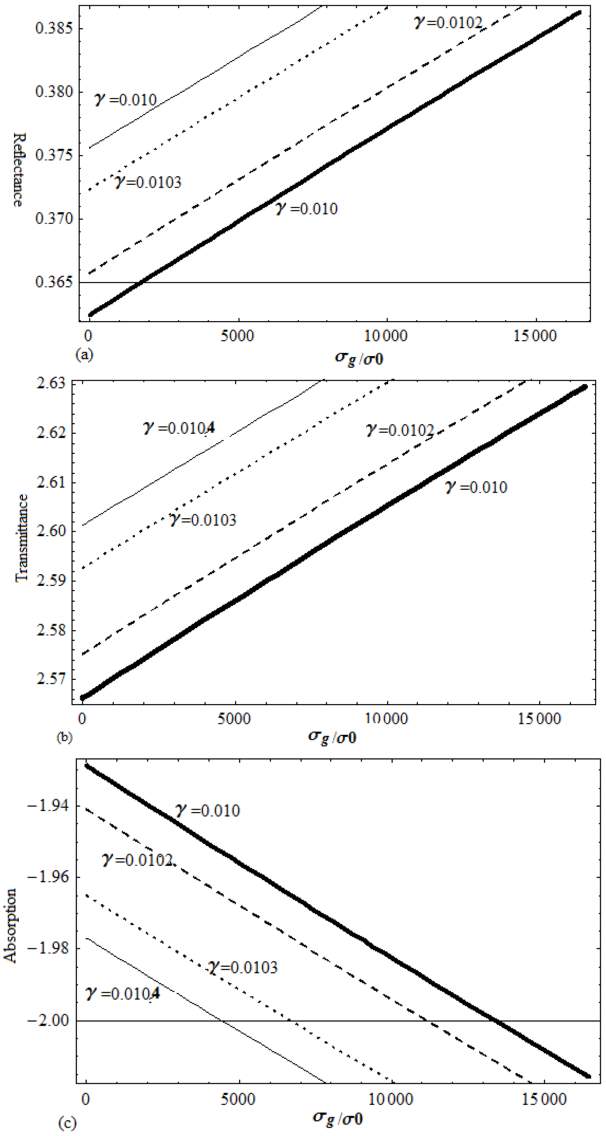

Fig. 4. The comparison of reflection coefficient R_{21} verses angle of incidence θ_2 at $\gamma = 0.0001$ (solid line), $\gamma = 0.001$(dot line), $\gamma = 0.01$(large dashed line) and $\gamma = 0.1$(thick line).

4. Conclusion

In this research the properties of reflection and transmission coefficients of chiral slab sandwiched between graphene layers are obtained analytically using boundary conditions. Numerical results for the reflectivity, transmitivity and absorptivity are presented for various values of chirality parameters, slab thickness and effect of conductivity of graphene so that the behavior of wave propagation from graphene to chiral medium and chiral medium to graphene can be clarified. The effects of change in the chirality parameter slab thickness and effect of conductivity of graphene are numerically computed. From these results we have concluded that strength of the reflectivity, transmitivity and absorptivity may be control from chirality parameters and conductivity of graphene. Through the results presented here may be have potential applications for the design of optical devices in the visible frequency range.

Acknowledgment

The authors would like to extend their sincere appreciation to the Deanship of Scientific Research (DSR) at King Saud University for its funding of this research through the Research Group Project no RG-1436-012.

References

[1] G. Wang, Z. Gao, G. Wan, S. Lin, P. Yang, Y. Qin, 2014.
[2] V. Gusynin, S. Sharapov, J. Carbotte, Physical Review Letters, **98**, 157402 (2007).
[3] F. H. Koppens, D. E. Chang, F. J. Garcia de Abajo, Nano letters, **11**, 3370 (2011).
[4] R. Nair, P. Blake, A. Grigorenko, K. Novoselov, T. Booth, T. Stauber, N. Peres, A. Geim, Science, **320**, 1308 (2008).
[5] S. Mikhailov, K. Ziegler, Physical Review Letters, **99**, 016803 (2007).
[6] S. D. Sarma, E. Hwang, W.-K. Tse, Physical Review B, **75**, 121406 (2007).
[7] K. Ziegler, Physical Review Letters, **97**, 266802 (2006).
[8] N. Peres, E. V. Castro, Journal of Physics: Condensed Matter, **19**, 406231 (2007).
[9] W. Hua-Qiang, L. Chang-Yang, L. Hong-Ming, Q. He, Chinese Physics B, **22**, 098106 (2013).
[10] G. Dash, S. R. Pattanaik, S. Behera.
[11] F. Kusmartsev, W. Wu, M. Pierpoint, K. Yung, Applied Spectroscopy and the Science of Nanomaterials, ed: Springer, 2015, pp. 191-221.
[12] T. Kuila, S. Bose, P. Khanra, A. K. Mishra, N. H. Kim, J. H. Lee, Biosensors and Bioelectronics, **26**, 4637 (2011).
[13] H. Y. Mao, S. Laurent, W. Chen, O. Akhavan, M. Imani, A. A. Ashkarran, M. Mahmoudi, Chemical reviews, **113**, 3407 (2013).
[14] T. Stauber, N. Peres, A. Geim, Physical Review B, **78**, 085432 (2008).
[15] Q. Bao, H. Zhang, B. Wang, Z. Ni, C. H. Y. X. Lim, Y. Wang, D. Y. Tang, K. P. Loh, Nature photonics, **5,** 411 (2011).
[16] D. A. Kuzmin, I. V. Bychkov, V. G. Shavrov, Photonics and Nanostructures-Fundamentals and Applications, **12**, 473 (2014).
[17] D. A. Kuzmin, I. V. Bychkov, V. G. Shavrov, Optics Letters, **40**, 890 (2015).
[18] J. Nilsson, A. C. Neto, F. Guinea, N. Peres, Physical Review B, **76**, 165416 (2007).
[19] S. Bassiri, C. Papas, N. Engheta, JOSA A, **5**, 1450 (1988).
[20] A. J. Viitanen,P. Puska, Microwaves, Antennas and Propagation, IEE Proceedings, 1998, pp. 299-302.
[21] A. Ghaffar, M. Arif, Q. A. Naqvi, M. A. Alkanhal, Optik-International Journal for Light and Electron Optics, **125**, 1589 (2014).

*Corresponding author: yasin306@uaf.edu.pk