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Broadening of Omnidirectional Photonic Band Gap in Graphene Based one Dimensional Photonic Crystals

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Abstract*—A simple design of one dimensional gradual stacked photonic crystal has been proposed. This structure exhibits a periodic array of alternate layers of Graphene and Silica. These are the materials of low and high refractive indices respectively. Here the structure considered has three stacks .Each stack has five alternate layers of Graphene and silica. The transfer matrix method has been used for numerical computation. In this paper, such a structure has wider reflection bands in comparison to a conventional dielectric PC structure and structure with Sio_2 and Si layers for a constant gradual constant ϒ at different incident angle.*

Keywords*—Photonic crystal; Graphene; transfer matrix; gradual costant.*

I. INTRODUCTION

Photonic crystals are periodic optical nanostructures that affect the motion of photons in much the same way that ionic lattices affect electrons in solids. Photonic crystals occur in nature in the form of structural coloration and promise to be useful in different forms in a range of applications.

Photonic crystals are composed of periodic dielectric, metallic-dielectric or even superconductor microstructures or nanostructures that affect the propagation of electromagnetic waves (EM) in the same way as the periodic potential in a semiconductor crystal affects the electron motion by defining allowed and forbidden electronic energy bands. Photonic crystals contain regularly repeating regions of high and low dielectric constant. Photons (behaving as waves) propagate through this structure – or not – depending on their wavelength. Wavelengths that are allowed to travel are known as modes; groups of allowed modes form bands. Disallowed bands of wavelengths are called photonic band gaps. This gives rise to distinct optical phenomena such as inhibition of spontaneous emission, high-reflecting Omni-directional mirrors and low-loss-wave guiding.

Here we are considering the graded material .the physical properties of the graded materials are different from both homogeneous and conventional materials .In general graded photonic crystal have a variation either in the refractive indices of the alternate layers or a variation in thickness.

This structure consist a periodic array of alternate layers of Graphene and Silica. These are the materials of low and high refractive indices respectively. Here the structure considered has three stacks .Each stack has five alternate layers of Graphene and silica.

Light absorption in thin films has always been a relevant topic in optics, especially from the application point of view. Graphene is in many ways the ultimate thin film, only one atomic layer thick, and has photonic properties of high interest for optoelectronic applications [1].besides this grapheme has a larger refractive index with excellent mechanical and thermal properties.

II. THEORY

The one-dimensional GSPC structure has been considered along x axis. It consists of alternate layers ofhigh and low refractive indices.The assembly is placed betweensemi-infinite media of refractive indices n_i (refractive index of the incident medium) and n_s (refractive index of the substrate), as shown in Figure 1.

By applying TMM, the characteristic matrices for the TE and TM waves is given by

$$M_j=\begin{bmatrix} cos\beta j & -\frac{isin\beta j}{qj} \\ -iqjsin\beta j & cos\beta j \end{bmatrix} \quad (1)$$

Where $q_j = n_j cos\theta_j$, (j = 1, 2; for the first and the second layers of theunit cell respectively) for the TE polarization and $q_j = cos\theta_j/n_j$ for the TM polarization, $\beta_j = (2\pi/\lambda)n_j d_j cos\theta_j$, θ_j is the ray angle insidethe layer of refractive index n_j and λ is the wavelength in the mediumof incidence. The total characteristic matrix for the N periods of thestructure can be expressed as

$$M = (M_1 \times M_2)^N = \begin{bmatrix} M11 & M12 \\ M21 & M22 \end{bmatrix} \qquad (2)$$

The reflection coefficient of the structure for TE and TM polarizations are given by

$$r = \frac{(M11 + qsM12)qi - (M21 + qsM22)}{(M11 + qsM12)qi + (M21 + qsM22)} \qquad (3)$$

where $q_{i,s} = n_{i,s} cos\theta_{j,s}$for TE wave and $q_{i,s} = cos\theta_{j,s}/ n_{i,s}$for TM wave, where the subscripts i and s belongs to the quantities in the incident medium and substrate respectively. Whereas, the reflectivity of the structure can be expressed as

$$R = |r|^2 \qquad (4)$$

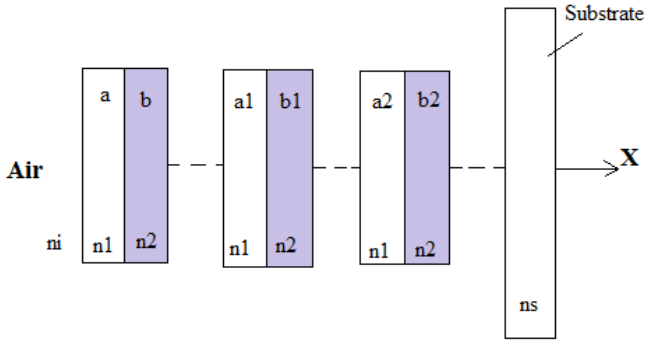

Fig 1. Schematic representation of GSPC structure

In one-dimensional PCs, there is no absolute photonic band gap (PBG) because of two factors. The first is as we increase the incident angle, the edges of PBG in certain direction will shift towards the higher frequency side .The second is that at the TM mode cannot be reflected at the Brewster angle. However, the absence of an absolute PBG does not mean that there is no Omni-directional reflection. There should no propagating modes that can couple with the incident wave this is the criterion for the existence of total Omni-directional reflection. From Snell's law,

We know $n_i \sin\theta_i = n_1 \sin\theta_1$ and $n_1 \sin\theta_1 = n_2 \sin\theta_2$

i.e., $\theta_1 = \sin^{-1}(n_i \sin\theta_i/n_1)$ and $\theta_2 = \sin^{-1}(n_1 \sin\theta_1/n_2)$

Where n_1 and n_2 are the refractive indices of the low and high index media respectively and n_i is the refractive index of the incident medium. The maximumrefracted angle is defined as $\theta_{max2} = \sin^{-1}(n_i / n_2)$ and Brewster angles $\theta_B = \tan^{-1}(n_1 \sin\theta/ n_2)$. If the maximum refracted angle is smaller than the Brewster's angle then the incident wave from outside cannot couple to Brewster's window which results to total reflection for all incident angles. Thus, the condition for Omni-directional reflection without the influence of the Brewster's angle is $\theta_B = \theta_{max2}$ [23]. This condition is satisfied by the selected parameters that we have taken for our numerical computations. Hence, in the present analysis there is noinfluence of Brewster's angle on the Omni-directional reflection bands.

III. Result & Discussion

From the computation of Equation (3), the reflection properties of one-dimensional GSPC can be represented graphically. For this purpose, we consider a GSPC structure having the following sequence — air/(AB)5/(A1B1)5/(A2B2)5/ Substrate(SiO2). For AB stack, we choose the material of layer A as Grephene and the material of layer B as Si having refractive indices 2.1 and 3.7 respectively. Here all the regions are assumed to be linear, homogeneous and non-absorbing. Also, the refractive indices of both the materials are considered to be constant. The thickness of the layers are taken as a = 283nm and b = 115 nm according to the quarter wave stack condition $a = \lambda_C/4n_1$ and $b = \lambda_C /4n_2$, where λ_C (= 1700 nm) is the critical wavelength which is the mid-wavelength of the wavelength range considered in our numerical computation. For A_1B_1 stack, we choose the material of layer A_1 as Grephene and the material of layer B_1 as Si in which the thicknesses of the layers A_1 and B_1 are taken as $a_1 = \Upsilon a$ and $b1 = \Upsilon b$ respectively, where Υ is defined as gradual constant. In a similar way, we choose the material of layer A_2 as Grephene and the material of layer B_2 as Si in which the thicknesses of layers A_2 and B_2 are taken as $a_2 = \Upsilon\, a_1$ and $b_2 = \Upsilon\, b_1$ respectively. The reflectance spectra for conventional PC can be obtained by choosing $\Upsilon = 1$ in this structure.

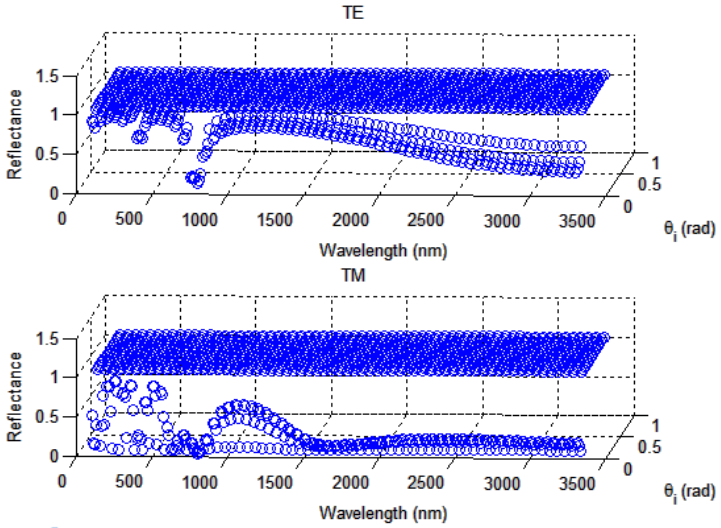

Fig 2. Reflectance spectra of SiO2/Si one-dimensional PC (ϒ = 1)for TE and TM polarizations.

We observe from Table that the TE polarization has its Omni- directional reflection range from 1289 nm to 2210 nm and the Omni- directional reflection range for the TM polarization from 1289 nm to 1929 nm. Therefore, the total ODR for both TE and TM polarizations when ϒ = 1, i.e., for the case of conventional PC, has the bandwidth ($\Delta\lambda = \lambda_H - \lambda_L$) of 640 nm. The upper wavelength edge of the ODR band is λ_H = 1929 nm and the lower wavelength edge is λ_L = 1289 nm. Hence, the normalized Omni-directional bandwidth is 37.65% of the total wavelength range considered around the critical wavelength λ_C = 1700 nm.

TABLE 1. Total reflection region and gap width for SiO2/Si one- dimensional PC (ϒ = 1).

Angle of incidence θ_i (degree)	**TE polarization**		**TM polarization**	
	Reflection range (nm)	**Gap width(nm)**	**Reflection range (nm)**	**Gap width(nm)**
0	1289–2342	1053	1289–2342	1053
30	1252–2379	1127	1298–2284	986
60	1210–2302	1092	1192–1971	779
85	1117–2210	1093	1197–1929	732

IV. CONCLUSION

To summarize, we have investigated theoretically the ODR range of one-dimensional GSPC structure. It is found that the ODR range of GSPC structure can be enhanced by changing the material si by Graphene with constant the value of gradual constant and that the ODR range for one-dimensional GSPC structure is more than that of conventional PC and simple graded structure. Hence, a one-dimensional GSPC structure can be used as a broadband optical reflector, and the range of reflection can be tuned to a desired wavelength region by changing the material by Graphene and also by choosing proper thickness of the period (d) of first stack and relative thicknesses of individual layers of the following stacks. These types of optical reflectors are compact in size and may have potential applications in the field of optical technology and optoelectronics.

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