International Journal of Engineering Sciences Paradigms and Researches (IJESPR)
Vol. 48, Special Issue, (TAME-2019, April 4-5, 2019)
(An Indexed, Referred and Impact Factor Journal approved by UGC- Journal No. 42581)
ISSN (Online): 2319-6564
www.ijesonline.com

OMNIDIRECTIONAL REFLECTION BAND IN MULTILAYERED POROUS SILICON (P-SI) BASEDPHOTONIC CRYSTAL STRUCTURE NANOSTRUCTURES

Vinod Chacko[1], Harshul Mahendroo[2], Dr.Sonia Bansal[3]

[123] Department of Humanities and Applied Sciences, JC Bose University of Science and Technology YMCA, Faridabad, Haryana, India
Email:[1]vinodchackophy@gmail.com

Abstract
It is well known that under certain conditions, one dimensional photonic crystal (1D-PC) displays total Omni-directional reflection (ODR) band gaps. The enhancement of total Omni-directional reflection band gap in 1D-PC is calculated theoretically using Transfer Matrix Method (TMM) and Bloch theorem, the reflectivity of one dimensional periodic structure for TE and TM mode at different angles of incidence has been calculated. We have observed an enhanced Omni-directional reflection (ODR) in the visible range from (576 nm-811 nm) in multilayered structures of nano porous Silicon (p-Si) and Tellurium (Te). The proposed structure can be used as wavelength filters for image sensing applications and other optoelectronic devices.

1.Introduction

Photonic crystals (PCs), characterized by electromagnetic forbidden bands or photonic band gaps (PBGs), are regular arrays of materials with different refractive indices. In other words, the propagation of electromagnetic waves, whose frequencies lie within the PBGs, is prohibited. Since the concept of was first proposed in 1984 [1,2],PCs have been a hot research topic and have attracted intensive attention [3-13]. PCs are classified mainly into three categories according to the dimensionality of the stack: one dimensional (1D), two dimensional (2D), and three dimensional (3D). PCs that work in microwave and far-infrared regions are relatively easier to fabricate. However, PCsthat work in visible and the infrared (IR)regions, especially, 3D PCs are difficult to fabricate because of their small lattice constants, which have to comparable to the wavelength[14]. Therefore ,1D PCs, which can easily be produced by the thin film deposition techniques , are preferable for use in the visible and IR regions. 1D PCs have a wide variety of applications. For instance, 1D PCs based on dielectric multilayer can be used as planar `antennae, in which complete reflectance at desired frequencies is achieved , due to PBGs; thus , the emission efficiency is greatly enhanced compared with ordinary planar antennas whose metallic substrates absorb much energy. Another application is the vertical cavity surface-emitting laser (VCSEL) [15],which has been recognized as an important light source for parallel optielectronic systems. Fink et al.have shown theoretically [16] and experimentally [17] that omni-directional PBGs can be obtained for both transverse- electric (TE) and transverse-magnetic (TM) polarizations within a IDPC. It offers the possibility of controlling the propagation of light in 1DPCs with a simple structure of multilayers , even for arbitrary incidence.

Porous silicon is a form of the chemical element silicon that has introduced nanoporous holes in its microstructure, rendering a large surface to volume ratio in the order of 500 m^2/cm^3. This work reports the reflectivity of multilayers composed of Nanoporous Silicon and Tethin films as a 1D PCs .

2. Theoretical Analysis

To calculate the dispersion relation and reflection characteristics forthe incident electromagnetic wave, the Maxwell's equation is solvednumerically by the transfer matrix method [19]

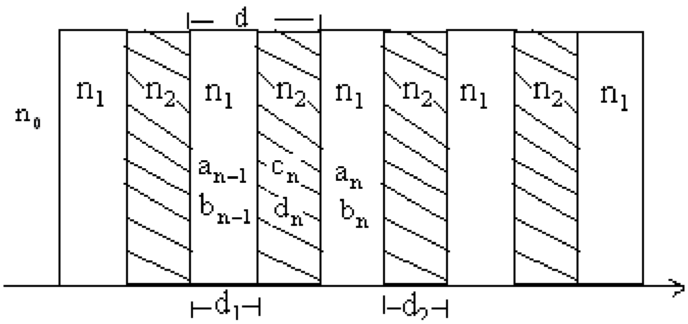


***Fig 1.** Periodic refractive index profile of the structure havingrefractive indices $n_1$and $n_2$respectively.*

The geometry of the structure under study is shown in the Fig. 1.Consider the propagation of EM wave along x-axis normal to the interface in one-dimensional system composed of periodic arrays of two different materials with a refractive index $n_1$and $n_2$and layer thickness $d_1$and d_2. The indices of refraction of the system are given as,

$$n(x) = \begin{cases} n_1, & 0 < x < d_1 \\ n_2, & d_1 < x < d_2 \end{cases} \text{ with } n(x) = n(x + d). \quad (1)$$

where $d_1$and $d_2$are the thicknesses of the layers and $d = d_1+d_2$is the period of the structure. The electromagnetic field distribution with in each layer can be expressed as the sum of right- and left-hand side propagating wave. The electric field within the both layers of the nth unit cell can be written as

$$E_1(x) = \left[\left(a_n e^{-ik_1(x-nd)}\right) + b_n e^{ik_1(x-nd)}\right] e^{i\omega t} \quad (2)$$

$$E_2(x) = \left[\left(c_n e^{-ik_2(x-nd)}\right) + d_n e^{ik_2(x-nd)}\right] e^{i\omega t} \quad (3)$$

Where $k_i = \left[\left(\frac{n_i\,\omega}{c}\right)^2 - \beta^2\right]^{\frac{1}{2}} = \frac{n_i\omega}{c}\cos\theta_i$;$\theta_i$is the ray angle in the i^{th}layer ($i = 1, 2$), β is the propagation constant and $n_i$is the refractive index of the constituent layers. The coefficients a_n, b_n, c_n, and $d_n$are related through the continuity boundary conditions at the interfaces.

This continuity condition leads to the matrix equations, which relates the coefficient in the first layer of the n^{th} cell, is given as

$$\begin{pmatrix} a_{n-1} \\ b_{n-1} \end{pmatrix} = T_n \begin{pmatrix} a_n \\ b_n \end{pmatrix} \quad (4)$$

where $T_n$is called the transfer matrix given by

$$T_n = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \quad (5)$$

The matrix elements A,B,C and D are

$$A = e^{ik_1 d_1}\left[\cos k_2 d_2 + \frac{1}{2} i\left(\eta + {}^{1}/_{\eta}\right)\sin k_2 d_2\right] \quad (6)$$

$$B = e^{-ik_1 d_1}\left[\frac{1}{2} i\left(\eta - {}^{1}/_{\eta}\right)\sin k_2 d_2\right] \quad (7)$$

$$C = e^{ik_1 d_1}\left[-\frac{1}{2} i\left(\eta - {}^{1}/_{\eta}\right)\sin k_2 d_2\right] \quad (8)$$

$$D = e^{-ik_1 d_1}\left[\cos k_2 d_2 - \frac{1}{2} i\left(\eta + {}^{1}/_{\eta}\right)\sin k_2 d_2\right] \quad (9)$$

The parameter η depends on the polarization. For the TE and TMpolarizations, η is given by

$$\eta_{TE} = \frac{k_1}{k_2} \quad (10)$$

and

$$\eta_{TM} = \frac{k_1 n_2^{\,2}}{k_2 n_1^{\,2}} \quad (11)$$

For finite stacks, the coefficient of right and left hand side propagating wave in both sides of the multilayer structure a_N and b_N, are calculated by multiplying transfer matrix of each cell as

$$\begin{pmatrix} a_0 \\ b_0 \end{pmatrix} = T_1\, T_2 \ldots .. T_N \begin{pmatrix} a_N \\ b_N \end{pmatrix} \quad (12)$$

where N is the total number of the cell. The coefficient of reflection is given by solving above matrix equation with the condition $b_N = 0$ as

$$r_N = \begin{pmatrix} b_0 \\ a_0 \end{pmatrix} \quad (13)$$

Thus the reflectivity (or reflectance) of the structure may be calculated as

$$R_N = |r_N|^2 \quad (14)$$

Now, according to Bloch theorem, the electric field vector is of the form

$E = E_{K(x)} e^{i(\omega t - Kx)}$,

where $E_{K(x)}$ is periodic with the period 'd'. For the determination of K as a function of eigen value, the equation is written as

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}\begin{pmatrix} a_n \\ b_n \end{pmatrix} = e^{iKd}\begin{pmatrix} a_n \\ b_n \end{pmatrix} \quad (15)$$

The solution of this matrix equation leads to the dispersion relation for the PC structure containing the alternate stacks of positive index materials, denoted by PC, is given by

$K(\omega)$
=

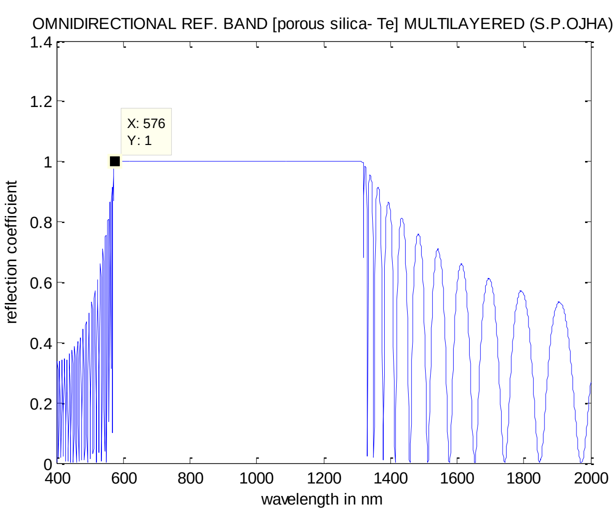
$$\left(\frac{1}{d}\right)\cos^{-1}\left[(\cos(k_1 d_1)(\cos(k_2 d_2) - \frac{1}{2}\left(\eta + {}^{1}/_{\eta}\right)\sin k_1 d_1 \sin k_2 d_2\right] \quad (16)$$

4. Results and Discussion:

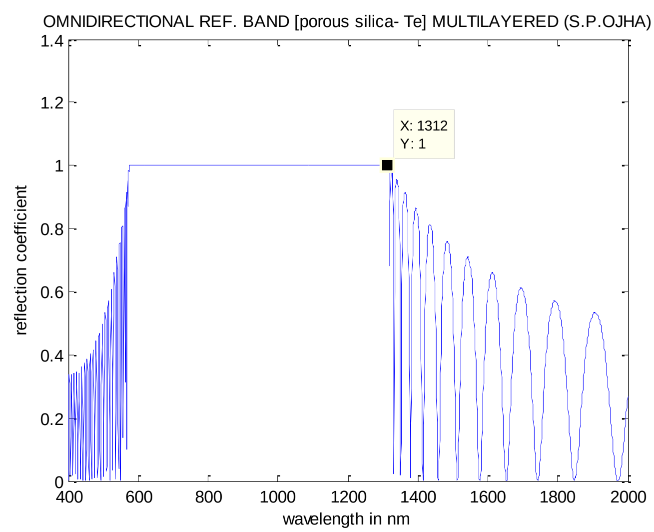
In this section we present the numerical analysis of the proposed PC structure and show the Omni-directional reflection bands for both TE and TM polarizations. The value of refractive index for the Nanoporous Silicon film is taken as 1.23 and Te is4.6 at 800nm. The thickness of the layers are taken as according to quarter wave stacks condition i.e. $d_1=\lambda_0/4n_1$ and $d_2=\lambda_0/4n_2$. The reflection spectra obtained for the total number of layers N=25 is depicted in Fig-2 for both TE and TM polarizations. From the study of these figures it is observed that as the angle of incidence increases the reflection band width increases for TE mode while it decreases for TM mode and at the same time the reflection band is shifted towards lower wavelength region (blue shifted). The width of reflection band has larger value for the TE mode in comparison to the TM mode. At oblique incidence, different polarizations (TE and TM) exhibit different reflectance. If a PC reflects light of both polarizations incident at any angle within a certain frequency range, The PC is said to have a complete Omni-PBG. The Omni-PBG is narrow, mainly because of the reason that the refractive index contrast between the two sub layers of the system is not too large. It may also partly be attributed to the strong effect of the Brewster angle for TM polarizations within the given system

	TE			TM		
	LOWER BAND EGDE (nm)	UPPER BAND EDGE (nm)	BAND GAP (nm)	LOWER BAND EGDE (nm)	UPPER BAND EDGE (nm)	BAND GAP (nm)
$\Theta=0^o$	576	1312	736	576	1312	736
$\Theta=30^o$	542	1297	755	559	1206	647
$\Theta=60^o$	472	1268	796	528	961	433
$\Theta=89^o$	440	1253	813	515	811	296
Omni directional reflection band = 811nm-576nm=235nm						

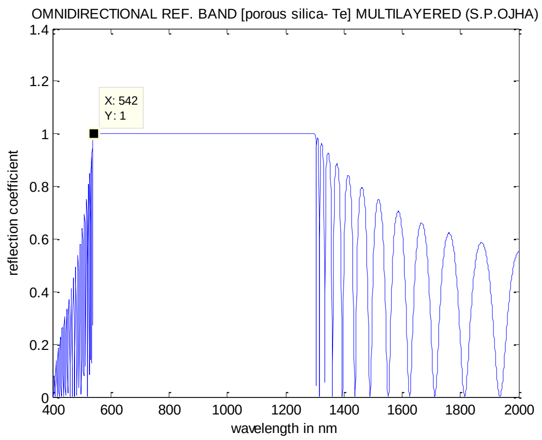
Table 1



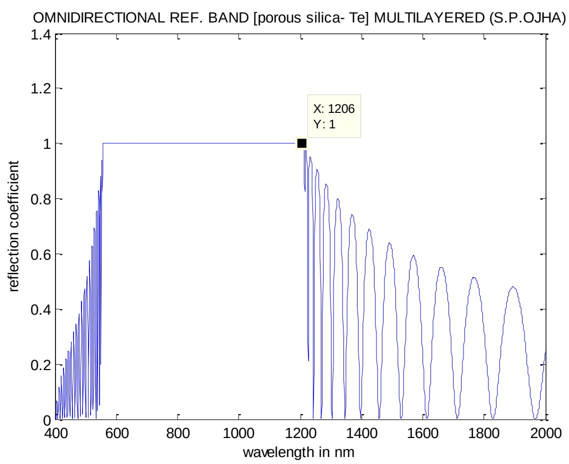
(a)



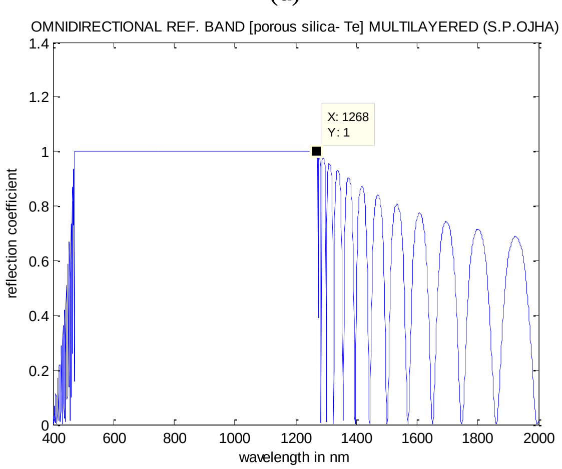
(b)



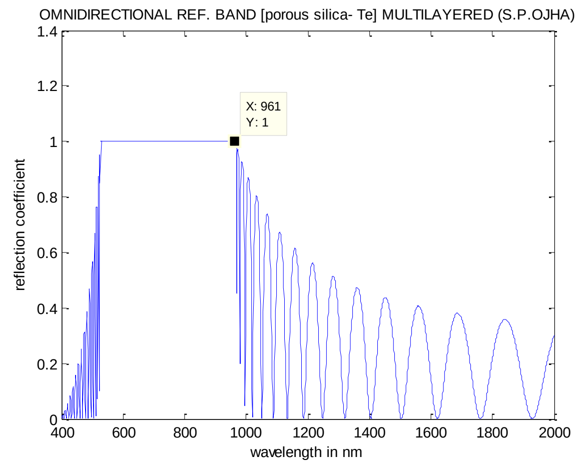
(c)



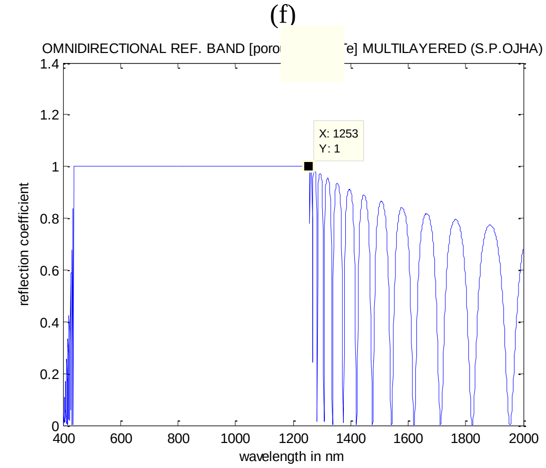
(d)



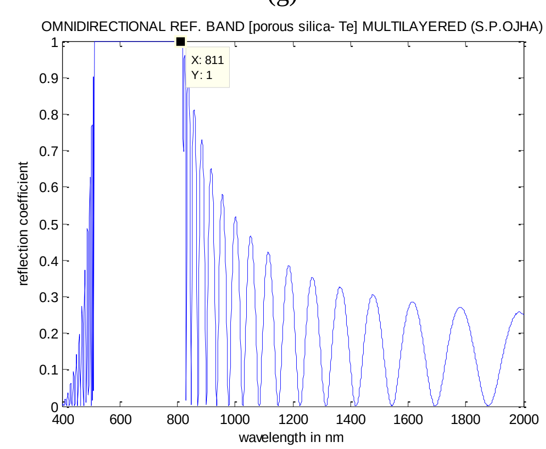
(e)



(f)



(g)



(h)

Fig 2 : *The reflectance spectra for TE and TM modes showing the total reflection region and bandwidth for* $n_1=1.23, n_2=4.6$*, d1=162.6nm, d2=43.47 nm and N=25 at various incident angles (a)* $\Theta= 0^0$ *,TE (b)* $\Theta=0^0$ *,TM (c)*

Ɵ=30⁰ ,TE (d) Ɵ=30⁰ ,TM (e) Ɵ=60⁰ ,TE (f) Ɵ=60⁰ ,TM (g) Ɵ= 89⁰ , TE (h) Ɵ= 89⁰ ,TM

5. Conclusion:

Thus one dimensional multilayered Nanoporous Silicon and Te photonic crystal structure can be used as a good candidate for making wavelength filters in the visible spectrum from 576nm to 811nm wavelength range when N is large enough. The proposed of these multilayered structures is in Antireflection coatings and wavelength filters.

References

[1] E.Yablonovitch,Phys.Rev.Lett. 58, 2059 (1987).
[2] S.John,Phys.Rev.Lett. 58, 2486 (1987)
[3] K.M.Ho, C.T.Chan and C.M.Soukoulis, Phys.Rev.Lett. 65, 3152 (1990).
[4] S.G.Jhonson and J.D. Joannopoulos, Appl. Phys. Lett. 77,3490 (2000).
[5] C.S.Kee.I.Park,H.Lim,J.E.Kim and H.Y.Park, Curr.Appl.Phys.1, 84 (2001).
[6] J.M. Lourtioz and A. Lustrac, Comtes Rendus Physique 3,79 (2002).
[7] K.Isamoto, T. Yamamoto, M.Inoue and T.Fujji, IEEE Trans. Magn.31, 3286 (1995).
[8] M.Inoue and T.Fujji, J.Appl. Phys 81, 5659 (1997).
[9] E.Takeda, N.Todoroki, Y.Kitmoto and M.Abe, J.Appl. Phys 87, 6782 (2000).
[10] M.Golosovsky, Y.Saado and D.Davidov, Appl. Phys. Lett. 75,4168 (1999).
[11] N.Y.Ha, J.W.Wu and B.Park, J. Korean Phys. Soc. 45, 108 (2004).
[12] S.H.Han, Q.Han Park, Y.S.Park, Y.Roh and H.S.Jeon, J. Korean Phys. Soc. 45, 112 (2004).
[13] S.H.Han, Q.Han Park, Y.S.Park, Y.Roh and H.S.Jeon, J. Korean Phys. Soc. 45, 9 (2004).
[14] K.Inoue and K.Ohtake, Photonic crystals – Physics, Fabrication and applications (Springer Press, Berlin, 2004).
[15] K.Iga, F.Koyama and S. Kinoshita, IEEE J.Quantum Electron. 29, 1845 (1988).
[16] J.N.Winn, Y.Fink, S.H.Fan and J.D.Joannopoulos, Opt. Lett. 23, 1573 (1998).
[17] Y.Fink, J.N.Winn, S.H.Fan, C.P.Chen,J.Michel, J.D.Joannopoulos and E.L.Thomas, Science 282, 1679 (1998).
[18] I.Abdulhalim, Opt.Commun. 174, 43 (2000).
[19] Yeh, P., Optical Waves in Layered Media, John Wiley and Sons, New York, 1988.
[20] Srivastava, S. K. and S. P. Ojha, "Enhancement of omnidirectional reflection bands in one-dimensional photonic crystal structures with left-handed materials," Progress In Electromagnetics Research, PIER 68, 91–111, (2007).
[21] Srivastava, S. K. and S. P. Ojha, "Omnidirectional reflectionbands in one-dimensional photonic crystal structure usingfluorescence films,"Progress In Electromagnetics Research,
PIER 74, 181–194, 2007.
[22]. Srivastava, R., S. Pati, and S. P. Ojha, "Enhancement ofomnidirectional reflection in photonic crystal heterostructures,"Progress In Electromagnetics Research *B*, Vol. 1, 197–208, 2008.