P: ISSN NO.: 2321-290X RNI : UPBIL/2013/55327 VOL-5* ISSUE-5* January- 2018
E: ISSN NO.: 2349-980X **Shrinkhla Ek Shodhparak Vaicharik Patrika**

An Omni-directional Reflector Using 1D Ge-SiO2 Based Photonic Crystal

Abstract

A simple design of an omni-directional reflector (ODR) based on Ge-SiO_2 bilayer system has been presented. The photonic band gaps (PBGs) of the proposed photonic crystal for both TE and TM modes at different angles of incidence is computed numerically using transfer matrix method. It is found that the proposed photonic crystal has omni-directional reflection in near infrared region. This type of ODR PBG can be used in various application in photonics such as deformable mirror, high resolution InAs camera etc.

Keywords: Photonic Band Gap, Omni-directional Reflection, Transfer Matrix Method.

Gulbir Singh
Associate Professor,
Deptt.of Physics,
S.G. (P.G.) College,
Saroorpur Khurd,
Meerut

Introduction

Photonic Band Gap materials, also known as photonic crystals, are materials which have alternate forbidden and allowed band gaps. The fabrication of photonic crystals can be possible in one, two, or three dimensions. Kumar et al. have been studied on some optical properties of one-dimensional photonic crystals. The forbidden band gap in photonic crystals represents the frequency/wavelength range where wave behaving photons cannot be transmitted through the material. An optical filter is a device which stops and/or allowed some frequency/wavelength range.

Aim of the Study

Photonic crystals are attractive optical materials for controlling and manipulating light flow. An omni-directional reflector (ODR) is a device which block cent percent radiation incident on it for all angles of incidence and both TE and TM mode of polarizations. The aim of the present study is to design omni-directional reflector in infrared region.

Review of Literature

Two pioneers Yablonovitch [1] and John [2] in 1987 published their work on photonic crystal (PC) leading to the new branch of Physics called Photonics. In recent years, researchers investigated that photonic crystal shows novel applications by controlling the structural parameters. PCs may have photonic band gap (PBG), in which electromagnetic wave cannot propagate through them. The PBG in PCs can be used in numerous diversified applications such as waveguides[3], filter switches [4, 5], lasers[6], sensors [7], DWDM applications[8], particular polarized filter[9] etc. PCs can be designed in one, two and three dimensions based on their periodicities but the fabrication of 1D photonic crystal at any wavelength scale is quite simple.

Presently, one of the most widely used optical devices using photonic crystals is omni-directional reflector. In 1998, Fink et. al.[10] demonstrated that 1D photonic crystal structures (such as multilayered sandwiched films) can exhibit complete reflection i.e. ODR of radiations in a given frequency range for all incident angles and polarizations. In 2007, Ojha et. al.[11] theoretically studied omni-directional reflector for a very wide range of wavelength in the visible and very narrow portion of near infrared region of EM spectrum using combination of fullerence–gallium arsenide (GaAS), fullerence-germanium (Ge) and fullerence-telurium (Te). Also Kumar et.al. have worked on photonic crystals based on dielectric and nonlinear materials [12-15].

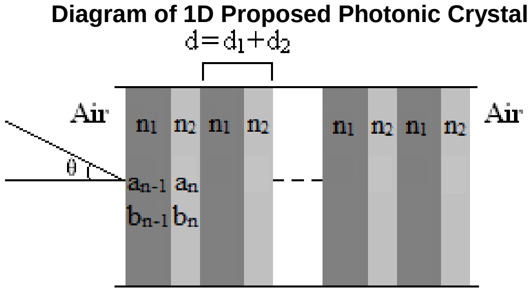
In the present communication, the structure consists of alternate layer of SiO_2 and Ge as the material of low and high refractive index materials has been studied. There are many advantages of Ge in photonic crystals because of its high refractive index. Pure Ge has very large refractive index in near infrared spectral range (n=4.2 at 1.55μm) much larger than the refractive index of Si(n=3.45). Due to which it is possible to obtain a large opening of photonic band-gap (PBG) depends on high refractive index contrast.

Theoretical Analysis

By employing transfer matrix method and Maxwell's equations the reflectivity of one dimensional (1D) system that consists of alternate layers of two different materials with different refractive indices n_1 and n_2 can be computed. The proposed structure is depicted in Figure 1

Figure 1

Diagram of 1D Proposed Photonic Crystal



Now applying proper boundary condition on E(x) and dE(x)/dx at the interfaces of two layers, the travelling wave coefficients can be related as the following matrix equation

$$\begin{pmatrix} a_{n-1} \\ b_{n-1} \end{pmatrix} = T_n \begin{pmatrix} a_n \\ b_n \end{pmatrix} \text{ with } T_n = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \qquad (1)$$

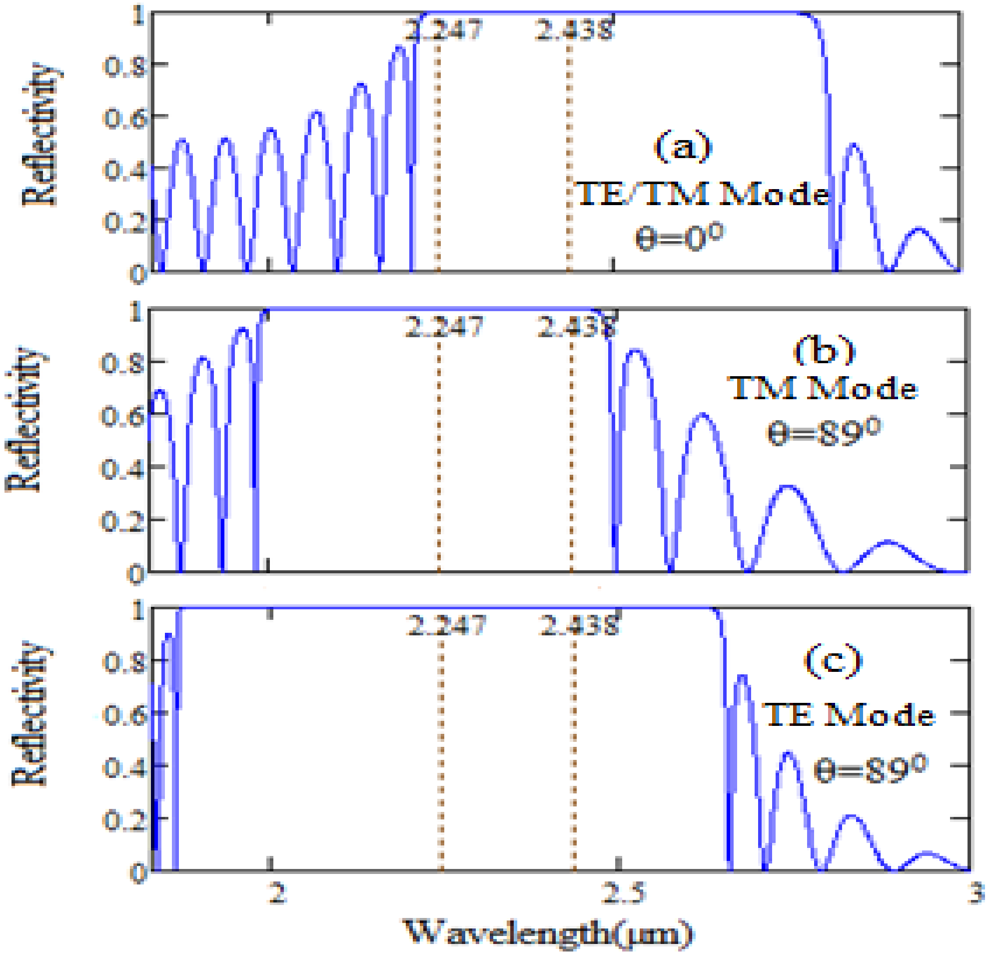
For the multilayer structure the total transfer matrix for all layers can be obtained by multiplying all individual transfer matrices of each layer of the medium.

$$\begin{pmatrix} a_0 \\ b_0 \end{pmatrix} = T_1.T_2.....T_n \begin{pmatrix} a_n \\ b_n \end{pmatrix} \qquad (2)$$

The reflectivity is determined by after some manipulations introduced by P.Yeh [12]

$$R = \frac{|C|^2}{|C|^2 + \left(\frac{\sin Kd}{\sin NKd}\right)^2} \qquad (3)$$

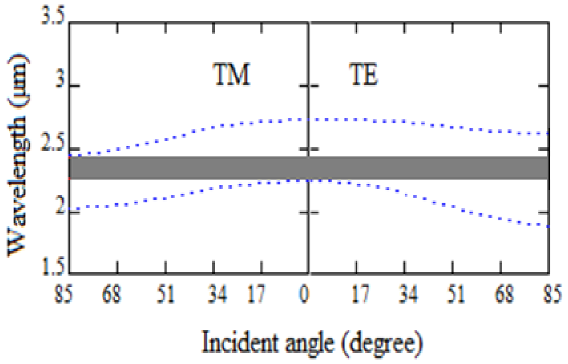
Figure 2 Reflection Spectra of Sio$_2$/Ge PC Structure



Results and Discussion

For computing the reflection response, the layer 1 and layer 2 are taken to be SiO_2 and Ge respectively. The refractive indices of SiO_2 and Ge are n_1= 1.5 and n_2=4.0 and their thickness are taken to be a=600nm & b=400nm respectively. The total number of unit cells N is taken to be 10. Using these structural parameters and employing equation (3) the graphical representation of reflectivity as the function of wavelength with different angle of incidence is shown in Figure 2. Figure 2(a-c) shows the reflectivity of calculated spectra at the angle 0º and 89º for TE and TM modes and the corresponding ODR is shown in Figure 3. Figure 3, represents the complete photonic band structure in two dimensions, which can be obtained by the projections of figure 2.

Figure 3 Projected Photonic Band Gap Structure of Sio_2/Ge Structure



In figure 3, the shaded region represents the total omni-directional reflection band. From these figures, it is clear that there is a region of unit reflectance with Omni-directional reflection for TE polarization from 2247nm to 2613nm and for the TM polarization from 2247nm to 2435nm respectively. So there is common region in TE and TM modes at which a unit reflectance at different angle of incidence is obtained. From figure 3, it is clear that the common range of unit reflectance is from 2247nm to 2438nm. So that total ODR range has the band width of 191nm. This ODR range can be controlled by structural parameters used in the calculations.

References

1. *E. Yablonovitch, Phys. Rev. Lett. 58, 2059-2062 (1987).*
2. *S. John, Phys. Rev. Lett. 58, 2486-2489 (1987).*
3. *P.R. Villeneuve, D.S. Abrams, S. Fan and J.D. Joanopoulos, Opt. Lett. 21, 2017-2019 (1996).*
4. *J.C. Knight, J. Broeng, T.A. Birks and P. St. J. Russell, Science 282, 1476-1479 (1998).*
5. *V. Kumar, Kh.S. Singh and S.P. Ojha, Int. J. of Microwave and Optical Technology 5(3), 162-165 (2010).*
6. *J.P. Dowling, Science 282, 1841-1842 (1998).*
7. *Kumar, V. Kumar, B. Suthar, A. Bhargava, Kh.S. Singh and S.P. Ojha, HINDAWI: Int. J. of Microwave Science and Technology 2012, 5 Pages, Article ID 182793, doi:10.1155/2012/182793*
8. *V. Kumar, B. Suthar, A. Kumar, Kh.S. Singh and A. Bhargava, Optik - Int. J. Light Electron Opt. 124(16), 2527-2530 (2013).*
9. *V. Kumar, B. Suthar, A. Kumar, Kh.S. Singh, A. Bhargava and S.P. Ojha, Silicon 6, 73-78 (2014).*
10. *Y. Fink, J. N. Winn, S. Fan, C. Chen, J. Michel, J. D. Joannopoulos and E. L. Thomas, Science 282, 1679-1682 (1998).*
11. *S.K. Srivastva and S.P. Ojha, Prog. Electromagn. Res. 74, 181-194 (2007).*
12. *P. Yeh, Optical waves in layered media, John Wiley and Sons, New York, 1988.*
13. *V. Kumar, A. Kumar, B. Suthar and J.V. Malik, Optik 126, 977–980 (2015).*
14. *Kumar, V. Kumar, B. Suthar, M. Ojha, Kh.S. Singh and S.P. Ojha, IEEE: Photon. Technol. Lett. 25(3), 279 (2013).*
15. *Kumar, V. Kumar, A. Nautiyal and S.P. Ojha, Optik 145, 473 (2017).*