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Enhanced ODR Reflection by Using Sio_2 Exponentially Graded Materials for 1D Photonic Crystals

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Abstract

An exponentially graded index material for one dimensional structure of binary & ternary photonic crystal has been proposed. It works as a perfect mirror at third transmission window (1550 nm).A transfer matrix method has been used to estimate the reflection properties of semiconductor materials. An enhanced ODR range is obtained by using both binary and ternary photonic crystal in which Ge as exponentially graded material. In the proposed structure when a third semiconductor layer (GaAs) is introduced between SiO_2 and Ge semiconductor photonic crystals the ODR range is increased. This property shows that one dimensional graded index ternary photonic crystal structures have widened ODR than Binary photonic crystals. Therefore broadband omnidirectional photonic bandgap is applicable for many prospects such as omnidirectional mirrors, optical switches, filters, WDM etc. for optical fiber communications.

Keywords: *Exponentially graded material, refractive index, optical mirror.*

1. Introduction

Photonic crystal is the most popular branch of science in which we deal omnidirectional mirror, optical filters, switches etc. The ODR involve the photonic bandgap of materials such as dielectric and semiconductors. For a particular wavelength and refractive index ODR mirror has been design. Also,photonic crystal exhibits photonic bandgap in which we design omnidirectional mirror, optical filter, wavelength division multiplexer, switches etc. [1-7]. Exponentially graded materials play an important role in photonic crystals. In comparison of nongraded materials they have larger photonic bandgap. The photonic bandgap also increases with increases the refractive index of the graded materials.

Many authors have been design ODR mirror and optical filters at a particular wavelength of different types of materials [8-13]. S. Sharma et al.[14] designed the omnidirectional mirror by using linearly graded index materials and theoretically observed that the omnidirectional range is increased by 70 nm when a third semiconductor layer of ZnSis introduced between two layers of binary photonic crystal (PbS/SiO_2). P. C. Pandeyet. al. [15]designed a multi-channel filter and tunable mirror by using one dimensional exponentially GPCs.S. Sharma et. al. [16] designed an ODR mirror by using one dimensional GaAs based exponentially graded photonic crystals.R. Kumar et al. [17] proposed a graded birefringent dielectric photonic crystal and found enhanced ODR bandwidth in comparison of nongraded birefringent dielectric photonic crystal. Here, exponentially graded photonic crystals are applicable to design of wavelength division multiplexer, optical filters, Omni-directional mirrors, Optical sensors, etc.

In this paper, we design anenhanced omnidirectional reflector (ODR) by using one

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dimensional exponentially graded index binary and ternary photonic crystals. The proposed structure containsthe alternate layers of semiconductor and dielectricmaterials. Here we consider two structures (i) SiO_2/Ge(ii) SiO_2/Ge/GaAs. In SiO_2/Ge binary photonic crystal and SiO_2/Ge/GaAs ternary photonic crystal structure we have chosen Ge as graded index semiconductor material whose refractive index profile varies exponentially from 1.38 to 4.23 at third transmission window (1550nm).

2. Theoretical Modal

Figure 1 shows the refractive index profile of one dimensional binary and ternary photonic crystal. Here, $n_i$and n_s denote the refractive indices of incident media and substrate. For binary and ternary PC structure it`s index profile is given by,

$$n(x)=\begin{cases}\begin{cases} n_1 & (n-1)t<x<(n-1)t+a \\ n_2(x)=n_0 e^{\left[\frac{x}{b} In\left(\frac{n_s}{n_o}\right)\right]} & (n-1)t+a<x<nt \end{cases} & (Binary) \\ \begin{cases} n_1, & (n-1)t<x<(n-1)t+a \\ n_2(x)=n_0 e^{\left[\frac{x}{b} In\left(\frac{n_s}{n_o}\right)\right]} & (n-1)t+a<x<(n-1)t+a+b \\ n_3, & (n-1)t+a+b<x<nt \end{cases} & (Ternary) \end{cases} \quad (1)$$

For both binary and ternary, $n_2(x)$denotes the refractive index profile of exponentially grading material Ge and n_0&n_{max}denotes the initial and highest value of refractive index varies from$x = 0$ to $x = b$ respectively. Also, a and$b$ are the width of SiO_2 and Ge and $x$is the grading distance from a to b.

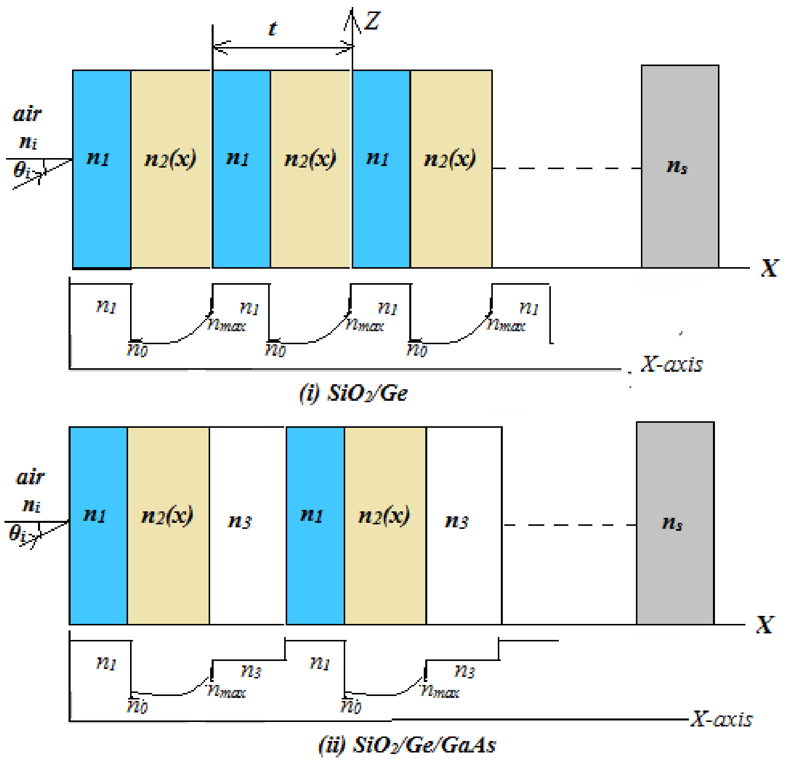

Figure1.Structure of the variation of refractive index (i) 1D binary exponentially graded material and (ii) ternary exponentially graded material.

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The characteristic matrices for both TE and TM waves by using the transfer matrix method have the form [18]

$$U[d] = \begin{cases} \prod_{i=1}^{l}\left[\begin{bmatrix} \cos\alpha_i & \frac{-i}{p_i}\sin\alpha_i \\ -ip_i\sin\alpha_i & \cos\alpha_i \end{bmatrix}\prod_{j=2}^{n}\begin{bmatrix} \cos\alpha_j & \frac{-i}{p_j}\sin\alpha_j \\ -ip_i\sin\alpha_j & \cos\alpha_j \end{bmatrix}\right] for\ binary \\ \prod_{i=1}^{l}\left[\begin{bmatrix} \cos\alpha_i & \frac{-i}{p_i}\sin\alpha_i \\ -ip_i\sin\alpha_i & \cos\alpha\alpha_i \end{bmatrix}\prod_{j=2}^{n}\begin{bmatrix} \cos\alpha_j & \frac{-i}{p_j}\sin\alpha_j \\ -ip_i\sin\alpha_j & \cos\alpha_j \end{bmatrix}\prod_{i=2}^{k}\begin{bmatrix} \cos\alpha_i & \frac{-i}{p_i}\sin\alpha_i \\ -ip_i\sin\alpha_i & \cos\alpha_i \end{bmatrix}\right] for\ ternary \end{cases} \quad (2)$$

Where, $\alpha_i = \frac{2\pi}{\lambda} p_i d_i \cos\theta_i,\ \ p_i = n_i \cos\theta_i$ and $\alpha_j = \frac{2\pi}{\lambda} p_j d_j \cos\theta_j,\ \ p_j = n_j \cos\theta_j$, and

$$\cos\theta_i = \left[1 - \frac{n_0^2 \sin^2\theta_i}{n_i^2}\right]^{\frac{1}{2}} \quad (3)$$

For unimodular matrix U$[d]$the structure for N-period can be written as,

$$U(d)^N = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}^N = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \quad (4)$$

The transmission (t) and reflection coefficient $r(\omega)$of the multilayer structures are given by,

$$t = \frac{2p_0}{(m_{11} + m_{12}p_0)p_0 + (m_{21} + m_{22}p_0)} \quad (5)$$

$$r(\omega) = \frac{(m_{11} + m_{12}p_0)p_0 - (m_{21} + m_{22}p_0)}{(m_{11} + m_{12}p_0)p_0 + (m_{21} + m_{22}p_0)} \quad (6)$$

Therefore the reflectance can be written as,

$$R = |r(\omega)|^2 \quad (7)$$

3. Result and Discussion

In this research paper, we are presenting two one dimensional binary (SiO_2/Ge) and ternary (SiO_2/Ge/GaAs) photonic crystals. In binary photonic crystal (SiO_2/Ge), we have taken Ge as a expnentially graded material whose refractive index exponentially vary from 1.38 to 4.23. Figure 2 shows the refractive index profile of Ge. In binary photonic crystal structure the number of alternate layer has taken to be 16.For exponentially graded material the refractive index of Ge varies from 1.38 – 4.23 in the range of wavelength of 1550 nm and SiO_2 has refractive index of 1.45 at this wavelength. D. G. Drummond et al. [19] used the data for SiO_2, from the range 1.5µm-9µm.Here, the thicknesses of layers SiO_2& Ge have taken to be $0.7t\ and\ 0.3t$ and lattice period tto be 145 nm. Figure 3 shows the refrectance spectra of SiO_2/Ge in which omnidirectional range is obtained when polarization angle for both TE & TM mode varies form 0^0 to 85^0. The proposed structure of SiO_2/Ge gives cent percent reflection for different angles of incidence, namely, 0^0, 45^0 and 85^0 for both TE & TM mode respectively. It is clear from Table 1 that the total omnidirectionalreflection (ODR) range of this structure is **92 nm** at third transmission window.

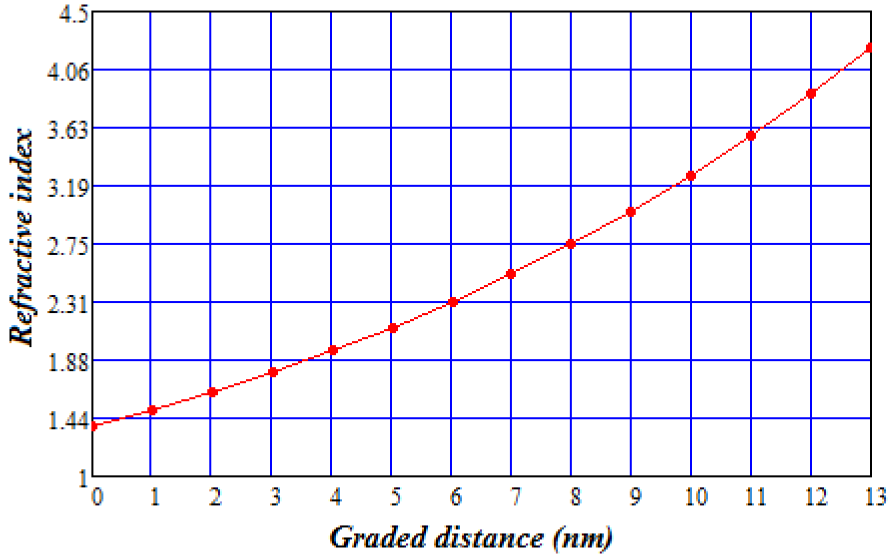

Figure 2.Variation of refractive index of exponentiallygraded Ge material.

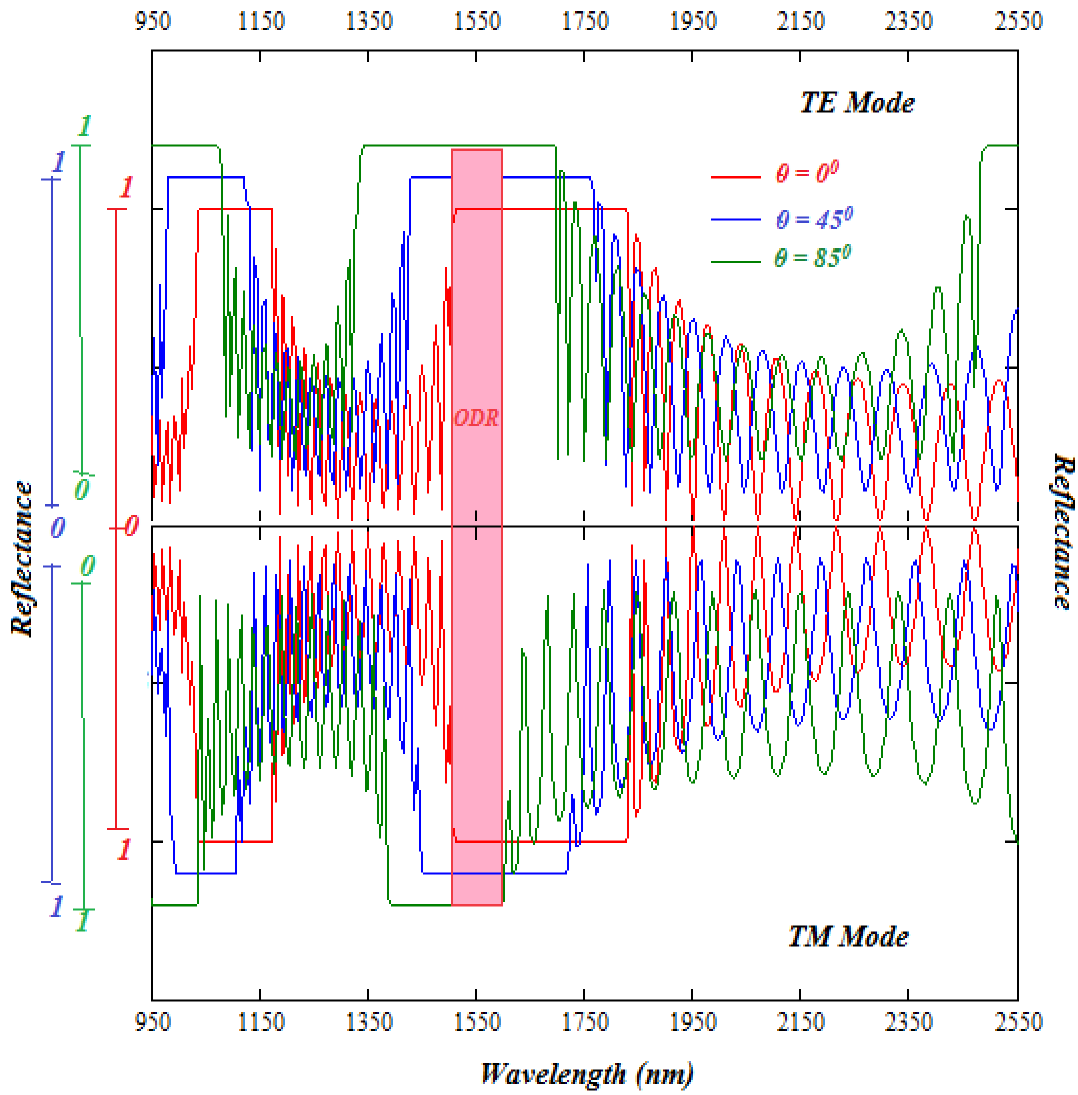

Figure 3. Omnidirectional reflection (ODR) spectrum of 1D binary photonic crystal (SiO_2/Ge)

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In ternary photonic crystal (SiO_2/Ge/GaAs), we have taken Ge is expnentially graded material whose refractive index exponentially vary from 1.38 to 4.23. In ternary photonic crystal structure SiO_2/Ge/GaAs the number of alternate layer has taken to be 16. Here, the thicknesses of layers SiO_2, Ge and GaAs have taken to be $0.6t, 0.1t$ *and* $0.3t$ and lattice period t to be 145 nm. Figure. 4 shows the refrectance spectra of SiO_2/Ge/GaAs in which omnidirectional range is obtained when polarization angle for both TE & TM mode varies form 0^0 to 85^0. The proposed structure of SiO_2/Ge/GaAs gives cent percent reflection for different angles of incidence, namely, 0^0, 45^0 and 85^0 for both TE & TM mode respectively. It is clear from Table 1 that the total omnidirectional reflection (ODR) range of this structure is **405 nm** at third transmission window.

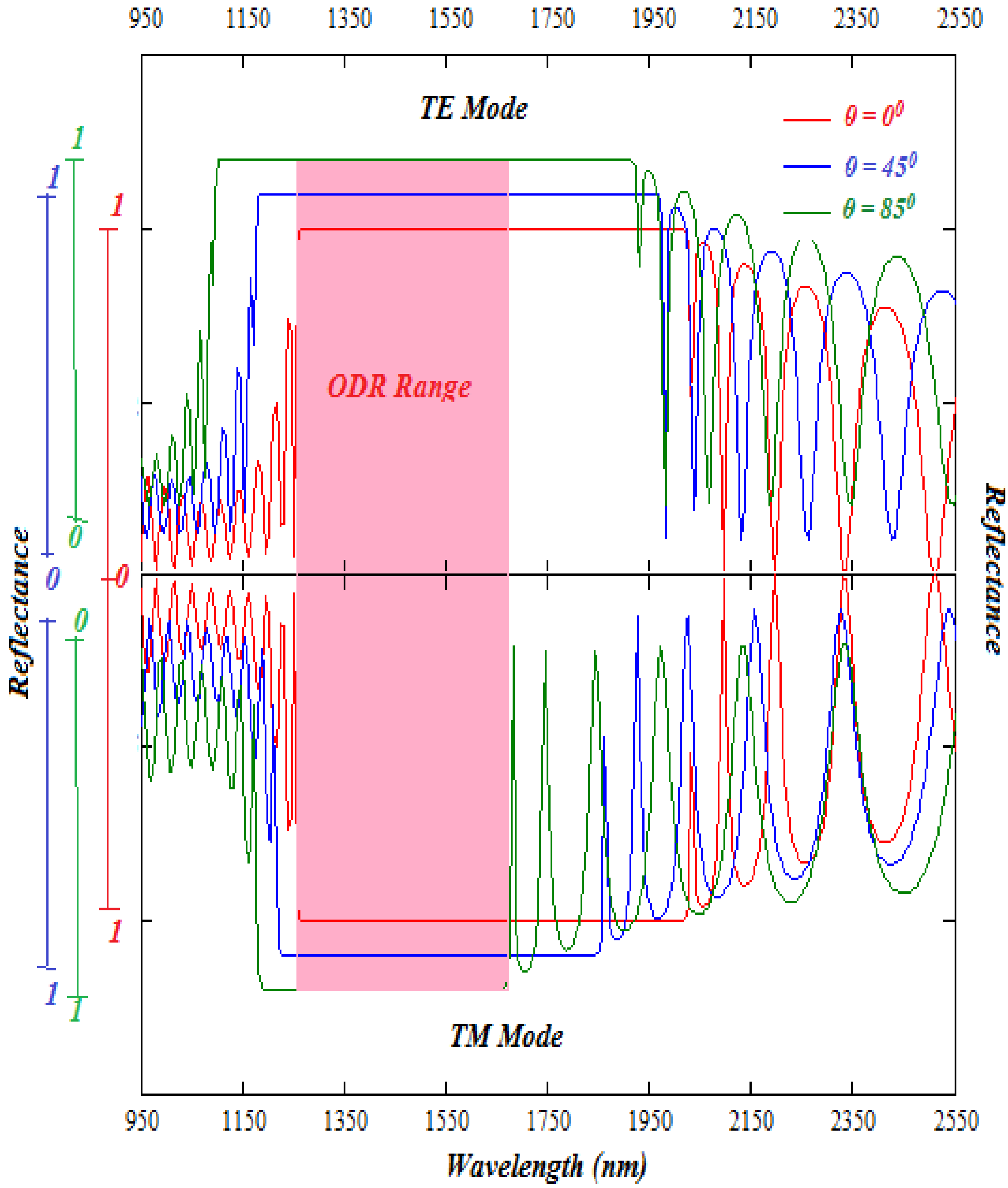

Figure 4. Omnidirectional reflection (ODR) spectrum of 1D Ternary photonic crystal (SiO_2/Ge/GaAs)

Table-1.Omnidirectional Range of both Binary &Ternary PCs at different angels.

Types of Crystals	*Incidence angle (θ) in deg.*	*TE polarization (nm)*	*Photonic bandgap width (nm)*	*TM polarization (nm)*	*Photonic bandgap width (nm)*	*ODR Range (nm)*
Binary (**SiO_2/Ge**)	0	**1510**-1825	315	1510-1825	315	**92**
	45	1425-1764	339	1452-1723	271	
	85	1340-1693	343	1390-**1602**	212	
Ternary (**SiO_2/Ge/ GaAs**)	0	**1260**-2020	760	1260-2020	760	**405**
	45	1180-1970	790	1228-1847	619	
	85	1102-1916	814	1187-**1665**	478	

From Table 1 it is clear that, the omnidirectional photonic bandgap width of one dimensional binary photonic crystal is exceed 313 nm when a third layer of semiconductor material is introduced in binary photonic crystals. Hence it`s a very popular method to theoretically design a broadband ODR photonic bandgap in the 1D ternary photonic crystal by introducing a third semiconductor layer within a binary photonic crystals.The variation of refractive index of exponentially graded materials for reflectance both binary &ternary photonic crystal shows the excellent result in case of omnidirectional reflector which can be used in optical fiber communication which fall in a wavelength range around 1550 nm (third transmission window). Such exponentially graded photonic crystals are applicable to design of wavelength division multiplexer, optical filters, Omni-directional mirrors, Optical sensors, etc.

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