DESIGN OF AN ODR MIRROR BY USING TEMPERATURE DEPENDENCE ZnS BASED 1D PHOTONIC CRYSTALS

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Abstract—The effect of temperature and angle of incidence on ZnS based 1D photonic crystal has been investigated. To design of an omnidirectional reflection (ODR)we have proposed a structure which is dependent on both temperature and angle of incidence. Also, the refractive index of ZnS material depends on both temperature and wavelength simultaneously. The ODR range of the structure increases with increases the temperature of the materials. At third transmission window (1550nm), we can design a narrow band omnidirectional mirror by varying the temperature of the semiconductor material.

Key words: *Photonic crystal, ODR, TMM.*

1. INTRODUCTION

Photonic crystals are periodically arranged structures that contain photonic bandgap in which electromagnetic wave propagate in it and give various properties such as omnidirectional reflection, transmittance etc. Photonic bandgap properties of the materials are used to confine the propagation of electromagnetic waves in the photonic crystals for various potential applications. To select a particular wavelength and refractive index of the semiconductor materials ODR mirror has been design. Also, photonic crystal exhibits photonic bandgap in which we design omnidirectional mirror, optical filter, wavelength division multiplexer, switches etc. [1-5].

A lot of authors have been theoretically design ODR mirror and transmission filters at a particular wavelength of different types of dielectric/semiconductor materials [6-7].F. C. Peng et al [8] studied tunable band-gap properties of the material in one-dimensional binary photonic crystals. In 2017, A. Cerjan and S. Fan [9] proposed the complete photonic bandgaps in supercell photonic crystals with the help of transfer matrix method. In 2013, T.W. Chang et al [10] theoretically analyzed the tuning of multichannel filter with the help of coupled defect introduced in a photonic crystal. Also in 2018, Z.Zare et al [11]investigated thermal tunable properties ofnano metallic photonic crystal filter with mirror symmetry with the help of FDTD method.

In this paper, we have design a narrow band omnidirectional reflector (ODR) by using one dimensional temperature dependent ZnS basedphotonic crystal. Here, the proposed structure consistsof alternate layers of ZnS and GaAs semiconductor materials in which GaAs semiconductor material is independent both of temperature and wavelength [12-13]. The property of temperature dependent ZnS material is that when temperature is increases the bandgap of the material also increases. With using this property of material we design anomnidirectional mirror and TE/TM mode filter.

2. THEORITICAL MODAL

The Schematic diagram of one dimensional photonic crystal structure is shown in Fig. 1. It consists of an alternate layers of semiconductor materials refractive indices $n_1$and n_2 with thicknesses aandbrespectively. It is assumed that the incident and emergent media of the structure is air (n_0= 1).

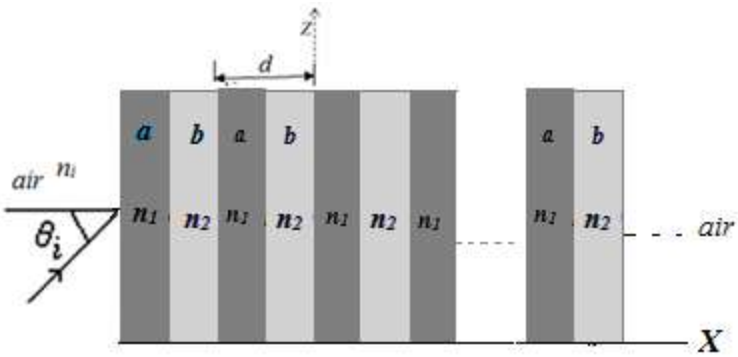

Fig.1.Structure of one-dimensional photonic crystals.

The characteristic matrices for both TE and TM waves by using the transfer matrix method have the form [14],

$$U[d] = \prod_{i=1}^{l} \begin{bmatrix} \cos\gamma_i & \frac{-i}{p_i}\sin\gamma_i \\ -ip_i\sin\gamma_i & \cos\gamma_i \end{bmatrix} \quad (2)$$

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

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

The refractive index of GaAsis independent of temperature and wavelengthbut the refractive index of ZnS layer is taken as a function of both wavelength and temperature. The refractive index ofZnSintheranges 1.2–14 µm and293–700Kis represented as [15].

$$n^2(\lambda, T) = \varepsilon(T) + \frac{G(T)}{\lambda^2 - \lambda_1^2} + \frac{H(T)}{\left(\frac{\lambda^2}{\lambda_2^2}\right) - 1}$$

Where,

$\lambda_1 = 0.23979 + 4.841 \times 10^{-5}T_{1,}\lambda_2 = 36.525 + 4.75 \times 10^{-3}T_{1,}andT_1 = T - 293$

$$\varepsilon(T) = 8.34096 + 1.29107 \times 10^{-3}T_1 + 4.68388 \times 10^{-7}{T_1}^2 - 1.31683 \times 10^{-9}{T_1}^3 - 6.64356 \times 10^{-12}{T_1}^4$$

$$\mathrm{G}(T) = 0.14540 + 1.13319 \times 10^{-5}T_1 + 1.05932 \times 10^{-8}{T_1}^2 + 1.06004 \times 10^{-10}{T_1}^3 + 2.27671 \times 10^{-13}{T_1}^4$$

$$\mathrm{H}(T) = 3.23924 + 1.096 \times 10^{-3}T_1 + 4.20092 \times 10^{-7}{T_1}^2 + 1.1135 \times 10^{-9}{T_1}^3 + 7.2992 \times 10^{-12}{T_1}^4$$

for $293\mathrm{K} \le \mathrm{T} \le 700\mathrm{K}$

3. RESULT AND DISCUSSION

In this section, we have design a narrow band omnidirectional reflector (ODR) by using one dimensional temperature dependent ZnS based photonic crystal. Here, the proposed structure consists of alternate layers of ZnS and GaAs semiconductor materials in which GaAs semiconductor material is independent both of temperature and wavelength. We have taken the refractive index of GaAsis3.37 which is independent both of temperature and wavelength. But the refractive index of ZnS layer is taken as a function of both wavelength and temperaturewhose refractive index variesfrom1.2–14 μm and temperature range varies from 300–700K.

Applying transfer matrix method, we have taken the thicknesses of ZnS and GaAs layers to be a = 390 nm, b = 310 nm and$d = a + b = 700\, nm$. By taking the combination of alternate thickness of ZnS and GaAs layers the ODR range of the structure can be observed. Fig. 2& Fig. 3 show the reflectance spectra of the materials for the variation of refractive index profile of ZnS materialsfor different temperature(300K and 700K)with different angles of incidence, namely, 0^0, 45^0 and 85^0 for TE and TM mode respectively and the ODR range for these angles of incidence also obtained in the shaded portion of Fig. 2 and Fig.3.

The schematic diagram in Fig. 2 and Fig. 3 represent the reflection spectra of semiconductor materials ZnS and GaAsfor different angles of incidence and temperature gives the 100 percent reflections which are tabulated in Table 1. From Table 1, it`s clear that at temperature T = 300K the total omnidirectional range (ODR) of wavelength for this multilayer structure is **72 nm** and at temperature T = 700K the omnidirectional range is **92 nm.** Hence when temperature increases the ODR range of the multilayer structure also increases.From Fig. 2 and Fig. 3, it is clear that, at a constant temperature when we increase the angle of incidence the photonic bandgap shift towards the shorter wavelength region. The ODR range of this structure at temperature T =300K and T = 700K are shown in Fig. 2 and Fig. 3.

Table-1 Omnidirectional reflection of 1D PC as a function of Temperature and angle of incidence.

Temperature T(K)	**Incidence angle (θ in deg.)**	**TE (nm)**	**Band width (nm)**	**TM (nm)**	**Band width (nm)**	**ODR Range (nm)**
300	0	1537-1790	253	1537-1790	253	**72**
	45	1427-1735	308	1460-1701	241	
	85	1289-1692	403	1382-1609	227	
700	0	1464-1777	313	1464-1777	313	**92**
	45	1347-1720	373	1387-1674	287	
	85	1220-1670	450	1309-1556	247	

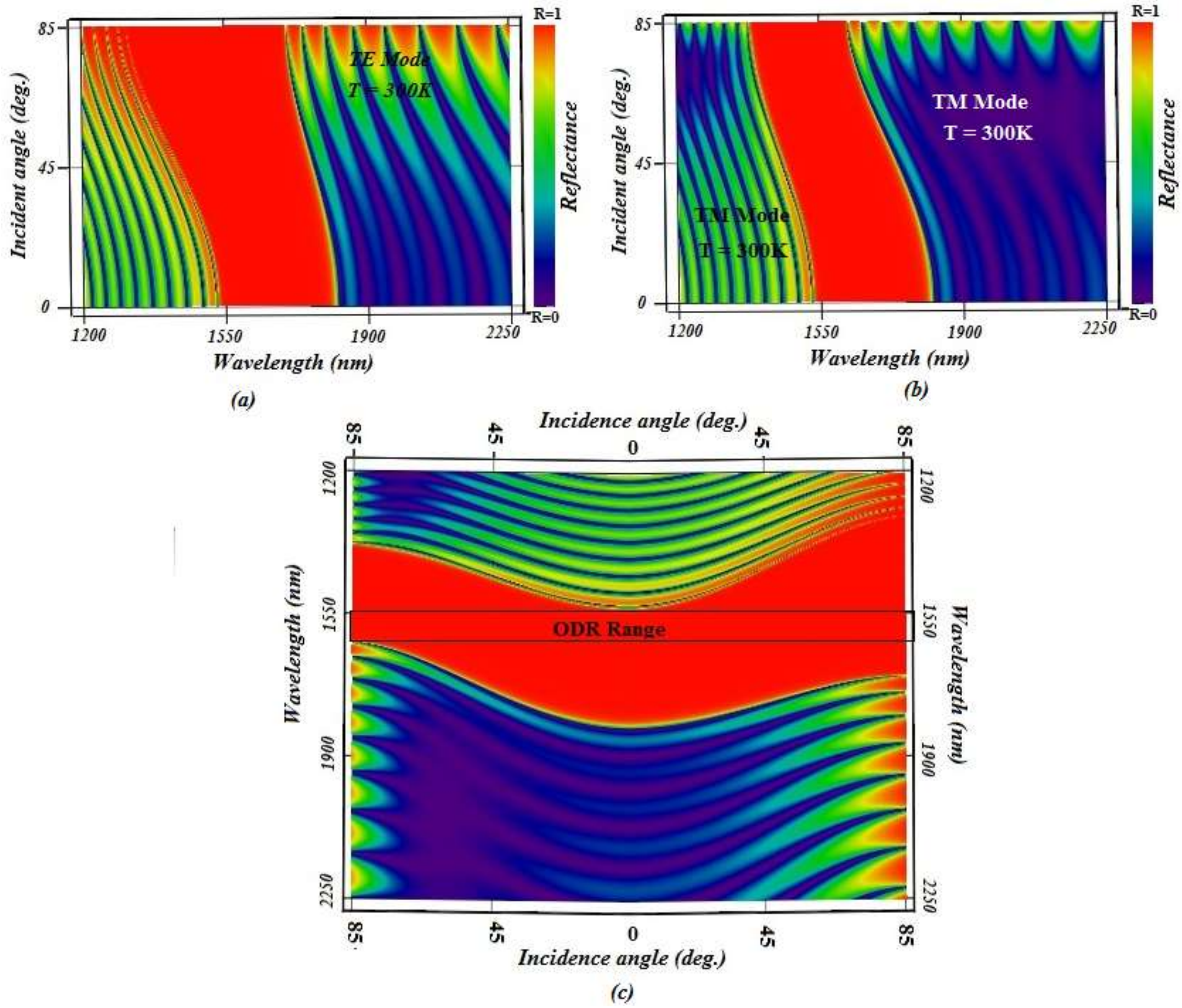

Fig. 2.ODR spectrum of 1D photonic crystals (ZnS/GaAs) at different angle of incidence at **T=300K**.

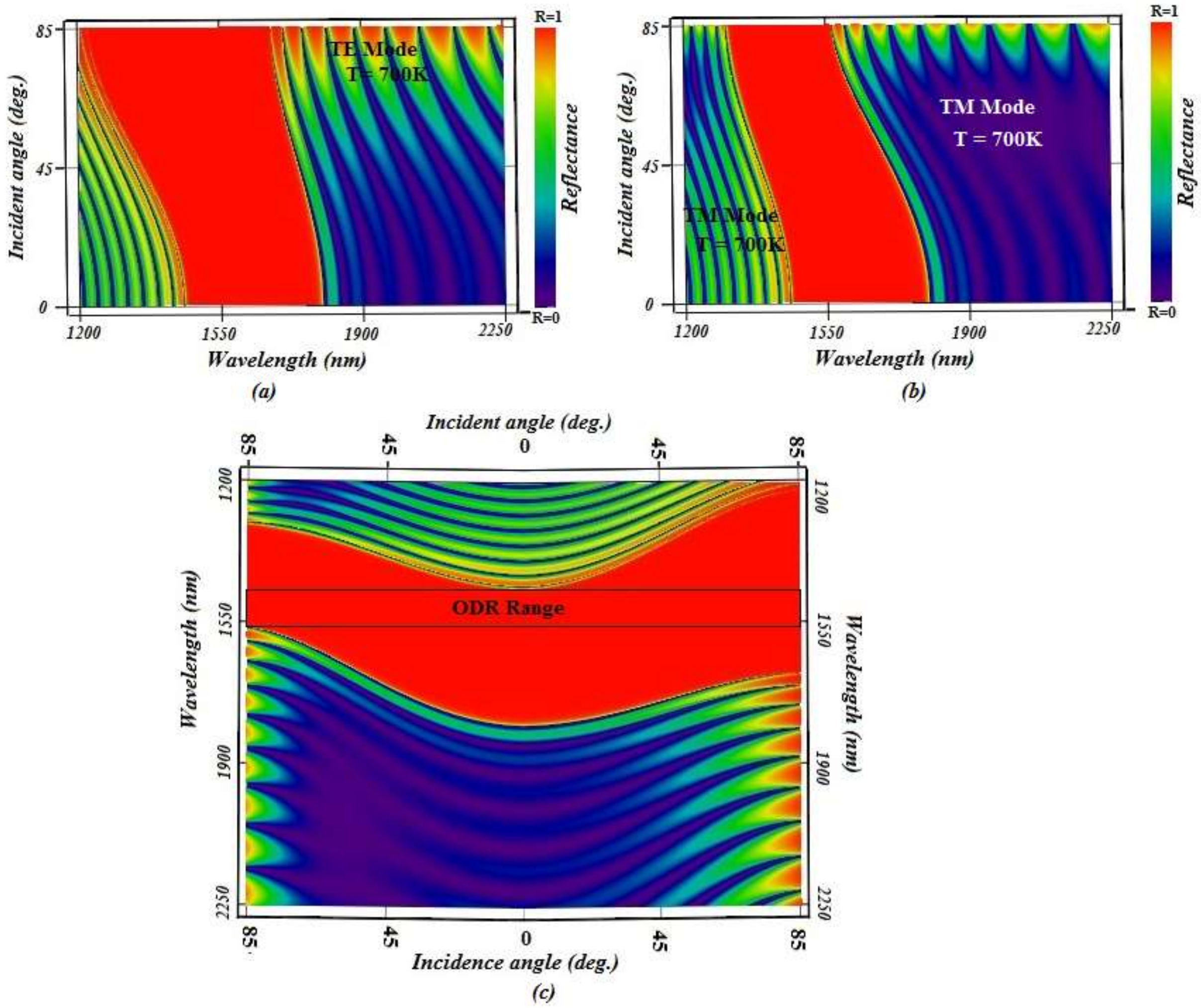

Fig. 3.ODR spectrum of 1D photonic crystals (ZnS/GaAs) at different angle of incidence at **T=700K**.

Hence, the semiconductor material ZnS is depending on the temperature, it can be used to design a thermally-tunable omnidirectional reflector. At third transmission window (1550nm) this multilayered can be used as an omnidirectional mirror in optical communication devices.

4. CONCLUSIONS

In this paper, we have theoretically designed a narrow band omnidirectional mirror at third transmission window by using one-dimensional photonic crystals composed of twosemiconductormaterials. In the present communication we observed that the ODR range of these semiconductor materials increases with increases temperature. At temperature T = 300K the total omnidirectional range (ODR) of wavelength for this multilayer structure is **72 nm** and at temperature T = 700K the omnidirectional range is **92 nm. Here, we** see that the ODR range of this structure is increased when temperature is increased. At temperature T = 300K to T = 700K the ODR range of this structure increases **20 nm** which can be used a narrow band omnidirectional mirror and tunable filter in fiber optic communication systems at third transmission window (1550 nm).

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