TEMPERATURE DEPENDENCE ZNS BASED ONE-DIMENSIONAL PHOTONIC CRYSTALS

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ABSTRACT

The temperature dependent properties of ZnS based one-dimensional photonic crystal has been investigated. Here we consider a periodic structure of semiconductor layer of ZnS/Ge. The effect of temperature and angle of incidence on omnidirectional reflection spectra of proposed structure has also been studied. The PBG can be tuned by varying the temperature of the semiconductor material. Also, the refractive index of ZnS layer to be dependent on temperature and wavelength simultaneously. The theoretical analysis shows that the proposed structure works as a perfect mirror within a certain wavelength range (1550 nm).

KEYWORDS: Photonic Crystal, ODR, Multilayered Mirror

INTRODUCTION

In 1987, Yablonovitch [1] and S. John [2] investigated the concept of photonic crystal structure. A class of photonic crystals exhibiting photonic bandgaps has become a field of intense research. These photonic bandgap are multilayer structures formed by using two or more materials. These multilayer structures lead to formation of photonic bandgaps, in which propagation of electromagnetic waves of certain wavelengths are prohibited. However, these bands or ranges depend upon a number of parameters such as refractive indices of materials, temperature and angle of incidence [3, 4]. If all other parameters such as temperature are kept constant, then any change in refractive index of a material will change the photonic bandgaps.

In 2002, Wing et al. [5] reported the enlargement of omnidirectional total reflection frequency range in one-dimensional photonic crystals by using photonic heterostructures. Also, Chigrin et al. [6] observed the observation of total omnidirectional reflection from a one dimensional dielectric lattice. Lee and Yao [7] studied theoretically and experimentally a wide range of structures for the fabrication of omnidirectional photonic crystals having photonic bandgaps in one-dimension. Ojha et al. [8, 9] theoretically studied omnidirectional high reflectors for infrared wavelengths, large omnidirectional reflection using combination of periodic and Fibonacci structures respectively. They found that the range of omnidirectional reflection can be increased by overlapping these photonic crystals.

In the present paper, we design a broad omnidirectional reflector (ODR) in one dimensional photonic crystal containing semiconductor layers. Also, the dielectric property of semiconductors depends not only on temperature but also on wavelength. Here we consider a semiconductor layer ZnS/Ge. The refractive index of Ge is independent of temperature and wavelength. But the refractive index of ZnS layer is taken as a function of
temperature and wavelength both [10, 11]. The semiconductor ZnS is depending on the temperature, it is possible to design thermally-tunable omnidirectional total reflector.

THEORETICAL MODEL

The one dimensional photonic crystal structure consisting of alternate layers of refractive indices \( n_1 \) and \( n_2 \) with thicknesses \( d_1 \) and \( d_2 \) respectively is depicted in Figure 1.

![Figure 1: Structure of One-Dimensional Photonic Crystals](image)

Applying transfer matrix method (TMM), we found out the properties of electromagnetic wave in layers of semiconductor materials. Therefore The reflection coefficient of the multilayer is given by,

\[
r(\omega) = \frac{(m_{11} + m_{12}p_0)p_0 - (m_{21} + m_{22}p_0)}{(m_{11} + m_{12}p_0)p_0 + (m_{21} + m_{22}p_0)}
\]

(1)

Where \( m_{ij} \) are the matrix elements and the reflectance for this structure can be written in the terms of reflection coefficient as

\[
R = |r(\omega)|^2
\]

(2)

Where, \( p_0 = n_0 \cos \theta_0 \)

In one dimensional photonic crystal we choose ZnS for material A, Ge for material B and \( N = 12 \), so the proposed structure will be [air/(ZnS/Ge)^12/air].

The refractive indices of Ge and ZnS are independent of temperature and wavelength. But the refractive index of ZnS layer is taken as a function of both wavelength and temperature. The refractive index of ZnS in the ranges 1.2–14 µm and 293–700K is represented as [14].

\[
n^2(\lambda, T) = \varepsilon(T) + \frac{A(T)}{\lambda^2 - \lambda_1^2} + \frac{B(T)}{(\lambda_2^2 - \lambda_1^2)} - 1
\]

(3)

Where,

\[
\lambda_1 = 0.23979 + 4.841 \times 10^{-5}T_1 \quad \lambda_1 = 0.23979 + 4.841 \times 10^{-5}T_1 \quad \text{and} \quad T_1 = T - 293
\]
RESULT AND DISCUSSIONS

In this section, we have presented the omnidirectional reflection spectra of one-dimensional photonic crystals. The refractive index of Ge is 4.23 which is independent of temperature and wavelength. But the refractive index of ZnS layer is taken as a function of both wavelength and temperature. Here, we have chosen the refractive index range of ZnS from 1.2–14 µm and temperature range from 300–700K.

Applying transfer matrix method, we have taken the thicknesses of Ge and ZnS layers to be $a = 250$ nm, $b = 200$ nm and $d = a + b = 450$ nm. At this particular combination of thickness of Ge and ZnS layers is choose such that ODR range in the reflection spectra of such a structure can be observed. Figure 2 & Figure 3 show the reflectance of the structure for the variation of refractive index profile of ZnS materials for different temperature (300K and 700K) and different angles of incidence, namely, 0°, 45° and 85° for TE and TM mode respectively and the ODR range for angles of incidence from 0° to 85° is shown in the shaded portion of Figure 2 and Figure 3.

From the plots of reflection spectra of ZnS and Ge for different angles of incidence, the 100 percent reflection ranges for different angles of incidence at Temperature 300K & 700K are tabulated in Table 1. It is clear from Table 1 that the total omnidirection range (ODR) of wavelength for this multilayer structure lies between 1534–1689 nm at T = 300K and the width of the omnidirection wavelength range is 155 nm and at T = 700K the omnidirectional range lies between 1460-1643 nm and the width of the omnidirection wavelength range is 183 nm. It is clear that when we increase temperature (at different angle of incidence) the bandgaps shift towards the shorter wavelength region which is shown in Figure 4.

Table 1: Photonic Bandgap Structure of 1d PC as a Function of Temperature and Angle of Incidence

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Angle Of Incidence (°)</th>
<th>TE (Nm)</th>
<th>TM (Nm)</th>
<th>TE (Nm)</th>
<th>TM (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0</td>
<td>1534-1837</td>
<td>1534-1837</td>
<td>303</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>1428-1799</td>
<td>1465-1765</td>
<td>371</td>
<td>370</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>1298-1778</td>
<td>1392-1689</td>
<td>480</td>
<td>297</td>
</tr>
<tr>
<td>700</td>
<td>0</td>
<td>1460-1830</td>
<td>1460-1830</td>
<td>370</td>
<td>370</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>1340-1791</td>
<td>1387-1742</td>
<td>451</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>1223-1762</td>
<td>1314-1643</td>
<td>539</td>
<td>329</td>
</tr>
</tbody>
</table>
Also, from this table it is clear that the omnidirectional bandgap shifts 4.2nm/100K at T=300K and 6.4nm/100K at T=700K towards the shorter wavelength region. Hence, this multilayered one-dimensional structure can be used as an omnidirectional mirror in optical communication devices. In this paper, we have chosen the parameters of this structure such that the 1550 nm wavelength which is third transmission window primarily used in optical communication falls in the omnidirectional reflection ranges of wavelength for these structures.

CONCLUSIONS

In this paper, we have designed a broad omnidirectional and thermally tunable PBGs in one-dimensional photonic crystals composed of the semiconductor-semiconductor materials. The angle and temperature dependence of these PBGs have been investigated. It is indicated that the bandgap width of these omnidirectional PBGs can be enhanced by increasing the temperature of this photonic crystal photonic crystal material layers. It is seen that the total omnidirection range (ODR) of wavelength for this multilayer structure is 155 nm at temperature T = 300K and at T = 700K the omnidirectional range is 183 nm. We see that the ODR range is increased when temperature is increased. At temperature T = 700K it increases 48 nm which can be used as omnidirectional reflectors in fiber optic communication systems which fall
in the wavelength range around 1550 nm (third transmission window). Such broad omnidirectional and thermally tunable PBGs will offer many prospects for omnidirectional mirrors, temperature sensing device, optical filters etc.

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REFERENCES
