P: ISSN NO.: 2394-0344 RNI No.UPBIL/2016/67980 VOL-2* ISSUE-8* November- 2017
E: ISSN NO.: 2455-0817 Remarking An Analisation

Narrow Band TM-Polarized Filter using 1D Dielectric Photonic Crystal

Abstract

An analytical study of one-dimensional photonic crystal with alternate layers of TiO_2 and SiO_2 has been studied. The reflectivity for TE and TM modes of proposed structure has been calculated theoretically employing Transfer Matrix Method. It is found that at communication wavelength (i.e. 1550nm) for an angle of incidence 78^0, the reflectivity of the TE mode for such a structure is unity and that of the TM mode is almost zero. This property may be exploited for the design of optical TE/TM mode filter.

Keywords: Photonic Crystal, Optical Filter, Transfer Matrix Method.

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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. 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. In the present study TM-polarized filter has been studied. The filter which allows passing TM-polarized wave but block TE-polarized wave through it is called TM-polarized filter. This type of structure can be exploited in designing optical switches, DWDM applications, optical sensors etc.

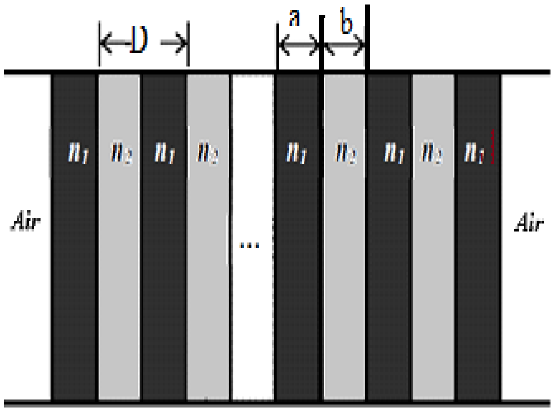
Review of Literature

Many studies on periodic structures for their optical properties have been worked out by many investigators in the last century. The concept of photonic crystals was put forward in the latter half of the 1980s. Notably, the pioneering works of by Yablonovitch[1] and John[2] may be considered as the new beginning of this exciting field of study. Generally, photonic crystal structures may be considered to be regular arrangements of dielectric materials which may lead to the formation of an energy band structure for electromagnetic wave propagating through them. The majority of applications of photonic crystals exploit the phenomenon of photonic band-gap (PBG). Photonic band-gap may be defined as a frequency region characterized by zero density of the electromagnetic states. The propagation of electromagnetic waves inside of a photonic crystal is, therefore, suppressed for the frequencies within PBG. Because of the existence of PBGs in certain photonic crystals, the design of efficient low-loss dielectric reflectors that can confine radiation in channels (waveguides) or localized defects (resonators) with sizes comparable to the wavelength of light has become a possibility.

The possibility of the design of optical band-pass filter in near and far infra-red regions based on one dimensional photonic crystals was suggested in 1992 by Ojha et al [3]. Later on Chen et al. calculated important results on photonic filters by using photonic air bridges[4]. Photonic band gap filter for wavelength division multiplexing was fabricated by D'Orazio et al. [5]. However, S.K. Singh et al. obtained large frequency range of omni-directional reflection by overlapping two photonic crystals[6]. In another investigation, Villar *et al*. have analyzed one-dimensional photonic band gap structures with a defect layer of liquid crystal for the development of fiber-optic tunable wavelength filters[7]. Recently, Kumar et al. proposed a simple design of a cascaded photonic band gap filter in ultraviolet region[8]. Qiao et al. [9] reported a new kind of photonic crystal constructed by different positive index materials is called Photonic Quantum Well (PQW). With the help of this structure photonic band gaps may be enlarged and narrow multichannel filters can be obtained[10-14].

In the present paper we use alternate layers of TiO_2 and SiO_2 .One of the most important properties of fused silica is its extremely low coefficient of expansion: 5.5 x 10^{-7} mm This makes the material particularly useful for optical flats, mirrors, furnace windows and critical optical applications On the other hand, titanium dioxide (TiO_2) is attracting wide attentions due to its novel applications in photo catalysts, sensors and solar cells. . First of all, TiO_2 has a fairly large refractive index which is large enough to form a photonic band gap in photonic structures. Secondly, the optical absorption loss of TiO_2 is about 10 times lower than that of silicon at the optical communication wavelength of 1.5μm. thirdly; its thermal expansion coefficient is very small.

Fig.1: Periodic Variation of One Dimensional Photonic Band Gap Structure



Theory

Using transfer matrix method, which is widely used for the description of the properties of stacked layers, used it to determine the reflectivity and transitivity of photonic structures.

Let us consider the stack of N layers perpendicular on the OZ axis as it can be seen in fig.1. The index of refraction profile in the form of rectangular symmetry is given by:

$$n(z) = \begin{cases} n_1, 0 < z < d_1 \\ n_2, d_1 < z < d_2 \end{cases}$$

Where

$$n(z) = n(z + md) \; and \; m = 0, \pm 1, \pm 2, ...$$

and d=d1+d2 is the lattice period.

To determine the electric field, we solve the following system and find the relation between A_0, B_0, A_s, B_s

$$\begin{pmatrix} A_0 \\ B_0 \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} A_s \\ B_s \end{pmatrix}$$

$$\begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} = D_0^{-1} \left[\prod_{i=1}^{2} D_i P_i D_i^{-1} \right]^N D_s$$

Where

$$D_i = \begin{cases} \begin{pmatrix} 1 & 1 \\ n_i \cos\theta_i & -n_i \cos\theta_i \end{pmatrix} & for \; TE wave \\ \begin{pmatrix} \cos\theta_i & \cos\theta_i \\ n_i & -n_i \end{pmatrix} & for \; TM wave \end{cases}$$

and $P_i = \begin{pmatrix} e^{j\phi_l} & 0 \\ 0 & e^{-j\phi_l} \end{pmatrix} \qquad with \phi_l = k_i d_i$

Where (l=1, 2 for the first and second layers of the unit cell respectively and N is the period of the structures). The reflectance and transmittance of the structure for TE and TM polarizations are given by

$$R = \left| \frac{M_{21}}{M_{11}} \right|^2 \; and \; T = \frac{n_s \cos\theta_s}{n_0 \cos\theta_0} \left| \frac{1}{M_{11}} \right| \qquad (3)$$

Where n_0 and n_s are the index of refraction of incident medium and substrate.

According to Bloch's theorem, the Bloch wave vector K is obtained by solving the eigen value problem. The dispersion relation between K and ω for Bloch waves, can be expressed as

$$K(\omega) = \frac{1}{D} \cos^{-1} \left[\frac{1}{2} \left(M_{11} + M_{12} \right) \right] \qquad (4)$$

Result and Discussion

In this section, by using equation (3) the reflection and transmission properties of one dimension photonic crystal have been presented. For numerical computation,we use Air/$(AB)_{16}$/Air structure, where $(AB)_{16}$ is the periodic multilayered structure consist of 16 sub-layers of AB unit cell. For AB stack, we choose the material of layer A as TiO2 and the material of layer B as SiO2 having refractive indices 2.65 and 1.45 respectively. The incident and emergent medium is taken as air .

(1)

Fig. 2: Dispersion Spectra of TiO_2 /SiO_2 one Dimensional PC for TE and TM Polarization with angle of incidence at 78^0

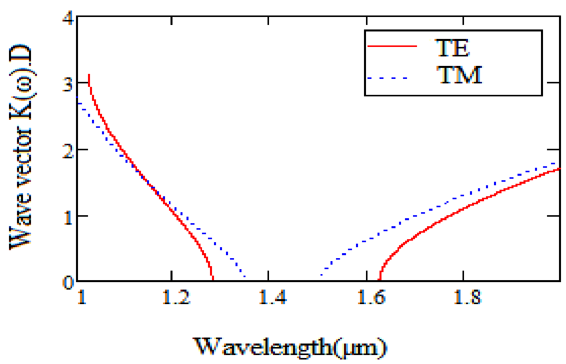


Figure 2 depicts the Dispersion spectra of photonic structure Air/ $(AB)_{16}$ /Air. From Figure2, it is clearly seen that there are photonic band gaps (PBGs) for TE 1.280-1.626 μm and TM 1.347-

1.504µm ranges of wavelength at angle 78^0.It is noticeable that at particular wavelength 1.55 µm TE mode present the band gap but TM mode does not .i.e. TE mode waves completely reflected and do not pass through the crystal on the other hand TM mode waves show vice versa properties. This phenomenon can also be studied with the help of figures 3, 4 and 5.

Fig. 3: Reflectance vs. Incident Angle at λ=1.55µm

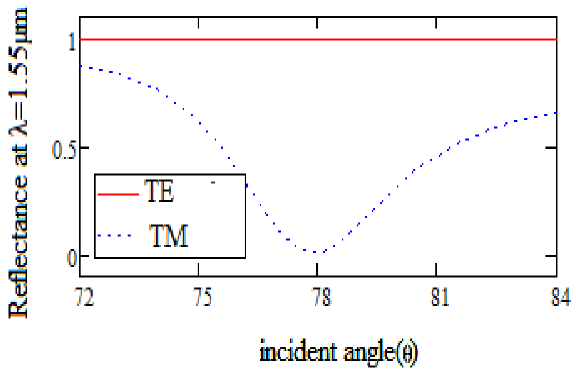


Fig. 4: Transmittance vs. incident angle at λ=1.55µm.

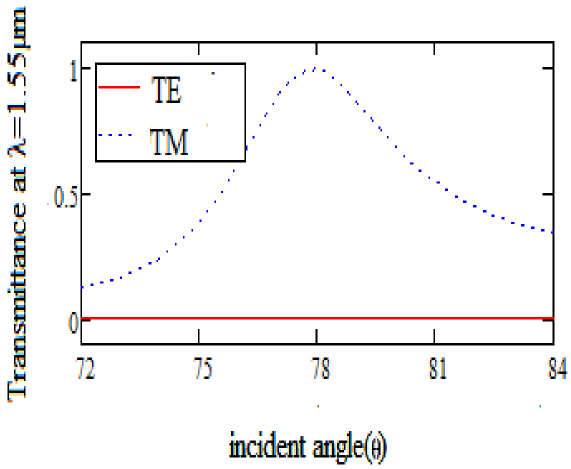


Fig. 5: Reflectance spectra at oblique angle of incidence78^0 of TiO_2/SiO_2 one dimensional PC for TE and TM polarizations

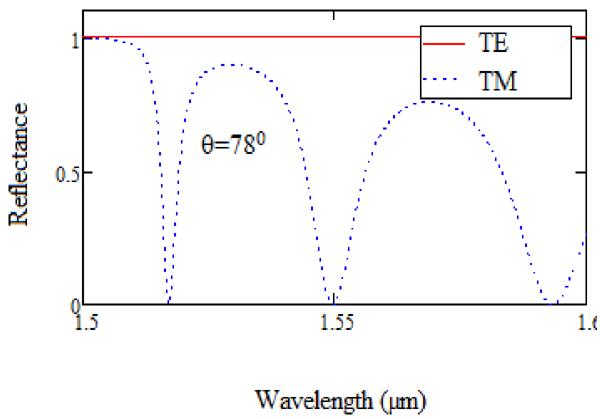


Fig.3, 4 shows the reflectivity and transmittivity of TE and TM mode at different angle of incidence. Fig. 5 shows the reflectivity at different wavelength. On studying this figure it is noticeable that at particular angle and wavelength TE and TM mode exhibit unique properties. At angle 78^0 and λ=1.55µm which is the mean wavelength of optical window and can be used in fiber optics communication, the reflectivity of TE mode is unity and its transmittivity is zero while TM mode shows vice versa i.e. TE waves are completely reflected and do not pass through the crystal but TM waves are completely transmitted at this wavelength and angle.

Conclusion

It can be concluded that it is possible to achieve TE and TM mode filter by using this property. It is also called as a demultiplexer because by using that type of photonic crystal we can increase the storage capacity of line in fibre optics communication. So we can use the proposed device as a tunable demultiplexer in optical communication. The proposed device may also be used as a single channel drop filter, and it may have many applications in different optical systems.

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