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The defect states in the photonic crystal introduce additional modes in the photonic band gap

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ABSTRACT

Introducing a defect layer in photonic crystals lead to additional mode of propagation in the photonic band gap. It can be seen that there is a sharp transmission peak in the gap. The transmission peak is caused by the defect state and when the order of the defect layer increases, additional modes occurs in photonic band gap.

KEYWORDS : Photonic Band Gap; 1D Photonic Crystal; Transmittance

1. Introduction

The concept of photonic crystals (PCs) was first pro-posed by Yablonovitch and John in 1987 [2] who found that using periodic arrangement of dielectric materials enables us to control the propagation of electro-magnetic waves. The most significant feature of a PC is the existence of photonic band gap (PBG), a frequency range in which the electromagnetic waves cannot propagate. The PBG in a PC is analogous to the electronic band gap in a solid because of the similarity between the structural periodicity of a PC and the periodic potential energy in a solid. If the periodicity of the PC is interrupted, such as the thickness of a layer being changed [3], or another medium being added into the structure [4], some defective modes could be generated within the PBGs. In a simple one-dimensional PC of AB n, the defect mode can be obtained in a defective structure like AB n D/B m AB n, where D is known as a defected layer. The defect mode is a strongly localized defect state which, in general, can be seen in the transmission spectrum with a sharp narrow resonant peak. With the presence of resonant peak in transmittance, the structure is often used as a narrowband transmission filter [5].

The PBG structures can be used in various applications such as add-drop multiplexers, waveguides, mirrors, and resonant cavities. Meanwhile, the optical confinement effect in photonic crystals with defects can be exploited to enhance the nonlinear optical effect. One possible method to realize a nonlinear photonic crystal structure is to insert a nonlinear optical material between two distributed-Bragg reflectors (DBRs), where each DBR consists of alternating high- and low-index layers with quarter-wave thicknesses [1]. Another possible method is to use a nonlinear optical material as a lattice element of the photonic crystal [2].

Linear and Nonlinear Optical Properties of Photonic Crystals

We consider a one-dimensional photonic crystal structure, as shown in **Figure 1**, the structure of this photonic crys

tal constituted of high (A) and low(B) refractive index materials with m layers of defect materials. Here the thickness of A and B i.e., SiO2 and Si is d 1 and d2, corresponding to the materials with refractive indices n1 and n2, respectively. The concept of defect in the PBG mate-rials has led to a large number of applications as for the semiconductor materials. The suitable thickness of BaTiO3, of m layers is introduced as the defect layer in the PC.

Figure:1. Schematic diagram of 1-D photonic crystal with defect.

For TE wave, the characteristic matrix for a single period is given by

$$M \quad \begin{matrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{matrix} \quad {}_{j\,1}^{N} M_j \qquad (1)$$

If the jth layer is characterized by the refractive index, n_j, the extinction coefficient, k_j, and the thickness, d_j then the individual transfer matrix, M_j, is given by

$$M_j \quad \begin{matrix} \cos\frac{2\pi}{} \quad {}_{p_j d_j} & i\frac{1}{p_j} \quad \sin\frac{2\pi}{} \quad {}_{p_j d_j} \\ \frac{2\pi}{} \quad {}_{p_j d_j} & \cos\frac{2\pi}{} \quad {}_{p_j d_j} \end{matrix} \qquad (2)$$

where p_j $N_j \cos_j$ N_j n_j ik_j is the complex refractive index of the jth layer, and θ_j is the angle of incidence for the jth layer. For the wavelength 0.633 μm .The overall structure remains HL[4] DL[m] HL[4], where H and L remain to be Si and SiO_2, respectively. The thickness of H and L layers remains to be 50 nm and the thickness of D layer is 150 nm. The refractive indices for A and B and defect layer are 3.45, 1.45 and 2.416 respectively [3]. Here we analysed the photonic band gap by suitable absorption mechanism. A saturable absorption-based photonic crystal is described by

$$\text{where } N_d^{NL} \quad n_d^{L} \quad ik_i^{NL} \quad n_h / n_l \; {}^{4} / \; N_d^{NL} / n_l \; {}^{m} / n_l \; / n_h \; {}^{4}$$

$$k_d^{NL} \quad \frac{k_d^{L}}{1 \;\; bI}$$

$$c^{b} \quad \frac{2\pi}{b}$$

Here, I is the laser-beam intensity at the sample posi-tion, and β is the nonlinear absorption coefficient that characterizes the saturable absorption of the nonlinear defect. To compute the defect mode in the transmission spectra, we employ the transfer matrix method (TMM) [4]. The transmission coefficient for tunneling through such as structure is given by

$$t \quad \frac{4}{m_{11} \quad m_{22} \;{}^{2} \quad m_{12} \quad m_{21} \;{}^{2}}$$

We now turn our attention to the voltage dependence of the defect modes with a nonlinear optical material, namely BaTiO3.

Bias Voltage Dependence of Defect Modes

When an external voltage is applied to the Defect layer, as depicted in figure 6 taking m = 2 for example, its index of refraction will change with the electric field due to the electro-optic effect.

The relation can be expressed as [15]:

$$n_{BT} \quad n_{BT}^{\frac{1}{2}} \quad n_{BT}^{3} \quad E_{BT}$$

where BT is the electro-optic coefficient of the Barium Titanante, with the value of BT is 820 × 10−12 m/V, and E is the externally applied electric field. The relation between E and the external applied voltage V is E = V/(0.4 mm), where 0.4 mm is the distance between the electrode pair. The index of refraction of Barium Titanate is 2.416 at zero bias voltage. The refractive index of Barium Titanante at various external voltage applied is calculated using the above formula. Hence, the transmit-tance peak in the photonic band gap is calculated at vari-ous voltages.

3. Results and Discussion

The photonic crystals consisting of Si-Sio2 with defect layer is analysed. The schematic diagram of 1D photonic crystals is shown in figure 1. Here, we have studied both linear effect and nonlinear effect of the photonic crystal. It was found that a photonic gap exists in the above said photonic crystal without the defect layer as suggested by some recent literature [1]. It is shown in figure 2. The value of the gap was found between 427 nm and 630 nm. We also found that when we introduce a defect layer BaTio3/Sio2 in the above said photonic crystals, an additional mode of propagation is obtained in the photonic band gap[8]. The photonic band gap is between 420 nm and 665 nm. It can be seen that there is a sharp transmission peak at 552 nm in the gap as shown in fig-ure 3. The transmission peak is caused by the defect state.

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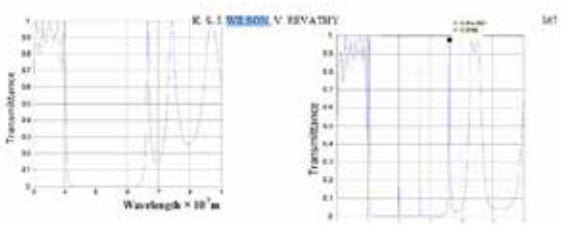

Figure 2. PBG crystal without defect. Figure3. PBG crystal with defect

Conclusion

The concept of defect in the PBG materials has led to a large number of applications as for the semiconductor materials. The defect states in the photonic crystal introduce additional modes in the photonic band gap. This can be greatly applied in many fields such as diode laser, non-threshold laser, PC fiber etc. It can be seen that there is a sharp transmission peak in the gap. The transmission peak is caused by the defect state.

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