Reflectance, Transmission and Absorption Spectra of Te/PS Multilayer Structure with Defect of Metamaterial at Terahertz Region

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Abstract

The interaction of wave with matter defines the optical properties of periodic of one-dimensional periodic structure (1DPS) of the materials. The optical properties like reflectance, transmittance and absorption spectra of one dimensional(1D) tellurium and polystyrene based symmetric and asymmetric periodic structure theoretically analysed with defect of meta-material using the transfer matrix method (TMM). Reflectance, transmittance and absorption spectra are analysed for symmetric structure found an enormous band gap which works as a broadband reflector and asymmetric structure shows the separated huge band gap in two parts. The defect of meta-material inserted in the tellurium and polystyrene based periodic structures are analysed the broadband reflector, multichannel filter and sensor applications at terahertz region.

Keywords: Tellurium, Polystyrene, Meta-material, Photonic Crystal, Broadband multichannel filter and Sensor.
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Introduction

A periodic stack structure of different dielectric materials, called photonic crystals (PCs), that controls the electromagnetic wave propagation by varying the parameters of dielectric constant. In 1987 first time Yablonovitch and John have proposed concept of photonic band gap (PBG) of the PCs due to wave resonance in the periodicity of the dielectric materials [1, 2]. A PBG depends upon the index of refraction, number of stacks, fraction of filling, and incident wave frequency range etc. [3]. The PBG periodic structures are used in various applications due to their unique properties for controlling the electromagnetic waves. These materials have potential candidates for the development in science and technology, particularly in the development of optical devices. The simplest PCsare the layered media having the periodicity of materials in one direction, called 1DPS, and can be fabricated easily using the technology of thin-film. 1DPS has various applications in optical and photonic devices, tunable filters, multichannel filters, broadband reflectors, microwave absorbers, optical sensors, optoelectronic devices, and omni-directional filters [4-23].

In 1968, Veselago theoretically predicted the concept of electric permittivity and magnetic permeability of the materials are the fundamental characteristics and it determines the electromagnetic wave propagation in the matter [24]. These materials, also known as meta-materials, double negative (DNG) materials, or negative index materials (NIMs), have both magnetic permeability and electric permittivity values that are negative at the same time. Double positive (DPS) materials, on the other hand, have positive magnetic permeability and electric permittivity. The Kramers-Kronig relation states that meta-materials are both dispersive and lossy. Therefore, meta-materials must have a complicated refractive index. The wave's propagation is shown by the real component of the refractive index, while the wave's attenuation or decay is indicated by the imaginary part. Meta-photonic crystals are double negative and double positive periodic formations. Because of factors including thickness, refractive index, contrast, and incident angles, these meta-photonic crystals also displayed two different kinds of band gaps: Bragg's gap and zero index gap [25-32].

Theoretical Methodology

The reflectance, transmittance and absorption of 1DPS containing tellurium and polystyrene and defect with meta-material are calculated using TMM. 1DPC is taken as symmetric structure $(AB)^N$ asymmetric structure $(AB)^{N/2}(AB)^{N/2}$ and $(AB)^{N/2}(M)(AB)^{N/2}$ where N=6 is a number of lattice period; A and B are represented as tellurium and polystyrene, and M denotes the meta-material, respectively. The relationship is used to determine the meta-material's magnetic permeability and electric permittivity [33].

$$\varepsilon_m(\omega)=1+\frac{5^2}{0.9^2-\omega^2-i\omega\gamma_e}+\frac{10^2}{11.5^2-\omega^2-i\omega\gamma_e}$$

$$\mu_m(\omega)=1+\frac{3^2}{0.902^2-\omega^2-i\omega\gamma_m}$$ and the index of refraction, $n_m=\sqrt{\varepsilon_m\mu_m}$, ω is the angular frequency in THz, γ_e and γ_m are the electric and magnetic damping frequencies.

By examining the characteristic matrix for the photonic crystal, the optical property of the structure is ascertained. i.e. $(AB)^N$ and it can be expressed by [34].

$$M(d)=\begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix} \quad (1)$$

where $M(d)=(AB)^N$; N is number of lattice period, M_A and M_B are the characteristics matrices of material A and B, respectively.

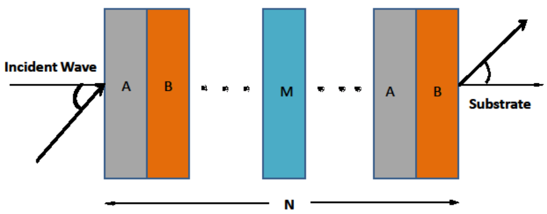

Figure 1: shows the tellurium (A) and polystyrene (B) with defect of meta-material (M) based 1D symmetric periodic structure.

The matrix M_i for each layer where $i = A\&B$ is calculated for the TE wave at the angle of incidence θ_0.

$$M_i=\begin{bmatrix} \cos\eta_i & -\frac{i}{p_i}\sin\eta_i \\ -ip_i\sin\eta_i & \cos\eta_i \end{bmatrix} \quad (2)$$

where $\eta_i=\frac{\omega}{c}n_i d_i\cos\theta_i$, c is the speed of light in vacuum, θ_i is the ray angle inside i[th] layer with a refractive index as, $n_i=\sqrt{\mu_i\varepsilon_i}$, $p_i=\sqrt{\frac{\varepsilon_i}{\mu_i}}\cos\theta_i$ and $\cos\theta_i=\sqrt{1-\frac{n_0^2\sin^2\theta_0}{n_i^2}}$ in which n_0 is the index of refraction of the air.

The coefficient of transmission of the 1DPS is calculated by,

$$t=\frac{2p_0}{(m_{11}+m_{12}p_s)p_0+(m_{21}+m_{22}p_s)} \quad (3)$$

where $p_0=n_0\cos\theta_0$ and $p_s=n_s\cos\theta_s$ where n_s is the index of refraction of the substrate, Θ_s is the ray angle.

The transmittance of the 1DPS is given by,

$$T=\left(\frac{p_s}{p_0}\right)|t^2| \quad (4)$$

The coefficient of reflection of the 1DPS is calculated by given relation-

$$r=\left|\frac{m_{11}+\frac{m_{12}}{p_0}-m_{21}p_0-m_{22}}{(m_{11}+\frac{m_{12}}{p_0})+(m_{21}p_0+m_{22})}\right| \quad (5)$$

where $p_0=n_0\cos\theta_0$ and $p_s=n_s\cos\theta_s$, n_s is the index of refraction of substrate.

The reflection spectra 1DPS are calculated by-

$$R=|r|^2 \quad (6)$$

Using the relations of T and R, the absorption spectra of 1DPS are given by;

$$A=1-R-T \quad (7)$$

Results Analysis

In this research article, we have theoretically analysed the reflectance, transmittance and absorption spectra of tellurium (Te) and polystyrene (PS) based 1Dperiodic symmetric, asymmetric and defect with meta-material using well known simple TMM. The parameters for tellurium (Te) and polystyrene (PS) material are $\varepsilon_{Tellurium}=21.16$,

$\mu_{Telluriumc} = 1$, $n_{Tellurium} = \sqrt{\varepsilon_{Tellurium}\mu_{Tellurium}}$

$d_{Tellurium} = \dfrac{\lambda}{4n_{Tellurium}}$ and $\varepsilon_{Polystyrene} = 2.56$,

$\mu_{Polystyrene} = 1$, $n_{Polystyrene} = \sqrt{\varepsilon_{Polystyrene}\mu_{Polystyrene}}$

$d_{Polystyrene} = \dfrac{\lambda}{4n_{Polystyrene}}$ where wavelength $\lambda = 1.55 \times 10^{-6}\,m$. The permittivity and permeability of the meta-material are calculated by using the relation [33].

$$\varepsilon_m(\omega) = 1 + \frac{5^2}{0.9^2 - \omega^2 - i\omega\gamma_e} + \frac{10^2}{11.5^2 - \omega^2 - i\omega\gamma_e},$$

$\mu_m(\omega) = 1 + \dfrac{3^2}{0.902^2 - \omega^2 - i\omega\gamma_m}$ and refractive index of the material $n_m = \sqrt{\varepsilon_m\mu_m}$ where ε_m and μ_m are the permittivity and the permeability and the thickness of meta-material $d_m = \dfrac{\lambda}{4n_m}$ of the meta-material (M) layer and ω is the frequency in THz.

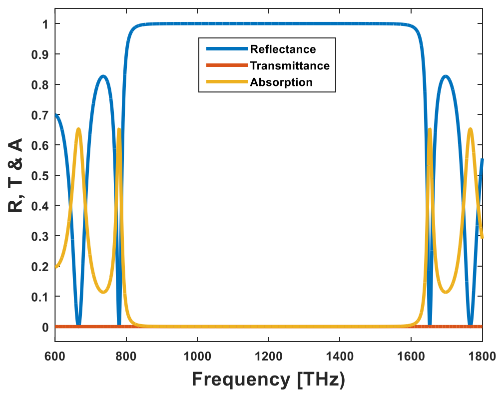

Figure 2: shows the reflectance, transmittance and absorption spectra of tellurium and polystyrene based 1D symmetric periodic structure.

The electromagnetic wave interaction with material plays a key role to analyse the optical properties of periodic structure. The optical properties like reflectance, transmittance and absorption spectra of tellurium and polystyrene based one dimensional symmetric and asymmetric periodic structure with defect of artificial meta-material are analysed using the concept of transfer matrix method in terahertz (THz) range of electromagnetic spectrum. The analysed result of tellurium and polystyrene based symmetric structure shows a huge band gap in terahertz region. Photonic band gap is the key role in the direction of optical properties of the periodic structure of the materials that controls the wave propagation in periodic structure. On the variation of the variable parameters the band gap can be tuned of the periodic structure. On the basis of the behaviour of tuned band gap that decides the applications in the direction of science and technology. The band gap of considered symmetry exists nearly frequency (800-1600 THz) region and this acts as a broadband reflector as shown in Fig 2. On changing the symmetry of considered periodic structure shows a huge band gap that separated in two parts and size of the band gap also increases on the variation of frequency (THz) range as shown in Fig 3.

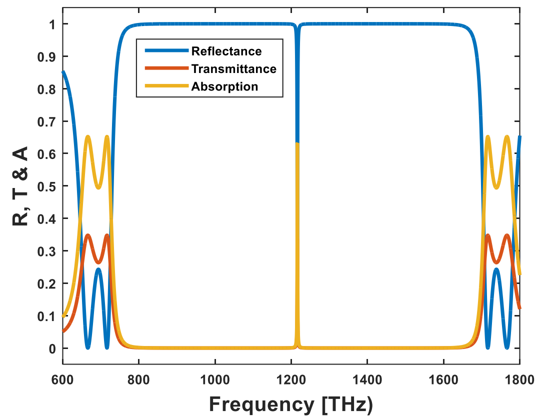

Figure 3: shows the reflectance, transmittance and absorption spectra of tellurium and polystyrene based 1D asymmetric periodic structure.

The defect behaviour is very enormous behaviour to analyse the optical property of periodic structure of the possible materials. The defected periodic structure can be tuning the possible variation of variable parameters that suggested to development of fabrication of optical device in the electromagnetic spectrum.

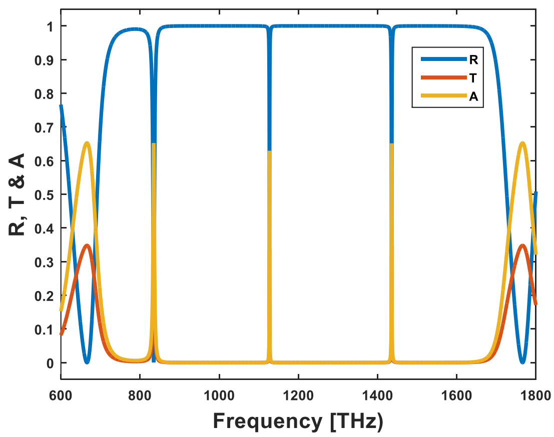

Figure 4: shows the reflectance, transmittance and absorption spectra of tellurium and polystyrene based 1DPS with defect of meta-material structure.

In our study, we have considered simple tellurium and polystyrene based periodic structure with defect of artificial meta-material to understand the concept of device fabrication. Reflectance, transmittance and absorption spectra of tellurium and polystyrene based periodic structure with defect of meta-material theoretically investigated the concept of multichannel filter at terahertz region. As we inserted the defect of meta-material layer in the considered periodic structure the behaviour of reflectance, transmittance and absorption spectra shows extremely behaviour to develop the multichannel filter and sensor and absorption-based devices at terahertz region as shown in Fig 4.

Conclusion

The calculated results of tellurium and polystyrene based one dimensional symmetric, asymmetric periodic structure and defect with meta-material shows exclusive result in terahertz region. The calculated results of considered one dimensional symmetric periodic structure acts as broadband reflector and asymmetric periodic structure shows the behaviour of tuned band gap on changing the symmetry of periodic structure. The defect of meta-material inserted in the tellurium and polystyrene based periodic structure and obtain innovative idea to fabricate the multichannel filter and sensor at terahertz region.

Conflict of interest

There is no conflict of interest.

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