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A PROPOSAL FOR ANTI-UVB FILTER BASED ON ONE-DIMENSIONAL PHOTONIC CRYSTAL STRUCTURE

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In this work we proposed an Anti-UVB filter based on 1D photonic crystal structures. The UVB radiation is very harmful for human beings and its range is between 280 nm and 320 nm of wavelengths. It can cause many skin disorders. It is harmful for eye and also affects DNA and drugs. So filtering it out of sun light is very important. In this paper we design a filter to forbidden this hazardous radiation. The proposed structure has a bandgap between 280 nm and 320 nm. Transfer Matrix Method (TMM) is used for simulation of this structure.

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1. Introduction

Human beings are daily exposed to Ultra Violet (UV) radiation from the sun. UVB (280nm- 320nm) makes up 4% to 5% of UV light but is the most effective constituent of solar light. UVB causes sunburn 1000 times more than UVA [1]. UVB radiation is the main culprit of various skin anomalies like erythema and edema [2]. Phototoxic effects induced by UVB radiation involve the generation of Reactive Oxygen Species (ROS) resulting in oxidative damage [3].

These events can ultimately lead to diseases related to UV radiation, such as irritation or sunburn, photo allergy and skin cancer [4]. UVB irradiation results in DNA damage and delayed apoptosis and cell death [5]. Photo aging is also occurring mainly due to UVB radiation [6]. UVB radiation has harmful effects on eyes and also some drugs and chemically alters their functionality. Furthermore increased levels of UVB radiation during winter and spring time threatens the survival of life on the earth, also by present trend of ozone depletion it became even worse.

According to above discussion filtering out the UVB radiation from the solar light is very crucial for human health. So in this work we aim to design a filter which is able to filter the UVB radiation and pass the rest of the sun light. For this purpose we suggest photonic crystals. Photonic crystals are the best candidates for designing ultra compact structures.

As far as we know photonic crystals are periodic arrays of dielectric layers with alternating refractive indices. The period of these arrays is called lattice constant. According to their structure and the periodicity of the refractive index distribution they are divided into three categories: one-dimensional, two-dimensional and three-dimensional photonic crystals (1D PhC, 2D PhC and 3D PhC). One of the most important characteristics of these artificial structures is their Photonic Band Gap (PBG). Photonic band gap is a special region in the band structure of photonic crystals in which no optical wave is allowed to propagate through them. That is, any optical ray striking to these structures, if it's wavelength be in the band gap range of the photonic crystal, the ray will be reflected completely and it won't be able to penetrate into the structure [7-8]. Optical circulators [9], optical switches [10], power splitters [11], optical demultiplexers [12-13] and optical filters [14] are some reported examples of photonic crystal based devices.

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One-dimensional photonic crystal filters are very popular among the researchers. Defect mode properties [15], light transmission characteristics [16] and photonic band gap controlling [17] in one-dimensional photonic crystals have been investigated. There has been much kind of one-dimensional photonic crystal filters. For example a 1D Si/SiO_2 photonic crystal filter for thermo photovoltaic applications has been proposed [18] in which large oscillations around 1.45-1.75 μm in the pass band of this PhC filter would reduce the above band gap power transmitted to cells, leading to discounts of system efficiency and power density. Another example of recent works on 1D photonic crystal is a narrow pas band and narrow transmission angle filter [19]. This structure was composed of two parts: the first part was a 1D PhC with positive refractive index defect layer and the second part was a 1D PhC with negative refractive index defect layer. So it was capable of filtering the incident angle and only the waves which are normal to the structure at the specified frequency are allowed to transmit through the filter.

In this work we propose a structure, a one-dimensional photonic crystal based filter whose band gap is such that it can filter the UVB radiation and so no UVB radiation is allowed to pass through this structure but other rays of the sun light can pass through it.

2. Mathematical theory

In order to design our anti-UVB filter based on photonic crystals we should calculate the band structure of the photonic crystal based filter and try to locate its band gap in the desired wavelength range. Transfer Matrix Method [20] is the simplest and the most straight forward tool for analyzing 1D PhC's so we employ it to do our simulations and calculations. Firs we briefly introduce the TMM method. The schematic of our one dimensional photonic crystal is shown in Fig. 1.

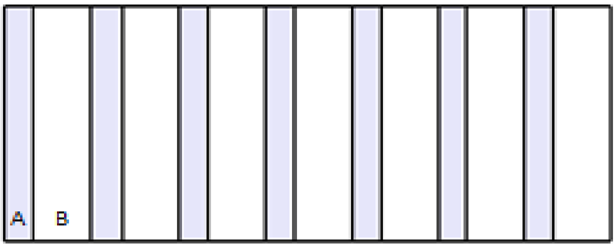


Fig. 1. The schematic of the proposed structure.

The transmittance in the structure:

$$T = |t|^2 \tag{1}$$

And the reflectance:

$$R = |r|^2 \tag{2}$$

are directly determined by the transmission coefficient t and the reflection coefficient r respectively. According to TMM, t and r are expressed as follow:

$$r = \frac{M_{21}}{M_{11}} \tag{3}$$

and

$$t = \frac{1}{M_{11}} \tag{4}$$

Where M_{11} and M_{12} are the matrix element of total transfer matrix M for the entire structure given by

$$M = \begin{bmatrix} M_{11} & M_{21} \\ M_{21} & M_{22} \end{bmatrix} = D_0^{-1} M_a^N D_0 \tag{5}$$

Where N is the number of the periods and M_a is the transfer matrix of one period given by

$$M_a = D_1 P_1 D_1^{-1} D_2 P_2 D_2^{-1} \tag{6}$$

Where D_m is the dynamical matrix given by:

$$D_m = \begin{cases} \begin{bmatrix} 1 & 1 \\ n_m cos\theta_m & -n_m cos\theta_m \end{bmatrix} & for\ TE\ wave \\ \begin{bmatrix} cos\theta_m & -cos\theta_m \\ n_m & -n_m \end{bmatrix} & for\ TM\ wave \end{cases} \tag{7}$$

Where m=0, 1 and 2 that m=0 represents the free space and θ_m is the the ray angle in each layer and P_m is the propagation matrix given by:

$$P_m = \begin{bmatrix} \exp(ik_m h_m) & 0 \\ 0 & \exp(-ik_m h_m) \end{bmatrix} \quad m = 1,2, \tag{8}$$

Where h_m is the thickness of the dielectric layers and $k_m = \omega n_m cos\theta / c$ in which ω is the angular frequency.

3. Calculations and results

Every one-dimensional photonic crystal is composed of two dielectric layers with different refractive indices which are repeated in one-direction. These refractive indices and the thickness of the layers are very important and directly control the band gap of the one-dimensional photonic crystal. The center wavelength of the photonic band gap of one-dimensional photonic crystal should satisfy the following relation:

$$n_a l_a + n_b l_b = \frac{\lambda_0}{2} \tag{9}$$

Where n_a and n_b are the refractive indices and l_a and l_b are the thicknesses of the first and the second dielectric layers, respectively and λ_0 is the center wavelength of photonic band gap. In order to have large band gap we use the following relation:

$$n_a l_a = n_b l_b = \frac{\lambda_0}{4} \tag{10}$$

As we know the UVB radiation wavelength lays between 280 nm and 320 nm. So we have to design a one-dimensional photonic crystal based filter such that its band gap lies between 280 nm and 320 nm. So our center wavelength is 300 nm. So we should have

$$n_a l_a + n_b l_b = 150\ nm \tag{11}$$

And the optical thickness ($n_a l_a$ and $n_b l_b$) of our layers should be:

$$n_a l_a = n_b l_b = 75\ nm \tag{12}$$

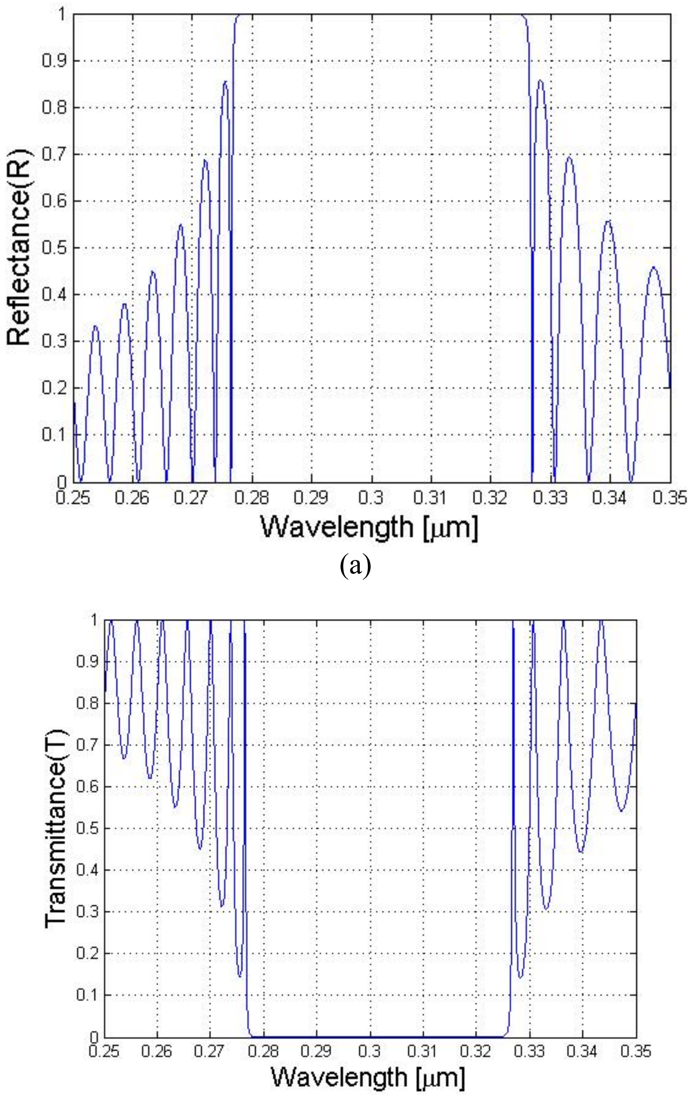
By trial and error to find the most suitable band gap we choose that the refractive index of the first and the second layer to be $n_a = 1.8$ and $n_b = 1.4$ which are correspondent to Au and MgF2, respectively. From equation (12) we calculated the thicknesses of the layers that are approximately as follow:

$$l_a = 42\ nm$$

And

$$l_b = 53\ nm$$

And the number of the periods is 10 it means that totally we have 20 layers consisting of 10 Au and 10 MgF2 layers the total thickness of our filter is 1.9 μm. The transmittance and reflectance spectrum of our filter is demonstrated in Fig. 2. As we can see from Fig.2 the band gap is in our desired range and all the UVB radiation will be reflected from it.



(b)

Fig. 2 (a) reflectance and (b) transmittance spectrum of the proposed filter.

As shown in reflectance characteristic of the structure, PBG is between 280 nm and 320 nm and we conclude that the proposed structure is useful for anti-UVB filtering.

4. Conclusion

In this paper we proposed a new one-dimensional photonic crystal based filter for filtering out the UVB radiation of sun light. Our filter is composed of 10 periodic bilayers of Au and MgF2.

The photonic band gap of our photonic crystal based filter is approximately between 275 nm and 325 nm which is suitable for filtering the UVB radiation.

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