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Invited paper

Study of one-dimensional nanolayered graded photonic crystal consisting of birefringent and dielectric materials

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ABSTRACT

In the present paper, we have studied a comparison between dielectric-dielectric photonic crystal (PhC) and birefringent-dielectric PhC structure with, and without, gradation in the thickness of the layers of the proposed structure. Graded birefringent-dielectric PhC has a linear change in the thickness of the layers. With the help of the transfer matrix method, the proposed structures have been extensively investigated. It is found that photonic band gap (PBG) width and omnidirectional reflection band width has been widely enhanced, in graded birefringent-dielectric PhC structure as compared to the non-graded birefringent-dielectric PhC structure, for both TE and TM polarizations. We have also found that the gradation in the thickness of the birefringent layer is more effective, as compare the gradation in the thickness of the dielectric layer, for enhancement of reflection band width. The results obtained are quite good and thus, it may be widely used as broad band optical and omnidirectional reflector.

1. Introduction

Photonic crystals (PhCs) have attracted much attention in the last few decades due to its peculiar optical properties and potential applications [1–5]. PhCs are periodically modulated multilayer structures which consist of alternate layers of high and low refractive indices. In PhCs, a certain range of wavelengths, where the electromagnetic waves are not allowed to pass, is known as photonic band gap (PBG). It is due to the interference of Bragg scattering from the periodic structure of the photonic crystal. Interference phenomena in PhC are angle and polarization dependent of the incident wave, hence the photonic band gap is also angle and polarization dependent.

Omnidirectional reflectors (ODRs) based on PhCs have been investigated by several researchers, and various mechanisms have been proposed, to enhance the omnidirectional band gap (ODBG) [6–20]. ODRs are due to total reflection for all incident angles and polarization states. The first ODR, which was fabricated by Fink et al. in 1998, has nine layers of polystyrene and tellurium [6]. The PhC heterostructure is one of the important structure which has large ODBG [15–17]. The PhC heterostructures are formed by combining two or more one-dimensional binary PhC structures but these structures are bulky, complicated to fabricate, and very costly. To overcome the limitation of PhC heterostructure and to enhance the ODR range, one-dimensional ternary PhC is one of the good choice [21]. In order to obtain the compact structure, several materials have been also investigated by many researchers. Birefringent material is one of them, whose refractive indices are direction and polarization dependent. Birefringent materials have low absorption for the infrared range of radiation. These materials are incorporated in the layered structure, by Abdulhalim and then Cojocaru, to study the enhancement in ODR and ODBG [22–25].

From the earlier investigations, the band gap of the PhC structure depends on the optical contrast and thickness ratio of the periodic layered structure. Thus, by changing the optical contrast or thickness ratio, we can control the band gap of the given PhC structure. The PhC structures, based on the variation in either the thickness or refractive indices of alternate layers, are called graded PhC (GPhC). GPhC is due to the gradual modification in PhC parameters i.e. filling factor, optical index, the lattice period, and is not strictly periodic in nature. Therefore, with the help of the small variation in the thickness and/or refractive indices, local properties can be easily tuned in the PBG structure [26,27].

In the present communication, we have proposed a model, to enhance the reflection band width and ODBG, to study the reflection spectra of graded birefringent dielectric PhC (GBD PhC) structure. The GBD PhCs have linear gradation in the thickness of the alternate layers in the proposed structure. The birefringent-dielectric PhC (BD PhC) has much larger reflection band width and

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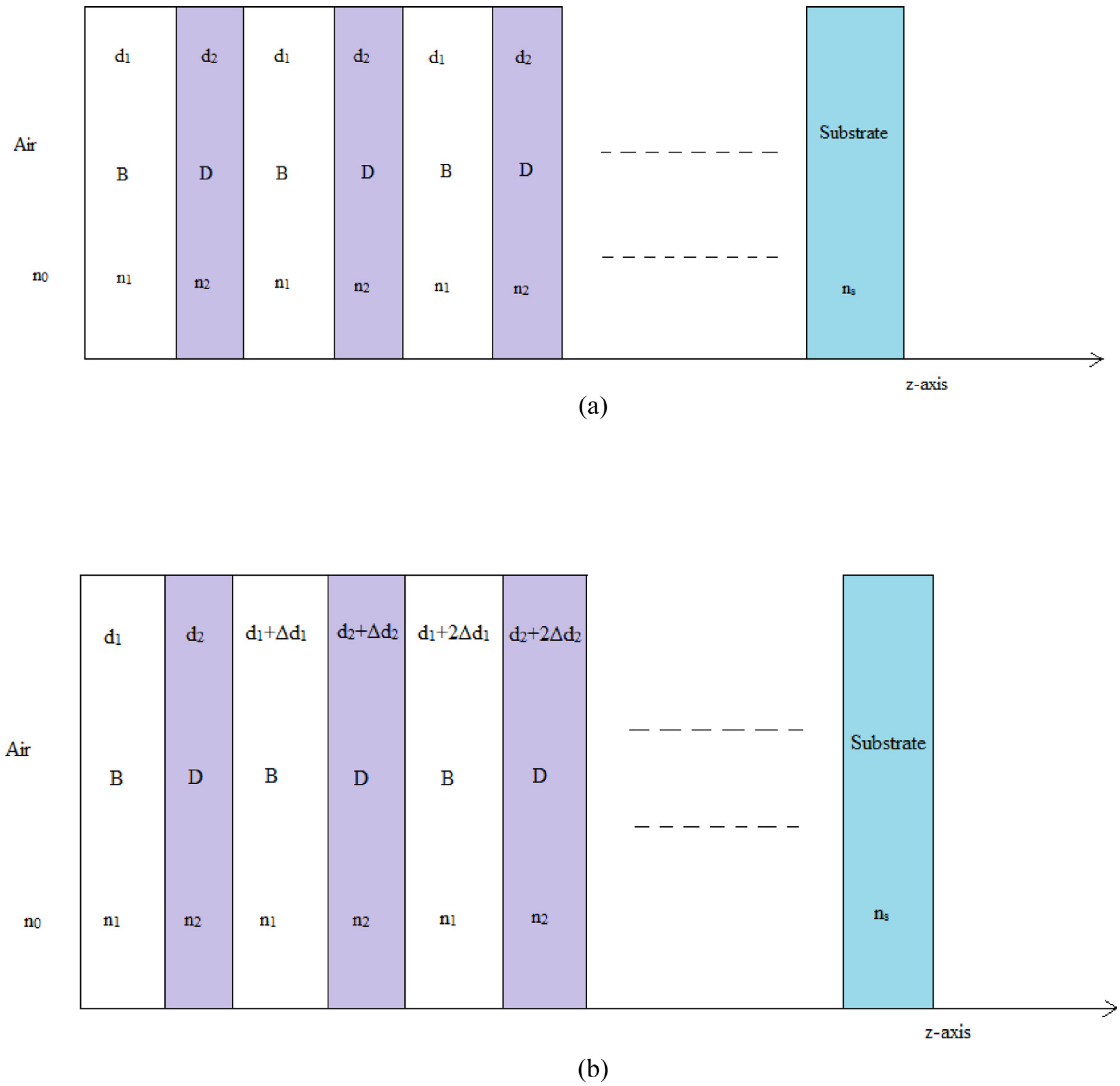

Fig. 1. (a) Schematic representation of non-GBDPhC (PC1) structure having alternate layer of birefringent KTP (B) and dielectric PbS (D) materials. (b) Schematic representation of GBDPhC structure having alternate layer of birefringent KTP (B) and dielectric PbS (D) materials with linear gradation in thickness.

ODBG in comparison to all dielectric-dielectric PhC (DDPhC) structure with the reduction in a number of layers [28]. So, we have adopted GBD PhC, with the reduction in the size of the structure, to enhance the reflection band width and ODBG in our proposed structure. In addition, we have also studied the effect of variation in the thickness of the layer, with different amount of gradation, on the reflection bands. Numerical results of reflection spectra indicate that the gradation in the birefringent layer leads a wider range of reflection band in comparison to the dielectric layer. The enhancement in ODBG is more effective in GBD PhC structure, as compared to the non-GBD PhC and GDD PhC structure, with the same amount of gradation in layer thickness while the other parameters remain the same. GBD PhC may be widely used in producing omnidirectional reflector, super bending effect, as a coupler for PhC waveguides and wavelength division multiplexer [29–32].

2. Theoretical details

The schematic diagrams of the proposed PhC structures are shown in Fig. 1(a) and (b). The proposed periodic multilayered structure consists of alternate layers of birefringent material (B) and dielectric material (D) along z-axis and placed between semi-infinite media of refractive indices n_0 and n_s which are the refractive index of incident medium and the substrate. The proposed structure has the form air/$(BD)^N$/substrate, where B and D represent the birefringent and dielectric layers having thicknesses d_1, d_2 and refractive indices n_1, n_2 respectively and N is the number of periods. There are several birefringent materials, KTP, Al_2O_3, $NaNO_3$, $LiNbO_3$, $LiTaO_3$, LiB_3O_5, $ZrSiO_4$, MgF_2 etc., and dielectric materials, SiO_2, PbS, TiO_2, SiC, Si, Na_3AlF_6, chalcogenide glasses, diamond, Teflon, SbSn, CeF_3, GaSb etc., that can be employed in our structure. We have chosen potassium titanyl phosphate (KTP) as birefringent material and lead sulphide (PbS), SiO_2, air as dielectric materials.

Materials whose refractive indices depend on the direction and state of polarization are called birefringent materials. Therefore, the refractive index of birefringent material in each direction has different values in each period. Let the birefringent material has refractive indices n_x, n_y, and n_z along x, y, and z-axes respectively. The effective refractive index (n_1) of birefringent material which