Chapter 9
Characteristics of One Dimensional Photonics Structures Having Different Types of Sequences

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Abstract We discuss the optical properties, in terms of light transmission, of 1D multilayer photonic structures in the cases of periodicity and disorder. The focus will mainly be on the study of the optical properties, from a theoretical point of view, of 1D periodic photonic crystals and 1D disordered photonic structures made with bi or mono- materials. All parameters for the analysis are chosen keeping in mind that the structures can be experimentally fabricated. The designed structures can be used as optical filters in optical communication networks.

9.1 Introduction

One dimensional (1D) photonic structures can be useful for several applications requiring light manipulation and have been used for filtering, sensing, lasing, LEDs solar cells, etc. [1, 2]. The structure-property relationship in 1D photonic structures, when they are characterized by periodic, aperiodic or disordered sequences, is an attractive field in the community of optics and photonics [3, 4]. A periodic arrangement of dielectric or metallic materials having suitable refractive index contrast is an optical analogy to a conventional crystal. They provide a possibility to control and manipulate light through it based on the dispersion relation i.e. the relation between the wave vector and wavelengths (λ) of the electromagnetic wave propagating through the structure. If, for certain wavelength range, no light of any polarization can propagate through it, the crystals is said to have photonic band gap (PBG). This phenomenon was first noticed by Lord Rayleigh in a 1D optical periodic structure in 1887. He also derived a general solution of 1D periodic media. The generalized concept of omni-directional photonic gap for two and three dimension was made clear by Yablonovitch and John after a century [5, 6] and those structures

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are named as photonic crystal (PhC) by Yablonovitch. However, nowadays, conventionally, all the one, two, three dimensional periodic structures are popularly known as PhCs. 1D photonic crystals are a mono-dimensional alternation of the high and low refractive index materials and for these structures the photonic band gap occurs only in the direction of such alternation. The possibility to fabricate 1D photonic structures is diverse and there are several techniques like spin coating, r-f sputtering and pulsed laser deposition, that can be used to study these structures with a desired arrangement.

9.2 Results and Discussion

In an initial attempt, a 1D bi-material structure ($(HL)^N L(HL)^N L$) is proposed using quarter wavelength thicknesses of two materials ($LiNbO_3$ as H and MgF_2 as L) wherein electro-optic property of $LiNbO_3$ is utilized to design electro optically tunable narrowband transmission filter (NTF). Here N is the number of bilayers. Tunability of the filter is shown in Fig. 9.1a [7]. Multiple transmission filters (MTF), which is another essential application of these type of structure, is also proposed here. The proposed design ($(LH)^{N1}L(LH)^{N1}(LH)^{N2}L(LH)^{N2}(LH)^{N3}L(LH)^{N3}(LH)^{N4}L(LH)^{N4}$) is an improved version of the conventional 1D PBG structures in a sense that it is designed with enhanced light capturing capacity. Number of peaks depends on the number of resonator pairs within the structure. After designing NTF and MTF, an attempt is made to design flattop transmission filter (FTF). Conventionally, PBGSs used for designing FTF, requires a combination of high and low index layers of very precise widths, either at the beginning or at the end or both (of the basic 1D PBG structure) to ensure flattop transmission. However, in this manuscript, a PBG structure for flattop transmission is proposed where the individual resonators are anti-symmetric ($(HL)^3 2H(LH)^3 L(HL)^4 2H(LH)^4 L(HL)^3 2H(LH)^3$) in nature and doesn't require any such compensating layers. Therefore, structure length is reduced because of reduced number of interface counts. For designing MTF and

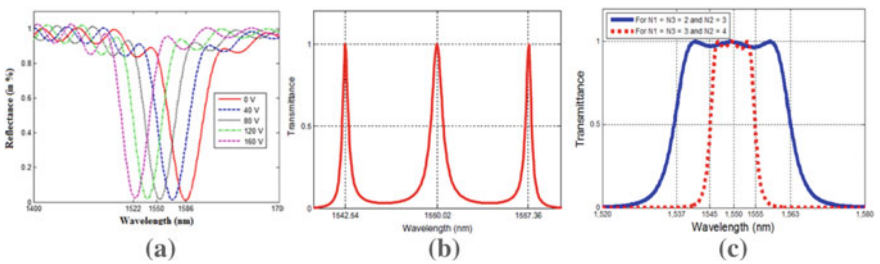

Fig. 9.1 **a** Tunability (4 nm/10 V) of the NTF by the application electric field across $LiNbO_3$ layers [7], **b**, **c** multiband and flattop transmission spectra resulted from the PBG structures mentioned here [8]

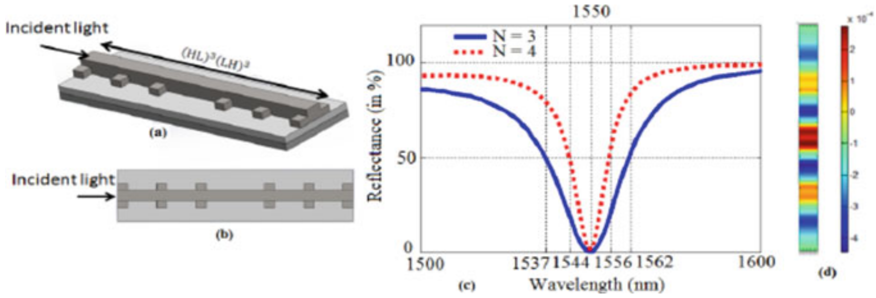

Fig. 9.2 **a** Cross-sectional view of the structure $(HL)^3(LH)^3$ formed by alternate rib and ridge sections, **b** plan view of the same structure, **c** reflectance spectra of the same structure when excited by the light with$\lambda = 1550$ nm, **d** electric field amplitude profile within the structure showing the resonance mode at the defect area [8]

FTF, EO polymer and TiO_2 are used as low and high index layers. Electro-optic property of EO polymer is explored in both the cases to study the tunability. Transmission spectra for MTF and FTF are shown in Fig. 9.1b, c respectively. Considering the fabrication challenges of multilayered 1D bi-material structures in sub-wavelength dimensions, the authors have already introduced a new concept of realizing the effect of multilayer structure of two different materials on a mono-material itself [4]. Here, that concept of virtual 1D PBG structure is utilized to realize virtual multilayer structure on a silicon waveguide structure for designing different types of optical filters, which can be a better alternative for the conventional bi-material 1D photonic structure as photonic filters. The cross-sectional and plan view of the structure are given in Fig. 9.2a, b respectively. Transmission spectrum of NTF designed with such waveguide based virtual PBG structure is shown in Fig. 9.2c along with the amplitude resonance mode within the structure in Fig. 9.2d.

9.3 Methods

In order to simulate the light transmission of the 1D photonic structures, the Finite Difference in Time Domain (FDTD) method using MATLAB is employed. For angle dependence studies, codes based on transfer matrix method are also developed. The developed codes are utilized to deal with the application of 1D photonic structures to design different types photonic filters, through theoretical studies of optical resonance in these structures which are discussed below.

9.4 Conclusions

The light transmission of different types of 1D photonic structures are discussed. Their optical properties are correlated with the distribution of the high refractive index layer between the low refractive index layers. These findings can be interesting, for a better understanding of the properties of 1D photonic structures, and for the fabrication of optical filters useful for optical communication networks.

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