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Photonic crystal-based optical filters for operating in second and third optical fiber windows

Mehdi Zamani

Faculty of Physics, Shahid Bahonar University of Kerman, Kerman, Iran

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A B S T R A C T

In this paper, the filtering properties of photonic crystals (PCs) to perform narrow-channel transmission-type filters in second and third optical fiber telecommunication windows have been studied. Filtration of these zero dispersion and low-loss windows have simultaneously been established by utilizing of a triple-cavity transmission-type one-dimensional PC that provides perfect transmittances and narrow-channels at corresponding wavelengths. Such PC-based optical filter can be used in wavelength division multiplexing (WDM) optical communications systems.

1. Introduction

Wavelength division multiplexing (WDM) is a technique which allows optical signals with different wavelengths to propagate in a single optical fiber without affecting one another [1–4]. Its role is to combine light from several sources, each operating at a particular wavelength carrying one channel, to the transmission fiber. Equivalently, a demultiplexer separates different wavelengths at the receiving end [2,5].

Attenuation of transmitted light through an optical fiber varies with the wavelength of light. The most common wavelengths used for optical communication span between 830 and 1550 nm (correspond to the fiber's low-loss region) [2]. There are three low-loss windows of interest: 850 nm, 1300 nm, and 1550 nm. Usually, low-loss air-core photonic bandgap fibers are designed for use at these wavelengths [6–9]. Early technologies used the 800–900 nm wavelength band (referred to as the first window) mostly because optical sources and photodetectors were available and inexpensive at these wavelengths. Second telecommunication window, centered at around 1300 nm, corresponds to zero dispersion of fiber. Dispersion is a consequence of the velocity propagation being different for different wavelengths of light. As a result, when pulse travels through a dispersive media it tends to spread out in time, the effect which ultimately limits speed of digital transmission. The third window, centered at around 1550 nm, corresponds to the lowest loss. At this wavelength, the glass losses approach minimum of about 0.15 dB km, hence, this window today is mainly of interest to long-distance telecommunications applications [7].

An optical filter (OF) in both add and drop wavelength configurations is one of the most interesting devices which has significant importance for WDM optical communications systems which in turn greatly enhance the capacity of optical communication networks [1,10,11]. Depending on the application type and the desired specifications, OFs can provides multichannel, wide band, narrow band, and selective pass or stop band at difference wavelength ranges [12,13].

E-mail address: m-zamani@uk.ac.ir.

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Nowadays, photonic crystal-based filters play a vital role in a wide range of applications for many areas of science [14,15]. With growing interest in using of photonic crystal-based optical filters in optical communications, better channel filter performances with controllable flat transmission/reflection bandwidth or sharp transmission/reflection band have been acquirable [16–20].

Photonic crystals (PCs) are artificial structures that consist of periodically repeated layers [21]. Not only due to the simplicity of fabrication, but also because of their undertaking applications, one-dimensional (1D) PCs have been the easiest types of them. They can generate photonic band gap (PBG) areas at certain wavelength ranges which there is no possibility about of wave propagation in the structure. Applications of PBG have provided the designing of various optical PC-based integratable devices in optical communications. For example, a 1D photonic crystal forms the basis of optical filters operating on different ranges of optical wavelengths [22–25]. Usually 1D PC-based OFs are created by inserting a defect layer in the periodic area. In this type of filter, the transmission peak is generally located in the PBG.

In general, the transmittance/reflectance light through the photonic crystal depends on the geometry and the compositional parameters. Hence, finding the best design according to the desired performance has been the effort of researchers and engineers. Consequently, plenty types of tunable PC-based filters have demonstrated with different materials and phenomena [26–29].

In this paper, we are going to introduce 1D PC-based optical filters with capability of filtering wavelengths of 1300 nm and 1550 nm respectively corresponds to the zero dispersion and the lowest loss wavelength of optical fiber. This aim can be acquired by introduce of a triple-cavity photonic crystal structure as $(L/H)^5(H/L)^1(L/H)^1(H/L)^5$, where H and L layers denote on Si and SiO materials, respectively. The introduced PC-based filter provides three transmission narrow-channels with perfect transmittances in accordance with the wavelengths of 1300 nm and 1550 nm accompanied by extra wavelength of 1922 nm. In other words, we have been focused on the optimization design for filters in the telecommunication region as well as the three defect modes so that two of them have located in the second and third optical fiber windows. The introduced PC-based optical filters have the capability of simultaneous filtration of mentioned optical fiber communication windows even in the presence of oblique incidence angles of light and for both TE- and TM-waves. Based on previous statements such photonic crystal-based optical filter can operate as a multiplexer/demultiplexer to pick up/dismount zero dispersion and low-loss wavelengths to/from an optical fiber at the sending/receiving end.

2. Numerical results and discussion

The numerical calculations we have used here are based on transfer matrix method (TMM) which is employed to extract transmission/reflection spectra, considering their sensitivity to constituent materials and structural variation of multilayer structures. To explain this method, we consider a beam of light impinging on top of the multilayer from the medium *i*. If P_m is the electric field at the bottom surface of the *m*th layer, then a relation between electric field in medium *i*, P_i, and that in final medium, P_f, can be given by Refs. [30,31].

$$\begin{aligned} A_iP_i &= A_1D_1P_1 = A_1D_1A_1^{-1}A_1P_1 \\ &= A_1D_1A_1^{-1}A_2D_2P_2 \\ &= \prod_{m=1}^{N}\left(A_mD_mA_m^{-1}\right)A_fP_f. \end{aligned} \tag{1}$$

In this situation, the matrix A_m is the medium boundary matrix. The other matrix, D_m, is the medium propagation matrix which relates the components of the electric field at the two surfaces of the *m*th layer. If we rewrite Eq. (1) as:

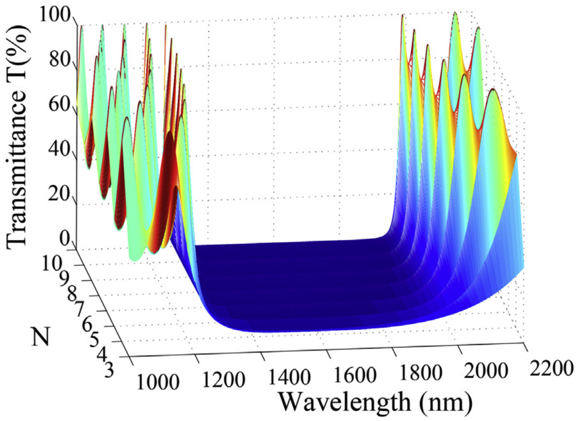

Fig. 1. The wavelength-dependent of transmittance for the defect-free PC as $(L/H)^N$ as function of stacking number of N for perpendicular incident light.