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Photonic crystal wavelength-selective attenuators: Design and modeling

Kiazand Fasihi

Electrical Engineering Department, Golestan University, Iran

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Abstract

The operation of a wavelength-selective attenuator, which is based on modified photonic crystal (PC) T and Y-branch waveguides, is analyzed using theoretical and numerical analysis. The coupling mode theory (CMT) is employed to drive the necessary conditions for achieving perfect transmission and reflection. It has been shown that when the decay rates into the three ports of the proposed device are equal, an attenuation between 0% and 100% can be obtained. The finite-difference time-domain (FDTD) simulation results of the proposed wavelength-selective attenuator which is implemented in two-dimensional PCs (2D-PC), show that the analysis is valid.

Keywords: Coupled-mode theory; Finite-difference time-domain; Waveguide splitter; Photonic crystal; Attenuator

1. Introduction

The significant and rapid growth of large-scale optical fiber communication networks has created a large demand for many optical components, including variable optical power splitters (VOPS), optical switches (OS), variable and fixed optical attenuators (VOAs and FOAs) [1,2]. The issue of employing large quantities of these optical components in optical networks for fiber-to-the-home applications while maintaining low-cost and compact is particularly important. Conventional mechanical optical components suffer from large size and large element mass; on the other hand, guided wave optical components show the disadvantages of high loss and long device length. Recently, there has been a growing interest in applying the integrated photonic technology to improve the performances and reduce the cost of the optical components. Photonic crystals (PCs) have gained great interest due to the availability of high density integrated optical circuitry [3–11]. This is mainly due to their capability of controlling electromagnetic waves with the existence of a photonic band gap. FOAs are precision devices designed to provide accurate attenuation for a variety of network applications, such as reducing the power level of an optical signal without significantly changing its waveform. Typical attenuation values of FOAs are between 3 and 20 dB and are used in optical systems where the optical power from a source is too high for the test equipment in use. In this paper, we present theoretical calculations for the construction of a wavelength-selective attenuator. Waveguide splitters, in which the input power is split into the output waveguides without significant reflection or radiation losses, play an important role in integrated circuitry and many investigations have been done in this field of study [12–17]. Fan et al. developed a general criterion for ideal performance of waveguide branches in photonic crystals

E-mail address: k.fasihi@gu.ac.ir.

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[12]. They proposed designs of PC waveguide branches with 180° branching angles that display near-zero reflection and almost-complete transmission. Furthermore, Boscolo et al. showed that by adding tuning holes to the input of waveguide splitters it is possible to achieve almost perfect impedance matching, leading ideally to unitary transmission through the junction [13]. The modified waveguide branch-based structures may be useful for the design of other all-optical functional circuits. Based upon our theoretical considerations, our proposed modified waveguide branches can be used as a fixed wavelength-selective optical attenuator device. The coupled-mode theory (CMT) is employed to analyze the behavior of this system. This design is also simulated by finite-difference time-domain (FDTD) method for the structures implemented in square and triangular lattices and the simulation results show the validity of the proposed design.

2. Theoretical model for waveguide branches with a reflection feedback

2.1. CMT method

When a local defect is created in a PC, e.g. by removing a single rod, a cavity is formed where light is confined in one or more bound states. Depending on the quality of the confinement, these states, or modes, exist only in a narrow frequency range. In general, a defect can have any shape or size; it can be made by changing the refractive index of one or more rods, modifying their radius, or removing them altogether [18]. General structures of PC based T and Y-branch waveguides with one waveguide terminated by a reflector are shown in Fig. 1(a) and (b). The branching region is treated as a cavity, a_1, that couples to the input and output ports and the reflector region is treated as a cavity, a_2, that its

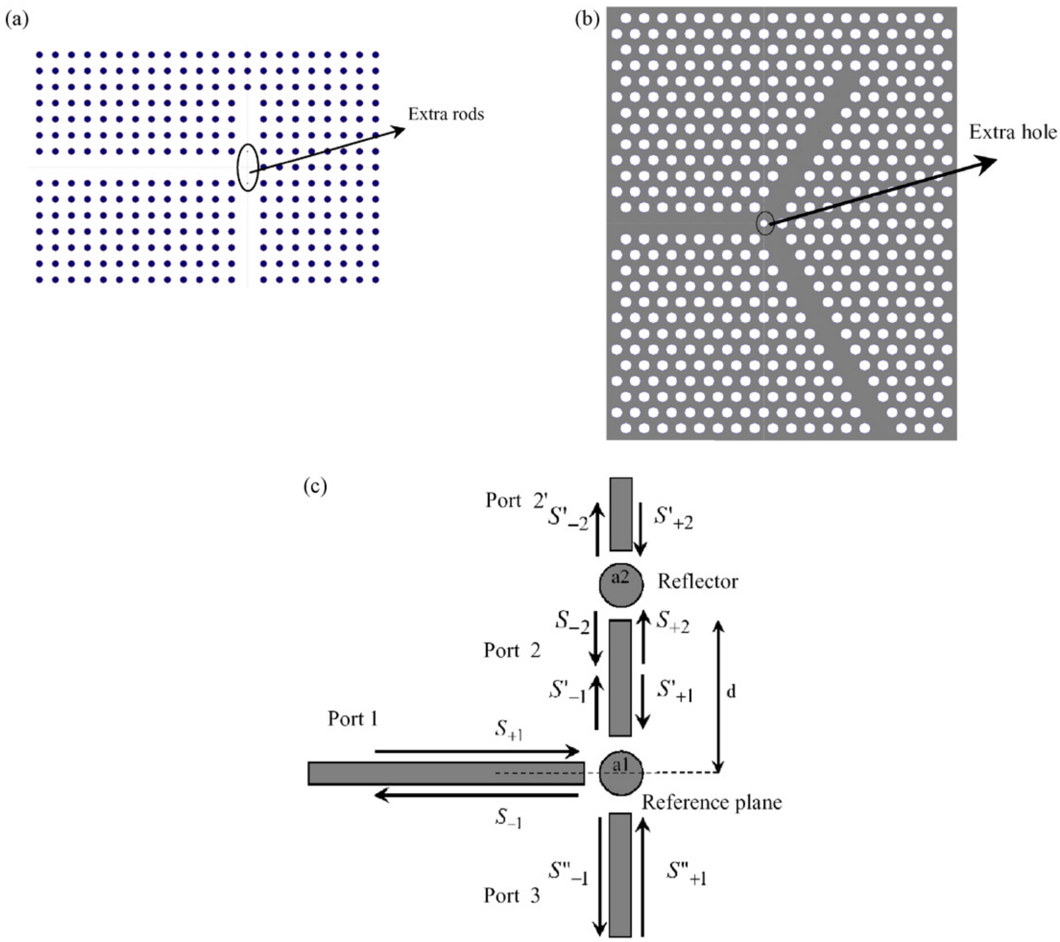

Fig. 1. (a) Structure of a T-branch waveguide with a reflection feedback (arrows denote extra rods, which are placed between input and output ports to satisfy the rate-matching condition). (b) Structure of a Y-branch waveguide with a reflection feedback (arrow denote extra hole, which is placed in the center of junction to reduce the optical size of the cavity). (c) Schematic diagram for the modified waveguide splitter based on CMT.