Optics Communications 316 (2014) 10–16

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Electro-optical channel drop switching in a photonic crystal waveguide-cavity side-coupling system

Kao-Der Chang [a], Cheng-Yang Liu [b],*

[a] Mechanical and Systems Research Laboratories, Industrial Technology Research Institute, Hsinchu, Taiwan
[b] Department of Mechanical and Electro-Mechanical Engineering, Tamkang University, No. 151, Ying-chuan Road, Tamsui District, New Taipei City, Taiwan

ARTICLE INFO

Article history:
Received 20 August 2013
Received in revised form
18 November 2013
Accepted 22 November 2013
Available online 5 December 2013

Keywords:
Resonator
Conductivity
Photonic crystal

ABSTRACT

The electro-optical channel drop switching in a photonic crystal waveguide-cavity side-coupling system is reported. The line waveguide is formed by removing a single row of dielectric cylinders. The twin optical microcavities side coupled between linear waveguides is studied by solving Maxwell's equations. We determine the general characteristics of the coupling element required to achieve channel drop tunneling. By modulating the conductance of the twin microcavities, the electrical tunability of the resonant modes is observed in the transmission spectrum. The spectral characteristics suggest a potential application for this switching device as an efficient multichannel optical switch in the photonic integrated circuits.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Recently, ultracompact optical integrated circuits have become the most attractive apparatus to be used for optical communication systems. Photonic crystals (PCs) are very suitable candidates for realization of the optical devices because of their ability to control lightwave propagation [1]. The electromagnetic wave is strongly confined in the defect channel, allowing low loss in line waveguides and a sharp-bending [2]. By introducing the different defects in the perfect PC structures, ultracompact optical components can be realized [3]. Channel drop filters are fundamental components of photonic integrated circuits and wavelength division multiplex systems. Several channel drop filters exist in different kinds of designs such as fiber Bragg gratings, arrayed waveguide gratings, and Fabry–Perot filters [4]. Resonant channel drop filters are attractive applicants for channel dropping because they can potentially be used to select a single wavelength with a very narrow line width [5–12]. Fan et al. reported a general analysis of the complete channel drop tunneling process through localized resonant states between one-dimensional (1-D) continuous microcavities. The channel drop resonators are consisted of one or two microcavities side coupled with a PC waveguide. The dimensions and refractive index of the microcavities are varied to match the desired resonance condition. In such a system, the transmission coefficient of the forward and backward channels varies 0% to 100% in a wavelength range narrower than the full width of the resonance itself.

In optical integrated circuits, the design of the tunable elements is very important. The tunable mechanisms of lightwave in two-dimensional (2-D) PC structures by operation of liquid crystals (LC) are discussed [13,14]. The authors also proposed the tunable PC components based on infiltration of LC [15–17]. The tunable photonic bandgap in the 2-D and three-dimensional (3-D) PC structures modulated by the nematic LC have been investigated [18,19]. The electro-optical devices are the major elements in the photonic integrated circuits. Recently, a tunable slow lightwave device is made from a mechanically adjustable coupled resonator optical PC structure [20]. An electro-optic PC superprism fabricated on a lithium niobate substrate is presented by Amet et al. [21]. The electro-optic effect modifies the propagation direction of the incident beam by a direct control of the band structures. The tunable electro-optical PC linear waveguides and microcavities are presented by the author [22,23]. The electric conductivity in the inner rods of the optical waveguides or cavities can be controlled to modulate the guided modes. In addition, the experimental studies of a tunable PC nanocavity resonator have been discussed [24]. The mechanical strain sensitivity between the applied strain and the shift in the resonant wavelength of the nanocavity are received.

In this paper, we theoretically demonstrate the electro-optical channel drop switching in a photonic crystal waveguide-cavity side-coupling system. The resonant modes can be controlled by changing the conductance of cylinders in the microcavities. The propagation properties of electromagnetic waves inside the side-coupled waveguide-cavity PC systems are calculated by the finite-difference time-domain (FDTD) simulations. We determine the

---

* Corresponding author. Tel.: +886 2 26215656x2061; fax: +886 2 26209745.
E-mail addresses: chenyang66@gmail.com, cyliu@mail.tku.edu.tw (C.-Y. Liu).

0030-4018/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.optcom.2013.11.044

general characteristics of the coupling element required to achieve channel drop tunneling. Such designs may potentially be used as tunable optical filters or switches. In Section 2, we describe the numerical method that we performed to simulate the validity of the model. Theoretical results are presented in Section 3. Finally, we conclude with remarks in Section 4.

2. Numerical method

The quantum scattering theory is used to examine the time dependent side coupling system [25–27]. This theory is provided for a single mode microcavity with a resonance wavelength, an intrinsic quality factor, and an external quality factor. The forms of the resonant characteristics depend critically on the relative positions of the resonant wavelength in relation to the microcavity. When the resonant wavelength corresponds with a maximum of the Fabry–Pérot oscillations, the transmission spectrum represents a symmetric Lorentzian-like line profile. The external coupling factor is responsible for the energy coupling of the microcavity to the nearby waveguides. The value of the external coupling factor is strongly dependent on the symmetry of the microcavity mode with respect to the waveguide modes. Therefore, the external coupling factor is very different for each microcavity mode. The MATLAB® code of the FDTD calculation [28] is used to simulate the PC devices, and the absorbing boundary conditions are assumed as the perfectly matched layers [29]. The central processing unit of Intel® Core i7 and random-access memory of 24 GB are used in this simulation. The PC waveguide-cavity side-coupling system is laid out in the x–y plane. The light beam is along the x direction. The Δx and Δy are the space steps of the FDTD in the x and y directions. The mesh size and time step used in this paper are $\Delta x=\Delta y=0.02\ \mu\text{m}$ and $\Delta t \le 1/c\sqrt{1/(\Delta x)^2+1/(\Delta y)^2}$, where c is the velocity of lightwave in free space. A square lattice of dielectric cylinders in air is considered in this paper and the electric field is parallel to the axis of cylinders for transverse electric mode. The energy density of each port is normalized to the energy density of the input port. The fast Fourier transform of the electromagnetic fields are calculated for the transmission spectra and the Poynting vectors over the cells of the output ports are integrated. We can receive the time-dependent lightwave propagation by using the Yee algorithm. The detailed Yee algorithm and FDTD calculation can be obtained in Ref. [28].

3. Channel drop switching

In general, the symmetry of the channel drop resonators is low that only 1-D irreducible representations are allowed. The even and odd resonances belong to different irreducible representations and an accidental degeneracy between the resonances must be forced. Here the design of an electro-optical channel drop resonator as shown in Fig. 1 is investigated. To realize the channel drop system, we consider the system of two PC waveguides and two single mode coupled microcavities. The 2-D square lattice PC is composed of dielectric cylinders surrounded by air. The lattice constant is a and the radius of cylinders is $r=0.2a$. The refractive index of the dielectric cylinders is $n=3.4$. The material is homogeneous in the z direction, and periodic along x and y with lattice constant. The two optical waveguides are formed by removing a single row of dielectric cylinders and the two microcavities are introduced between the waveguides by reducing the radius of a single cylinder whose radius is $r_i<r$. Each microcavity supports a localized monopole state which is singly degenerate. An accidental degeneracy is enforced by reducing the dielectric constant of four specific cylinders in the PC system to $n=3.08$, as show in Fig. 1 (gray circles). The exact cancellation could equally have been accomplished by reducing the radius of the cylinders instead of their dielectric constant. The resonant modes can be made by changing the radius r_i of a single cylinder. For the 1550 nm center wavelength, we assumed the PC system of 229.4 nm diameter dielectric cylinders arrayed in a square lattice $a=573.5$ nm in an air background. Fig. 2 depicts the resonant center wavelength as a function of radius r_i. The resonant center wavelength increases as r_i increases. The 1550 nm resonant center wavelength can be achieved for $r_i=0.061a$. The structural parameters are chosen as an example. The resonant center wavelength is scalable in respect of the structural parameters.

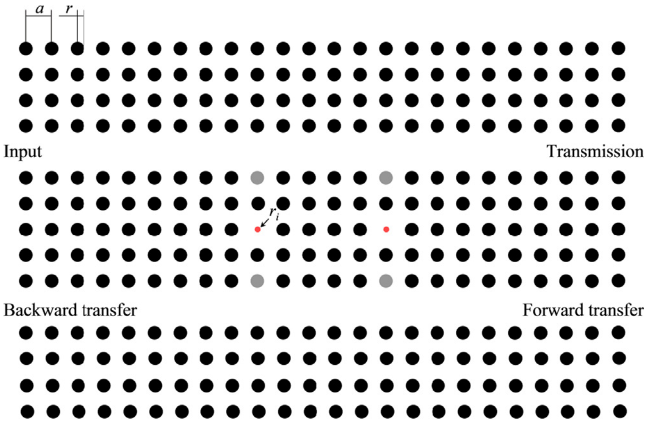

Fig. 1. Schematic view of the proposed electro-optical channel drop resonator. Photonic crystal system has two waveguides and two microcavities. The line waveguide is formed by removing a single row of dielectric rods. A point defect created by reducing the radius of a single rod whose radius is $r_i<r$.

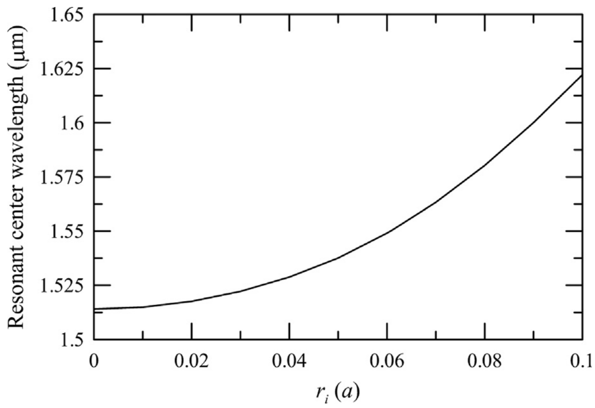

Fig. 2. Resonant center wavelength as a function of radius r_i.

Soref et al. (1987)have experimentally investigated the electro-optical effects in silicon and disclosed that a modification of the refractive index in silicon due to plasma dispersion can be achieved by injecting/depleting electrons/holes in the intrinsic silicon region [30]. The variations of optical absorption coefficient produced by the free carrier injection/depletion can be calculated from the concentration values of the electrons and holes in the structure via $\Delta\alpha=-[8.5\times10^{-18}\times\Delta N+6.0\times10^{-18}\times\Delta P]$, where ΔN and ΔP are electron and hole concentration changes in cm^{-3}. In this paper, the electro-optical modification of the dielectric material in the microcavity is proposed. The change in optical absorption coefficient $\Delta\alpha$ is employed and the change in conductance $\Delta\sigma$ is proportional to $\Delta\alpha$. The behavior is analogous to that discussed in [31,32] where electric absorption was assumed to reduce the quality factor of micro-ring resonators coupled to strip channel waveguides. The optical absorption of dielectric material

Download English Version:

https://daneshyari.com/en/article/7931582

Download Persian Version:

https://daneshyari.com/article/7931582

Daneshyari.com