فیلتر نوری فوق فشرده مبتنی بر کریستال های فوتونیکی با استفاده از کاواک رزونانسی دارای ناراستی

پریسا عبداله زاده بدلبو و حامد علیپور بنایی
دانشگاه آزاد اسلامی، واحد تبریز، گروه مهندسی برق، تبریز، ایران

چکیده - در این مقاله فیلتری نوری مبتنی بر کاواک های رزونانسی دارای ناراستی براساس کریستال فوتونیکی ارایه کردیم. مهمترین ویژگی فیلتر پیشنهادی ابعاد بسیار کوچک و فشرده آن می‌باشد. کل سطح مقطع فیلتر ما ۳۴ میکرومتر مربع می‌باشد. این سطح مقطع کوچک باعث می شود که این ساختار برای استفاده در مدارات مجتمع نوری مناسب باشد. دامنه خروجی این فیلتر نزدیک به ۸۹٪ می باشد. نشان داده شد که رفتار نوری فیلتر به ضریب شکست و شعاع میله های ناراستی وابسته است.

کلیدواژه: باند ممنوعه، فیلتر نوری، کاواک رزونانسی، کریستال فوتونیکی، ناراستی.

Ultra-compact optical photonic crystal based filter using defective resonant cavity

Parisa Abdollahzadeh-Badelbou and Hamed Alipour-Banaei[2]

Department of Electronics, Tabriz Branch, Islamic Azad University, Tabriz, Iran,

Abstract-In this paper we proposed an optical filter based on photonic crystal defective resonant cavity. The most significant characteristic of our filter is its ultra-compact dimensions. The total footprint of our filter is 34 □m^2. This ultra-compact property makes the proposed structure very suitable for optical integrated circuits. The transmission efficiency of the filter is about 89%. It has been shown that optical behavior of the filter depends on the refractive index and the radius of defect rods.

Keywords: Band gap, Defect, Optical filter, Photonic crystal, Resonant cavity.

1. Introduction

Optical filters [1-2] are crucial devises for WDM and DWDM systems. Beside omitting the noise from channel information optical filters are used for separating the undesired WDM and DWDM channels from desired channels. Other crucial applications of filters are in demultiplexing multiple channels in WDM and DWDM systems. Since the discovery of photonic crystal in 1987 [3], designing compact and highly selective optical filters become possible. PhCs mainly are composed of 2 different dielectric materials with different refractive indices. The arrangement of these 2 dielectric materials is such that the distribution of refractive index is periodic. According to this periodicity these artificial structures are divided into 3 categories: 1D, 2D and 3D PhCs. Because of their periodic distribution of refractive index they have the ability to confine light in very small spaces which was one of the major problems for designing ultra compact optical devices. Another feature of PhCs is their Photonic Band Gap (PBG), a wavelength region in their band structure in which no electromagnetic wave can propagate inside these crystals [4].

Due to importance of optical filters different methods have been proposed for designing PhC-based optical filters. Creating defect layers [5], quantum wells [6], employing superconducting layers [7] and thue-morse structures are some common methods used for designing optical filters based on 1D PhCs. 1D PhC do not have complete PBGs, therefore their optical behavior is very dependent upon the direction and angle of the incident optical waves, such that by very slight variation in the incident angle the optical performance of the filter varies harshly. For this reason 2D PhCs are good structures for designing all optical filters suitable for optical communication networks. Photonic crystal ringresonators (PhCRRs) are the most common mechanisms used for designing optical channel drop filters. Different kinds of resonant rings have been proposed for realizing channel drop filters based on PhCRRs, such as square rings, quasi square rings, circular rings, and X-shaped rings [8-11]. Most recently Mehdizadeh et al [12] proposed a PhCRR based channel drop filter by combining 12-fold quasi crystal with square lattice PhC structure. They investigated the effect of different parameters on the resonant wavelength of the filter and found that the resonant wavelength of PhCRRs depends on the refractive index and dimensions of the resonant ring. Resonant cavities [13-14] are also used for designing all optical PhC based filters.

In this paper we are going to propose a new defective resonant cavity for realizing optical filter suitable for optical communication applications. Then we are will investigate the effect of refractive index and radius of defect rods on the resonant wavelength of the defective cavity and optical filter. The rest of the paper was organized as follows: in section 2 we proposed the design procedure of the filter, section 3 was devoted to the simulation process and discussing the results and finally we conclude from the paper in section 4.

2. Design procedure

For designing the proposed filter we used a 21*11 array of dielectric rods with square lattice in air background. The refractive index of the dielectric material is 3.46 and the radius of dielectric rods is r=0.2*a, where a=570 nm is the lattice constant of the PhC structure. Currently the best way to extract the properties of PhC and study the behavior of electromagnetic waves in periodic structures such as PhCs is numerical methods. First step in designing and studying PhC based structures is extracting their band structure and obtaining their PBG. One of the most popular numerical methods for calculating the PBG of these structures is Plane Wave Expansion (PWE) [15]. The band structure of the fundamental structure was calculated and presented in figure 1.As we see there are 3 PBGs in the band structure diagram, two PBG in TM mode (blue colored areas) and one in TE mode (red colored area). The TM PBGs are in $0.283 < a/\lambda < 0.417$ and $0.718 < a/\lambda < 0.738$ range and the TE PBG is in $0.814 < a/\lambda < 0.828$ range. Only the first PBG in TM mode is wide enough for covering the sufficient wavelengths for optical communication applications. Considering a=570 nm the PBG will be $1366 \text{ nm} < \lambda < 2014 \text{ nm}$, that is in the range of optical communication applications. The filter is shown in figure 2. As we see it consists of 2 line defects as input and output waveguide that were connected to each other via defective resonant cavity. For creating the defective resonant cavity we removed some dielctric rods from the basic PhC structure and also change the radius of 4 inner rods inside the resonant cavity into R=120 nm. These defect rods are shown with green color at figure 2. The refractive index of these defect rods is the same as the entire structure. The total footprint of the proposed structure is 34 μm^2, which proves the ultra compactness of the filter.

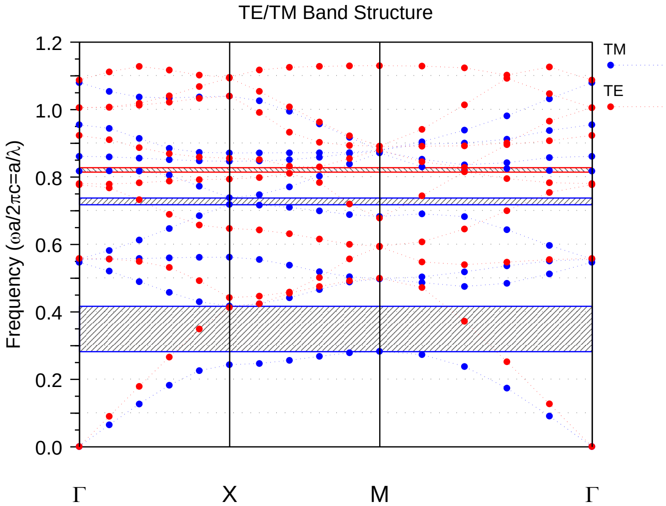

Figure 1. The band structure of the basic PhC structure

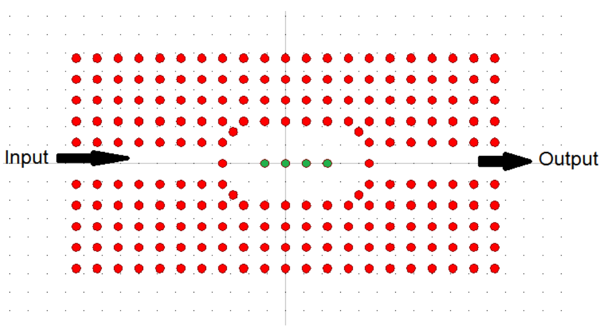

Figure 2. the final sketch of the proposed filter

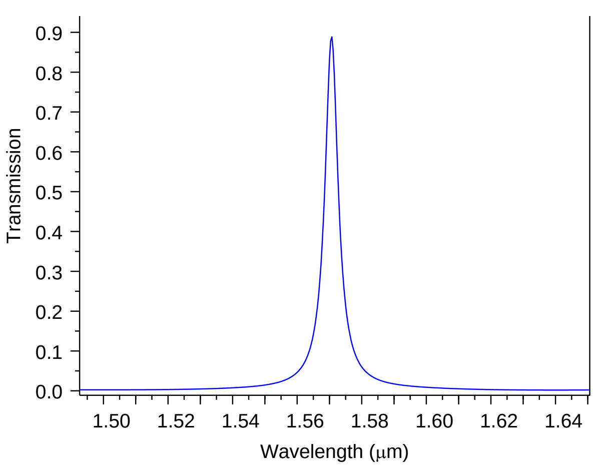

Figure 3 The output spectrum of the proposed filter

For simulating the proposed structure and obtaining the output spectrum of the filter we used Fullwave simulation tool of RSoft photonic CAD software, which employs Finite Difference Time Domain (FDTD) method [16] for simulation the PhC based devices. The output spectrum of the proposed filter is dhiwn in figure 3. According to figure 3 the transmission efficiency of the filter at l=1570.7 nm is about 89%. After simulating the filter and extracting the output spectrum of the filter we investigated the effect of different parameters on the filtering behavior of the structure.

The output spectra of the structure for different radiuses of the defect rods (R) is shown in figure 4. As shown in figure 4 by increasing the refractive index of the dielectric rods, the output wavelengths shift toward higher wavelengths. Such that for R=110 nm, 115 nm, 120 nm, 125 nm, 130 nm, and 135 nm the output wavelengths are λ=1563.5 nm, 1567.1 nm, 1570.8 nm, 1574.7 nm, 1579 nm and 1584.8 nm respectively.

The output spectra of the structure at port C for different refractive indices of the dielectric rods (n) is shown in figure 5. As shown in figure 5 by increasing the refractive index of the dielectric rods, the output wavelengths shift toward higher wavelengths. Such that for n=3.43, 3.44, 3.45, 3.46, 3.47, and 3.48 the output wavelengths are λ=1559 nm, 1560.1 nm, 1561.2 nm, 1562.3 nm, 1563.4 nm and 1564.5 nm respectively.

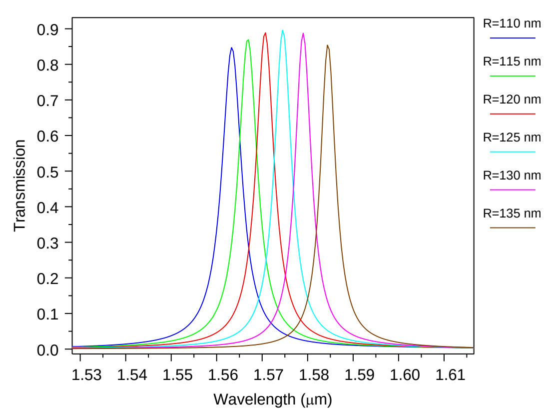

Figure 4. The output spectra of the proposed filter for different values of R

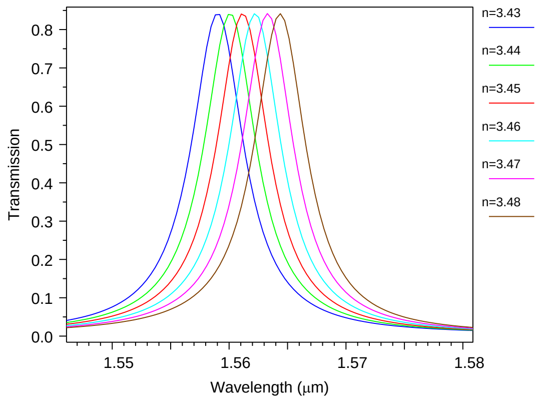

Figure 5. The output spectra of the proposed filter for different values of refractive index

In this paper we proposed a defective cavity structure for designing all optical photonic crystal based filter suitable for optical communication applications. This filter has a transmission efficiency of 89% at λ=1570.8 nm. The most significant characteristic of the filter is its ultra compact dimensions which makes it suitable for all optical integrated circuits. The total footprint of the structure is 34 μm^2. The results of our simulations show that by increasing the refractive index and the radius of defect rods the output wavelengths shift toward higher values.

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