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Design of a novel photonic crystal 1.31/1.55 μm bi-band filter for near infrared application

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A novel design of a double selective filter for integrated optics in two-dimensional photonic crystals operating at a wavelength of 1.31 and 1.55 μm is proposed in this paper. We focus particularly on filters transmission and selectivity enhancement. The two-dimensional photonic crystals filters are simulated by using a combination of three cascaded waveguides; these later are conceived by one missing row and with different rods radii for efficient filtering purpose. The properties of these photonic crystal structures are numerically investigated by using the two-dimensional finite-difference time-domain method and the numerical results are given for incident light wave having transverse electrical polarization. A final synthesized filter topology is presented and the maximum of transmission is found around 70% and 60% localized respectively near 1.31 and 1.55 μm wavelengths.

Keywords: finite-difference time-domain (FDTD), photonic crystals, waveguide W1KA, selective filters.

1. Introduction

Since the first citations [1, 2] photonic crystals (PCs) have presented extensive attention with their fantastic abilities and advantages to control the light ever since they were proposed two decades ago owing to the potential applications in integrated optical circuits and communication devices. Planar PCs [3] suitable to the applications in optical communications are defined by a periodic modulation of the refractive index, with a periodicity generally of order 0.30–0.50 μm. The two-dimensional PC slab waveguide structures [4–6] offer a practical geometry for the implementation of PCs devices by means of conventional planar lithography and semiconductor processing techniques.

One of the most unique properties of PCs is the existence of a PC band gap [7]. Techniques for terahertz (THz) generation and detection have generated great interest in the corresponding applications in THz sensing [8], imaging [9–12] and communication [13].

To obtain these kinds of application systems, several components (THz switches, filters and splitters) are required. Selective filter is a component whose objective is to select only one wavelength from the electromagnetic spectrum and eliminate the others. Selective filters are very interesting for integrated optic since it acts as a demultiplexer to select a particular channel or multiple channels in dense wavelength division multiplexed (DWDM) communication system. Recently, more attention has been paid to such filters and many works have investigated different varieties of filters in order to improve their transmission characteristics [14–22].

In this paper, using the finite-difference time-domain (FDTD) method [23, 24], we attempt to design a new high selective bi-band filter in two-dimensional PCs resonate at the wavelength of 1.31 and 1.55 μm which correspond respectively to normalized frequency $a/\lambda = 0.394$ and $a/\lambda = 0.333$. In order to eliminate unwanted peaks, we add in the same structure two small cylindrical holes with normalized radius of 0.18 between the two half-planes of PC strong lateral confinement and near the second guide.

2. Bi-band filters design

In this section, we propose a new topology of a selective bi-band filter which consists of three guides W1KA coupled in a cascade arrangement within the same cell of a PC having a triangular lattice; a single full row is removed. We carry in the y-axis direction, 6 rows of air holes on both sides of the single removing row and in the x-axis direction 45 rows of holes as shown in Fig. 1. The filter size is set as: 23.013 μm × 5.61 μm and length channel is 0.40 and 0.52 μm, respectively. Doped InP/GaInAsP/InP is the material most commonly used in telecommunication applications based on PC. In our simulations, physical and geometrical parameters of the PC are set as follows: the dielectric matrix has a relative permittivity of 10.5 and a refractive index of 3.24, the lattice constant $a = 0.516$ μm and the filling factor of the holes is about 44%. This triangular structure is excited in transverse electrical (TE) polarization. We simulate the

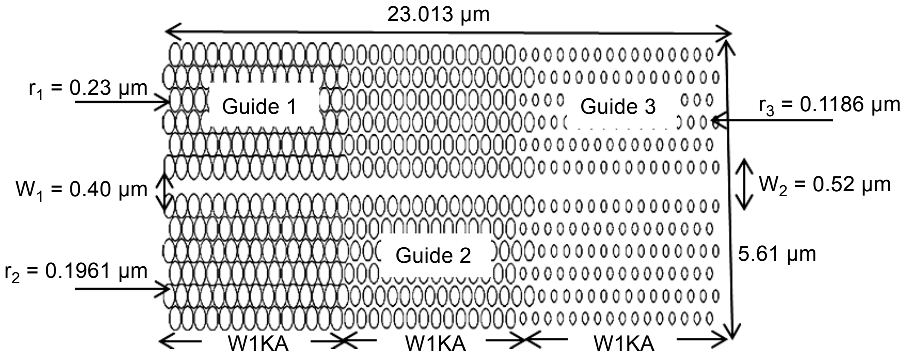

Fig. 1. Two-dimensional PCs selective filter structure achieved by combining three W1KA waveguides by removing one single row of air holes in triangular lattice.

propagation of electromagnetic waves using FDTD methods using the perfectly matched layer boundary conditions. Gaussian pulse source is employed to excite the fundamental mode at the input of the waveguide. The space step is chosen such that $\Delta x = \Delta y = 0.04$ μm and 50000 as a total number of time iterations.

The simulation results of each single guide W1KA forming our proposed filter (see Fig. 1) are shown in Fig. 2.

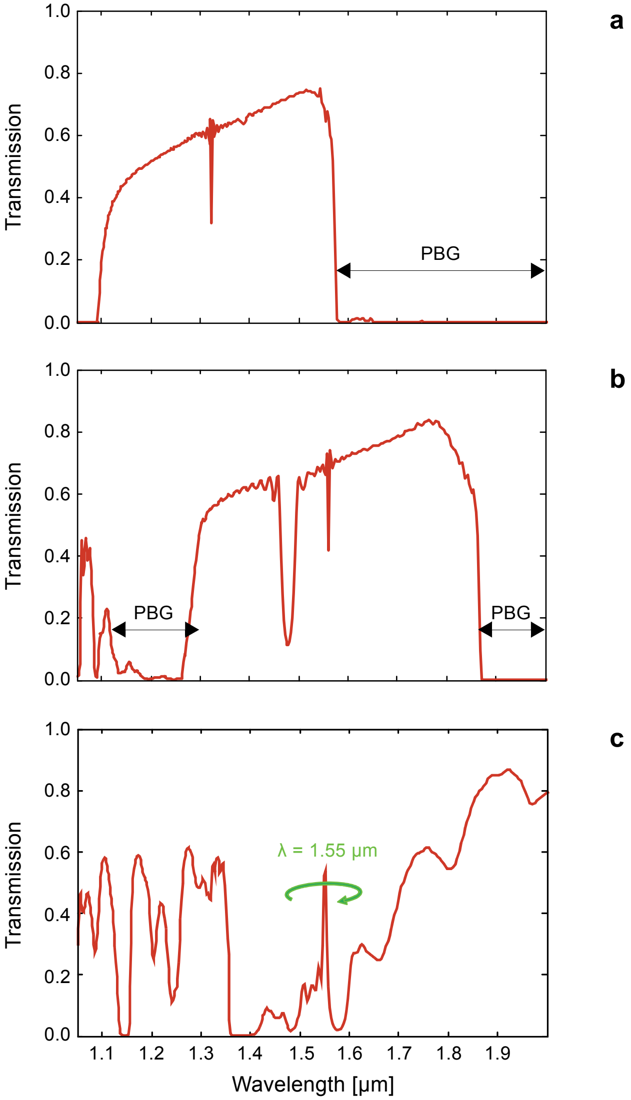

Fig. 2. Normalized transmission spectra. Single guide W1KA in triangular lattices with $r_1 = 0.23$ μm (**a**), $r_2 = 0.1961$ μm (**b**), and $r_3 = 0.1186$ μm (**c**).

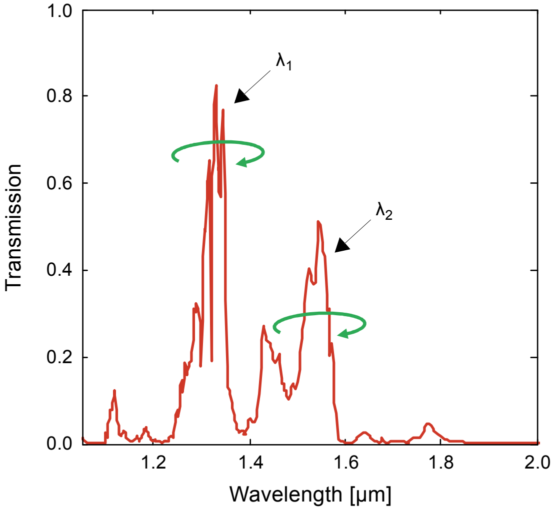

Fig. 3. Computed transmission coefficients for the simulated selective bi-band filter with $r_1 = 0.23$ μm, $r_2 = 0.1961$ μm, and $r_3 = 0.1186$ μm.

According to Figs. 2**a** and 2**b**, large transmission achieves the value of 50% to 85% extending over a wavelength band 1.29–1.85 μm.

Figure 3 shows the bi-band filter transmission spectrum *vs*. the wavelength computed by the two-dimensional FDTD simulation and corresponding to the structure illustrated in Fig. 1. We observe that the response of the filter is peaked around 1.31 and 1.55 μm with respectively 82% and 50% in the transmission peak. We also note the presence of a large band gap in the interval 1.58–2 μm and this reflects the selectivity of this bi-filter of the two desired wavelengths. However, other peaks appear in the wavelength band with a high transmission coefficient in the wavelength band 1.40–1.52 μm and which exceeds 25%.

3. Bi-band filter enhancement

Another two-dimensional PC bi-band filter is simulated in order to eliminate unwanted peaks and filter the desired wavelengths, based on the same first topology with the three W1KA but we add two small cylindrical holes with normalized radius of 0.18 between the two half-planes of PC strong lateral confinement near the second guide. The difference from the previous case is the rods radius which is the key parameter. The photonic band gap (PBG) is used to cancel transmission in the filter design.

The second topology of our proposed bi-band filter with all geometrical parameters is displayed in Fig. 4.

According to the plot shown in Fig. 5 and in comparison with the first topology, the transmission power reaches 70% around 1.31 μm wavelength and improved to 60% for the second wavelength. One observes a significant improvement in the disappearance

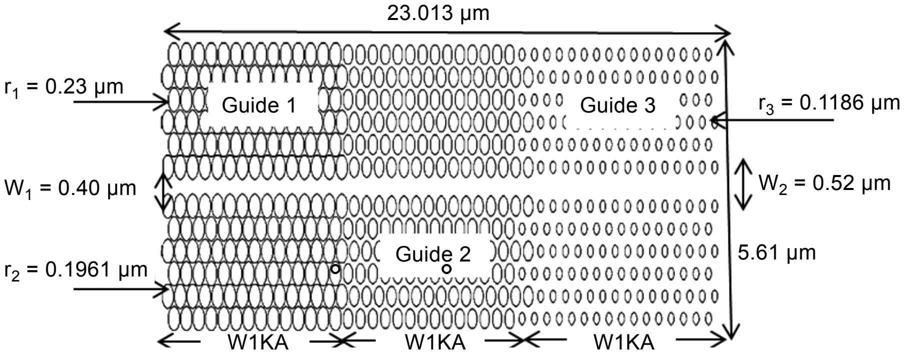

Fig. 4. Two-dimensional PCs enhanced selective bi-band filter structure achieved by combining three W1KA waveguides and having two cavities inside the missing row near the second guide.

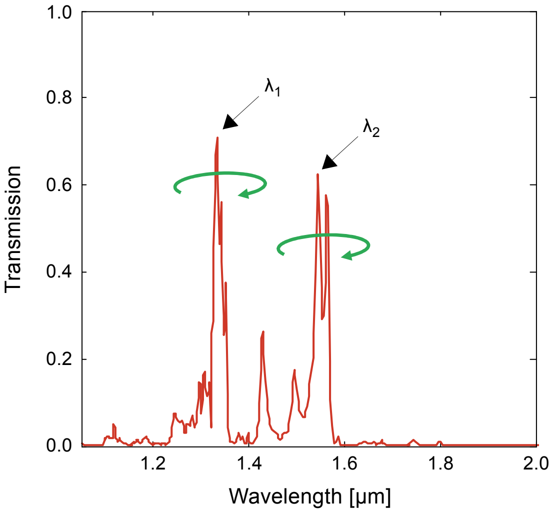

Fig. 5. Computed transmission coefficients for the simulated selective bi-band filter with two cavities having radius of 0.18 μm.

of undesirable peaks around the desired selective wavelength with a slight decrease occurring in the range of modes of occurrence and which did not exceed 26%. The rejection of any transmitted signal in the wavelength bands 1.05–1.24 μm and 1.57–2 μm is recorded, which leads to the widening of the band gap in the same intervals.

The magnetic field pattern inside the selective bi-band filter corresponding to the second topology with a spectral response close to 1.31 and 1.55 μm wavelengths is reported in Fig. 6 for different step time iterations (2000, 5000 and 6500). These figures show the light-guiding propagation of the electromagnetic field inside the empty row along the waveguide with confinement. We can observe that one part of electromagnetic energy is transmitted and reaches the end of the PC with a wavelength belonging

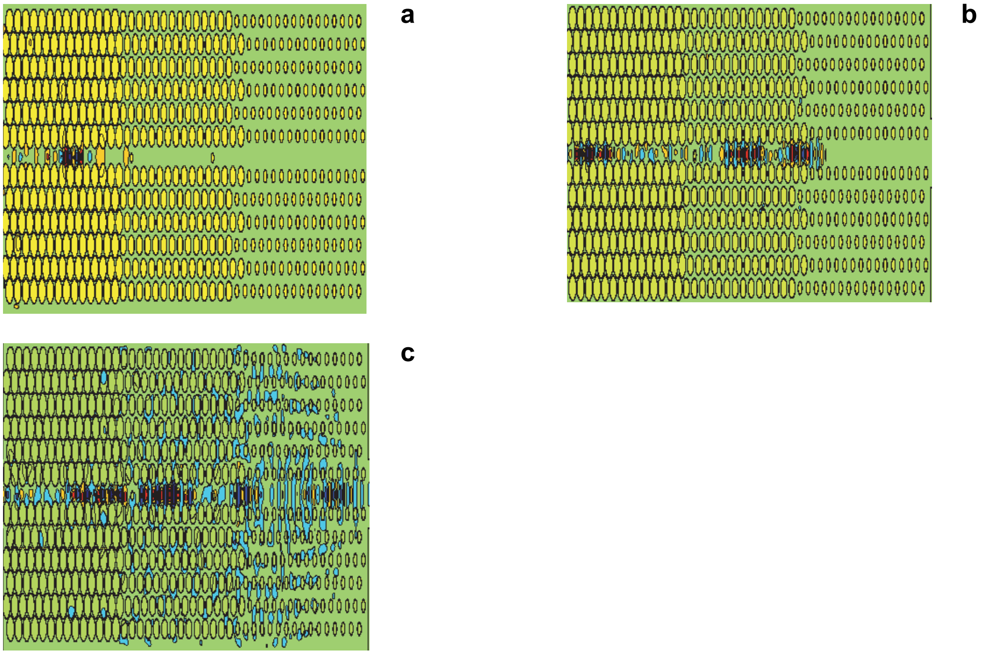

Fig. 6. The magnetic field H_z distribution of the excited TE mode of the synthesized bi-band filter, $\Delta x = \Delta y = 0.04$ µm; 2000 iterations (**a**), 5000 iterations (**b**), and 6500 iterations (**c**).

to the gap, and the other part of energy with no allowed wavelength is reflected by the added inclusions embedded in the dielectric matrix in an empty row.

4. Conclusions

This paper depicts a novel design for a PC bi-band filters around 1.31 and 1.55 µm; their performances were investigated using the two-dimensional finite-difference time-domain method. Two filters have been proposed achieved by using cascaded W1KA waveguides obtained by one missing row with different rod radii. We found that the best performance is produced when we added two small cylindrical holes with normalized radius of 0.18 between the two half-planes of photonic crystal strong lateral confinement near the second guide. The maximum of transmission is around 70% and 60% localized at 1.31 and 1.55 µm, respectively.

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