A Compact Double Phase-Shifted Photonic Crystal Filter

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Abstract—This document present a simple 2D filter structure build up of a narrow ridge waveguide with high lateral index contrast and equipped with a 2D photonic crystal consisting of a single row of air holes. The structure is investigated using finite difference time domain method. The classical high-Q transmission filter design is considered with a double phase-shifted photonic crystal waveguide grating. In order to improve the filter characteristic of a phase-shifted grating filter multiple phase-shift sections can be used. The phase-shift region is introduced by the insertion of an unmodulated waveguide region which is 0.5a long. This phase-shift is placed in the center of the photonic crystal waveguide grating. Three cases with the outer waveguide grating lengths of 8a, 9a, and 10a are used.

Keywords—photonic crystal; filters; phase silt region; microcavity; finite difference time domain; resonance; waveguide

I. INTRODUCTION

Photonic crystal waveguides are attractive components for optical signal processing. Due to the achievable high refractive index contrast, photonic crystal devices can be made very small in the range of only several multiples of the used wavelengths. Concerning optical communications, various kinds of filters are needed.

The PCF consist of an array of air/dielectric filled holes running along its length and it has many unique properties which are not realizable in traditional optical fibers such as endless single mode operation, high birefringence and low nonlinearity, low dispersion etc.[5]-[1]. The parameters that affect the dispersion of the PCF include its profile shape, number of air holes, distance between two adjacent air holes and diameter of the air holes [1]. Several variations of the structure in terms of the above mentioned parameters of the PCFs have been investigated in the literature [1] from the point of view of improvement in the dispersion and attenuation and other important properties of the PCF. For instance in [9], many propagation properties of index guided PCFs with air holes have been discussed. A comparison of the effect of the changes in the hole structure from circular to elliptical in the hybrid square lattice PCF is done in [1].

We uses a narrow waveguide with an embedded 1D periodic structure [7,11]. In addition to single channel filters, multichannel filters with 1D photonic crystal structures were also designed [11]. It is successfully demonstrated [10] that hole diameter and position tapering outside and within the cavity significantly increases the optical transmission and enhances the resonance Q-factor of single-row photonic crystals embedded in photonic wire waveguide micro cavities. By introducing a series of 1D periodic sections separated by phase-shift regions and by properly choosing their locations and magnitudes, a nearly rectangular shape of the band pass transmission spectrum [12] can be obtained, however, at the cost of an increased device length. So, a band pass transmission filter based on 2D photonic crystals including multiple phase-shifted waveguide gratings was presented [5]. By means of an appropriate choice of the magnitude of the phase-shifts and the lengths of the waveguide gratings a nearly flat-top is achievable.

In this paper, compact phase-shifted band pass transmission filter based on 1D photonic crystal waveguides is presented. Besides the small size, special emphasis on design also given how to precisely adapt the shape of the transmission characteristic in a compact photonic crystal filter to a flat-top design.

The proposed structure is analysed with the full vector mode solver using FDTD method. The simulations are carried out using OptiFDTD simulator. By introducing a series of 1D periodic sections separated by phase-shift regions and by properly choosing their locations and magnitudes, a nearly rectangular shape of the band pass transmission spectrum [12] can be obtained.

II. DESIGN AND SIMULATION

The initial considerations use a simple 2D filter structure build-up of a narrow ridge waveguide with high lateral index contrast and equipped with a 1D photonic crystal. First, the classical high-Q transmission filter design is considered with a single phase-shifted photonic crystal waveguide grating as depicted in Fig.1. The radius of the air holes is r = 0.2a, with the lattice constant a = 282.2 nm. The dielectric medium has a refractive index of nd = 3.4. A single-mode photonic crystal waveguide is formed by limiting the width of the dielectric medium to a value of 0.3 µm. For simplicity this medium is assumed to be surrounded by air on both sides. The phase-shift region is introduced by the insertion of an unmodulated waveguide region which is 0.5a long.

A. Single phase shifted waveguide filter

A single-mode photonic crystal waveguide is formed by limiting the width of the dielectric medium to a value of 0.3 µm. For simplicity this medium is assumed to be surrounded by air on both sides. The phase-shift region is introduced by the insertion of an unmodulated waveguide region which is 0.5a long. This phase-shift is placed in the center of the photonic crystal waveguide grating. The lengths of two uniform grating sections around the phase-shift region are defined in units of a as 9a. The spectral transmission
characteristic is obtained using the Fourier transform of the impulse response. The impulse response itself is calculated with a 2D finite difference time domain method for TM polarization shown in fig.1

![Fig. 1 Single phase shifted waveguide filter](image1)

**B. Double phase shifted waveguide filter**

In filter for a high ratio R, the number of phase-shift regions has to be large and thus the total length of the filter structure is also increased. To maintain the compact size of the photonic crystal device, the introduction of two phase-shift region is suggested as shown in Fig.2,3,4. Three cases with the outer waveguide grating lengths of 8a, 9a, and 10a are investigated. The inner waveguide length is kept constant at 18a.

![Fig. 2 double phase shifted photonic crystal waveguide grating with the outer waveguide grating lengths of 8a](image2)

![Fig. 3 double phase shifted photonic crystal waveguide grating with the outer waveguide grating lengths of 9a](image3)

**III. EVALUATING THE CHARACTERISTICS OF FILTER**

In this section we present the simulation results of the proposed structures carried out in the OptiFDTD software. The wafer dimensions in the simulation are chosen for each structure in a manner to accommodate all the air holes of the proposed structure while maintaining the lattice constant uniform throughout the structure. The lattice constant, which is centre to centre spacing between two nearest air holes, gives the characteristics of lattice of the PCF.

Photonic crystals have gained significant interest in filters. These are periodic structures composed of alternating regions of high and low dielectric constant. They possess a photonic band gap (PBG) which does not allow a particular range of frequency to pass through the structure unless there is a defect in the perfect photonic crystal. The range of band gap depends upon the structural parameters including diameter of dielectric rods, lattice constant and refractive indices of wafer and dielectric rods. Defects can be introduced by changing the size of a phase shifted region.

Quality factor is major factor responsible for improving the quality of double phase sift filter in comparison with single phase shift filter. The calculated transmission spectrum of the photonic crystal waveguide grating with single and double phase-shift.

Fig.5, 6, 7, 8 shows the plot of transmission spectra against wavelength obtained through FDTD simulation. A Gaussian modulated input is used in phase shifted filters made up of multiple phase shifted photonic crystal waveguide grating with the outer waveguide grating lengths of 8a, 9a and 10a.

![Fig. 4 double phase-shifted photonic crystal waveguide grating with the outer waveguide grating lengths of 10a](image4)

![Fig. 5 the plot of transmission spectra of Single phase shifted waveguide filter](image5)
In fig. 6, 7, 8 Results of double phase shifted filter show that with increasing monitor value with outer waveguide grating lengths, the transmission spectra shifts to longer wavelengths in double phase-shifted photonic crystal waveguide grating.

![Graph](image)

Fig. 6: The plot of transmission spectra of double phase-shifted photonic crystal waveguide grating with the outer waveguide grating lengths of 8a.

As mentioned earlier, quality factor and sensitivity are two important metrics to quantify the performance of biosensor. Results of three different samples are listed in Table I.

<table>
<thead>
<tr>
<th>Filter Type</th>
<th>outer grating lengths</th>
<th>Resonant Wavelength (µm)</th>
<th>Monitor Value (a.u.)</th>
<th>FWHM (nm)</th>
<th>Quality Factor (Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>single phase-shifted filter</td>
<td>9a</td>
<td>1.55</td>
<td>1.160</td>
<td>0.021</td>
<td>73.80</td>
</tr>
<tr>
<td>double phase-shifted filter</td>
<td>8a</td>
<td>1.395</td>
<td>1.760</td>
<td>0.009</td>
<td>153.36</td>
</tr>
<tr>
<td>double phase-shifted filter</td>
<td>9a</td>
<td>1.395</td>
<td>1.806</td>
<td>0.009</td>
<td>153.36</td>
</tr>
<tr>
<td>double phase-shifted filter</td>
<td>10a</td>
<td>1.395</td>
<td>1.842</td>
<td>0.009</td>
<td>153.36</td>
</tr>
</tbody>
</table>

According to resonant wavelength and FWHM, the values of quality factor are calculated for each filter. Resolution is inversely proportional to FWHM and directly proportional to quality factor (Q). As proved from the results highest Q of 153.36 is obtained. And also the property of spectral shift of monitor value in double shifted waveguide filter with change in outer waveguide grating lengths.

IV. CONCLUSIONS

We use a narrow waveguide with an embedded 1D periodic structure. In addition to single channel filters, multichannel filters with 1D photonic crystal structures were also designed. It is successfully demonstrated [ZGCSR08] that hole diameter and position tapering outside and within the cavity significantly increases the optical transmission and enhances the resonance Q-factor of single-row photonic crystals embedded in photonic wire waveguide micro cavities. By introducing a series of 1D periodic sections separated by phase-shift regions and by properly choosing their locations and magnitudes, a nearly rectangular shape of the band pass transmission spectrum can be obtained, however, at the cost of an increased device length. So; a band pass transmission filter based on 2D photonic crystals including multiple phase-shifted waveguide gratings was used.

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REFERENCES


