New Design of Optical Add-Drop Filters based on Photonic Crystal Ring Resonator

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ABSTRACT: In this paper, a new design of add-drop filters based on two-dimensional photonic crystal ring resonator is proposed. The structure is made of a square lattice of silicon rods with the refractive index \(n_1=3.46\) in coefficient of air with refractive index \(n_2=1\). The normalized transmission spectra of photonic crystal ring resonator are taken using Two-dimensional (2D) Finite Difference Time Domain (FDTD) method. The photonic band gap is calculated by Plane Wave Expansion (PWE) method. Full Width Half Maximum (FWHM) bandwidth of the filter at the output transmission spectrum - from 1.647–1.662\(\mu\)m – and dropping efficiency are 15nm, 107\%, respectively The proposed structure is small and the overall dimension is 12.4\(\mu\)m×13.6\(\mu\)m which is suitable for optical integrated circuits and optical communication systems.

Keywords: Photonic Crystal, ring resonator, optical integrated circuits

Abbreviations: ADFs- Add-drop filters, 2D-Two-dimensional, FDTD-Finite Difference Time Domain, PWE-Plane Wave Expansion, FWHM-Full Width Half Maximum, PCs-Photonic Crystals, PBG-Photonic Band Gap, WDM-Wavelength Division multiplexing, CDFs-Channel Drop Filters, PCRR-Photonic Crystal Ring Resonator

INTRODUCTION

Since 1987, the science of using Photonic crystals is rapidly developing and receives special attention by the scientific and research communities (Joannopoulos et al., 2008). Photonic Crystals (PCs) are composed of periodic dielectric or metallo-dielectric nanostructures that have alternate low and high dielectric constant materials (refractive index) in one, two or three dimension(s), which possesses Photonic Band Gap (PBG), where the transmission of light in certain frequency range is absolutely zero (Inoue et al., 2004; Mansouri-Birjandi et al., 2008). Photonic crystals are very suitable candidates for realization of future passive and active optical devices because of their ability to control light-wave propagation, high speed of operation, better confinement, long life period and suitability for integration (Mahmoud et al., 2012; Taalbi et al., 2012). By introducing some defects (point and/or line and/or both) in these structures, the periodicity and thus the completeness of the band gap are disturbed and the propagation of light can be localized in the PBG region. This can lead to design of PC based optical devices in the PBG region (Robinson et al., 2012). In recent years many of optical devices made were based on PCs. i.e. multiplexers(Manzacca et al.,2007), de-multiplexers(Ghaffari et al.,2008), polarization beam splitters(Zabelin et al.,2007), add-drop filters, channel-drop filters and so on (Qiang et al.,2007; Wang et al.,2010; Fan et al.,1998). Add-drop filters (ADFs) plays an important role in a wavelength division multiplexing (WDM) system, which enables to transmit data at multiple carrier wavelengths simultaneously throughout optical fibers for the substantial demand of the optical transmission bandwidth in optical communication networks (Hwang et al., 2005).Various channel drop filters (CDFs) exist, such as fiber Bragg gratings. Fabry–Perot filters, and arrayed waveguide gratings and ring resonator. Resonant CDFs, which involve waveguide-cavity interaction, are other attractive applicants for this intention (Ghaffari et al.,2008; Zabelin et al.,2007; Qiang et al.,2007).Generally, the ring resonator based on ADF provides efficient wavelength selection, scalability, narrow line width, flexible mode design and small channel spacing (Robinson et al., 2012). In this paper a two-dimensional add-drop filters by using photonic crystal ring resonator is designed and investigated. The desired wavelength performance window is located within L-band and the U-band of optical telecommunication bands. Simulation of the designed filter is carried out by 2D-FDTD method. The Plane Wave Expansion method is employed to calculate photonic band gap.
The rest of the paper is arranged as follows: in the second part of the paper, we discuss the design procedures. We discuss the simulation results in Section 3 and finally in the last section of the paper we express the conclusions.

**Structure Design**

The design in this paper is based on two-dimensional Square lattice of silicon rods (refractive index $n_{si}=3.4641$) in an air background ($n_{air}=1$). The number of rods in the x-z plane is $21 \times 23$.

To find the best rod's radii for which the PBG is maximum in the TE polarization, we draw the gap map in terms of filling ratio ($r/a$). The best filling ratio that the broadest PBG occurs for it, obtains for $r/a = 0.17$.

There are two TM PBGs exist in the structure which are indicated by blue region. As TE PBG is not present in the structure, TM polarization is considered for this simulation. The normalized frequency of first reduced TE PBG is observed from $0.284 \ a/\lambda$ to $0.441 \ a/\lambda$ whose corresponding wavelength ranges from $2073 \ nm$ to $1335 \ nm$ and second PBG is from $0.704 \ a/\lambda$ to $0.749 \ a/\lambda$ whose corresponding wavelength spans from $836 \ nm$ to $786 \ nm$.

Figure 1 shows the PC's perfect lattice band diagram which is also known as PBG and it is calculated for $r/a=0.17$.

Compared to point or line defects, ring resonators offer scalability in size, adaptability in structure design because of vast design parameters and flexibility in mode design due to their multi-mode nature. Some of these parameters are radii of scattting rods and the dielectric constant of the structure. The ring resonator coupled to a line defect waveguide from its side, traps photons at resonant frequency from the waveguide through evanescent coupling modes, and emits almost whole of them in the drop waveguide. Using this method, perfect power transfer and complete wavelength selective operation from the bus waveguide to the drop waveguide are obtained in our filters (Robinson et al., 2012).

Figure 2 shows the PCRR structure that was created by removing a circular row of rods and concoction two circles half.

As shown in Figure 2, by adding the four extra scatterer rods at each corner of the ring resonator with 1.4 rods radius, which are the same as other rods, the performance of the ring resonator is improved. Back-reflections at the sharp corners of the ring lead to appear undesirable propagating mode. Adding the four extra rods, act like a right-angled reflector, minimizes the effect of these modes. The inner rods designed perfectly circular to improve the PCRR performance. To form the circular shape of our PCRR outer rods and to optimize its efficiency, we moved defects labeled as D1 and D2 from their primary places.

**Add-Drop Filters**

Figure 3 shows the final design of our proposed channel add-drop filter. Which consists of bus and dropping waveguides and diamond resonator (coupling element) Also, it has four ports, among them ports A and B are the input and transmission output terminals whereas ports C and D are forward and backward dropping terminals, respectively. The overall dimension of the structure is about $12.4 \mu m \times 13.6 \mu m$ which is small. The filter's desired wavelength performance is the conventional L and U bands of optical telecommunications.
RESULTS

A Gaussian optical pulse, covering the whole frequency range-of-interest, is launched at the input port. Power monitors were placed at each of the other three ports (A, B) to collect the transmitted spectral power density after Fourier-transformation. The filter’s transmission features are calculated using the FDTD numerical method with perfectly matched layers (PML) absorbing boundary conditions. Figure 4 demonstrates the numerical simulation results for the resonant mode at 1.655μm and non-resonant mode at 1.60μm.

At resonant wavelength, the electric field of the waveguide is completely coupled to the ring and reaches to output, where at off resonance, i.e. Figure 4(b) 1.60μm, it doesn’t couple with the ring and the fields are reflected in the counter direction.
The filter's power transmission spectrum response is calculated as the relation of transmitted power versus different wavelengths. Figure 5 shows the numerical simulation results for the wavelengths range 1.60-1.70μm. The filter’s dropping efficiency is 107% at the 1.655μm and FWHM bandwidth of 15nm- from 1.647-1.662μm- is achieved at the output transmission spectrum.

CONCLUSION

We proposed an optical add-drop filters based on two-dimensional photonic crystal ring resonators. The widest photonic band gap obtained for the filling ratio of $r/a = 0.17$. Filter’s dropping efficiency for the operational window which was in the L and U bands of optical telecommunications, obtained 107% and Full Width Half Maximum bandwidth of the filter at the output transmission spectrum - from 1.647-1.662μm - was 15nm. Our proposed structure is small and the overall dimension is 12.4μm×13.6μm which is suitable for photonic integrated circuits.

REFERENCES

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