Abstract — A two Dimensional Photonic Crystal based Bandpass Filter (2D-PCBPF) is proposed for C-Band of CWDM applications. It is designed with two quasi waveguides and a circular Photonic Crystal Ring Resonator (PCRR). The simulation results are obtained using 2D Finite Difference Time Domain (FDTD) method. The Photonic Bandgap (PBG) is calculated by Plane Wave Expansion (PWE) method. The proposed PCBPF is covered the entire C-Band, which extends from 1530 nm to 1565 nm. Close to 100% output efficiency is observed for the wavelength ranging from 1536 nm to 1558 nm through this simulation with 32 nm of (Full Width Half Maximum) bandwidth. The size of the device is drastically reduced from a scale of few tens of millimeters to the order of micrometers. The overall size of the proposed PCBPF is around 13 µm × 11.5 µm.

Keywords - Photonic crystal ring resonator; photonic bandgap; CWDM; bandpass filter; FDTD method; PWE method;

I. INTRODUCTION

Photonic Crystals (PCs) have acquired worldwide fascinating interest in the past two decades due to the existence of bandgap and the capability to control the electromagnetic waves. The bandgap in PCs is more convenient for the design of required optical devices. The devices based on photonic crystal structures usually have the benefit of significant size reduction (10-100 times) compared with their conventional devices. The other related features of devices such as operating speed, life time, Q factor and output efficiency are not affected due to miniaturization, which are inevitable for the design of integrated optics.

PCs are composed of periodic dielectric or metallo-dielectric nanostructures that have alternate low and high dielectric constant materials (Refractive Index) in one, two and three dimensions, which affect the propagation of electromagnetic waves inside the structure. As a result of this periodicity, PCs exhibit an unique optical property, namely photonic bandgap (PBG) where the electromagnetic modes propagation is absolutely zero due to reflection. Hence, the density of states becomes negligible.

By introducing a defect (point or line or both) in these structures, the periodicity and thus the completeness of the bandgap are broken and the propagation of light can be localized in the PBG region. This can lead to PC based optical devices in the PBG region.

2DPCs are receiving increased attention from the scientific community because it has relatively simple fabrication, better confinement of light, accurate bandgap calculation, effective control of spontaneous emission and easy integration compared to conventional devices. In general, 2DPCs, triangular and square lattice can give either TE or TM PBG within identical frequency region.

Recent years, many PC based optical devices are proposed both theoretically and experimentally. To name a few, add-drop filters [3], power splitters [4, 5], channel drop filters [6-8], multiplexers and demultiplexers [9, 10], polarization beam splitters [11, 12], triplexers [13, 14], switches [15], directional couplers [16], bandstop filters [17], bandpass filters [18-22] etc.

PCBPF is one of the inevitable components for CWDM system and integrated optics because it can act as multiplexer to allow a single or multiple bands. The waveguide coupled ring resonator based BPF provides better selectivity, scalability in size and flexibility in mode design. It has been done in the literature by introducing point defects and/or line defects [18, 19], biperiodic structures [20] and using liquid crystal photonic bandgap fibers [21] and PCRR [22]. The PC based BPF has been demonstrated theoretically for L-Band in WDM system [19].

In this paper, a circular PCRR based BPF is proposed and designed for single mode C-band of CWDM applications without disturbing neighboring bands, S-band (1460 nm - 1530 nm) and L-band (1565 nm -1625 nm). The Plane Wave Expansion (PWE) method is the most popular method to calculate the bandgap of the structure that has been used for calculating the PBG. A 2D FDTD method has been employed to obtain the wavelength response of the PCBPF. Both PWE and 2D FDTD methods are simulated by Bandsolve and Fullwave Simulator of Rsoft.

The paper is arranged as follows: In Section II, the structure design of circular PCRR based BPF is presented. Simulation results are discussed in Section III and Section IV concludes the paper.
II. STRUCTURE DESIGN

The proposed PCBPF is designed by two dimensional square lattice PCs. The distance between the two adjacent rods is 555 nm, which is termed as lattice constant. It is denoted by ‘a’. The radius of the rod is 1 µm and the Si rod with refractive index 3.4641 is embedded in air. The number of rods in x and y directions are 23 and 21 respectively. The PC structure has a PBG for Transverse Electric (TE) modes. However, no Transverse Magnetic (TM) modes are observed as shown in Fig. 1. Hence, we restrict our attention to TE PBG only, whose electric field is parallel to the rod axis.

The band diagram in Fig. 1 gives the propagation modes of the structure. The first reduced PBG extends from $0.295 \frac{a}{\lambda}$ to $0.435 \frac{a}{\lambda}$ whose wavelength ranges from 1241 nm to 1830 nm and second PBG spans from $0.732 \frac{a}{\lambda}$ to $0.754 \frac{a}{\lambda}$ whose wavelength ranges from 716 nm to 737 nm. In this paper, the first reduced Transverse Electric (TE) PBG is considered for C-Band CWDM applications.

When the defects are introduced in the structure, the PBG is broken and the guided modes are propagated inside PBG region as shown in Fig. 2. The line defects for quasi waveguide and point defects for circular ring cavity are introduced.

The gapmap shown in Fig. 3 (a), (b) and (c) represent variation of TE/TM PBG, which is obtained by varying the defect size (a), the radius of the rod and lattice constant (b) and refractive index difference (c). In these Figures, the blue region indicates the variation of TE PBG with respect to radius of the rods, period and delta similarly red region indicates for TM PBG. The vertical yellow line over blue region shows the TE PBG region of the structure without introducing defects. The values to design the PCBPF in the first reduced TE PBG are optimized through gapmap, which are rod radius (0.1 µm), refractive index (3.4641) and period (555 nm) is indicated in the below gapmap.

![Fig. 1 Band diagram of the 21x23 PC square lattice structure (without introducing any defects)](image1)

![Fig. 2 Band diagram of the PC structure after the introduction of line and point defects](image2)

![Fig. 3 Effect of gapmap by varying (a) Radius of the rod (b) Period (Lattice constant) and (c) Delta (Index contrast)](image3)
FDTD method is used to simulate the PC structure and the Perfect Matched Layer (PML) is placed as absorbing boundary condition [22]. The PWE method is used to calculate the PBG of the PC structure with and without introducing the defects.

The Fig. 4 sketches the PCBPF based on circular PCRR, which consists of two quasi waveguides in horizontal (r-x) direction and a circular PCRR between them. The input Gaussian signal is applied to the port marked ‘A’ with arrow in the left side of top quasi waveguide and the output is detected by using power monitor at the output port marked ‘B’ with arrow right side of the bottom quasi waveguide. The quasi waveguides are formed by introducing the line defects whereas the circular PCRR is shaped by point defects. The circular PCRR is constructed by varying the position of inner rods and outer rods from its original position towards center of the origin. The inner rods and outer rods are built by varying the position of adjacent rods in the four sides, from its center, by 25% in both x and z directions. The position of the rods is varied by varying the lattice constant.

The rods which are inside the circular PCRR is called as inner rods. The coupling rod which is placed between circular PCRR and quasi waveguides is marked as ‘c’. The reflector is placed above and below the right side and left side of circular PCRR as shown in Fig. 4, which is used to improve the output efficiency of the PCBPF by reducing the counter propagating modes. In order to enhance the output efficiency, the number of periods (Si rods) in the reflector is kept as constant (10a). It ensures maximum signal transfer from input to output at resonance condition.

III. SIMULATION RESULTS

A Gaussian input signal is launched into the input port. The normalized transmission spectra of port ‘B’ is obtained by conducting Fast Fourier Transform (FFT) of the fields that are calculated by FDTD method. Fig. 5 shows the normalized transmission spectra of PCBPF. The output efficiency, close to 100% is obtained for the wavelength ranging from 1536 nm to 1558 nm. Also, a Full Width Half Maximum (FWHM) bandwidth of 32 nm at the output spectrum is achieved through this simulation. The observed range of wavelengths and bandwidth covers almost the entire C-Band without affecting S-Band and L-band of CWDM system.
The Fig. 6 (a), (b) and (c) depict the electric filed pattern of stop region, pass region and stop region at 1525 nm, 1550 nm, and 1575 nm respectively. At resonant wavelength $\lambda=1550$ nm, the electric field of the quasi waveguide is fully coupled with the ring and reached to its output port, where as at off resonance, 1525 nm and 1575 nm, it doesn’t couple with the ring (The signals are reflected to the counter direction).

IV. CONCLUSION

A PCBPF is proposed and designed based on circular photonic crystal ring resonator. The output efficiency and bandwidth of the PCBPF are investigated through simulation. The output efficiency of PCBPF is approximately, 100% over the wavelengths ranging from 1536 nm to 1558 nm. Also, a bandwidth of 32 nm is observed. The rod radius, index contrast and lattice constant are optimized from gapmap. The proposed circular PCRR based BPF would be the foremost BPF for C-Band of CWDM applications. The suggested PCBPF is compact and overall size of the chip is about $13 \mu m \times 11.5 \mu m$.

REFERENCE


