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Tunable Optical Add/Drop Filter for CWDM Systems Using Photonic Crystal Ring Resonator

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In this paper an add/drop filter based on a two dimensional (2D) photonic crystal ring resonator (PCRR) is proposed and its performance is studied. This device is comprised of a hexagonal PCRR between two parallel waveguides formed by creating line defects in a 2D lattice structure with an array of 20 × 20 Si (Silicon) rods in air host. The lattice constant a is 636 nm and the radius of silicon (Si) rods r is $0.2a$. The size of the add/drop filter is 6 μm × 6 μm. We have achieved nearer to 100% dropping efficiency when the wavelength (λ) of the optical input signal is 1.55 μm. Optical signal can be made to drop at a different port by varying its wavelength or radius of Si rods. Simulation of the device is performed using a licensed RSoft FullWAVE tool based on a finite difference time domain (FDTD) simulator. The proposed structure could be used as an add/drop filter in the wavelength division multiplexing.

Key words: Photonic crystal ring resonator (PCRR), resonant wavelength, photonic bandgap, add/drop filter

INTRODUCTION

There is an ever-increasing demand for higher bandwidth and speed of the Internet worldwide. This demand can be fulfilled by replacing electronic communication with optical communication due to enhanced durability and speed of optical devices especially in photonic integrated circuits. Lot of research is being done on optical devices constructed on 2D photonic crystal (PhC) as they weigh in as electronic devices in size, durability, speed and are also, appropriate for photonic integrated circuits. In this regard researchers have studied various optical devices such as add/drop filters,[1] channel drop filters using directional couplers,[2] band stop filters,[3] decoder,[4] demultiplexer and adders circuits.[5] An optical add/drop filter is an important device used for adding or dropping a specific wavelength signal in Wavelength Division Multiplexing (WDM) as WDM plays a crucial part in multiplexing and routing optical signals into or out of a single mode fiber.[6]

We focus on the design of an add/drop filter based on a 2D silicon PCRR. We have used the Plane Wave Expansion (PWE) method to obtain the photonic bandgap and Rsoft FDTD full wave simulator for performing simulations of the proposed structure and analyze the propagation of light.

PROPOSED STRUCTURE OF ADD/DROP FILTER

Structure of an add/drop filter designed on a 2D hexagonal photonic crystal, with 20 Si rods in X direction 20 Si rods in Z direction is shown in Fig. 1. The index of refraction of Si rods n_s = 3.476[7] and air host n_a= 1.00. The distance between two rods, lattice constant a is 636 nm and radius of the Si rods r is $0.2a$. These values for designing an add/drop filter are chosen from a band diagram with respect to TE/TM photonic bandgap (PBG) calculated by using PWE method. The projected add/drop filter supports two transverse electric (TE) modes as shown in Fig. 2 wherein one of the TE

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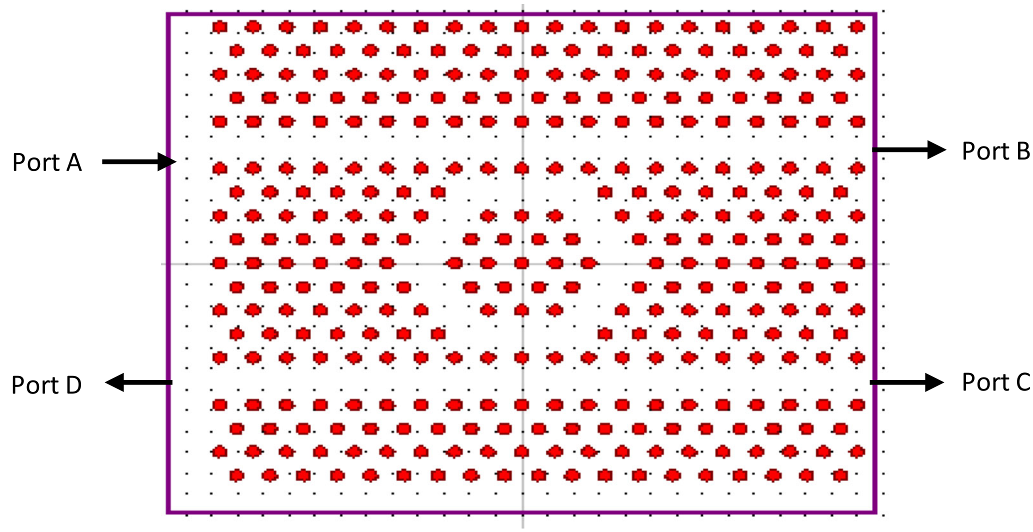

Fig. 1. Schematic diagram of a hexagonal ring resonator based add/drop filter on a triangular lattice PhC, formed by Si rods in air background.

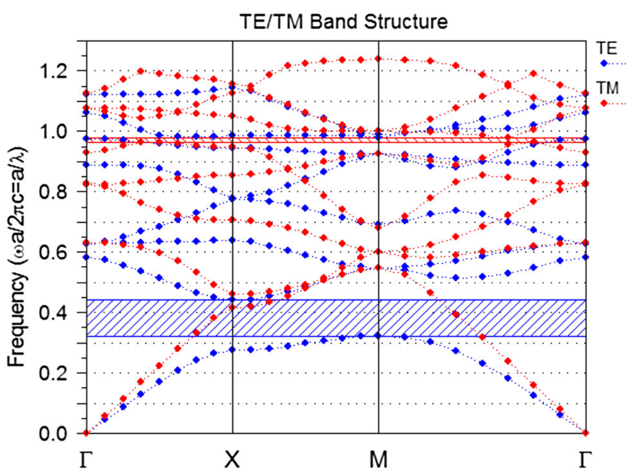

Fig. 2. Band diagram of 20 × 20 lattice structure.

mode range from 0.278 (a/λ) to 0.438 (a/λ) whose corresponding wavelength range from 1452 nm to 2287 nm. We focus to the first TE PBG as its wavelength coincides with the third window of optical communications and provides excellent performance with low losses in the WDM network. The properties of an optical ring resonator can be realized by changing the refractive index of Si rods, by varying the radius of the Si rods or by varying wavelength of the input light signal launched at port *A*.

The proposed add/drop filter structure is formed by creating two parallel line defects that form the waveguides. The waveguide created above the ring resonator is called the bus waveguide and below the ring resonator as the drop waveguide.[8] A hexagonal photonic crystal optical ring resonator is located between two parallel waveguides which couples light between two waveguides. In ray optics, if the ring resonator and the waveguide are nearby, the light propagating in the waveguide will be coupled into the ring. The amount of light coupled depends on the distance, the coupling length and the refractive indices.[9,10]

The proposed add/drop filter consists of four ports, port *A* is used as input port where input signal is launched, port *B*, port *C* and port *D* are used as output ports. Depending on the wavelength of the input applied at port *A*, the output optical signal is observed at port *B*, *C*, and *D*, respectively. Port *B* is used as transmission port, port *C* as forward dropping port and port *D* as backward dropping port.

RESULTS AND DISCUSSION

Dropping efficiency of the proposed structure can be determined by observing the electromagnetic spectrum at the output port. Electromagnetic spectrum is obtained by using FDTD based RSoft Full wave licensed simulator. RSoft CAD, is the control program for simulators such as FullWAVE, DiffractMOD, BeamPROP, FemSIM and BandSOLVE. Add/Drop filters are used for WDM systems to separate different wavelength optical signals. This can be achieved by varying the radius of silicon rods, refractive index and lattice constant. Firstly, the radius of Si rods is kept as *0.2a* and wavelength of the launched optical input signal is varied to obtain the optical signal at different ports. Later the effect of variation in radius of Si rods is investigated. When a continuous Gaussian optical signal of resonant wavelength, $\lambda_1 = 1.55\ \mu$m is launched at input port *A*, the light signal couples in PCRR as this resonant wavelength coincide with dropping wavelength of the structure and drops out at port *D* with nearer to 100% backward dropping efficiency.[11] Whereas at another wavelength input optical signal will not couple to the ring resonator.[12] Figure 3 shows the electromagnetic field pattern and Fig. 4 shows intensity of the optical signal at

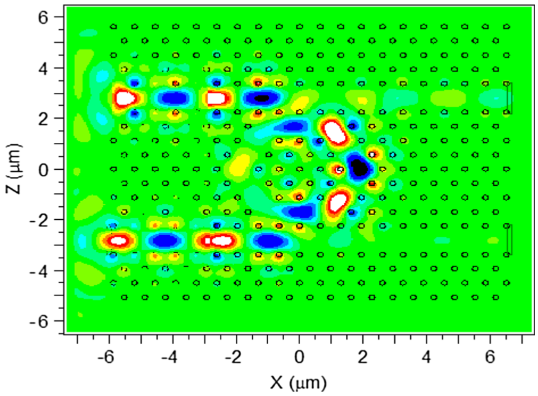

Fig. 3. The steady state electric field distribution at resonant wavelength of 1.55 μm.

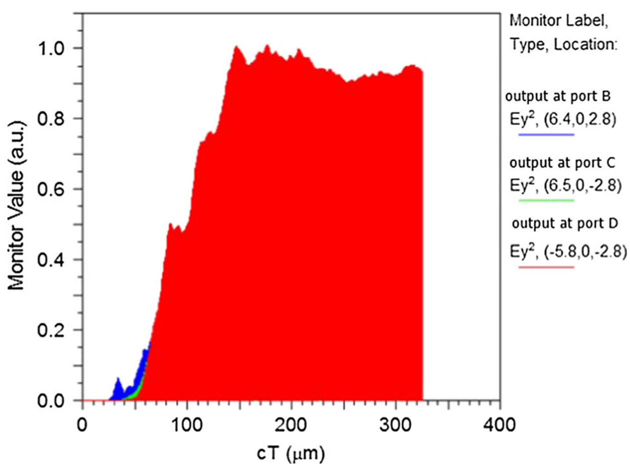

Fig. 4. Intensity of optical output signal at port D when wavelength of input signal is 1.55 μm (Color figure online).

output port D. Ey^2 in the monitor output shown in Fig. 4 is the square of the field component of TE mode in 2D.

We can calculate the response time of the device by observing time evolving curve as shown in Fig. 4. The cT on the x axis represents current Time taken by the device to reach at different levels of output.[13]

For 90% of output, cT = 130 μm, which gives $T2$ = 130 μ/3E8 = 0.433 ps.
For 10% of output, cT =60 μm, which gives $T1$ = 60 μ/3E8 = 0.20 ps.
Response time = ($T2$ − $T1$) * 4 = 0.932 ps

To analyze the performance of the filter we simulate the filter for different wavelengths. When wavelength, λ_2 = 1.53 μm is launched into port A, light will couple to the ring resonator and drop at forward dropping port C as this wavelength coincides with dropping wavelength of port C. Figure 5 shows the electromagnetic field pattern and Fig. 6 shows intensity of the optical signal at output port C.

Similarly, when an optical input signal with wavelength, λ_3 = 1.48 μm is launched at port A the

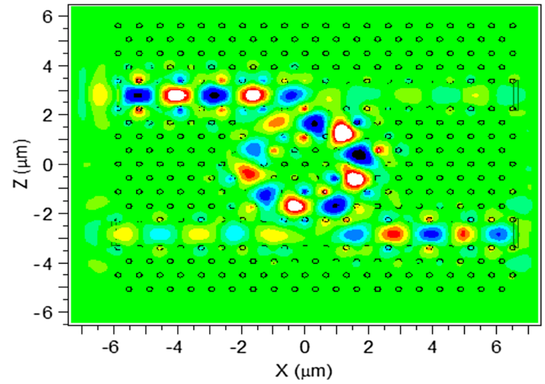

Fig. 5. The steady state electric field distribution at resonant wavelength of 1.53 μm.

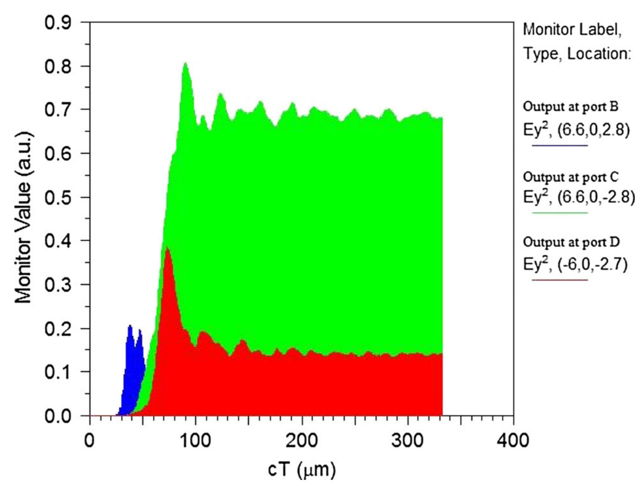

Fig. 6. Intensity of optical output signal at port C when wavelength of input signal is 1.53 μ (Color figure online).

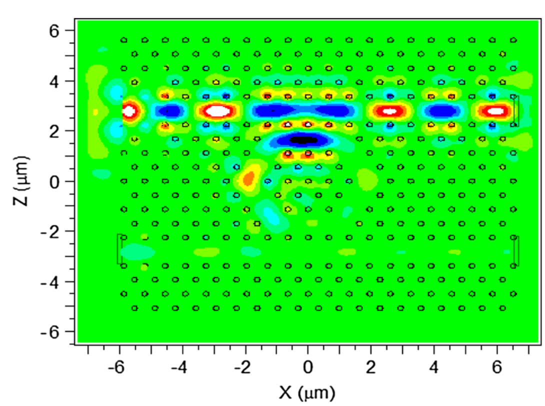

Fig. 7. The steady state electric field distribution at resonant wavelength of 1.48 μm.

optical input signal will not couple and propagate through the top waveguide and reach transmission port B. Figure 7 shows the electromagnetic field distribution and Fig. 8 shows the intensity of the optical signal at port B. The blue, green and red

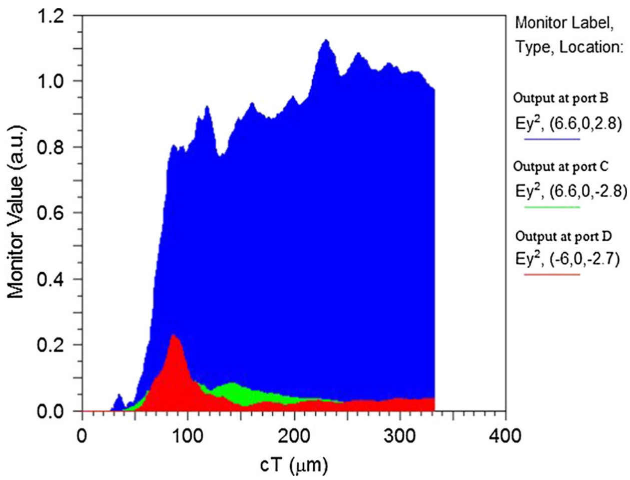

Fig. 8. Intensity of optical output signal at port *B* when wavelength of input signal is 1.48 μm (Color figure online).

Table I. Dropping efficiency of the filter for different wavelengths

	Dropping efficiency in %		
Wavelength λ	**Port *B***	**Port *C***	**Port *D***
1.47 μm	95	0	02
1.48 μm	80	0	10
1.49 μm	40	40	20
1.53 μm	0	90	07
1.54 μm	20	40	40
1.55 μm	0	0	98

color output in Figs. 4, 6, and 8 shows output at monitors of port *B*, *C* and *D,* respectively.

The dropping efficiency at different ports varies with the variation in the wavelength of the optical input signal applied at the input port. The resonant wavelength of this filter is 1.55 μm, 1.53 μm and 1.48 μm. The resonant wavelength and dropping efficiency at different ports are shown in Table I

Since the resonant wavelength of the add/drop filter is influenced by parameters such as refractive index of Si rods, radius of the dielectric rods and distance between Si rods called lattice constant, these filters can be considered as tunable.

In Fig. 9 we have analyzed the performance of a ring resonator by varying the radius of Si rods[14] and found that dropping efficiency of the transmitted optical input signal at port *D* is varied from 10% to 98% when radius of Si rods in the structure is varied from 0.17a to 0.2a and drops back to a lower value for increase in radius.[15] It is also analyzed from Table I that; this structure has efficient coupling of nearly 90–98% of the input to one port at resonant wavelength.

We have noticed that size of our structure is small, has efficient coupling, high dropping

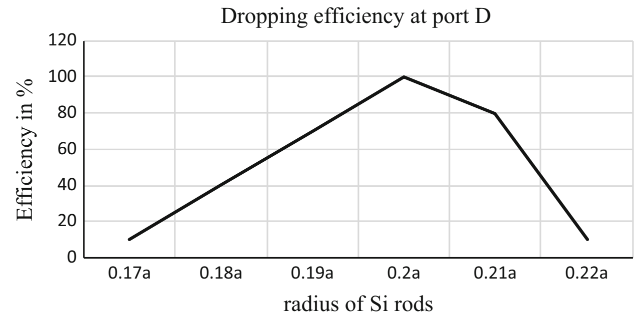

Fig. 9. Effect of variation in radius of Si rods on dropping efficiency at port *D*.

efficiency and fast response time. The proposed structure is performing better as compared to a reported survey and can be used to realize Wavelength Division Multiplexing and Demultiplexing circuits in optical communication.

CONCLUSION

We have proposed a 2D photonic crystal ring resonator based on an add/drop filter, which can be used for wavelength division multiplexing in optical communication. We have observed that optical signals with different wavelengths can be made to drop at different ports. Performance of the proposed filter is investigated by changing the radius of Si rods and wavelength of the optical input signal. Bandgap for the proposed structure is obtained by using the Plane Wave Expansion method indicating the wavelength range from 1452 nm to 2287 nm. We have performed the simulation using the RSoft full wave tool with operating wavelength of 1550 nm structure which gives dropping efficiency nearer to 100% at resonant wavelength and the overall size of the device is about 6 μm $\times$ 6 μm. This property of an add/drop filter can be used to realize multiplexer circuits in all optical communication.

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