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4-Channel DWDM demultiplexer on silicon photonic crystal slab

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Abstract. A novel DWDM device based on Silicon Photonic Crystal (PC) slab is proposed. Hexagonal ring resonators are used for channel dropping purpose. Channel dropping is achieved by fine tuning of lattice constant inside the ring resonators. The device is designed in such a way that the demultiplexed wavelengths are in C band of electromagnetic spectrum where EDFA is applicable. An average channel spacing of 0.8 nm is obtained and the maximum cross talk between the adjacent channels is found to be a fraction of 0.07 of the applied input intensity. The coupling efficiency of the input power to the channels is observed to be 60%. Approximate footprint of the device is found to be 475 μm^2.

Keywords. WDM; channel dropping filters; ring resonators; photonic crystal resonators; integrated optics; silicon photonics.

1. Introduction

Silicon photonics became attractive field as integrated optical devices are crucial in various electronic, sensing and communication applications. Parallelly need for all-optical devices is increasing in various fields where integrated optics is essential. As it is necessary to integrate different components in these applications, there is so much of scope for PC based devices. This is possible due to their ultra-small size, negligible bending loss and strong confinement of light. Existence of photonic forbidden bandgap towards certain range of wavelengths is responsible for miniaturization and low bending losses of these devices. PCs are materials with periodic refractive index variation. The forbidden bandgap may be tuned by adding appropriate defects in the unperturbed PCs [1]. By adding suitable defects devices are reported for various applications like chemical sensor to sense pH and ionic strength [2], bio sensor [3], temperature sensor [4], force sensor [5], optical memories [6], logic gates [7, 8].

Wavelength demultiplexer is a very important device in modern optical communication systems. DWDM devices are preferable for long distance communication. Two-dimensional PC slabs are chosen for this application due to their simple refractive index profile, light confinement ability in both in-plane and out of plane directions. To name a few, DWDM devices reported on PC platform include directional couplers [9], PC nanowire [10], resonator cavities [11], ring resonators [12–16]. Among the specified categories of PC devices, ring resonators are special due to simple wavelength tuning method and significantly more flexibility in the design of the device in comparison with the other devices.

In this work we present a novel design of DWDM device using PC of airholes on Silicon device layer of SOI platform. The proposed design is based on PC ring resonators. Four PC hexagonal ring resonators are cascaded to obtain four different wavelength channels. Many of the devices that are reported in the literature are based on tuning the properties of air hole or dielectric pillar. Instead, in this work channel dropping is achieved by careful engineering of lattice parameters inside the ring resonators.

2. Design of PC ring resonator

Photonic crystal of airholes formed on Silicon slab of 220 nm thickness in hexagonal lattice with filling factor of 0.3 and lattice period of 410 nm. This unperturbed structure exhibits a complete photonic bandgap over a wavelength range of 1250 – 1600 nm equivalent to 0.26 – 0.33 normalized frequency. Open source software tool MPB that uses Plane Wave Expansion method [17] is used to compute the band structure of the PC shown in figure 1. In this computation permittivity of the considered structure air/220 nm thick Si/air is taken as 1/3.46/1. The range of wavelengths of our interest that is 1530 to 1565 nm is within the bandgap of the considered PC structure. Hence strong light confinement with negligible radiation losses are expected. Appropriate defects should be added in the PC to trap electromagnetic modes corresponding to the preferred wavelengths within the bandgap region. Accordingly,

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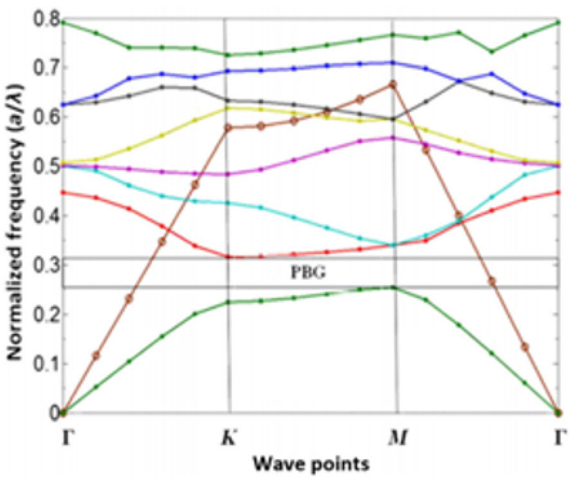

Figure 1. Band structure of the Photonic crystal.

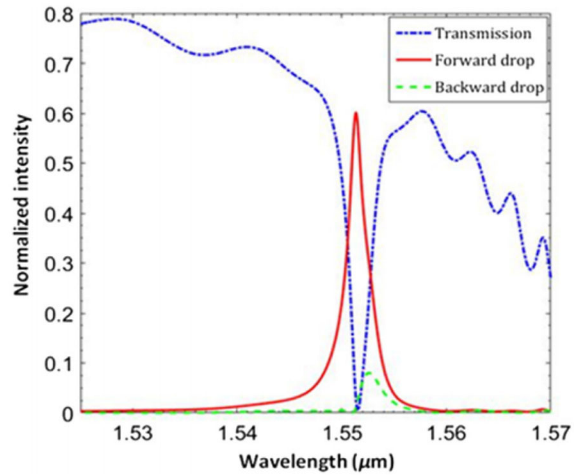

Figure 3. Outputs at various ports of PC ring resonator.

hexagonal ring resonator defect with two bus waveguides is added as shown in figure 2. The shown layout consists of four different ports namely input port, transmission port, forward drop port and backword drop port. Spectra of signals at various ports due to the input source launched at input port are computed using 3D Finite Differential Time Domain (FDTD) method. In these computations also permittivity of the considered structure air/220 nm thick Si/air is chosen to be 1/3.46/1, respectively. Gaussian light source centred at 1550 nm wavelength is used as input source at input port of the device model. The results of the computations are plotted in figure 3.

It is clear from the spectra that the PC ring resonator acts as asymmetric channel dropping filter coupling 60% of input power to forward drop port and only 10% of power to backword drop port at a wavelength of 1550 nm. Quality factor of the resonant peak is found to be approximately 3000, where Full width half maximum of the resonant peak is computed by using Lorentzian fit. Hence forward drop port may be used as channel dropping port and the ring resonator is suitable for DWDM application if the backword drop port is closed. The next section deals with the design of DWDM device.

3. Design of dense wavelength division multiplexer (DWDM) device

As it is mentioned in the previous section backword drop port is closed and forward drop port is kept at the end of extended 120^0 bent waveguide as shown in figure 4. Here wavelength tuning is achieved by appropriate modification of the lattice period inside the respective ring resonators, as shown in figure 4. As the lattice constant is increased the corresponding photonic bandgap is expected to be shifted to the lower frequency range and the wavelength range of the bandgap should increase [18, 19]. But as we are tuning lattice constant within the individual resonators alone, only the corresponding resonant wavelengths will be affected. The first ring resonator from the left is kept unchanged with

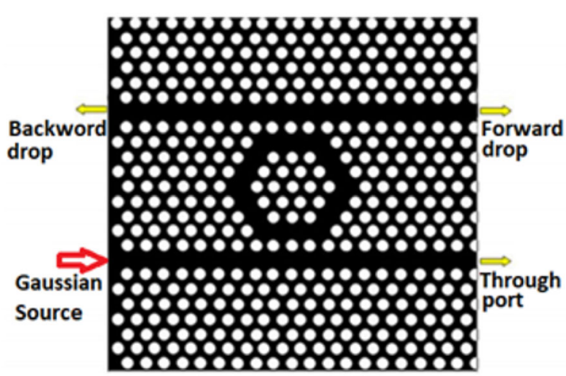

Figure 2. Hexagonal ring resonator in Photonic crystal.

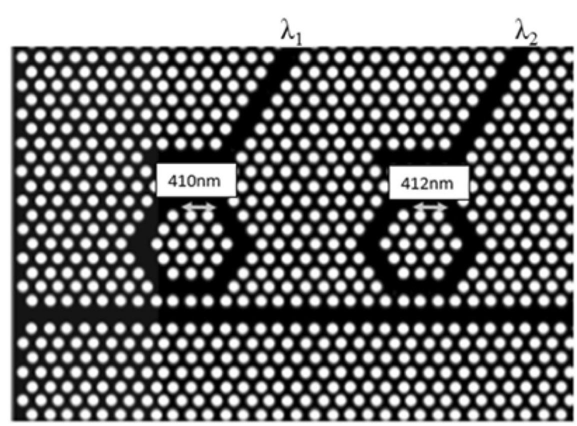

Figure 4. Two channel DWDM Demultiplexer.

original 410 nm lattice constant whereas in the second resonator lattice period is varied appropriately as 412 nm to get shift in resonant wavelength.

3D FDTD computations are performed for the device with two cascaded hexagonal ring resonators shown in figure 4. Spectra at output ports obtained in the computations are presented in figure 5. Two resonant peaks are observed at wavelengths 1535.7 nm, 1534.6 nm due to first and second resonator, respectively. Normalized intensities are found to be 25% and 20% with Q factors of 1900. This reduced coupling into channel and low Q factors are improved by adding blocking holes at the end of input waveguide and scattering holes at the 120^0 bend of each output waveguides. Two more such ring resonators with varied lattice periods of 414 nm and 416 nm, respectively are cascaded with the above-mentioned modifications to get decent coupling efficiency and Q factors as shown in figure 6. A separation of five lattice periods is kept between adjacent resonators. The corresponding spectra of 4-channel DWDM demultiplexer at the four output ports are plotted in figure 7.

Four resonant peaks are obtained for four ring resonators at wavelengths of 1535.7 nm, 1534.6 nm, 1533.8 nm and 1532.6 nm, respectively with an average channel spacing of 0.8 nm. An average coupling efficiency of 60% with Q factor of 6000 is achieved. Resonant peaks denoted by λ_1 and λ_4 in the figure 7 correspond to the left most and the right most ring resonators in figure 6, respectively. Maximum and minimum cross talks between adjacent channels are found to be 0.09 and 0.05, respectively. These results are compared with the reported DWDM device in the literature [16] and tabulated in Table 1.

As shown in Table 1 the current contribution is better in various aspects except in average cross talk which is tolerable if the coupling efficiency is significantly high. Since the wavelength tuning is done by varying lattice period instead of varying air hole size, there is improved flexibility in the design. Relatively more number of channels can be realized as we need to vary lattice constant alone.

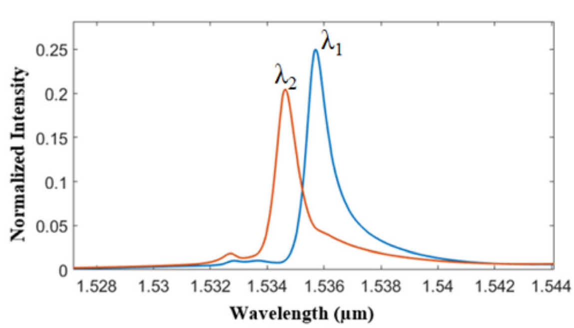

Figure 5. Spectra of two channel DWDM device.

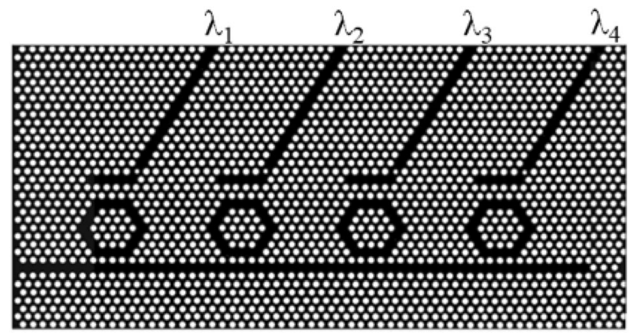

Figure 6. 4-Channel DWDM device with blocking and scattering holes.

Table 1. Comparison of current work with the relevant recent contribution in various aspects.

Parameter	Channel spacing	Average cross talk	Average Q factor	Coupling efficiency
Current work	0.8 nm	0.07	6000	60%
Reference [16]	1 nm	0.02	5000	55%

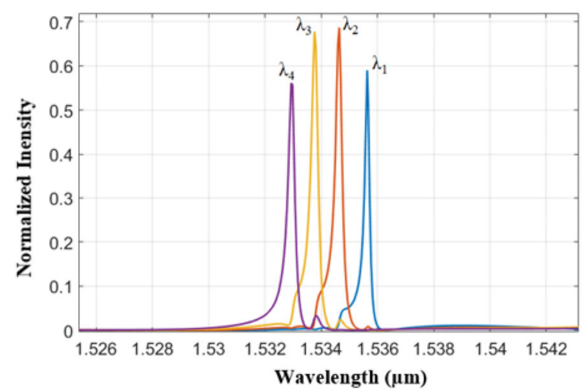

Figure 7. Spectra of four channel DWDM device.

4. Conclusion

A novel 4-Channel DWDM demultiplexer is proposed based on photonic crystal ring resonators. Instead of modifying air hole dimensions, lattice constant is chosen as the design parameter. Improvement in the performance is observed in the aspects of channel spacing, Q factor, coupling efficiency and flexibility. Since there is no restriction of airhole dimension in the proposed design, hence relatively more number of channels may be implemented and the design is suitable candidate for DWDM technology.

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