Resonant Cavity Based Wavelength Demultiplexer for ITU-T G694.2 O+C Band WDM System

Chandraprabha charan¹, Vijay Laxmi Kalyani² & Shivam Upadhyay³

¹²³ M.Tech Scholar, Govt. Mahila Engineering College Ajmer.
²Assistant Professor, Govt. Mahila Engineering College Ajmer

Abstract: The performance of a demultiplexer is measured in terms of structure footprint, quality factor, transmission efficiency and crosstalk level. In the proposed paper we present a novel structure for demultiplexing 1.31µm and 1.55µm wavelength which are corresponding to original (o) band and conventional (c) band respectively. The structure utilizing resonant cavities introduced in silicon slab type photonic crystal structure. The proposed structure is made of a hexagonal lattice of air holes in silicon slab with the refractive index of 3.47. The numerical results show that proposed structure can play an important role in fiber access networks. The structure size of proposed demultiplexer is about 45.82µm² (7.9µm × 5.8µm) that make it suitable for photonic integrated circuits. The mean transmission efficiency and cross-talk is about 93.32% and -14.55 dB. The quality factor measured for 1.31µm and 1.55µm are 687 and 630 respectively.

Keywords: Photonic crystals(Phcs); Resonant cavity; photonic band gap(PBG).

1. Introduction

Since the discovery of photonic crystals (Phcs) in 1987 [1] the optical devices based on Phcs have receiving greater attention due to their ultra-compact structure, high capacity, high performance, high speed and long life Which makes them suitable for ultra-small integration purpose. Phcs have the ability to confine the light inside the structure. Phcs also exhibits photonic band-gap (PBG) by which Phcs can prohibit the propagation of electromagnetic wave in certain range of frequency.[2]-[4]. Now a day’s research increases the attention to develop Phcs based devices like multiplexers/de-multiplexers, add-drop optical filters (ADF), polarization beam splitters, optical switches and channel-drop optical filters and so on [5],[10]. Phcs have the ability select different wavelengths by introducing various defects in structure such as hetero-structure with ring resonator, resonant cavity, super-prism phenomena in filter structure, radius defects, etc. [6]. Recently Phcs based demultiplexers play an important role in wavelength division multiplexed system and fiber-to-the-home (FTTP) based systems. Phcs based wavelength demultiplexers have been proposed in several papers: M.M Parvez and et.al proposed a wavelength demultiplexer for 1.31µm and 1.55µm wavelength. The efficiency of transmission is only 20% and 70% for 1.31µm and 1.55µm respectively. Also the wavelength 1.31µm is associated with high crosstalk [7]. A hybrid photonic crystal based demultiplexer based on coupled line defect channels has been proposed by M.H. Yusoff. The device has power efficiency of about 88% also extinction ratio obtain for 1.31µm and 1.55µm are -25.8db and -22.9db [8]. In the proposes structure Silicon slab is used because it provides several advantages like: we confine electromagnetic (EM) wave horizontal plan and guide it within this plan using photonic crystal structure, Refractive index of silicon allow planar EM wave confinement [10]. According to fabrication point of view the proposed structure uses a Phcs structure with air holes etched in silicon slab because light confinement is better in such a structures as compared to silicon rods in air background structures.

In this paper an ultra-small structure with air holes in silicon slab is used. The structure uses 2D photonic crystals (Phcs) based hexagonal structure with RI= 3.47. A simple resonant cavity is utilized for separating two optical window wavelengths. The quality factor of proposed structure for 1.31µm and 1.55µm is 687 and 630 respectively. The efficiency of transmission for 1.31µm and 1.55µm wavelengths is 96.37% and 90.26% respectively also cross-talk i.e. one of the critical factor in designing a demultiplexer is between -10.67dB -18.42dB.
2. Structure Design and Analysis

The first purpose in designing a demultiplexer is that it should be simple in construction so that there should not have any complexity in design and fabrication. Also for ultra-small integration purpose the dimension of structure should be compact. After that the cross-talk level must be low so that wavelength can be separated with high accuracy and minimum cross-talk level.

The quality factor of structure and transmission power also determines the resolution power and accuracy of structure. In the proposed structure two resonant cavities are introduced for separating 1.31µm and 1.55µm wavelengths. The resonant cavity is created by changing the radius of certain air holes in structure. The resonant cavity couple a particular wavelength from input waveguide to output waveguide. In structure air holes are introduced in silicon slab. Two dimensional (2D) Phcs with hexagonal lattice structure is chosen because hexagonal symmetry have smaller angle for bending the electromagnetic wave that result in lower losses and scattering inside the structure. It is found using simulations that a hexagonal lattice with r/a =3.173 yield a wide band gap where r=0.11µm is radius of air holes and a=0.349µm is lattice constant of structure.

3. Layout of Proposed Structure

![Figure 1. Layout of Proposed Structure and Resonant Cavity](image)

Figure 1 shows the layout of proposed structure. It consisting an input waveguide, two resonant cavities and two output waveguides. The input waveguide and output waveguide are created by removing air holes in structure. Two resonant cavities are created by changing the radius of three air holes along each output waveguide where each resonant cavity couples a desired resonant wavelength from input waveguide to output waveguide. The first resonant cavity is created along straight path for demultiplexing 1.31µm wavelength. The radius of central hole is 0.085µm taken also the radius of side holes are 0.053µm taken. Again our goal to design a demultiplexer that is capable of separating two wavelengths with high transmission efficiency to do so the resonant cavities should be different from each other so the second resonant cavity is created along banded path for demultiplexing 1.55µm wavelength. The radius of central hole is 0.04µm taken also the radius of side holes are 0.027µm taken. In such a way the desired wavelength is selected with high transmission efficiency and low cross-talk level where each resonant cavity is sensitive to change in radius of air holes along output waveguide.

4. Simulation and Results

After finalizing the structure Optiwave software tool is used for simulation. The photonic band gap (PBG) is calculated by plane wave expansion (PWE) method also finite difference time domain (FDTD) method is used for numerical computation.

![Figure 2. The Band Gap for Proposed Demultiplexer Structure](image)

As shown in figure 2 that the structure have a band gap from 0.21243(a/λ) to 0.29687(a/λ ) which cover the wavelength range from 1175nm to 1642nm. The Gaussian modulated continuous wave is used for the excitation of the input plane also the perfect matched layer (PML) boundary condition has been used because of its high accuracy and high performance. The structure is composed of 15 × 20 air holes with structure lies in the x-z plane. The transverse electric (TE) polarization is selected for the propagation of light in z-direction. The structure uses 30,000 time step for simulation. The simulation results for proposed demultiplexer are shown in figures below.
Figure 3. Transmission Power Efficiency for (a) 1.31µm and (b) 1.55µm

The output transmission efficiency obtained for 1.31µm and 1.55µm is 96.37% and 90.26% respectively. The cross-talk level for 1.31µm and 1.55µm is -10.67dB and -18.42dB respectively. In this structure each resonant cavity is tuned in such a way that minimum crosstalk is occur with high transmission efficiency. Another important parameter that determines the resolution of wavelength selection is quality factor. The quality factor is defined as the ratio of resonant wavelength (λ) to the full width at half power (Δλ) i.e. $Q = \frac{\lambda}{\Delta \lambda}$. The quality factor for proposed structure is 687 and 630 for 1.31µm and 1.55µm respectively. Figure 4 shows the FDTD simulated results of the steady state electric field distribution for 1.31µm and 1.55µm

Figure 4. Steady State Field Distribution for (a) 1.31µm and (b) 1.55µm

5. Conclusion

In this work we have demonstrated 2D photonic crystals (Phcs) based demultiplexer for separating 1.31µm and 1.55µm wavelengths. Two resonant cavities are introduced in silicon slab. The total size of structure is 45.82µm² (7.9µm × 5.8µm) i.e. smaller than conventional demultiplexer. The simple and ultra-compact structure makes it suitable for fabrication purpose. Again the proposed structure consisting of features like high quality factor, high transmission efficiency and quite low cross-talk that make it suitable candidate for FTTP and WDM based systems.
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7. References


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