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Optimization of optical waveguide for optical DEMUX at optical windows

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ABSTRACT

This paper investigates the structure, operation and simulation of Optical Waveguide for Optical Demultiplexer (DEMUX) at three optical communication windows. Optical waveguide is realized by 2D photonic crystal structure with 3 × 3 silicon rod. Photonic band gap of 2D photonic crystal structure is simulated by plane wave expansion method. Here, two types of reflections, external and internal are considered to obtain the photonic band gap. Simulation results reveal that lattice parameter and diameter of silicon rod play vital role to design the optical Demultiplexer. Again, this result showed that photonic crystal having diameter of silicon rod of 129 nm and lattice spacing of 428 nm allows wavelength, 850 nm, diameter 97 nm and 194 nm allows wavelength, 1310 nm, diameter 36 nm and lattice spacing of 180 allows wavelength, 1550 nm.

1. Introduction

Nowadays, optical waveguide is a key element for the design of photonic integrated circuits. Different sorts of optical waveguide performs different application [1,2]. Out of these, wavelength division multiplexer (WDM) is a special application using same waveguide [3]. WDM is a novel technique where data compression takes place [4]. In this case, the information transmitting over the waveguide is separated over several information channels. Each channel is presented by modulated laser beam with specific wavelength.

Main device in WDM system is multiplexer/demultiplexer (MUX/DEMUX), which is usually used both for gathering and separation of channels. Typical DEMUX is used in WDM systems employ Mach – Zender interferometers, fiber arrays, etc. [5,6]. All these devices are quite large, so that their inclusion of phonic crystal based integrated circuits is intricate.

To avoid the above entanglement, this paper emphasizes on the size of the optical DEMUX, which is designed by using two dimensional photonic crystal structures

As far as literature survey on optical demultiplexer is concerned, in reference [7], author deals with the experimental results of a demultiplexer using a diffraction grating for a WDM system at wavelength 800 nm only. Similarly in reference [8], authors present results on the use of multilayered a-SiC—H heterostructures as a device for wavelength-division demultiplexing of optical signals. Also, it is seen that few authors deals with the same with the use of optical fiber [9,10]. Apart from this, though similar types of works are appeared in few papers, but, this paper deals with optical DEMUX with silicon photonic crystal structures [11–13].

This paper is organized as follows: design of optical DEMUX including the structure of 2D phonic crystal is proposed in Section 2. Computation methodology for the sake of simulation is presented in Section 3. Section 4, discusses the operation of optical DEMUX. Simulation results and discussion is mentioned in Section 5. Finally conclusions are drawn in Section 6.

2. Design of optical DEMUX

The design of proposed optical DEMUX using 2D photonic crystal structure is shown in Fig. 1.

Fig. 1 represents the wavelength division DEMUX based on two dimensional photonic crystal structures having 3 × 3 silicon rod. As far as the feasibility of fabrication of optical DEMUX is concerned, experimental set up is carried out for similar types of works using photonic crystal structure [14,15].In reference [14] author designed photonic crystal waveguide for add-drop multiplexer using polymer, where in reference [15], author deals with photonic crystal waveguide using silicon nitride for 4-channel optical demultiplexer.

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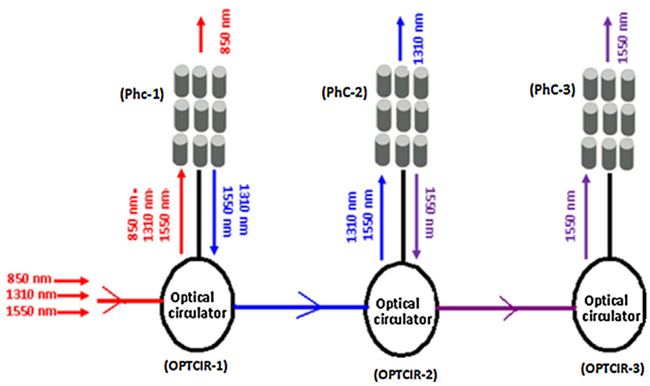

Fig. 1. Schematic diagram of optical demultiplexer.

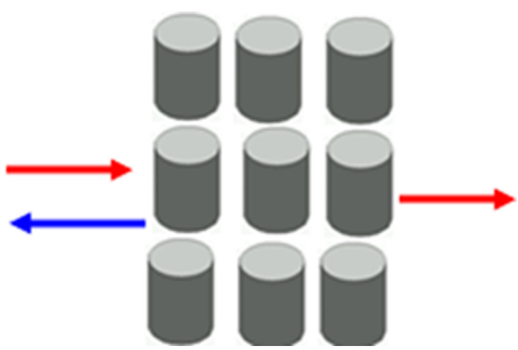

Fig. 2. 2D photonic crystal structure with incident, reflected and transmitted light.

Analyzing above works, the design of silicon based photonic crystal waveguide may be possible for optical DEMUX. Again, considering the components of DEMUX, optical circulator (OPTCIR) and photonic crystal structure (PhC) play a vital role to discuss the operation of the same. Out of these, this paper completely focuses on photonic crystal structure, which is directly responsible to allow or disallow our desire wavelength. The schematic 2D photonic crystal structure is shown in Fig. 2.

The above figure is a structure of 2D photonic crystal structure, which consists of 3×3 silicon rod and these are placed on substrate (air). The arrow marks show the direction of incident, reflected and transmitted light. The reflected light (photonic band gap) is controlled by different in parameters of the same structure such as, lattice spacing and radius of silicon rod.

3. Operation

As far as operation of optical DEMUX is concerned, 2D photonic crystal structure deals with reflection and transmission characteristics. From Fig. 1, it is seen that light having different wavelengths, 850 nm, 1310 nm and 1550 nm, which refers as first, second and third optical communication window is allowed to incident on first optical circulator (OPTCIR-1), then OPTCIR-1 bends these light to first photonic crystal (PhC-1) structure, here PhC-1 is designed in such a way that it transmits the light of wavelength 850 nm and reflects 1310 nm and 1550 nm. And these reflected light again come back to OPTCIR-1 and then it circulates to the optical circulator 2 (OPTCIR-2). Considering similar technique, second photonic crystal (PhC-2) structure is designed in such way that, it allows the wavelength 1310 nm and reflects 1550 nm. Again, based on same principle, the reflected wavelength of 1550 nm reaches at third optical circulator (OPTCIR-3) and passes through third photonic crystal structure (PhC-3).

4. Computation methodology

The propagation of electromagnetic waves through photonic crystal structure is governed by Maxwell's four equations [16]. Using these equations, we can set the decoupled equation, which is known as Helmholtz equation and it is given by

$$-\{\frac{\partial}{\partial x}\frac{1}{\in(r_{||})}\frac{\partial}{\partial x}+\frac{\partial}{\partial y}\frac{1}{\in(r_{||})}\frac{\partial}{\partial y}\}H_z(r_{||})=\frac{\omega^2}{c^2}H_z(r_{||}) \quad (1)$$

Here, $r_{||}$ is 2D vector in xy plane.

The wave functions are represented in terms of Bloch waves and expanded into Fourier's series over the lattice vectors. Inversed dielectric constant is also expanded into Fourier series. Substituting this in Eq. (1), the Eigen value for Fourier expansion coefficient is obtained as:

$$\sum_{G_{||}}\chi(G_{||}-G'_{||})\ \ |K_{||}+G'_{||}|^2 E_{z,K_{||},n}(G'_{||})\ \ =\ \frac{\omega^{(E)^2}_{K_{||}n}}{c^2}\ \ E_{z,K_{||}n}(G_{||}) \quad (2)$$

where, $G_{||}$ and $G'_{||}$ are in plane reciprocal lattice vector.

$K_{||}$ is in plane vector and $\omega^{(E)}_{K_{||},n}$ is the frequency of TM mode.

$\chi(G_{||})$ for silicon rods can be expressed as

$$\chi(G_{||})=2f(\frac{1}{\in 1}-\frac{1}{\in 2})\frac{J_1(G_{r||})}{G_{r||}} \quad (3)$$

where, $J_1(G_{r||})$ is the first order of Bessel's function.

For simulation, we compute the photonic band gap (dispersion curve) using Eq. (3) and limit the variation of Brillioun zone $-\pi T\ldots -\pi T$, G and G' within $-2\pi NT\ldots 2\pi NT$, where $(2N+1)$ is the number of plane waves taken into account

Using Eq. (2), we write down the matrix differential operator for each values of wave vector within the selected range and the eigen states of obtained matrix is computed

5. Simulation

With reference to operational principle of optical DEMUX, which is described in Section 4, there are three types of photonic crystal structure with different structure parameters having 3×3 silicon rods are chosen in such way that the first (PhC-1), second (PhC-2) and third (PhC-3) structures allows the wavelength of 850 nm, 1310 nm and 1550 nm, respectively. To desire the same operation of the same DEMUX, the intrinsic properties (photonic band gap) of photonic crystal structure should be considered. The photonic band gap of the crystal structure depends on its position and configuration including the nature of background and column (rod) materials, for example, radius of the rod, lattice spacing of the structure and permittivity of both rod and background material. Again, keeping the view of allow or forbidden wavelength (850 nm, 1310 nm and 1550 nm), the radius of silicon and lattice spacing of the structure are chosen in such way that, first structure (PhC-1), will allow 850 nm and disallow (reflect) other two wavelengths (1310 nm and 1550 nm). Again, radius of silicon rod and lattice spacing of the structure is chosen in such way that, second structure (PhC-2) will allow 1310 nm and reflect 1550 nm. In similar way, both radius and lattice spacing of the structure is chosen in such way that, third structure (PhC-3) will allow the light having wavelength 1550 nm. To obtain the same, simulations for PhC-1, PhC-2 and PhC-3 are done for band gaps using plane wave expansion method [16]. The simulation results for PhC-1, PhC-2 and PhC-3 are shown in Fig. 3, Fig. 4 and Fig. 5, respectively.

The above diagrams represent the dispersion diagram of 2D photonic crystal structure, where the normalized frequency (a/λ) is