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Slow light transmission in a photonic crystal power splitter with parallel outputs

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Abstract

In this paper, we investigate coupling of light to slow modes in a photonic crystal power splitter composed of a Y-junction and two 60° bends. First, a combination of two cascaded bends which is commonly used in integrated photonic crystal circuits is studied in slow light frequency regime. We propose a structure that its transmission spectrum covers the high group-index frequencies near the band edge. Also, by structural modifications, high transmission near to 95% is achieved in slow light bandwidth. Next, we study the complete structure of a photonic crystal power splitter with parallel outputs based on a Y-junction integrated with two 60° bends. Using modified bends and reducing sharpness of Y-junction, the efficiency of splitting increases in both high and low group-index frequency bands. The optimized structure has an average efficiency of 82% in slow mode regime. This structure can be used in photonic crystal based slow light devices, such as Mach-Zehnder interferometers.

Keywords: Slow light; Photonic crystal; Power splitter

1. Introduction

Photonic crystal (PC) is an appealing structure for fabrication of optical devices and components in the next generation of integrated photonic circuits. In contrast to conventional integrated optical circuits, photonic crystal based devices are smaller and can be designed in wavelength scale [1]. Also, the desired dispersion characteristics and the level of light matter interaction in a PC can be engineered. Low loss waveguides, bends, Y-junctions and cavities can also be made and connected in a PC platform with low mismatch [2–4]. In addition, photonic crystal waveguide (PCW) is one of the most successful devices in generation of slow light [5]. Slow light technology plays an important role in the future of optical buffers, optical logical gates, and optical signal processing. Slow light in a PCW can be engineered by modifying the structure. It works at room temperature for a desired wavelength and also provides larger bandwidths compared with other methods, such as electromagnetically induced transparency [6]. Slow light in PCW can be used in many applications such as optical delay lines, buffers, and switches [6]. By using slow light PCW in an optical switch or modulator, a greater phase shift per unit length

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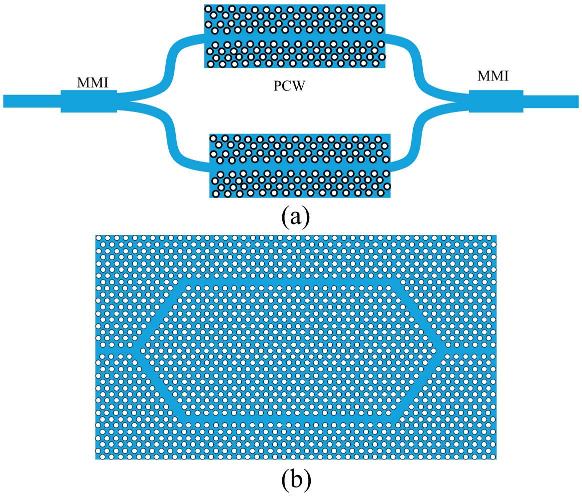

Fig. 1. Slow light MZI structure based on (a) strip waveguides and MMI couplers and (b) PC branches and bends.

is obtained and the switching length or modulation voltage can be reduced. It also enhances nonlinear effects by spatial pulse compression.

Using slow light PCWs, optical modulators based on Mach-Zehnder interferometer (MZI) have been already proposed which demonstrate reduction of modulation voltage and switching length [7–10]. The MZI structures proposed so far have not been based on only PC structure. As shown in Fig. 1(a), they were usually composed of photonic wires connected to PCWs in interferometer's arms for supporting slow modes and increasing the phase shift [7–10]. However, they suffer from the splitting/combining loss and coupling inefficiency from strip waveguide to engineered PCWs even by using coupling parts [10,11]. On the other hand, using photonic crystal based structures as shown in Fig. 1(b), reduces the size of the optical component and increases the device packaging density. For example, lightwaves can be routed around sharp bends with bending radii on the order of a wavelength, while in the MZI structures proposed in Refs. [8,9] which have structures as shown in Fig. 1(a), the bending radii are around 5 μm. Also, in the PC based structure of Fig. 1(b), both PCWs are fabricated in one platform, in one fabrication step and in a distance much lower than the corresponding distance in the structure shown in Fig. 1(a) [8,9,12].

In construction of interferometer structures, such as MZI, power splitters are fundamental elements. The 1×2 splitter which is the common one has been designed and fabricated in PC by direct splitting mechanism, such as Y-junctions [3,4], T-junctions [13], and also by directional coupling [14] and multi-mode interference [15,16]. Y-junction has a compact size, broad bandwidth and low losses; hence, it is usually used for constructing a power splitter in PC integrated circuits. A common 1×2 PC power splitter is also composed of two sharp bends for directing light signals. Sharp bends and Y-junctions which are fundamental elements for photonic crystal integrated circuits have been widely studied [4,17–21]. Although a significant amount of work has been done for improving the transmission of 60° bends and Y-junctions in triangular PC lattices, the fast wave parts of modes were mainly considered in these researches. It means that structures with high transmission were achieved in wave numbers far from the band edge [4,17–20]. For example, Yang et al. investigated the structure of a power splitter with parallel outputs based on a Y-junction integrated with 60° bends and they studied the fast-mode transmission far from the band edge [4]. To directly excite the slow light in a power splitter, Ref. [16] used the multimode interference (MMI) structure. In this structure, the two output ports are in a distance of four lattice constants from each other. This is not suitable for integrated circuit devices, such as MZI.

In this paper, we study the transmission from a PC power splitter based on Y-junction and bends with two parallel outputs in slow mode frequency region. In the first part, we study the transmission of slow light to a PCW through two cascaded 60° waveguide bends and propose a method for increasing the transmission over slow light bandwidth. The proposed structure of two cascaded waveguide bends can support slow light frequencies. Then, we study a Y-junction based splitter. Using modified bends and reducing the Y-junction sharpness result in a power splitting structure which can transfer slow modes to two output ports. Optimization of Y-junction parameters increases the efficiency of structure in slow band to more than 80%.

2. Slow light transmission through a 60° bend

Guiding lightwaves around sharp corners with high efficiency is very important in photonic integrated circuits. In three dimensional (3D) photonic crystals, the lightwave can be guided through sharp bends with very high transmission efficiency due to photonic band gap (PBG) effect and the absence of radiation loss [19]. Another way to obtain a PBG is to use a two-dimensional (2D) PC slab. In a PC slab, the lightwave is guided in the in-plane direction, and the refractive index contrast confines light in the vertical direction [2]. One constrain in using 2D PC slabs is the existence of leaky