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A novel 1×2 optical power splitter with PBG structures on SOI substrate

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ABSTRACT

A novel 1×2 optical power splitter in size of 8.0 μm × 4.2 μm is presented in this paper, by using photonic bandgap (PBG) structures on silicon-on-insulator (SOI) substrate. The splitting ratio can be adjusted by changing the air hole position to get wide tuning range. The design is examined by the commercial finite-difference-time-domain (FDTD) software for various splitting ratios. Some approximated formulas are obtained through curve-fitting to facilitate design process.

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1. Introduction

Optical power splitter is the basic component for optical communication networks. Traditionally, the splitter is designed by fiber couplers or planar optical circuits with branch waveguide structures [1]. These approaches, however, are not easy to make any power splitting ratios which may be useful in fiber-to-the-home or optical cable TVs. Though the variable splitting ratio configuration is available in literature [2], but too complicated assembly with microoptics-type devices makes it not practical for low lost applications. Some other simple and cost effective methods for adjusting power splitting ratio, taking advantages of modern semiconductor technologies, are still valuable for communications industries.

On the other hand, silicon-on-insulator (SOI) technologies often arose for integrated optics and optical waveguide elements in last decades. The SOI is a structure based on planar layers of $Si/SiO_2/Si$ substrate, which is compatible with standard semiconductor manufacturing processes. Since the complementary metal oxide semiconductor (CMOS) electronic devices on SOI substrates shows promising results in low-power and high-speed applications, the study of SOI optoelectronic devices becomes an important topic [3] for integrating electronics and optics on a single chip. That makes the basic motivation of this work.

The optical wave propagation in the SOI structure conventionally is guided by the dielectric slabs. The introduction of photonic crystals (PCs) changed the design concept of optical waveguides. One key point is that the period of PCs can be set to equal or near the wavelength, the optical wave within the structure is forbidden—the light is not allowed for propagation. This photonic bandgap (PBG) phenomenon is very useful on controlling the direction of optical waves. However, as an irregular atom is introduced into a uniform crystal, a resonant mode appears in the PBG. Similarly, when a series of irregular atoms are introduced, a guided mode appears in the PBG due to the coupling of resonant modes. These properties are expected to provide a novel way for light emitting and guiding. Recently, PBG structures have been suggested for various opto-electronic applications, such as ultra-low threshold lasers and high transmission waveguides with a bending radius comparable to the light wavelength [4]. These periodic structures were investigated energetically in recent years.

In this paper, a novel 1×2 optical power splitter, combining PBG structures and SOI technology, is presented to show design flexibility in splitting ratio and low cost feature due to its compact size. The designed splitter, occupying only 8.0 μm × 4.2 μm chip area, has the feature for easily changing the output power ratio by adjusting the position of a triangular air hole element. The splitter is examined by the commercial finite-difference-time-domain (FDTD) software, in which the electric and magnetic fields defined on the mesh can be shown for each simulation time step. The final simulation results show its capability on the wide tuning range in the power splitting ratio with low insertion loss characteristics. The integrated design has the potential for applications of optical add/drop switch router and optical switches in optical communications.

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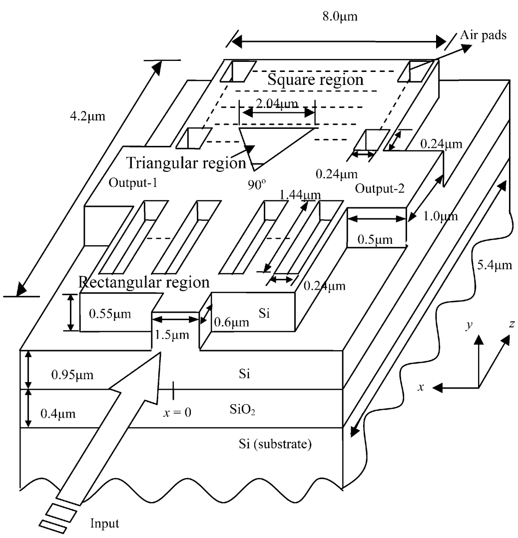

Fig. 1. The schematic diagram of the 1 × 2 PBG optical power splitter.

2. Design of 1 × 2 optical power splitter

The schematic diagram of the proposed 1 × 2 PBG optical power splitter is shown in Fig. 1. It is built on the Si/SiO_2/Si structure with many air holes in different sizes and shapes as the photonic crystals. The buried oxide slab is the role of the lower cladding ($n_{SiO_2} = 1.5$) layer and the surface silicon layer ($n_{Si} = 3.5$) is the waveguide core with the top cladding of air ($n_{air} = 1$). The widths of the input and the output rib waveguides are 1.5 μm and 1.0 μm, at the front end and the left/right side, respectively. The working wavelength is 1.55 μm in this study case due to its low loss characteristics in the medium.

The designed device can be categorized into three regions according to the air hole shapes: rectangular region, triangular region and square region. In the rectangular region, 22 rectangular air holes with length of 1.44 μm and width of 0.24 μm are placed in parallel as PBG structure to keep the beam propagation along the straight direction. Besides, the rectangular air holes also make the multimode interference (MMI) for the input beam as preparation of changing the propagation direction into left and right sides. Subsequently the triangular air hole located around the center of the MMI rectangular section in angle of 90° splits the optical fields into two output ports at left and right sides. To prevent the optical power leakages to the rear end, 85 square air holes with 0.24 μm a side in five rows provide the PBG function in the square region. The total size of the optical power splitter is 8.0 μm in width and 4.2 μm in length. For the sake of convenience in the software simulation, the input and output ports are set in lengths of 0.6 μm and 0.5 μm, respectively.

3. Simulation results

The commercial FDTD simulation software (RSoft FullWAVE V1.0) is utilize to examine the designed 1 × 2 optical power splitter. The transverse-electric (TE) field in the fundamental mode is launched for the input port to simulate the propagation condition along the device worked at wavelength of 1.55 μm. This operating condition results the single mode propagation in smallest insertion loss. Fig. 2(a) shows the simulation results on the electric fields as the triangular air hold is placed at the center of x-axis. One can find the triangular air hole in the center of the waveguide bends the optical fields in 90° and then propagates the waves into two ways with opposite directions. The optical beam then is split into the two output ports successfully in almost equal power transmissions. The

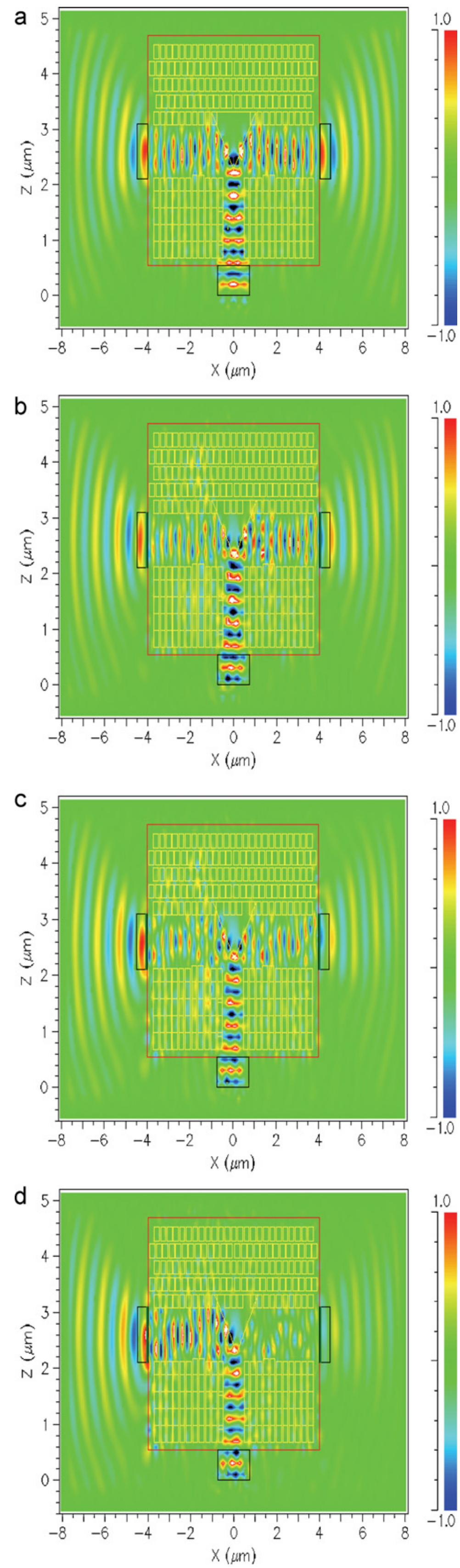

Fig. 2. The FDTD simulated top view of various splitting ratios of light propagation (a) 5:5; (b) 6:4; (c) 7:3; (d) 8:2.

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