Design and analysis of a novel tunable optical power splitter

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A novel tunable optical power splitter, with a Y-branch waveguide based on the total internal reflection and a microprism with tunable index refraction, is presented. Numerical simulation of its optical performance shows that a high dynamic range, low optical loss, and relatively low wavelength-dependence can be achieved. This component offers numerous advantages such as ease for fabrication, low cost, and compact size, which are very useful for potential application in integrated optical devices.

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Optical power splitters are important components in integrated photonic systems, which are used for splitting and combining optical signals. Several schemes for optical power splitters have been recently reported[1−6]. However, their branching ratios, which could not be controlled dynamically, were generally fixed, once these optical power splitters have been fabricated. Their structural parameters should be modified to obtain different branching ratios but it is a serious limitation in their practical application. With the rapid development of integrated optical devices, however, optical power splitters with tunable branching ratios are strongly desired. Furthermore, there is an increasing need for these components. Hence it is very indispensable to design and fabricate these devices with tunable optical power output.

Currently, the reports about tunable optical power splitters are few. In 2007, Thapliya *et al*. proposed a tunable optical power splitter by using electro-optic multimode interference device[7]. Unfortunately, its branching ratio was sensitive to operation wavelength and polarization state, and its tuning range was relatively narrow. In integrated photonic systems, however, tunable optical power splitters with wavelength independence, a large dynamic range, low cost, ease for fabrication, and compactness are preferred. In this letter, to the best of our knowledge, we first present a novel optical power splitter with a tunable branching ratio to achieve the required optical performance.

The schematic of a novel tunable optical power splitter is depicted in Fig. 1(a). Its structure is simply divided into four regions. The waveguides AB and DE act as the input and output, respectively, whereas BC is a tapered waveguide that acts as a pre-splitter by transforming the single-mode pattern into a super-mode one. For waveguide CD, the total internal reflection occurs at the inner interface between its core and cladding. In this structure, relatively large branching angles can be achieved with low optical loss. The lengths of waveguides AB, BC, CD, and DE are denoted by l_1, l_2, l_3, and l_4, respectively, whereas the branching angle is signified by θ. Figures 1(b) and (c) show the close-up view in the tapered waveguide region and the cross-section view of the waveguide, respectively. The refractive indices are represented by n_1, n_2, and n_3, for the upper cladding, the core, and the lower cladding, respectively, whereas the core width, slab, and ridge heights are represented by W, d, and h, respectively.

As shown in Fig. 1, the tunable optical power splitter we propose is a novel component, in which a symmetric Y-branch waveguide is combined with three wedge electrodes in the tapered waveguide region. This Y-branch waveguide based on total internal reflection has a very low dependence on operation wavelength, wide angle, low optical loss, a compact structure, and ease of fabrication[8], which is unique in tunable optical power splitters. Three wedge electrodes, as top electrodes, are introduced in the tapered waveguide region to produce two different microprisms with tunable refractive indices in their corresponding regions using the electro-

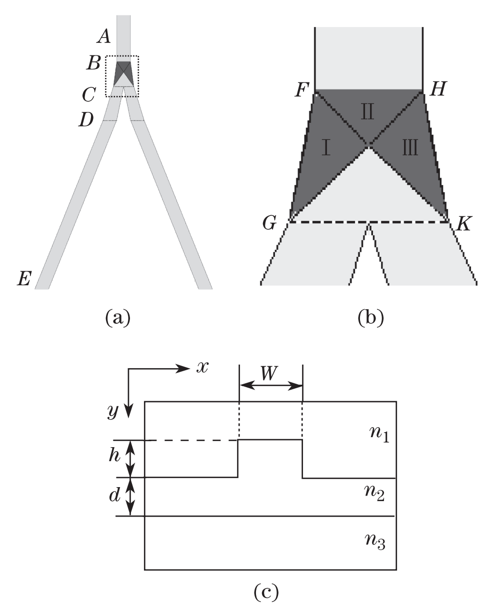

Fig. 1. (a) Schematic of novel tunable optical power splitter, (b) close-up view of the tapered waveguide region, and (c) cross-section view of the waveguide. x and y denote the coordinate axes of horizontal and perpendicular directions in the cross-section of waveguide, respectively.

optic effect. The shape of the wedge electrodes is usually determined by the branching angle of the Y-branch waveguide and the maximum change in the refractive index of the microprism region.

In Fig. 1(b), the microprism with variable refractive index in triangular region *FGH* can be achieved by simultaneously applying equivalent variable voltages on wedge electrodes I and II. If wedge electrodes II and III are simultaneously supplied with equivalent variable voltages, then the refractive index of the microprism in the triangular region *FHK* is variable. The gap between the wedge electrodes should be less than 500 nm. The two microprisms with tunable refractive indices act as phase-front accelerators, wherein the light propagation direction can be purposely changed, in which deviation angle is closely related to the tunable refractive index. Therefore, the optical branching ratio at the output ports can be adjusted as it is applied by different electric fields.

Generally, polymer materials have high electro-optic coefficients compared with inorganic materials. For the simulation, the polymer material polysulfone/IPC-E (25 wt.-%), with a refractive index of 1.67 at an operation wavelength of 1.55 μm, was chosen as the core waveguide. The cladding materials were NOA 61 and UV-15, with refractive indices of 1.55 and 1.50, respectively[9]. The parameters of the waveguide structure were as follows: (1) The lengths of waveguides AB, BC, CD, and DE were 130, 70, 95, and 405 μm, respectively, (2) the branching angle was 6°, (3) the slab and rib heights, and core width were 1.0, 0.8, and 5.0 μm, respectively, (4) the upper and lower widths of the tapered waveguide were 5.0 and 7.5 μm, respectively, and (5) the length of the tapered waveguide was 200 μm. The parameters of the three wedge electrodes were determined according to the design in Fig. 1(b). The incident optical field was assumed as the transverse magnetic (TM) polarization state. According to Ref. [10], the electro-optic coefficient of the chromophore could be increased to 500 pm/V. For simplicity, the refractive index variation Δn ranges from 0.000 to 0.015 was assumed possible in the microprism region to simulate the optical branching ratio change with its refractive index. Here, its optical performance was evaluated using the finite-difference beam propagation method, which is an effective, widely used technique for studying optical waveguide devices based on the numerical solution of the scalar Helmholtz equation[11,12].

The normalized optical power of the left and right output ports at the different changes in the refractive index of microprism FGH are shown in Fig. 2, wherein the curves with ■ and ▲ symbols represent the normalized optical power outputs of the right and left branches, respectively. As the change in the refractive index of the microprism in triangular region *FHK* increases from 0.000 to 0.015, its normalized optical power outputs are contrary to those given in Fig. 2, which widens its dynamic range. The simulated results suggest that the branching ratio can be arbitrarily distributed by adjusting the refractive index of the microprism. Based on the simulated results, the dynamic range of the optical branching ratio increases with the refractive index variation range. In addition, the optical loss was about 0.09 dB, which mainly results from the optical scattering loss in the microprism region. This low optical loss is useful for its practical application.

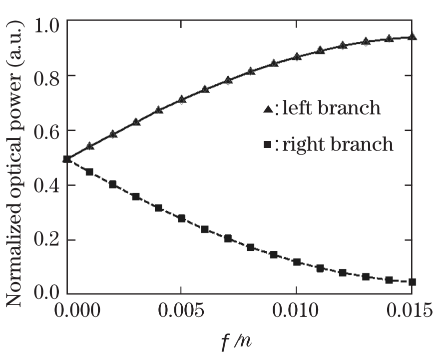

Fig. 2. Normalized optical power output at the left and right output ports with different increases in refractive index of microprism *FGH*.

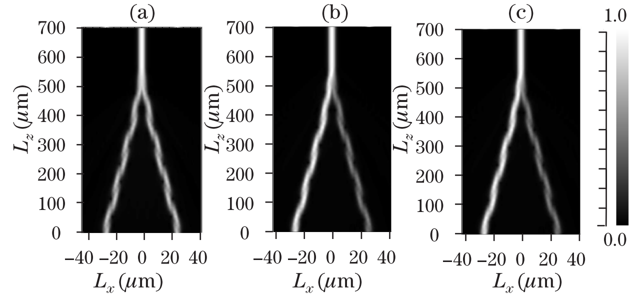

Fig. 3. Simulated results of the optical field propagation in the tunable optical power splitter, under index refraction changes of (a) 0.000, (b) 0.0075, and (c) 0.015 in microprism FGH. L_x and L_z stand for the lengths of the corresponding corrdinate in x and z axes, respectively.

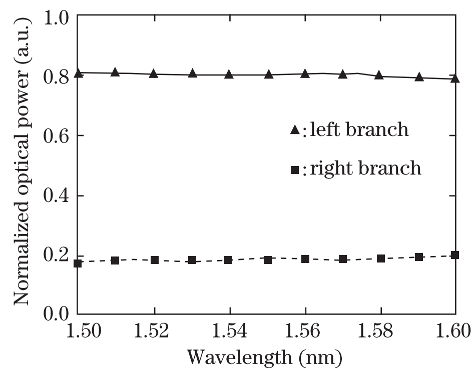

Fig. 4. Normalized optical power output at the left and right output ports with different light wavelengths.

Figure 3 shows the optical field propagation in the tunable optical power splitter at index refraction changes of 0.0000, 0.0075, and 0.015 of microprism FGH. The branching ratios between its left and right output ports are 1:1, 4.43:1, and 22.8:1, respectively. These are controlled by the microprism that acts as a phase-front accelerator. From Fig. 3, an approximate periodic change in the optical field distribution is observed along the propagational direction, which originates from optical interference between different guided modes.

For the simulation results shown above, the incident optical wave is monochromatic. However, the actual laser source has a spectrum width ranging from nanometers to several tens nanometer. The simulated results under different incident wavelengths are shown in Fig. 4. The refractive index change Δn was 0.0075 and the other parameters are the same as those in Fig. 2. The refractive indices of the core and the cladding are assumed to be constant in spectrum rang of 100 nm. Accordingly, the fluctuation of optical power at each output port was less than 0.02, indicating that the optical branching ratio changed little at large spectrum scope of 100 nm. As shown in Fig. 4, the tunable optical power splitter has minimal wavelength dependence, which is useful for potential applications in integrated photonic devices.

Finally, it should be pointed out that tunable optical power splitters based on polymers have simple structures that are easily fabricated using techniques for processing semiconductors. The details of the fabrication have been reported by Thapliya *et al.*[7]. In addition, the Y-branch waveguide has a relatively large fabrication tolerance, which has been analyzed in previously reported literatures[6,8]. Since the wedge electrodes were used as a microprism by applying the external voltage, their precise fabrication is imperative. Based on the current microfabrication technology, a processing error of less than 100 nm can be easily achieved. Thus, the effect of the fabrication error on the optical branching ratio is rather small.

In conclusion, a novel optical power splitter with a tunable branching ratio has been proposed, in which a microprism with a tunable refractive index is introduced by applying voltage on the wedge electrodes. The simulated results show that the tunable optical power splitter has a high tunability range, low optical loss, and very low wavelength dependence. The proposed component has wide range of potential applications in the integrated photonic systems.

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