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Three-port mode-(de)interleaver in silicon waveguide

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ABSTRACT

We propose a three-port silicon mode-(de)interleaver (TSMIL) using an asymmetric multi-arm Y-junction to flexibly address optical modes and efficiently increase the ports with less cascaded stages in mode-division multiplexing transmission. The design criteria developed for multi-port mode-(de)interleaving is presented. The qualitative functionality of the device is mainly determined by the widths of the arms. The example of a six-mode TSMIL is designed and analyzed in detail. Numerical simulations show that a low excess loss (<1 dB) and a low mode crosstalk (<-17 dB) over a 60 nm wavelength range can be obtained.

1. Introduction

To meet the future requirements for ultrafast and ultrahigh bandwidth communication among massively parallel chip multi-processors, silicon-based optical interconnects provide a promising approach [1–3]. Wavelength division multiplexing (WDM), polarization division multiplexing (PDM), and multilevel modulation format are traditional methods to increase the capacity of an interconnect link. However, the link capacity realized with these methods is close to its theoretical limit [4,5]. Recently, mode-division multiplexing (MDM) in which each optical mode is considered as an independent data channel has been regarded as an attractive option for expanding the link capacity further.

Mode (de)multiplexers are one of the key components in MDM transmission. Previously, an enormous amount of research effort has been focused on realizing silicon mode (de)multiplexers, which are based on asymmetric Y-junctions [6], multimode interferometers (MMI) [7–9] and couplers [10–15]. Like the (de)interleavers in WDM transmission, mode (de)interleavers are another important components that should be considered for MDM transmission [16]. Multi-port optical mode (de)interleavers are designed with great interest to efficiently increase the capacity and provide more flexibility for addressing individual modes in MDM transmission. To the best of our knowledge, multi-port optical mode (de)interleavers have never before been discussed.

In this paper, a three-port silicon mode-(de)interleaver (TSMIL) based on an asymmetric multi-arm Y-junction is proposed and designed. Due to the simple configuration, as shown in Fig. 1, more individual modes can be excited and combined or transformed and separated with the aim of efficiently increase the channel counts with less cascaded stages to expand the capacity. The behavior of a six-mode TSMIL is numerically analyzed as an example by using the three-dimensional beam propagation method (3-D BPM). The designed device has a maximum excess loss of 0.73 dB at a wavelength of 1550 nm and mode crosstalk lower than -17 dB over a wide bandwidth of 60 nm.

2. Principle

A two-arm asymmetric Y-junction in which the arms have differing propagation constants can be used as a two-mode sorter, such that the mode conversion factor defined in reference [17,18] is taken larger than the chosen threshold value of 0.43. While the assumption of only fundamental modes exiting the output arms continues to be maintained, the principle of mode-sorting can be extended to multimode, multi-arm Y-junctions [18]. However, the principle of mode-interleaving has not yet been developed for the cases of asymmetric multi-arm Y-junctions with higher-order modes excited in each arm. In this work, a three-port mode (de) interleaver is designed based on the asymmetric multi-arm Y-junction with higher-order modes excited in each arm. The working mechanism is described as follows.

As illustrated in Fig. 2(a), the proposed device has a straight waveguide which is referred to here as the stem with the width of W and three arms with the widths of W_0, W_1 and W_2 ($W_2>W_1>W_0$, $W=W_0+W_1+W_2$). If the modes in the stem waveguide propagate forward through the junctions, the $3i$-th-order

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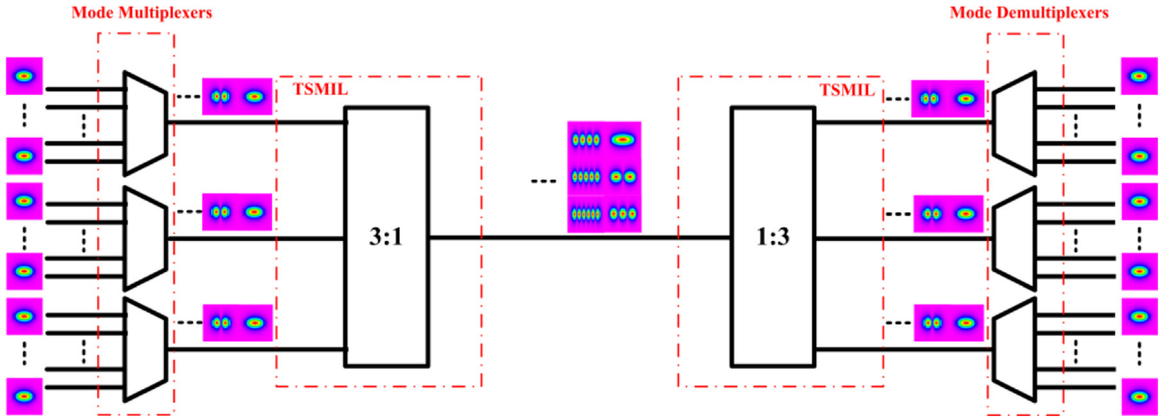

Fig. 1. The schematic configuration of TMSILs and mode (de)multiplexers for MDM transmission.

(i=0, 1, 2..) modes, the ($3i+1$)-th-order modes and the ($3i+2$)-th-order modes are separated and transformed into the i-th-order modes of arm B, arm C and arm A. Conversely, when the i-th-order modes of three arms are propagating in the opposite direction, the $3i$-th-order, ($3i+1$)-th-order and ($3i+2$)-th-order modes of the stem waveguide are excited and combined. These transitions occur because the propagation constants of the modes in the three arms are satisfying the inequalities given below.

$$\beta_{B,i+1} < \beta_{A,i} < \beta_{C,i} < \beta_{B,i} \quad (1)$$

where $\beta_{A,i}$, $\beta_{B,i}$, and $\beta_{C,i}$ are the propagation constants of the i-th modes in arm A, arm B and arm C.

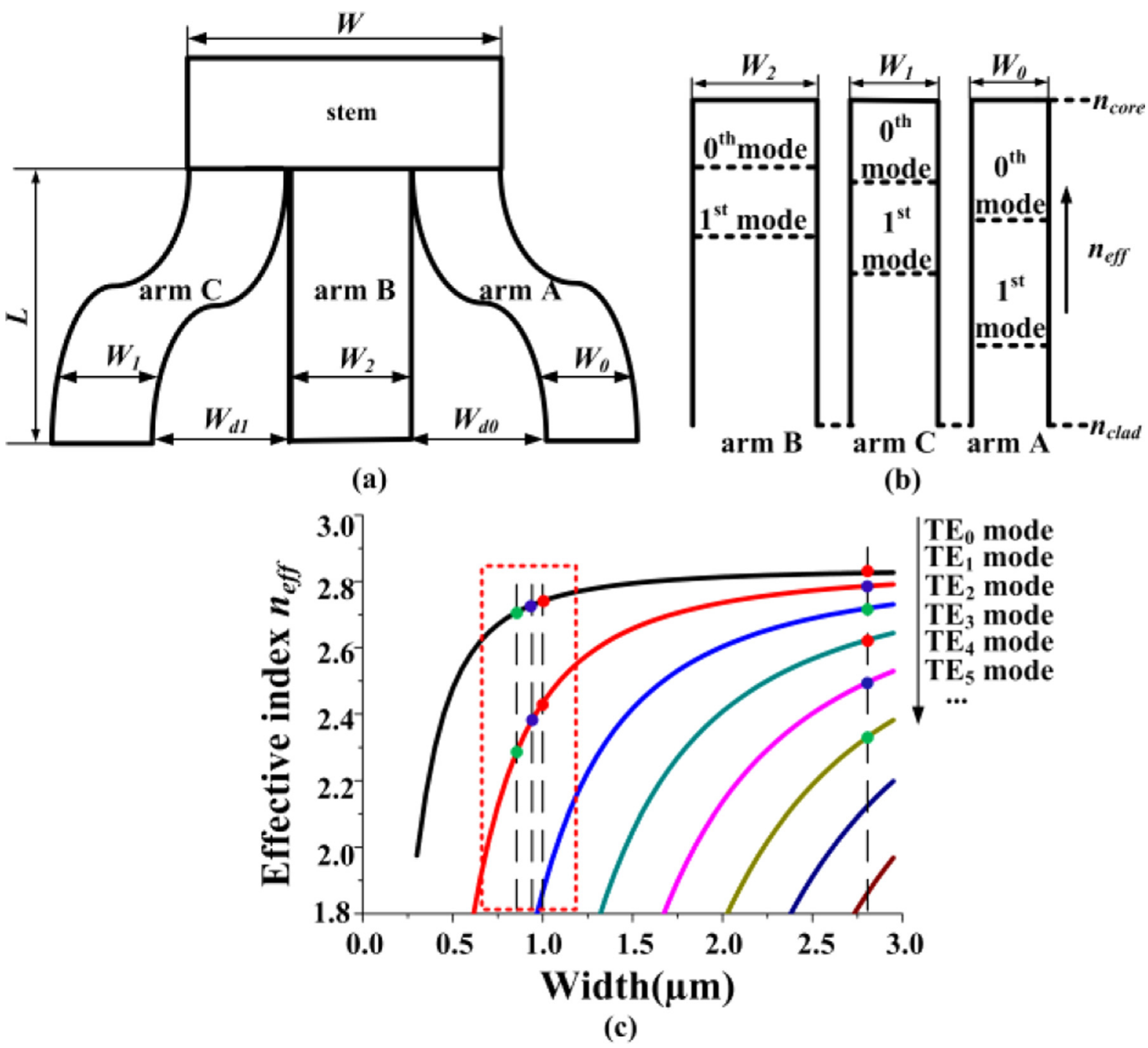

Fig. 2. (a) Structure of the TSMIL. (b) Image of effective indices of the modes in three arms. (c) Effective indices of the TE modes in a silicon strip waveguide as a function of the waveguide width.