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Design of an ultra-broadband silicon mode (de)multiplexer

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ABSTRACT

We propose a low-crosstalk and broadband mode (de)multiplexer. It is designed by cascading mode (de) interleavers utilizing silicon waveguide asymmetric Y-junctions. Asymmetric Y-junctions of each stage are modular. For each asymmetric Y-junction, the even (odd) modes of the stem separated from the odd (even) modes evolve into the low-order modes of the wide (narrow) arm by controlling the widths of the two arms, and vice versa. A four-channel mode (de)multiplexer for TE polarization is analyzed as an example. Simulations show the four-channel mode (de)multiplexer pair has a low crosstalk (< -14.1 dB) over a common spectral bandwidth of 280 nm.

1. Introduction

Due to a rapid increase in the demand for bandwidth, on-chip optical interconnect with ultra-high capacity is desired [1]. As is well known, wavelength-division multiplexing (WDM), polarization division multiplexing (PDM), and multilevel modulation format have been introduced to expand the transmission capacity. In order to satisfy the increasing bandwidth demand further, mode-division multiplexing (MDM) technology offers an attractive approach [2,3].

Mode (de)multiplexer with low loss, low crosstalk, and broad bandwidth is one of the key components in on-chip MDM transmission. Several mode (de)multiplexers have been reported based on multimode interference (MMI) waveguides [4–6], adiabatic couplers (ACs) [7], tapered directional couplers (TDCs) [8,9], asymmetrical directional couplers (ADCs) [10–12], and grating-assisted contra-directional couplers (GACCs) [13]. For MMI, ACs, and TDCs-based devices, they are good candidates for mode (de) multiplexers with broadband operation. But they are less flexible to expand more mode channels. ADCs-based devices require accurate control of the coupling length and coupling strength, and GACCs-based devices have a limited bandwidth.

Asymmetric Y-junction are useful structures. They have been developed to act as polarization splitters, mode combiners, mode splitters, and wavelength multiplexers [14–18]. Recently, asymmetric Y-junctions have been proposed as candidates for mode (de)multiplexers with broadband operation. Under the condition for mode-sorting with only the fundamental modes excited in the arms, the devices based on asymmetric Y-junctions can be designed as mode sorters [19–21]. A pair of asymmetric Y-junctions in silicon waveguides used as two-mode multi/demultiplexer with demultiplexed crosstalk as low as -30 dB, lower than -9 dB over the C band have been presented [21]. Taking advantage of the inter-conversion of highest-order modes in the stems and the fundamental modes in the narrow arms, the device based on cascaded asymmetric Y-junctions (CAYJs) can be designed as mode (de)multiplexer [22]. CAYJs-based four-mode (de)multiplexer is realized in weak guidance.

Silicon photonics based on silicon-on-insulator (SOI) technology provides a promising option for realizing efficient and high-capacity on-chip communication networks, due to the advantage of multidimensional orthogonality and compatibility with the CMOS fabrication technology [23,24]. In this paper, a mode (de) multiplexer consisting of multi-stage mode (de)interleavers (MMILs) is proposed and designed based on SOI platform for enabling MDM or MDM-WDM transmissions on chip. For the mode (de)interleaver of each stage, an asymmetric Y-junction is used to realize modularity. Each mode (de)interleaver based on asymmetric Y-junction flexibly separates the even modes from the odd modes in the multimode waveguide and converts the high-order modes of the stem into the lower-order modes of the arms by carefully controlling the widths of the arms. The behavior of a four-channel MMILs mode (de)multiplexer is studied as an example by using the three-dimensional beam propagation method (3-D BPM). Numerical simulations show the four-channel MMILs mode (de)multiplexer pair with mode crosstalk as low as -37.7 dB, lower than -14.1 dB over a common spectral bandwidth of 280 nm is achieved.

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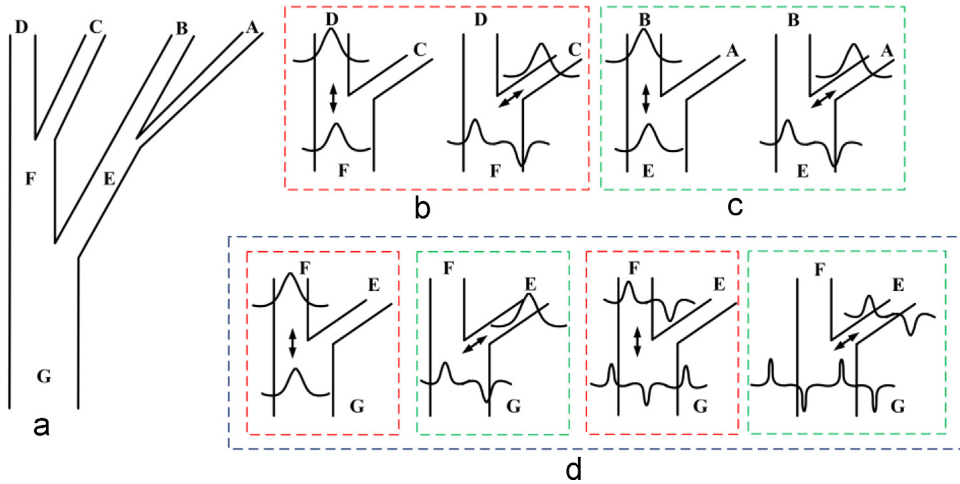

Fig. 1. (a) The schematic drawing of a MMILs mode (de)multiplexer (b) Evolution of the even (odd) mode between the first-stage stem F and arm D (C) (c) Evolution of the even (odd) mode between the first-stage stem E and arm B (A) (d) Evolution of the even (odd) modes between the second-stage stem G and the first-stage stem F (E).

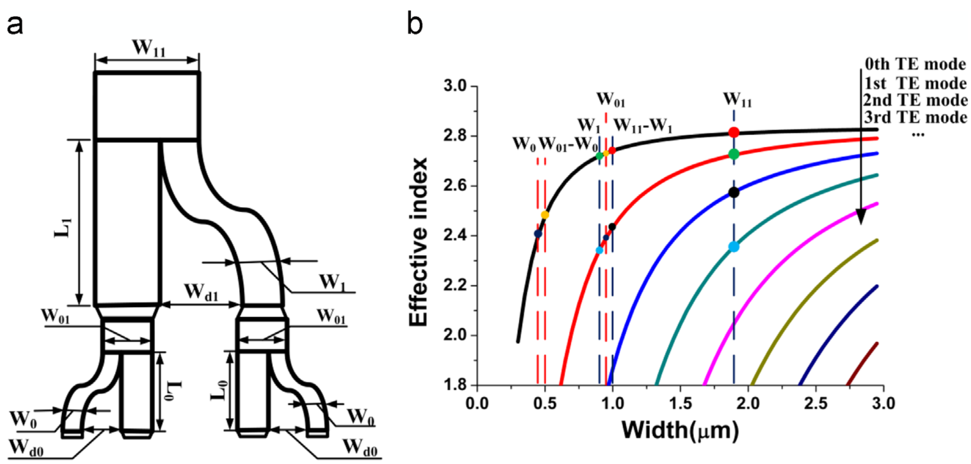

Fig. 2. (a) Schematic configuration of the proposed four-channel MMILs mode (de)multiplexer (b) Calculated effective indices of the guided-modes as a function of the core width in a silicon strip waveguide with a height of 220 nm.

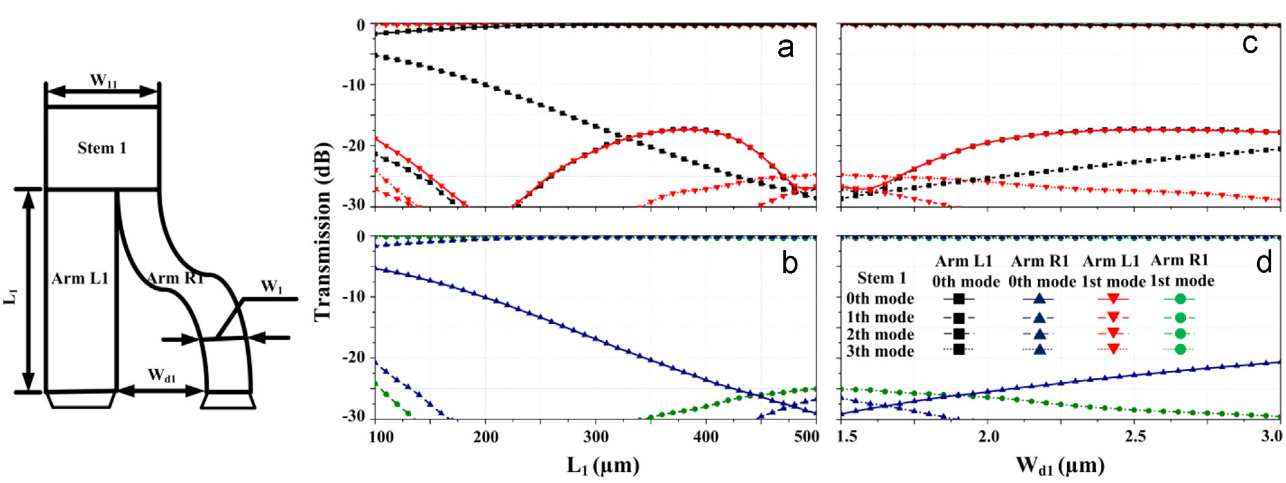

Fig. 3. Optical transmission of the four modes from the Stem1 to Arm L1 (up figures) and Arm R1 (bottom figures) as a function of L_1 in (a) and (b) (W_{d1}=1.75 μm used) and W_{d1} in (c) and (d) (L_1=470 μm used). The solid, dashed, dash-dotted, and dotted curves are for the case of the fundamental, first-order, second-order, and third-order modes in the Stem1.

2. Principle and device design

Fig. 1(a) schematically shows the proposed MMILs mode (de) multiplexer. To achieve *N*-channel (de)multiplexer, log2(*N*) stages of mode (de)interleavers using asymmetric Y-junctions are cascaded. At each stage, the stem of asymmetric Y-junction supports multiple eigen modes and the two arms support not just the fundamental modes. In addition, the two arms should satisfy the constraint conditions of the propagation constants [25]. As illustrated in Fig. 1(b), (c), and (d), when the optical modes appear in