Compact Silicon Mode Converter using Fast Adiabatic-evolution-based Y-junction with Wide Bandwidth

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Abstract: A broadband mode converter based on an asymmetric Y-junction is proposed and experimentally demonstrated. The device has a compact evolution length (<12 μm) and a wide bandwidth.

1. Introduction

In order to increase the capacity of optical interconnects, silicon on-chip mode-division multiplexing (MDM) has attracted much attention benefitting from its compact footprint and compatibility with the complementary metal-oxide-semiconductor (CMOS) fabrication process [1, 2]. Mode converters are the key components in MDM systems, which are capable of converting fundamental modes to higher modes. Various on-chip mode converters have been proposed based on directional couplers [3], tilted sub-wavelength gratings [4], and multi-mode interferometers [5]. A compact mode converter with a wide operation bandwidth is highly desired to meet the demand of high-capacity MDM systems based on silicon-on-insulator (SOI) platform. Y-junction is a competitive candidate for achieving mode conversion due to its property of broad bandwidth. However, the evolution length of a conventional Y-junction is relatively long (more than 60 μm), which is challenging for high-density integration.

In this paper, we propose a compact mode converter based on a Y-junction structure with a fast adiabatic evolution scheme. By engineering the angle (θ) between two branches of the Y-junction, a shortcut to adiabatic passage [6] can be achieved and a compact mode evolution region is implemented. In addition, by optimizing the θ and length of the structure, modes on different wavelengths can accomplish fast evolution at selected regions thus a mode converter with a broad bandwidth can be achieved. The proposed structure has a compact footprint with an evolution length of 12 μm and a broad operation bandwidth ranging from 1350 nm to 1750 nm according to simulations. Experimental results show that the conversion losses are lower than 5.2 dB and the crosstalk values are below −9.8 dB for the TE_0-to-TE_1 and TE_0-to-TE_2 mode converters in a wavelength range of 50 nm, limited by the measurement equipment and the grating couplers.

2. Device design and operation principle

For a conventional Y-junction, the fast-adiabatic evolution scheme can be achieved by manipulating the cross-section area and the gap of the waveguides along the direction of propagation [6]. It is viable to engineer θ between the two branches [7], for example, by introducing segmented waveguides that with different θ relative to the stem. The schematic of the proposed asymmetric Y-junction mode converter is shown in Fig. 1 (a). The width of arm A (W_A) is normally narrower than arm B (W_B). Two mode conversion regions are employed to convert modes on different wavelengths. The structural parameters of the device are optimized by using 3D-Finite-Difference-Time-Domain (FDTD) simulations. We choose W_1 = 450 nm, W_2 = 480 nm, the optimized parameters are shown in Table 1. Simulated electric field distributions (E_y) of the mode converter for TE_1 and TE_2 modes, at the wavelength of 1350 nm, 1550 nm and 1750 nm are shown in Fig. 1 (b-f), respectively. The injected TE_0 modes are gradually converted to TE_1 and TE_2 modes. Simulated transmission responses are shown in Fig. 2 (a) and (b), indicating that our device exhibits conversion losses lower than 1 dB over 1350 nm to 1750 nm, with a minimum of 0.1 dB. The mode purity is larger than 85% for both TE_0-to-TE_1 and TE_0-to-TE_2 mode conversion.

Table 1. Detailed structural parameters for the proposed mode converters

Mode converter	L_1 [μm]	L_2 [μm]	θ_1 (°)	θ_2 (°)
TE_0-to-TE_1	5	5	0.72	1.15
TE_0-to-TE_2	7	5	0.72	1.32

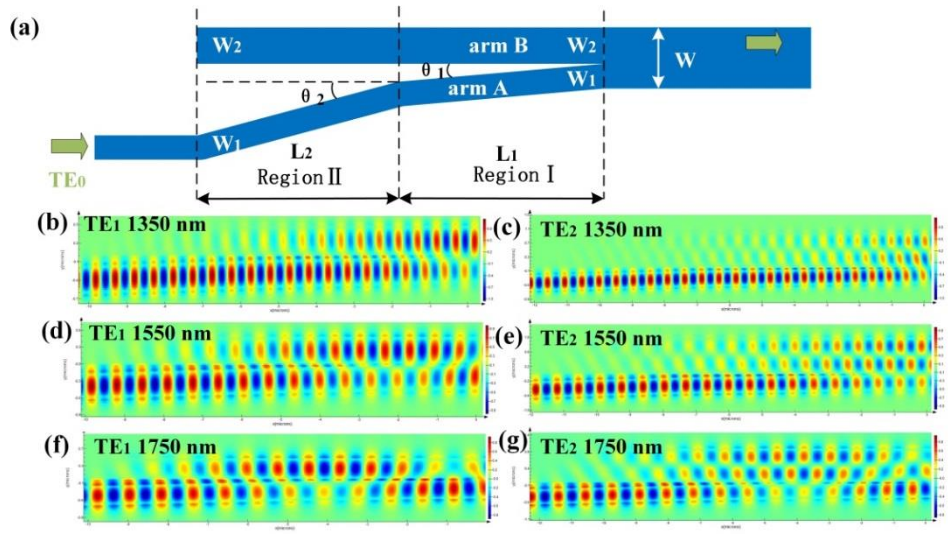

Fig. 1 (a) Schematic of mode converter based on asymmetric Y-junction and simulated electric field distributions (E_y) of the mode converter device for (b), (d), (f) TE_0- to-TE_1, (c), (e), (g) TE_0-to-TE_2 at the wavelength of (b), (c) 1350 nm, (d), (e) 1550 nm and (f), (g) 1750 nm, respectively.

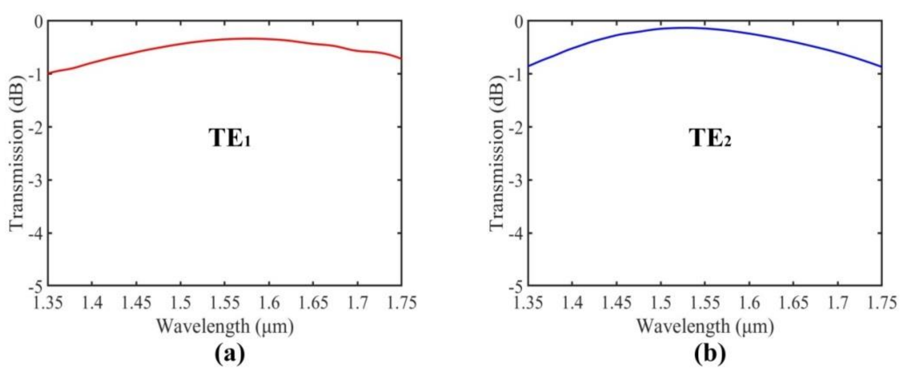

Fig.2 Simulated transmission spectra of the (a) TE_0- to-TE_1 mode converter and (b) TE_0-to-TE_2 mode converter in the wavelength range from 1350 nm to 1750 nm.

3. Device fabrication and measurement results

The mode converters were fabricated on a silicon-on-insulator wafer with a 3-μm-thick silica buried oxide layer and a 220-nm-thick top layer. The structures were patterned and etched by E-beam lithography (Vistec, EBPG-5200$^+$) and inductively coupled plasma (ICP, SPTS). The optical microscope photos of the device are shown in Fig. 3 (a) and (c). To characterize the conversion losses and crosstalk values of the fabricated mode converters, mode (de)multiplexers based on asymmetrical directional couplers (ADC) [4, 8] are cascaded to the mode converters to recover the output higher-order mode signals to TE_0 modes for the measurements. A tunable continuous-wave laser (Keysight 81960A) and an optical power meter (Keysight N7744A) were used to characterize the performances of the devices. Grating couplers were employed to couple light beam into and out of the fabricated device, with a coupling loss of~6.8 dB/facet. Due to the bandwidth limits of the laser source and the grating couplers, we only characterize the performance of the proposed device in a wavelength range from 1540 to 1590 nm.

Measured transmission responses and crosstalk values at the output ports of the fabricated mode converters are shown in Fig. 3 (b) and (d). The transmission responses are normalized to that of the grating couplers and ADCs fabricated on the same chip. For the TE_0-to-TE_1 mode converter, the mode conversion loss is lower than 4.8 dB, and the crosstalk value is below −12.3 dB in a wavelength range of 1540 nm to 1590 nm. For the TE_0-to-TE_2 mode converter, the mode conversion loss is < 5.4 dB and the crosstalk value is < −9.8 dB over a 50-nm wavelength range from 1540 nm to 1590 nm. Compared to the simulation results, the measured mode conversion losses are larger, which can be attributed to the fabrication deviations and unstable performances of ADCs. Further experiments will be carried out to optimize the performance of the devices.

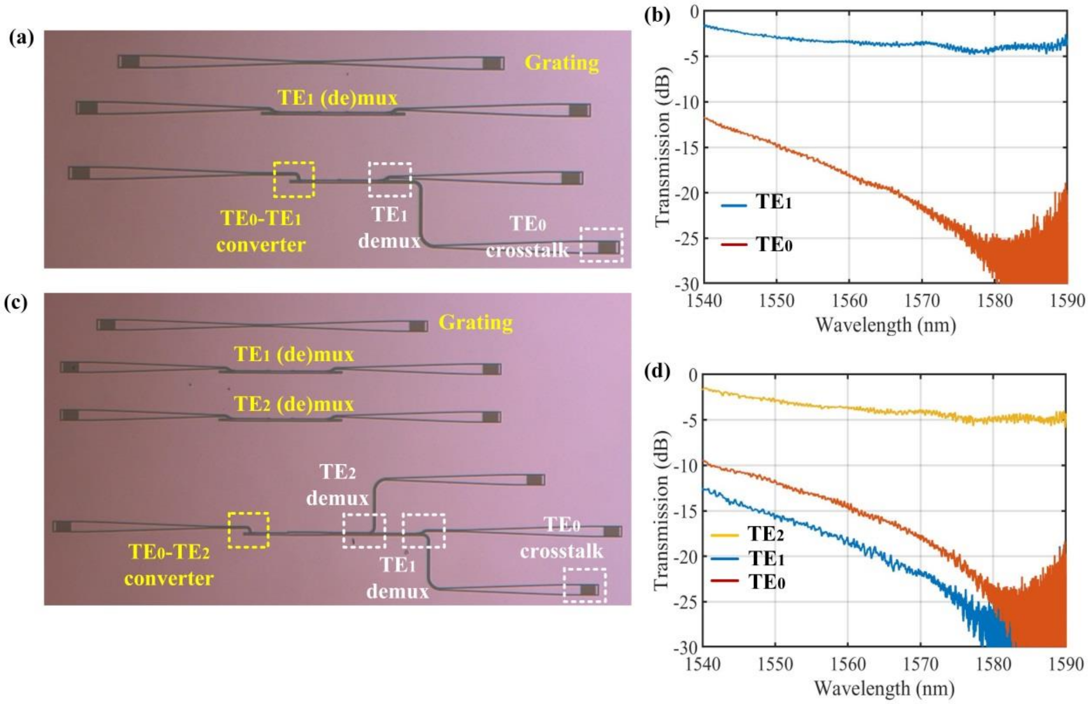

Fig.3 Optical microscope photos of the (a) a fabricated TE_0-to-TE_1 mode converter, (c) a fabricated TE_0-to-TE_2 mode converter. Measured transmission spectra of (b) TE_0-to-TE_1, (d) TE_0-to-TE_2 .

4. Conclusion

We proposed and experimentally demonstrated a compact mode converter by using a fast adiabatic evolution-based Y-junction. The proposed device has a broadband operation bandwidth (1350 nm ~ 1750 nm in simulation). The measurement results show that the crosstalk values are lower than −9.8 dB and the conversion loss is < 5.4 dB over the wavelength range from 1540 nm to 1590 nm, limited by the tunable laser and the grating couplers. The proposed device has the potential to achieve higher-order mode conversion and wider bandwidth to further scale the transmission capacity.

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