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Reconfigurable optical add-drop multiplexer based on thermally tunable micro-ring resonators

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ABSTRACT

We report on an eight-channel reconfigurable optical add-drop multiplexer (ROADM) based on micro-ring resonators (MRRs). The effective footprint of the device is about $1000 \times 760\ \mu m^2$. The free spectral range (FSR) is about 18 nm. The adjacent channel crosstalk ranges from −19.02 dB to −8.29 dB. With the help of the multi-wire structure heaters, compact footprint and high tuning efficiency are achieved simultaneously. Therefore, the minimum average tuning efficiency is 2.723 mW/nm.

1. Introduction

With the development of fiber optical communication technology, the silicon photonics is expected to be the platform for chip-level interconnect technology. Wavelength division multiplexing (WDM) system is required to improve the optical transmission capacity. As one of the key components of WDM optical networks, the reconfigurable optical add-drop multiplexers (ROADMs) can achieve the functionality of multiplexing or demultiplexing without optical-electro-optical conversion and greatly reduce the conversion cost. The optical-node is expected to replace the electro-node to achieve all optical network. Several schemes of ROADMs based on various technologies have been proposed. However, the ROADMs based on fiber Bragg's grating (FBG) [1] and array waveguide grating (AWG) [2] with switch arrays are usually large in dimensions. The ROADMs based on the Mach Zehnder interferometer (MZI) [3] with diffraction gratings have a limited tuning range and are harsh in fabrication process. One promising scheme is based on micro-electromechanical systems (MEMS) [4] optical switch matrices, which have the characteristic of flat filtering pass band and flexible signals upload/download. However, the use of free-space switches makes the aligning and packaging difficult, and the multi-channel configuration makes the production cost higher. Another promising scheme is based on micro-ring resonators (MRRs), which can provide a compact, highly flexible, low-power consumption, and fully CMOS-compatible interconnection system.

The MRRs have been widely applied in the active and passive optoelectronic devices, such as modulators [5,6], lasers [7,8], decoders [9,10], switches [11] and optical sensors [12,13]. The reconfigurable functionality is of vital importance, which can improve the utilization and the flexibility of device. Furthermore, silicon has a relatively high thermo-optic coefficient (1.86×10^{-4}/K), which provides a relatively larger modulating range. In addition, MRRs are very sensitive to the variation of the dimension and environment. The thermo-optic effect can compensate the resonance wavelength shift induced by both fabrication errors and environmental changes. Previously demonstrated vertically coupled micro-ring resonator (VCMRR) filters [14] have a lower crosstalk less than −30 dB and the ring core are composed of the compound glass Ta_2O_5–SiO_2, but the device cannot be tuned by thermal to achieve the reconfigurable functionality. Another ROADM based on vertically coupled thermally tunable Si_3N_4–SiO_2 MRRs [15] have a tuning bandwidth of 4.18 nm and an average tuning power efficiency of 26.6 mW/nm. The radius of the ring is 50 μm which is relatively large for integrated optics. The recent works of ROADM based on MRR [16] can achieve uniform channel spacing of 100 GHz which aligned to ITU specifications. And the average tuning efficiency are about 6.187 mW/nm [17] and 4.5 mW/nm [16] which can be optimized. In this paper, we fabricated a high performance ROADM based on thermally tunable micro-ring resonators. Using the multi-wire structure heaters [18],

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compact footprint, large FSR, uniform channel spacing, high tuning efficiency, and fast response speed are achieved simultaneously, which has a better performance than previous work [14–17].

This paper is arranged as follows. In Section 2, the design and fabrication of the ROADM are described. In Section 2.1, the design of the ROADM is given, including the single-mode waveguide and the structure of ROADM. In Section 2.2, the fabrication of the ROADM is demonstrated in detail. In Section 3, the device is measured and the main performance of the ROADM is reported. In Section 3.1, the static response of the ROADM is measured, including four working modes in various conditions. In Section 3.2, we analyses and calculates the tuning efficiency of the device. In Section 3.3, the dynamic response of the ROADM is measured. In Section 4, the conclusion draw from the experiment and the possible improvement method is introduced.

2. The design and fabrication of the device

2.1. Device structure

Fig. 1(c) shows the cross-section of rib waveguide with a width of 400 nm, height of 220 nm and slab thickness of 70 nm, which only exists TE fundamental mode. Fig. 1(b) shows the single-mode condition calculated by the Film Mode Matching (FMM) method. And eight multi-wire structure heaters [18] are fabricated on the top of the corresponding MRRs. The isolation layer thickness should be thick enough to ensure that the guided mode in core layer is completely isolated with the heaters since metal has a strong absorption of light in C-band. The isolation layer thickness is 1.5 µm which compromises between the insertion loss and the thermal consumption loss.

The structure of the device is illustrated in Fig. 1(a), which is composed of eight reconfigurable add-drop MRRs. When using as an optical drop multiplexer, the multi-wavelength signals are fed into the input port and pass through the eight MRRs. Then the signals which meet the resonance conditions of MRRs (R1–R8) are respectively download to the D1–D8 ports. When using as an optical add multiplexer, the specific signals that coupled into the A1–A8 ports is uploaded into the backbone through the MRRs (R1–R8). When the heaters fabricated on the top of the MRRs are heated up, the resonance peaks of MRRs have a red-shift. And each MRR can be tuned individually. The radius of the MRR is around 5 µm which make a relatively high free spectral range (FSR). The radius of MMR1 to MRR8 are 5 µm, 5.03 µm 5.06 µm, 5.09 µm, 5.12 µm, 5.15 µm, 5.18 µm. The gap between the MRR and the straight waveguide is about 180 nm. The crossings between the add/drop ports and the backbone can induce large transmission loss and crosstalk. We employ an inverted elliptical mode expander [19] with a long axis of 5 µm and a short axis of 1 µm to optimize the waveguide crossing. The spot size converters (SSCs) [20,21] are employed in each ends of the waveguides which improve the coupling efficiency between the waveguides and the fiber.

2.2. Device fabrication

The ROADM is fabricated on SOI with 220-nm-thick top Si layer and 1-µm-thick buried SiO_2 layer. Deep ultraviolet photolithography is used to define the device pattern. An inductively coupled plasma etching process is used to etch the top silicon layer. After the waveguide is etched, a 1.5-µm-thick SiO_2 cladding layer is deposited onto the silicon core layer by plasma enhanced chemical vapor deposition (PECVD). The multi-wire structure Titanium heaters with a thickness of 150 nm and a length of 140 µm are fabricated on the top of the corresponding MRRs by deep ultraviolet photolithography and dry etching. The multi-wire structure heaters which increase the length of heater can improve the utilization efficiency of the tuning consumption power. Aluminum electrodes and pads with the thickness of 1 µm are fabricated after the heaters are done. The micrograph of the whole device is showed in Fig. 2(c). The dashed areas are the micro-ring resonator with multi-wire structure heaters (Fig. 2(a)) and the spot size converter (Fig. 2(b)).

3. Device measurement and discussion

3.1. Static response of the ROADM

The experimental setup for the static response characterization of the device is shown in Fig. 3(a). A broadband source, a polarization controller, a tunable voltage source, an optical spectrum analyzer (OSA) and an adjustable platform (Fig. 3(b)) is adopted to characterize the static response of the fabricated ROADM. A broadband source is coupled into the SSC through a single-mode polarization-maintaining fiber (PMF). A polarization controller is employed to control the polarization state of the signals. The

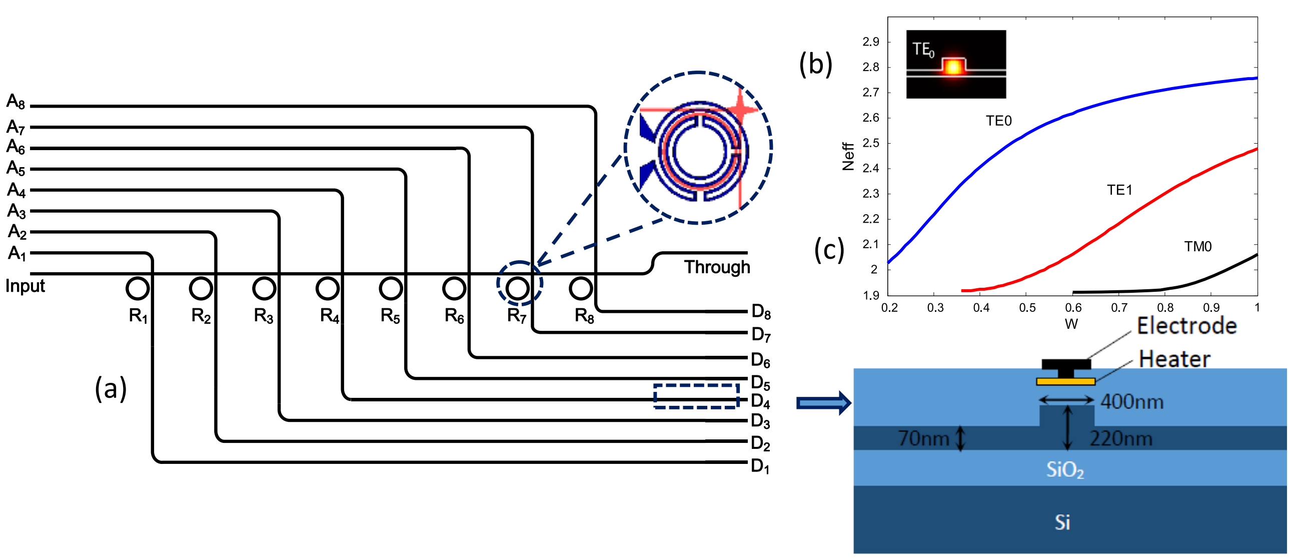

Fig. 1. (a) The sturture of the ROADM; (b) the single-mode condition; (c) the cross-section of the waveguide.