Orbital Angular Momentum Mode Multiplexer Based on Multimode Micro-Ring Resonator with Angular Gratings

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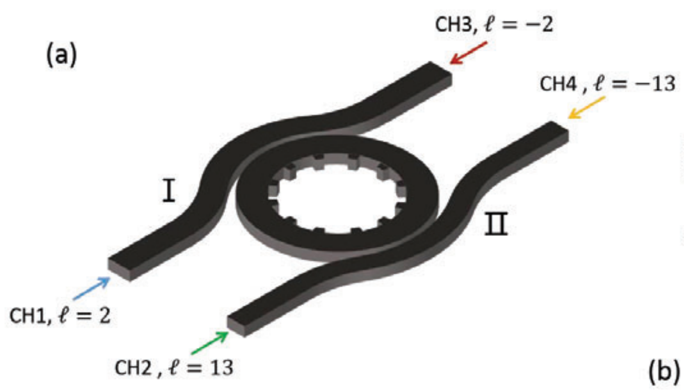
Abstract: We demonstrate silicon photonic orbital angular momentum multiplexing devices based on mulitmode microring resonator. Up to four optical beams carrying different orbital angular momentum states can be selectively excited from different input ports.

OCIS codes: (130.3120) Integrated optics devices; (060.4230) Multiplexing; (050.4865) Optical vortices.

1. Introduction

Orbital angular momentum (OAM) multiplexing is a promising technology to expand the transmission capacity of either free space optical communication or fiber communication [1, 2]. Previously, we have demonstrated a compact silicon photonic OAM emitter capable of generating single but arbitrary OAM states. The operation principle of the device is based on the coupling of whispering gallery modes (WGMs) in a micro-ring resonator to OAM modes through an angular grating embedded within the micro-resonator. This device is capable of generating any OAM states by simply changing the input wavelength. However, this wavelength dependent approach made it difficult to achieve OAM multiplexing, which is of vital importance for the application of OAM-based optical communications Here, based on our previous work [3], we demonstrate integrated OAM multiplexer on 220nm silicon-on-insulator material. As shown in Fig. 1, the device consist of a multi-transverse mode microring resonator with angular grating embedded in the innerwall, and two bus waveguides (I and II) with different width. The ring resonator waveguide supports two transverse electric modes, TE0 and TE1. The widths of the resonator waveguide and the two input waveguide are engineered in such a way that bus waveguide I and II selectively excite TE0 and TE1 WGMs in the resonator waveguide at a wavelength near 1550nm. The excited TE0 and TE1 WGMs are then coupled to different OAM mode by the angular grating with mode order $l=p-q$ (p is the WGM optical periods and q is the number of grating elements). This approach allows combining or multiplexing up to four OAM modes because each input waveguide has two ports, and both clockwise and counter clockwise WGM can be excited.



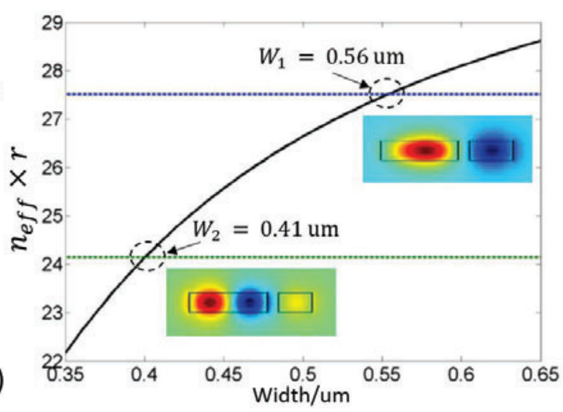


Fig. 1. (a)Structure of the proposed OAM mode multiplexer consists of a multimode micro-ring resonator with angular gratings and two bus waveguides; (b) Simulated propagation constant of the optical modes in bend bus waveguide

2. Design and Fabrication

The radius of the resonator is 10μm, and the width of the resonator waveguide is set to 1μm. The bus waveguides are designed to be bent waveguide concentric to the ring resonator. We fixed the gap between the bus and the resonator waveguide to be 150nm, and then optimized the width of the individual bus waveguide to be phase matched to the target TE0 and TE1 WGMs (see Fig.1b). When the bus waveguide width corresponds to 560 nm or 430 nm, the propagation constants of TE0 or TE1 respectively match the propagation constant of TE0 mode of the bus waveguide I and II.

We fabricated the switch on silicon-on-insulator (SOI) for high-confinement and compact structures. First, the 220-nm thick waveguides were patterned using electron beam lithography and etched through. The devices were then clad with SiO2.

3. Experimental Characterization

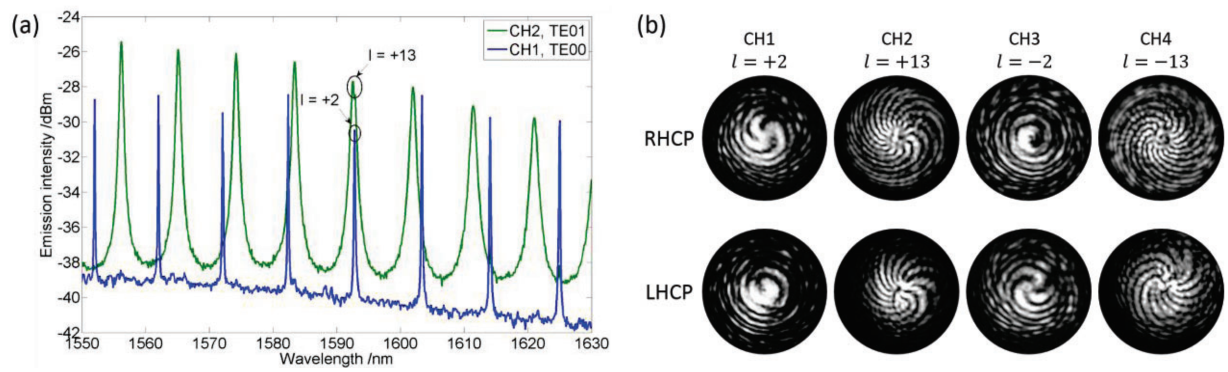


Fig. 2. (a) Radiation spectrum of the multiplexer for the fundamental mode and second-order mode from the CH1 (blue curve) and CH2 (green curve), respectively. (b) The interference patterns of the RHCP and LHCP components with base Gaussian beam.

Fig. 1(b) shows the emitted spectrum of the device with input power from bus waveguide I and II. Two sets of spectra are measured with different free spectral range (FSR) due to different effective index of TE0 and TE1 WGMs, which suggested the cross talk is low. As shown in Fig.1b, both TE_0 and TE_1 WGMs are resonant at 1592.7nm, which is the wavelength of achieving OAM multiplexing.

Following the procedure described in Ref. [3], we did interference experiment to measure the OAM mode order from the four input ports (CH1, CH2, CH3 and CH4) from two bus waveguides, and the results is summarized in Fig. 2 (b). Due to the vector nature of the the state of polarization of the generated beam, the beam from each port is associated with two sets of interference pattern with right-hand circularly polarized (RHCP) and left-hand circularly polarized (LHCP) reference beams. These results confirm that at wavelength of 1592.7nm, this device is capable of multiplexing OAM value of l= -2, l= +2, l= -13 and l= +13. We further measured the cross talk (defined as the ratio of desired generated OAM mode power to the overall power) from each channel, and the worst case cross talk is 13dB.

4. Conclusion

We have experimentally demonstrated silicon photonic orbital angular momentum multiplexing devices based on mulitmode microring resonator. Up to four optical beams carrying different orbital angular momentum states can be selectively excited from different input ports. The device can be further integrated with micro-heaters to make it work at different wavelength [5]. More channels are possible with larger ring resonator supporting more modes.

5. References

[1] Jian Wang, Jeng-Yuan Yang, Irfan M. Fazal, Nisar Ahmed, Yan Yan, Hao Huang, Yongxiong Ren, Yang Yue, Samuel Dolinar, Moshe Tur and Alan E. Willner, "Terabit free-space data transmission employing orbital angular momentum multiplexing," Nature Photonics 6, 488-496 (2012).

[2] Nenad Bozinovic, Yang Yue, Yongxiong Ren, Moshe Tur, Poul Kristensen, Hao Huang, Alan E. Willner, Siddharth Ramachandran, "Terabit-Scale Orbital Angular Momentum Mode Division Multiplexing in Fibers," Science 340, 1545-1548 (2013).

[3] Xinlun Cai, Jianwei Wang, Michael J. Strain, Benjamin Johnson-Morris, Jiangbo Zhu, Marc Sorel, Jeremy L. O'Brien, Mark G. Thompson, Siyuan Yu, "Integrated Compact Optical Vortex Beam Emitters," Science 338, 363-366 (2012).

[4] Bryce A. Dorin and Winnie N. Ye, "Two-mode division multiplexing in a silicon-on-insulator ring resonator," Opt. Express 22, 4547-4558 (2014)

[5] Michael J. Strain, Xinlun Cai, Jianwei Wang, Jiangbo Zhu, David B. Phillips, Lifeng Chen, Martin Lopez-Garcia, Jeremy L. O'Brien, Mark G. Thompson, Marc Sorel and Siyuan Yu, "Fast electrical switching of orbital angular momentum modes using ultra-compact integrated vortex emitters," Nature Communications 5, 4856 (2014)