Multimode add/drop multiplexer Based on Dense Waveguide Array

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***Abstract*—Reconfigurable multimode multiplexers are important devices in multimode division multiplexing systems. In this paper, we proposed and demonstrated a multimode add/drop multiplexer based on a dense waveguide array. The proposed structure is very flexible in mode (de)multiplexing and add/drop, and it could find applications in a reconfigurable multimode system.**

Keywords—multimode, add/drop, dense waveguide array

I. INTRODUCTION

In recent years, multimode silicon photonics has attracted more and more attention because of its unique advantages[1].On the one hand, the optical link capacity of a single wavelength can be enhanced heavily by introducing higher-order modes as independent transmission channels. On the other hand, some devices with special features can be achieved with the assistance of higher-order modes. As an essential element of the mode-division multiplexing(MDM) system, mode (de)multiplexers have been investigated extensively. Various structures have been proposed to achieve mode multiplexers, such as multimode multiplexers based on asymmetric directional couplers(ADCs)[2], Y-branch[3], and dual-core adiabatic tapers[4]. These mode multiplexers are placed in the transmitting and receiving terminal of an MDM system, and prohibit adding/dropping a desired mode to the multimode bus waveguide. Flexible multimode add/drop is significant for a reconfigurable MDM system. Some structures have been developed to construct multimode add/drop multiplexers, such as Mach-zehnder interferometer (MZI)[5], micro-ring[6], and subwavelength grating(SWG)[7]. Multimode add/drop multiplexers based on MZI and micro-ring involve the processes of mode multiplexing and de-multiplexing, thus usually having a large footprint. Recently, an SWG-based multimode add/drop multiplexer was proposed, and the SWG is used to redistribute the mode fields, thus one can add/drop arbitrary supporting modes of the multimode bus waveguide by matching its' effective mode index (N_{eff}) with that of drop waveguide[7]. Although this scheme is very compact and flexible, the SWG structure is strict on fabrication. It's worth noting that most of the aforementioned mode (de)multiplexers do not support the flexible add/drop of the desired mode without influencing the transmission of other modes.

In this paper, we propose a multimode (de)multiplexer that can flexibly add/drop all three TE modes without influencing other transmission modes. The dense waveguide array(DWGA) is used as the multimode bus waveguide thus manipulating the mode distribution of the bus waveguide. At the same time, the mode matching between the coupling waveguide and the bus waveguide is realized to add or drop arbitrary mode. Compared with the previous mode add/drop multiplexers [7], our scheme is more simple in principle and easy to fabricate. The preliminary results show our scheme is advantageous.

II. PRINCINPLE,STRUCTURE AND DESIGN

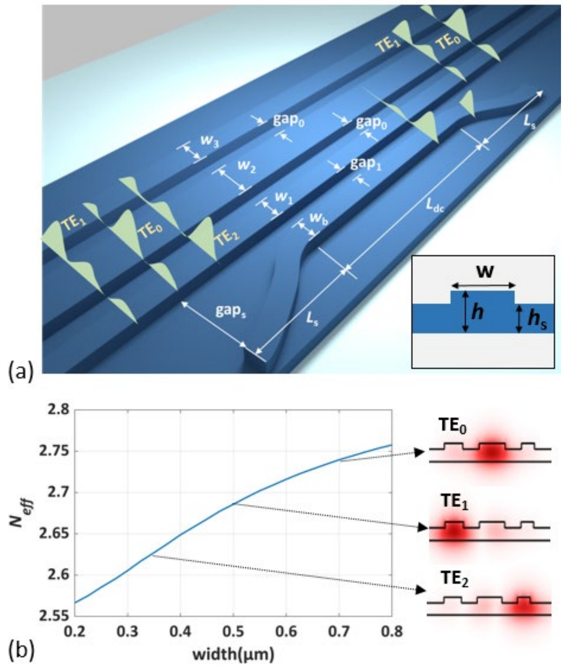

Fig 1 (a) Schematic configuration of the proposed multimode add-drop multiplexer; (b) Effective index of the single-mode as the width varies.

Fig.1(a) shows the 3D schematic diagram of the proposed multimode add/drop multiplexer, and the inset shows the waveguide cross-section. The demonstrated device is designed based on the SOI platform with a h=220-nm-thick top-silicon layer (n_{Si}=3.45), a 2-μm-thick silica buffer layer (n_{SiO2}=1.444), and a 2-μm-thick silica upper cladding. Shallow-etched waveguide with a slab thickness h_s of 150 nm is chosen to enhance the mode coupling efficiency, thus making the overall structure more compact. On the other hand, the shallow-etched waveguides can obtain lower transmission loss than full etching. As an example, a device supporting three modes is designed here. As shown in Fig.1(a), when the TE_0~TE_2 modes are launched from the left port of the device, the mode to be dropped (Here, TE_2 as an example) will be coupled to a narrow waveguide close to the DWGA. Meanwhile, the other modes (TE_0 and TE_1) pass through the coupling region directly. It should be noted that the order of the dropping mode needn't obey the rules from higher to lower, which is different from the ordinary designs. Fig.1(b) shows the dispersion curve of the shallowly etched waveguide. The bus waveguide comprises three such adjacent single-mode waveguides with different widths, thus localizing the modes in corresponding waveguides. The mode field can be redistributed by adjusting the width and the gap of the dense waveguide array. The mode field distribution of TE_0, TE_1 and TE_2 modes are shown in Fig. 1 (b). It can be seen that the most energy of TE_0 mode is localized in the widest waveguide, and few of them is distributed in the adjacent waveguide. While the highest-order TE_2 is mainly localized in the narrowest waveguide. Any mode in the bus waveguide can be dropped/added arbitrarily by adjusting the width w_b of the coupling waveguide, thus the effective mode index (N_{eff}) of the coupling waveguide and the bus waveguide get phase-matched. The mode coupling coefficient between the drop waveguide and its' nearest waveguide of DWGA is the largest. Therefore, when we need to drop the mode with energy distribution in the middle waveguide, we need to exchange it with the mode at the lateral waveguide, thus making sure the largest coupling efficiency. To implement such a mode exchange process, one just needs to exchange the widths of these two waveguides adiabatically.

III. Fabrication and Characterization

Fig. 2(a) shows the fabricated SOI sample, it consists of two multimode add-drop multiplexers connected back to back. The enlarged view of the coupling region for the TE_2 mode is shown in Fig. 2(b).

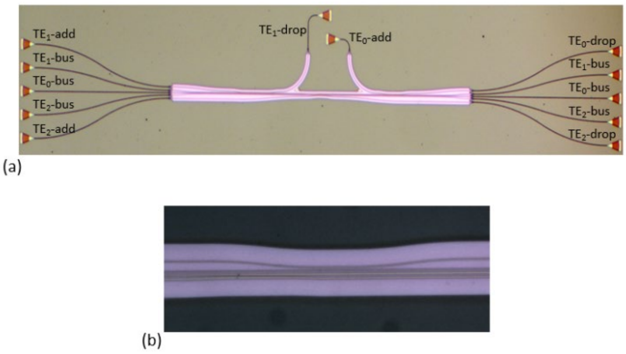

Fig 2 Schematic configuration of (a) the fabricated sample and (b) the coupling region for TE_2 mode.

To characterize the device, the light is launched into TE_0~TE_2 bus ports on the left panel of Fig. 2(a), respectively, and the output light of the TE_0~TE_2 bus ports and drop port on the right panel of Fig. 2(a) is received with an optical spectrum analyzer (OSA). The normalized results are shown in Fig. 3. The extinction ratios of the TE_1 and TE_2 modes are about 10 dB. While the extinction ratio of the TE_0 mode is not good enough, it is supposed to be aroused by the fabrication error.

IV. Conclusion

In this paper, we proposed and demonstrated a multimode add/drop multiplexer based on the dense waveguide array. The measurement results show that the fabricated device has a 10 dB extinction ratio for TE_1 and TE_2 modes. The proposed scheme has a flexible (de)multiplexing function and add/drop function for all three modes, which is very important for the construction of reconfigurable multimode systems. For example, one can realize a reconfigurable hybrid multiplexing system by combining this structure with micro-ring or array waveguide grating. In addition, the proposed scheme is also very scalable, and the mode channels can be easily expanded by increasing the number of the dense waveguide array.

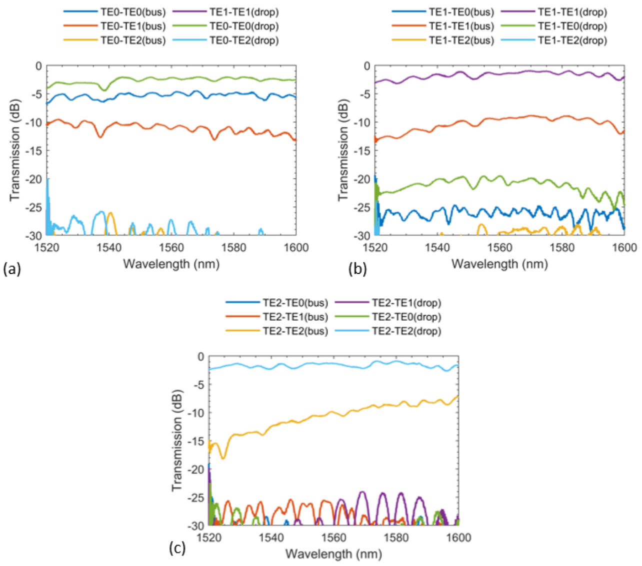

Fig 3 Transmission of the fabricated device for (a) the TE_0, (b) the TE_1 and (c) the TE_2 modes.

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