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Design and Fabrication of Thermo-Optic 4×4 Switching Matrix in Silicon-on-Insulator*

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Abstract: A rearrangeable nonblocking thermo-optic 4×4 switching matrix, which consists of five 2×2 multimode interference-based Mach-Zehnder interferometer(MMI-MZI) switch elements, is designed and fabricated. The minimum and maximum excess loss for the matrix are 6.6 and 10.4dB, respectively. The crosstalk in the matrix is measured to be between −12 and −19.8dB. The switching speed of the matrix is less than 30μs. The power consumption for the single switch element is about 330mW.

Key words: integrated optics; silicon-on-insulator; matrix switches; PLC technology
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1 Introduction

Optical matrix switches are indispensable for future fiber-optic communication systems. They have been implemented for the connections with wavelength multiplexers for reconfiguration in the optical cross connect (OXC). Matrix switches have been successfully fabricated on the $LiNbO_3$, SiO_2, and polymer bases[1~3]. However, the architectures employed in these matrixes all require a big number of switch elements and cascaded ranks, which result in big device size. Furthermore, these switches have the drawback of the inability to be integrated with other optical devices in the silicon substrate, which prevents their application to large-scale integration. Therefore, there have been considerable interests in optical switches based on silicon-on-insulator(SOI) platform[4,5]. In this paper, we report a rearrangeable nonblocking 4×4 matrix switch composed of five 2×2 switch elements in SOI technology.

2 Architecture of a 4×4 switching matrix

A SOI thermo-optic switching matrix reported in this paper is constructed from five 2×2 multimode interference-based Mach-Zehnder interferometer(MMI-MZI) switch elements, as shown in Fig. 1. It requires a small number of switch elements and ranks, which ensure a smaller chip size than conventional crossbar and tree architecture. This layout also has the advantage of requiring a small number of waveguide bends and no intersecting waveguide, unlike tree architecture.

A 2×2 MMI-MZI switch element consists of two general interference couplers connected by two

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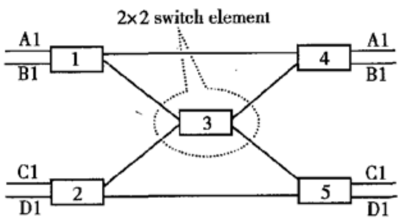

Fig. 1 Layout of SOI 4×4 switch matrix

phase-shifting arms, as shown in Fig. 2. MMI couplers operate in a 3dB state and the optical length difference between the two arms is modulated by thin film heaters. By controlling the electrical currents applied to the heaters, a switch element in the cross-state can be switched to the bar-state. The access waveguides in the matrix are based on a multi-micron, large cross-section rib structure in order to load the fundamental mode[6].

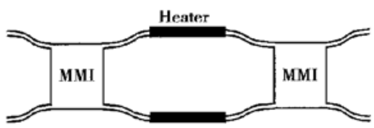

Fig. 2 Architecture of 2×2 MMI-MZI switch element

3 Design and fabrication

Bonding and back-etching SOI wafer with a 5μm top single crystal silicon layer was chosen for our investigation. Rib waveguides were formed by inductively coupled plasma(ICP) dry etching using an anisotropic $C_4F_8/SF_6/O_2$ process. The ridges were precisely etched to a depth of 1.75μm. Then a 200nm thick cladding oxide was grown by PECVD. On top of the cladding layer, an aluminum layer was sputtered and lithographically patterned. Finally, the wafer was thinned and cleaved for the purpose of measurements. Straight waveguides were formed on the side of the matrix for relative excess loss measurement. The total length of the matrix is about 49mm.

4 Experimental results

To demonstrate the spacing routing of the matrix, light from a 1.55μm laser diode was coupled into an input port and switched to output ports of the 4×4 matrix. Figure 3 shows the 1×4 connections between the input port A1 and the four output ports. The switching state of the single element are marked by a cross(×) or a bar(=) sign. It should be noted that some connections between an input port and an output port possibly have two paths. For example, the connection A1→A2 has the paths of 1→4 and 1→3→4. Here, the longer path is chosen for the measurement of excess loss and crosstalk.

Fig. 3 Switching states and measured near-field patterns of a rearrangeable nonblocking 4×4 switching matrix

Excess loss and crosstalk characteristics of the matrix switch were measured, as summarized in Table 1. The matrix has similar results when light was coupled from the other input ports. The optical path experiencing two switch elements has a smaller excess loss than that of the path passing through three elements. The minimum and maximum excess loss for the matrix is 6.6dB and 10.4dB, respectively. The relatively high excess loss is mainly caused by the sidewall roughness of the rib wave guides. The propagation loss for a straight SOI rib waveguide is about 3.5dB/cm. The crosstalk in the switch matrix is measured to be between − 12 and − 19.8dB. The only possible source for this crosstalk is the nonperfect cross-state of some of the single 2×2 switch element. It was assumed that improvement on the accuracy of etching depth and uniformity of large-area etching for ICP would contribute to the reduction of the crosstalk. Thanks to the high thermal conductivity and to the strong thermo-optic effect present in silicon, the matrix shows relatively good performance. The switching time is less than 30μs. The power consumption for the single switch element is about 330mW.

Table 1 Measured excess loss and crosstalk for 4×4 matrix switch

Connected path	Excess loss, Crosstalk /dB			
	A2	B2	C2	D2
A1→A2	10.3	-12	-18.5	-15.2
A1→B2	-12.4	6.8	-18	-15.7
A1→C2	-12.1	-19	10.1	-16.3
A1→D2	-13.2	-18.6	-14.9	9.6

5 Conclusion

A rearrangeable nonblocking thermo-optic 4×4 switching matrix operating at 1.55μm is designed and fabricated in silicon-on-insulator waveguide system. The matrix is composed of five 2×2 MMI-MZI switch elements, which result in a smaller device size than the conventional architectures. The minimum and maximum excess loss for the matrix is 6.6dB and 10.4dB, respectively. The measured crosstalk is between -12 and -19.8dB. The switching time of the matrix is less than 30μs. The power consumption of each switch element is about 330mW.

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SOI 热光 4×4 光开关阵列的研制*

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摘要: 设计和制作了由 5 个 2×2 多模干涉马赫-曾德开关元组成的重排无阻塞型 SOI 4×4 热光开关阵列. 阵列的最小和最大附加损耗分别为 6.6 和 10.4dB, 阵列的串扰为 -12 ~ -19.8dB, 光开关阵列的开关速度小于 30μs, 单个开关元的功耗大约为 330mW.

关键词: 集成光学; 马赫-曾德干涉仪; 开关阵列; 光开关

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