SOI Optical Switch Matrix Integrated with Spot Size Converter (SSC) and Total Internal Reflection (TIR) Mirrors

Jinzhong Yu*, Shaowu Chen, Zhiyong Li, Yuanyuan Chen, Yuntao Li, Yanping Li, Jingwei Liu, Di Yang
State Key Laboratory on Integrated Optoelectronics
Institute of Semiconductors, Chinese Academy of Sciences
P. O. Box 912, Beijing 100083, CHINA

*E-mail: jzyu@red.semi.ac.cn; Tel: 86-10-8230 4503, Fax: 86-10-8230 5052

ABSTRACT

SOI (Silicon on Insulator) based photonic devices has attracted more and more attention in the recent years. Integration of SOI optical switch matrix with isolating grooves, total internal reflection (TIR) mirrors and spot size converter (SSC) was studied. A folding re-arrangeable non-blocking 4×4 optical switch matrix and a blocking 16×16 matrix with TIR mirrors and SSC were fabricated on SOI wafer. The performances, including extinction ratio and the crosstalk, are better than before. The insertion loss and the polarization dependent loss (PDL) at 1.55 µm increase slightly with longer device length, more bend and intersecting waveguides. The insertion losses decrease 2~3 dB when anti-reflection films are added in the ends of the devices. The rise and fall times of the devices are 2.1 µs and 2.3 µs, respectively.

Keywords: SOI, optical switch matrix, photodiodes, optical interconnection

1. INTRODUCTION

Si-based photonics has gotten considerable expansion and development. 10 GHz Si-based optical modulator [1] and pulsed stimulated emission from Si diode were successfully demonstrated [2]. By using epitaxy and binding techniques, SiGe/Si RCE photodiode (PD) with different structures such as MQWs (multi-quantum well) and MQDs (multi-quantum dot) has been studied [3]. A 1.55um Ge island RCE detector with the responsivity of 0.028 mA/W has been presented. The emphasis will played on our current results of SOI-based thermo-optic waveguide matrix switches. A study on integration between SOI optical switch matrix with isolating grooves, total internal reflection (TIR) mirrors and spot size converter (SSC) was presented in the paper.

2. DESIGN and FABRICATION of SOI OPTICAL SWITCH MATRIX

Both of thermo-optical and electro-optic switches were successfully made in our laboratory [4,5]. For 2×2 thermo-optical switch, extinction ratio of 12 dB, insert loss of 18 dB, consumption power of 190 mW and switch time of 10 µs were achieved. A rearrangeable nonblocking thermo-optic 4×4 switching matrix operating at 1.55 µm was also fabricated using SOI waveguide system. The matrix is composed of five 2×2 MMI (multimode interferometer)-MZI switch elements, which result in a smaller device size than the conventional crossbar and tree architecture. Based on accurate simulation tools, we designed and fabricated single mode rib waveguides, multimode interference couplers and optical matrix switches on SOI by both anisotropic wet etching and inductively coupled plasma (ICP) reactive ion etching (RIE).

2.1. Isolating grooves

As shown in Fig.1, the function of isolating grooves paralleling with waveguide in SOI device is keeping heat from lateral diffusion, decreasing power consumption and crosstalk, preventing coupling of different waveguides, etc. To
avoid such coupling, a deeply etched isolating groove is introduced to prevent the cross coupling between the two neighboring MZI arms, as shown in Fig.2. Those grooves vertical to waveguide are also deeply etched to prevent disperse light of the chip.

![Fig.1 The structure of switch element](image1)

![Fig.2 Cross-section of the phase-shifting arm](image2)

Comparison between characteristics of 8×8 blocking switch matrix with paralleling grooves and those without grooves shows that the crosstalk can be decreased from -17 ~ -14 dB to less than -18dB. Both of power consumption and response time are decreased. The response time at the rising and the falling edges are 4.6 µs and 1.9 µs. The power consumption of the switch cell with grooves is about 200mw.

2.2 Spot size converter (SSC)

Coupling light into and out of a silicon chip is very challenging due to the large mode mismatch between SOI single mode waveguides and standard fibres. One way to overcome the large differences in effective index, core size and symmetry is to use a tapered waveguide. The results using a pseudo-vertical taper structure, formed by selective single-crystal epitaxial silicon overgrowth, have given coupling losses as low as 0.5 dB/facet. In our device (Fig.3), the spot size converter structure is formed by ICP-RIE for two times, and it has a uniform height but varying width. For perfect alignment the calculated coupling loss of the SSC is approximately 0.44 dB. Measurement result shows the loss of the SSC is 1.81dB, including transmission loss, coupling loss and reflection loss.

![Fig.3 The schematic diagram of Spot size converter](image3)

![Fig.4 SEM image of TIR mirror](image4)

SOI thermo-optical matrix switches, integrated with SSCs in input and output ports, are fabricated. For 4×4 rearranged non-blocking switch array, the insertion loss and PDL are less than 10 dB and 1dB, respectively. The extinction ratio is large than 18 dB. While as to 8×8 blocking switch array, the insertion loss and PDL are less than 14 dB and 2 dB, respectively. The crosstalk is less than -18 dB and the extinction ratio is close to 20 dB or larger.

2.3 Performance of S-shaped bend waveguide and reflection mirrors

To overcome the disadvantages of conventional structure, we fabricated a novel folding matrix optical switch in which switch elements are connected by TIR mirrors instead of S-bends. The scattering derived from rough mirror surfaces is the greatest factor in excess loss of mirrors. So wet etching is usually employed to fabricate very smooth mirror surfaces. The SEM image of TIR mirror is shown in Fig.4. The roughness of mirror facet testified from AFM is ~1.49 nm.
3. 16×16 SOI OPTICAL SWITCH MATRIX

Among topological structures for matrix switches, the blocking matrix needs the least number of cells. A blocking 16×16 optical switch matrix with 4.5 cm long and 2.15 mm wide is made by ICP-RIE, which is composed of 32 switch units through 4-stage interconnections. The fabrication difficulty of these switches is reduced because the number of switch cells is much smaller than that of the non-blocking matrix. The length of each 2×2 switch unit is 0.6 cm and the width is only 120 µm. The isolating and blocking grooves are also used in the optical matrix switches. In order to enhance the coupling efficiency between the single mode fiber and input waveguide, the thickness of the top silicon layer is selected as 8 µm and the spot size converter in the input and output ports is designed as described in preceding text. The last results of our experiments show that the insertion loss measured is 21.7~27.1dB and the crosstalk is –12.6 ~ -33.2 dB. The extinction ratio is 13.8 ~ 22.3 dB and the power consumption is about 200mW. The matrix also shows characteristics of fast response with rise time and fall time, 2.1 µs and 2.3 µs respectively. This is also the largest scale SOI blocking optical switch matrix that has been reported.

4. CONCLUSION

The research on SOI optical waveguide device has been a focus in recent years. Based on accurate simulation tools, we designed and fabricated single mode rib waveguides, MMI couplers and optical matrix switches on SOI by both wet etching and dry etching. Integration of SOI optical switch matrix with isolating grooves, total internal reflection (TIR) mirrors and spot size converter (SSC) was studied. By advanced process technology and higher quality SOI wafer, we would obtain improving performance of these devices. Great progresses of SOI based photonic devices made in the past two years were exciting and promising greatly. As men are foreseeing, SOI based photonics will be key elements of the optical information processing.

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