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Fabrication and analysis of 2 × 2 thermo-optic SOI waveguide switch with low power consumption and fast response by anisotropy chemical etching

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Abstract

A low power consumption 2 × 2 thermo-optic switch with fast response was fabricated on silicon-on-insulator by anisotropy chemical etching. Blocking trenches were etched on both sides of the phase-shifting arms to shorten device length and reduce power consumption. Thin top cladding layer was grown to reduce power consumption and switching time. The device showed good characteristics, including a low switching power of 145 mW and a fast switching speed of 8 ± 1 μs, respectively. Two-dimensional finite element method was applied to simulate temperature field in the phase-shifting arm instead of conventional one-dimensional method. According to the simulated result, a new two-dimensional index distribution of phase-shifting arm was determined. Consequently finite-difference beam propagation method was employed to simulate the light propagation in the switch, and calculate the power consumption as well as the switching speed. The experimental results were in good agreement with the theoretical estimations.

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Keywords: Thermo-optic switch; Silicon-on-insulator; Anisotropy chemical etching; Finite-element method; Finite-difference beam propagation; Switching time; Power consumption

1. Introduction

Optical switch is one of the key devices for optical communication systems. It plays an important role in the applications including optical cross connection (OXC) and optical add-drop multiplexing

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(OADM) systems [1]. Planar waveguides technologies, based on silica-on-silicon [2–4] and silicon-on-insulator, are very popularly employed for optical switching application, and some switches with small port count have been fabricated [5–8].

A 2 × 2 MZ optical waveguide switch often consists of two paired couplers (i.e. multi-mode-interference (MMI) couplers or directional interference couplers) joined by two phase-shifting arms. The couplers act as 3 dB splitter and combiner. With silicon, there are two possible choices for phase-shifting: thermo-optical (TO) effect and free carriers (FC) dispersion effect. The FC effect requires high free carrier injection to reduce index significantly [9]. Unfortunately, such high current density contributes to rising of temperature that will increase the refractive index. Therefore, the effect of carrier injection will be weakened seriously. Additionally, the free carriers inevitably induce considerable absorption loss. Therefore, a good choice for phase-shifting is TO effect since silicon has high thermo-optical coefficient and thermal conductivity.

Fischer et al. [6] have fabricated 2 × 2 thermo-optical switch, which showed an 85 mW switching power, but no results about the switching speed were reported. In 2003, House et al. [5] realized high speed 2 × 2 thermo-optical switch with a 10-μs switching time, but the device showed a high switching power of 440 mW. In order to get smoother interface, we fabricated 2 × 2 thermo-optic switch recently by anisotropy chemical etching in stead of conventional dry-etching [8]. However, in the reported device, switching speed is rather low (about 60 μs) [8].

Furthermore, it is important to picture temperature field in the phase-shifting arm accurately. A one-dimensional (1D) method can be used to estimate the temperature simply [10]. But the SOI waveguide often has a large area rib-shape cross-section in order to achieve a high coupling efficiency. On the other hand, the waveguide will have a trapezoidal cross-section instead of a regular rectangular one if the wet etching method is adopted. Then, the 1D method is not suitable for describing the temperature field and determining switching speed as well as power consumption accurately.

In this paper, a 2 × 2 thermo-optic switch with MMI couplers was fabricated on SOI wafer. A bonding and back-etching SOI (BE-SOI) wafer with a 5-μm top silicon layer and a 1-μm buried silicon oxide was used here. Anisotropy chemical etching was used similar with [8]. Blocking trenches were etched near the phase-shifting arms to shorten the device length and reduce the power consumption. A top cladding layer is thin enough to reduce power consumption and switching time. The device achieved good characteristics including the low switching power of 145 mW and the fast switching speed measured to be about 8 ± 1 μs. These values are much better than our former results [8].

Two-dimensional finite element method (2D-FEM) has been chosen for temperature field simulation to overcome the drawbacks of the previous 1D method. According to this temperature field, a new 2D index distribution of the phase-shifting arm was obtained, and then, finite-difference beam propagation method (FD-BPM) was used to simulate its light propagation. Meanwhile, the power consumption and the switching speed were determined.

2. Design

Fig. 1 shows a structure of the proposed 2 × 2 TO-MZ switch with MMI splitter and combiner. It consists of four input/output ports with S-bend connectors, two MMIs, two straight phase-shifting arms, two heaters, and some blocking trenches. Considering single-mode condition for SOI rib waveguide with trapezoidal cross-section [11], the

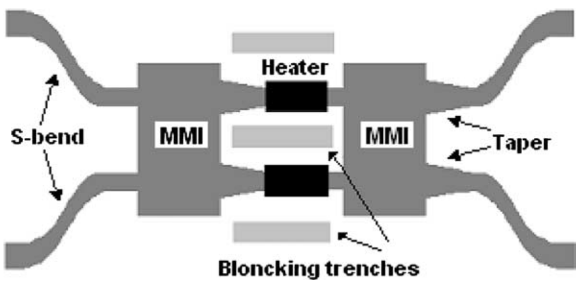

Fig. 1. Schematic structure of the 2 × 2 TO MZ-MMI switch.