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Photonic crystal thermo-optic switch

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1. Introduction

The optic switch is one of the most indispensable devices used in optical network systems, particularly in future photonic network systems, where the development of compact, cross-connect, optic switches is urgently required. Therefore, we studied photonic-crystal (PhC) slab-based thermo-optic switches, whose size could be drastically reduced due to the slow group velocity of light-waves in the PhC waveguide. According to our calculations, device length could be shortened more than one order of magnitude, compared with conventional lithium niobite (LN) or semiconductor-based optical switches[1,2]. Quite recently, Camargo et al. reported a thermo-optic switch with 12-μm-long AlGaAs/GaAs-based PhC slab waveguides[3]. However, the Si-PhC slab-based optic switch is much more attractive, if we consider the future integration of electric and optical devices on the one Si chip.

In this paper, we present an optical switch with a Si based 2D-PhC slab, and discuss its switching operation. The device structure, the fabrication process, and the measurement results are also reported.

2. Structure and Fabrication

The PC optical switch was fabricated by using a SOI wafer with a 0.25-μm-thick top Si layer and a 1-μm-thick embedded SiO_2 layer on a Si substrate. The top Si layer was patterned to form the switch device. Figure 1 outlines the structure of the Mach-Zehnder (MZ) interferometer-type optical switch we fabricated. Two 2D-PhC slab line-defect waveguides were connected to two branches of the Y-splitters made of Si-wire waveguides. The PhC waveguides were 80 μm long, and the total device area was 800 x 220 μm. The length was about one order of magnitude shorter than conventional optical switches[4,5]. The 2D-PhC slab structure was based on a hexagonal lattice of air holes; the lattice constant of the PhC was 0.45 μm, and the air-hole diameter was 0.26 μm. The Si-wire waveguide was formed with a width of 0.48 μm on the same SOI wafer.

The fabrication process was carried out as follows. First, the top Si layer of the SOI wafer was patterned with electronic beam lithography. Then, the Si layer was etched down to the SiO_2 layer with an inductively coupled plasma (ICP) dry etcher. Next, the PhC and Si-wire waveguide pattern formed in the top Si layer were embedded with a 0.6-μm-thick SiO_2 layer. Finally, a metal thin-film heater with two gold electrode pads was sputtered on the PC waveguide of a branch of the MZ interferometer. The micro-heater can create temperature difference of 0~90 ^{o}C between the two PC waveguides, and partially changes the refractive index of the PC waveguide through the thermo-optic effect. This creates phase shift in the light wave propagating through the PhC waveguide of one branch of the MZ interferometer, achieving optical switching. Figure 2 shows a microscopic view of the optical switch we fabricated.

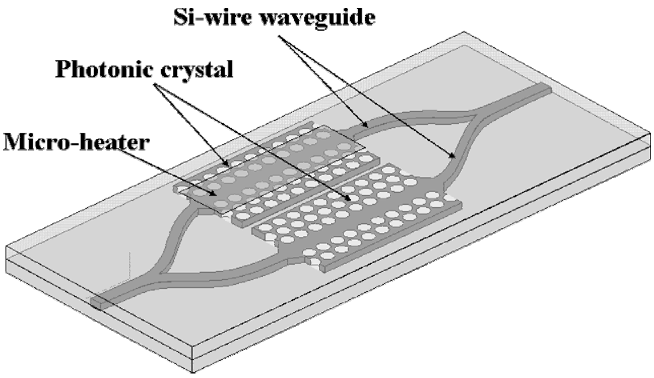


Fig. 1, Structure of fabricated PhC optical switch.

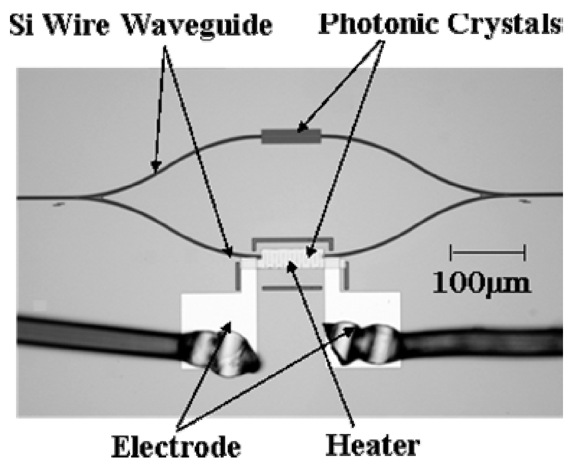


Fig. 2, Microscopic view of fabricated PhC optical switch.

3. Measurements

The optical characteristics of the optical switch we fabricated were measured by optically coupling tapered optic fibers to the input and output port of the switch. A TE-polarized (electric vector parallel to the substrate) 1580-nm-wavelength laser beam was introduced into the input facet of the Si-wire waveguide of the switch for the measurement. The light output from the other end facet of the Si-wire waveguide of the switch was measured. A DC-power supply was used to turn the current to the micro-heater.

First, the output power was measured while increasing the heating current (power). Figure 3 plots the switching characteristics. Below a heating power of 80 mW, the light output power slightly increased with increased heating, and it decreased with increased heating above 80 mW. The output power had a minimum value at a heating power of 200 mW, and increased again by increasing the heating power above 200 mW. Therefore, the heating power needed for switching was about 120 mW, and the maximum extinction ratio obtained was 22dB.

We also measured the switching speed of the optical switch with a pulse current source. Figure 4 plots the time response for the output power while the heating current was turned ON and OFF. The light output power was rapidly decreased and increased by turning the heating current on and off. The estimated switching speed was less than 200 μs. This means that the switch can be used as a burst switch in photonic network systems.

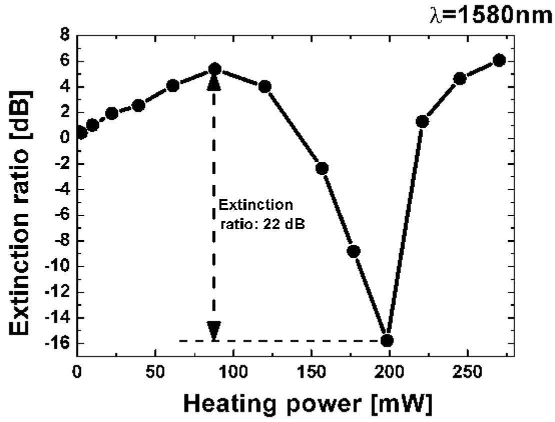
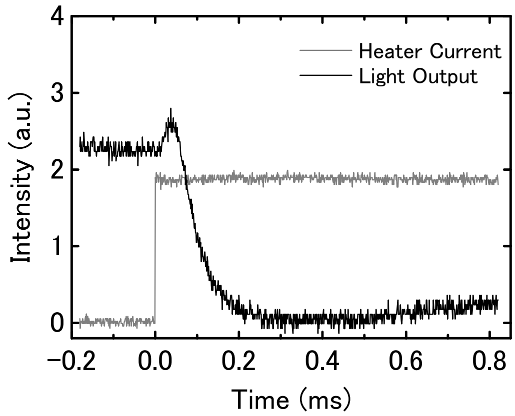
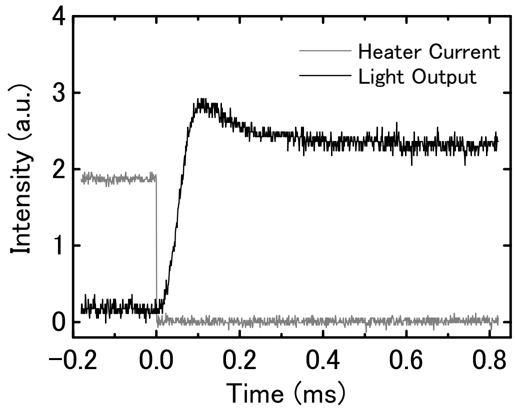


Fig. 3 The switching characteristics of PC optical switch.



(a) Time response for heating current ON



(b) Time response for heating current OFF

Fig. 4 Time response characteristics of PhC optical switch.

4. Conclusions

We fabricated a thermo-optic switch in silica buried Si photonic-crystal slabs with a hexagonal lattice of air holes. Switching operation was demonstrated by heating the micro-heater formed on the switch. The maximum extinction ratio was 22 dB, and the switching speed reached 200 μs. Further improvements in device performances (throught reduced switching power and shorter device) are expected by optimizing the device structure, such as the micro-heater and PhC structures.

Acknowledgements

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