Extremely low power consumption thermooptic switch (0.6 mW) with suspended ridge and silicon-silica hybrid waveguide structures

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Abstract

We demonstrated an extremely low power consumption thermooptic switch using suspended ridge and silicon-silica hybrid waveguide structures. The switching power was successfully reduced to only 0.6 mW.

Introduction

Silica based thermooptic (TO) switches based on planar lightwave circuits (PLCs) are key devices for constructing various large-scale switches [1] for reconfigurable add/drop multiplexing (ROADM) and optical crossconnect (OXC) systems. Since several tens to several hundreds of switch elements are integrated in these large-scale switches, there is an urgent need to reduce the switching power. Several approaches to the design of low power consumption switches have been reported [1-4], and these can be classified in terms of two strategies. The First employs a heat insulated structure that improves the efficiency of the waveguide core heating by suppressing undesirable heat diffusion [1, 2]. The second uses waveguide materials with a large TO coefficient such as silicon and polymer [3, 4]. We have mainly focused on the low power consumption structure, and successfully reduced the power consumption of a silica-based switch to about 20 mW by employing a suspended ridge structure [1]. To reduce the power to sub-milliwatt level we must employ a waveguide material with a larger TO coefficient.

In this paper, we report a TO switch with an extremely low power consumption that uses a hybrid suspended ridge and silicon-silica waveguide structure. By utilizing the large TO coefficient of silicon, which is 20 times greater than that of silica glass, we achieved a record low switching power of 0.6 mW for a Mach-Zehnder interferometer (MZI) type TO switch.

Configuration and fabrication

The configuration of the proposed low power consumption switch is shown schematically in Fig. 1. Figure 1(a) shows the top view and (b) shows a cross-sectional view along line A-A’ in (a). The switch consists of an MZI with two 3-dB directional couplers (DCs) and thin film heaters on the surface of the waveguide arms. This switch has a low power consumption structure, called a suspended ridge structure [1, 2]. Heat insulating grooves are formed beside the two waveguide arms to suppress heat diffusion in the lateral direction. The heat flow to the

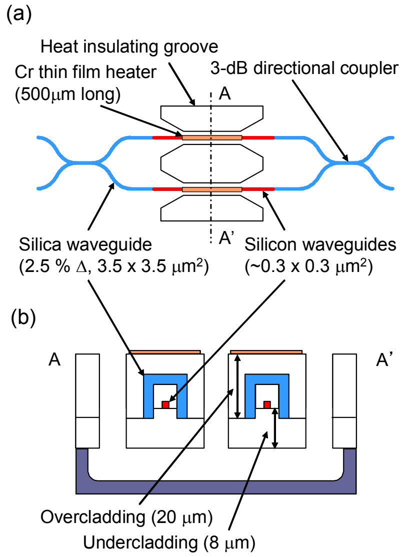

Figure 1: Schematic structure of proposed low power consumption switch: (a) Top view, (b) cross-sectional view along line A-A’ in (a).

silicon substrate is also suppressed by suspending the waveguide ridges above the substrate. The channel waveguides including two couplers are formed by using silica waveguides with a refractive index difference (Δ) of 2.5 % and a core size of 3.5 x 3.5 μm^2. The silicon wire waveguides are embedded only in the waveguide arms. Since the propagation loss of a silica waveguide is much smaller than that of a silicon waveguide, we minimize the silicon waveguide length to suppress the insertion loss increase. Both ends of the silicon waveguides are tapered to reduce the mode field conversion loss between the silicon and silica waveguides. The overcladding and undercladding thicknesses are 20 and 8 μm, respectively. The waveguide ridge is 6 μm wide.

The proposed switch is fabricated as follows. We used a silicon-on-insulator (SOI) wafer with a 0.8 μm thick silicon top layer and an 8 μm thick buried silicon-dioxide layer as a substrate. First, 1.3 μm wide silicon waveguide patterns were formed by a combination of photolithography and reactive ion etching (RIE). With this RIE process, the buried

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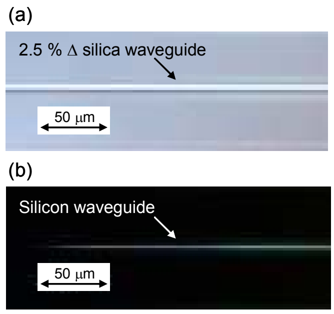

Figure 2: Photographs of the fabricated silicon-silica hybrid waveguide: (a) bright-field view and (b) dark-field view images.

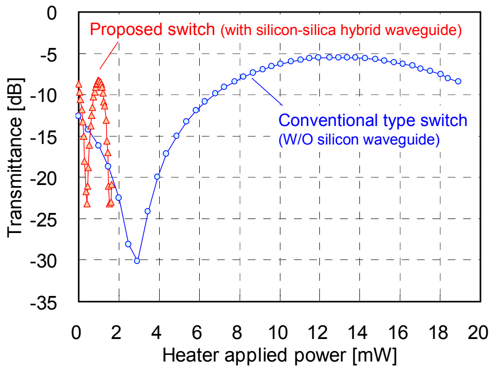

Figure 3: Switching characteristics of the proposed and conventional switches for TE polarization.

layer is also etched simultaneously to match the vertical positions of the silicon and silica waveguides. Then, the top and side surfaces of the silicon patterns that were about 0.5 μm thick were oxidized in a thermal oxidation furnace, thus forming silicon wire waveguides with a core size of about 0.3 x 0.3 μm^2. Next, the embedded silica waveguides and Cr thin film heaters were fabricated on the wafer by using the conventional PLC switch fabrication process. Finally, the cladding glass beside the waveguide arms and the silicon under the waveguide ridges were removed by highly directional and isotropic dry etchings, respectively.

Figure 2(a) and (b), respectively, show bright- and dark-field view photographs of the fabricated silicon-silica hybrid waveguide. The silicon waveguide is embedded in the center of the silica waveguide and is smoothly tapered.

Experimental results and discussion

We fabricated two switches: one was our proposed switch and the other was a conventional switch without silicon waveguide arms. Figure 3 shows the measured switching characteristics of both switches for TE polarization. The switching powers of the proposed and conventional switches were 0.6 and 10.3 mW, respectively. The power consumption was greatly reduced to about 1/18 of its former value by using the silicon-silica hybrid waveguides. We also measured the switching characteristics for TM

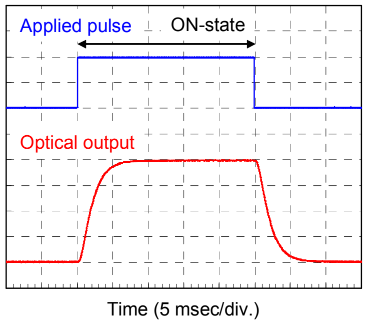

Figure 4: Step pulse response of the proposed low power consumption switch. Applied step pulse (top line) and optical output power (bottom line).

polarization. We confirmed good switching characteristics with an extinction ratio of about 15 dB for both polarizations. An insertion loss of about 8.4 dB and a polarization dependent loss of about 0.3 dB were obtained in the ON-state. This insertion loss value includes the coupling loss between a single-mode fiber and a 2.5 % Δ silica waveguide of 3.8 dB (= 1.9 dB/facet x 2 facets) and the MZI excess loss caused by the DC's splitting ratio error of 1.8 dB. The latter can be eliminated easily by design optimization. The excess loss caused by the silicon-silica hybrid waveguide was about 2.8 dB, which is the difference between the insertion losses of the proposed and conventional switches. The excess loss budget is roughly estimated to be the propagation loss of the silicon waveguide of about 2 dB and the connection loss of two silicon-silica waveguide joints of about 1 dB. The measured step pulse response of the proposed switch is shown in Fig. 4. Both rise and fall times (10% - 90%) are 3.6 msec, which is sufficiently short for optical path switching applications.

Conclusion

We proposed and demonstrated a novel thermooptic switch with extremely low power consumption that employs suspended ridge and silicon-silica hybrid waveguide structures. With the fabricated switch, the switching power is greatly reduced to only 0.6 mW. This value is about 1/20 and 1/200 those of a previously developed low power consumption TO switch [1] and a commercially available TO switch, respectively.

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