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Low Switching Power Silica-Based Super High Delta Thermo-Optic Switch with Heat Insulating Grooves

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1. Introduction

The recent rapid progress made on multimedia communication systems has created a demand for much greater traffic capacity in the network. This requires the construction of a photonic network based on wavelength division multiplexing (WDM) technologies. Optical signal processing is essential to these technologies for providing a large throughput at such network nodes as optical cross connect (OXC), and optical add-drop multiplexing (OADM) systems. Optical switches are key devices in these systems.

We have developed a silica-based thermo-optic switch (TOSW) using planar lightwave circuit (PLC) technology [1]. The silica-based PLC has many advantages including low loss, long-term stability, the capacity for high density integration, and ease of fiber matching. Our 2x2 TOSW with a Mach-Zehnder interferometer (MZI) configuration operates by employing the TO effect, and 2x2 switches integrated on a large scale constitute our 1xN or NxN matrix TOSWs. We have realized 1x32 and 16x16 matrix switches using conventional high delta (HΔ) waveguides with a refractive index contrast between their core and cladding (Δ) of 0.75%. The increase in the number of wavelength channels in WDM systems means that large scale and more compact switches are required. We can use the super high delta (SHΔ; Δ=1.5%) waveguide [2], which allows a smaller waveguide bending radius, for larger scale switches without the need for a larger wafer. With large scale switches we have to consider the increase in the driving power. A conventional 2x2 TOSW needs about 450 mW for switching, and this gives a driving power of 14 W for a 16x16 matrix switch. With larger scale switches there will be problems related to radiating heat in practical systems. To overcome these problems we have studied ways of reducing the switching power of the 2x2 TOSW. We have already achieved a switching power of as low as 90 mW using a Si trench structure and heat insulating grooves with a HΔ waveguide [3]. As regards the SHΔ waveguide, which is useful for high density integration, the conditions for realizing low switching power have not yet been optimized.

This paper reports our application of heat insulating grooves to a SHΔ 2x2 TOSW. We achieved a switching power of 45 mW even without Si trenches. We also describe the optical characteristics of this switch.

2. Configuration & Simulation

Figure 1 shows the schematic configuration of our 2x2 TOSW. This switch consists of an MZI based on silica waveguides, heat insulating grooves, and thin film heaters as phase shifters. The MZI has two 3-dB directional couplers and two equal length arms. The waveguide structure is shown in Fig. 1 (b). The heat insulating grooves are etched into the Si substrate and arranged symmetrically with respect to the MZI arms.

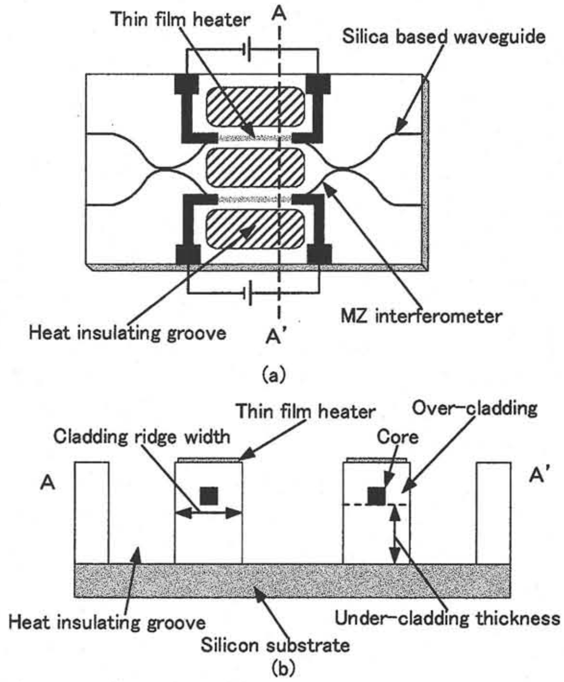

Fig. 1 Configuration of low power consumption SHΔ 2x2 TOSW with heat insulating grooves. (a) Top view. (b) Cross-sectional view along line A-A'

The switching power and the response time depend on the under-cladding thickness and the cladding ridge width. Initially, we set these two parameters based on our theoretical analysis. We carried out a thermal analysis of the waveguide structure with heat insulating grooves using the finite element method. We fixed one parameter while analyzing the other parameter at a cladding ridge width of 40 μm and an under-cladding thickness of 50 μm. The calculation results are shown in Figure 2. As the under-cladding becomes thicker, the switching power becomes lower, however, the response time becomes slower. By contrast, with the narrower cladding ridge width, the switching power becomes lower without large changes in response time. Therefore, a narrow cladding ridge is much

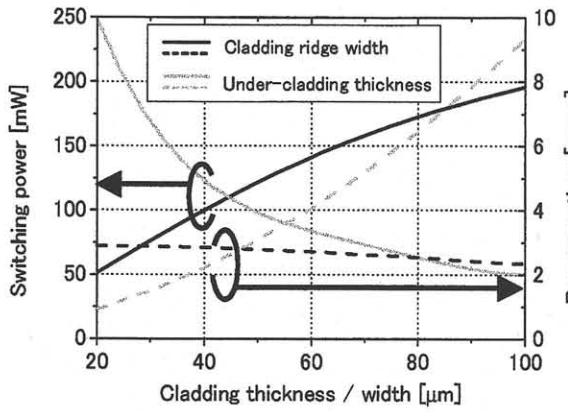

Fig. 2 Theoretical simulations of switching power and response time dependence on under-cladding thickness and cladding ridge width.

more effective in reducing the switching power and maintaining a conventional response time than a thick under-cladding. The SHΔ waveguide has an advantage in that it allows us to reduce the cladding thickness because the spot size in SHΔ waveguides is smaller than that in HΔ waveguides. With the SHΔ waveguides, we assumed the cladding ridge to be reduced to 20 µm and expected that the switch described in this paper could achieve a very low switching power of 50 mW as shown in Fig. 2.

3. Switching experiment

We fabricated our SHΔ 2x2 TOSW with heat insulating grooves as follows. First we fabricated the switch waveguides using a combination of flame hydrolysis deposition and reactive ion etching (RIE) with a SiO_2 cladding and a GeO_2-SiO_2 core. Then we patterned the PLC surface with thin film heaters and Au electrical wires. The core size was 4.5x4.5 μm^2 and Δ was 1.5 %. Finally, we again used RIE to form the heat insulating grooves. We also fabricated plain switches without heat insulating grooves as a reference. We set the under-cladding thickness at 20 to 50 µm, and the cladding ridge width at 20 to 60 µm.

Figure 3 shows the dependence of the experimental switching powers on the cladding ridge width and the under-cladding thickness. The open plots show data for the plain switches. The solid lines are theoretical curves based on the calculations described in section 2. The switching power decreases as the cladding ridge becomes narrower and under-cladding becomes thicker. We achieved a very low 45 mW switching power with an under-cladding thickness of 50 µm and a cladding ridge width of 20 µm. This is only 10 % that of a conventional TOSW, and agrees with the theoretical estimation. With this low power switch, the driving power of a 16x16 matrix switch can be as little as 1.4 W. Figure 4 shows that the insertion loss of this switch was 4 dB, including a single-mode fiber connecting loss of 3dB. This is the same as the plain switch even with a cladding ridge width of 20 µm. Therefore, we found the scattering loss of almost nothing through the use of this narrow cladding ridge width. The cross port extinction ratio

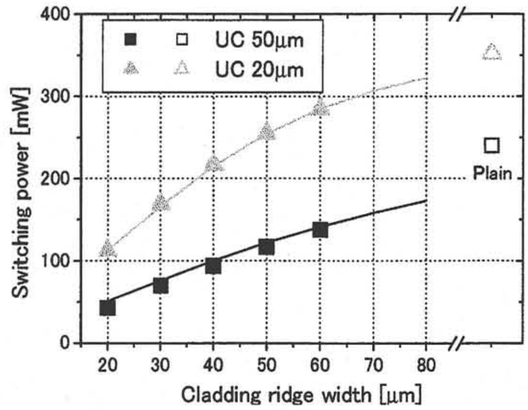

Fig. 3 Dependence of switching power characteristics on cladding ridge width. The plots are experimental values, and the solid lines are theoretical curves.

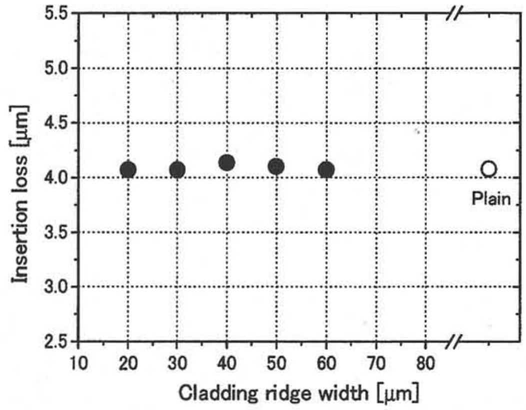

Fig. 4 Insertion loss dependence on cladding ridge width at an under-cladding thickness of 50 µm.

was 35 dB, and this ratio is as high as that of a plain switch. The response time of the grooved switch is about 3 msec (plain switch: 2 msec). This response is good enough for our switch to be employed in OXC or OADM systems.

4.Conclusion

We have successfully fabricated a silica-based SHΔ 2x2 TOSW with heat insulating grooves, and achieved a very low switching power of 45 mW. We also obtained characteristics, including insertion loss, extinction ratio, and response time, that were the same as those of a plain switch without grooves. This low power is very useful for high density integration, and simplifying the switch module configuration.

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