Fast Switching of 84 μs for Silica-based PLC Switch

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Abstract: We have reduced the switching time of a silica-based thermo-optic switch to 84 μs by utilizing a thin cladding layer and a novel driving techniques. The resultant high-speed switch should be suitable for intra-datacenter networks.

1. Introduction

Network traffic is growing continuously as the speed of processors increases, and this is causing a significant increase of network power consumption [1]. To resolve this problem, optical switches can play an important role, since their power consumption is very small. However, power reduction techniques utilizing optical switches are rarely applied to short-reach networks such as intra-datacenter networks because the switching time of switches in practical applications of telecom networks (such as the wavelength selective switch (WSS) and multicast switch (MCS)) is around the order of milliseconds, which is relatively long for use in intra-datacenter networks, where the traffic flow changes frequently. If we can find a way to utilize these techniques widely, their power reducing effects will be significant and they stand to be greatly promising for optical switch applications. So far, several approaches have been demonstrated to realize faster optical switching using Si photonics [2], lithium niobite [3], and so on. However, they have problems in polarization insensitization, insertion loss or scalability for practical use.

In this study, we have developed a technique that reduce the switching time of silica-based thermo-optic planar light wave circuit (PLC) switches to record-shortest 84 μs. The silica-based PLC switch utilized in various practical applications like MCS, matrix switch and variable optical attenuator, has the advantages of low loss, polarization independence, and high reliability [4]. By adding a new feature, namely, the short switching time, we can achieve a novel switching device suitable for intra-datacenter networks.

2. Approaches

The structure of a silica-based PLC device which is shown in Fig. 1(a) comprises an under cladding layer, a waveguide layer, and an over cladding layer of silica glass deposited in this order on a Si substrate. The configuration of the switching element is performed by a Mach-Zehnder interferometer in which thin film heaters are loaded just above the arm waveguides as shown in Fig. 1(b). The output ports of the element are switched by heating with the thin film heater so as to change the optical path length of the waveguide by $\lambda/2$ [4]. The switching time corresponds to the time required for the temperature of the waveguide layer to rise to a predetermined level and then to return from the heated state to the initial state. Therefore, shortening both the distance from the waveguide to the thin film heater and to the substrate is effective in terms of shortening the switching time, since the heat propagation distance of silica glass with low thermal conductivity is shortened. However, it is impossible to reduce the thickness of the cladding layer infinitely because the optical field in the waveguide is affected by silicon substrate and/or thin film heater, which results in propagation loss increase. In this study, we reduce the thickness of the cladding layer to 20 μm (10-μm under cladding and 10-μm over cladding) from standard 50 μm in order to both shorten the switching time and maintain the low loss property of less than 0.07 dB/cm and low polarization dependent loss of less than 0.01 dB/cm when the delta of the PLC is around 1.5% [4].

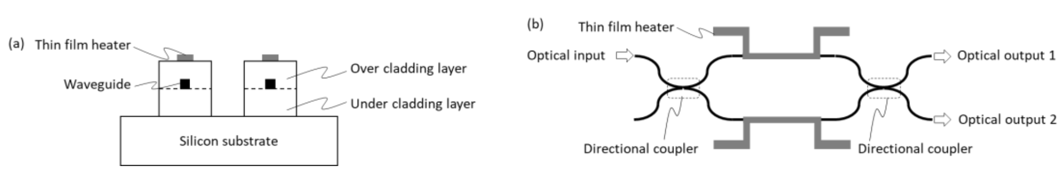

Fig 1. (a) Structure of a silica-based PLC device. (b) Configuration of a switching element.

The shortest recorded switching time with an 11-μm cladding layer is 180 μs [5], which suggests it seems impossible to achieve a switching time of less than 100 μs by simply reducing the thickness of the cladding layer. Therefore, in order to enable further shortening, we adapted a driving method that features the addition of an acceleration driving pulse to the head of the driving signal. Specifically, when the arm waveguide is heated to change the output port, a pulse of a high voltage (V_1) for a short time (T_1) is added to the initial stage of the driving signal of the thin film heater, and then the driving signal is shifted to a steady state voltage (V_2). When the arm waveguide is cooled to return to the original output port, the application of V_2 is stopped, and a pulse of a high voltage (V_1) for a short time (T_2) is applied to the other thin film heater to make the temperature of both arm waveguides the same. Thereafter, the temperature of both waveguides is cooled to the original temperature.

It is well known that the heat-insulating groove is effective for reducing the power consumption of a silica-based PLC switch. On the other hand, an existing report [6] in which a similar driving method was applied to a Si photonics switch argued that it is not always appropriate to utilize the revised driving method for a switch with heat-insulating grooves because the grooves prevent the cooling process and thereby increase the switching time. However, in the case of both changing and returning to the output port, our adapted method can shorten the switching time by heating the waveguide in a short time, and thus the existence of grooves preventing waveguide cooling should not affect the switching time. Moreover, since the heat generated by the thin film heater will be guided to the arm waveguides more efficiently by the heat-insulating groove, we expect the switching time to be even further reduced. Therefore, we added heat-insulating grooves in the fabricated prototype switch element as shown in Fig. 1(a). It should be noted that, because the cooling of the arm waveguide is prevented by the heat-insulating groove, the time required for returning to the initial temperature after the output port is returned to the original becomes long. In order to clarify this effect, the operation when the output port is changed again after the output port returns to the original and before the temperature of the waveguide returns to the initial temperature is also specifically verified.

3. Experiments

On the basis of the above approaches, we fabricated a Mach-Zehnder interferometer circuit with a 20-μm-thick cladding layer featuring a heat-insulating groove and then measured the switching time. Figures 2 and 3 show the observed waveforms when the switch is driven by the standard rectangular signal and by the revised signal utilizing a high-voltage pulse, respectively. Figure 2(a), (b) and Fig. 3(a), (b) show the optical output, and Fig. 2(c), (d) and Fig. 3 (c)–(f) show the driving signal. Figure 2(a), (c), and Fig. 3(a), (c), and (e) correspond to the timing of the change from OFF to ON, and Fig. 2(b), (d) and Fig. 3(b), (d), and (f) correspond to the timing of return from ON to OFF. In all graphs, control of changing or returning to the output port starts at the origin of the X-axis. When driven by a standard rectangular signal, the switching time was observed to be 351 μs while the optical output level changed from 10% to 90%, and was 290 μs while the optical output level changed from 90% to 10%. On the other

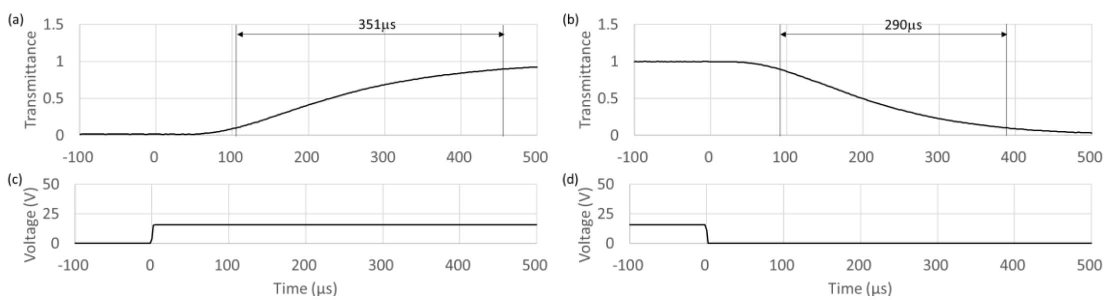

Fig. 2. Switching waveforms with standard driving. (a) Optical output changing from OFF to ON. (b) Optical output returning from ON to OFF. (c) Driving signal of (a). (d) Driving signal of (b).

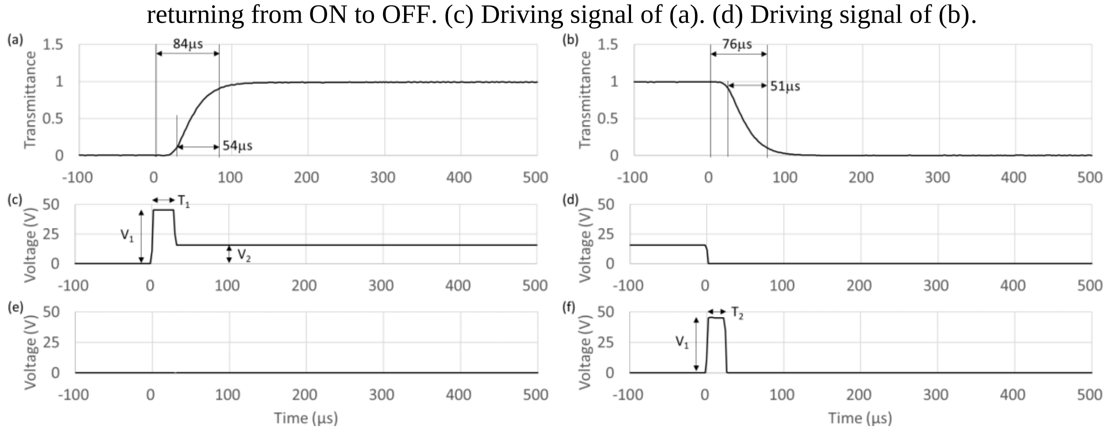

Fig. 3. Switching waveforms with revised driving. (a) Optical output changing from OFF to ON. (b) Optical output returning from ON to OFF. (c) 1st heater driving signal of (a). (d) 1st heater driving signal of (b). (e) 2nd heater driving signal of (a). (f) 2nd heater driving signal of (b).

hand, when driven by the proposed driving signal, it was shortened to 54 μs and 51 μs, respectively. In the above definition of switching time, the dead time from the start of the control to the start of the output signal change, that is, the time until the heat generated by the thin film heater propagated to the arm waveguide, is not considered. To compensate for this disadvantage, the required times to reach the optical output level of 90% or 10% from the start of control were observed. Results showed that 84 μs was required to reach 90% and 76 μs was required to reach 10%.

Next, we verified the operation when the output port was changed again after the output port returned to the original and before the temperature of the waveguide returned to the initial temperature. From Fig. 2(b), we can see that 500 μs or more is required to return to the initial temperature after the start of switch control. In the experiment, we investigated 300 μs corresponding to the first half of the cooling time. After 50–300 μs (increments of 50 μs) had elapsed from the start of the control to the return to the optical output port, the optical output port was controlled to change again. The driving signals applied to change the output ports at the first and second times were identical. Figure 4 shows the observed waveform of the optical output together with the waveform at the first output port change. In the graph, control of changing the output port starts at the origin of the X-axis.

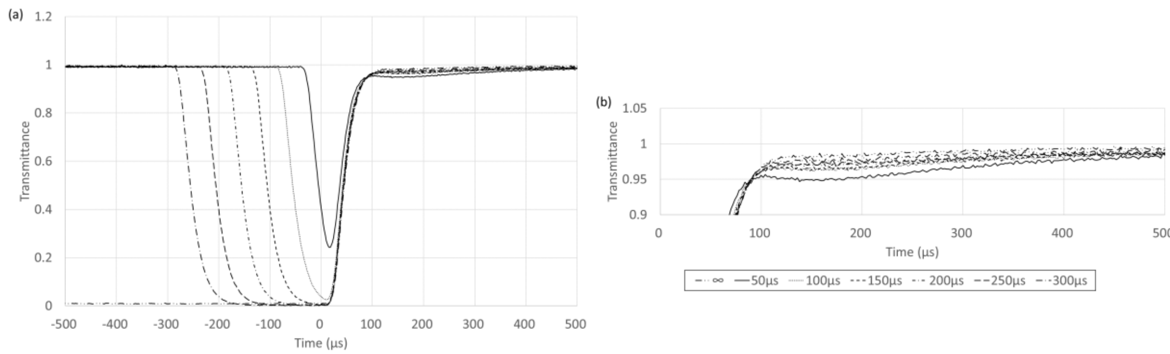

Fig. 4. Observed waveforms when the output port is changed before the temperature returns to the initial. (a) Overall view. (b) Enlarged view.

The waveform shown in Fig. 4 indicates that the optical output was stable if the change control of the output port was performed while the two arm waveguides were being cooled. The output waveform is substantially the same as that of the first change. Furthermore, in the case of the elapsed time of 50 μs and the arm waveguides being heated, the optical output was also stable and the output port also changed. However, as shown in the enlarged view of Fig. 4(b), the observed waveforms were slightly different and the optical output level stayed around 95% at 200 μs after the start of control in the case of 50 μs of elapsed time. Therefore, the interval between the control of return and re-change should be more than 100 μs so that the waveguide heating process can be completed and the optimal output waveform can be obtained. The reason such a small interval is sufficient for operation stems from the small temperature dependence of the thermo-optical constant of the silica-based optical waveguide over a wide temperature range.

4. Conclusion

In this study, we have experimentally shown that the switching time of a silica-based PLC switch using the thermo-optical effect can be dramatically reduced to record-shortest 84 μs. The key technical features for shortening the switching time are thinning of the cladding layer, a driving signal modification utilizing short- and high-voltage pulses, and the addition of a heat-insulating groove. None of these features significantly change the basic structure of the switch device. These results demonstrate the possibility of achieving a practical high-speed optical switch with a switching time of less than 100 μs while maintaining the low loss, polarization independence, and high reliability of the silica-based PLC device. We believe this high-speed switch will greatly expand the application area of optical switches to the intra-datacenter network and beyond.

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