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Compact optical switch using phase-change material for transparent photonic network

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ABSTRACT

We have fabricated optical switches using Si waveguides and phase-change material. The switch is based on an asymmetric Mach-Zehnder interferometer, and thin film $Ge_2Sb_2Te_5$ is deposited onto the Si waveguides. We observe the change in transmission spectra of the switch by laser pulse irradiations repeatedly. The phase change of the $Ge_2Sb_2Te_5$ film with only 1-μm-square is sufficient for π-phase shift and switching.

Key words: GeSbTe, Optical Switch, Si Waveguide

1. INTRODUCTION

Recently, with the rapid development of digital coherent technology, transmission capacity per single core of an optical fiber is greater than 100 Tbit/s. On the other hand, optical signal routing in an optical node has a bottle neck of electronic signal processing and switching performances. The use of optical technology may be a solution for such a problem. In particular, large-scale, low-power consumption optical switches will play an important role to realize high-throughput optical nodes. The application of phase change material (PCM) to optical switches is very attractive because the size of the switch can be very small due to the large refractive index difference of the crystalline state and the amorphous state, compared to the switch using other index control mechanism. Moreover, it has self-holding characteristics and energy efficient. Therefore, it is very suitable for an optical node in transparent photonic network.
The number of switches can be integrated and the switching times for various kinds of optical switches are shown in Fig. 1. The PCM switches potentially can be very large scale and operated at relatively high-speed; it will be one of the enabling technologies of fast reconfigurable optical network system.

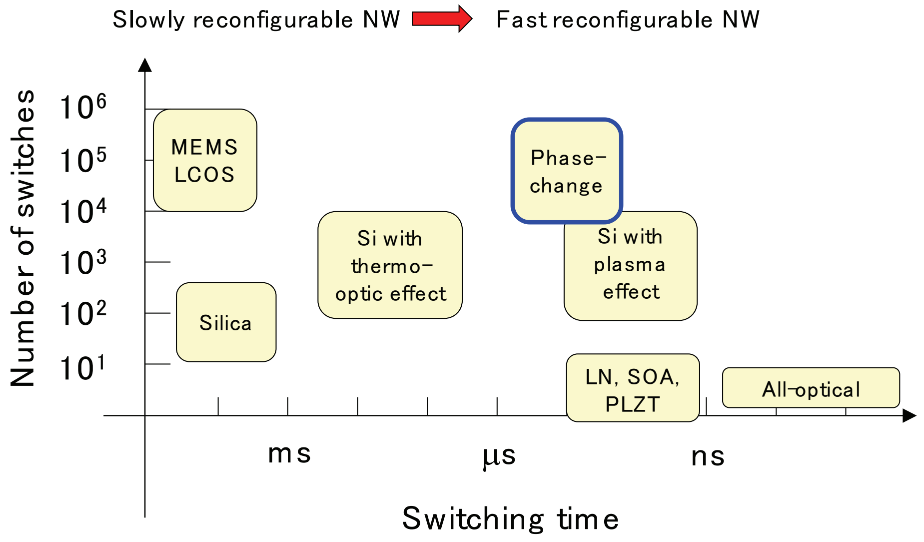

Fig. 1. Number of switches can be integrated and the switching times for various kinds of optical switches.

Previously, we had proposed optical switches using PCM [1-3], and showed optical gate operation [4-5]. They could be switched more than two thousand times [6].

In this paper, an optical switch based on asymmetric Mach-Zehnder interferometer [7] was fabricated and switching characteristics were measured.

2. DEVICE STRUCTURE

Figure 2(a) and 2(b) show the schematic structure of the optical switch and the enlarged structure of the switching region. The typical waveguide width was 0.45 µm, and the height was 0.21 µm, respectively. The optical switch is based on an asymmetric Mach-Zehnder interferometer (MZI) with an arm length difference, ΔL. The free spectral range (FSR) of the asymmetric MZI was about 4 nm, which was corresponding to ΔL of 150 µm. Multimode interference (MMI) couplers were used for splitting input light equally and combining lights propagating two arms. The switching region consisted of taper waveguides with a length of 100 µm, 5-µm straight waveguide, and two square patterns of the thin film $Ge_2Sb_2Te_5$ deposited on, as shown in Fig. 2(b). The thickness of $Ge_2Sb_2Te_5$ film was 30 nm.

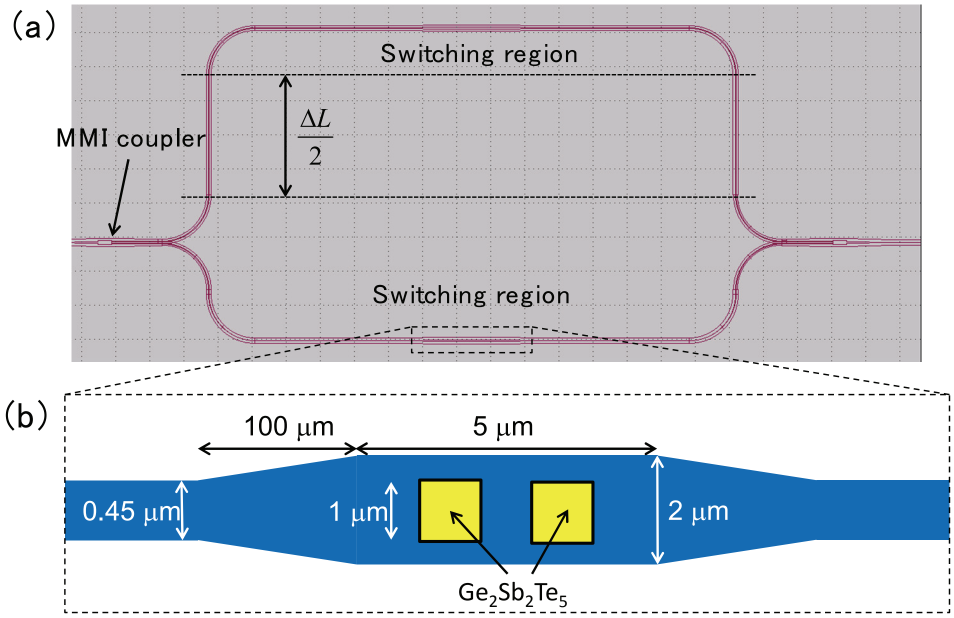

Fig. 2. Schematic structure of (a) optical switch and (b) enlarged structure of the switching region.

The fabrication process of the optical switch is as follows. A silicon-on-insulator (SOI) wafer with a top Si layer of 210 nm-thick was used for the substrate. The Si waveguides were formed in the top Si layer by reactive ion etching (RIE). A resist pattern for the thin $Ge_2Sb_2Te_5$ film was formed by EB lithography and $Ge_2Sb_2Te_5$ was deposited by sputtering. Then, square $Ge_2Sb_2Te_5$ patterns were formed by a lift-off process. Finally, a 2 µm-thick SiO_2 over-cladding layer was deposited by plasma-enhanced chemical vapor deposition (PCVD). The photos after patterning of the resist film to form $Ge_2Sb_2Te_5$ are shown in Fig. 3(a) and 3(b).

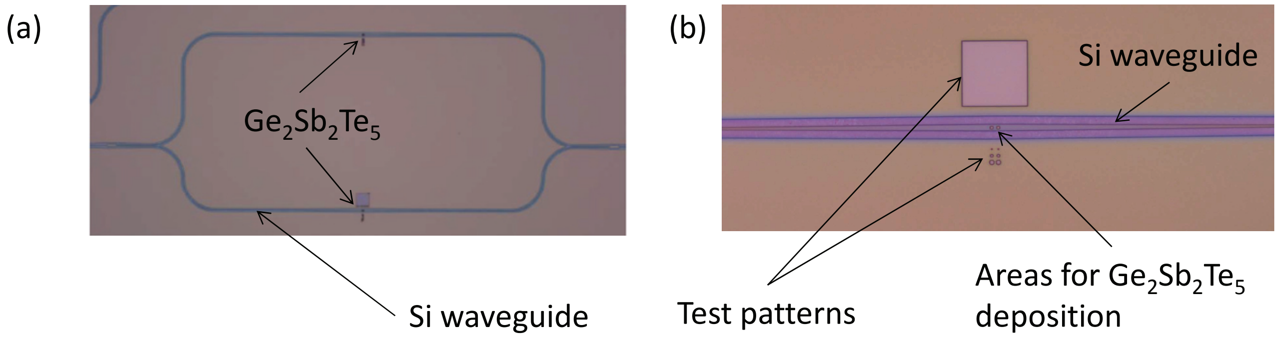

Fig. 3. (a) Photo after patterning of the resist film to form $Ge_2Sb_2Te_5$, and (b) enlarged photo near switching region.

3. EXPERIMENTAL RESULTS

The experimental setup is shown in Fig. 4. For optical switching operation, the laser diode (LD) with a lasing wavelength of 660 nm was directly modulated. Generated optical pulses were guided by single mode fiber (SMF) and focused on to $Ge_2Sb_2Te_5$ film with a spot-size of about 1 μm using a lens with a numerical aperture (NA) of 0.8. The transmittance of the optical switch was measured by scanning the lasing wavelength of the tunable laser source (TLS). The transverse electric (TE) mode of the light was used. We optimized the pulse conditions, and decided to use a pulse with a width of 400 ns and a peak power of 70 mW for crystallization, and a pulse with a width of 70 ns and a peak power of 160 mW for amorphization.

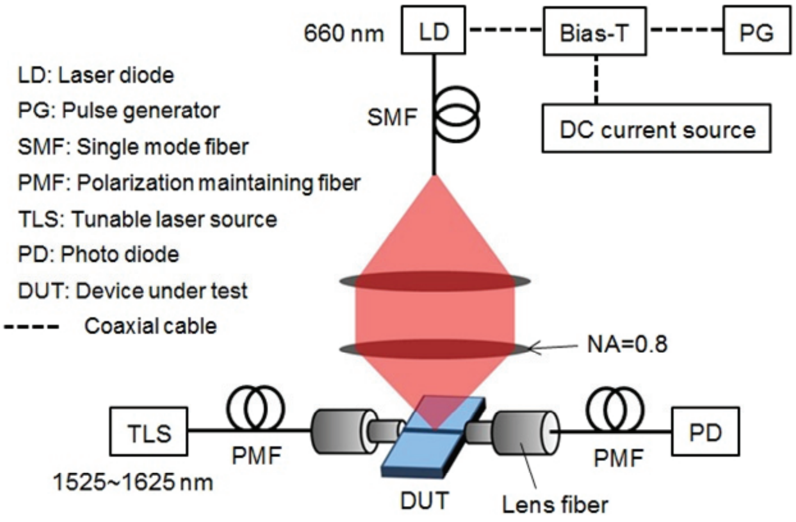

Fig. 4. Experimental setup for measuring optical switching characteristics.

Figure 5 shows transmission spectra when $Ge_2Sb_2Te_5$ films on both arms were crystalline (red curve); and when $Ge_2Sb_2Te_5$ films on the one-side arm were crystalline and $Ge_2Sb_2Te_5$ films on the other side arm were amorphous (blue curve). The interference peaks shifted by about a half of FSR. If the input light wavelength was tuned to one of the peak, the extinction ratio would be 15 dB.

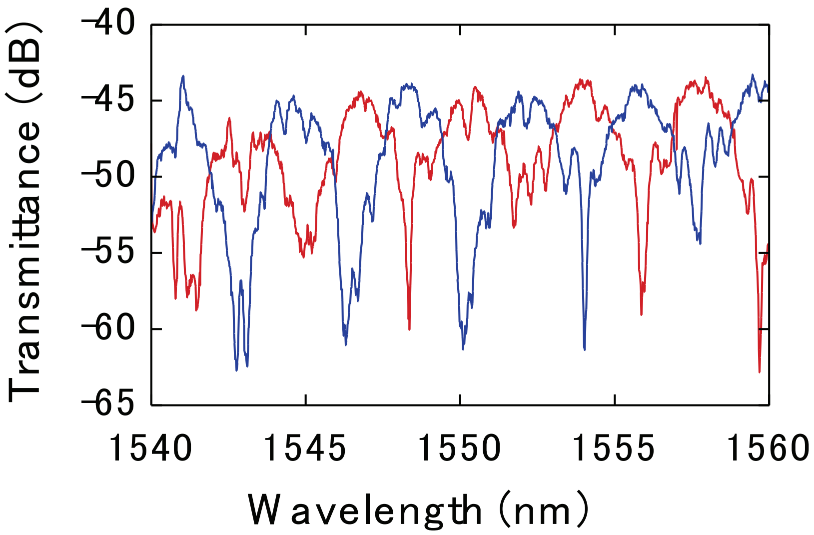

Fig. 5. Transmittance spectra change by controlling the phases of $Ge_2Sb_2Te_5$ films. Red curve; all of the $Ge_2Sb_2Te_5$ films were crystalline. Blue curve; $Ge_2Sb_2Te_5$ films on the one-side arm were crystalline and those on the other side arm were amorphous.

4. CONCLUSION

A small-sized optical switch using $Ge_2Sb_2Te_5$ thin films was designed and fabricated. Phase changes of two $Ge_2Sb_2Te_5$ thin films of 1-μm-square were sufficient for π phase shift and switching. The loss of the device was still high due to coupling losses from optical fibers and Si waveguides, and to large absorption in crystalline $Ge_2Sb_2Te_5$ thin films.

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