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Proposal of a small self-holding 2×2 optical switch using phase-change material

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Abstract: A small and fast self-holding 2×2 optical switch using phase change material is proposed. This switch is based on a directional coupler in which a short waveguide made of a phase-change material (PCM) is sandwiched between two Si waveguides. The characteristics of the proposed switch were simulated by a beam propagation method (BPM). This switch can be as small as $3\,\mu$m $\times$ $21\,\mu$m because the change in the refractive index of PCMs between the crystalline and amorphous states is very large; in addition, by utilizing the self-holding characteristics, it has the potential for low power consumption. The loss and the crosstalk were calculated to be 2.5 dB and −20.4 dB in the bar state and 1.3 dB and −14.3 dB in the cross state, respectively.

Keywords: optical switch, phase change material, optical waveguide

Classification: Photonics devices, circuits, and systems

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1 Introduction

Optical switches are of growing importance in network nodes for configuring optical add-drop multiplexers (OADMs) and optical cross connects (OXCs). Optical packet switching, which has the advantages of fast-operation and low-power consumption, is needed as an alternative to electrical packet switching. Here, we propose a 2×2 Mach-Zehnder type optical switch using a phase-change material (PCM), such as In-Ag-Sb-Te alloy or Ge-Sb-Te alloy, which are currently used in rewritable optical media such as DVD-RAM [1, 2]. The advantages of using PCM for optical switches are; (1) the size of the switch can be very compact because the change in the refractive index of PCMs between the crystalline and amorphous states is usually greater than 30%, and (2) the power consumption can be extremely low because power is consumed only when the state changes. Furthermore, the phase change transition time is less than 100 ns [3]. We can change the state of the PCM by injecting current as in phase change RAM (PRAM) or by laser light irradiation as in rewritable optical media. For the work reported in this paper, we proposed and designed a novel optical switch using a PCM based on silicon-wire waveguide technology.

2 Configuration of the Optical Switch

Figure 1 shows a schematic of the proposed switch. This consists of a directional coupler and a sandwiched PCM waveguide. W, L, and D are the core width and length of the PCM waveguide and the gap between the PCM and Si waveguides, respectively. The amorphous and crystalline states of the PCM waveguide correspond to the cross and bar operation of the switch, respectively. The principle of the switch is based on the mode coupling of three identical parallel waveguides [4]. During the cross state the light input to waveguide A couples to the PCM waveguide and then to waveguide B. The power transition ratio of the directional coupler depends on the difference between the propagation constants. Therefore, W has to be set to match the propagation constant of the PCM waveguide in the amorphous state to that of the Si waveguide. On the other hand, during bar operation the incident light does not couple to the PCM waveguide because the propagation constant of the PCM waveguide in the crystalline state is significantly different from the Si waveguides.

It is important that absorption in the amorphous structure is low in order to minimize loss. A very low absorption index, k, of less than 0.01 in the amorphous state, has been accomplished by alloying some amount of additional elements in $Ge_2Sb_2Te_5$ (GST-225) [5]. The k of less than 0.01 for the amorphous state is sufficient for realizing a low-loss switch. When the PCM is in the amorphous state, power transition between the Si and PCM waveguides occurs and the switch is in the cross state. Therefore, the light input to Port 1 is guided to Port B. On the contrary, the large absorption of the crystalline structure suppresses coupling between the Si and PCM waveguides and the switch is then in the bar state. The light input to Port

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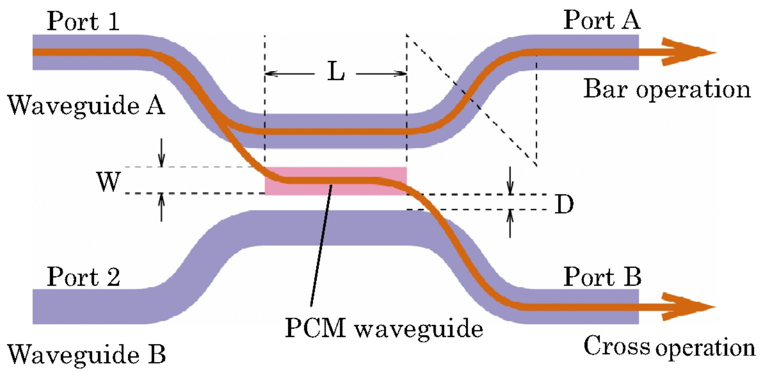

Fig. 1. Schematic of the proposed switch.

1 is guided to Port A.

3 Simulation of the Switching Characteristics

We simulated the characteristics of the switch using a two-dimensional (2D) beam propagation method (BPM). The switch was designed for TM light. It does not work with TE light because the difference of the effective refractive indices of high contrast waveguides for the TE and TM modes is large. The complex refractive indices of the silica cladding and the Si core were $1.45 + 0i$ and $3.45 + 0i$, and those of the amorphous and crystalline states of the PCM were $3.6 + 0.01i$ and $5.1 + 0.5i$, respectively [5]. The Si core size, W, L and D were assumed to be $0.3\,\mu\text{m} \times 0.3\,\mu\text{m}$, $0.224\,\mu\text{m}$, $9\,\mu\text{m}$ and $0.25\,\mu\text{m}$ respectively. The total size of the switch was only $3\,\mu\text{m} \times 21\,\mu\text{m}$. The light propagation in the bar and cross states is shown in Fig. 2 (a) and 2 (b), respectively. Figure 3 shows the wavelength dependences of the loss and crosstalk for both states. Loss of less than 2.5 dB and crosstalk of less than −20.4 dB in the bar state, and loss of less than 1.3 dB and crosstalk of less than −14.3 dB in the cross state for wavelengths between 1530 and 1565 nm were obtained.

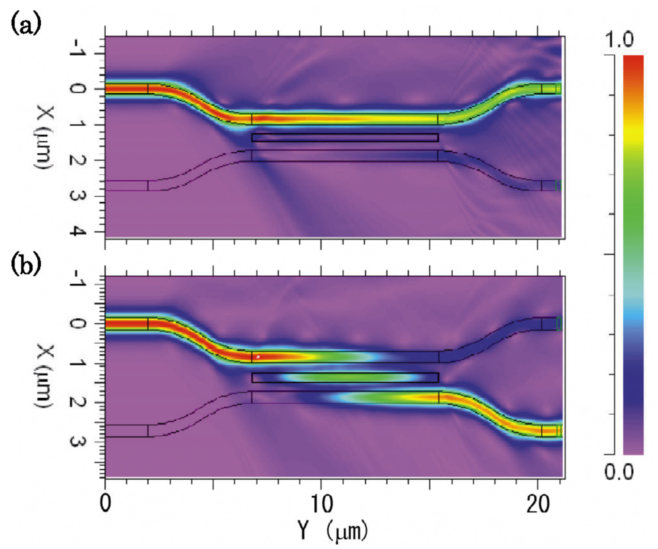

Fig. 2. Contour map of the electrical field in the bar state (a) and the cross state (b).

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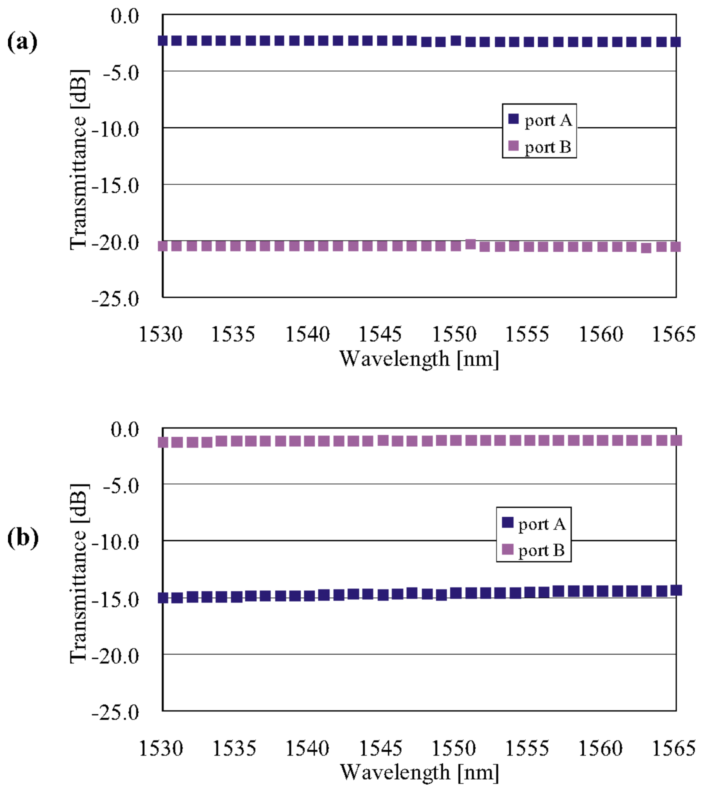

Fig. 3. The transmittance from Port 1 to Ports A and B in the bar state (a) and the cross state (b).

4 Conclusion

We proposed a novel 2×2 optical switch using a phase change material. The switch has self-holding characteristics; therefore, the power consumption may be very low for packet switching or burst switching applications. The size of the switch was just $3\,\mu\text{m} \times 21\,\mu\text{m}$. The loss and the crosstalk were simulated using 2D-BPM; for wavelengths from 1530 to 1565 nm, they were 2.5 dB and -20.4 dB for the bar state and 1.3 dB and -14.3 dB for the cross state, respectively.

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