Crosstalk-Enhanced DOS Integrated with Modified Radiation-Type Attenuators

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ABSTRACT—This letter presents a crosstalk-enhanced polymer thermo-optic digital optical switch operating at a low power consumption. Modified radiation-type attenuators are integrated in a series with a conventional 1 × 2 digital optical switch. A low optical crosstalk of less than -45 dB is attained at a low applied switching power of 60 mW, and an insertion loss of about 1.1 dB is exhibited.

Keywords—Polymer, thermo-optic, digital optical switch (DOS), attenuator, optical crosstalk, radiation, Y-branch.

I. Introduction

Optical switches have been considered an essential device for realizing reconfigurable optical add-drop multiplexing (ROADM) systems. There are various types of optical switches using the well-known thermo-optic or electro-optic effect which have the configurations of planar lightwave circuit devices such as the directional coupler [1], the Mach-Zehnder interferometer [2], the X-junction [3], or the Y-branch [4]-[7]. Among them, polymer-based Y-branch digital optical switches (DOSs) are preferable due to the low power consumption resulting from the large thermo-optic coefficient of polymer materials and due to the low dependence on polarization and wavelength compared to interference-type switches [6]-[8]. However, these DOSs generally have difficulty achieving low optical crosstalk in a conventional structure because of the poor fabrication tolerance due to their very narrow Y-branch angles (usually below 0.15°). The tolerance can be raised by using wide Y-branch angles, but the resulting crosstalk degradation needs to be compensated and further improved.

To overcome these problems and achieve an acceptable crosstalk level of less than -40 dB, several types of DOSs have been proposed [5]-[7]. A low crosstalk polymer DOS with radiation-type attenuators connected to both ends of the Y-branch arms of the conventional DOS was developed in [7], but the power consumption was rather high.

In this letter, we report on a new thermo-optic polymer DOS in which the optical crosstalk is enhanced at an identical power consumption as that of the DOS proposed in [7]. Our DOS is composed of the 1×2 conventional DOS and modified radiation-type attenuators connected to its arms. Especially for the reduction of the optical crosstalk, the tapered waveguides are used in the attenuators, and the heater electrodes are slightly shifted aside from the top center of the waveguides. The optical properties of our DOS are compared with those of the previous DOS [7] in which a tapered waveguide structure and heater shift were not applied.

II. Structure of Crosstalk-Enhanced DOS

Figure 1 shows a schematic configuration of our crosstalk-enhanced polymer thermo-optic DOS. Our DOS consists of a conventional 1×2 Y-branch DOS and modified radiation-type attenuators which are connected to the ends of the Y-branch arms. Heater electrodes for the thermo-optic switching operation are formed on the top surface of the upper-cladding of a waveguide as shown in Fig. 1. Generally, the attenuator-integrated DOSs (including the DOS proposed in [7]) operate in the following sequence of procedures. When a heater

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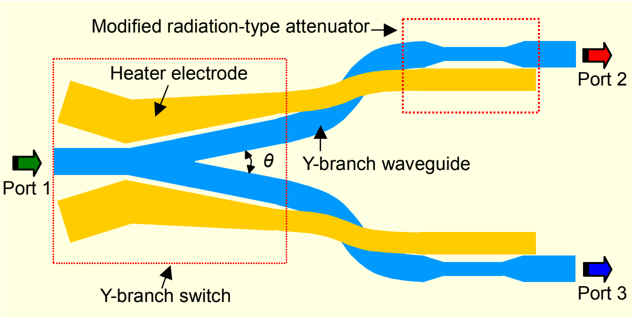

Fig. 1. Schematic configuration of our crosstalk-enhanced polymer thermo-optic DOS with modified radiation-type attenuators.

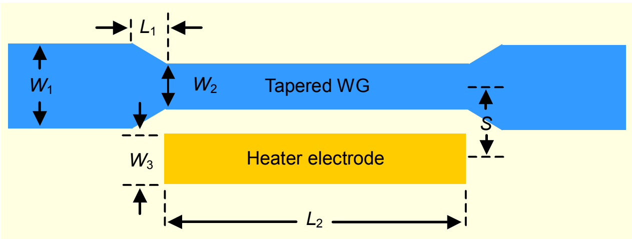

Fig. 2. Top view of modified radiation-type attenuator.

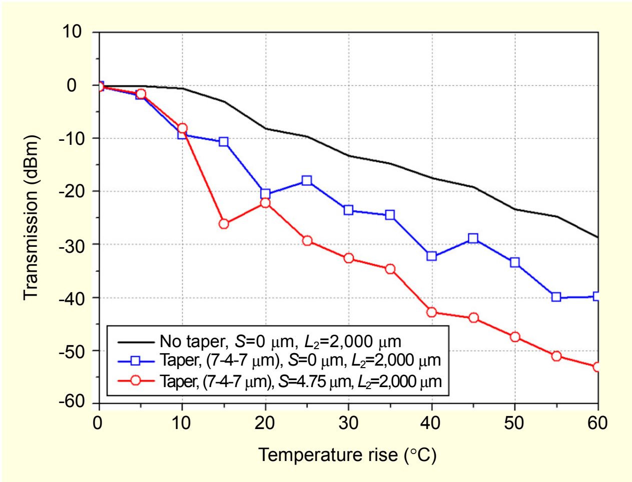

Fig. 3. Simulated attenuation characteristics of the modified radiation-type attenuator as a function of temperature rise (3D-BPM).

electrode on one of the Y-branch waveguides is heated, the refractive index is decreased by a negative thermo-optic coefficient of polymers. The light input from the fiber passes through the other Y-branch waveguide (through state), and the integrated-attenuator in the heated Y-branch arm fairly radiates away the residual optical crosstalk (attenuation state). To further improve the crosstalk level and reduce the power consumption to a lower level than that achieved by the DOS of [7], the attenuators are modified as shown in Figs. 1 and 2. Specifically, a taper structure is introduced to weaken the confinement of the guiding modes in the straight waveguides connected to the ends of the Y-branch arms, which can thus be easily radiated away from the straight waveguides when the heater electrodes are turned on. In addition, the heater electrodes in the attenuators are slightly shifted aside from the top center of the arm waveguide as shown in Fig. 2. Thus, the modes propagating along the straight arms can be efficiently deflected away from the tapered waveguide to free spaces due to the slant-inclined and distorted index distribution caused by the non-symmetric thermal gradient of the shifted heater electrodes.

For the design of the Y-branch section in the proposed DOS, we used the same design parameters as those of the previous DOS [7]. The polymer waveguide has a core size of 7 μm × 7 μm with a relative index contrast of 0.34%, a bending radius of 25,000 μm, an output port pitch of 127 μm, and a Y-branch angle (θ) of 0.2°. The heater electrodes in the Y-branch switch section have a width transition from 10 μm to 5 μm as shown in Fig. 1. The optimal design process for the Y-branch switch section was described in detail in [7]. In this work, polymer materials other than those used in the previous DOS were chosen. The refractive index of the core and that of the cladding are 1.393 and 1.388 at 1,550 nm, respectively. The thermo-optic coefficient of the polymers used in this study was -2.5×10^{-4}/°C.

The optimum parameters of the structure depicted in Fig. 2 were extracted by the 3D beam propagation method (3D-BPM) using the commercial BeamPROP simulator. The simulated attenuation characteristics of the modified radiation-type attenuator are shown in Fig. 3. The tapered waveguide structure was designed to have a width transition from 7 μm (W_1) to 4 μm (W_2) with a length of 150 μm (L_1). The heater electrode of the attenuator has a width of 5 μm (W_3) and a length of 2,000 μm (L_2). As shown in Fig. 3, the maximum attenuation was calculated to be -50 dB with the following parameters: a waveguide width transition of 7 μm to 4 μm to 7 μm, a shifted distance (S) of 4.75 μm, and a temperature rise of 55°C. The calculated performance of the modified radiation-type attenuators was superior to that of attenuators used in the previous DOS (black line) and to that of the structure (blue line with squares) with a width transition of 7-4-7 μm but no heater shift. Therefore, we believe that the proposed DOS would greatly improve optical crosstalk and power consumption compared to the previous DOS.

III. Experimental Results

The polymer waveguide was fabricated on a silicon substrate by the conventional processes of spin coating, standard photolithography, and dry etching. LFR series UV-curable polymer materials [9], synthesized by ChemOptics Inc., were

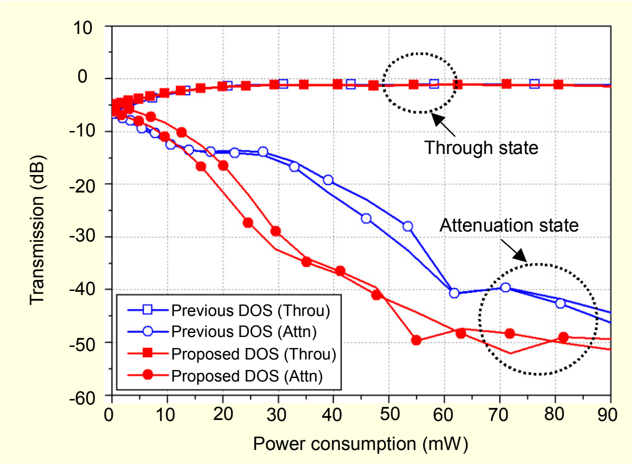

Fig. 4. Measured switching characteristics of fabricated DOSs as a function of applied electrical power, where the proposed DOS was compared with the previous DOS (Throu: through state; Attn: attenuation state).

used for the core and cladding. The measured propagation loss of the slab waveguide was below 0.1 dB/cm at 1,550 nm and the birefringence was as low as about ±0.0005 [9]. The fabricated waveguide has a lower-cladding thickness of 15 μm and an upper-cladding thickness of around 5 μm from the core top surface. Cr-Au heater electrodes were deposited by e-beam evaporation and were patterned by a liftoff process. The wire bonding pads were gold-electroplated. Next, both end-facets of a diced DOS chip were polished, and pig-tailing to the chip was accomplished by attaching slant-polished single-mode fiber blocks. The final chip size was as short as 14 mm.

To compare the performance of the proposed DOS with that of the previous DOS, the two types of DOSs were fabricated using identical polymer materials. The fabricated DOS chips, which were designed to be employed in the wavelengths of the *C*-band (1,530 nm to 1,562 nm), were evaluated using a 1,550 nm tunable laser, a linear polarizer, a polarization controller, an electrical source meter, and an optical power detector.

Figure 4 shows the measured switching characteristics of the fabricated DOS chips as a function of applied electrical power. After the polarization controller was adjusted and the transmission power of the DOS reached the maximum and minimum values (at two linear polarization states) at an applied power of 60 mW, the data was obtained in the through state and the attenuation state of the DOS as shown in Fig. 4. The insertion loss for both chips was measured to be about 1.1 dB in the through state (turn-on at 60 mW). This insertion loss included the propagation loss of the channel waveguide of about 0.3 dB/cm and a total excess loss of 0.68 dB, such as input-output fiber coupling loss and bending loss. The polarization dependent loss was as low as 0.1 dB in the through state. For the attenuation state, the proposed DOS showed far better switching characteristics than the previous DOS. The power consumption for a crosstalk value of -45 dB was estimated to be below 60 mW and above 90 mW for the proposed DOS and the previous DOS, respectively. The modified radiation-type attenuators clearly operated quite efficiently and greatly improved the power consumption compared with the conventional attenuators used in the previous DOS.

IV. Conclusion

We demonstrated an optical crosstalk-enhanced thermo-optic polymer DOS with a low power consumption which uses modified radiation-type attenuators. The fabricated DOS showed a good switching property with crosstalk below -45 dB at a low switching power of 60 mW. It also has a low insertion loss of about 1.1 dB. Compared to the previous DOS, the proposed DOS greatly decreased power consumption from 90 mW to 60 mW for a crosstalk of -45 dB. Therefore, our proposed DOS structure is suitable for application in switch array devices for the ROADM systems, which require low optical crosstalk and low power consumption.

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