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Polarization-insensitive thermo-optic switch based on multimode polymeric waveguides with an ultralarge optical bandwidth

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A promising polarization-insensitive thermo-optic switch based on multimode polymeric waveguides is reported. This device has a packing density of 40 channels/cm. Simulation result shows that an extinction ratio of greater than 20 dB can be achieved with the device–electrode interaction length of 30 mm. The thermo-optic switch operating at wavelengths of 632.8 nm and 1.3 μm has been demonstrated experimentally with extinction ratios of 21 and 22 dB, respectively. Such a device has an intrinsic wide optical bandwidth due to the large dynamic range of the phase-matching condition implied by the multimode waveguides. The material employed provides us with a switching speed of 100 μs. © *2000 American Institute of Physics.*
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Integrated optics plays an important role in several areas of optical communication, such as advanced information processing, optoelectronic interconnections, and fiber-optic communications.[1,2] High performance waveguide modulators and switches are important devices to fully utilize the opportunities provided by integrated optics.[3–5] All major optical modulators and switches used in telecommunication applications use single mode to cover the long distance requirements. From the packaging point of view, a few defects in waveguides and slight misalignments during device fabrication will degrade device performance significantly. Moreover, devices based on single-mode waveguides can only work within a narrow wavelength range. For example, a Mach–Zehnder interferometer designed to work at a certain wavelength will have problems when it is used at some other wavelengths. Switches and modulators based on multimode waveguides, because of their large dimension, can be made under relatively easier fabrication conditions and packaging reliability. Furthermore, coupling light between multimode waveguides and multimode optical fibers is usually easy and efficient. Therefore, multimode waveguides devices are compatible with data communication applications for short interconnection distance.

In this letter, we present a thermo-optic switch based on multimode polymeric waveguides. This device has such advantages as large fabrication tolerance, high device packing density of 40 channels/cm, and an ultrawide operating wavelength range.

The schematic and real device structures of the multimode thermo-optic switch are shown in Figs. 1(a), and 1(b), respectively. The device consists of a multimode guiding channel, a pair of heating electrodes, and a planar dumping waveguide under the guiding channel. The planar dumping layer is designed to be highly lossy ($\sim$26 dB/cm) so that optic energy coupled from the guiding channel can be efficiently dumped in the dumping layer. As a result, optical energy can only be coupled from the guiding channel to the dumping layer, while the coupling from the dumping layer to the guiding channel is minimized. Thus, the unidirectional coupling is achieved.[6] The electrodes were implemented to thermo-optically control the phase matching condition[7] of the coupling between the guiding channel and the dumping layer. Because there is only one channel per switch in this structure, the device packing density (number of switches per unit area) can be twice that of devices with a coplanar configuration,[6] where guiding channel and dumpling channel are implemented in the same layer.

Based on the unidirectional coupling mechanism,[6] we simulated the dumping efficiency from the guiding channel to the planar dumping layer. Figure 2 shows the simulation result of the sum of the dumping efficiencies to all modes of the dumping layer. Note that the dumping efficiency of more than 20 dB can be achieved with the channel length of 30 mm. This shows that the planar dumping layer can effectively improve the dumping efficiency.

To control the phase matching condition thermo-optically, a pair of heating electrodes was implemented on top of the guiding channel. By applying current induced heat through the electrodes, the temperature difference between the guiding channel and the other areas of the device (ΔT) can be changed continuously. Beam propagation software (BeamProp®) was used to simulate the device operations at two switching states ($\Delta T = 0$ and 30 °C) at 632.8 nm and 1.3 μm, respectively. The simulation result of 632.8 nm is

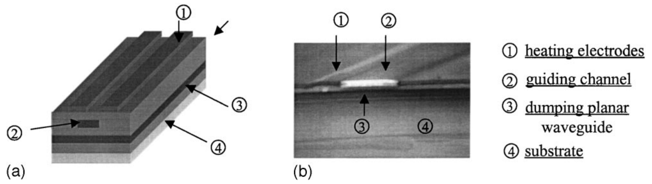

FIG. 1. Structure of the unidirectional thermo-optical switch. (a) Schematic view of the device structure. (b) SEM view of the device structure.

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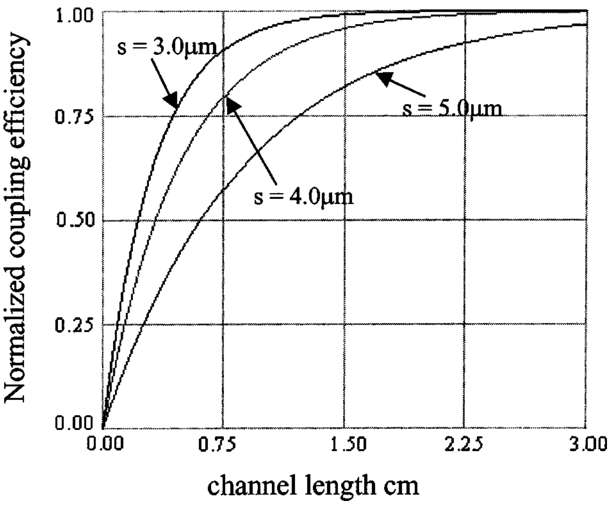
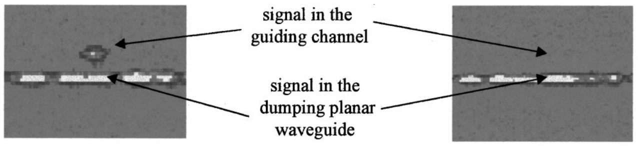
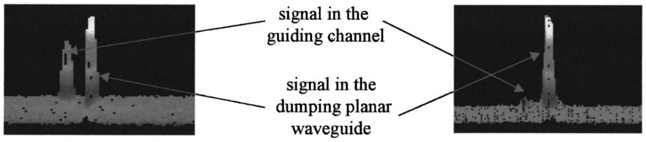


FIG. 2. Normalized coupling efficiency as function of channel length.



(a) 0 mA heating current (b) 62mAheating current



(c) 0 mA heating current (d) 62mA heating current

FIG. 4. Experiment results of the near field output patterns of the thermo-optical switch at 633 nm. (a), (b) 2D view, (c), (d) 3D view. (a), (c) Without heating current. (b), (d) With heating current of 62 mA.

shown in Fig. 3. The output optical energy of guiding channel was high [Fig. 3(a)] when ΔT was 0 °C. When ΔT was 30 °C, the light in the multimode guiding channel was coupled to the dumping layer, which was highly multimode planar waveguide. The output optical energy of guiding channel became low [Fig. 3(b)], which corresponding to the phase match condition was satisfied.

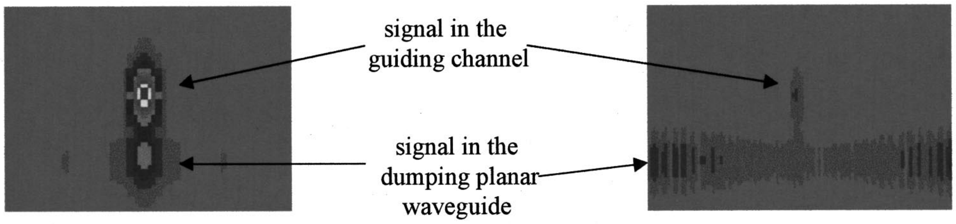
The fabrication of the device followed the conventional lithography technique used in very large scale integrated (VLSI) fabrication. Master Bond UV15® was used as both the top cladding and the bottom cladding. Photolime gel[8] was used to make guiding channel and dumping layer. The thickness of guiding, dumping, and cladding layers were measured to be 4.2, 4.4, and 4.1 μm, respectively. The multimode channel waveguide of 20.0 μm×4.2 μm was defined using lithography and then reactive ion etching (RIE) techniques. The top heating electrodes were formed by conventional liftoff method. The length of the electrodes and the total device were 3.0 and 3.6 cm, respectively. The resistance of the electrodes was measured to be 78 Ω. A 632.8 nm wavelength laser beam was endfire coupled into the device through a 40× objective lens. The output light was focused through another 40× objective lens and then imaged onto a screen. An IR camera was used to obtain the near field real-time image, which was then collected by a computer and analyzed by a Spiricon™ beam analyzer. An optimized 5 V voltage was applied on the electrode, corresponding to the heating current of 62 mA.

Unlike conventional single mode devices which are highly wavelength sensitive, the device reported herein is an intrinsically wide-band device due to the large dynamic range of the phase match conditions.[6,9]

Experimental results of 632.8 nm and 1.3 μm are reported in this section. For the case of 632.8 nm, the two-dimensional (2D) and three-dimensional (3D) view of near field output patterns are shown in Fig. 4. With no heating current, the output of the guiding channel was high [Figs. 4(a) and 4(c)], i.e., the phase matching conditions were not satisfied. The light in the guiding channel was dumped to the dumping layer and the output of the guiding channel was low [Figs. 4(b) and 4(d)] when a heating current of 62 mA was applied. The phase matching conditions were induced and a high extinction ration of −21 dB was observed.

To observe the switching operation at the wavelength of 1.3 μm, a 1.3 μm wavelength laser beam was coupled into the same device through the same experimental setup using the same switching voltage. The three-dimensional (3D) view of near field output patterns at 1.3 μm is shown in Fig. 5. With no heating current, the output of the guiding channel was high [Fig. 5(a)]. When heating current was 62 mA, the light in the guiding channel was dumped to the dumping layer and the output of the guiding channel was low [Fig. 5(b)]. The extinction ratio was measured to be −22 dB, which is almost the same as that of 632.8 nm operation. Note that both 632.8 nm and 1.3 μm laser beams were random polarized. Unlike the EO effect, which is polarization sensitive, the TO switching device reported herein is polarization insensitive due to the direction independence of thermal effect $(\partial n/\partial T)$.

In summary, we report on a multimode thermo-optic polymeric switch, covering an ultralarge optical bandwidth. Due to the vertical layout of the dumping planar waveguide, the device has a device-packing density of 40 channels/cm to match 250 μm fiber array spacing. The dumping efficiency of greater than 20 dB was achieved with the interaction



(a) $\Delta T = 0°C$ (b) $\Delta T = 30°C$

FIG. 3. Simulation result of near-field output pattern of the thermo-optical switch. (a) When the temperature difference ΔT was 0 °C. (b) When the temperature difference ΔT was 30 °C.

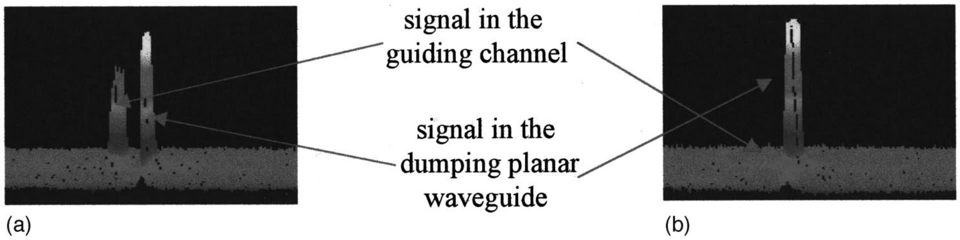


FIG. 5. Experiment results of the 3D near field output patterns of the thermo-optical switch at 1.3 μm. (a) Without heating current. (b) With heating current of 62 mA.

length of 30 mm. Thermo-optic switching for randomly polarized light at wavelengths of 632.8 nm and 1.3 μm has been observed experimentally using the same device.

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