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A 1 ×4 Polymeric Digital Optical Switch Based on the Thermo-Optic Effect *

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Abstract: We present a 1 ×4 Y-branch digital optical switch in which S-bend variable optical attenuators are integrated. The S-bend waveguides, which are always introduced to connect the switch and the standard fiber array, are made use of and designed as variable optical attenuators. A compact device with low crosstalk and larger branching-angle is obtained. The device is fabricated on the thermo-optic polymer materials, and the performance of the device is measured. With an applied driving power of less than 200mW, the device has a low crosstalk of less than - 35dB at a wavelength of 1.55μm.

Key words: bend waveguide; variable optical attenuator; thermo-optic effect; digital optical switch; integrated optics

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1 Introduction

Optical switches are key components of optical communication systems. The Y-branch digital optical switch (DOS) has attracted extensive attention because of its digital response, low polarization- and wavelength-sensitivity, high optical bandwidth, and stable switching characteristics[1~3], but it still has the problem that the conventional Y-branching angle is limited within a very small range from 0.05° to 0.12°, making the fabrication process difficult and the device long. Researchers have attempted to design a large-angle DOS without affecting its switch characteristics[4~6]. Integrating the switch with variable optical attenuators (VOAs) is a good way to realize low crosstalk while reducing the requirement for the branching angle[7]. In this paper, we report a 1 ×4 Y-branch DOS in which S-bend VOAs are integrated. The device is fabricated on polymer, and the thermo-optic effect is applied.

2 Principle and design

A schematic view of the proposed switch is shown in Fig. 1. The 1 ×4 DOS consists of three Y-branch switch units in a tree configuration. The device operates through adiabatic mode evolution and the thermo-optic effect of polymer materials[6].

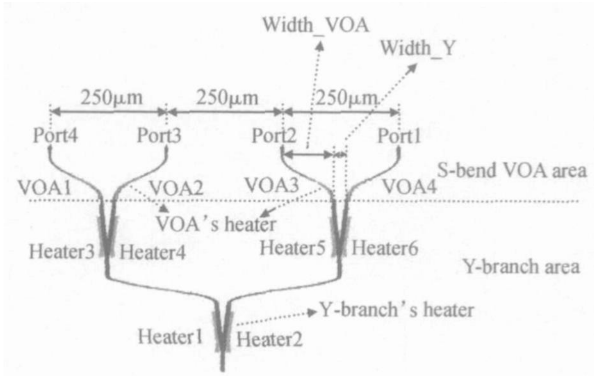

Fig. 1 Schematic of 1 ×4 DOS

In the 1 ×4 DOS, the four bend waveguides, which are commonly used to achieve a 250μm separation between adjacent output ports for fiber-array coupling, are designed as a kind of S-bend thermo-optic VOA. A top view and a cross section of a VOA are shown in Fig. 2. The S-bend VOA does not work when the electric current does not flow through its heaters. Once electric power is supplied to the heaters, a temperature gradation and refrac-

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tive index gradation will form in the vertical direction[8] ,and the optical power in the vertical direction will leak because of the negative thermo-optic coefficient of the polymer materials. According to the theory of radiation loss of the bend waveguides ,the same phenomena occur in the optical power in the horizontal direction ,and the horizontal displacement of the heaters from the bend waveguide even aggravates the leakage. The heaters 'action in the vertical and horizontal directions destroys the mode confinement ,leading to optical power loss in both directions ,which means the S-bend waveguide functions as a VOA. Low insertion loss and low crosstalk of the VOA can be achieved by optimizing the radius of the bend waveguide and the position of the heaters[9] .

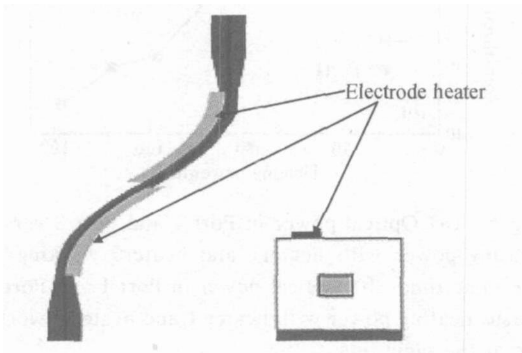

Fig. 2　Top view and cross section of S-bend VOA

With the employment of the S-bend VOAs , the proposed 1 ×4 DOS can be realized with low crosstalk. When electric power is supplied to heater 1 ,the refractive index will decrease because of the negative thermo-optic coefficient of the polymer material. Thus most of the input signal is transferred to the right arm of the lower Y-branch due to the mode evolution. The electric power is also supplied to heater 6 at the same time ,so the majority of the signal in the right arm is directed to port 2. The residual optical signal in port 1 is further attenuated by its S-bend VOA ,thus greatly improving the crosstalk characteristic. The only function of the three Y-branch switch units is optical energy switching without realizing low-crosstalk. We can choose a larger branching angle θ as 0. 3 °,and thus the fabrication process becomes easier and the device becomes smaller.

In our experiments , ZPU12-464 and ZPU12-459 ,the polymer materials of ZPU12-RITM series from Zen Photonics Ltd Co ,are used as the core layer and the cladding layers ,whose refractive indexes are 1. 464 and 1. 459 at the wavelength of 1. 55μm ,respectively. The thermo-optic coefficient is $-1.7 \times 10^{-4}\,K^{-1}$,and the thermal conductivity is 0. 17W/ (m ·K) . The device is fabricated on glass. By our analysis and optimization ,the radius of the S-bend VOA is designed to be 34000μm ,which results in an insertion loss of about 0. 3dB ; Width_VOA and Width_Y,as shown in Fig. 1 ,are 111. 5 and 27μm , respectively ; the size of the S-bend waveguide is 5μm ×5μm , while that of the Y-branch waveguide is 7μm ×7μm , so tapers are introduced to connect the two upper Y-branches and the four S-bend waveguides ; the width of VOA 's heaters and that of the Y-branches 'heaters are designed to be 4 and 7μm ,respectively ,and the heaters of the two upper Y-branches and the heaters of their corresponding S-bend VOAs are connected in series ; the distance between the adjacent S-bend outputs is 250μm so as to couple with a standard fiber array.

Obtained by the beam propagation method (BPM) , Figure 3 shows output powers in port 1 and port 2 as functions of the temperature when heater 1 and heater 6 are working at the same time.

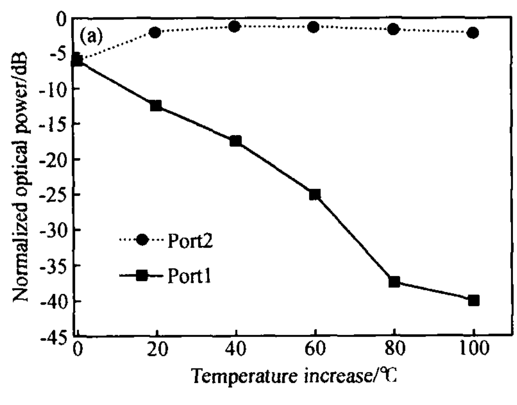

Fig. 3　Simulation of the output with heater 1 and heater 6 working at the same time

3 Experiment

In the fabrication process , a promoter (ZAP1020) was first spin-coated on the substrate. Then the lower clad and core layers were spin-coated with thicknesses of 20 and 7μm , respectively. After each spinning ,layers were exposed to ultraviolet light for curing and were then baked at 160 ℃ for 1h. The waveguides were patterned by photolithography and an inductively coupled plasma (ICP) etching process using O_2 plasma. The upper layer was then spin-coated and cured. Through E-beam evaporation, photolithography, and etching, the Ti-Au heaters were made.

To characterize the switch, the laser at the wavelength of 1.55μm was coupled directly to the device through a single mode fiber. We took the pictures at the end of the output waveguide with an infrared camera. Figure 4 illustrates the switching of the output optical power from port 1 to port 4 when different heaters are running. It can be seen that the paired output ports, ports 1 and 2 or ports 3 and 4, show great extinction ratios while the

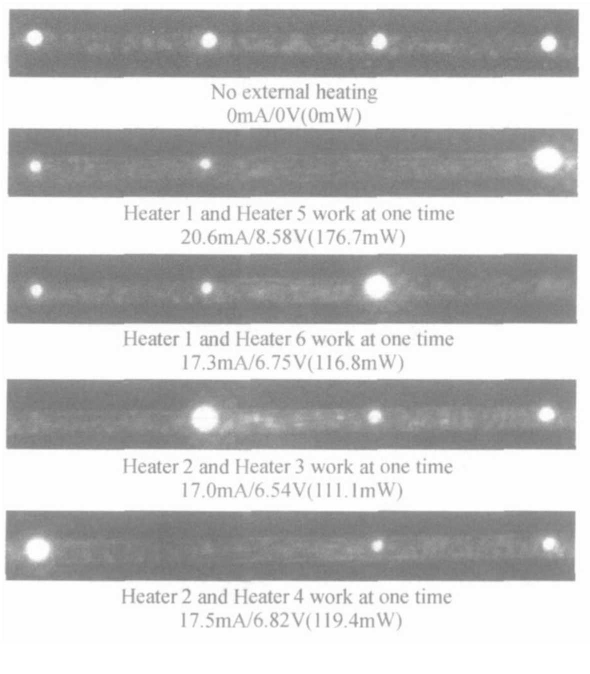

Fig. 4 Four different output states under certain driving power when the corresponding heaters work at the same time

crosstalk of the other ports is worse, which is expected to improve by applying driving power on the corresponding VOAs. The device was also qualitatively measured. Limited by the experimental equipment, only two channels can be investigated at one time, so the paired output ports were measured. The switching properties are shown in Fig. 5 (a) when heater 1 and heater 6 are running at the same time and in Fig. 5(b) when heater 1 and heater 5 are running at the same time. From Fig. 5(a), it can be seen that as the output power of port 2 in-

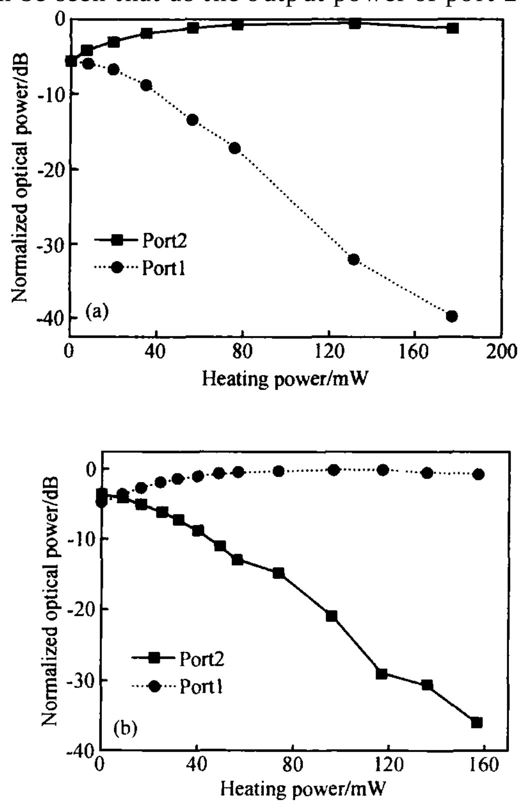

Fig. 5 (a) Optical power in Port 1 and Port 2 versus heating power with heater1 and heater6 working at the same time; (b) Optical power in Port 1 and Port 2 versus heating power with heater 1 and heater 5 working at the same time

creases slowly, the power of port 1 decreases rapidly due to the attenuation function of VOA 4; the driving power is about 180mW, and the crosstalk is about -37dB. From Fig. 5(b), as the output power of port 1 increases slowly, the power of port 2 decreases rapidly due to the attenuation function of VOA 3; the driving power is about 160mW, and the crosstalk is about -35dB. Similar results are obtained when heater 2 and heater 3/ heater 4 are electrically driven, and we conclude that the crosstalk reaches below -35dB while the switching power is below 200mW. The insertion loss is measured to be about 5dB, which includes a 0.5dB loss caused by the device structure, about 3dB of loss introduced by the polymeric materials and the imperfect waveguides, and about 1.5dB of fiber-coupling loss. The loss can be minimized by improving the fabrication processes and fiber-coupling technique. The switching time is about 3～4ms.

4 Conclusion

In summary, a 1 ×4 optical switch with S-bend VOAs integrated in it is experimentally demonstrated. Through directly designing variable optical attenuators in the S-bends, a low-crosstalk optical switch, which is most desirable for large-scale photonic networks, is realized. The fabrication becomes easier, and the device can be made smaller because the Y-branch can be designed with a large branching-angle. With an applied driving power of less than 200mW, it has a low crosstalk of less than -35dB at the wavelength of 1.55μm. The insertion loss is about 5dB. The switching time is about 3～4ms. This device will find applications in integrated optical circuits.

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基于热光效应的 1 ×4 聚合物数字光开关 *

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摘要: 提出了基于热光型聚合物的集成有 S 弯曲光衰减器的 1 ×4 Y 分叉数字光开关. 利用开关与光纤阵列耦合用的 S 弯曲,将其设计成可变光衰减器,这使得器件更紧凑,并获得低串扰和大分叉角. 在小于 200mW 的驱动功耗下,器件串扰可低至 - 35dB.

关键词: S 弯曲; 可变光衰减器; 热光效应; 数字光开关; 集成光学

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