Free-space 1×2 wavelength-selective switches for wavelength-division multiplexing optical networks

Xiaoqi Li (李小奇)[1,2], Jingqiu Liang (梁静秋)[1*], Degui Sun (孙德贵)[1], Wei Li (李 伟)[1,2], and Zhongzhu Liang (梁中翥)[1]

[1]*State Key Laboratory of Applied Optics, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China*

[2]*Graduate University of Chinese Academy of Sciences, Beijing 100049, China*

**E-mail: liangjq@ciomp.ac.cn*

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A free-space 1×2 wavelength-selective switch (WSS) based on thin-film filter technology is proposed. The 1×2 WSS is fabricated with an electromagnetic actuator, a reflecton prism, a narrow-band thin-film filter, and three fiber collimators. The working principle and the configuration of WSS are illuminated. The experimental results indicate a fiber-to-fiber insertion loss ranging from 1.109 to 1.249 dB with 2-V voltage input, which satisfies the application of optical fiber communication.

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With the wide employment of wavelength division multiplexing (WDM) networks, devices capable of wavelength routing have become increasingly desirable. The optical communication market has now clearly embraced wavelength-selective switch (WSS) technology for wavelength cross-connects (WXCs) and reconfigurable optical add/drop multiplexers (ROADMs) as a type of basic device due to their ability to route different wavelength channels independently[1−8]. Tsai *et al*. and Chi *et al*. have proposed WSSs based on gratings and proved the advantages of the WSS devices[9,10]. Both of their configurations were shunt-wound, which limited their expansibility, and the optical insertion losses were too high to be used in commerce. To solve these problems, a free-space WSS based on thin-film filters (TFs) is proposed in this letter. Owing to the maturity of the TF technology, the use of TF-based WSS offers lower optical insertion loss, higher extinction ratio, independence from wavelengths and polarizations, and well expansibility and integration.

We propose a new structure of TF-based 1×2 WSS that can be used to form a large 1×N WSS system. The key idea is to create a wavelength sensitive 1×2 switch by using a desired static TF and placing a movable two-reflecting-side-prism at the desired direction between fiber collimators and the TF. With this structure, the optical insertion loss of the device can be reduced and the extinction ratio can be improved greatly.

The basic structure of the 1×2 WSS is shown in Fig. 1. It consists of a reflection prism, a narrow-band thin films filter, an electromagnetic actuator, and three fiber collimators. The prism is attached to the electromagnetic actuator which can take it up/down with low operating voltage. Two states of the electromagnetic actuator are shown in Figs. 1(a) and (b), respectively. In Fig. 1(a), the reflection prism is in the optical path and reflects the beam to the TF when the actuator is "on", then the aimed wavelength signal passes the filter and is coupled in the fiber collimator OUT1, while the other signals are reflected by the filter to the prism and reflected again to the fiber collimator OUT2 at last. In Fig. 1(b), when the actuator is "off", the reflection prism is out of the optical path, the beam passes from the fiber collimator IN to the fiber collimator OUT2 directly, and the signal is not separated. The fiber collimators are used at both

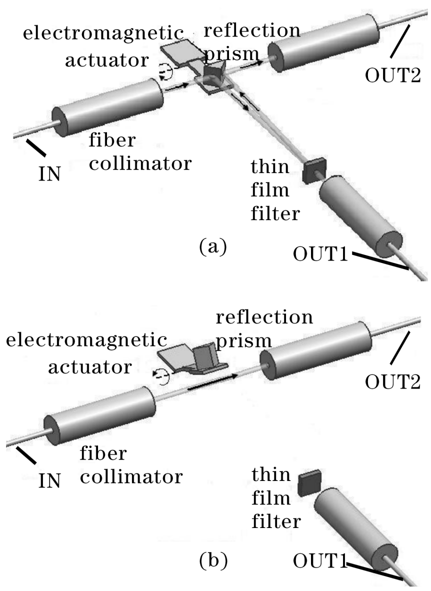

Fig. 1. Schematic diagram of a 1×2 wavelength-selective switch. (a) The actuator is "on", and (b) the actuator is "off".

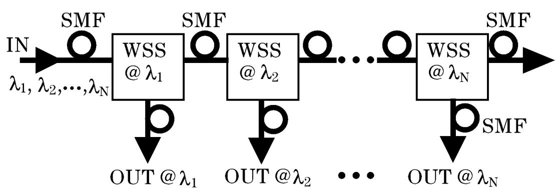

Fig. 2. A large 1×N switch network arrangement using our proposed 1×2 WSSs. SMF: single-mode fiber.

input and output ports.

Based on the micro-optical-electro-mechanical system (MOEMS) with 1×2 WSS operation principle above, N of the proposed 1×2 WSSs can be cascaded to form a large 1×N WSS system, as shown in Fig. 2[5]. N different wavelengths can be selected by such a WSS system.

The electromagnetic actuator is one of the most important devices in the designed WSS, and its capability could almost determine the performance of the WSS[11]. The schematic diagram of the electromagnetic actuator with a reflection prism is shown in Fig. 3. The polyimide (PI) cantilever was fabricated using micro electro-mechanical system (MEMS) technology with copper windings embedded in it. The magnetic fields with different directions can be attained by changing the direction of the electric current in the copper windings, which drives the cantilever up/down with the effect of the magnet. The reflection prism is in/out of the optical path, as shown in Figs. 3(a) and (b), and the electromagnetic actuators are "on" and "off", respectively. The photo of the electromagnetic actuator is shown in Fig. 4, where the inset is the copper windings. The thickness and width of the copper line are 23 and 50 μm, respectively. The fabricated actuator with a prism was tested by applying a direct current (DC) across the two poles of the copper windings. The displacement of the prism was up to 1.5 mm at 2-V input, which satisfies the practical requirement of the device completely.

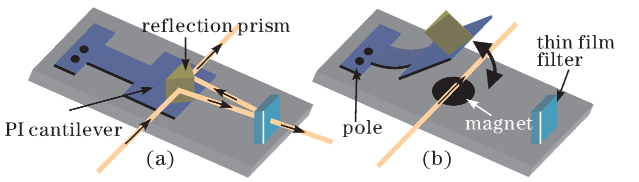

Fig. 3. Schematic diagram of an electromagnetic actuator with a reflection prism at the states of (a) "on" and (b) "off".

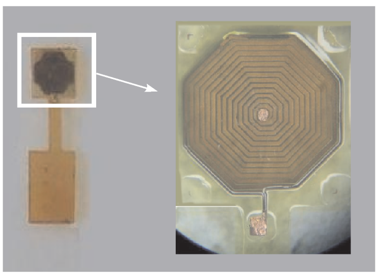

Fig. 4. Top-view of the electromagnetic actuator.

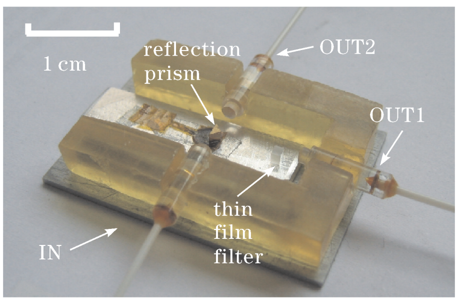

Fig. 5. Photo of the 1×2 WSS.

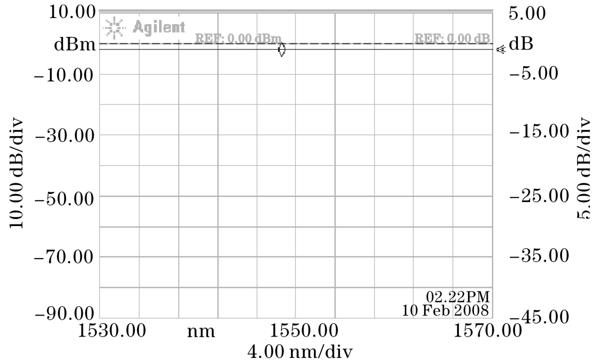

Fig. 6. Spectra from OUT2 when the WSS is "off".

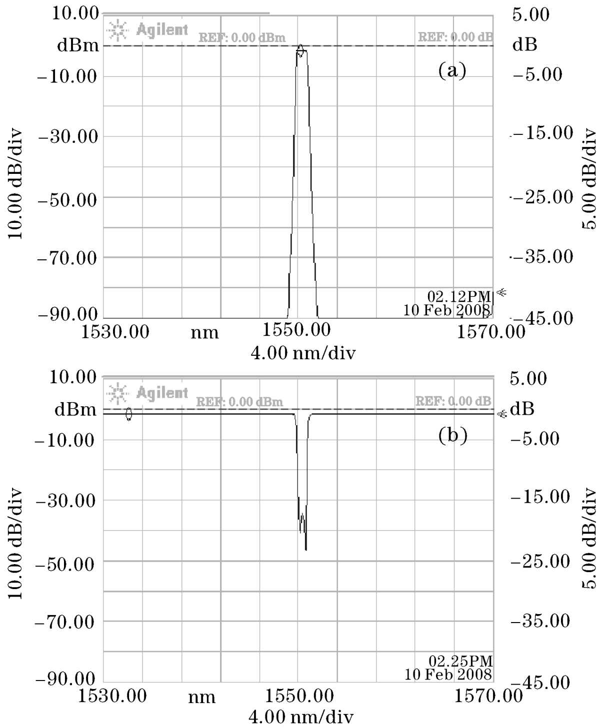

Fig. 7. Spectra when the WSS is "on". (a) From OUT1 and (b) from OUT2.

The photo of the 1×2 WSS is shown in Fig. 5. Three fiber collimators with the beam radius of <0.48 mm are used in this system. A reflection prism with an effective reflecting area of 1.5×1.5 mm^2 coated by Ge films which have a high reflectivity of >99.5%, is attached on the electromagnetic actuator. The TF is selected for this system with an effective reflecting area of 1.4×1.4 mm^2 and a full-width at half-maximum (FWHM) of <2 nm, and its transmissivity at the central wavelength and reflectivity at other residual wavelengths are both >98%.

An external cavity laser with the wavelength from 1530 to 1570 nm was used as the light source. The spectra from OUT2 are shown in Fig. 6 when the WSS is "off". In this condition, the beam transmits from the fiber collimator IN to the fiber collimator OUT2 directly without any operation, and no signal is separated, so the losses from 1530 to 1570 nm are almost the same. The optical loss measured at 1548.64 nm was 1.249 dB, and the extinction ratio was 50 dB.

The spectra from OUT1 are shown in Fig. 7(a) when the WSS is "on". The measured center wavelength was 1550.20 nm, and the optical insertion loss was 1.139 dB. The FWHM was <2 nm. The parameters are almost the same when another wavelength in the same range is separated because they are determined by the TF, and the parameters of TF could be almost the same in this wavelength range. The spectra from OUT2 are shown in Fig. 7(b) when the WSS is "on". Obviously, the wavelength of 1550.20 nm has been separated from OUT1, and the losses of the residual wavelengths are almost the same. The measured optical insertion loss at 1532.64 nm was 1.109 dB. Compared with Fig. 6, the loss is smaller after being reflected by the prism and the filter, because the optical path approaches the work distance (WD) of the collimators with the reflection. The coupling loss of fiber collimators is determined by the distance between them, and the distance is called WD when the best coupling loss is obtained. The coupling loss would be decreased when the distance approaches the WD, which is 100 mm in this WSS. In the condition of Fig. 7, the optical insertion loss is smaller after reflection, because the additional reflection loss is smaller than the decreased coupling loss of the fiber collimators.

In conclusion, the design, fabrication, and testing results of a WSS based on TF technology are reported in this letter. The device can achieve wavelength selection at low voltages of 2 V. A fiber-to-fiber insertion loss of 1.109−1.249 dB and a high extinction ratio of 50 dB have been achieved. The WSS could satisfy the requirements of WXC and ROADM.

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