Wavelength-selective switch based on a high fill-factor micromirror array

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A novel design and fabrication approach for a high fill-factor micro-electro-mechanical system (MEMS) micromirror array-based wavelength-selective switch (WSS) is presented. The WSS is composed of a polarization-independent transmission grating and a high fill-factor micromirror array. The WSS is successfully demonstrated based on the fabricated high fill-factor micromirror array. Test results show that the polarization-dependent loss (PDL) is less than 0.3 dB and that the insertion loss (IL) of the wavelength channel is about –6 dB. The switching function between the two output ports of WSS is measured. The forward switching time is recorded to be about 0.5 ms, whereas the backward switching time is about 7 ms.

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With the rapid development of optical communications, all-optical switching networks have become more important. The wavelength switching architecture is one of the most promising methods because it enables the management of optical networks at the wavelength level. One of the key modules in the optical network is the wavelength-selective switch (WSS).

Various technologies have been explored in order to achieve the WSS function, such as free-space grating micro-electro-mechanical system (MEMS)[1−5] and free-space grating liquid crystal on silicon (LCOS) system[6,7]. Compared with the LCOS technology, the MEMS WSS has drawn considerable attention due to its advantages of lower optical insertion loss (IL) and crosstalk, faster switching speed, higher extinction ratio, and especially, being polarization independent. In the free-space grating MEMS, the polarization problem is primarily due to diffraction grating. In a previous study, an anisotropic uniaxial crystal and a half-wave plate have been used to eliminate the polarization sensitivity of the diffraction grating[4]. However, the anamorphic prism pair has large size and makes the optical system assembly more complicated.

To avoid an additional polarization management devices, a novel design and the fabrication approach for a high fill-factor micromirror array-based WSS have been demonstrated in this letter. A polarization-independent transmission grating has also been introduced to provide spatial dispersion, and this successfully achieved a low polarization dependent loss (PDL). The switching function between two output ports of the WSS has been measured and discussed based on successfully fabricated micromirror array.

A schematic view of the presented WSS system is shown in Fig. 1. The free-space grating MEMS optical system contains three major sub-assemblies, cylindrical optics, a polarization-independent transmission grating, and a MEMS micromirror array.

As the key switching component, in order to meet the full requirement of optical system, the micromirror array must have a high fill-factor (>92%), a large micromirror (800 × 120 (μm)), and ~1° rotation angle with a limited driving voltage (<200 V). The resonance frequency of the micromirror actuator is required to be higher than 3.5 KHz to ensure a good anti-vibration performance. Various micromirror arrays have been reported in Refs. [8–10], but none of them demonstrates a performance that meets all the above-mentioned requirements.

The schematic diagram of the proposed high fill-factor micromirror array with a bumper and multi-terraced electrode is shown in Fig. 2(a). The close-up view of a unit of the micromirror is shown in Fig. 2(b), where a cantilever beam with a micromirror plate, multi-terraced

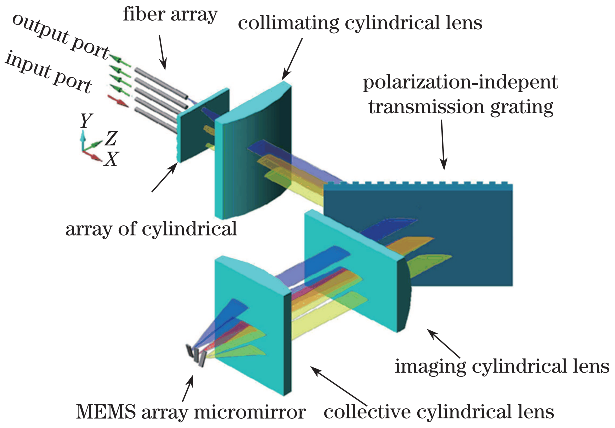

Fig. 1. Schematic diagram of the proposed WSS.

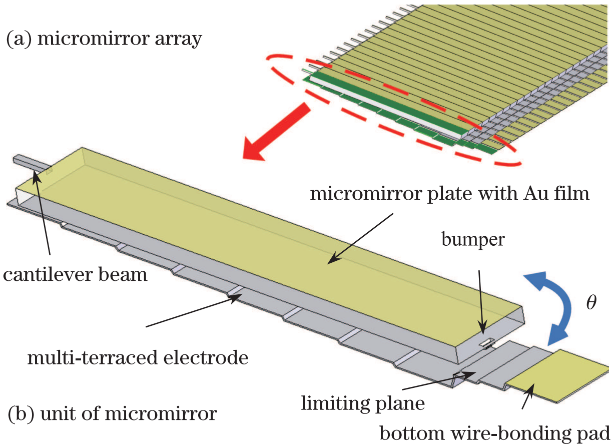

Fig. 2. Schematic diagram of a high fill-factor micromirror array with a bumper and multi-terraced electorodes. (a) Micromirror array and (b) a unit of micromirror.

electrode, a bumper, and limiting planes are designed.

Compared with traditional parallel-plate electrodes, the multi-terraced electrode is designed to reduce the driving voltage. To prevent the stick or damage caused by the pull-in effect or some instances of vibration, a bumper, which is silicon salient with two micron silicon oxide film, and limiting plane structures have also been introduced. The cantilever-type structure is utilized for micromirror rotation and high fill-factor of the micromirror array. The resonance frequency of the micromirror was selected to be 4 kHz to achieve a good anti-vibration performance. Figure 3 shows the comparison of the driving voltage of the micromirror with parallel-plate and multi-terraced electrodes. The test results also demonstrated a better and more desired performance.

In previous studies, surface micromachining has been frequently used to fabricate the micromirror[10−12]. However, the residual stress of surface micromachined thin films causes wrap and reliability problems. Figure 4 shows the scanning electron microscope (SEM) images of the fabricated micromirror array using bulk micromachining technology, including a wafer bonding process. The fabricated micromirror array with a high fill-factor of 97% is shown in Fig. 4(a). The cross-section view of the micromirror is illustrated in Fig. 4(b), which shows the cantilever-type micromirror plate, multi-terraced bottom electrodes, the bumper, as well as limiting plane.

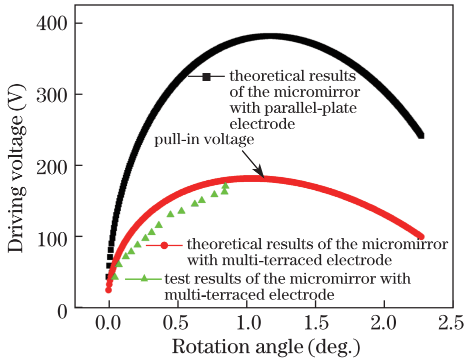

Fig. 3. Contrast curve between the driving voltage and the rotation angle based on different bottom electrodes.

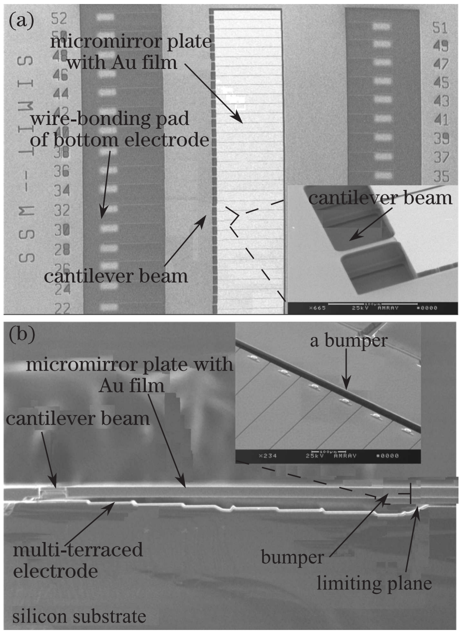

Fig. 4. SEM images of fabricated micromirror structures. (a) Micromirror array and (b) cross-section view of micromirror.

A dense wavelength division multiplexing (DWDM) test system (IQS-12004B, EXFO) was used to measure the IL and PDL of the WSS. The preliminary measured results indicated that the IL of each wavelength channel was about −6 dB, while the PDL was less than 0.3 dB. A small oscillation of the PDL was observed in the gap areas between the mirrors, which might be caused by the fabrication imperfections in the gap areas. Some of the test results are shown in Fig. 5.

The inter-port transient responses of the fabricated WSS were characterized using an oscilloscope (AQ6370B, YOKOGAWA). The results are shown in Fig. 6. The forward switching time in Fig. 6(a), defined as the time when the micromirror is switched from the output ports 1 to 2, is about 0.5 ms. In Fig. 6(b), the backward switching time, which is defined as the time elapsed between the micromirror being switched back from the output ports 2 to 1, is about 7 ms. The small oscillation shown in Fig. 6(a) was caused by the temporary free vibration of the cantilever beam when it was switched to the output port 2, where the mirror reflected light beam. The difference between the forward switching and the backward switching times may be caused by the difference between capacitor charging and discharging time.

In conclusion, a novel WSS based on a high fill-factor micromirror array is proposed and achieved successfully. The WSS contains polarization-independent transmission grating and micromirror array. The grating has the advantages of low PDL and having no requirement for additional polarization controlling devices. High fill-factor micromirror arrays are designed and fabricated using bulk micromachining technology, including a wafer bonding process. The measurement results show that the IL and PDL of the novel WSS are $\leqslant -6$ and <0.3 dB, respectively. The forward switching time is

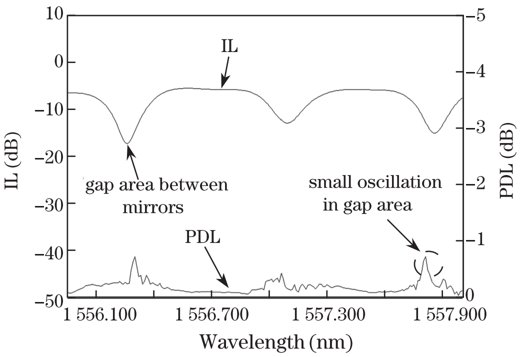

Fig. 5. The IL and PDL test results of WSS by using a DWDM test system.

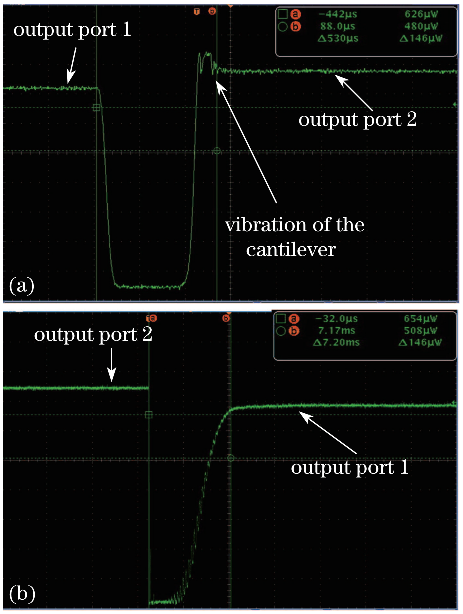

Fig. 6. Measured dynamic responses of the WSS. (a) mirror switched from the first stable position to the second stable position and (b) mirror switched from the second stable position to the first stable position.

about 0.5 ms, while the backward switching time is about 7 ms.

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