Compact 1x8 MEMS Optical Switches Using Planar Lightwave Circuits

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Abstract: A compact 1x8 optical switch is realized by directly butt-coupling a MEMS mirror to a planar lightwave circuit (PLC). A cylindrical microlens is microfabricated on PLC to reduce diffraction loss. A fiber-to-fiber loss of 6.3 dB is measured.

OCIS codes: (060.1810) Couplers, switches, and multiplexers
(060.4510) Optical communications

1. Introduction

Free-space MEMS (micro-electro-mechanical-systems) optical switches offers many advantages, including high port count, low insertion loss and crosstalk, optical transparency, and polarization insensitivity [1-4]. However, their sizes are often limited by the bulk optical elements (such as lenses) and the long free-space propagation distances. Optical alignment and assembly are also tedious.

Very compact switches can be realized by combining MEMS and planar lightwave circuits (PLC). PLC-MEMS switches have been demonstrated using bubble actuation [5-7] and moving waveguides. No optical alignment or mechanical assembly is needed. However, the basic switching elements in these switches have very small port counts (1x2 or 2x2). As a result, a large number of them needs to be cascaded to form large switches. This leads to reliability concerns as well as cumulative losses and crosstalkes.

In this paper, we proposed and demonstrated a novel 1x8 optical switches by combining a PLC with a MEMS scanning mirror. By employing a fan waveguide array and a microfabricated cylindrical microlens, the MEMS mirror can be directly butt-coupled to the PLC without using any bulk lenses. Our theoretical calculation shows that very low insertion loss (0.5 dB) can be achieved. Experimentally, we have fabricated a PLC fan waveguide array with integrated microlenses. A fiber-to-fiber insertion loss of 6.3 dB and a switching time of 1 msec have been achieved. The switching voltage is less than 8V. This switch configuration is scalable to larger port count. The 1xN switches can potentially be integrated with array waveguide gratings (AWGs) to form multi-port wavelength-selective switches on a single chip. They can also be cascaded for NxN switches.

2. Device Design and Simulation

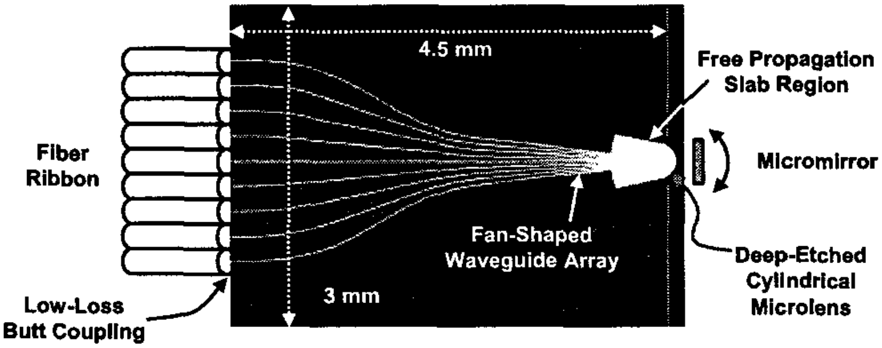

Fig. 1. Schematic of the PLC-MEMS 1x8 optical switch.

The schematic of our PLC-MEMS 1x8 optical switch is shown in Fig. 1. It consists of two chips: a PLC chip with nine waveguides, and a MEMS chip with an analog scanning mirror. The waveguides are arranged in a fan shape towards a free propagation slab region. A cylindrical lens is microfabricated at the end of the slab to collimate the optical beam and compensate for the beam divergence in the lateral direction. The mirror is positioned at the extrapolated intersection point of the fan waveguide array, taking into consideration the refraction at the PLC/air interface. The detailed schematic of the switch around the slab region is shown in Fig. 2. The center waveguide is used as the input waveguide. The reflected light from the micromirror can be steered to any of the eight output waveguides. The optical beam diverges slightly in the vertical direction between the PLC and the micromirror. To minimize the diffraction loss, the mirror is kept very close to the PLC (~ 10 μm). To facilitate optical packaging, the waveguide spacing is gradually increased to 250 μm at the input end. This enables low-loss butt-coupling between the PLC chip and a fiber ribbon.

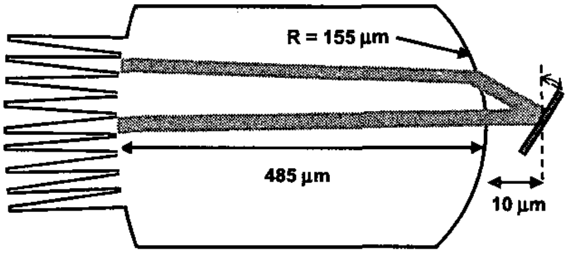

Fig. 2. Detailed device configuration and design parameters.

The MEMS micromirror used in this experiment has been previously reported [8]. Using a hidden vertical combdrive actuator underneath the mirror, the scanner has a continuous scan range of +/- 6° (mechanical angle) and a very low actuation voltage of 8 V. The mirror area (154 μm x 160 μm) is 4.8 times larger than the size of the optical beam (1/e diameter = 32 μm). The resonant frequency is 3.4 kHz. The mirror is made by the surface micromachining process through the SUMMiT-V process at Sandia National Lab.

We use both ABCD matrix formulation and Beam Propagation Method (BPM) to optimize the design parameters and estimate the optical insertion loss. The maximum angle between the highest and the lowest waveguide is designed to be 6.8°, corresponding to a mirror rotation angle of +/- 5° mechanically. A 15-μm spacing between waveguides is required to avoid inter-channel crosstalk. With a 485-μm-long slab region, the optimum microlens radius is found to be 155 μm. The calculated waveguide-to-waveguide insertion loss is as low as 0.5 dB for a 10-μm spacing between the mirror and the microlens. If no microlens is used, the insertion loss will increase to 6.6 dB. This design is insensitive to wavelength and is free of spherical aberration.

3. Fabrication

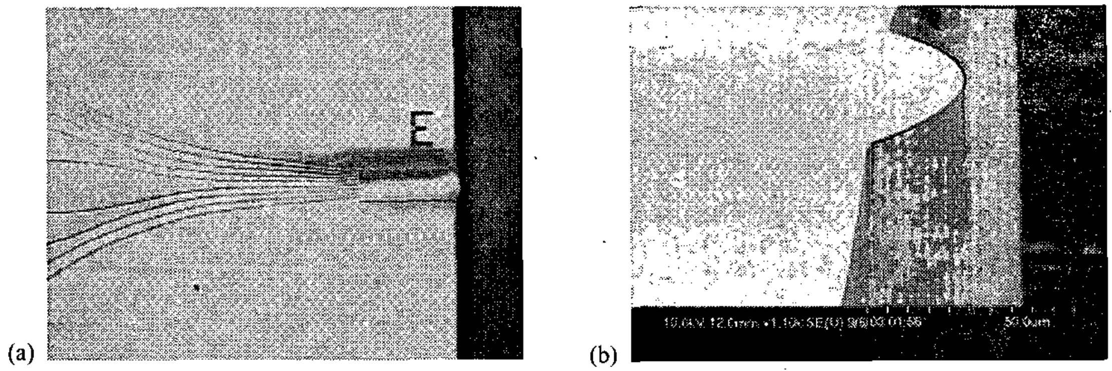

Fig. 3. (a) Optical micrograph of the PLC chip with on-chip microlens. (b) SEM of the cylindrical microlens at the edge of the PLC. It is created by deep reactive ion etching through the PLC layers. Vertical sidewall is achieved.

The PLC waveguides with a super high index difference of 1.5% is fabricated by processes similar to the AWG devices [9,10]. The effective waveguide core size is 4.5um x 4.5 um. The waveguide bending loss is negligible when the bending radius is greater than 2 mm. The cylindrical microlens is realized by etching through the 40-μm-thick PLC layers using STS Advanced Oxide Etch (AOE). We used a 4-μm-thick electroplated nickel as the etching mask. The etch stops selectively at the silicon substrate. After etching, the PLC chip is diced into individual chips. The exposed Si substrate is selectively etched by XeF_2. Fig. 3(a) shows the optical micrograph of fully processed PLC. Detailed view of the on-chip microlens is shown by the scanning electron micrograph (SEM) in Fig. 3(b). Very straight sidewall is achieved for the microlens. The sidewalls in the upper cladding layer and the core region are very smooth. The lower cladding layer has slightly larger surface roughness.

4. Experiment Result and Test

Ribbon fiber was not available during the time of our measurement. Instead, individual lensed fibers were used to couple light to PLC. The MEMS chip is wirebonded and mounted vertically on a micropositioning stage. Channel 3 (the third waveguide from the top) is used as the input waveguide. At zero bias, the reflected light is coupled to channel 8 (the symmetric waveguide at the lower half). When a voltage of 2.3V is applied to the micromirror, light is switched to channel 6. When the voltage is increased to 7.6V, light is coupled back to channel 3. The fiber-to-fiber insertion loss is measured to be 6.3 dB. This is higher than our theoretical estimation. The increase is attributed to the non-optimized coupling between fiber and PLC, non-perfect optical alignment, and the residue scattering loss from lens surface. The extinction ratio is 27 dB. The wavelength dependent loss is measured using an amplified spontaneous emission (ASE) source and an optical spectrum analyzer (OSA). The loss variation over a 60-nm band (1520nm to 1580nm) is less than 1dB. The temporal response of the switch is shown in Fig. 4. The switching time is less than 1 msec.

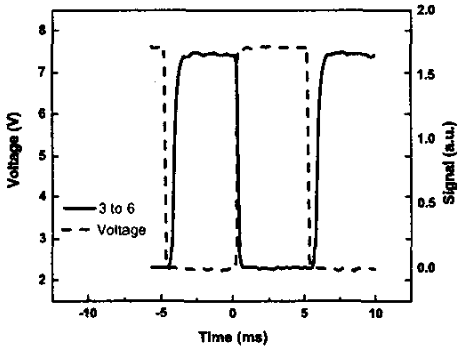

Fig. 4. Temporal response of the PLC-MEMS optical switch. Light is switched back and forth between channel 3 and channel 6. Switching time is less than 1 msec.

5. Conclusion

We have presented the design, fabrication, and testing results of a novel 1x8 MEMS optical switch using planar lightwave circuits (PLC). A cylindrical lens is microfabricated on the PLC to compensate beam divergence in the lateral direction. A fiber-to-fiber insertion loss of 6.3 dB, an extinction ratio of 27 dB, a switching time of < 1 msec, and a wavelength-dependent loss of < 1 dB have been achieved. The insertion loss can be further reduced by improving the fiber/PLC coupling. Even though separate MEMS and PLC chips are used in this demonstration, they can be monolithically integrated on the PLC chip. The switch is scalable to a larger port count, and can be integrated with array waveguide grating (AWG) to implement multi-port wavelength-selective switches.

This project is supported by DARPA CS-WDM program under MDA972-02-1-0020.

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