Solid-Immersion Micromirror with Enhanced Angular Deflection for Silicon-Based Planar Lightwave Circuits

Chao-Hsi Chi[1,2], Jui-che Tsai[1,2], Dooyoung Hah[2], Ki-Hun Jeong[1] and Ming C. Wu[1]
[1] Berkeley Sensors & Actuators Center (BSAC) and Department of Electrical Engineering and Computer Sciences
University of California, Berkeley, CA 94720-1770, USA
[2] Electrical Engineering Department, University of California, Los Angeles, CA 90095-1594, USA
Tel: +1-310-460-80●2, Fax: +1-510-643-6637, E-mail: josh@eecs.berkeley.edu

Abstract
We report on a MEMS-based on-chip solid-immersion micromirror (SIM), which provides enhanced angular deflection and reduced diffraction loss. The SIM is driven by rotary comb-drive actuators. Maximum mechanical scan angle of 8 degree is achieved.

Keywords: MEMS, on-chip micromirror, planar lightwave circuits, rotary comb-drive, SIM, solid-immersion micromirror.

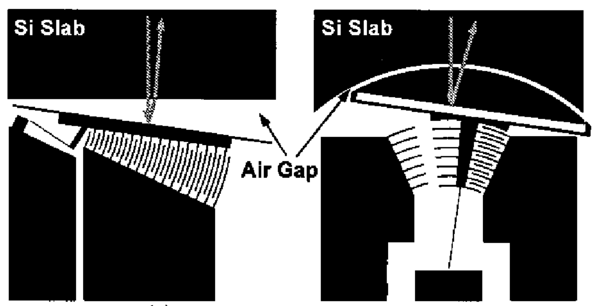
1 INTRODUCTION

Integration of planar lightwave circuits (PLC) and MEMS micromirrors can greatly reduce the size of optical MEMS systems [1-5]. Si-based PLC is particularly interesting for this application because the PLC and the MEMS micromirrors can be monolithically integrated on silicon-on-insulator (SOI) platform. Recently, we have reported a monolithic 1x4 wavelength-selective switch with on-chip vertical micromirrors [5]. Dynamic switching has been demonstrated. However, there are two drawbacks when using conventional flat micromirrors in such systems: (1) the deflection angle is reduced when the light beam re-enters the Si slab; and (2) the large air gap between the slab and the mirror results in high diffraction loss. Fig. 1(a) shows the schematic of a Si PLC MEMS with a flat micromirror driven by a rotary comb-drive actuator. The angular deflection is reduced by refraction at silicon-air interface. The reduction factor η can be calculated by Snell's law:

$$\eta = \frac{\sin^{-1}\left(\frac{1}{n}\cdot\sin\theta\right)}{\theta} \approx \frac{1}{n},$$

Where θ is the optical scan angle of the micromirror and $n = 3.5$ is the refractive index of Si. Therefore, 3.5 times larger scan angle is required for the micromirror. The other drawback is the higher diffraction loss. The optical beam diverges when propagating in the air gap. It in turn causes a diffraction loss when coupled back to the silicon slab. Fig. 2 shows the diffraction loss as a function of gap distance in the air for a 5μm-thick silicon slab. Since the air gap widens with increased rotation angle for the flat micromirror, it causes higher and angular dependent diffraction loss.

In this paper, we report on a novel on-chip solid-immersion micromirror (SIM), as shown schematically in Fig. 1(b). Instead of using the front Si-air interface, the micromirror is now coated on the back interface. The air gap between the Si slab and the SIM follow a curved contour so that light always passes through the Si-air interface at nearly normal incidence. The deflection angle inside Si slab is enhanced by approximately n times compared with conventional flat micromirrors. Since the air gap follows the curved trace of mirror rotation, the gap distance remains constant during rotation. This greatly reduces the diffraction loss, especially for large rotation angle.



(a) (b)

Figure 1. Schematic of on-chip micromirrors (a) flat micromirror (b) solid-immersion micromirror

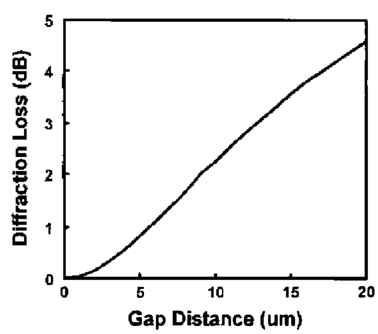
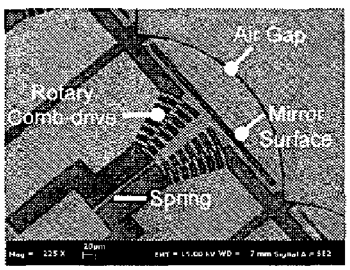


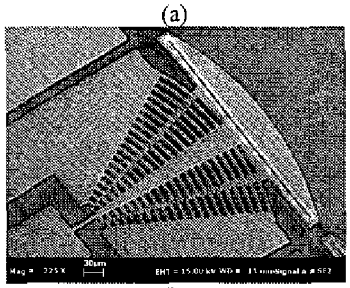
Figure 2. Diffraction loss versus the gap distance between the 5μm-thick silicon slab and the micromirror.

2 FABRICATION

The device is fabricated on an SOI wafer with a 5μm-thick device layer. The on-chip micromirrors and waveguides were etched in an Applied Materials Precision 5000 etcher. Low stress silicon nitride was deposited on the sidewalls by low-pressure chemical vapor deposition (LPCVD) for anti-reflection coating. The mirror surface was coated by aluminum by e-beam evaporation with a 30° tilting angle. The backside of micromirror was etched by deep reactive ion etching (DRIE), followed by a dry release process, in which the buried oxide was removed by a plasma etch. The scanning electron micrographs (SEM) of two SIM devices are shown in Fig. 3.



(a)



(b)

Figure 3. SEM pictures of the fabricated SIM with (a) 123μm spring length and 340μm effective mirror width, and (b) 53μm spring length and 355μm effective mirror width.

3 DEVICE PERFORMANCES

The DC characteristics of the micromirrors is shown in Fig. 4. The maximum mechanical scan angle is 5° for design (a) at 122V bias, and 8° for design (b) at 48V bias. The optical functionality was tested using an integrated chip with an array of waveguides in a fan-shaped layout and SIM in design (a). The input signal (λ=1550nm) at the central port (Port 5) was switched to Port 2 and Port 3 at 33V and 64V respectively. The IR image of the optical beam was observed at the output ports as shown in Fig. 5. The resonant frequency of the micromirror is calculated to be 5.38 kHz.

4 CONLUSION

We have demonstrated a novel solid-immersion micromirror (SIM) driven by rotary comb-drive actuators. A maximum mechanical scan angle of 8° is achieved at 48V. The optical scan angle inside the Si slab, 16°, is 3.5 times larger than that using flat micromirrors. The optical switching function has been confirmed by observing the IR image at the output ports.

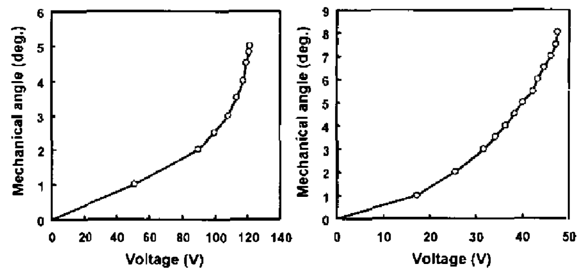


Figure 4. DC characteristics of SIM with (a) short structure (b) long structure.

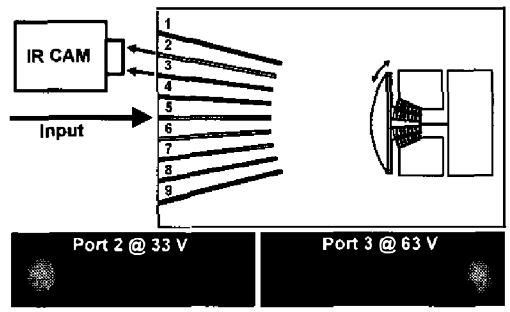


Figure 5. Optical test configuration and IR image of two output ports at corresponding voltages.

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