FABRICATION OF A MEMS BASED SYMMETRICALLY DEFORMABLE CONVEX MIRROR

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ABSTRACT

This paper presents a fabrication process of improved MEMS deformable convex micromirror system design in which a metalized polymer membrane is suspended on a uniform cylindrical air-filled cavity in order to obtain perfectly spherical convex shape, and a polycarbonate glass microstructure is used for easy adhesive bonding with PDMS membrane. The 3.5 mm diameter free standing circular membrane showed a 13.18 μm center deformation with symmetric spherical surface shape at applied current of 0.70 A to the electromagnetic solenoid. It was also investigated that the micromirror device could be integrated in beam guiding optical systems.

INTRODUCTION

Convex mirror, usually called secondary mirror, is one of the key functioning components in two-mirror based reflective objective spectroscopy systems such as Cassegrain configuration or Schwarzschild objective-type optics. It plays the important role of multiplying the focal length of another mirror, usually large concave primary mirror, by bouncing the light toward the primary mirror or an effective direction to produce better image [1-3]. Those convex mirrors are generally very larger compare to the size of micro-scale optical devices, and designed for fixed focal length which leads the overall system in limited applications and mechanical tunability with changing the mirrors positions in holder tube or otherwise. However, very few research groups have recently concentrated their attention to design the dynamic focal length variable convex micromirrors using the fabrication process of micro-electro-mechanical-systems (MEMS) technology [4-6]. Extensive research on designing for efficiently controllable focal length varying deformable convex micromirror, fabrication process and characterizations may lead a look for more stringent design of micro-optical devices.

Previously, our laboratory reported a variable focus control MEMS based convex mirror [7] consisting with a wet-etched free-standing mirror membrane, and a thin poly-dimethylsiloxane (PDMS) membrane bonded poly-methyl methacrylate (PMMA) microstructure for supporting the electromagnetic actuator components combination of a permanent magnet and a copper coil solenoid. To create a strong bonding between the PMMA microstructure and PDMS membrane, it was passed through a complex oxygen plasma treatment and cleanroom processing. Even though the reported device has its own advantages over operation principles and larger deformation stroke, it has shown imperfectly deformed curvature of membrane due to the asymmetrical cavity corner that leads to non-uniform initial stress in the free- standing mirror membrane. As a result, the reflected light beam from the convex mirror is scattered non-uniformly in wide-spread ways.

The study shown in this paper is concentrated on the fabrication of a symmetric shaped deformable MEMS based convex mirror with polycarbonate glass made microstructure that exempts the requirement of complicated oxygen plasma treatment and cleanroom facilities for bonding with PDMS membrane. Moreover, laser beam direction controlling and reflected light beam-spot observation has been demonstrated for investigating the device performance.

DEVICE DESIGN

Figure 1 shows the schematic diagram, and operation principle of modified MEMS deformable convex micromirror system. In this proposed design, the aluminum reflecting layer coated SU-8 thin film is hung freely on a cylindrical instead of truncated pyramid shaped [7] air-filled cavity within a silicon frame in order to balance uniformly the initial stress in the SU-8 mirror film against the driving force. The polycarbonate (PC) glass microstructure is used for holding the electromagnetic actuator components. When the electrical signal is applied to the actuator solenoid, the induced electromagnetic repulsive force pushes the permanent magnet and air pressure increases inside the cavity. The additional air pressure is balanced by changing the surface curvature into symmetrically spherical shape and consequently the reflected light beam direction is changed and focused in different location as illustrated in Figure 1(b).

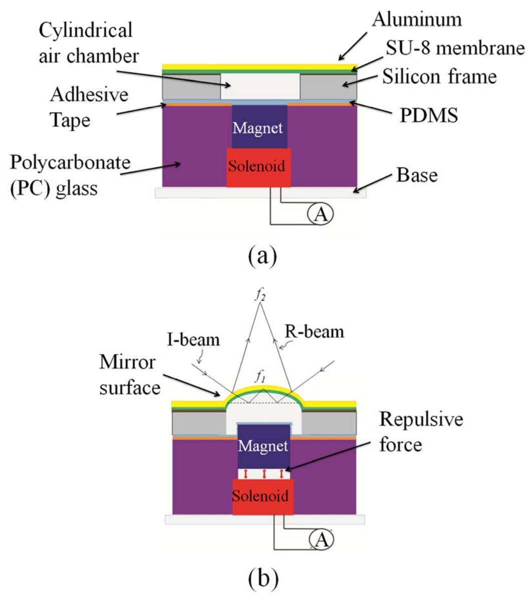
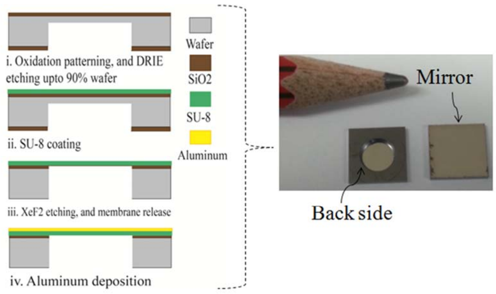
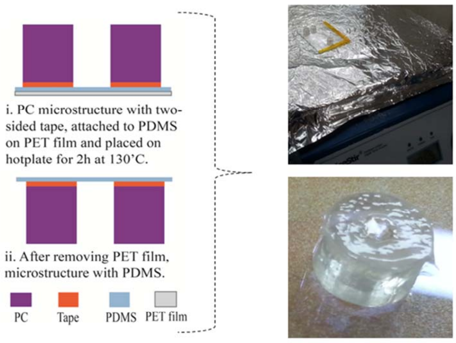


Figure 1: (a) Schematic diagram of deformable convex micromirror, and (b) Principle of operation, and the variation of beam focusing location with surface curvature.



(a)



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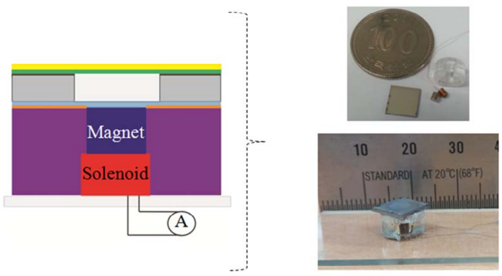

(c)

Figure 2 : Fabrication procedures and the photographs of components of the deformable convex mirror (a) membrane mirror, (b) actuator frame, and (c) bonding of system parts.

FABRICATION PROCESS

The fabrication procedures and the component photographs of the proposed deformable MEMS based convex mirror are shown in Figure 2. The mirror membrane was fabricated using MEMS technologies such as thermal oxidation and patterning, deep reactive ion etching (deep RIE) process, SU-8 film coating and Xenon difluoride (XeF_2) etching, buffered HF (BHF) etching and metal deposition. The controlling parameters of deep RIE and XeF2 etchings are shown in Table 1.

The polycarbonate (PC) glass microstructure, meanwhile, was fabricated using computer numerical control (CNC) machining technology. Afterwards, the PC glass microstructure and the PDMS membrane bonding was performed using two-side adhesive tape with the hotplate curing temperature of 130' C for 2 hour. Later, the PDMS coated microstructure and the mirror membrane suspended frame was bonded together with ensuring air-sealed chamber by another PDMS solution. Finally, the actuator components, NdFeB magnet and coil solenoid were installed and sealed with a glass substrate by adhesive.

Table 1: The parameters for deep RIE and XeF_2 dry etchings.

Parameters		**Conditions**
Deep RIE	SF_6	450 (sccm)
	O_2	45 (sccm)
	ICP power	2800 w
	Platen Temp.	20 'C
	Mask	Oxide (1 μm) and photoresist (6 μm)
	Si (100) etch rate	17 μm/min
XeF_2	XeF_2	9 sccm
	N_2	50 sccm
	Chamber pressure	9 Torr
	Platen Temp.	24 'C
	Si (100) etch rate	0.4 μm/min

EXPERIMENTAL RESULTS

When the significant amount of electrical bias current is applied to the coil solenoid, the free-standing planer mirror surface is changed to perfectly spherical shape as shown in Figure 3.

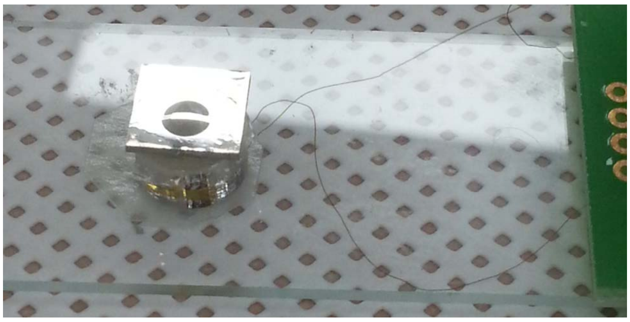

Figure 3: Photograph of the symmetric spherical surface shape, when the fabricated device is actuated with applied current.

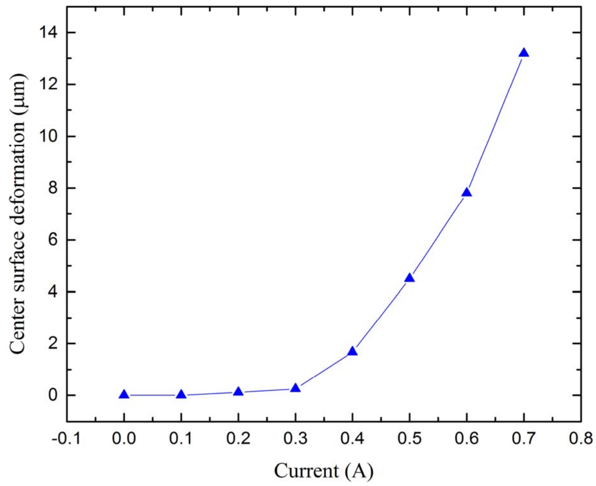

Figure 4: Center surface deformation vs. applied current to solenoid.

The mirror surface deformation was measured using Michelson interferometer setup as follows our earlier reported procedures in [7]. It has been observed that the

3.5 mm diameter free-standing mirror membrane shows a 13.18 µm center deformation with respect to the edge at an applied current of 0.70 A. Figure 4 shows the relation of center deformation of the mirror surface and the input currents to the coil solenoid.

To demonstrate how well the fabricated symmetrically deformable convex micromirror could uniformly direct the reflected beam, a laser beam tracking experimental setup was considered as depicted in Figure 5. The laser beam from the source was incident on the deformable mirror surface such an angle that the reflected beam was directed toward the screen (Figure 5(a)). When the electrical current was applied to the device solenoid, the mirror surface bulged symmetrically to spherical shape. Consequently, the reflected laser beam from mirror surface moved to new location in the screen as illustrated in Figure 5 (b). The laser beam profiler in the screen shows that the beam spot size became thin and almost uniform in shape with increasing the actuation current to solenoid (Figure 5 (c) and (d)). These demonstrate that the reflected beam travels the path with uniformity without significant scattering because of the symmetric spherical deformation of the mirror surface. Hence, this micromirror can be used in miniature reflective optical applications where the beam direction controlling is desirable.

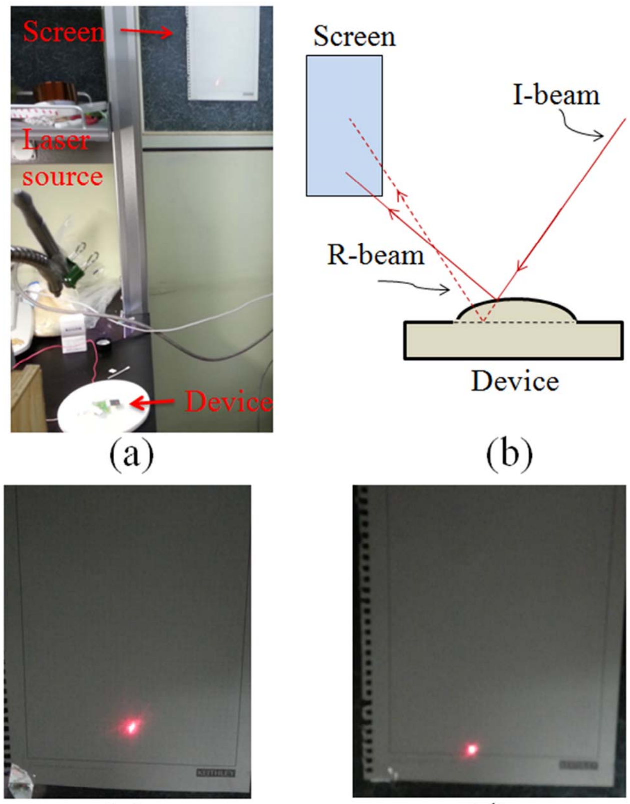

Figure 5: Laser beam track controlling (a) experimental setup, (b) optical configuration, and (c) and (d) beam profile in the screen for applied current of 0.2 A and 0.7A respectively.

CONCLUSION

In this paper, an efficient fabrication process of improved MEMS based design of a convex mirror for symmetrically spherical deformation has been presented. The 3.5 mm diameter mirror membrane shows a maximum center deformation of 13.18 µm with spherical surface shape at the controlling current of 0.70 A. The laser beam tracking performance affirms the potential integration of this device in micro-optical scanning systems.

ACKNOWLEDGEMENTS

This study was supported by the BK21 Plus project funded by the Ministry of Education, Korea (21A20131600011).

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