A Two-Axis Electrothermal SCS Micromirror for Biomedical Imaging

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Abstract: This paper reports a 1mm^2, two-axis, single-crystalline-silicon (SCS)-based aluminum-coated micromirror with large scanning angle (up to 40°), which can be used for biomedical imaging. The micromirror is fabricated by a deep-reactive-ion-etch post-CMOS micromachining process.

1. Introduction

MEMS mirrors with large scanning angles have great application potential in the fields of medical imaging, laser beam steering and interferometer systems. This paper presents a two-axis, single-crystalline-silicon (SCS)-based aluminum-coated micromirror that can be used for biomedical imaging. SCS micromirrors have been explored because of the manufacturability and flatness of SCS-based microstructures [1,2,3], while the use of electrothermal actuators allow for large angles of rotation at low driving voltages[4].

2. Micromirror Design and Fabrication

The schematic drawing of the 1mm^2 micromirror device is illustrated in Fig. 1(a). The mirror is attached to the outer frame by a set of aluminum/silicon dioxide bimorph beams (mirror actuator). As shown in Fig. 1(b), the mirror plate consists of a 40μm thick structural SCS layer that guarantees the mirror flatness. The polysilicon resistor embedded in the silicon dioxide is used as a heater to thermally actuate the mirror along the first axis of rotation. The mirror frame is attached to the substrate by another set of identical bimorph beams (frame actuator) that rotates the frame along the second axis of rotation. The residual stresses and different coefficients of thermal expansion of the bimorph materials result in the beams curling out of the plane of the substrate. The micromirror (Fig. 2) is fabricated using deep-reactive-ion-etch (DRIE) CMOS-MEMS processing [5]. The process flow, outlined in Fig. 3, uses only four dry etch steps. The process starts with a backside silicon etch, followed by a frontside anisotropic oxide etch using interconnect metals as etching mask. Next, a deep silicon trench etch is used to release the microstructure. The last step is an isotropic silicon etch to form bimorph thin-film beams. There are no substrate or thin-film layers directly above or below the mirror microstructure, so large actuation range is allowable.

3. Characterization

Fig. 4 shows the measured rotation angles at different currents for the two independent axes. The mirror frame rotates 40° at 6.3mA or 15V, while the frame rotates to 25° at 8mA or 17V. Mirror rotation angles up to 50° are observed at higher currents, but the high stress results in mirror instability. Therefore the usable range of the mirror is 40° for the first axis and 25° for the second axis. The frame provides additional thermal isolation to the mirror actuator, so that the same current will cause larger rotation angle for the first axis than that for the second axis. The mirror actuator burns out at a current of 8mA. The open circuit polysilicon resistances of the mirror and frame actuators are 1.09kΩ and 1.26kΩ, respectively. The DC current dependence of the resistors is plotted in Fig. 5. The resistances of the polysilicon heaters change significantly with current because the heating effect of the current causes temperature change that in turn induces stress change in the bimorph beams. The resonant frequencies of the mirror and frame actuator structures are 445 Hz and 259 Hz, respectively. The radius of curvature of the mirror is 0.33m.

4. Conclusion

An electrothermal micromirror that can independently scan in two axes has been demonstrated. Tilt angles of more than 25° and resonant frequencies of more than 250 Hz in both axes have been achieved with this initial design. Higher speeds (up to a few kilohertz) are achievable at the price of greater power consumption or smaller mirror size. This type of 2D micromirror may be applied into optical switching or 3D biomedical imaging.

References

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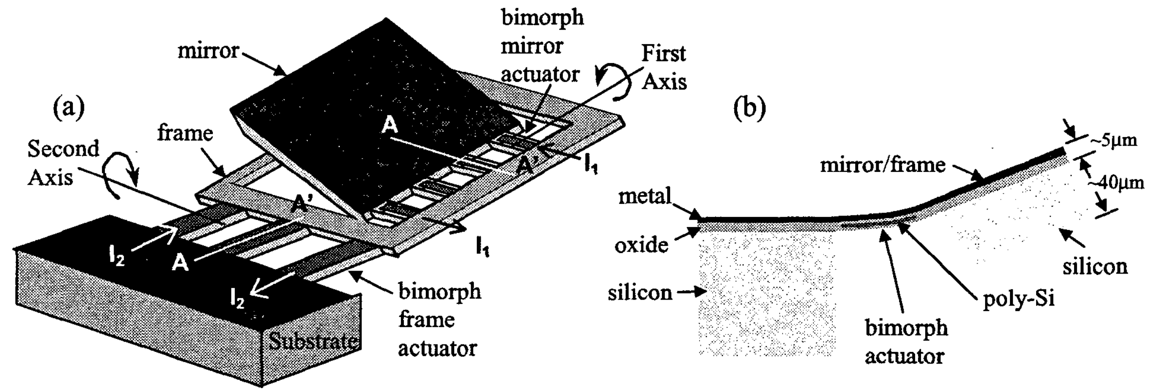

Figure 1: (a) Design Schematic of the two-axis mirror; and (b) crossectional view of A-A'

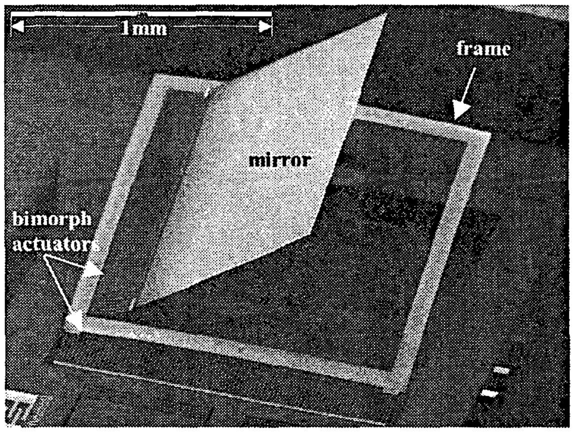

Figure 2: SEM of the two-axis electrothermal mirror

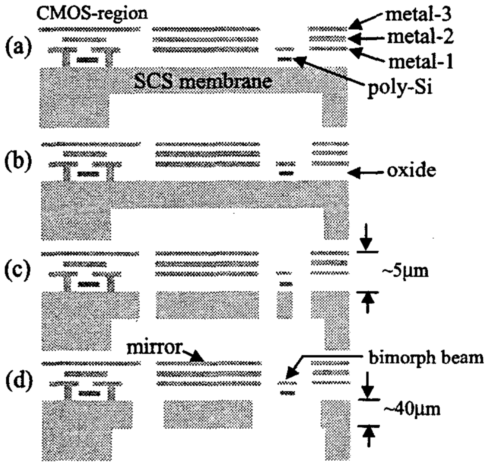

Figure 3. DRIE CMOS-MEMS process flow: (a) backside etch; (b) oxide etch; (c) deep Si etch; and (d) Si undercut

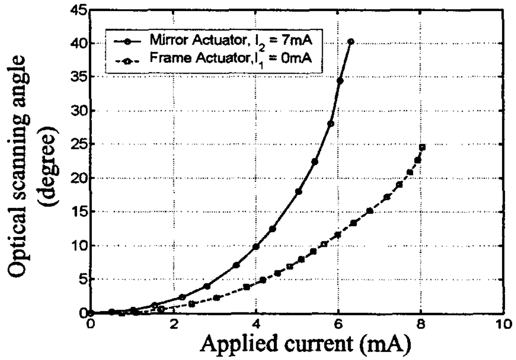

Figure 4: Plot of the rotation angle versus current for the two axes

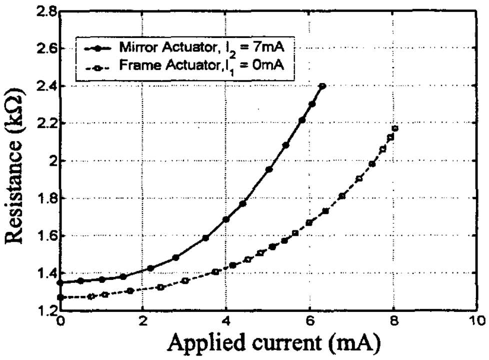

Figure 5: Plot of the poly-Si heater resistance versus current for the two axes