A Single-Crystal Silicon-Based Micromirror with Large Scanning Angle for Biomedical Applications

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Abstract: This paper reports a single-crystalline silicon (SCS)-based micromirror with large scanning angle (up to 31°) which can be used for biomedical imaging. The micromirror is fabricated by using a deep reactive-ion-etch (DRIE) post-CMOS micromachining process. Thin bimorph actuation structures and movable bulk silicon structures are simultaneously achieved. The micromirror is 1 mm by 1 mm in size, coated with aluminum, and thermally actuated by an integrated polysilicon heater. The radius of curvature of the mirror surface is about 50 cm. The mirror rotates 31° at 9 mA. The resonant frequency of the device is 380 Hz.

OCIS codes: (230.0230) Optical devices; (230.4040) Mirrors

1. Introduction

Large, flat micromirrors with large scanning angle are required by applications such as medical imaging, interferometer systems and laser beam steering. Single crystal silicon (SCS) micromirrors with two-level comb drives [1], curled comb drives [2], or an SCS mirror assembled on top of polysilicon actuators [3] have been reported. In prior work, a 1mm-by-1mm SCS mirror with bimorph thermal actuation rotates 17° when 15 mA current is applied [2]. However, the buckling of the employed bimorph mesh structure causes a discontinuity in the angle versus current curve, which limits the usable angle range to about 5°. This paper introduces an improved design with no discontinuity in the response curve and even larger rotation angle.

2. Structural Design

The schematic of the mirror design is shown in Fig. 1. The mirror is attached to a bi-layer aluminum/silicon dioxide mesh with polysilicon encapsulated within the silicon dioxide to form a bimorph thermal actuator. The mesh

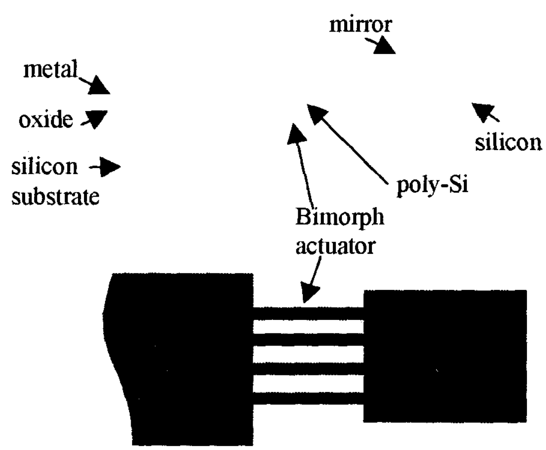
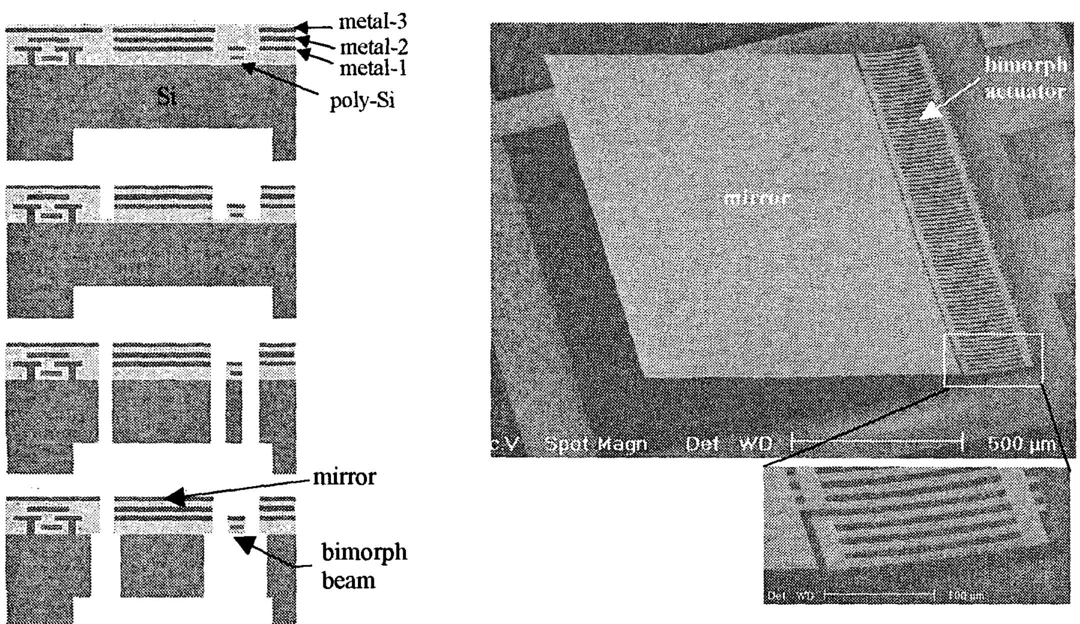


Figure 1. The mirror design. (a). Cross-sectional view; and (b) top view.

curls up after being released due to the tensile stress in the aluminum layer and compressive residual stress in the bottom silicon dioxide layer.

3. Device Fabrication

The micromirror is fabricated with deep reactive-ion-etch (DRIE) CMOS-MEMS processing [4]. The process flow is shown in Fig. 2(a), which includes 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 deep 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 there is no mechanical limit to the actuation range. Fig. 2(b) shows a scanning electron micrograph (SEM) of a fabricated micromirror. The structural SCS layer backing the mirror surface is about 40 μm-thick and provides very good flatness across the 1 mm surface. Polysilicon in the beams is used as a heater to actuate the mirror. Due to the different residual stress and coefficients of thermal expansion of the embedded materials, the hinge curls out of the substrate plane.

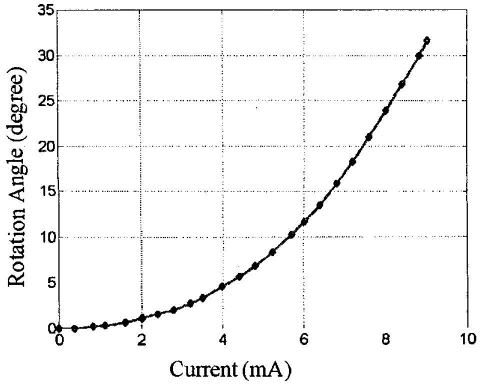


(a) (b)

Figure 2. Device fabrication. (a) Process flow. (b) SEM of a released device.

4. Characterization

Fig. 3 shows the measured rotation angles at different currents and the current dependence of the polysilicon resistor. A rotation angle of 31° is achieved at 9 mA or 18 V. The response curve is smooth over the whole scanning range. So this mirror design eliminates the discontinuity problem observed in [2]. The resistance of the polysilicon resistor changes significantly with current, because large stress is induced by the large deformation of the bimorph beams due to heating. The resonant frequency of the mirror is 380 Hz.



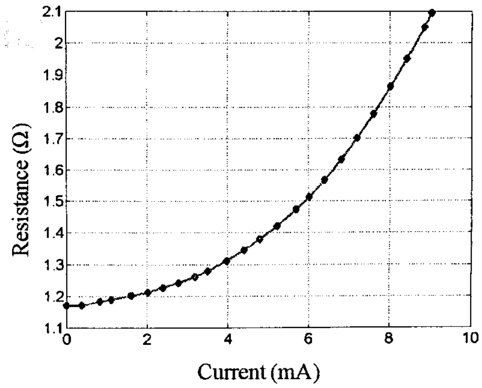


Figure 3. Measurement results. (a) Plot of the rotation angle versus current. (b) Plot of the resistance of the polysilicon heater versus current.

5. Conclusion

A large single-crystal micromirror with large scanning angle has been demonstrated. It has potential applications for biomedical imaging.

6. References

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