A 3-D Micromirror Utilizing Inverted-Series-Connected Electrothermal Bimorph Actuators for Piston and Tilt Motion

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ABSTRACT

A new electrothermal micromirror with large piston and tilt motions was proposed and fabricated. Large initial tilt angles and optical path shifting of previously fabricated thermal micromirrors were eliminated by employing inverted-series-connected (ISC) bimorph actuators.

1. INTRODUCTION

Micromirrors have applications in optical displays, optical switches, and biological imaging systems [1-2]. Problems with many micromirror designs include limited static angular displacements, high actuation voltages, size limitations, and fabrication difficulty. Previous CMOS-compatible electrothermal designs have been shown to achieve high static angular deflection at low actuation voltages, but exhibit large initial tilt angles and optical path shifting [2]. In this paper, we present a three-dimensional (i.e. two axis rotations plus phase only motion) electrothermal micromirror design that eliminates large initial tilt angles and optical path shifting by employing inverted-series-connected (ISC) bimorph actuators. The same actuator concept was previously reported for piezoelectric bimorphs [3] and a similar MEMS actuator using thermal bimorphs has been used previously for the lateral actuation of a tunable capacitor [4].

2. DESIGN

The ISC bimorph actuator consists of two S-shape bimorph sections attached end-to-end as shown in Fig. 1. An individual S-shape section consists of two bimorph sections attached in series where one section has a top layer high-CTE metal (Al) and bottom layer low-CTE dielectric (SiO_2) and the adjacent section has opposite layer composition. This alternating construction of the material layers allows each bimorph section to have equal and opposite curvature upon actuation so that the beam deforms to an S-shape and has zero tangential angle at the end. Fig. 1 also shows how an ISC bimorph displaces in response to a rise in temperature. Note that each S-shape section has a lateral displacement when actuated, point *A* in Fig. 1(b) moves in both *x* and *z* directions. However, the lateral shifts of S_1 and S_2 cancel each other, resulting in a pure *z*-displacement at point *B*.

ISC bimorphs are attached to the center of each side of a 500 µm × 500 µm mirror plate as shown in Fig. 2. Each ISC bimorph is composed of four 10 µm × 100 µm bimorph beams. The ISC bimorphs are attached to the substrate by external heaters composed of a polysilicon resistor embedded in SiO_2. Thermal isolation regions, composed of eleven 8 µm × 20 µm SiO_2 beams, connect the ISC bimorphs to the mirror plate. The thermal isolation regions prevent heat conduction between the ISC bimorphs and the mirror plate and eliminate thermal coupling between actuators. The combination of the external heater attachment and thermal isolation is designed to give an approximately uniform temperature about the length of the ISC when a voltage is applied to the polysilicon resistor. Thus each bimorph section of the ISC will have equal curvature change when heated and the ISC will exhibit displacement in one direction at the end. Vertical piston-mode actuation is achieved by applying an equal voltage to each heater. Tilt-mode actuation is achieved by combining a common voltage (represented by V_P) to all actuators with additional voltages of equal magnitude and opposite polarity (represented by $V_{T\text{-}x}$ and $V_{T\text{-}y}$) to two heaters on opposite sides of the mirror plate. During tilt-mode actuation, the oppositely positioned heaters will increase and decrease temperature by an equal magnitude. Therefore the ISC actuators on each side of the mirror plate will displace in the *z* direction by equal and opposite magnitudes. This allows the mirror to rotate about a fixed axis so that the center of the mirror does not shift laterally in space. A light beam directed to the center of the mirror will reflect off of the same point in space, thus the optical path will not shift. Scanning is possible by applying out of phase AC voltages to actuators on opposite sides of the mirror plate.

3. SIMULATION

The electrothermomechanical behavior of the device was simulated using FEM (CoventorWare). The material parameters used in the simulation were based on published data. Piston-mode actuation was simulated for an applied voltage range of 0 – 7 V where vertical displacement of 103 µm was obtained for an applied voltage of 7 V. Tilt-mode actuation was simulated using a common voltage of 5 V applied to all actuators plus a tilt-mode voltage range of ±2 V applied to actuators on opposite sides of the mirror plate where a rotation angle of ±3.5° was obtained for a tilt-mode voltage of ±2 V. Fig. 3 shows an image of the mirror rotation at +2 V. Fig. 4 shows a plot of the rotation angle versus voltage obtained from the FEM tilt-mode simulation.

4. FABRICATION AND INITIAL TESTING

The device was fabricated using the AMI 1.5 µm conformal CMOS process followed by a post-CMOS process for device release. The conformal deposition of the process is utilized to provide the alternating layer construction of the ISC bimorph. The post-CMOS process (shown in Fig. 5) starts with a backside silicon etch to define an Si membrane thickness under the mirror plate which ensures mirror flatness. A partial SiO_2 etch follows that exposes metal-2 but leaves metal-1 with SiO_2 protection. Next a partial Al wet etch reduces the thickness of metal-2. Metal-2 provides protection of the top layer SiO_2 of the ISC bimorphs during the following anisotropic SiO_2 RIE etch that exposes the Si substrate. Ion-milling of Al in the SiO_2 RIE etch eliminates the remaining metal-2. Finally anisotropic DRIE and isotropic Si etches release the structure. Residual stresses in the Al and SiO_2 layers cause the device to have an initial displacement of 70 µm. Fig. 6 shows an SEM of a released device.

To qualitatively measure the displacement of the micromirror, the micromirror was placed on a hot plate and observed under a microscope. It was found that the micromirror surface displaced by approximately 70 µm to become flat with the substrate plane at a temperature of approximately 130 – 140 °C. Characterization experiments are currently being conducted.

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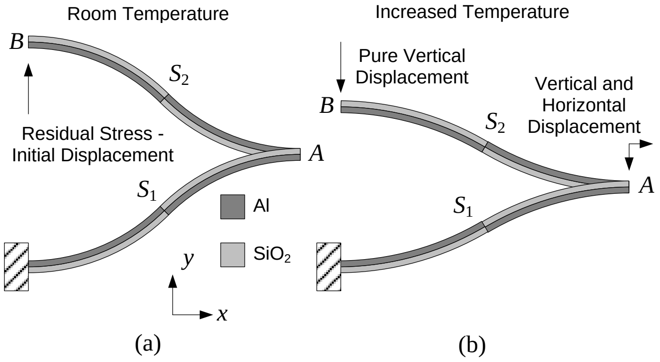

Fig. 1: Diagrams showing the ISC bimorph deformation at (a) room temperature (b) an increased temperature.

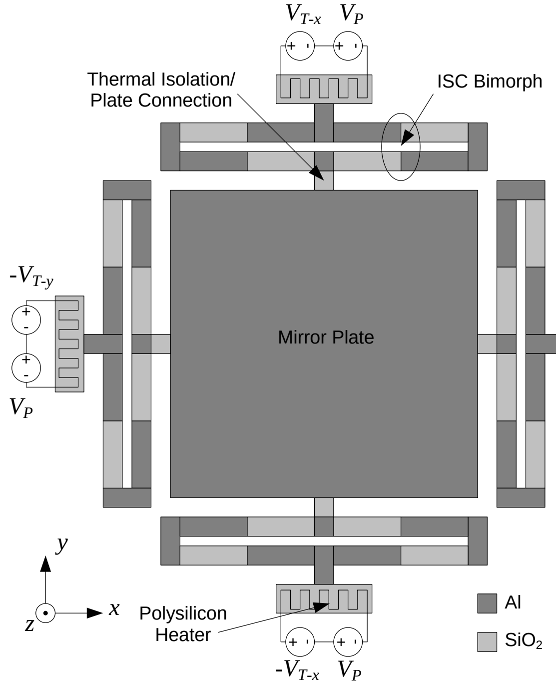

Fig. 2: Top-view schematic of the micromirror design.

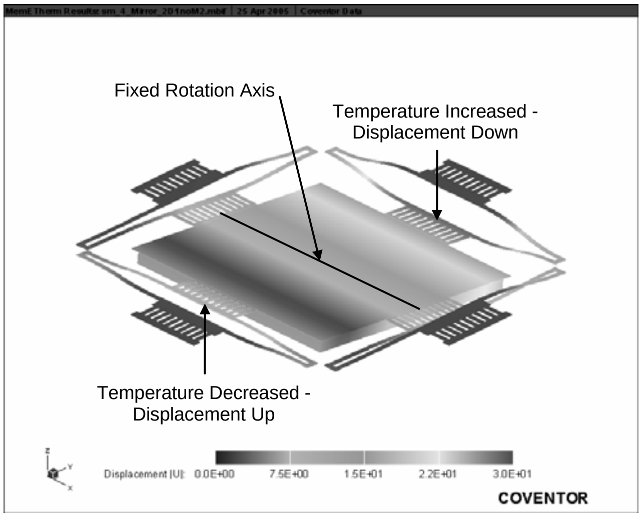

Fig. 3: FEM simulation image of tilt-mode actuation at +2 V.

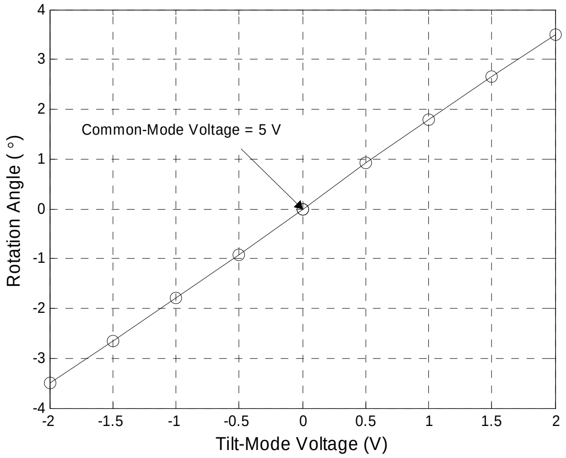

Fig. 4: FEM simulation of rotation angle versus tilt-mode voltage.

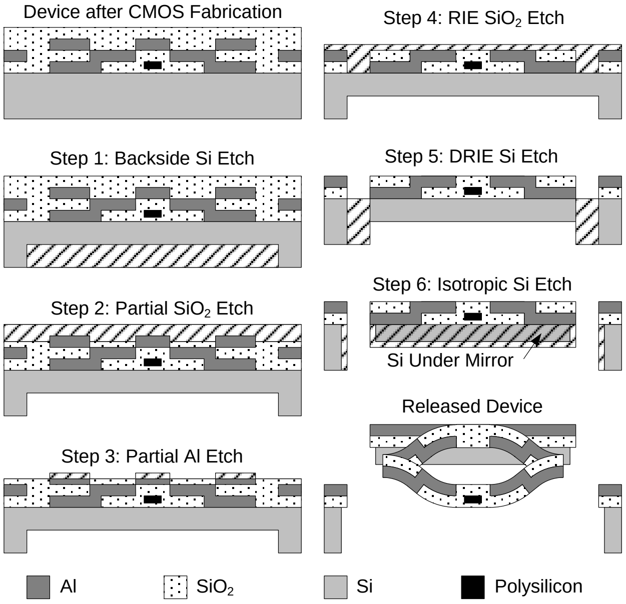

Fig. 5: Post-CMOS fabrication process.

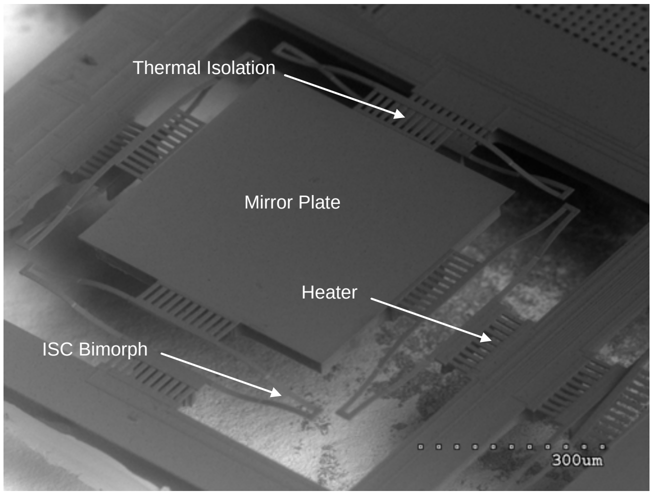

Fig. 6: SEM image of a released micromirror.