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An electro-thermally driven microactuator with two dimensional motion

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Abstract In previous literatures, most of the microactuators were designed to deflect in one dimension only. Here, an electro-thermally driven microactuator with out-of-plane and in-plane two dimensional motion is designed, fabricated and tested. This microactuator comprised of a series of bimorph beams, a moving plate, a lateral driven unit, and contact pads. The out-of-plane motion is produced due to the bimorph effect and residual stress between the layers of Au and polysilicon when they are heated. The in-plane motion is obtained by heating the lateral driven unit which consists of two adjacent beams with different cross sections but the same length, then the asymmetrical thermal expansions in two adjacent beams lead to lateral deflection. The microactuator proposed here is fabricated by surface micromaching technique. A two-step releasing method is used here to free the microactuator successfully. The testing results show that the lateral driven unit can produce 10 μm lateral displacements at input voltages of 5 V, and bimorph structures at the same voltage can produce about 12 μm downward displacement. It is also found that this two dimensional motion can be controlled almost independently.

1 Introduction

In microactuators, the popular actuation methods include piezoelectric, thermal, magnetic, electrostatic and other technologies. The motion directions of microactuators usually can be divided into in-plane motion (included lateral and rotary motion) and out-of-plane motion. Comb-drive [1] and micromotor [2] are the examples of in-plane motion. Deformable mirror [3], polyimide V-groove joint [4] and bimorph beams [5, 6] are the examples of out-of-plane motion. Despite the large number of papers on microactuators, very few have discussed the design and fabrication of microactuators to move more than one direction.

Here, an electro-thermally driven microactuator is proposed by integrating bimorph beams and a lateral driven unit to provide two dimensional motion, in out-of-plane and in-plane directions, which has not been reported before. The design, fabrication, and testing of such microactuator are presented below.

2 Concept design

A schematic view of the proposed microactuator is shown in Fig. 1. This microactuator comprised of a series of $70 \times 10 \times 2.5$ μm bimorph beams, a $500 \times 100 \times 2$ μm moving plate, a $600 \times 24 \times 2$ μm lateral driven unit with 6 μm gap distance between two beams, and contact pads. At initial state, the bimorph beams with the moving plate will bend upwards due to the residual stress difference in bimorph beams. When the bimorph beams are heated, the moving plate with the lateral driven unit will bend downwards to achieve out-of-plane motion. For in-plane motion, it is obtained by heating the lateral driven unit, which consists of two beams with different cross sections [7]. When two beams are heated by applying electric voltage, two beams will deflect laterally due to the asymmetrical thermal expansions. Then the two dimensional motion can be achieved by controlling the input modes of the electrical voltage.

3 Fabrication

The proposed device is fabricated by the MUMPs (Multi-User MEMS Process) [8]. The fabrication process for this microactuator is shown in Fig. 2. First a 600 nm low-stress LPCVD (low pressure chemical vapor deposition) silicon nitride layer is deposited on the wafers as the isolation layer (Fig. 2a). A 2.0 μm phosphosilicate glass (PSG) is then deposited by LPCVD as the sacrificial layer (Fig. 2b). The sacrificial layer is also lithographically patterned to form the dimples and anchor.

After etching anchor and dimples, the first structural layer of polysilicon (Poly 1) is deposited at a thickness of 2.0 μm (Fig. 2c). A thin layer of PSG (200 nm) is deposited over the polysilicon as the hard mask for the subsequent polysilicon etch. The polysilicon and this PSG masking layer are patterned to form the conducting pads, moving

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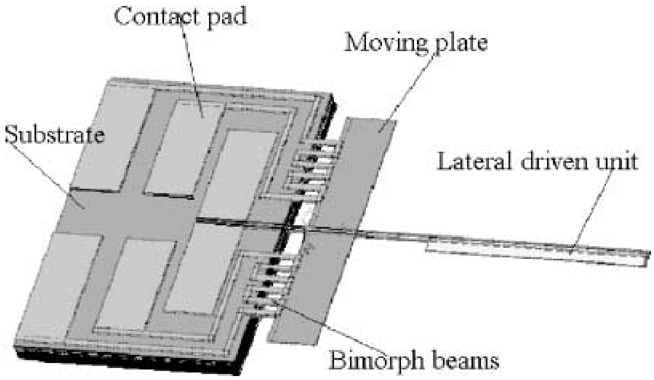

Fig. 1. Schematic view of the proposed electro-thermally driven microactuator

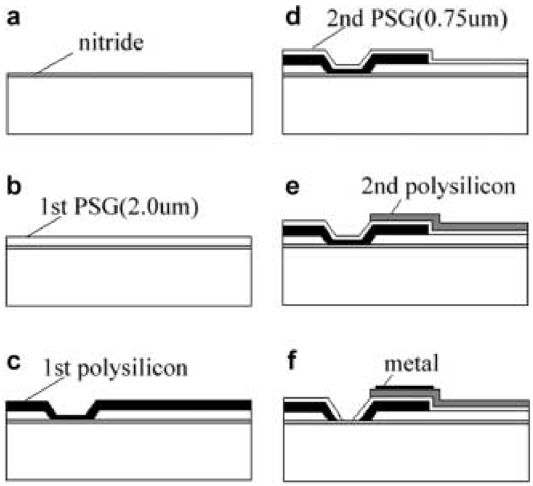

Fig. 2. Fabrication process

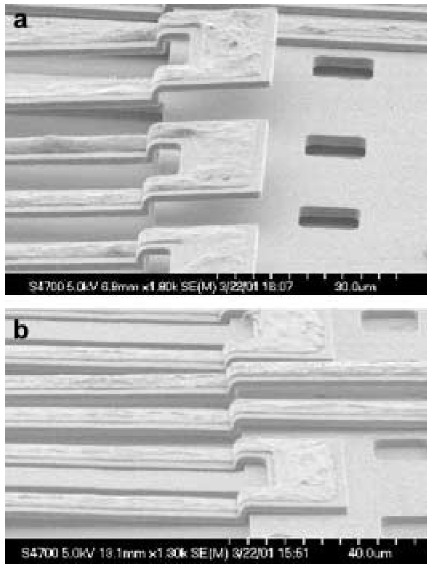

Fig. 3. **a** The initial fabrication result by one-step releasing process. **b** The final fabrication result by modified two-step releasing process

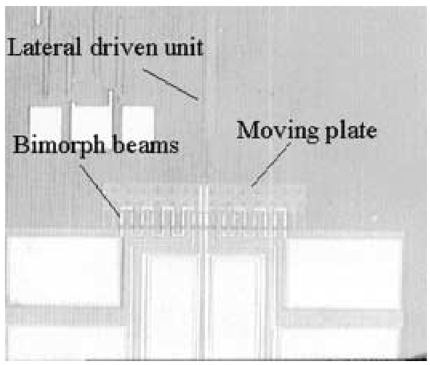

Fig. 4. The top view of the fabricated result of the microactuator

plate, and lower layer of bimorph structures in this first structural layer Poly 1. After etching the polysilicon, the remaining PSG hard mask is removed by RIE.

Then, another PSG layer of 0.75 μm is deposited to act as the adhesion layer to connect the moving plate and bimorph structures (Fig. 2d). The second structural layer, Poly 2, is then deposited with 1.5 μm and the deposition of 200 nm PSG is performed. As Poly 1 level, the thin PSG layer acts as an etch mask. The Poly 2 and this PSG layer are then patterned to form the lateral driven unit (Fig. 2e). After that, the masking PSG layer is removed.

The final deposited layer is the 0.5 μm metal layer, as shown in Fig. 2f. The metal on the beam structures that are produced in Poly 1 level form the bimorph beams.

The releasing process, in the beginning, was performed by immersing the chip in a bath of 49% HF (at room temperature) for about 10 min, several minutes in DI water and alcohol to reduce stiction, then at least 10 min in an oven at 110 °C. The fabricated results from this one-step releasing is shown in Fig. 3a. It is found that the moving plate and bimorph beams are separated. The reason is that this device has several PSG layers. The upper 0.75 μm PSG layer between the moving plate and bimorph beams (10 μm width) is used as a adhesion layer to connect the moving plate and bimorph beams, and the lower 2 μm PSG layer under the moving plate is used as the sacrificial layer. The etching time to remove the sacrificial layer is about 10 min in HF solution, but this etching time will causes the adhesion PSG layer to be depleted thoroughly also, then the moving plate and bimorph beams can no longer be connected.

In order to avoid the adhesion PSG layer being etched away completely, a two-step releasing process is proposed. The upper 0.75 μm PSG layer is etched first, and another mask is added to protect the PSG between the moving plate and bimorph beams. After that, the chip is immersed into Buffer Oxide Etchant (B.O.E) for 2 h to release the PSG sacrificial layer, then several minutes in DI water and 30 min in alcohol, which is the same as the one-step releasing processes. After modification on the release process, the moving plate connected with the bimorph beams is successfully fabricated, as shown in Fig. 3b.

4
Results and discussion

The top view of the fabricated result is shown in Fig. 4. The SEM of the lateral driven unit and bimorph beams

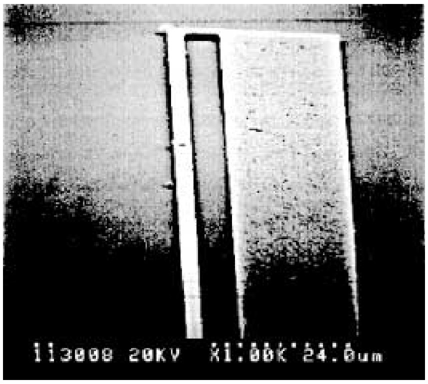

Fig. 5. The SEM of the lateral driven unit

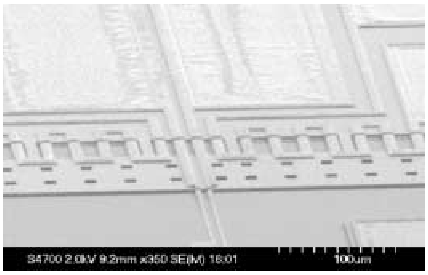

Fig. 6. The SEM of the bimorph beams, moving plate and contacted pads

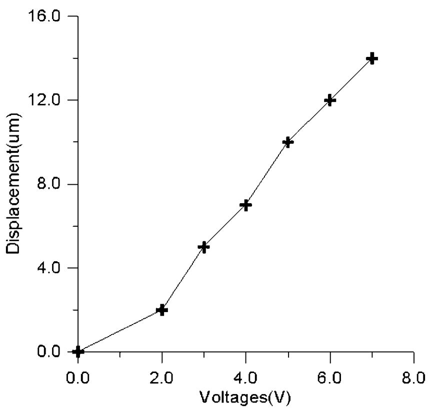

Fig. 7. The measured lateral displacements of the lateral driven unit under different input voltages

with moving plate are shown in Figs. 5 and 6, respectively. In testing, various d.c. voltages are applied to the contact pads to generate different motion modes. The lateral displacements are measured from the pictures captured by image capture software from the video. The downward displacements are determined by focus/defocus method on the optical microscope, which gives the measurement error about 1 μm.

In the initial state, it is observed that the end of the moving plate curled up about 12 μm from the substrate, 4° in angular displacement, due to the residual stress in bimorph beams. Figure 7 shows the testing results of the lateral driven unit under various input voltages. The lateral displacement up to 14 μm can be achieved at input voltage of 7 V. Also, the testing results of the bimorph beams are

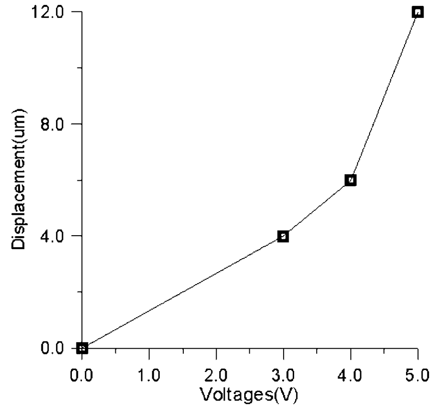

Fig. 8. The measured downward displacements at the end of the moving plate under different input voltages

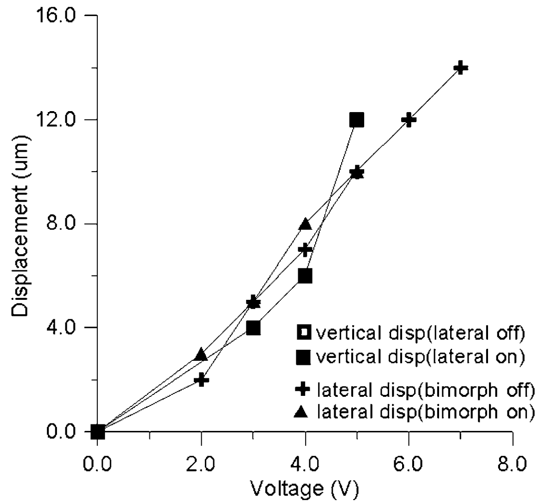

Fig. 9. The measured displacements in coupling test where the lateral driven unit and bimorph beams are operated at the same input voltages simultaneously

shown in Fig. 8, where 12 μm downward displacement is achieved at 5 V before touching the substrate.

In addition, two-dimensional tests are performed to see if there is coupling effect where both bimorph beams and the lateral driven unit are operated under the same input voltages. Figure 9 shows that no matter the lateral driven unit is operated or not, the vertical displacements of bimorph beams under different voltages are not affected. Similar testing results are also found in lateral displacements. No matter the bimorph beams are turned on or turned off, the maximum difference in lateral displacement is only about 1 μm, which is within the measurement error range. From Fig. 9, it is shown that the coupling effect between the vertical and lateral direction is very small, and these testing results demonstrate the capability of providing two dimensional motion with the proposed microactuator.

5
Conclusions

An electro-thermally driven microactuator with two dimensional motion is designed, fabricated and tested here. Some features of this microactuator are summarized below.

(1) The residual stress difference in two layers of bimorph beams produces the initial out-of-plane motion. It is undesired to has the residual stress in the IC fabrication. But we use this effect to have initial out-of-plane displacements.
(2) The fabrication of this microactuator is compatible with IC processes. This makes the microactuator suitable to be integrated with other IC components on the same chip.
(3) This microactuator is shown to be able to deflect in two dimensions and nearly uncoupled.
(4) This microactuator is self assemblied and does not need any locking structures or external manipulation.
(5) Modified releasing processes is helpful in fabricating this microactuator.

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