The Fabrication and Multi-Physics Simulation of a Novel Low Power Electrothermal Bimorph Actuator

Lou Wen-zhong*, Guo Ming-ru*, Lv Yong-jia*, Song Rong-chang*, Liu Peng*

* Science and Technology on Electromechanical Dynamic Control Laboratory, Beijing Institute of Technology, 100081 Beijing, China

ABSTRACT

This paper presents the multi-physical simulations and fabrication of a novel electrothermal bimorph actuator. The dimension and structure of the actuator is improved based on the theory of optimal thickness configuration, and its three-dimensional modeling is conducted with the software CoventorWare. To confirm the performance of the new micro-actuator, many simulations are made by a method of multiphysical coupling supplied by the simulation software COMSOL Multiphysics. The results of multi-physical simulations show that the device could achieve large displacement with low-power in short response time. Finally, an available fabrication process flow is presented. Currently the novel electrothermal bimorph actuator is in production, and its performance will be tested when the processing is ended.

Keywords: MEMS, Electrothermal bimorph actuator, Multi-Physics simulation,Optimal thickness, Fabrication

1 INTRODUCTION

As an important MEMS device, micro actuator transfers the energy of electrical, heat, light and other forms into mechanical energy, generating displacement and force. These actuators have been used widely in microsystems, such as micromirrors, RF switches, nanoprobes, IR detectors and read-write cantilevers used in data storage [1]. According to the different working principles, micro actuators can be divided into electrostatic actuators, piezoelectric actuators, electrothermal actuators, magnetic actuators, etc.

The electrothermal bimorph actuator is a kind of electrothermal actuators works based on the principle of hot deformation of two kinds of metals with different thermal expansion coefficients. This kind of actuator could achieve large displacement with low power and simple structure, and there is a linear relationship between the displacement and the driven power. So it draws the attention of many researchers.

Reithmüller and BeneckeReithm demonstrated a electric bimorph actuator based on the material of gold and silicon [2]. The actuator realized 100 μm offset with 200mW of power. The structure of the actuator is shown in Figure 1. A polycrystalline silicon layer is embedded into the bimorph layers as a heating layer. The actuator has the highest efficiency of 570 μm/W (actuating displacement/input power), the heat conversion rate of 0.17 μm/K (actuating displacement/metal layer temperature), and the actuator structure response time of less than 30ms.

Besides, researchers of Texas Institute of Technology designed a V-shaped-beam electrothermal actuator to drive a ratchet [3]; Kevin.R and his team of University of Maryland designed a kind of optical switch based on the electrothermal actuator [4].

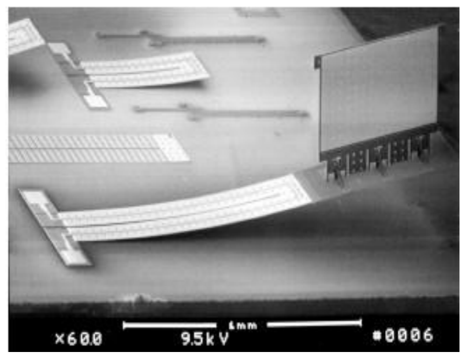


Figure 1: A micromirror based on bimorph actuator [5].

2 DESIGN

2.1 Optimal Thickness Ratio

The electrothermal bimorph actuator works based on the principle of hot deformation of two kinds of metals with different thermal expansion coefficients.

According to the double metal membrane curvature formula [1], the relationship between end tangent angle and the actuator input energy could eventually be expressed as bellow:

$$\theta = \beta_\rho \frac{L_A}{t_A} \Delta\alpha_T \Delta\overline{T} \qquad (1)$$

$$\beta_\rho = 6 \frac{(1+m)^2}{\frac{1}{mn} + m^3 n + 4m^2 + 6m + 4} \qquad (2)$$

So we could get the maximum bending constant when mn2= 1 and β_ρ=1.5, and get the optimal thickness ratio m_0 [2].

A simulation proved that the actuator could get the the maximum displacement at the optimal thickness ratio. The result of the simulation is shown in Figure 2.

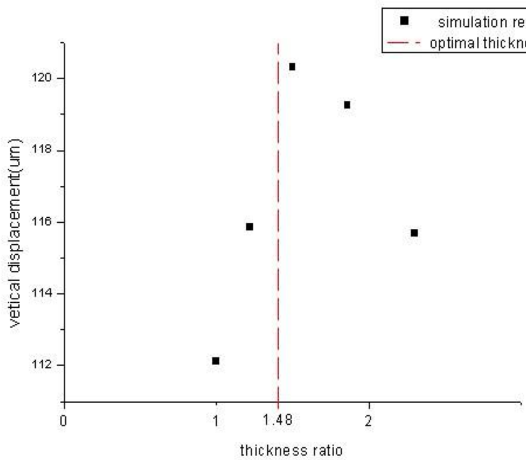


Figure 2: Simulation of optimal thickness ratio.

2.2 Position of the Heater

The position of the heating layer will affect the performance of actuator. A set of simulations are conducted with the heater located at different position. The location of the heater and the corresponding results of the simulations are shown in Figure 3.

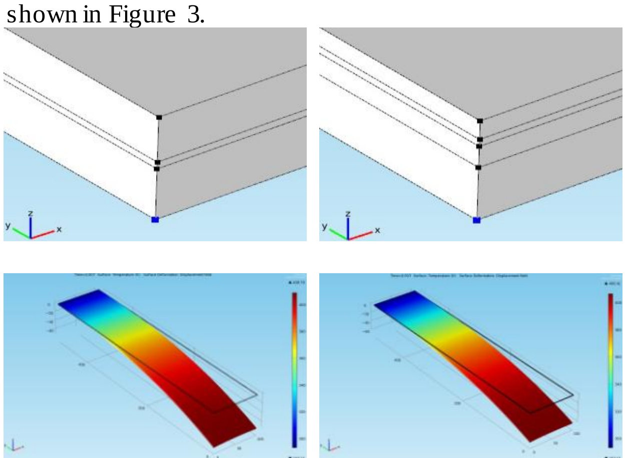


Figure 3: Position of tht heater.

The results show that when the electric heating layer is located between the two layers, the electrothermal bimorph actuator realizes the maximum displacement, which is 15% larger than embedded in the layer with larger thermal expansion coefficient.

2.3 Model of the Aactuator

A novel electrothermal bimorph actuator is designed with its dimension and structure optimized based on the theory of optimal thickness ratio and the results of the simulations. Then its modeling is conducted with the software of CoventorWare as shown in Figure 4.

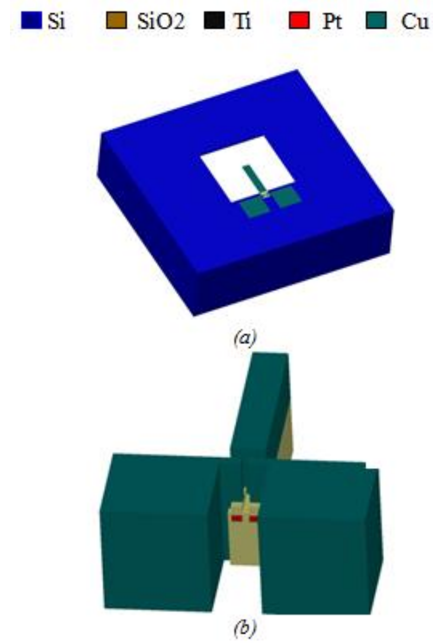


Figure 4: The model of electrothermal bimorph actuator.

3 SIMULATIONS

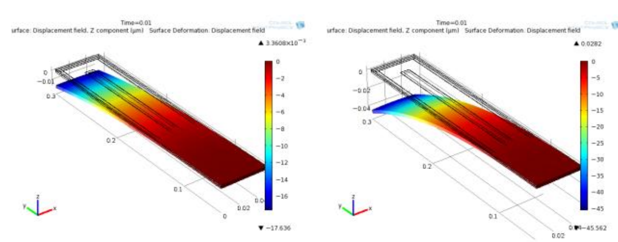
To confirm the performance of the new electrothermal bimorph micro-actuator, many simulations are conducted by a method of multiphysical coupling supplied by the simulation software COMSOL Multiphysics.

3.1 Simulations on Displacement

Maximum displacement is the key factor to measure the performance of a actuator. Applied different voltages, the actuator produced different displacements as bellow.

Voltages [V]	Displacements [μm]
0.5	-17.636
0.8	-45.562
1.0	-69.566
1.2	-101.2

Table 1: Voltages and displacement.



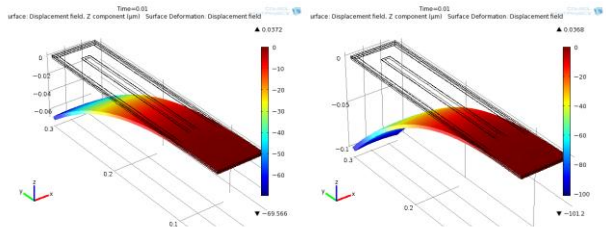


Figure 5: Results of simulations on displacement.

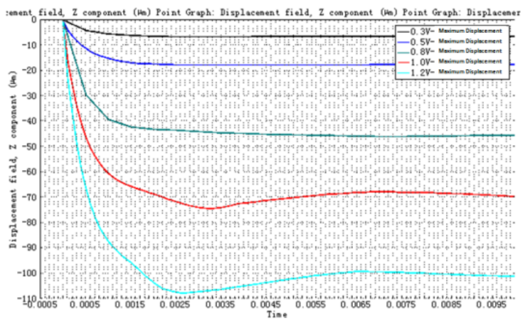


Figure 6: Maximum displacement of different voltage.

According to the results of the simulations, the largest displacement is achieved at the free end of the actuator.

3.2 Simulations on Temperature

The distributing and maximum temperature is also impartment for the actuator. The conditions and results of simulations are shown in Table 2, Figure 7 and Figure 8.

Voltages [V]	Temperatures [K]
0.5	699.86
0.8	553.85
1.0	395.09
1.2	877.26

Table 2: Voltages and Displacement.

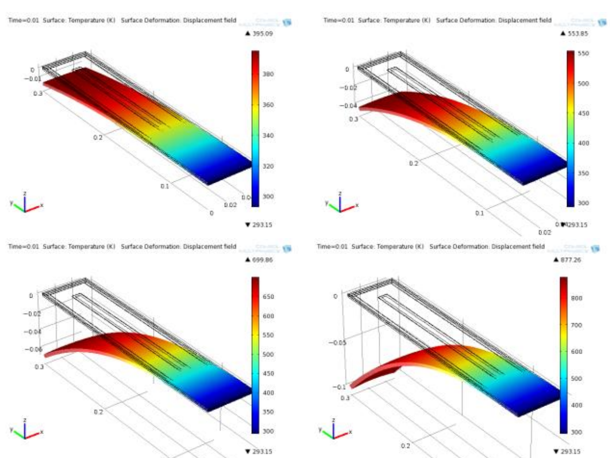


Figure 7: Simulations' results on temperature.

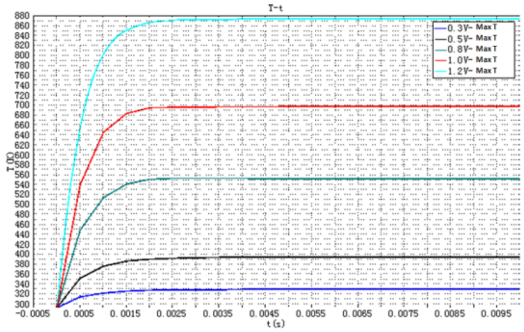


Figure 8: Maximum temperature of different voltage.

3.3 Multiphysical Simulation

Finally, a multiphysical simulation is conducted to test the integral performance.

When supplied by electrical power of 300mW, the actuator gets high response below 10ms while reaching temperature of 1444K and a vertical displacement of 140μm, which are shown in Figure 9. The response and displacement are both outstanding in novel actuator.

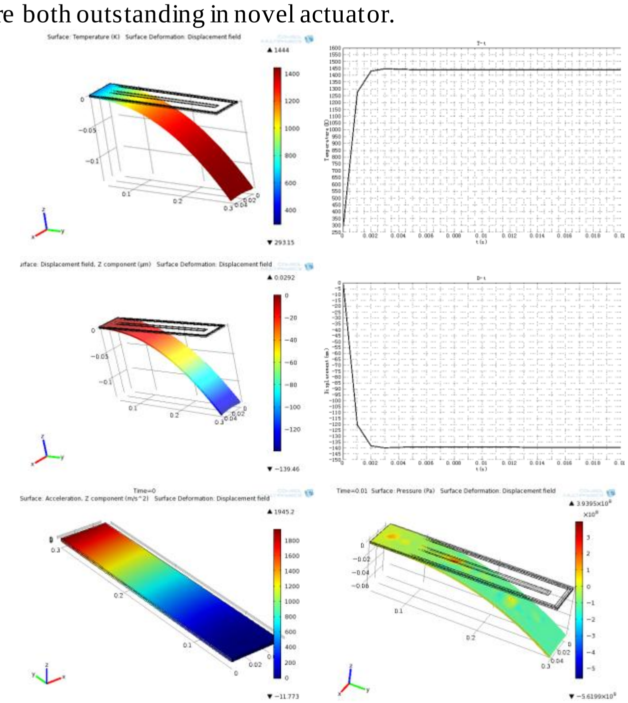


Figure 9: Multiphysical simulation result.

4 FABRICATION

As the electrothermal bimorph actuator is simple in structure, it can be fabricated using standard integrated circuit processing methods. One fabrication of the novel bimorph actuator is developed as shown in Figure 10.

First, the P-100 silicon is prepared and the blast furnace is cleaned. Then the oxidation is conducted at the SOI panel, and a SiO_2 layer of 1.5μm thick is formed at the front of the panel while the functional materials with smaller thermal expansion coefficient and a SiO2 layer of 0.1μm thick formed at the back of the panel as a mask for further corrosion of the substrate of Si. Pt and Ti are evaporated to the SiO2 layer with the stripping lithography technology. Pt layer works as electrically heater, converting electrical energy to heat. Ti layer is located between the Pt layer and the SiO2 layer, serving to increase the adhesion and to prevent the SiO2 layer stripping caused by thermal cycling stress.

Another 0.4μm SiO2 layer is sediment as an insulating layer, later generating the shape of actuator on it with dry etching method as well as two holes, which are used to form the electrode channel to help the electrode metal having direct contact with the Pt as a pathway. Aluminum sediment is wet etched to form the function layer with larger thermal expansion coefficient.

Finally the actuator is released. After the etching of SiO2 layer mask on the back stops, carve further corrosion of the openings in the Si substrate using dry etching; and then positive adhesive is laid to prevent the KOH etching out the actuator. The first step of carrying out the substrate release thinning is the anisotropic etching of the KOH back, and then time the etching with estimating the remaining silicon film of less than 30μm to remove the glass clamps. After the rest of the Si surface undergoes dry XeF etching, all the Si is cleaned off, and the net bimetal electric actuators are released.

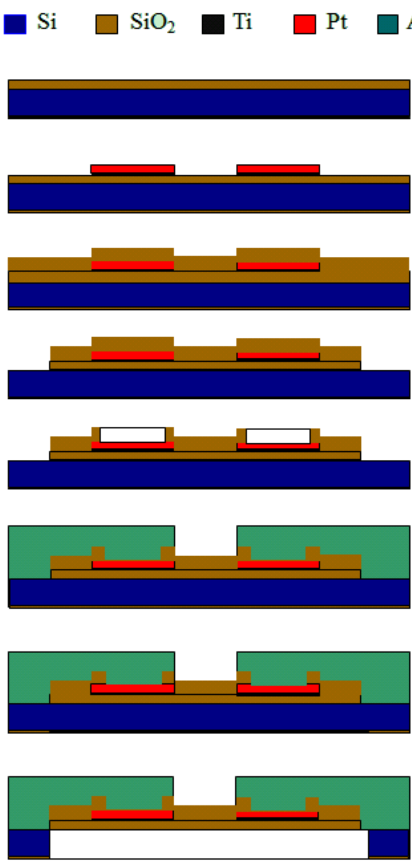


Figure 10: Fabrication of the bimorph actuator.

5 CONCLUSION

This paper presents the multiphysical simulations and fabrication of a novel electrothermal bimorph actuator. During the research, some conclusions are formed as follow:

1. The theory of the optimal thickness ratio is proved by simulation and is used to design the actuator.
2. The effect of the location of the heater is analyzed. The result s introduced into the design of the actuator.
3. The performance of the new electrothermal bimorph micro-actuator is tested by multiphysical simulations; the results show that the actuator could achieve large displacement in less than 10ms.
4. Finally the paper gives out the fabrication of this electrothermal bimorph actuator which makes it possible to be produced with standard IC processing methods.

Now the novel electro thermal bimorph actuator is being produced, and its performance will be tested when the production is ended.

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Corresponding author: Lou Wen-zhong, Science and Technology on Electromechanical Dynamic Control Laboratory, 5 South Zhongguancun Street, Haidian District, Beijing 100081, P. R. China,
e-mail: louwz@bit.edu.cn