# Large Displacement Polymer Bimorph Actuator for Out-of-Plane Motion

**Won-Kyu Jeung†, Seog-Moon Choi* and Yong-Jun Kim****

**Abstract** - A new thermal bimorph actuator for large out-of-plane displacement is designed, fabricated and tested. The deflecting beam is composed of polyimide, heater, and polyvinyl difluorides with tetrafluoroethylene (PVDF-TrFE). The large difference of coefficient of thermal expansion (CTE) of two polymer layers (polyimide and PVDF-TrFE) can generate a significant deflection with relatively small temperature rise. Compared to the most conventional micro actuators based on MEMS (micro-electro mechanical system) technology, a large displacement, over 1 *mm* at 20 *mW*, could be achieved. Additionally, we can achieve response time of 14.6 *ms*, resonance frequency of 12 Hz, and reliability ability of $10^5$ cycles. The proposed actuator can find applications where a large vertical displacement is needed while maintaining compact overall device size, such as a micro zooming lens, micro mirror, micro valve and optical application.

**Keywords**: Micro Actuator, Polymer, Thermal bimorph, zooming lens.

## 1. Introduction

There have been many efforts to realize micro actuators using MEMS technology. These include piezoelectric materials (Piezoceramic, PZT, Polyvinyl difluorides (PVDF)) [1], electro static force, shape memory alloys [2], voice coil motor (VCM), and bimorph structures [3 ~ 4], which are a generalization of conventional bimetals. In spite of these efforts, there are many problems involved in mass production manufacturing. In case of piezoelectric materials, they have small displacement because of small maximum strain, fatigue problem during repetitive actuating, and complex accessories due to high operation voltage. In case of electro static force, it has small displacement and complex structure. In case of shape memory alloys, they have slow response time and large power consumption. In case of conventional bimorph structures, they have maximum displacement, which is up to hundreds of μm. In this paper we focus on the last type, the bimorph structures. The thermal bimorph actuators can generate relatively large displacement, relatively small power consumption, simple structure, simple operating principle, low-cost and constant force regardless of their deflection.

Since the last few decades, electrical equipments have continually progressed toward being ultra small in size and extremely light weight. There have been many needs that have large deflection while maintaining relatively compact overall device size. For example, there were many applications, such as small camcorder and miniaturized zooming lens for mobile phones, which require relatively larger, in MEMS point of view, displacement up to several *mms*.

In this paper, we introduce a new design for the thermal bimorph micro actuator that has larger displacement. For the large deflection, beams of circular type were chosen due to their superior deflection characteristics and beams which are consisted two polymers, PVDF-TrFE and polyimide, were chosen due to their large difference of CTE. This can generate a large deflection with relatively small rise in temperature.

## 2. Design Consideration

### 2.1 Basic Concept of Bimorph Structure

Fig. 1 presents the basic concept thermal bimorph structure. The structure is consisted of two materials with a heater between them (Fig. 1-a)). In comparison with material 2, material 1 has a smaller CTE. The heater can generate heat. This heat can expand two layers proportional to CTE, and two layers are fixed to each other. Consequently, the bimorph structure has bending deflection toward material 1 side (Fig. 1-(b)).

In this paper, we chose polymers for the bimorph structure layers. They have the advantage of large deflection

† Corresponding Author: Process Development Center, Central R&D Institute Samsung Electro-Mechanics, Korea. (mecclein@samsung.com, sms.choi@samsung.com)

* School of Electrical and Mechanical Engineering, Yonsei Univerity, Korea . (yjk@yonsei.ac.kr)

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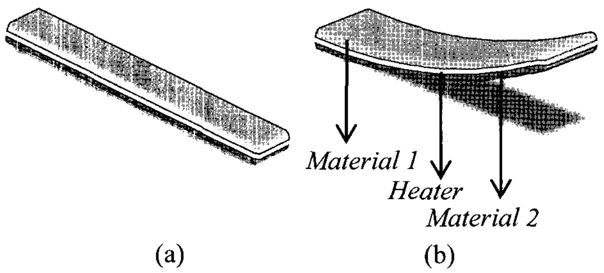


**Fig. 1** Schematic diagram of proposed bimorph structure

by flexibility and thermal insulation by low thermal conductance. PVDF-TrFE was chosen for the layer that has higher CTE and polyimide was chosen for the lower CTE (Table 1). An aluminum heater was chosen as the heat source. It is positioned between two polymer layers for thermal insulation. Currents in the aluminum heater will generate heat by Joule heating, and this heat will generate bending force on the bimorph beams.

**Table 1.** CTE of some materials

| Material | Coefficient of Thermal Expansion [10-6/K] |
|---|---|
| Si | 2.6 |
| SiO2 | 0.4 |
| Si3N4 | 2.8 |
| SiC | 3.5 |
| Poly-Si | 2.33 |
| Al | 23 |
| Au | 14.3 |
| Pt | 8.9 |
| Cu | 16.7 |
| Ni | 12.8 |
| Pb | 28.7 |
| Polyimide | 3 |
| PVDF-TrFE | 122 |

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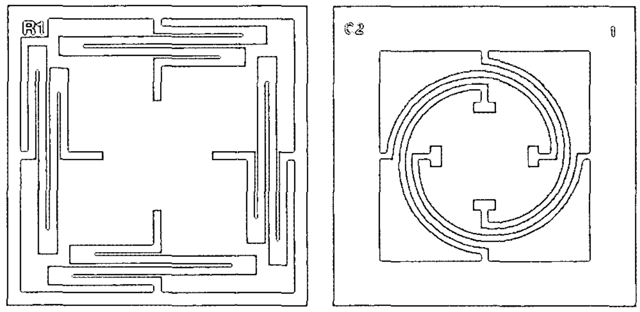
### 2.2 Design & Simulation

We consider some beam structure designs for achieving large out-of-plane deflection while maintaining relatively compact overall device size (Fig. 2). After numerical analysis using commercial 3-D simulation programs, the circular type actuator (Fig. 2-(b)) has been chosen over the square type actuator (Fig. 2-(a)) due to its superior deflection characteristics (Fig. 3).

Consequently, the schematic diagram of the proposed actuator is shown in Fig. 4. A movable platform is attached on the end of beams, at the center portion of the actuator. In this case, we use a glass mirror as a movable platform for out-of-plane deflection measurement. For other applications, alternative components such as optical lens or micro valves can replace the glass mirror.




(a) Square Type (b) Circular Type

**Fig. 2** Designs for large displacement out-of-plane actuator.

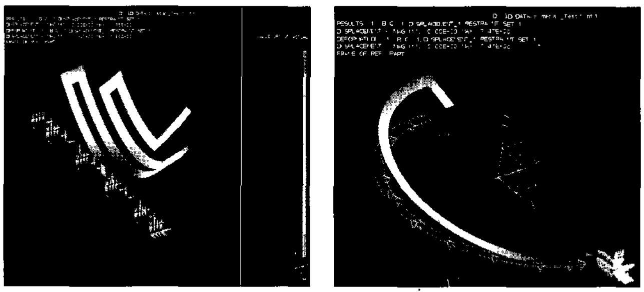


**Fig. 3.** Simulation data for suggested beam structures.

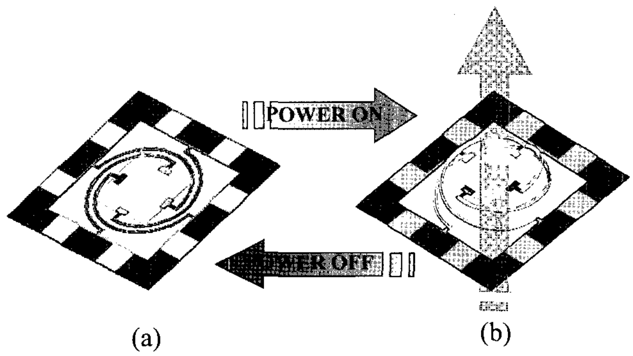



**Fig. 4.** Schematic diagram of out-of-plane movement for proposed actuator

### 3. Fabrication Process

Fig. 5 shows the simplified fabrication process to realize the proposed large displacement thermal bimorph actuator. Fabrication starts with a <100> silicon wafer that has a 1 μm thickness oxide film. The first step is anisotropic wet etching of silicon (Si) for the anchor element using a THAH (Tetramethyl ammonium hydroxide) solution. Etch depth is 470 μm (a). Polyimide (PI2611D from Dupont Co.) is spin-coated at 900 rpm for 45 seconds and cured at 350℃ for 1 hour. This step creates polyimide layer (b). A layer of aluminum (Al) is evaporated and patterned using standard photolithography and wet-etched in Al etching solution. This step makes embedded heater (c). The PVDF-

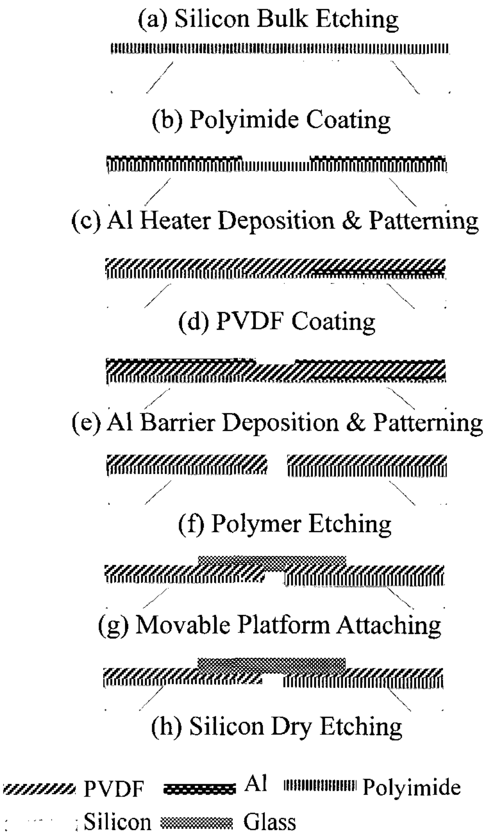


**Fig. 5** Simplified fabrication process

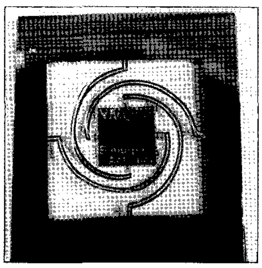


**Fig. 6** Realized thermal bimorph actuator

TrFE (Kynar 7201 from ATOFINA Co.) is then spin-coated from a solution of N-dimethyl acetamide (DMAc) at 2000 rpm for 20 seconds. This film is soft-baked at 95℃ for 15 minutes and hard-baked at 160℃ for 2 hours. This step results in PVDF-TrFE layer (d). An Al layer for barrier is evaporated and patterned (e). For constitution of bimorph beam structure, polymers are then plasma-etched from the top in O2/CF4 plasma (f). A movable platform, glass mirror, is attached on the end of beams using UV epoxy (g). The thin Si layer (30 μm) left underneath the polymer structures are removed by dry etching from the back side in O2/SF6 plasma. This step generates released beams (h). Fig. 6 shows the realized thermal bimorph actuator.

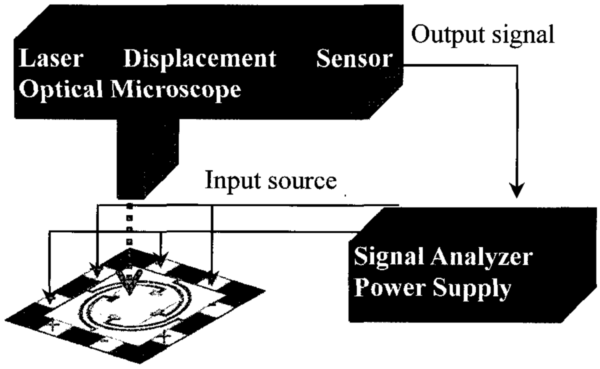


**Fig. 7** Schematic diagram of test apparatus

## 4. Experimental Results

Out-of-plane displacement of the thermal bimorph actuator has been optically measured as shown in Fig. 7. The overall size of the actuator used in this experiment was 9.7 *mm* X 9.7 *mm* with 23 *μm* thickness. Fig. 8 shows displacement vs. AC input power characteristics. A maximum deflection of 1.18 *mm* upward from the original surface plane was observed with the input of 500 *mV* AC voltage at 6 *Hz*, sine wave. This displacement is measured using a laser displacement sensor and signal analyzer. Fig. 9 shows displacement vs. DC input power characteristics. A maximum vertical deflection of 2.29 *mm* was observed with the input of 4 *V* DC voltages. This deflection is measured using optical microscope and power supply. All of the AC and DC experiments show good linearity in zero to maximum displacement range with various input power amplitudes. The linearity is 98% F.S. Fig. 10 shows dynamic characteristics, linearity with the input of 500 *mV* AC voltages at *6 Hz*, sine wave. Fig. 11 presents displacement versus operating frequency. This test was performed with the input of 500 *mV* AC voltage. We can obtain resonance frequency at 11 Hz. Additionally, we have experimentally measured the response time of this actuator. To estimate the actuator's response time, we plotted the relationship between the time and the displacement and input voltage. The response times of this actuator are 14.6 *ms* when the applied voltage is 500 *mV*. Fig. 12 shows this characteristic. Our thermal bimorph actuator performs the lifetime studies. The device lifetimes in excess of $10^5$ cycles are observed. These tests were performed at 23 ℃ ambient room temperature. Actuation amplitudes, which were measured by laser displacement sensor, are about 1 *mm* at 11 *Hz*. Upon repeated actuation the thermal bimorph actuator gradually degrades in amplitude. Fig. 13 presents the degradation curves. Significant reduction in amplitude is observed within the first $10^5$ cycles.

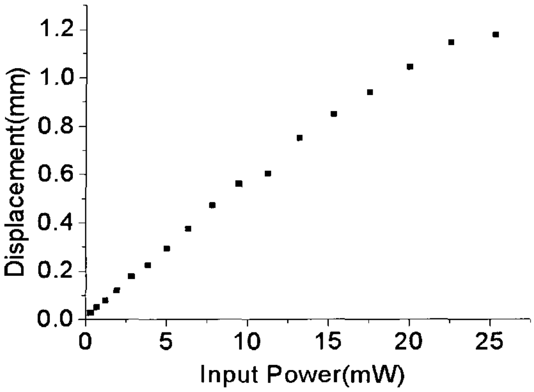



**Fig. 8** Displacement vs. input power (AC)

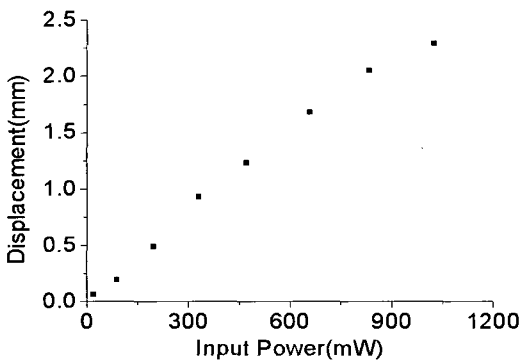



**Fig. 9** Displacement vs. input power (DC)

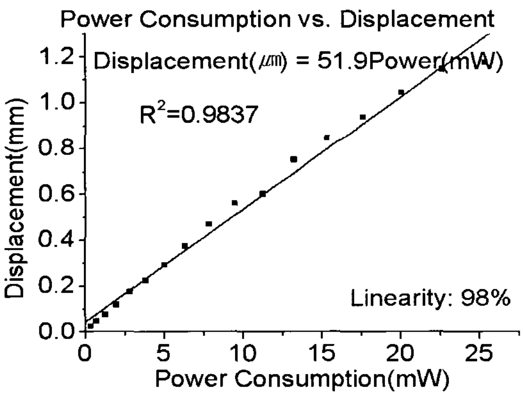



**Fig. 10** Displacements vs. power consumption characteristics

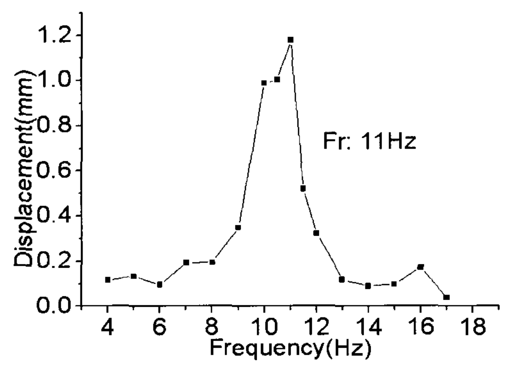



**Fig. 11** Displacements vs. frequency characteristics

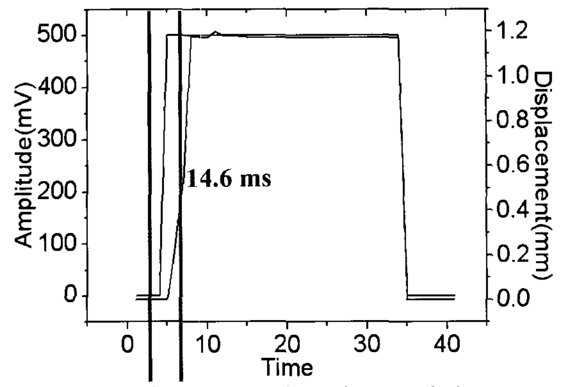



**Fig. 12** Response time characteristics

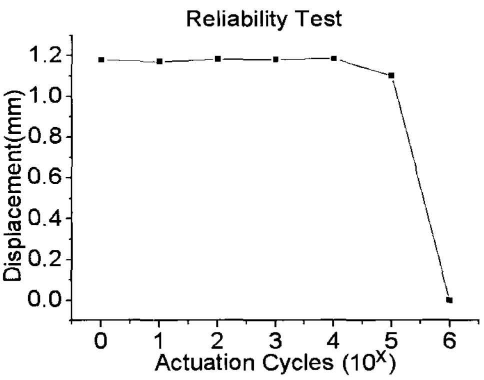



**Fig. 13** Measured curves for degradation displacement

## 5. Conclusion

A new concept, circular type of thermal bimorph actuator that is composed of PVDF-TrFE, Polyimide, and embedded Al heater between two polymers has been found to be a suitable structure for the large out-of-plane displacement. We obtained a maximum deflection of 2.29 mm upward from the original surface plane. This actuator is realized with simple MEMS technology. It is fabricated to be small in size, lightweight and low in cost. It is suitable for mass production. The presented actuator can find applications where a large vertical displacement is needed while maintaining compact overall device size, such as in the case of a small camcorder, mobile phone with camera that has a micro zooming lens, micro valve, optical switch and display.

## References

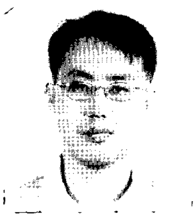
[1] Conway, N.J. Sang-Gook Kim, "Large-strain, piezoelectric, in-plane micro-actuator" Micro Electro Mechanical Systems, 2004. 17th IEEE International Conference on MEMS, pp. 454 – 457, Jan. 2004.

[2] Bhuiyan, M.M.I. Haga, Y. Esashi, M. "Large

displacement optical switching mechanism using SMA microactuator and magnetic latch" Micro Electro Mechanical Systems, 2004. 17th IEEE International Conference on MEMS, pp. 61 – 64, Jan. 2004.
[3] Rashidian, B. Allen, M.G. "Electrothermal micro-actuators based on dielectric loss heating" MEMS '93, Proceedings 'An Investigation of Micro Structures, Sensors, Actuators, Machines and Systems'. IEEE, pp. 24 – 29, Feb. 1993.
[4] Riethmuller W., Benecke W., "Thermally excited silicon microactuators" Electron Devices, IEEE Transactions on MEMS. Volume 35, Issue: 6, pp. 758 – 763, June 1988.

**Won-Kyu Jeung**

He received his B.S. degree in Mechanical Engineering from Hanyang University in 1998. He received a Master's of Mechanical Engineering from Yonsei University in 2005. He is currently a Research Engineer at Central R&D Institute in Samsung Electro-Mechanics Co., LTD. His research interests are MEMS and Packaging.



**Seog-Moon Choi**

He received his B.S. degree in Mechanical Engineering from Yonsei University in 1989. He received a Master's of Mechanical Engineering from Yonsei University in 1991. In 1991, he joined the R&D Institute in Samsung Electro- Mechanics Co., LTD. where he conducted research as a senior research engineer. In 1998, he joined Dr. Sang-Jo Lee's Micromachining & Manufacturing Group in Yonsei University where he conducted research as a Graduate Research Assistant. His research in micromachining and MEMS includes design and fabrication of microactuators for high density magnetic recording. In February 2003, he received his Ph.D. from Yonsei University. Currently, he is a principal research engineer at Central R&D Institute in Samsung Electro-Mechanics Co., LTD. His research interests are MEMS and Packaging.

**Yong-Jun Kim**

He received the Bachelor of Engineering in electrical engineering from Yonsei University, Seoul, Korea, in 1987. He received the Ph.D. degree in electrical engineering from Georgia Institute of Technology in 1997. His thesis work involved the application of polymer/metal multilayers to MEMS.

From 1996 to 2000, he was with Samsung Electronics Co. as a senior engineer and project leader working on electronic packaging and various MEMS devices. Since 2000, he joined the faculty of Yonsei University as a Professor in the School of Mechanical Engineering. His current research includes general micromachining, bio and environmental sensors, RF-MEMS, and flexible electronic packaging.

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[2] W.-K. Chen, *Linear Networks and Systems*. Belmont, CA: Wadsworth, 1993, pp. 123–135.

*Periodicals:*

[3] J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices*, vol. ED-11, pp. 34–39, Jan. 1959.

[4] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev.*, vol. 134, pp. A635–A646, Dec. 1965.

[5] E. H. Miller, "A note on reflector arrays," *IEEE Trans. Antennas Propagat.*, to be published.

*Articles from Conference Proceedings (published):*

[6] D. B. Payne and J. R. Stern, "Wavelength-switched passively coupled single-mode optical network," in *Proc. IOOC-ECOC*, 1985, pp. 585–590.

*Papers Presented at Conferences (unpublished):*

[7] D. Ebehard and E. Voges, "Digital single sideband detection for interferometric sensors," presented at the 2nd Int. Conf. Optical Fiber Sensors, Stuttgart, Germany, 1984.

*Standards /Patents:*

[8] G. Brandli and M. Dick, "Alternating current fed power supply," U.S. Patent 4 084 217, Nov. 4, 1978.

*Technical Reports:*

[9] E. E. Reber, R. L. Mitchell, and C.J.Carter,"Oxygen absorption in the Earth's atmosphere," Aerospace Corp., Los Angeles, CA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1968.

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