Fabrication of Piezoelectric Micro Bending Actuators Using Sol-Gel Thick PZT films

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ABSTRACT

Fabrication and electrical and mechanical properties of piezoelectric micro bending actuators (PMBA) using sol-gel multi-coated thick PZT films and MEMS processes were investigated. PMBA could be used for design and fabrication of micro fluidic devices, for example, micro-pumps, micro dispensers, and so on. PMBA were fabricated using 2 μm-thick PZT films on Pt (350 nm)/SiO_2 (500 nm)/Si (300 μm) substrates and MEMS processes. 7 types of PMBA were fabricated with areas of silicon diaphragms, PZT films and top electrodes. When the sizes of silicon diaphragms, PZT films and Pt top electrodes were reduced from 3000×1389 μm, 4000×1000 μm and 4000×900 μm down to 14%, 14% and 11% of them, respectively, the center displacements of PMBA were decreased from 0.68 μm to 0.10 μm at 5 Hz and 12 Vpp. So, PMBA with large areas showed larger displacements than PMBA with small areas and experimental results were also good agreement with the plate and shell theory.

Key Words : Piezoelectric, Actuator, MEMS, Diaphragm, Displacements

1. Introduction

Piezoelectric micro-bending actuator is a piezoelectric body adhered on elastic body. If an electrical field is applied to z-axis, the piezoelectric body expands along z-axis and contracts along the x- and y-axis. The elastic body is deflected due to the generated bending moment. Displacements and forces from the piezoelectric bending actuators can be used for micro-pump, drug delivery system, motor and micro phone and so on[1-6].

In order to design the piezoelectric actuators, bimorph model [7], multi-morph model [8], or general plate theory are used. Bending type actuators such as PZT-FBAR(film bulk acoustic resonator), PZT gas sensors, micro pump were reported for μ-TAS (total analysis system) applications, but bending type actuators using thick PZT films have been seldom reported. Also thick PZT films were required for micro size devices applications such as micro pump, micro phone, SAW device and so on [9-14].

From the plate and shell theory [15], the displacements δ(r) at any radial point r from the center of the membrane can be shown to be:

$$\delta(r) = \lambda\ d_{31}(R^2 - r^2)\ U/2t^2 \qquad (1)$$

where R is the radius and t is the thickness of the piezoelectric disc and d_{31} is the piezoelectric charge constant in the directional normal to the disc. From equation (1), the maximum deflection of the membrane which occurs at the center of the disc is proportional to applied voltage U. The λ is constant.

Integration equation (1), we obtain the pump flow rate as:

$$Q = \lambda \cdot \pi/4 \cdot U\ d_{31}\ R^4/\ t^2 f \qquad (2)$$

where, f is the frequency of the excitation voltage. The flow rate is thus seen to be a linear function of the applied voltage and excitation frequency. It offers

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the possibility of controlling the pump flow rate through the applied voltage and excitation frequency.

In this report, fabrication and electrical and mechanical properties of piezoelectric micro bending actuators (PMBA) for design and fabrication of micro pumping devices using sol-gel multi-coated thick PZT films and MEMS processes were investigated.

2. Experiment

2.1. Fabrication

Fig. 1 shows the fabrication flow of PMBA using thick PZT film and MEMS processes. Piezoelectric micro-bending actuators were fabricated by using 2 μm-thick PZT films on Pt (350 nm)/SiO_2 (500 nm)/Si (300 μm) and dry etching process of Pt and PZT films, and Si wet etching of the backside of substrate. They were fabricated with various Pt top electrodes, PZT and diaphragm sizes. Top electrode, PZT of front side and SiO_2 of back side for silicon diaphragm definition after passivation using thick AZ1512 photoresist were patterned using RIE processes. Finally, bulk silicon micromachining was done using 20 wt% TMAH solution at 80°C. During agitation using magnetic stirrer, a protection jig for front side passivation was used. Silicon etching rate was about 0.9~1 μm.

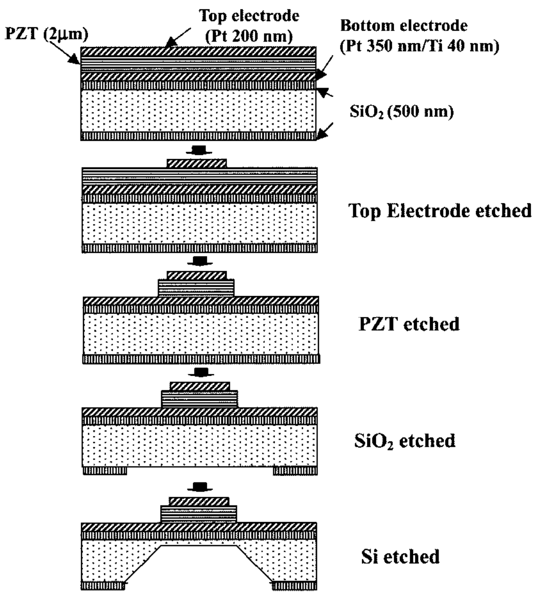

Fig. 1. Fabrication flow of PMBA using thick PZT film.

2.2. Measurement

2.2.1. Electrical properties

The dielectric and ferroelectric properties of the PZT films were measured using an impedance analyzer (HP 4194A) and a P-E measurement system (Precision Pro, Radiant Technologies) after top Pt electrode deposition, respectively. Samples for measuring effective transverse piezoelectric coefficient ($e_{31,f}$) using thick PZT films with thicknesses of 2 μm were fabricated using MEMS processes. They were characterized by using a self-fabricated $e_{31,f}$ measurement system before and after poling. The $e_{31,f}$ was calculated from the measured charge (Q) produced by an outer input force and parameters of electrode geometry at specimens [14].

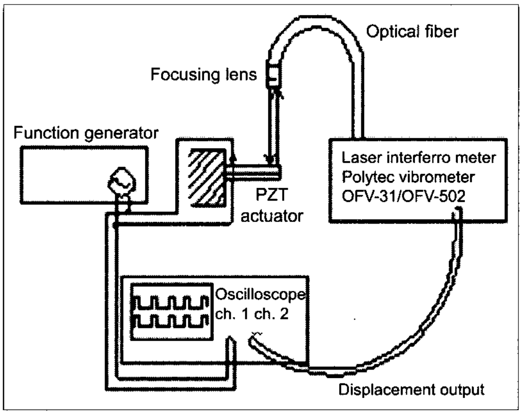

Fig. 2. Measurement system for dynamic displacement using laser interferometer.

2.2.2. Mechanical properties

Fig. 2 shows schematic illustration of displacement measurement system for PMBA fabricated as shown in Fig. 1. Center displacements with frequency were measured using laser interferometer (Polytec OFV-502 and Polytec OFV-301). Displacement of those with diaphragm sizes and frequency were measured by a laser interferometer. The frequency of input square wave signal was 5 Hz, which was much less than the mechanical resonance frequency of the bending actuators.

3. Results and Discussions

3.1. Electrical properties

Dielectric constant, dielectric loss, P_r and $e_{31,f}$ of 2 μm-thick PZT film on Pt (350 nm)/SiO_2 (500 nm)/Si (300 μm) were 860 at 1kHz, 2.5% at 1kHz, 33 μC/cm^2, and 9.86 C/m^2 at 3 Hz before poling and 46.9 C/m^2 at 3 Hz after poling, respectively. The value of P_r after complete fabrication of PMBA using MEMS process was decreased from 33 μC/cm^2 to about 22 μC/cm^2 due to degradation of PZT film properties during MEMS processes.

3.2. Mechanical properties

For evaluation of mechanical properties of thick PZT films, 7 types of piezoelectric micro-bending actuators were prepared by MEMS process.

Table 1 shows silicon diaphragm, PZT and top electrode sizes of 7 types PMBA.

Cross sectional FESEM images of one of fabricated PMBA as shown in Fig. 3.

Fig. 4 shows fabricated silicon diaphragm thicknesses of 7 types of PMBA. They were in the range of 12 μm to 20 μm. It was thought that differences were occurred from different silicon etching rates at local area of wafer surface. So, the control of uniform silicon etching rate was important to fabricate PMBA with uniform silicon diaphragm thicknesses.

Fig. 5 shows the center displacements of the bending actuators of various silicon diaphragms and top electrode sizes by applying the square wave voltage of 12 V_{pp} and frequency of 5 Hz. For comparison, we could observe the size effect at same input signal and obtain a large displacement more than 100 nm. Center displacements of PMBA were decreased from 0.68 μm to 0.10 μm at same driving conditions of the square wave voltage of 12 V_{pp} and frequency of 5 Hz with decreasing areas from silicon diaphragm size of 3000×1389 μm, PZT size of 4000×1000 μm, and top electrode size of 4000×900 μm down to 14%, 14%,

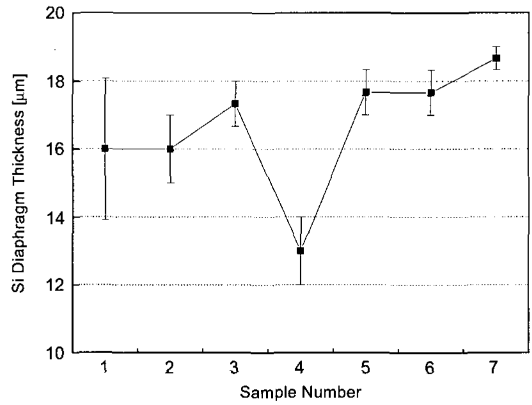

Fig. 4. Fabricated silicon diaphragm thicknesses of 7 types PMBA.

Table 1. Silicon diaphragm, PZT and top electrode sizes of 7 types PMBA.

Size (μm) \ No	1	2	3	4	5	6	7
Si Diaphragm	3000 by 1389	3000 by 1042	3000 by 694	3000 by 486	3000 by 347	3000 by 278	3000 by 194
PZT	4000 by 1000	4000 by 750	4000 by 500	4000 by 350	4000 by 250	4000 by 200	4000 by 140
Top Electrode	4000 by 900	4000 by 650	4000 by 400	4000 by 250	4000 by 150	4000 by 140	4000 by 100

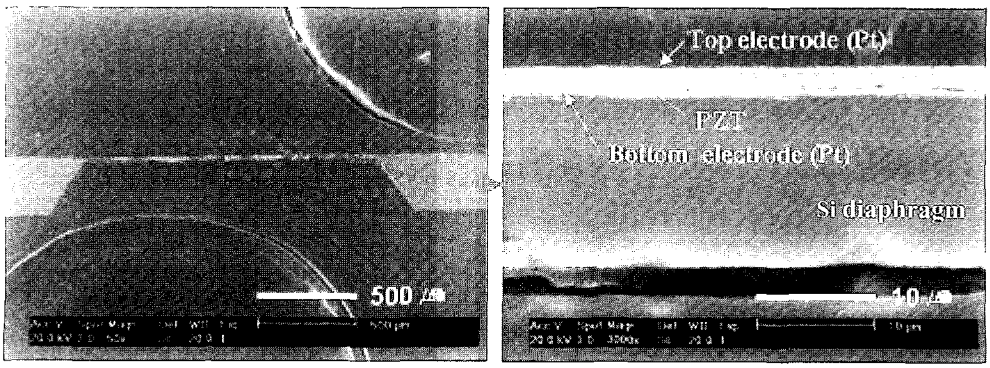

Fig. 3. Cross sectional FESEM images of one of fabricated PMBA samples.

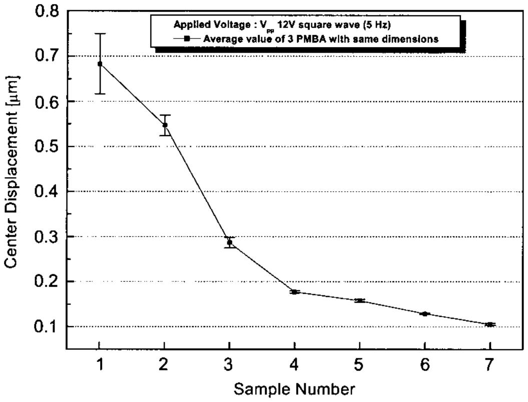

Fig. 5. Center displacements of 7 types of PMBA actuated at 12 V_{pp} and 5 Hz.

and 11% of them, respectively. So, PMBA with large areas showed larger displacements than PMBA with small areas and experimental results were also good agreement with the plate and shell theory.

4. Conclusions

In this report, fabrication and electrical and mechanical properties of piezoelectric micro bending actuators (PMBA) using sol-gel multi-coated thick PZT films and MEMS processes were investigated. Piezoelectric micro bending actuators (PMBA) were fabricated using 2 µm-thick PZT films on Pt (350 nm)/SiO_2 (500 nm)/Si (300 µm) substrates and MEMS processes. 7 types of PMBA were fabricated with areas of silicon diaphragms, PZT films and top electrodes. When the sizes of silicon diaphragms, PZT films and Pt top electrodes were reduced from 3000×1389 µm, 4000×1000 µm and 4000×900 µm down to 14%, 14% and 11% of them, respectively, the center displacements of PMBA were decreased from 0.68 µm to 0.10 µm at 5 Hz and 12 V_{pp}. So, PMBA with large areas showed larger displacements than PMBA with small areas and was also suitable for micro pumping devices using volume change of chamber.

Acknowledgements

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References

1. Brooks, K. Damjanovic, D. Kholkin, A. Reaney, I. and Setter, N., Integrated Ferroelectrics Vol. 8, pp. 13-23 (1995).
2. Ederer, I. Raetsch, P. Schullerus, W. Tille, C. and Zech, U., Sens. Actuators A62, pp. 752-755 (1997).
3. Muralt, P. Kholkin, A. Kohli, M. Maeder, T. and Setter, N., Microelec. Eng. 29, pp. 67-70 (1995).
4. Lee, S. S. and White, R. M., Micromech. Sys., ASME Winter Annual Mtg. San Francisco, USA, pp. 231-235 (1995).
5. Olsson, A. Enoksson, P. Stemme, G. and Stemme, E., The 9th Ann. Int. Workshop on Micro Electro Mech. Sys., San Diego, USA, pp. 479-484 (1996).
6. Stehr, M. Messner, S. Sandmaier, H. and Zengerle, R., The 9th Ann. Int. Workshop on Micro Electro Mech. Sys., San Diego, USA, pp. 485-490 (1996).
7. Steel, M. R. Harrison, F. and Harper, P. G., Phys, J. D11, pp. 979-989 (1978).
8. DeVoe, D. L. and Pisano, A. P., J. Micro Electro Mech. Sys. 6, 3, pp. 266-270 (1997).
9. Zhao, H. J. Ren, T. L. Liu, J. S. Liu, L. T. and Li, Z. J., Proceedings of Transducers '03, Boston, USA, 1, pp. 234 -237 (2003).
10. Kirby, P. B. Su, Q. X. Komuro, E. Zhang, Q. Imura, M. and Whatmore, R. W., Proceedings of the 2001 IEEE International Frequency Control Symposium and PDA Exhibition, Seattle, USA, pp. 687-694 (2001).
11. Gwirc, S. Gomez, H. Nagreira, C. Malatto, L., IEEE Ultrasonics Symposium Proceedings, Toronto, Canada, 1, pp. 427-431 (1997).
12. Deng, J. Zhu, W. Tan, O. K. and Yao, X., Sens. Actuators B77, pp. 416-420 (2001).
13. Park, J. S. Yang, S. J. Park, K. B. Yoon, D. W. Park, H. D. Kim, S. H. Kang, S. G. Choi, T. H. Lee, N. K. and Na, K. H., KSME Spring Meeting, Pusan, Korea, p. 1326 (2003).
14. Park, J. S. Yang, S. J. Kang, S. G. and Na, K. H., J. Kor. Int. Met. & Mater. 41, 9, pp. 594-599 (2003).
15. Timoshenko, S. P. and Woinowsky-Krieger, S., Theory of Plates and Shells, pp. 5-400, McGraw-Hill, 2nd edition (1970).