

Piezoelectric Microactuators Composed of PZT Thin Films on Si Substrates

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Introduction

Recently, piezoelectric microactuators have been attractive attentions in MEMS devices because fast response and large force can be generated especially by low voltage. In this study, we develop piezoelectric microactuators using PZT thin films to realize low-voltage driven RF-MEMS switches. A variety of MEMS switches has been investigated as one of the essential devices for portable millimeter wave communication products. In the microactuator for a MEMS switch, an electrostatic force is widely adopted because design and fabrication are easy using well-established Si microfabrication technologies [1]. However, electrostatic MEMS switches need relatively large operation voltage more than 30 V, which is not compatible with portable products. In previous study, we fabricated piezoelectric MEMS switches with the shape of both cantilever and fixed-fixed beam structures composed of piezoelectric PZT thin films [2,3], however serious problems emerged such as large initial bending due to large internal stress of the films for the cantilever, or insufficient displacement for the fixed-fixed beam actuator. In this study, we modify the design and structure of the microactuator to satisfy both of the flatness without voltage and large displacement by applied voltage. In this paper, we describe novel design of the piezoelectric microactuator, and characterization of the actuation properties using FEM simulation and experiments.

Actuator design and simulation

The piezoelectric microactuators have unimorph structures composed of a piezoelectric PZT film and a metal layer. In order to satisfy both of flat beam

and large displacement, we introduce a X-shaped structure in the middle of the fixed-fixed beam as shown in Fig. 1. This structure can not only suppress the bending of both beam ends, but release residual stress of piezoelectric and metal films. The actuator is composed of two cantilevers of 350 μm -long connected by the X-shaped connector. The width and thickness of the beam is 200 μm and 3.3 μm , respectively. To verify the effect of the X-shaped connector, we conducted FEM simulation for 1/2 model of the beam. The deflection of the beam under 5V_{pp} was calculated and the result is shown in Fig. 2. The beam deflects with maximum displacement of 3 μm /5V. This result indicates that switching of rf-signals is possible if a transmission line is placed with a gap less than 3 μm from the contact pad at the center of the X-shape in the beam.

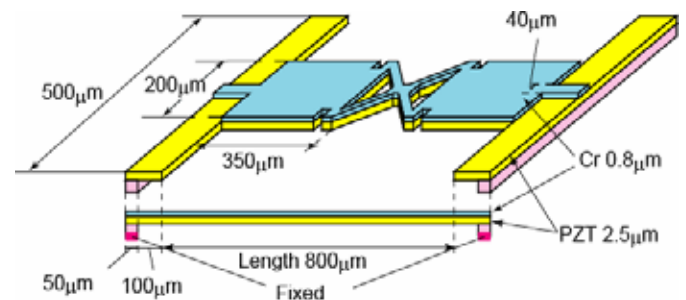


Fig.1 Structure of piezoelectric unimorph microactuator.

Fabrication process

The microactuators were fabricated according to the design as illustrated in Fig. 1. The fabrication process is shown in Fig. 3. The piezoelectric PZT

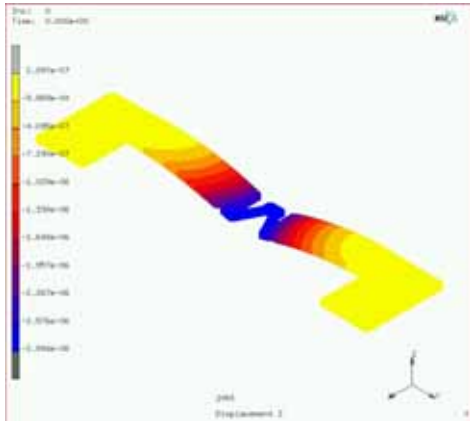


Fig.2 FEM simulation of deflection of microactuator (1/2 model under 5Vpp)

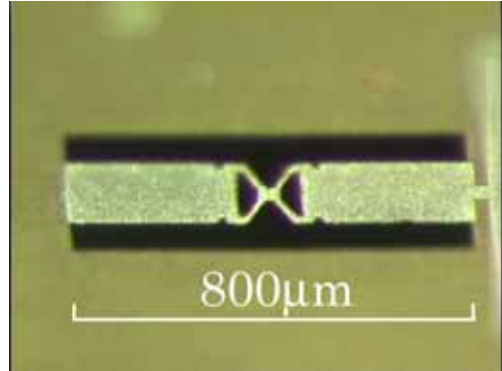


Fig.4 Photograph of piezoelectric microactuator with the X-shaped connector at the center of the beam.

films of 2.5 μm in thickness are deposited on Pt/Ti-coated Si substrates using the rf-sputtering machine (ULVAC SME-200), which can deposit PZT films on large area up to 200mm in diameter with high deposition rate more than 3 $\mu\text{m}/\text{h}$. Successively, 0.8 μm -thick Cr elastic layer is deposited onto the PZT film and patterned by lift-off process. The PZT film is etched in HF+HNO₃ solution, and emerged Pt/Ti electrode is patterned by Ar plasma etching. Finally, Si substrate beneath the beam is etched out by RIE. The photograph of the resulting actuator is shown in Fig. 4. We can confirm that the beam with X-shaped connector is very flat structure due to the release of the internal stress of the PZT and Cr layers.

Actuator performance

The detailed structure of the microactuators was measured using an interferometer (Wyko NT-1100), and 3D profile is shown in Fig. 4. The measurement revealed that the beam shows concave curve along the width, while the center of the beam becomes higher along the length. The difference of the height is as low as 3 μm , and we will reduce the bending of the beam by control of the stress of the Cr metal layer.

The displacement of the beam was measured by a laser Doppler vibrometer. A sine wave signal is applied between bottom Pt electrode and Cr elastic layer, and the vibration of the beam was measured. Figure 5 shows the displacement as a function of frequency under applied voltage of 0.1V. At the frequency of 14.6kHz, clear resonance is observed.

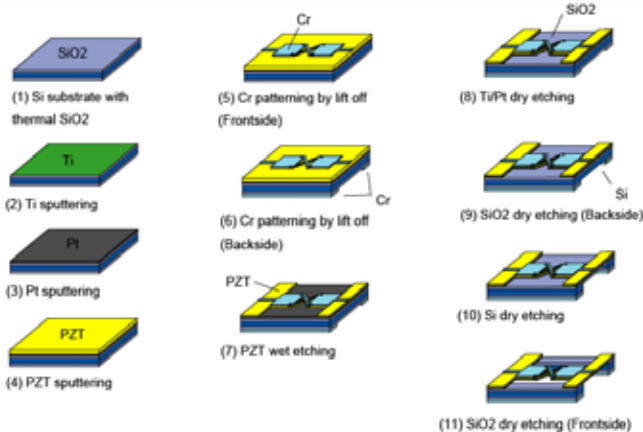


Fig.3 Fabrication process of piezoelectric microactuators

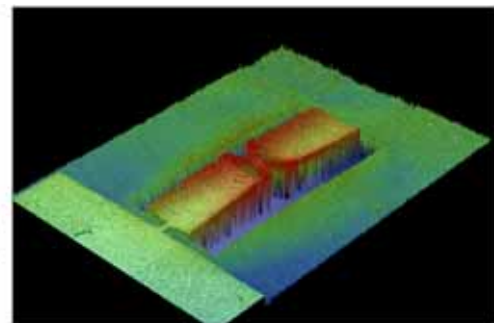


Fig.5 3D profiles of piezoelectric microactuator observed by optical interferometer. The scale of z-direction is exaggerated.

Previously, we fabricated unimorph cantilever of 500 μm in length, which showed the resonance at 7kHz. Since resonant frequency is proportional to $1/l^2$, the fixed-fixed beam acts as two connected cantilevers. The relationship between displacement and applied voltage is shown in Fig. 7. The measurement was conducted at 1kHz, lower frequency of resonance. The displacement of the center of the beam increases proportionally with the voltage, and maximum displacement reaches 1.5 μm at 15V. The displacement of the beam, however, is lower than the results of the FEM calculation. The low displacement is attributed to the curvature of the beam along the width which increases the stiffness of the beam. Another possible reason is the deterioration of the piezoelectric coefficient during the microfabrication. However, this type of microactuator can realize large displacement of 1 μm at 10V, which is still higher than the conventional electrostatic actuators. The optimization of the stress balance of the multilayered films leads to increase of the performance of the actuators.

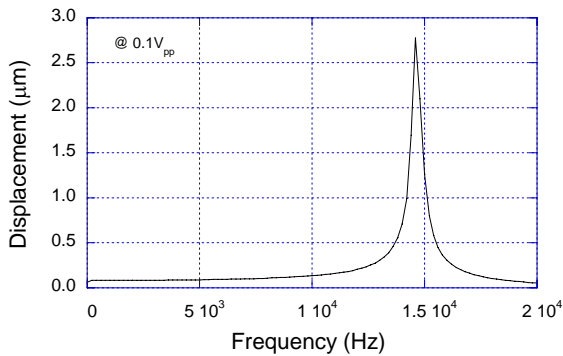


Fig.6 Displacement of the beam as a function of frequency.

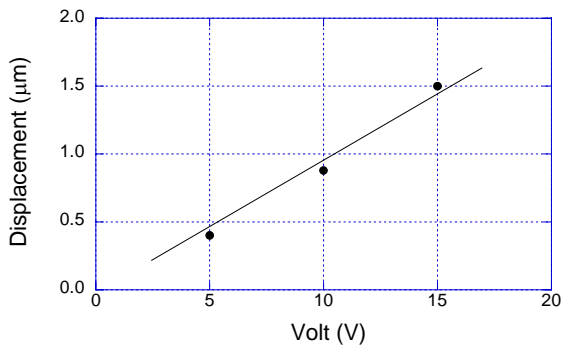


Fig.7 Displacement of the beam as a function of applied voltage.

Summary

We developed piezoelectric microactuators for low-voltage RF-MEMS switches. In order to satisfy both of flat beam structure and large displacement, X-shaped connector is introduced at the center of the beam. FEM simulation indicates that the maximum displacement can reach 3 $\mu\text{m}/5\text{V}$. The piezoelectric PZT films on Si substrates were microfabricated into microactuators of 800 μm in length and 200 μm in width. The X-shaped structure effectively release the stress of the multilayered beam and flat actuators were obtained. The displacement of the beam was measured using a laser Doppler vibrometer. The displacement is 1.5 $\mu\text{m}/15\text{V}$, which is lower than the calculated value. The optimization of the films stress will lead to the enhancement of the actuator characteristics and low voltage MEMS switch can be realized.

Acknowledgments

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