# Haptic MEMS

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## ABSTRACT

*We have developed a novel "Haptic MEMS" devic-es, in which ultra-thin PZT/Si actuator array is inte-grated on flexible substrate. The haptic MEMS can express spatial tactile sensation with the distribution of vibration stimuli. In the present study, haptic MEMS with 2x2 ultra-thin PZT/Si actuator array is demonstrated.*

## 1 Introduction

Haptic technology is being installed in game controllers and smartphones and is becoming a familiar technology for us. In the future, in AR/VR technology, haptics technology will be indispensable as a means of transmitting not only visual and auditory senses but also tactile senses. Various haptic gloves have been developed for AR/VR applications. However, since conventional haptic devices use pneumatic actuators, eccentric motors, etc., it has been difficult to make gloves smarter.

In recent years, various thin skin stimulation devices such as an electrically stimulating finger cot [1], a hydraulically amplified electrostatic actuator [2], and a dielectric elastomer actuator [3] have been developed based on microtechnology. It is expected that such a thin skin stimulating device will realize smart gloves. However, electrical stimulation has a problem that the stimulation intensity changes due to individual differences in contact impedance and the influence of sweat. Since the electrostatic actuator and dielectric elastomer actuator apply a voltage of 100V or more, there is a problem that they are dangerous to the human body.

To date, we have developed a technology for integrating a piezoelectric thin film with a thickness of 10 μm or less on a flexible substrate [4,5]. In the previous research, ultra-thin PZT/Si was fabricated by MEMS technology, released from a Si substrate and transferred onto a flexible substrate to fabricate a 5x5 PZT/Si array sheet device as shown in Fig. 1 [6]. Using the sheet device, we succeeded in monitoring the strain distribution of road bridges and visualizing cracks. PZT/Si was used as a piezoelectric sensor for strain monitoring. Inversely, by applying a voltage to PZT/Si, it becomes a thin piezoelectric actuator. Therefore, we decided to utilize the ultra-thin PZT/Si array sheet, which is based on the ultra-thin MEMS technology, to haptics application. We call such a device as "Haptic MEMS" [7].

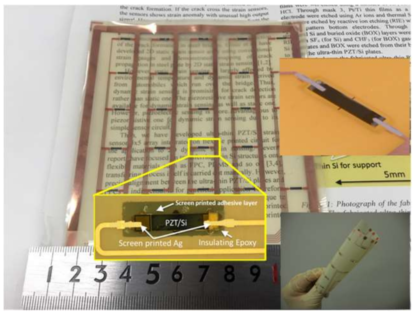

**Figure 1. 5x5 ultra-thin PZT/Si strain sensor array for structural health monitoring [6].**

## 2 Fundamental property of ultra-thin PZT/Si actuator.

Before we develop haptic MEMS devices, we evaluated the fundamental property of ultra-thin PZT/Si actuator. Figure 2(a-c) shows the developed ultra-thin PZT/Si actuator. Ultra-thin PZT/Si structure is fabricated by conventional piezoelectric MEMS technology and released from Si substrate as shown in Fig. 2(b). Total thickness is lower than 10 mm as shown in Fig. 2(c).

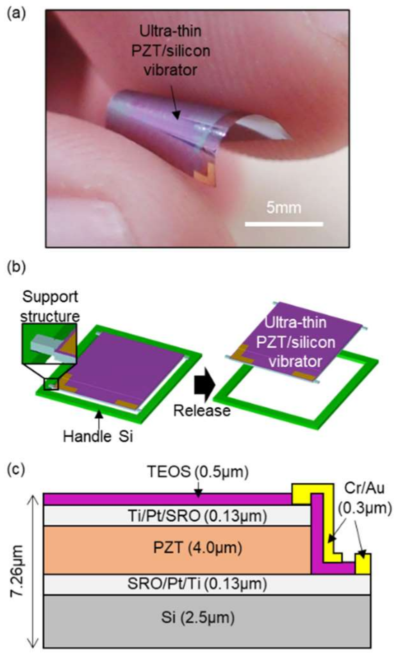


**Figure 2: (a) Overview, (b) fabrication process, and (c) cross-section ultra-thin PZT/Si actuator.**

Figure 3 shows fabrication process of a haptic device for a fundamental evaluation experiment using the ultra-thin PZT/Si actuator. An adhesive paste (thickness: ta) was pasted on a substrate (thickness: $t_s$) (step1,2). The ultra-thin PZT/Si actuator was bonded on the substrate (step 3). After that, the top and bottom electrodes of the ultra-thin PZT/Si acutator were wired by conductive paste and enamel wire (step 4) Finally, the substrate was attached to a frame which was fabricated by 3D printed by adhesive paste (step 5). The size of the vibrator was w × w mm. To evaluate the haptic device, four samples (Sample 1-4) were prepared. The parameter and mechanical properties of each sample were shown in Table.1.

Fig.4(a) shows the picture of the haptic device (Sample 1). When the actuation voltage was applied between the top and bottom electrodes, the center of the surface of the substrate was deformed. In the experiment, DC voltage was applied. The displacement was measured by a microscope with a micrometer. Fig.4(b) shows a deformation image of the surface of the substrate. The contour plot described the displacement in the z-axis direction. Fig.5 shows the experimental and simulated results of Sample 1,2,3 and 4, respectively. The voltage was varied from 0V to 30V and the displacement was dependent on the applied voltage. When the applied voltage was 30V(DC) in the experiment, the displacement of each sample (Sample 1,2,3 and 4) was 50.3μm, 45.1μm, 24.5μm, and 28.4 μm, respectively. Since the displacement threshold which the skin can feel is 1μm, the displacement of all samples is large enough for a haptic device.

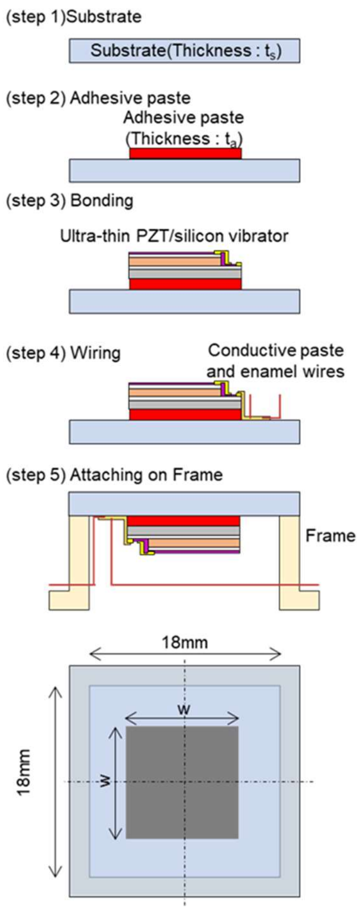


**Figure 3: Fabrication process of haptic MEMS device for fundamental evaluation of ultra-thin PZT/Si actuator.**

**Table 1: Size, material and mechanical properties of the haptic devices for fundamental evaluation experiment (Sample 1,2,3 and 4).**

| | | Sample1 | Sample2 | Sample3 | Sample4 |
|---|---|---|---|---|---|
| Substrate | Material | PVC | PVC | Glass | Glass |
| | Young's ratio | 3.3 GPa | 3.3 GPa | 64 GPa | 64 GPa |
| | Thickness ($t_s$) | 210 μm | 210 μm | 145 μm | 145 μm |
| Adhesive paste | Material | Epoxy | Epoxy | Epoxy | Epoxy |
| | Young's ratio | 6.6 GPa | 6.6 GPa | 6.6 GPa | 6.6 GPa |
| | Thickness ($t_a$) | 20 μm | 20 μm | 20 μm | 20 μm |
| Ultra-thin oscillator chip | Size (w) | 8mm | 11mm | 8mm | 11mm |

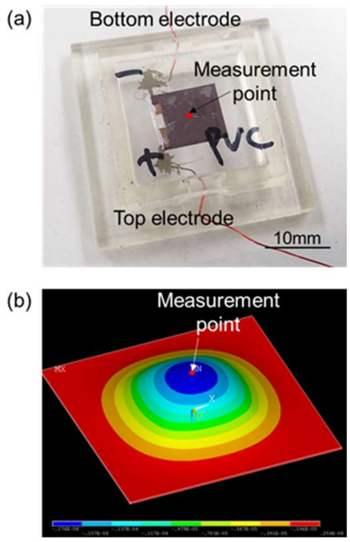


**Figure 4: (a) Picture of haptic device for fundamental evaluation experiment and (b) simulated result.**

## 3 Demonstration for Spatial Tactile Expression by Distributed Vibration Stimulation

In order to demonstrate the spatial tactile expression, we have fabricated haptic MEMS sheet with 2x2 ultra-thin PZT/Si actuator array shown in Fig. 6(a). Different voltages were applied to each of the ultra-thin PZT/Si actuators to give some kinds of distributed vibration stimulus to several subjects as shown in Fig. 6(b). In Fig. 6(b), red cell means active and white cell means inactive. The actuation condition for the ultra-thin PZT/Si actuators are 0-30V, 1sec/1cycle, and 240Hz.

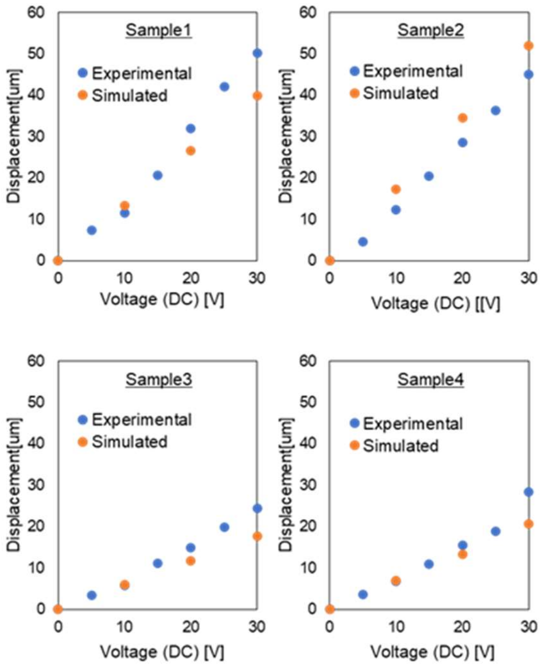


**Figure 5: Displacement of the haptic MEMS devices as a function of actuation voltage.**

Discrimination test for various distributed vibration stimulus is conducted as follows: The subject pinched the haptic MEMS sheet with fingers in blind. The ultra-thin PZT/Si actuators were driven by one pattern, and the subject answered the distributed vibration stimulus pattern A, B, or C. The test was repeated 50 times for one subject. Fig. 5(c) also shows the result of the discrimination test. The percentage means the correct answer rate of an average of 5 subjects. The correct answer rate of patterns A, B, and C were 51.8%, 97.5%, and 57.6%, respectively.

The correct answer rate was highest for pattern B. This is probably due to all inactive state of ultra-thin PZT/Si actuator in pattern B. In contrast, two PZT/Si actuators were always active in pattern A and C. Therefore, the subject classified pattern B by feeling all inactive state.

On pattern A and C, the correct answer rate was about 50%. When the subject answered incorrectly, subjects misrecognized pattern A as pattern C or vise versa. This may be due to propagation of vibration through flexible substrate from the active PZT/Si actuators to the inactive ones. In order to solve the problem, we are now considering the novel design of flexible substrate to reduce the propagation of vibration.

## 4 Summary

We have developed “Haptic MEMS” devices, in which ultra-thin PZT/Si actuators are arrayed on the flexible substrate. Discrimination test of some kinds of distributed vibration stimulus is conducted for several subjects. The results indicated the potential of “Haptic MEMS” to express various kinds of spatial tactile expression.

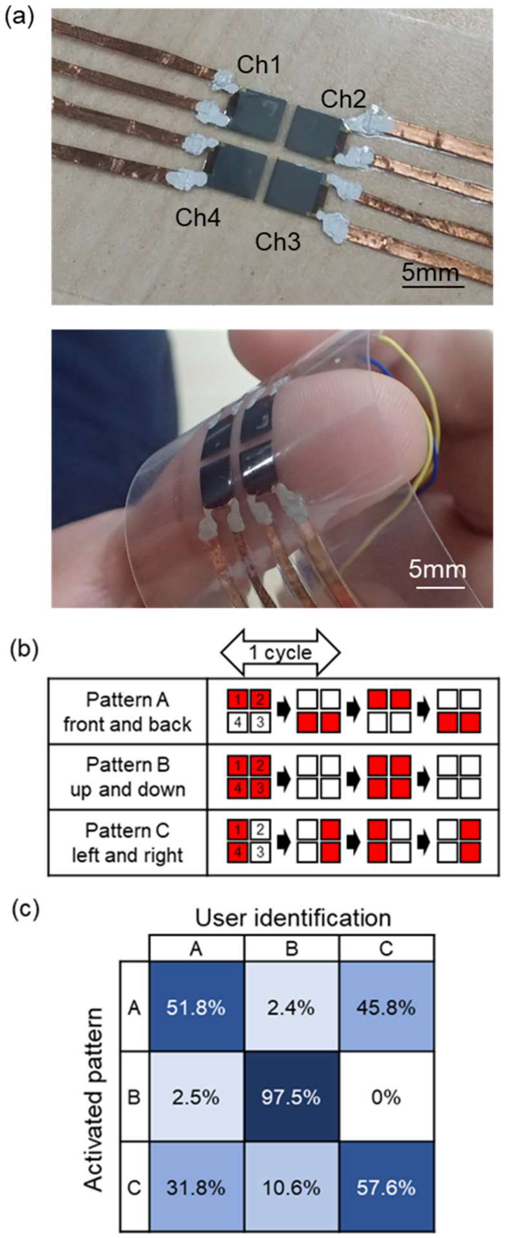


**Figure 6: (a) Overview of the fabricated haptic MEMS sheet with 2x2 ultra-thin PZT/Si actuator array. (b) Tested distributed vibration stimulus. (c) Result of the discrimination test.**


## Acknowledgement

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