A NOVEL TYPE OF MECHANICAL POWER TRANSMISSION ARRAY FOR SWITCHING DENSELY –ARRAYED ACTUATOR SYSTEMS

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ABSTRACT

This paper proposes a novel type mechanical transmission system for driving arrayed elements. The main advantage of this system is that it is able to operate individually arrayed elements with high-power. It was fabricated by MEMS technologies, and was confirmed that we are able to individually drive the arrayed elements by selectively driving tulip-shaped electrostatic clutch devices that transmit large power coming from a single power source. The transmitted stroke was 20 μm for this experiment.

1. INTRODUCTION

Up to now, many types of micro-actuators have been proposed for various MEMS applications. These devices basically put out power using micro-actuation techniques, such as, electrostatic, magnetic, piezo-electro, heating, and optical. However, the smaller the pitch of the micro-actuator arrays, the more they are unable to put out a large stroke and large power. Konishi, et al. proposed a micro-actuator based on an inchworm motion for driving arrayed elements [1]. The device is able to achieve large stroke with high accuracy. However, it is difficult to transmit high-power to the elements, because it has a slippage limitation in the electrostatic gripping mechanism for limiting the use of an external force.

We propose a novel type mechanical transmission system for driving arrayed elements. Our aim is to operate individually arrayed elements with high power and large stroke.

2. SYSTEM DESIGN

System composition and principle

Figure 1(a) shows a schematic view of the proposed mechanical transmission system for driving arrayed elements. It consists of an arrayed end effector element, a plural number of blocks with a clutch mechanism as the force/displacement transmitter, and a single small-sized actuator for the large power and large displacement. Each diaphragm has a mesa structure at the center. First, the clutch mechanism moves a block under the mesa structure of the diaphragm (Fig. 1(b)). Next, the small-sized actuator lifts the entire clutch mechanism. When the block of the clutch mechanism meets the mesa structure of the diaphragm, the power and displacement of the small-sized actuator is transmitted to the diaphragm (Fig. 1(c)). Therefore, we are able to drive individual diaphragms by controlling the block position on the transmission, regardless of the power transmitted from the small-sized actuator to the mesa of the diaphragm.

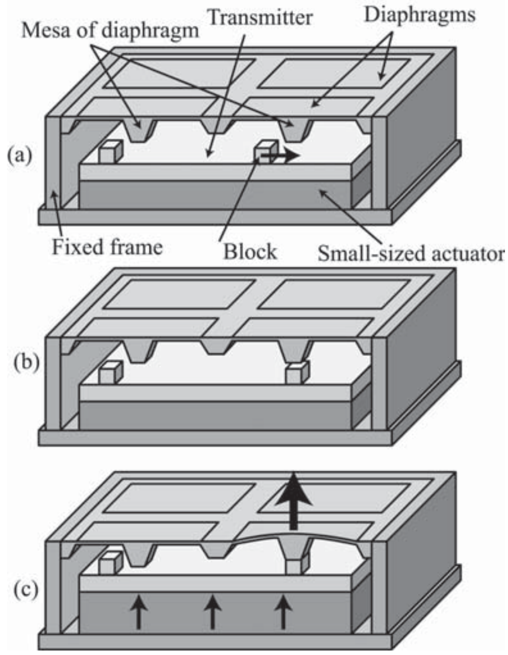

Fig. 1. Schematic view of proposed mechanical transmission system

Arrayed end effector element design

Figure 2 shows the fabrication process for the arrayed end effector element and the fabricated arrayed-end effector element. First, a [1 0 0] silicon wafer is selected as the substrate. After some standard rinse steps for substrate preparation, a 3-μm SiO_2 is thermally grown on the wafer (Fig. 2(a)). Two etching processes produce the diaphragm mask with an island pattern (Figs. 2(b) an (c)). This is a very important process for making the step of the mesa and the supporting frame. Next, half the thickness of the substrate is etched (Fig. 2(d)). After the dioxide on the supporting frame is removed, silicon rubber is coated on the wafer (Figs. 2(e) and (f)). Finally, the front side of the silicon is further etched, while the mesa at the center is protected (Fig. 2(g)), and the dioxide is removed (Fig. 2(h)).

We fabricated the arrayed element using spin-coated silicone rubber, and anisotropic wet etching. The sizes of the diaphragm and mesa were 1.0 x 1.0 x 0.02 mm^3 and 0.1 x 0.1 x 0.2 mm^3, respectively. The thickness of the mesa was 40 μm thicker than that of the supporting frame, to prevent any physical interference between the frame and the electrostatic clutch during operation. We used silicone rubber for the diaphragm to decrease the spring constant, and fabricated it in a 4 x 4 array arrangement.

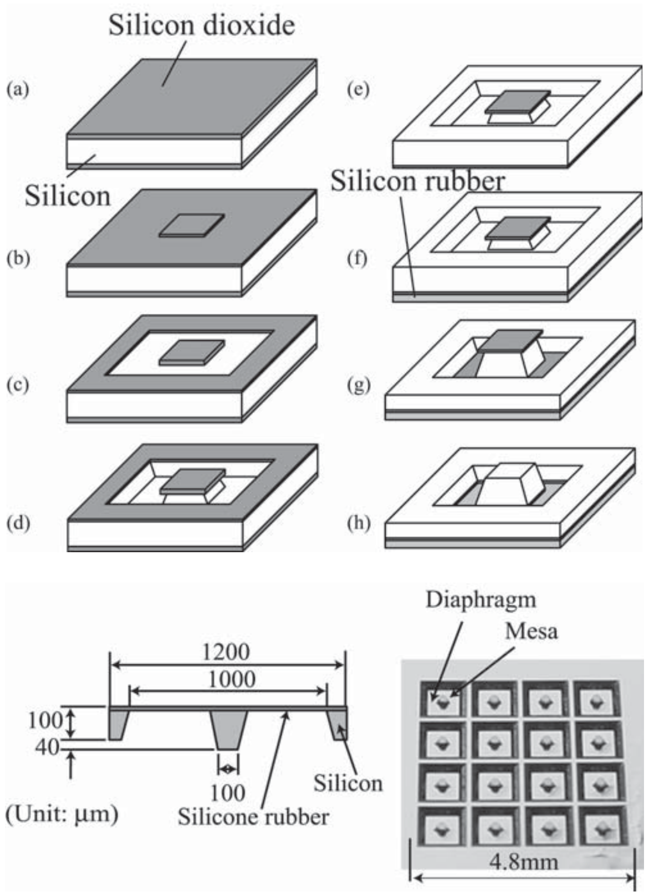

Fig. 2. Fabrication process and Fabricated arrayed end effector element

Transmission system design

To move the block of the transmission, the clutch mechanism must be a micro actuator generating a large displacement, when taking into consideration the size of the block. Figure 3 shows the tulip-shaped electrostatic clutch that controls the block position on the transmission. It consists of a cantilever shaft with the block at the end, and a pair of driving quadratic-curved electrodes. The block position is controlled by an electrostatic force working between the cantilever and the driving electrode (Fig. 3).

We used an SOI wafer for the transmission device material, and fabricated the tulip-shaped electrostatic clutch device using Deep-RIE (Fig. 4).

Figure 5 shows the fabricated tulip-shaped electrostatic clutch. The height of the device was 20 μm, which corresponds to the transmitted stroke. The surface of the device was covered with a thermally oxidized silicon layer with a 1.0 μm insulation layer. The width of the cantilever was 5.0 μm. The minimum gap between the bottom of the cantilever and driving electrode was 1.5 μm.

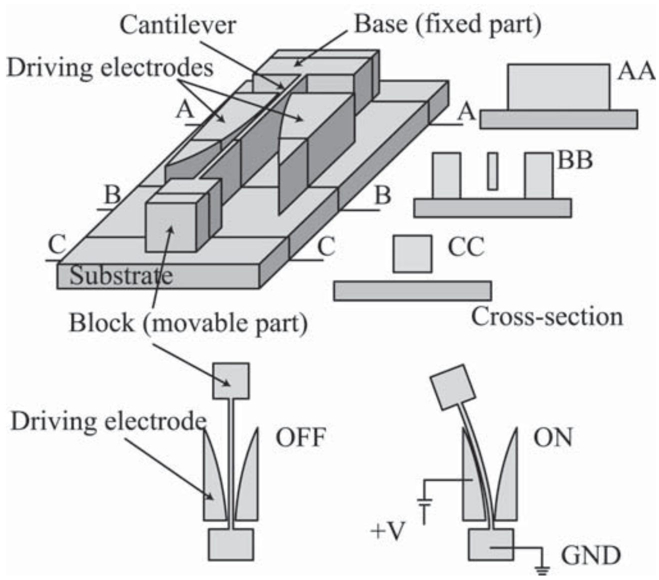

Fig. 3. Tulip-shaped electrostatic clutch device

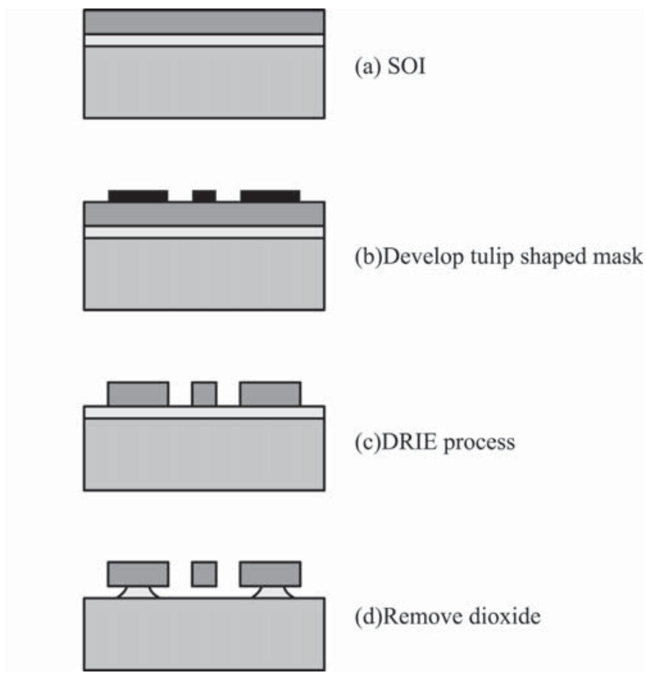

Fig. 4. Fabrication process of tulip-shaped electrostatic clutch device

3. SIMULATION AND EXPERIMENTAL RESULTS OF TULIP-SHAPED ACTUATOR

We used a two-dimensional model based on the analytical energy methods. Figure 6 shows the basic design of the cantilever beam and the curved electrode.

Figures 7 and 8 show the simulation results based on the energy methods and the experimental results, respectively, where *h* is the width of the beam.

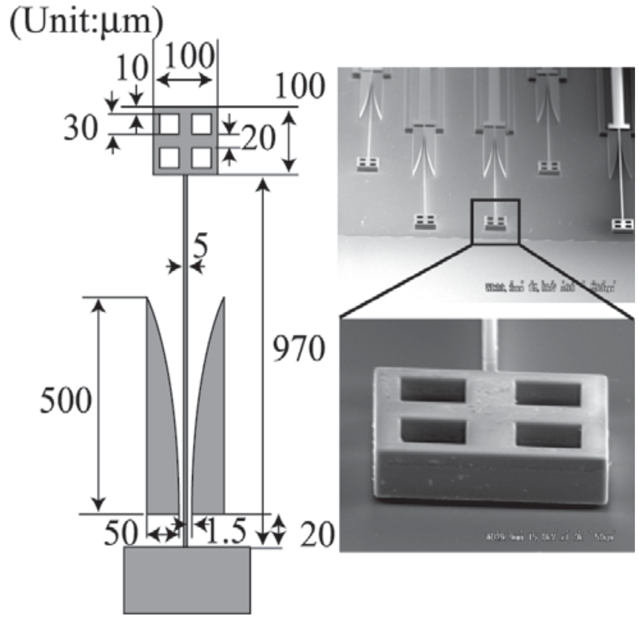

Fig. 5. Fabricated tulip-shaped electrostatic clutch device

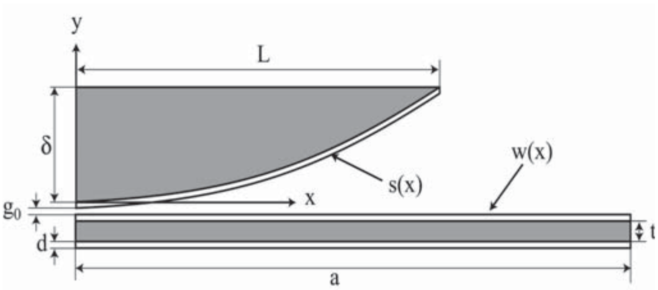

Fig. 6. Basic design of cantilever beam and curved electrode

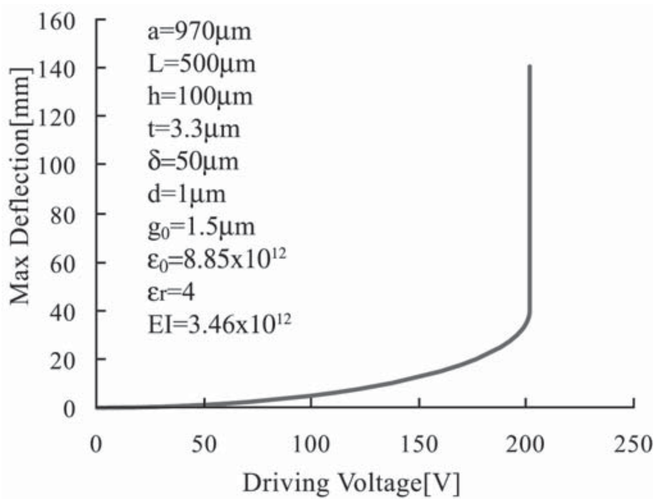

Fig. 7. Designed tulip shaped actuator deflection vs. driving voltage

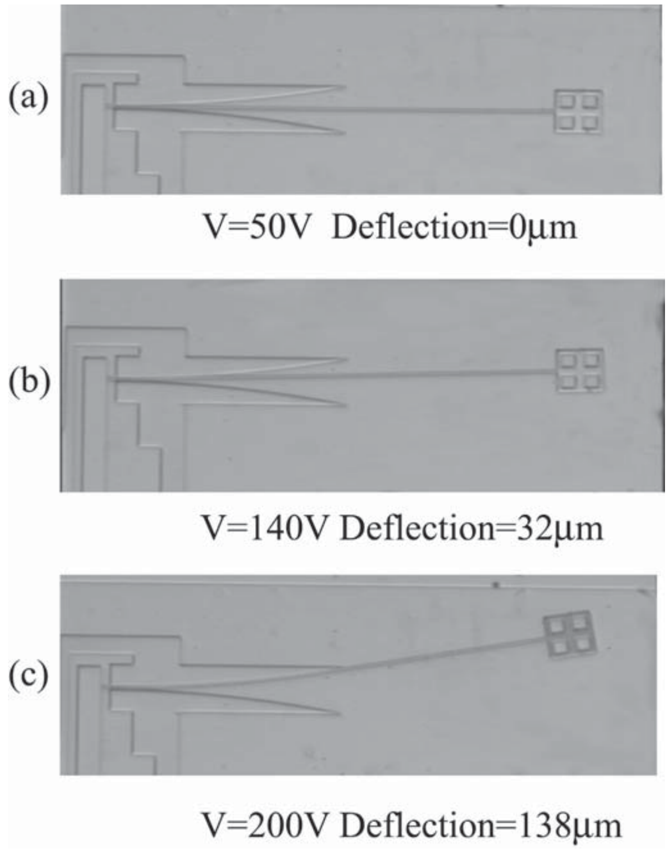

Fig. 8. Photograph of designed tulip-shaped actuator applied driving voltages of 50 V, 140 V, and 200 V

4. IMPLEMENTATION

This time, we used a mechanical Z-stage as an actuator to confirm the performance of the electrostatic clutch devices and the arrayed element. Figure 9(c) shows the assembled mechanical transmission system.

5. EXPERIMENTS

Each arrayed element was successfully operated vertically with the movement of the Z-stage, as shown in Fig. 10.

6. CONCLUSION

We propose a novel type mechanical transmission system for driving arrayed elements, and developed a prototype of it. The advantages of this system are as follows.

(1) The system can transmit a large force, because of a high compressive strength of the clutch block.

(2) The system can also transmit a large stroke of displacement that is determined by the heights of the clutch block.

(3) The high pitch density of the arrayed actuator system is obtained because of the smallness of the electrostatically driven clutch.

We are now trying to develop a small-sized actuator using a mm-sized stepping motor, which is able to achieve several Newtons of power with a hundreds of microns stroke, for fabricating small-sized haptic display systems.

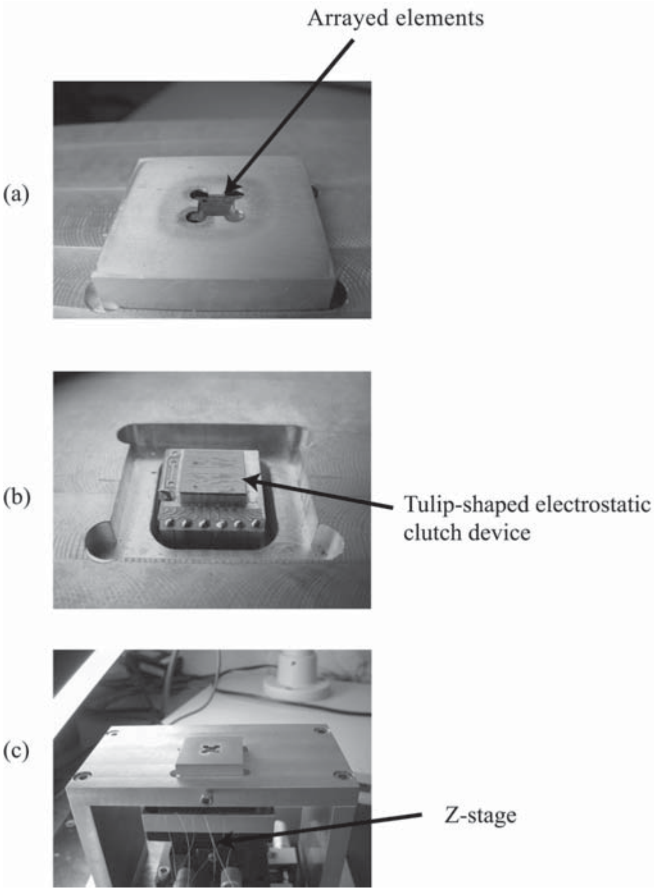

Fig. 9. Assembled mechanical transmission systems

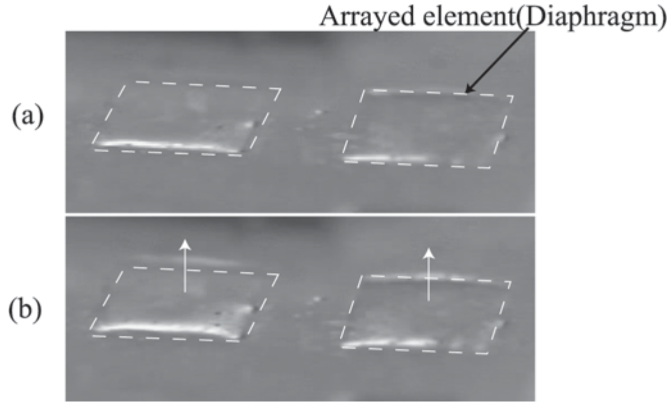

Fig. 10. Arrayed elements operated in vertical direction
(a) Before Z-stage movement
(b) After Z-stage movement

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[1] S. Konishi, et al., "Vertical motion microactuator based on the concept of ECLEA", Proc. MEMS 2002, 602-605.