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BUBBLE DRIVEN ARRAYED ACTUATOR DEVICE FOR A TACTILE DISPLAY

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Abstract: We designed and made a micro meter sized arrayed actuator device for use in a tactile display. Each actuator uses a liquid-vapor phase change to drive a micro needle that stimulates receptors in a finger that is in contact with the array. The actuators consist of a flexible diaphragm structure and a bottom plate, which are bonded to create a cavity between them. A micro needle and a micro heater are formed on the diaphragm and the plate, respectively, of each actuator, and the sealed cavity that is thereby created is filled with an operating liquid. We manually assembled these components to form a 3x3 arrayed actuator device, 15x15x1 mm in size. Increasing the pressure in the cavity by activating the heater and generating bubbles, deformes the flexible membrane and drives the needle upwards. We experimentally evaluated the device and obtained a large needle displacement (61 µm) with 457-mJ input energy. This magnitude of displacement should easily stimulate receptors on the tips of fingers.

Keywords: Bubble, Tactile display, PDMS, Parylene-C

1. INTRODUCTION

Tactile senses give us important information. For example, we instinctively use tactile information when handling something. Blind people also use it for communicating. It is now being applied to car navigation systems to enable drivers to receive information without taking their eyes off the road. It is also expected to be useful in computer interfaces and virtual reality applications.

Many researchers use pin-type structure arrays to physically stimulate finger receptors. The sensitivity of the receptor depends on the amount of deformation and the velocity of the pin. The sensitivity is maximum when humans touch objects that are vibrating at around 200 Hz. At this frequency, the human is able to perceive a 1.0-µm step on the surface; however, a nearly 100-µm deformation is needed if we physically stimulate the receptor with pins in a quasi-static mode.

Matsunaga, et al. developed a small-sized actuator based on shape-memory alloy spring, and realized a palm-top sized tactile display system by applying it for blind human [1]. The arrayed pins are individually driven up and down in the vertical direction. The system has potential as a Braille display. Yoshikawa, et al. proposed a mm-sized haptic display [2]. The device has an advantage that it can drastically reduce the volume of the system, however, it has to be improved the actuation method to generate a large force. Other various types of actuating systems, for example polymer gel [3], pneumatics [4], and piezoelectric elements [5] have also been used to make tactile displays, however they are large and complicated.

We designed and made a micrometer-sized thermal 3x3 arrayed actuator device driven by bubble generation, which significantly reduces the volume of the device.

2. OPERATION PRINCIPLE

A change from a liquid to a vapor phase yields a huge increase in volume. This means that one is able to obtain a relatively large stroke using a small amount of liquid. We made use of this phenomenon in making our micrometer-sized actuator device. Figure 1 shows a schematic diagram of the proposed bubble-type actuator device for a tactile display. Each actuator consists of a needle on a flexible membrane, a heater on a glass substrate, and driving liquid sealed in a cavity. Figure 2 shows the principle of its operation. Bubbles are rapidly generated by the heater by applying an electrical current, causing the flexible membrane to deform upwards. The deformation pushes the needle up into any finger placed on upper frame of the actuator.

3. FABRICATION

The bubble driven actuator device is constructed from three components: an upper frame with needles on membrane, a lower

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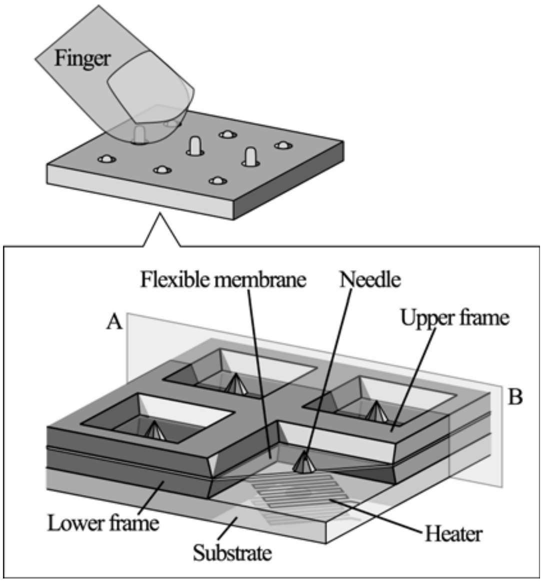

Fig.1 Schematic diagram of tactile display.

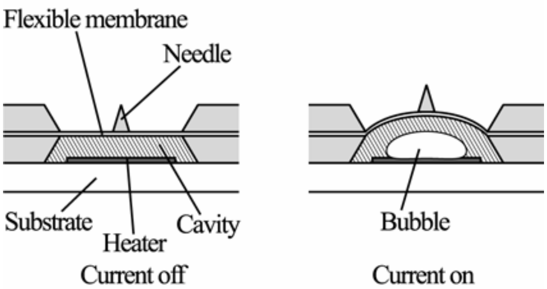

Fig.2 Schematic diagram of operation principle (cross-section along line AB in Figure 1).

frame, and a substrate. We fabricated each component by MEMS technology and assembled them.

Figures 3 show the fabrication process of the upper and lower flames, and the substrate respectively.

3.1 Upper frame fabrication

We used 40% KOH solution as the anisotropic wet etching solution of Si wafer and PDMS resin as the membrane material. PDMS resin is transparent and has a low Young 's modulus of 2.0 MPa. However the PDMS membrane formed on Si wafer begins to fall away after about an hour of wet etching process. We divided the wet etching process into two and shortened the time of the second etching process that was after the membrane formation. As a result, we could prevent the PDMS membrane from falling away. Figure 3(a) shows the following fabrication process of the upper flame.

(1) A 3.0-µm-thick layer of SiO_2 was grown

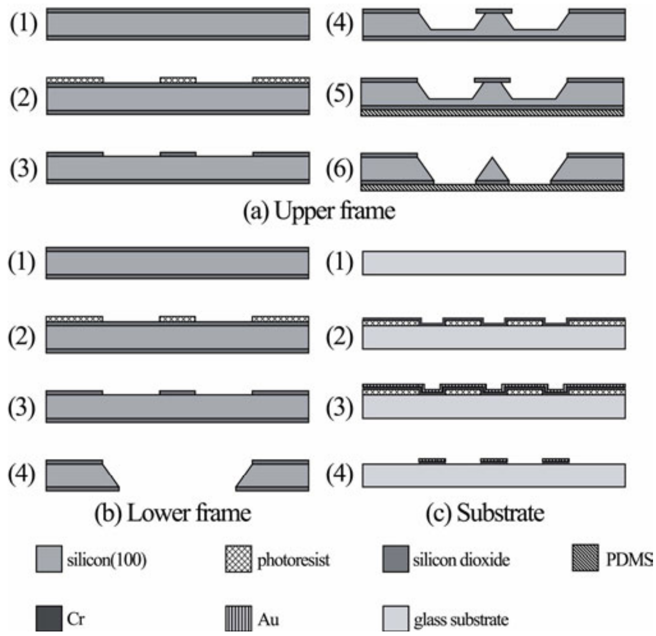

Fig.3 Fabrication process of three components.

on a 200-µm-thick Si (100) wafer using thermal oxidation.

(2) Photoresist was coated on the Si wafer using a spinner, and it was patterned using photolithography.

(3) The pattern was etched onto the SiO_2 mask, and then the photoresist was removed.

(4) The Si substrate was etched anisotropically until the thickness of the diaphragm became 30-40 µm.

(5) A 20-µm-thick layer of PDMS was coated onto the back side of the wafer using a spinner, and baked at 125-°C for 20 min.

(6) The Si substrate was etched anisotropically again, and the needles on the PDMS membrane were formed.

The needle heights and upper frame thickness were the same: 200 µm, and the size and thickness of the PDMS membrane were 2.5 mm square and 20 µm, respectively.

3.2 Lower frame fabrication

The fabrication of the lower frame was basically the same that of the upper one, except the upper frame had a PDMS coating (Fig. 3(b)). We fabricated the upper and lower frame using the same photo-mask. The thickness of the flames was 200 µm.

3.3 Substrate fabrication

We used a glass plate as the substrate with a thickness of 0.5 mm and formed the Au/Cr heater on the substrate using sputtering and

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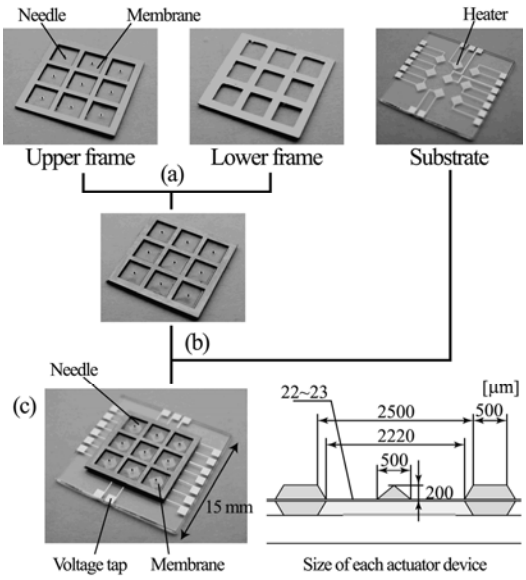

Fig.4 Assembly procedure.

lift-off process (Fig. 3(c)). The resistance of each heater is 31.4 Ω.

3.4 Assembly

First, we bonded the upper and lower frames, as shown in Fig. 4(a), using a glass binders. Then, we coated all the surfaces of the bonded structure with parylene-C film. This step had two purposes: reducing the gas permeability of the PMDS membrane, which has a high gas permeability and would therefore enable the bubbles generated by the heater to escape if the film not there; and sealing the two bonded structure because parylene-C has uniform deposition. Next we coated the back side of the two bonded structure with photo-curable resin that is gradually getting rigid. After radiating to the resin with UV light, we finally attached the bonded structure to the substrate to form a bubble driven actuator device, as shown in Figs. 4(b)-(c). We assembled them submerged in the driving liquid to avoid aeration, which would form air bubbles in the cavity. This process was performed at room temperature. Therefore, we were able to use FC-72 (3M Chemicals), which has a low boiling point (56 ^{o}C), as the driving liquid. It is also inert, noncorrosive, and electrically insulating. Figure 4(c) shows the fabricated 3x3 actuator array and a section size of each actuator device. The needle pitch on the membrane is 3.0 mm, which is the limit of feeling of the human finger. The overall size of the device is 15.0 mm square and 1.0 mm in height.

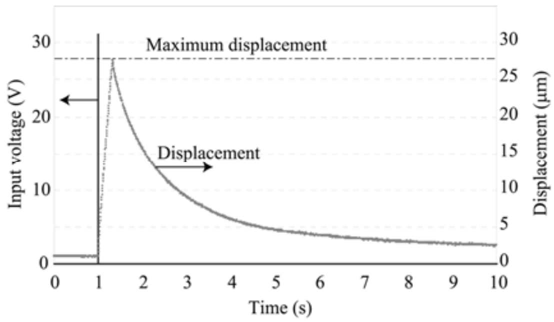

Fig.5 A typical transient displacement applied a pulse voltage.

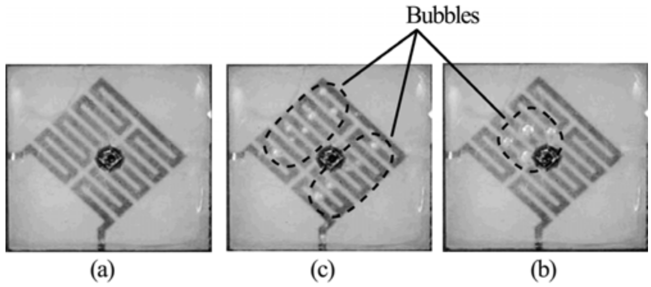

Fig.6 Images of bubbles in a cavity, as seen through flexible membrane.

4. EXPERIMENTAL RESULTS

We applied a pulse voltage, which was generated by a pulse generator and then amplified by a power amplifier, across the heater. A laser displacement meter was used to detect the displacement of the needles in the array. The bubble generation was observed through an optical microscope at 1.66 magnification and recorded on video.

Figure 5 shows a typical needle displacement when a pulse voltage was applied as a function of time. The horizontal axis indicates time, in which the origin was set to be when the pulse voltage was applied. The vertical axis indicates the applied driving pulse voltage and the needle displacement. The width and voltage of the applied pulse voltage were 5 ms and 31.25 V, respectively. The displacement reached at a maximum of 27.7 μm after 330 ms and then fell to 2.5 μm. It did not return to the original value even after several seconds.

Figure 6 shows optical images of bubbles generated in a cavity as observed through the membrane. The input voltage was 15.5 V. Figure 6(a) is before the voltage was applied. No bubbles were observed in this state. Figure 6(b) is the image showing bubble generation at maximum displacement. We observed a large number of tiny bubbles coming off the heater. Some of them disappeared quickly, however,

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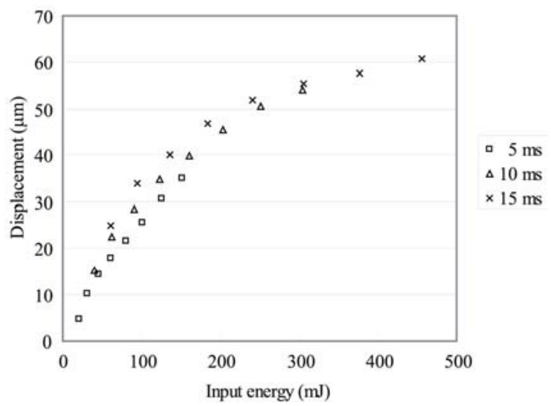

Fig.7 Maximum needle displacements as a function of input energy.

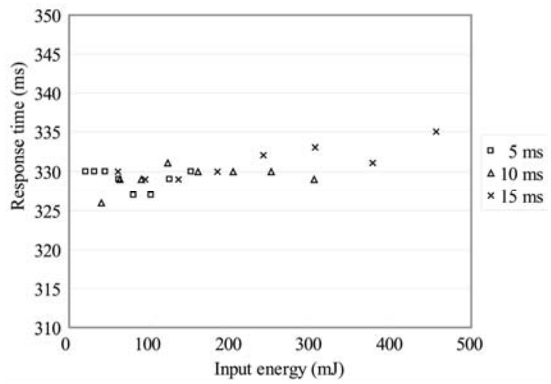

Fig.8 Response time as a function of input energy.

others coalesced and formed several slightly larger bubbles in the cavity. Figure 6(c) is the image taken after 1 s. Several bubbles remained in the cavity. These bubbles finally coalesced into one large bubble after 3 s. This single large bubble gradually shrank but still remained intact.

Figure 7 shows the maximum displacement at various pulse voltages (various pulse widths and amplitudes). The horizontal axis indicates the energy input, which was calculated from the input voltage, pulse width (5, 10, 15 ms) and heater resistance (31.4 Ω). The vertical axis indicates the maximum needle displacement. The needle displacement increased with the increase of the input energy, and did not depend on the pulse wave forms if the input energy was the same. We therefore concluded that the input energy determines the needle displacement in our device. The large displacement of 60.7 μm was obtained when the input energy was 457 mJ (the pulse width and the amplitude were 15 ms and 28.7 V, respectively). We also examined how much the needle displacement was needed to stimulate the human finger by our device, and obtained the value of 32 μm (The human could perceive the needle stimulation when the needle displacement is over 32 μm).

Figure 8 shows a resoponse time at various pulse voltages. The horizontal and vertical axises are the input energy and the response time (the time to be needed to reach the maximum value of the needle displacement), respectively. The response time did not depend on both of the input energy and the pulse wave form, and became the value of 330 ms. We think this reslut means that the volume change by the bubble generation in the cavity dominates the resoponse in our device.

5. CONCLUSION

We designed and made a micrometer-sized 3x3 arrayed actuator device for a tactile display. Each actuator uses bubbles that are generated by a heater, similar to the process in a thermal ink jet. The overall size of the device is 15.0 mm square and 1.0 mm in height. Passing an electrical current through the heater at 457-mJ input energy caused 60.7 μm displacement of the needle, and we could perceive the displacement tactilely.

REFERENCES

[1] T. Matsunaga, W. Makishi, M. Esashi and Y. Haga, “2-D and 3-D Tactile Display Using SMA Micro-coil Actuator and Magnetic Latch”, Tech. Dig. Transducers‘05, Seoul, June 5-9, pp. 325-328, 2005.

[2] W. Yoshikawa, A. Sasabe, K. Sugano, T. Tsuchiya, O. Tabata and A. Ishida, “Vertical Drive Micro Actuator Using SMA Thin Film For A Smart Button”, Tech. Dig. MEMS ‘06 , Istanbul, January 22-26, pp. 734-737, 2006.

[3] F. Takemura, M. Enomoto, T. Tanaka, K. Denou, Y. Kobayashi and S. Tadokoro, “Development of the balloon-cable driven robot for information collection from sky and proposal of the search strategy at a major disaster”, Proc. IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Monterey, July 24-28, pp. 658-663, 2005.

[4] M. Takaiwa and T. Noritsugu, “Development of Pneumatic Human Interface and Its Application for Compliance Display”, Proc. of 2000 IEEE Int. Conf. on Industrial Electronics, Control and Instrumentation IECON-2000, CD-ROM, October, 2000.

[5] Y. Ikei and S. Fukuda, “Tactile Display for a Surface Texture Sensation,” Proc. 1997 ASME Design Eng. Technical Conf, pp. 1-8, 1997.

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