MICROMACHINED DISPENSER WITH HIGH FLOW RATE AND HIGH RESOLUTION

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ABSTRACT

A micromachined dispenser with a high flow rate and high resolution for chemical analysis is described. The flow rate as a function of the actuation frequency increases linearly up to a frequency of 700 Hz with a final value of about 148 μl/s using water as a pump medium. The dispensing accuracy is better than 1 % (coefficient of variance) at a dispensing volume of 56 μl. This dispenser shows good dispensing performance thanks to its precise valve structure and surface-treated nozzle.

INTRODUCTION

Dispensers are widely used in industrial production and chemical-analysis systems because of the ability to dispense liquid precisely. As shown Fig. 1, reagents are conventionally dispensed on micro-plates one by one, which is time-consuming. To increase the throughput, we proposed the multi-arrayed micromachined dispenser (illustrated in Fig. 1 (b)). It is based on a piezoelectrically driven diaphragm actuator . There was a head of the ink-jet printer as well as a micro-device that discharge had a small quantity liquid[1][2][3]. But, the amount of discharge and reappearance aren't sufficient to use it for dispensing the reagents.

In this paper, we describe our dispenser and discuss its performance.

DESCRIPTION

Design

As shown in Fig. 2, the micromachined dispenser consists of four single-crystal silicon layers, each 14×14×0.5 mm, two passive check valves (inlet/outlet), a micro-nozzle, and a piezoelectrically driven diaphragm actuator. The silicon diaphragm is 8×8×0.3 mm, and the piezoelectric element is 7×7×0.3 mm. Dispensers used for chemical analysis require a high flow rate (~ 100 μl/s) and high resolution (~ 0.1μl/step). One way to increase the flow rate without decreasing the resolution is to increase the actuation frequency of diaphragm. However, this tends to increase the reverse-flow caused by the opening of a valve that should be closed. Also when the resolution of dispensing is increased, the liquid tends to remain in the nozzle, and the discharge is less precise. To overcome these problems, we

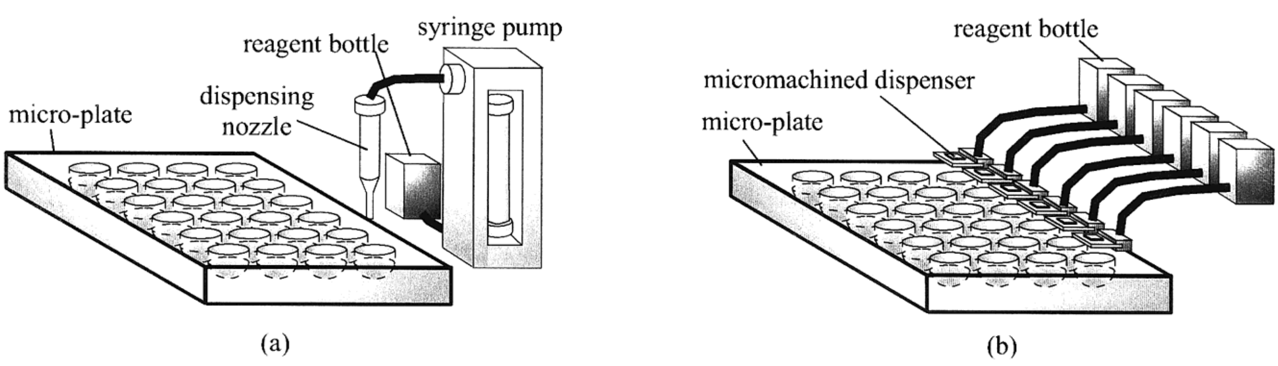

Fig. 1 Concept of (a) conventional dispenser and (b) arrayed micromachined dispensers

developed a very precise valve structure with a preload and a surface-treated micro-nozzle. To achieve a precise fit, the four silicon layers are produced using a multi-step anisotropic etching technique [4] and are bonded using a Si-Si direct bonding technique [5].

Valve structure

As shown in Fig.3 (a) and (b), the outlet valve is suspended by four beams. Figure 3(c) shows a cross-sectional view of the valve structure. The valve shuts the valve port by using preload with four beams. The preload reduces the contraflow caused by opening both the inlet and outlet valves at the same time. As shown by the X-ray transparent image in Fig. 3 (d), it knows the thing that a valve is pressed against the port due to the deflection of the beam [6].

To produce this 3-D structure, we perform the anisotropic etching in four steps (Fig.4). Prior to etchig, the four mask patterns to be used are formed in layers on a flat wafer surface. These masks are removed one by one with each etching. This four-layer etching mask consists of silicon dioxide, which is formed by thermal oxidation. This process makes it easy to create a three-dimensional silicon structure.

Surface-treated micro-nozzle

Figure 5 shows a photograph of the surface-treated nozzle. The frame of the nozzle is 20 μm wide and 100 μm high. It is covered with water-repellent film, which reduces the adhesion of the water when it is dispensed.

This nozzle is also produced using multi-step anisotropic etching, as shown in Fig. 6. After the etch front partially penetrates the wafer, the silicon wafer continues to be exposed to the etchant until the frame of the nozzle becomes 20 μm wide due to the disappearance of the convex structure. This

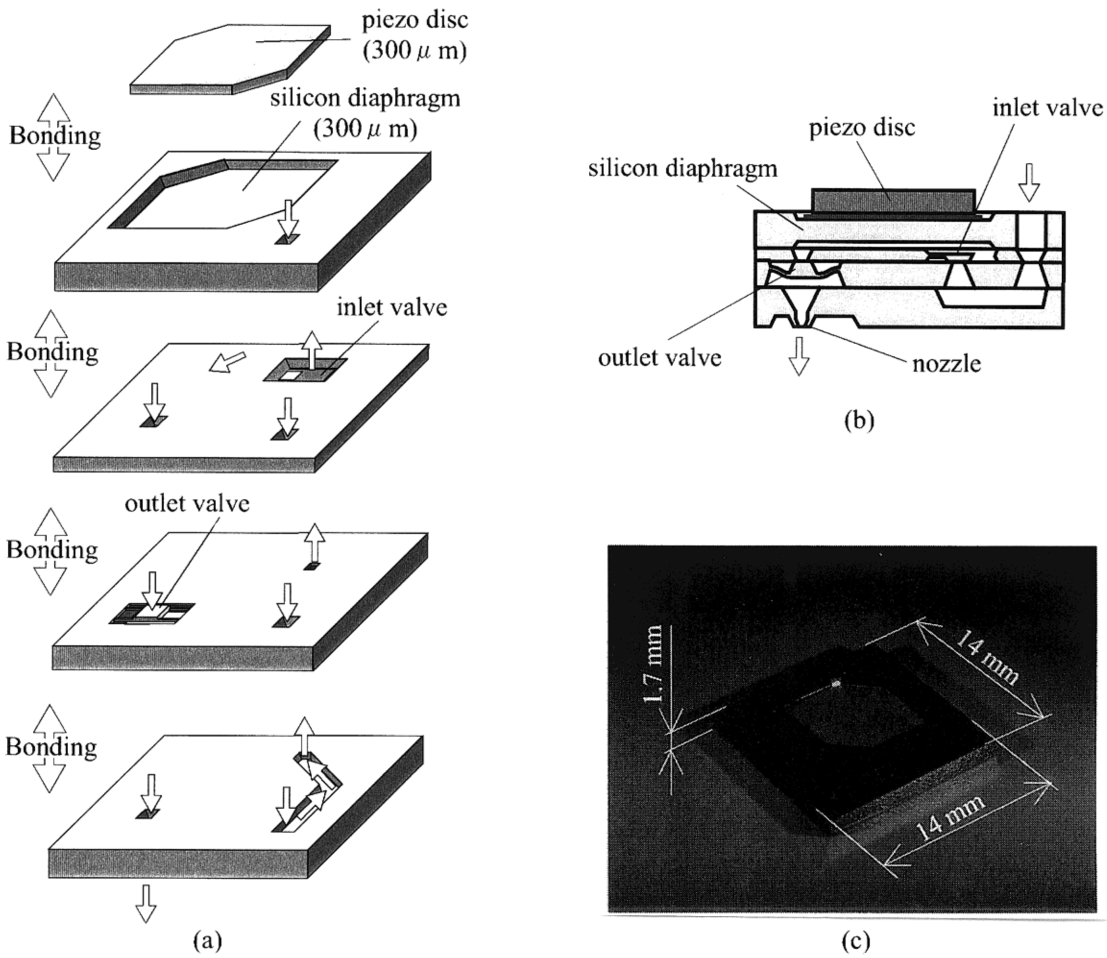

Fig. 2 (a) Principle design, (b) crosssectional view, and photograph of micromachined dispenser

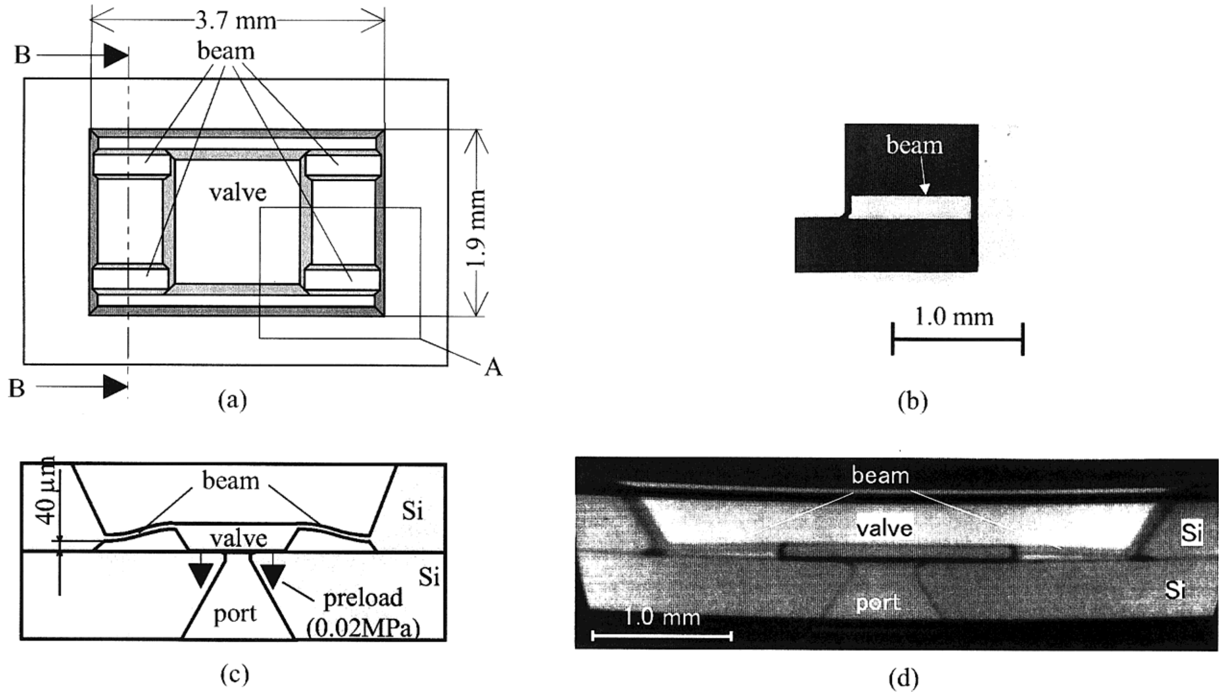

Fig. 3 (a) Bottom view of outlet valve, (b) photograph of section A in (a), (c) crosssectional view of valve, and (d) x-ray image of valve.

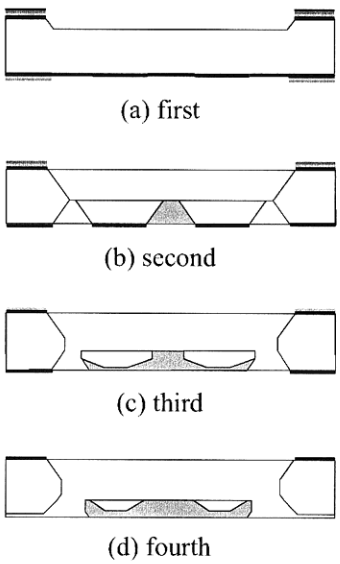

Fig.4 Crosssectional view of four anisotropic etching steps for producing 3-D structure. (Fig. 3 B-B cross-section)

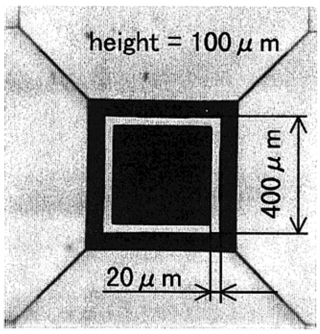

Fig. 5 Photograph of surface-treated nozzle.

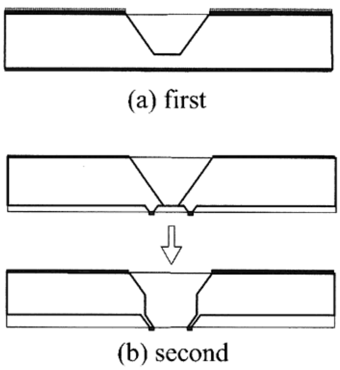

Fig.6 Crosssectional view of two anisotropic etching steps for producing the nozzle.

process makes it eacy to achieve a precise silicon structure.

PERFORMANCE EVALUATION

The experiment apparatus we used to evaluate dispensers performance is shown in the Fig. 7. The performance of the valve was estimated from the relation between the pressure and the flow rate, as illustrated in Fig. 8. The outlet valve can shut the port up to a pressure of 0.02 MPa in the forward direction. The valve can thus shut the port before the inlet valve is opened by the pressure in the forward direction. This increases the flow rate to the high-frequency range.

The flow rate as a function of the actuation frequency is shown in Fig. 9 using water as a pump medium. The flow rate was estimated from the weight of the dispensed water, and the displacement of the diaphragm was measured using a laser -displacement measurement system, as shown in Fig. 7. The dispenser was driven by a sine signal ranging from -150 to 300 V. The displacement of the center of the diaphragm was about 12 μm at frequencies ranging from DC to 700 Hz. The flow rate increased linearly up to a frequency of 700 Hz, with a final value of about 148 μl/s. This indicates that the very precise valve structure contributes to obtaining a high flow rate.

To check the ability of the nozzle, we observed the dispensed water by using a high-speed video-camera system (Fig. 7). The dispenser was actuated by a sine signal ranging from -100 to 250 V. The actuation frequency was 400 Hz.

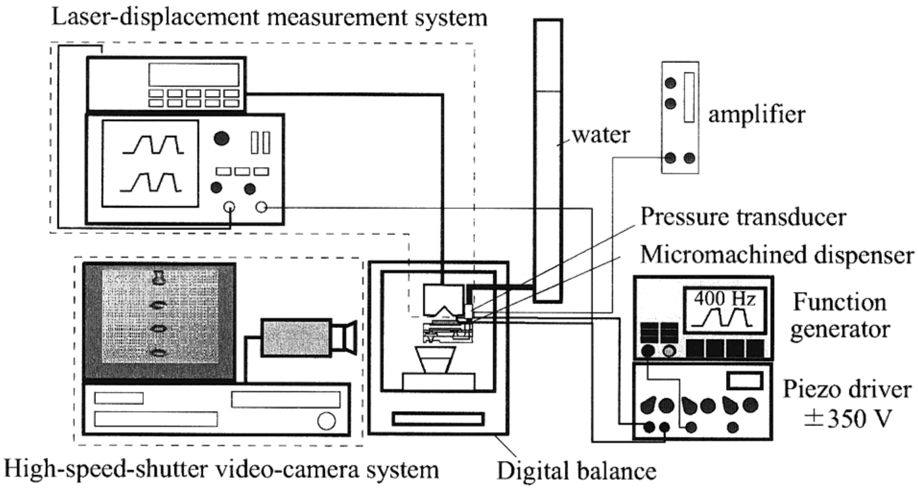

Fig. 7 Experimental setup

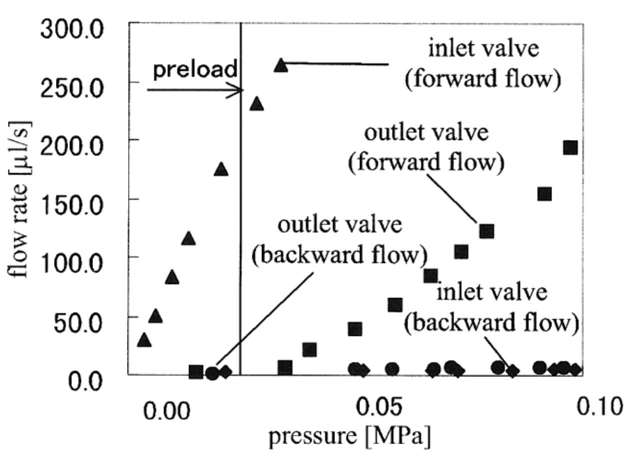

Fig. 8 Capacity to resist pressure of inlet/outlet valve

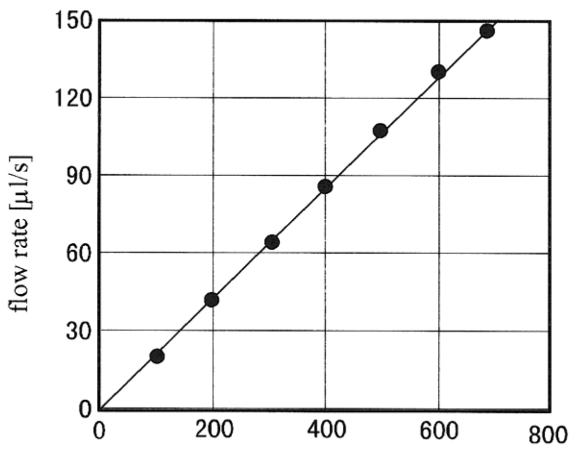

Fig. 9 Frequency dependence of micromachined dispenser at zero backpressure (-150 ~300 V)

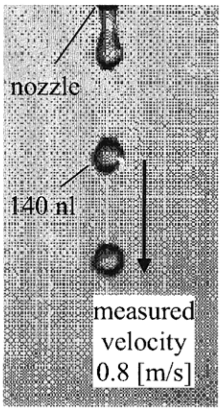

Fig. 10 Ejection of water droplets at 400Hz

We observed stable droplets, about 140 nl in volume, and no satellite droplets (Fig. 10) . This shows that we can accurately control the total volume of water dispensed, with a deviation of the volume of the last droplet volume.

Finally, we checked the dispensing performance. The accuracy of the dispensed water volume is shown as a function of the droplet count in Table 1. The dispenser was actuated by a sine signal ranging from -100 to 250 V. The actuation frequency was 400 Hz. The flow rate was 56 μl/s, and each droplet had a volume of 140 nl. The dispensed volume increased linearly with the droplet count, and the accuracy was within 1 % for 56 μl. This result shows that the coefficient of variance mostly depends on the last droplet's volume and that we can control the total dispensed water volume by controlling droplet count. As shown in Table 2, the micromachined dispenser is very small and cheap compared with commercial dispensers without a reduction in performance. It is thus suitable for use in arrays of dispensers.

CONCLUSION

We have described a micromachined dispenser with a high flow rate and a high resolution. The outlet valve can shut the port up to a pressure of 0.02 MPa in the forward direction. The valve can thus shut the port before the inlet valve is opened by the pressure in the forward direction. The flow rate as a function of the actuation frequency increases linearly up to a frequency of 700 Hz with a final value of about 148 μl/s. We observed stable droplets, about 140 nl in volume, and no satellite droplets. The dispensing accuracy is under 1 % even for 56 μl. This dispenser shows good performance thanks to its precise valves structure and surface-treated nozzle, making it suitable for use in chemical analysis.

Table. 1 Accuracy of dispensed water volume at 400 Hz sine-wave drive(-100 ～ 250 V).

droplet count	40	200	400
volume [μl]	5.6	28.1	56.2
σ [μl]	0.04	0.10	0.12
C.V. [%]	0.72	0.36	0.22

σ : standard deviation
C.V.: = (σ /average) × 100
(coefficient of variance)

Table. 2 Performances of micromachined and commercial dispensers

	Micromachined	Commercial
C.V.	0.22 % (56 μl)	>1 % (100 μl)
size [mm]	14W × 14D × 2H	490W × 450D × 354H
arrayed dispensers	easy	difficult, expensive

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