Extended Abstracts of the 2001 International Conference on Solid State Devices and Materials, Tokyo, 2001, pp. 452–453

A-7-3

Micro-Liquid Handling Devices for Miniaturized Chemical Analysis Systems

Ryo Miyake , Akira Koide, Yasuhiko Sasaki, and Yasuhiro Yoshimura

Mechanical Engineering Research Laboratories, Hitachi, Ltd.
502 Kandatsu, Tsuchiura, Ibaraki 300-0013
Phone:+81-298-32-4424 Fax:+81-298-32-2804 E-mail: miyake@merl.hitachi.co.jp

1. Introduction

There is a growing interest in the research on miniaturized chemical analysis systems together with micro-mixers, micro-filters, separation channels, micro-valves, micro-pumps, detection micro-flow cells, and micro-connectors as illustrated in figure 1[1]. Advantages these miniaturized systems are (a) improvement of accuracy due to their small internal volume, (b) suitable for onsite-monitoring due to the small system size and their portability, and (c) high throughput analysis by arraying the system. Even though many concepts have already been proposed such as micro-flow injection analysis systems, micro-chromatographs, flow-cytometers etc, we have few practical analysis systems. One of the technical obstacles is not to have appropriate liquid handling devices such as sampling, shipping, switching, etc. Particularly, as the shipping devices, stable flow speed is necessary for the precise analysis and higher flow rate for efficient washing and cleaning. In this paper, we describe a micro-liquid shipping device suitable for miniaturized chemical analysis systems.

2. Micro-liquid shipping device

As shown in figure 2, the micro-machined shipping device consists of four single-crystal silicon layers, each 14 x 14 x 0.5 mm, two passive check valves (inlet/outlet), and a piezoelectrically driven diaphragm actuator. The silicon diaphragm is 8 x 8 x 0.3 mm, and the piezoelectric element is 7 x 7 x 0.3 mm. 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. To overcome these problems, we developed a very precise valve structure with a pre-load. To achieve a precise fit, the four silicon layers are produced using a multi-step anisotropic etching technique[2] and are bonded using a Si-Si direct bonding technique [3]. As shown in figure 3(a) , the outlet valve is suspended by four beams. Figure 3(b) shows a cross-sectional view of the valve structure. The valve shuts the valve port by using pre-load with four beams. The pre-load reduces the reverse-flow caused by opening both the inlet and outlet valves at the same time. As shown by the X-ray transparent image in figure 3(c), it shows that a valve is pressed against the port with the deflection of the beam [4].

3. Feasibility test

The function of the valve was evaluated from the relation between the pressure and the flow rate, as illustrated in figure 4. The outlet valve can shut the port up to a pressure of 0.02 MPa in the forward direction. The outlet valve can thus shut the port before the inlet valve is open 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 figure 5 using water as a shipping medium. It increases linearly with the actuation frequency. The accuracy of the shipping volume is also evaluated by counting the volume of ejected droplets in Table 1. It was actuated by a sinusoidal 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 accuracy was within 1 %.

4. Conclusions

A micro-liquid shipping device with a high flow rate and a high resolution was described. Si-direct bonding technique allows precise valve structure and contributes to gaining high performance appropriate for miniaturized chemical analysis systems.

References

[1] A. Manz, N. Graber, and H.M.Widmer, "Miniaturized Total Chemical Analysis Systems: A Novel Concept for Chemical Sensing", Sensor & Actuators, B1, pp.244-248, 1990.

[2] A. Koide, K. Sato, S. Suzuki and M. miki, "A Multistep Anisotropic Etching Process for Producing 3-D Silicon Accelerometers", The 11th SENSOR SYMPOSIUM, 1992, pp. 23-26

[3] Y. Sasaki, A. Kouno, M. Horino, M. Usami, M. Tokuda and T. Tase, Quarterly Journal of The Japan Welding Society, Vol.17, pp. 264-271. 1999(in Japanese)

[4] N. Watanabe, A. Koide, Y. Nagaoka, R. Miyake and T. Terayama, "A New Visualizing Technique for Micro-Channels Using Micronsized Focal Spot of X-Raysource", Transducers'99, June 7-10, 1999, Sendsai, Japan, pp. 1380-1383.

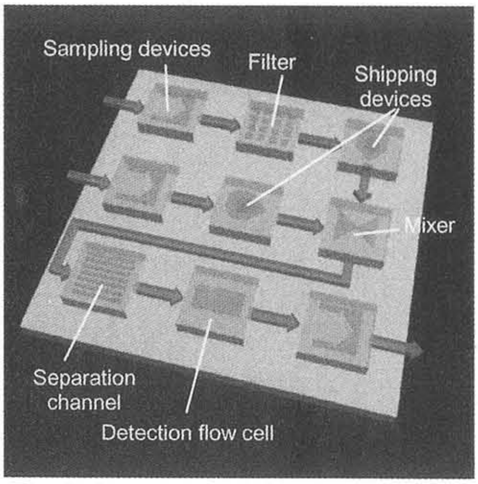


Fig. 1. Concept of miniaturized chemical analysis systems

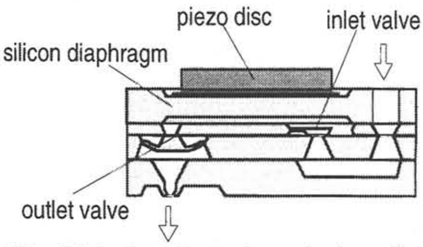


Fig. 2(a). Configuration of micro-liquid shipping devices

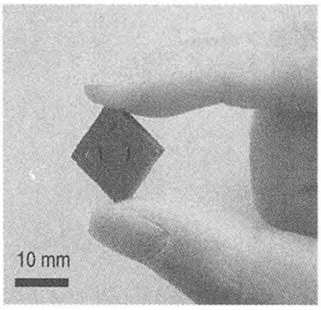
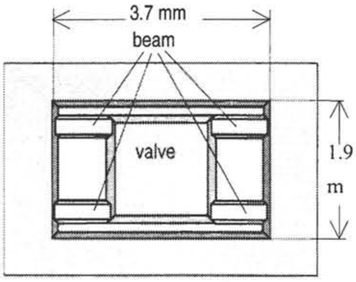


Fig. 2(b) Proto-type of shipping device

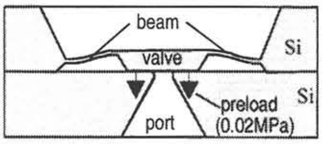
Table 1. Accuracy of shipping volume

Droplet count	40	200	400
Volume (μL)	5.6	28.1	56.2
σ (μL)	0.04	0.1	0.12
C.V.[%]	0.72	0.36	0.22

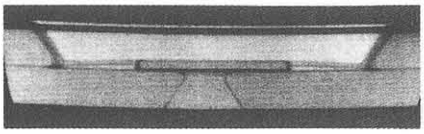
C.V.[%] : Coefficient of Valiance



(a)



(b)



(c) X-ray photo

Fig. 3. Valve structure (outlet)

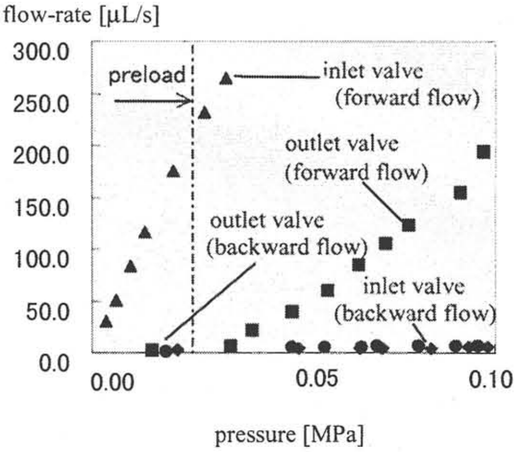


Fig. 4. Capacity to resist pressure of valves

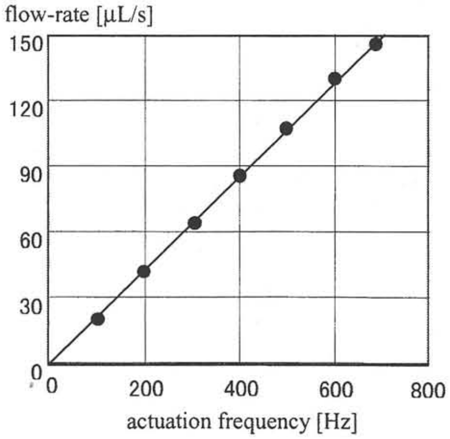


Fig. 5. Flow-rate with actuation frequency