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Fabrication and testing of a pair of passive bivalvular microvalves composed of p+ silicon diaphragms

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Abstract

A pair of one-way passive microvalves is fabricated by using the p+ etch-stop method. The two valves have a simple structure and are easy to fabricate. Each valve consists of several p+ silicon diaphragms and is designed to open and close depending on the pressure difference. The fabrication process of the valves consists of a boron diffusion and simple anisotropic etch processes. According to the experimental results, the water flow rate is 1.6 ml min^{-1} at 4 kPa of forward pressure and -0.05 ml min^{-1} at 4 kPa of backward pressure.

Keywords: Passive bivalvular microvalves; Etch-stop method; p+ silicon film; Static flow testing

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1. Introduction

Microvalves have been studied by many researchers for flow control [1–7]. There are two types of valves being studied and fabricated. One is of active type [1–5] and the other is of passive type [6,7]. The active valve is to control the flow rate under a certain pressure difference. In the case of the passive valve, the flow rate is controlled by the pressure difference. Both microvalves usually have complex structures and are fabricated through a complex process including bonding of two silicon wafers or a silicon wafer and a Pyrex glass. For a micropump equipped with an actuator, passive valves are preferred because they are simple with regard to their structure and fabrication process in comparison with active valves. Smith and Hök [7] fabricated self-aligned passive valves on a silicon wafer. The structure of the valve is simple and can be fabricated mainly by p+ diffusion and several etch processes.

In this paper, a pair of passive bivalvular valves of a simple structure are designed for use in the flow of fluids containing cells. They are fabricated by means of a simple and highly reproducible process. The opening and closing behaviour of the valve is observed under static pneumatic pressure, and the water flow rate through the valves is measured under forward and backward static pressures.

2. Structure and principle

The structure of a pair of the bivalvular microvalves is shown in Fig. 1. The two valves are of the same size (780 μm × 1580 μm) and formed on either side of a silicon wafer in opposite directions. Each valve has two flexible wings of p+ silicon 2 μm thick. The angle between the wing and the wafer surface is designed to be 54.74° in consideration of the anisotropic etching. The bivalve slit between two wings is normally open. The valve slit width can be designed as small as desired within the limit of the minimum line width of the facilities available. The backward leakage is expected to decrease as the slit width decreases. In this study, the valves

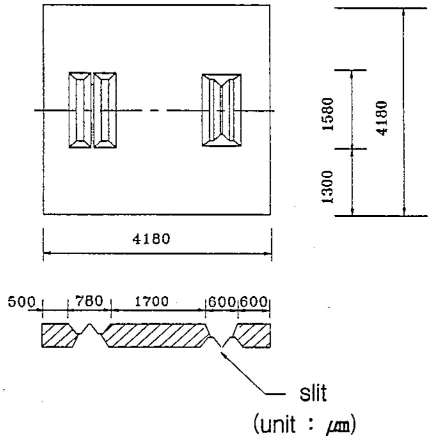

Fig. 1. The structure of two bivalvular microvalves (not to scale).

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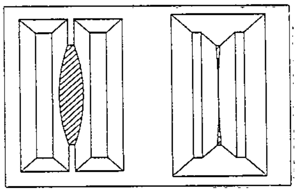
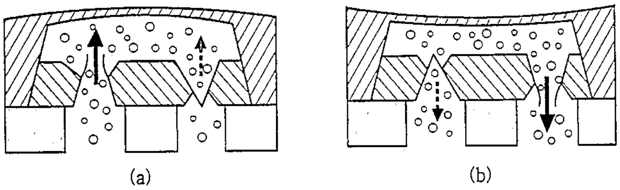


Fig. 2. The opening and closing of the bivalve slit.



(a) (b)

Fig. 3. The operation principle of the bivalves for a micropump. (The dashed arrows mean small leakage flow.) (a) Intake, (b) exhaust.

are to pass fluids containing cells or particles, so the slit width is designed to be 25 μm. This is wide enough to pass particles up to 25 μm in size.

When pressure is applied to the wings, they deflect. The middle of the slit deflects more than the sides of the slit as in Fig. 2, which shows the flexible wings of a pair of valves. The bivalves open and close depending on the pressure difference, and the forward and backward flow characteristics are different. If this structure is assembled with a flexible diaphragm as shown in Fig. 3, it can make a micropump. When the diaphragm is actuated up and down, the fluid is supposed to flow in and out. Since the intake and discharge flow rates of the two symmetric valves are different, there can be a net flow in one direction [8]. This paper concerns only the valve without actuation.

3. Fabrication process

Fig. 4 shows the fabrication process of the bivalves. The starting material used is an n-type (100)-oriented silicon wafer 330 μm thick. Two valves on either side are simultaneously fabricated on a single silicon wafer. First, silicon dioxide layers 0.5 μm thick are grown thermally. To make a front-to-back alignment reference, the alignment holes are patterned and etched through the silicon wafer. The wafer is etched at 115 ± 2°C in an anisotropic etchant, EPW (ethylenediamine, pyrocatechol and deionized water mixed in the ratio 250 ml:40 g:80 ml). The purity of the deionized water is about 18–20 MΩ cm. The V-grooves on both sides of the wafer are etched by EPW. To make p+ etch-stop layers, boron is diffused inside the V-grooves except at the edges that make the valve slit. In this process a boron nitride solid source (BN1100, manufactured by Spirox Holding, Inc.) is used at 1100°C for 7 h. The low-temperature oxidation process is performed at 900°C for 20 min. After the removal of borosilicate glass in buffered HF, a drive-in process is performed at 1000°C for 1 h. By etching the backside of the V-grooves and removing the residual oxides, the bivalves and slits are completely fabricated. Fig. 5 is an SEM photograph of two bivalves.

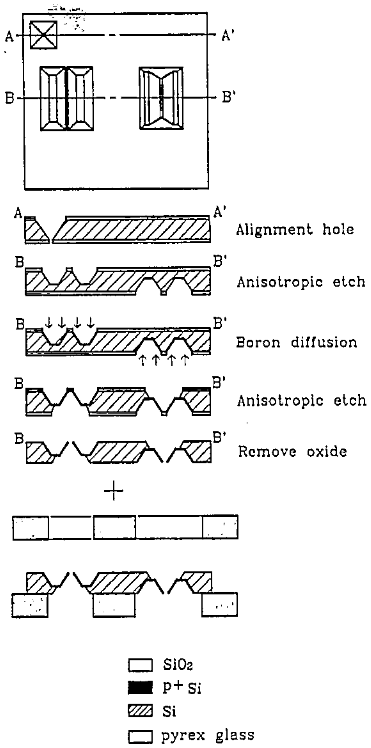


Fig. 4. The fabrication process.

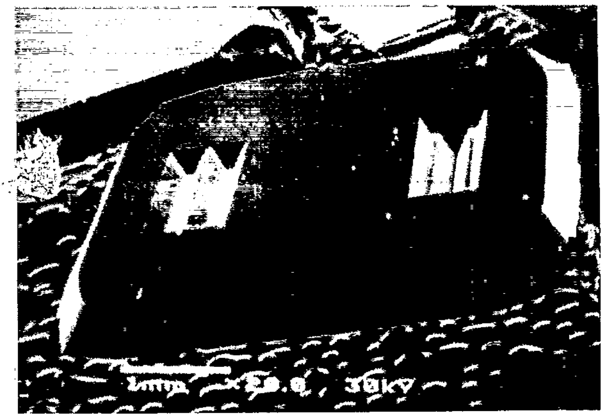


Fig. 5. SEM photograph of two valves.

For the static flow test of the bivalves, both sides of the silicon wafer are bonded with Pyrex glasses. The anodic bonding is performed at 300°C with 800 V applied. The inlet and outlet channels in the lower Pyrex glass are made by electrochemical discharge machining before the anodic bonding.

4. Measurements

As a test of the static characteristic of the bivalve, the valve slit width is observed with a microscope. Fig. 6 shows the measurement set-up for the observation of the slit width of

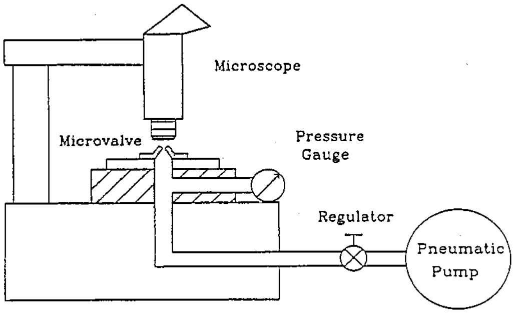


Fig. 6. The slit-width measurement system.

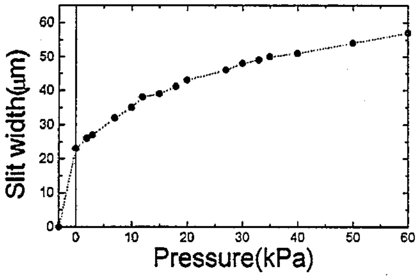


Fig. 7. The middle slit width of the bivalve vs. the pneumatic pressure.

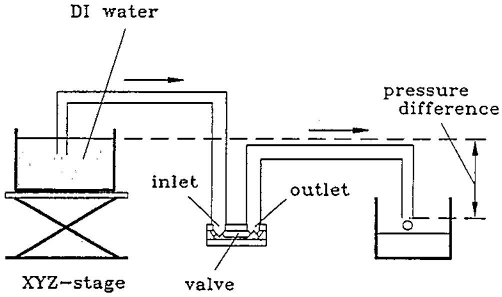


Fig. 8. The flow-rate measurement system.

one bivalve. Fig. 7 shows the plot of the slit width of the middle of the bivalve versus the pneumatic pressure. The positive and negative pressures mean the forward and backward pressures, respectively. As the forward pressure increases, the valve slit opens wide. The slit width is 57 μm at 60 kPa of forward pneumatic pressure. If the backward pressure increases, the valve slit becomes narrow. The middle parts of the valve slit edges make contact at 4 kPa of backward pneumatic pressure. It seems that the slope of the curve at the backward pressure is steep due to buckling under the residual stress in the p+ diaphragms.

Another static test is the flow rate measurement of the water passing through two bivalves at the steady state for various pressure differences from −4 to 4 kPa. Fig. 8 illustrates the measurement set-up for the static flow-rate test of the bivalves. The flow rate is measured using a mass cylinder. The plot of the flow rate versus the pressure difference is shown in Fig. 9. The flow rate is 1.6 ml min^{-1} at 4 kPa of forward pressure, and −0.05 ml min^{-1} at 4 kPa of backward pressure. There is little leakage flow under backward pressure. When passive valves of this type are applied to a micropump, the backward leakage makes the pumping performance poor. By means of repeated pumping actuation at a frequency ranging from several hertz to several hundreds of hertz, however, some effective net flow is expected since the backward leakage flow rate is much smaller than the forward flow rate.

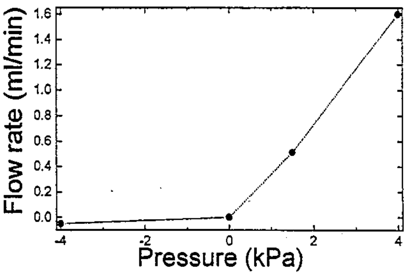


Fig. 9. The flow rate vs. the pressure difference.

5. Conclusions

Two passive bivalvular valves have been fabricated using p+ silicon diaphragms and two static flow characteristics have been tested. The valves are simply fabricated by boron diffusion, anisotropic etching and anodic bonding processes. For the test of the static characteristics of the bivalve, the valve slit width has been observed for various pneumatic pressure differences, and the water flow rate at the steady state has been measured for various pressure differences. From the results of the test, a net fluid flow in the forward direction through two passive valves is expected when the pump is actuated dynamically. Since the centre of the valve slit is easily closed at the backward pressure, it acts like a one-way passive valve which can be used as a delivery system for small particles.

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Biographies

Eui Hyeok Yang was born in Korea in 1967. He received his B.S. and M.S. degrees in control and instrumentation engineering from Ajou University in 1990 and 1992, respectively. He also received his Ph.D. degree in the field of microelectromechanical systems from Ajou University. He was then a research fellow at the Research Institute of Computer and Electrical Engineering of the same university. He is currently working as a JSPS Postdoctoral Research Fellow at the Institute of Industrial Science of the University of Tokyo, Japan. His research interests include the mechanism, actuation and fabrication of microsensors and microactuators.

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