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Diffuser micropump structured with extremely flexible diaphragm of 2 micron-thick polyimide film

Yingwei Liu, Hiroki Komatsuzaki, Zongfan Duan and Yasushiro Nishioka

Department of Precision Machinery Engineering, College of Science and Technology, Nihon University
7-24-1 Narashinodai, Funabashi, Chiba 274-8501, Japan
Phone: +81-47-469-6482 E-mail: lyw0806@hotmail.com, nishioka@eme.cst.nihon-u.ac.jp

1. Introduction

Miniaturized pumps for microfluidics, and more recently nanofluidics integrated lab-on-a-chip, or biomedical devices are of significant interest in the MEMS research fields. Surface micromachining techniques have advantage to fabricate the miniaturized devices. The diffuser micropumps were of particular interest for microfluidic applications due to their simple configurations and fabrication processes. In order to increase the deflection of diaphragms, some polymer diaphragms were utilized to fabricate diffuser pumps [1-2]. There were some reports on micropumps utilizing polyimide (PI) films as the membrane [3-4]. However, many of them were fabricated using bulk micromachining techniques.

In this paper, we report on fabricating a valveless micropump with the extremely thin and flexible polyimide diaphragm on the extremely thin Si wafer using surface micromachining techniques. The membrane was actuated by alternating air pressure.

2. Structure of the Micropump

Figure 1 (a) shows the structure of the micropump. The first PMMA plate has two opening holes for the tubes, the second PMMA plate has an opening at the center for air actuation, and these plates are used to fix the micropump chip. The micropump chip was fabricated on a 60 μm-thick silicon wafer. The thickness, *t* of polyimide membrane was 2.1 μm, the diameter, ϕ of the chamber was 2 mm, the height, *h* of the micropump chamber was 60 μm. The designed diffuser was shown in Fig.1 (b), the throat width *w1*, *w2* were 50 μm and 185 μm, the length of the diffuser, *L* was 900 μm, and the diffuser angle, *2θ* was 10º.

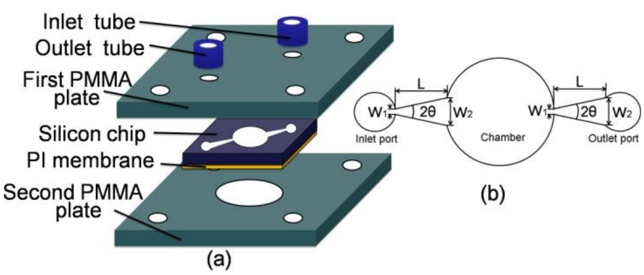

Fig. 1 Structures of micropump and diffuser.

3. Fabrication and Characterization

Fabrication processes

As show in Fig. 1 (a), the micropump chip consists of two different layers: the 60 μm-thick Si layer and the polyimide membrane layer. Figure 2 shows the fabrication process flow of the micropump. At first, the polyimide layer was coated on the backside of Si wafer by spin-coating. The thickness of the polyimide layer was controlled by adjusting the rotation speed of the spin-coater, and the resulting thickness was 2.1 μm. The chip was baked at 120 ℃ for 5 min, 200 ℃ for 5 min, and 350 ℃ for 10 min to cure the polyimide. Then, the photoresist (S1830) was spin coated on the other side of Si wafer. The thickness of photoresist was 3 μm. The micropump structure was optically defined by a photolithography process. After this, the silicon was partially removed by the inductively coupled plasma (ICP) etching. The Polyimide film showed the excellent immunity in SF_6 and C_4F_8 plasmas.

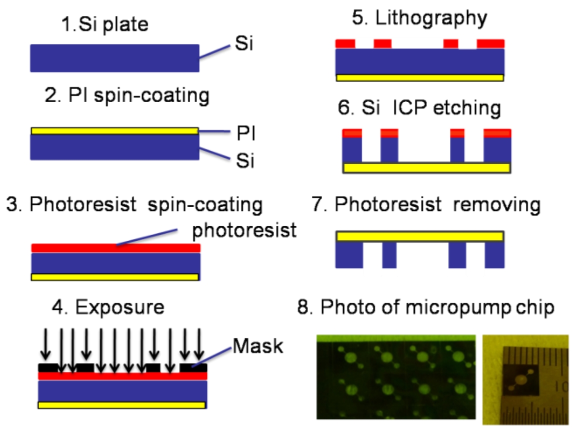

Fig. 2 Fabrication process flow and photo of the micropump.

Model of Polyimide Diaphragm

The deflection is the displacement of the diaphragm at the center of the diaphragm. The theoretical pressure-deflection relation of a flat uniformly loaded circular membrane was given as follows:

$$\frac{P}{\omega} = \frac{4t}{R^2}\left[\delta_i + \frac{2E}{3(1-\vartheta)}\left(\frac{\omega}{R}\right)^2\right] \quad (1)$$

where P is the applied pressure, ω the center deflection of the diaphragm, t the diaphragm thickness, R the diaphragm radius, δ_i the residual stress of the membrane caused by the thermal processes related to the PI film deposition, E the Young's modulus, and ϑ the Poisson's ratio. In equation (1), the values of E=2.6 GPa and ϑ=0.34 were used as suggested by the polyimide supplier.

4. Experiment results

Membrane characterization

Figure 3 describes the measurement system to characterize the deflection behaviors of the membrane actuated by static air pressure. The air pressure on the membrane was supplied by the syringe and monitored by the air manometer. The deflection of membrane was measured from the backside of the device using a laser displacement sensor. All the static characteristics measurement has been accomplished on an active vibration isolation table.

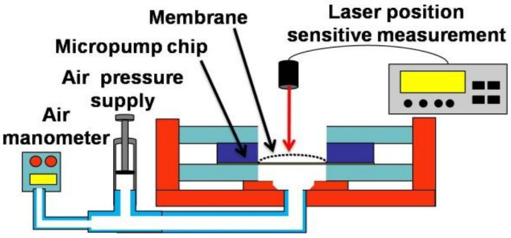

Fig. 3. Schematic illustration to measure membrane deflections.

In Fig. 4, the measured pressure-deflections characteristics for the PI membrane were compared. The curve corresponds to the deflection ω and the air pressure dependence as described in equation (1), where the membrane thickness t=2.1 μm, the diaphragm radius R=1 mm, the residual stress δ_i=16.8 MPa. Negligibly small hysteresis was observed in the deflection vs air pressure relationships as seen in Fig. 4. This means that the plastic deformation of the PI membrane was extremely small. The deflection of the film was founded to be very large.

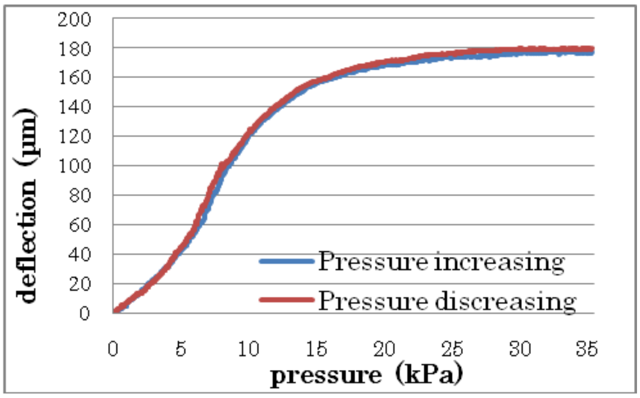

Fig. 4 Relationship between deflection and air pressure.

To observe the dynamic behavior of the membrane with alternating air pressure, the micropump membrane was actuated by 5 kPa air pressure at 0.5 Hz, 1 Hz and 1.5 Hz. Figure 5 shows the measured deflection curve, the amplitudes for the 0.5, 1, and 1.5 Hz curves are approximately 40, 40 and 34 μm, respectively. The reproducible deflection is an important characteristic for the membrane of micropumps. The membrane was actuated at the same pressure for appointed times, the scattering of the membrane deflections were nearly less than 10%.

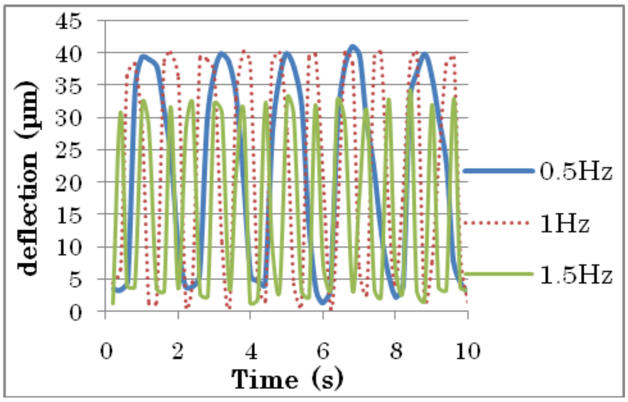

Fig. 5. Dynamically measured deflection of a 2mm diameter membrane under 5 kPa pressure for 0.5, 1 and 1.5 Hz .

The results from the dynamic deflection of the membrane characterization were shown in Fig. 6. The amplitudes at 1 Hz for 5 kPa, 7.5 kPa and 10 kPa curves are approximately 40, 45 and 100 μm, respectively.

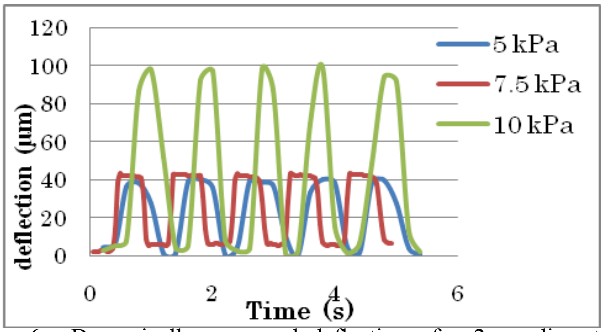

Fig. 6. Dynamically measured deflection of a 2mm diameter membrane at 1 Hz with 5 kPa, 7.5 kPa and 10 kPa air pressure.

Flow rate measurements

Measurement results for the relationships between the alternative air pressure, frequency and flow rate will be reported at the conference.

5. Conclusions

The simple structured air-actuated valveless micropump with the 2.1 μm-thick polyimide membrane was designed, fabricated and measured. The micropump was fabricated on the 60 μm-thick thin Si wafer using surface micromachining techniques. The diaphragm with the diameter of 2 mm showed the deflection of 100 μm under static pressure of 10 kPa.

Based on the advantage of surface micromachining techniques and nice mechanical characteristic of the polyimide diaphragm, we may be able to fabricate further miniaturized micropumps.

References

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