PASSIVE FLOW-RATE REGULATORS
USING PRESSURE-DEPENDENT AUTONOMOUS
DEFLECTION OF PARALLEL MEMBRANE VALVES
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ABSTRACT
We present passive flow-rate regulators using a self-adjustable flow resistor, capable to maintain constant flow-rate at the varying inlet pressure supplied from micropumps. Compared to previous works, the present passive flow-rate regulators are capable to achieve flow-rate regulating function at the minimum threshold inlet pressure as low as 20kPa with a simple structure formed by single mask process. The prototype fabricated by PDMS (PolyDiMethylSiloxane) showed the constant flow-rate of 6.09±0.23µL/s over the inlet pressure range of 20~50kPa. In this work, we have verified its strong potential for use in precise liquid control systems.

KEYWORDS: Flow-rate Regulator, Autonomous Regulation, Parallel Membrane Valve

INTRODUCTION
Integrated micropump systems such as lab-on-a-chip (LOC), drug delivery system (DDS), and fuel cells (FC) require precise flow-rate control (less than 5% accuracy) for the liquid handling and control, over wide range of pressure and frequency in micropumps. Since most micropumps cannot generate a constant pressure, there has been a lot of researches on flow-rate regulators, maintaining a constant flow-rate over pressure variation. Among them, passive type is widely used because it does not require an external power source, flow-rate sensor, and external control circuitry. Previous passive flow-rate regulators [1-4], however, are difficult to be integrated with micropumps, not only because of complex multi-layer structures [1-3] but also because of higher threshold inlet pressure required for flow-rate regulation (e.g., 60kPa, [4]), than the maximum pressure generated by micropumps (e.g., 50kPa, [5]). In this study, we present new passive regulators, capable to achieve flow-rate regulating function at the minimum threshold inlet pressure as low as 20kPa with a simple structure formed by single mask process.

Figure 1. Working principle of flow-rate regulators using the autonomous deflection of parallel membrane valves: (a) for the inlet pressure, \( p \); (b) for the increased inlet pressure, \( p+\Delta p \).
THEORY

The passive flow-rate regulator (Fig.1a) uses a variable fluidic resistor composed parallel membranes, whose gap forms a fluidic resistor in a microchannel when the other sides are exposed to inlet pressure through the subchannels. The membrane deflects autonomously depending on the pressure difference between the gap pressure and inlet pressure. As inlet pressure changes from \( p \) to \( p + \Delta p \) (Fig.1b), fluidic resistance between the membranes changes from \( R \) to \( R + \Delta R \) due to the autonomous membrane deformations; thus compensating inlet pressure variation to maintain a constant flow-rate, \( Q \), as shown in Eq.(1).

\[
Q = \frac{p}{R} = \frac{(p + \Delta p)}{(R + \Delta R)}
\]  

(1)

We designed four different prototypes of W20, W30, W40, and W50, having fluidic resistor widths (Fig.1a) of 20, 30, 40 and 50\( \mu \)m, respectively. In numerical estimation using 3D FSI (Fluid-Structure Interaction) simulation, flow-rate regulators with parallel membranes achieve constant flow-rate regulation at the threshold inlet pressure (11kPa for W20), which is much lower than that (43kPa) of previous passive regulators with single flap [4].

EXPERIMENTS

The prototypes are fabricated by the PDMS (PolyDiMethylSiloxane) molding using 100\( \mu \)m-thick SU-8. Figure 2 shows a fabricated passive flow-rate regulator. Using the experimental setup of Fig.3, we measure the deformation of parallel membranes and the flow-rate depending on the inlet pressure.

![Figure 2. Fabricated passive flow-rate regulator with an enlarged view of the parallel membranes.](image)

![Figure 3. Experimental setup for the measurement of flow-rate.](image)

![Figure 4. Measured and estimated flow-rates depending on inlet pressure for the prototype W20 with and without parallel membrane valves.](image)

![Figure 5. Measured and estimated flow-rates depending on the inlet pressure for the prototype W20, W30, W40 and W50 with parallel membranes.](image)
RESULTS AND DISCUSSION

Figure 4 compares the flow-rate of the prototype W20 with and without parallel membranes, respectively, for varying inlet pressure. The flow-rate of W20 without parallel membranes is increased with the inlet pressure due to the constant fluidic resistance, while W20 with parallel membranes is saturated to a constant value over the threshold inlet pressure of 20kPa. Figure 5 compares the flow-rates measured and estimated for the 4 different prototypes with membrane valves. The prototype W20, having the width of 20μm, shows the constant flow-rate of 6.09±0.23µL/s over the inlet pressure range of 20~50kPa. For the other prototypes of W40 and W50, the fluidic resistance change was not enough to perform full regulation functions upto the inlet pressure of 50kPa due to wide channel widths of 40 and 50μm.

CONCLUSIONS

We have verified that passive flow-rate regulators having the variable membrane fabricated by single mask process performs autonomous flow-rate regulating function at the threshold inlet pressure as low as 20kPa; thus demonstrating its strong potential for use in precise liquid control systems.

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REFERENCES


