PUMPLESS FUEL SUPPLY USING PRESSURIZED FUEL REGULATED BY PASSIVE PRESSURE COMPENSATION VALVES

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Abstract: We present a pumpless fuel supply method using pressurized fuel and pressure compensation valves for fuel cell applications. In a previous pumpless fuel supply methods, flow-rate is affected by the chemical reaction rate of fuel cell and the control of venting valve is required. In this work, flow-rate from the pressurized fuel is maintained constant by the autonomous regulation of pressure compensation valves in a microchannel without any external control. The prototypes were fabricated by the PolyDiMethylSiloxane (PDMS) molding process. In the experimental study, we interconnected the prototypes to the fuel chamber (100ml), filled with DI water (50ml) and pressurized up to 100 kPa by air. The fabricated prototype with pressure compensation valves showed the constant flow-rate of 5.89±0.62 μl/s during 130 min, while the prototype without pressure compensation valves showed decreasing flow-rate during 30 min. We have verified that the present pumpless fuel supply method was capable to maintain constant flow-rate, thus demonstrating its strong potential for use in the fuel supply systems in fuel cell applications.

Key words: Pumpless Fuel Supply, Pressurized Fuel, Pressure Compensation Valves

1. INTRODUCTION

Portable electronic devices such as cell phones, PDAs, and lab-top computers require a high-density power sources. Direct Methanol Fuel Cell (DMFC) is the most promising candidate as the power source of these portable applications, because of easy fuel storage, low temperature operation, and simple structure. In Liquid Fuel Cells (LFC) such as DMFC, liquid fuel has to be supplied with optimal flow-rate by micropump, in order to maximize fuel cell efficiency and operation time. Micropumps in fuel cell, however, have complex structure and consume the electrical energy (25% of total generated energy is used for fuel pump in DMFC, [1,2]). Therefore, passive fuel supply without micropumps makes it possible to provide cheaper and more efficient fuel cells than conventional fuel cells with micropumps.

Previous methods for passive fuel delivery use a natural circulation [3] and anodic exhaust gas [4]. They are based on the pressure of the reaction gas generated at a fuel cell, for fuel supply. These methods, however, flow-rate is affected by the chemical reaction rate of fuel cell and the control of venting valve is required.

In this work, we present pumpless fuel supply method by using pressure fuel and pressure compensation valves [5] as shown in Fig.1. The pressure compensation valves regulate flow-rate from the pressurized fuel chamber, thus maintaining constant fuel flow-rate. Since the pressure compensation valves operate autonomously depending on fuel pressure, the present method can provide a constant flow-rate without any control of valves.

2. WORKING PRINCIPLE AND DESIGN

2.1 Working Principle

Figure 1 illustrates the schematic view of pumpless fuel supply method. Fuel is supplied to reaction chamber by the pressurized fuel chamber and the pressure compensation valves, placed between fuel chamber and reaction chamber, maintain a constant fuel flow-rate. Flow-rates from the pressurized fuel chamber with and without pressure compensation valves are compared in Fig.2. Without pressure compensation valves, fuel flow-rate from the

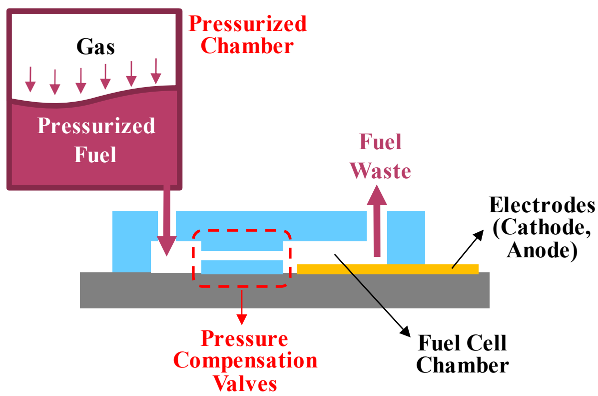

Fig. 1: Schematic view of the present pumpless fuel supply method using pressurized fuel regulated by passive pressure compensation valves.

pressurized fuel chamber decreases rapidly as shown in Fig.2a, because the pressure of gas in the chamber decreases as it expands. The passive pressure compensation valves, however, regulate fuel flow-rate from the pressurized fuel to a constant level, Q_o, as well as increase the total time of fuel flow from t_1 to t_2 (Fig.2b).

The pressure compensation valves [5] uses a variable fluidic resistor composed parallel membranes, whose gap forms a variable fluidic resistor, while the other sides of membranes are exposed to inlet pressure through the subchannels as shown in Fig.5a. The membrane deflects autonomously depending on the pressure diffrence between the gap pressure, p_g, and inlet pressure, p_i. As the inlet pressure, p_i, changes from p to $p+\Delta p$ (Fig.3b), the fluidic resistance between the membranes changes from R to $R+\Delta R$ due to the autonomous membrane deformations, thus

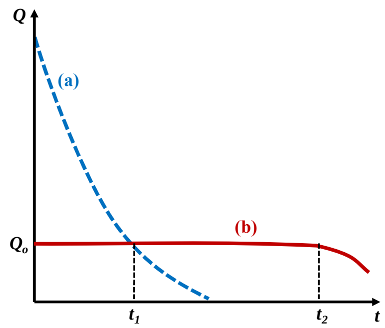

Fig. 2: Comparison of fuel flow-rate (Q): (a) flow-rate using pressurized fuel only; (b) flow-rate using the pressurized fuel regulated by the passive pressure compensation valves.

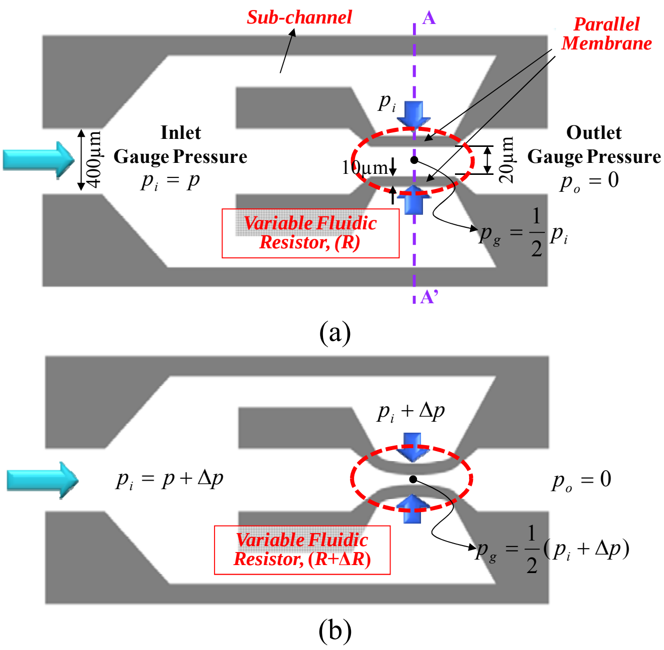

Fig. 3: Working principle of flow-rate regulators [5] using the autonomous deflection of parallel membrane valves: (a) for the inlet pressure, p_i; (b) for the increased inlet pressure, $p_i+\Delta p$.

compensating the inlet pressure variation to maintain a constant flow-rate, Q_o, as shown in Eq.1.

$$Q_o = \frac{p}{R} = \frac{p+\Delta p}{R+\Delta R} \qquad (1)$$

2.2 Design

The prototype has been designed to have the 10 μm [width] × 100 μm [height] × 100 μm [length] of parallel membranes and 20 μm gap between parallel membranes (Fig.3a). We have estimated the flow-rate from the pressure compensation valves depending on the inlet pressure, by using 3D FSI (Fluid-Structure Interaction) model. We use an incompressible Navier-Storks model for water having the viscosity of 0.001Pa·s in a fluid domain, and solid stress-strain model for PDMS (PolyDiMethylSiloxane) having the Young's modulus of 995 MPa and Poisson's ratio of 0.49 in solid domain. The numerical estimation shows that the pressure compensation valves provide a constant flow-rate (less than ±5% variation) over the inlet pressure of 20 kPa. We have designed two different prototypes (I and II). Prototype I have the pressure compensation valves, while prototype II doesn't have ones but the identical dimension of fluidic resistor.

3. FABRICATION

The prototype was fabricated by PDMS molding process using SU-8 2100 negative PR (PhotoResist) as shown in Fig.4. In order to define vertical SU-8 structure of 10:1 aspect ratio (parallel membrane), we used a back-side exposure [6] as shown in Fig.4. We deposited a 2000Å-thick Cr layer and patterned on a

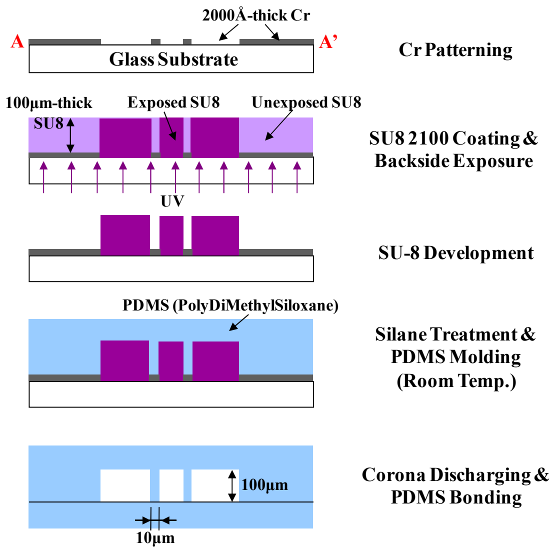

Fig. 4: Fabrication process of the pressure compensation valves at the cross-section A-A' in Fig.3.

Pyrex glass wafer. After spinning 100μm-thick SU-8 2100 PR over the Cr layer, we exposed UV light from the back side of wafer. Developed SU-8 structure was used as a master for the PDMS molding. We treated trichlorosilane on SU-8 mold in order to facilitate PDMS demolding. PDMS was prepared with 10:1 (wt) mixtures of base and curing agent, and cured at room temperature to minimize thermal shrinkage of PDMS. Figure 5 shows the fabricated pressure compensation valves with an enlarged view of parallel membranes.

4. EXPERIMENTAL RESULTS

Figure 6 shows an experimental setup for flow-rate measurement using DI water as a fuel. The chamber (100ml) was filled with DI water (50ml) and pressurized up to 100 kPa by air. The pressurized chamber was left for 1 hour with the outlet valve closed in order to check any pressure drop due to the gas leakage or dissolution into DI water. Then, we opened the outlet valve of the pressurized chamber. Flow-rate from prototypes was obtained by measuring the mass change of outlet reservoir for every 2 minutes and the deformation of pressure compensation valves was observed by an optical microscope.

The measured DI water flow-rate of the prototype I and II was compared in Fig. 7. Since the pressure compensation valves in the prototype I adjusted the fluidic resistance autonomously, it showed almost constant flow-rate (5.89±0.62μl/s) during 130 min, while the flow-rate from prototypes II decreased rapidly during 30 min. The total 47.3ml and 53.71ml of DI water were measured in the outlet reservoir for prototype I and II, respectively.

In the experimental study, we clearly verified that the pressure compensation valves maintained a constant flow-rate, by changing the fluidic resistance of microchannel autonomously. The regulated constant flow-rate could be adjusted by changing the gap between parallel membrane and material [5].

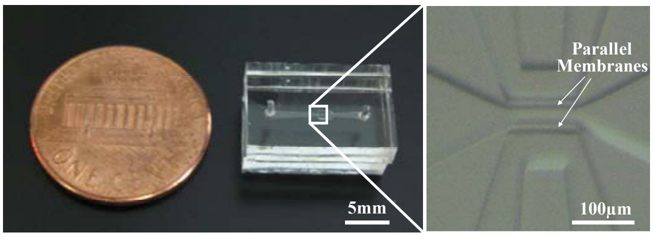

Fig. 5: Fabricated prototype with an enlarged view of the parallel membranes.

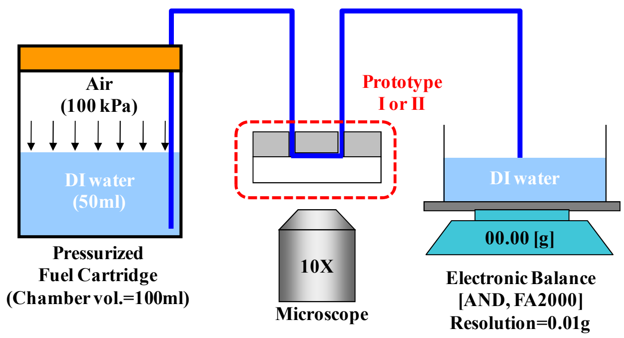

Fig. 6: Experimental setup for flow-rate measurement using DI water as a fuel.

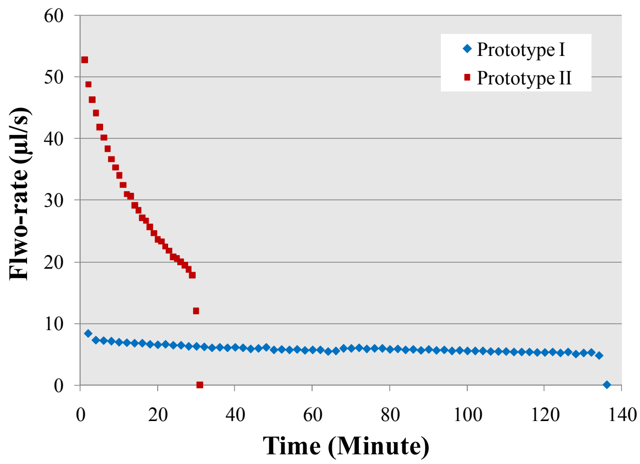

Fig. 7: Measured DI water flow-rate of the prototype I (with pressure compensation valves) and II (without pressure compensation valves). Both prototypes are connected to the identical pressurized chamber (100ml), filled with DI water (50ml) and pressurized upto 100 kPa by air.

5. CONCLUSIONS

In this work, we present pumpless fuel supply method using pressurized fuel and pressure compensation valves for fuel cell applications. Flow-rate from the pressurized fuel is maintained constant by the autonomous regulation of pressure compensation valves in a microchannel without any external control. The prototypes were fabricated by the PDMS molding process. In the experimental study, we interconnected the prototypes to the fuel chamber (100ml), filled with DI water (50ml) and pressurized up to 100 kPa by air. The fabricated prototype with pressure compensation valves showed the constant flow-rate of 5.89±0.62 μl/s during 130 min, while the prototype without pressure compensation valves showed decreasing flow-rate during 30 min. We have verified that the present pumpless fuel supply method was capable to maintain constant flow-rate, thus demonstrating its strong potential for use in the fuel supply systems in fuel cell applications.

ACKNOWLEDGEMENT

This work has been supported by the National Creative Research Initiative Program of the Ministry of Education, Science and Technology (MEST) and the Korea Science and Engineering Foundation (KOSEF) under the project title of “Realization of Bio-Inspired Digital Nanoactuators.”

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