PowerMEMS 2013 IOP Publishing
Journal of Physics: Conference Series **476** (2013) 012045 doi:10.1088/1742-6596/476/1/012045

Advanced combinational microfluidic multiplexer for fuel cell reactors

D W Lee,[1,†,‡] I Doh,[2,†] Y Kim,[1] Y –H Cho[1]

[1]Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
[2]Korea Research Institute of Standards and Science, Daejeon, Republic of Korea
[†]Both authors contributed equally to this work
[‡]Present Address: Samsung Electromechanics Co., Ltd., Suwon, Korea

E-mail: nanosys@kaist.ac.kr

Abstract. An advanced combinational microfluidic multiplexer capable to address multiple fluidic channels for fuel cell reactors is proposed. Using only 4 control lines and two different levels of control pressures, the proposed multiplexer addresses up to 19 fluidic channels, at least two times larger than the previous microfluidic multiplexers. The present multiplexer providing high control efficiency and simple structure for channel addressing would be used in the application areas of the integrated microfluidic systems such as fuel cell reactors and dynamic pressure generators.

1. Introduction

The micro fuel cell system requires simple and effective fluidic control system for the optimal amount of fuel delivery into multiple reaction chambers. Without effective fluidic control, the micro fuel cell requires numerous fluidic components in proportional to the number of the chambers, thus increasing costs for fuel cell systems. The effective microfluidic control system is essential to develop cheaper and more reliable micro fuel cell system.

Several microfluidic multiplexers for channel addressing have been proposed. The binary multiplexers analogic to electronic multiplexers are based on digital operation of pneumatic valves. They addressed up to $2^{n/2}$ channels using n control lines [1]. Previously, we had reported a high-radix microfluidic multiplexer based on the ternary or quaternary operation of pneumatic valves [2]. The valves in the high-radix multiplexers have different threshold pressures according to the membrane areas, thus providing high-radix operation. The ternary and quaternary multiplexers were capable to address $3^{n/2}$ and $4^{n/2}$ channels, using n control lines, respectively.

In this work, the proposed advanced combinational multiplexer based on the pressure combination in the control lines. By using 4 control lines, the present advanced combinational multiplexer can address up to 19 fluidic channels, at least three times larger than the previous binary and combinational multiplexers capable of only 4 and 6 channels, respectively. Even the ternary multiplexer was able to address 9 channels, a half of the proposed multiplexer using the same control lines. The present advanced combinational multiplexer having the high efficiency and simple structure can be widely used in the application areas of the integrated microfluidic systems such as fuel cell reactors and dynamic pressure generators.

2. Working Principle and Design

The present multiplexer is composed of control, membrane and channel layer (Fig. 1). The pneumatic pressure supplied from an external pressure source is delivered to membrane and the membrane deforms to the bottom channels by acting like pneumatic valves. The threshold pressure for valves is the minimum control pressure required to block the channel completely. Since a small membrane is hard to deform, it requires higher threshold pressure than larger membrane as shown in Fig. 1.

As an example for working principle of the advanced combinational multiplexer, two different pressures (50 and 100 kPa) and four control lines (C_1, C_2, C_3, C_4) are used as shown in Fig.2. Single inlet is branched to 19 channels and, in each control line, pneumatic valves having 50 and 100 kPa of threshold pressures ($V_{50\ kPa}$ and $V_{100\ kPa}$) are located. Among the total eight options (two different levels of pressures and four control lines), the selection of 4 maximizes the number of the pressure combinations and consequently the number of addressable fluidic channels [3].

Unfortunately, all selections of control pressures are not independent. When the control pressure of 100 kPa is selected in a control line, both $V_{100\ kPa}$ and $V_{50\ kPa}$ should be selected in the control line, because 100 kPa is higher pressure and covers the lower range of pressure. Therefore, selection of 100 kPa in a control line includes the selection of both $V_{50\ kPa}$ and $V_{100\ kPa}$ in the control line. All the channels having $V_{50\ kPa}$ or $V_{100\ kPa}$ in the control line are blocked. When we select two control lines for 100 kPa, all 4 options were chosen, since both $V_{50\ kPa}$ and $V_{100\ kPa}$ in two lines are selected. By

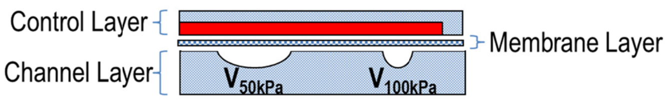
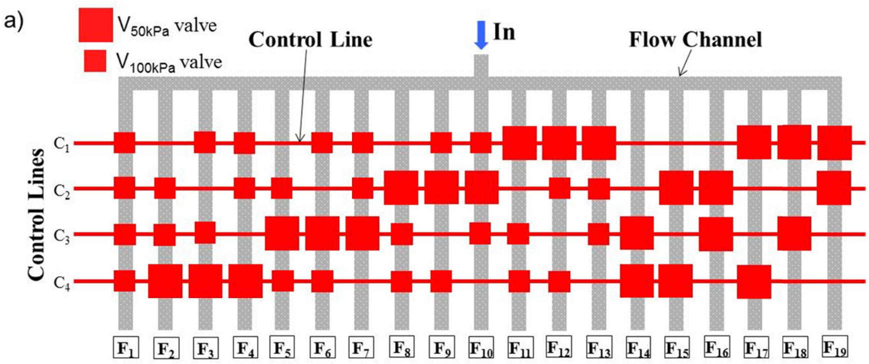


Figure 1. Cross-sectional view of pneumatic valves in the multiplexer, where $V_{100\ kPa}$ valve having smaller membrane area than $V_{50\ kPa}$ has higher threshold pressure for valve operation.



b)

C_1	50	100	50	50	100	50	50	100	50	50	-	-	-	100	100	100	-	-	-
C_2	50	50	100	50	50	100	50	-	-	-	100	50	50	100	-	-	100	100	-
C_3	50	50	50	100	-	-	-	50	100	50	50	100	50	-	100	-	100	-	100
C_4	50	-	-	-	50	50	100	50	50	100	50	50	100	-	-	100	-	100	100
	Case 1 (a_1=4, a_2=0)	Case 2 (a_1=2, a_2=1)												Case 3 (a_1=0, a_2=2)					

Figure 2. Schematic view of the present multiplexer capable to address 19 fluidic channels using 4 control lines: (a) Top view of the multiplexer; (b) Pressure combinations (kPa) in 4 control lines according to fluidic channels.

considering this dependency, the combination of four option selection needs to be divided into the following three cases,

Case 1) Four control lines are 50 kPa
All four control lines are selected as 50 kPa. The number of control pressure combination is ${}_4C_4 = 1$.

Case 2) One control line is 100 kPa, two control lines are 50 kPa
Due to the dependency of control pressure as we explained above, 100 kPa in a control line requires the selection of 50 kPa in the same control line. Once we choose one among four control lines for 100 kPa, 50 kPa is automatically selected and we lose one option. So cases are to choose two control lines among the four control lines for 50 kPa (${}_4C_2$) and choose one control lines among the remaining two (${}_2C_1$). Therefore, overall number of pressure combinations is ${}_4C_2 \times {}_2C_1 = 12$.

Case 3) Two control lines are 100 kPa
In this case, we need two control lines with 100 kPa. Each 100 kPa require 50 kPa in the same control line and no other options are left. The pressure combination is to choose two among four control lines, ${}_4C_2 = 6$.

Totally, the present advanced combinational multiplexer using 4 control lines can address 19 fluidic channels:

$$F = {}_4C_4 + ({}_4C_2 \times {}_2C_1) + {}_4C_2 = 19$$

3. Experimental Results

The device was fabricated by multi-layer soft lithography using Polydimethylsiloxane (PDMS). The SU-8 (Microchem. Co.) negative photoresist was patterned on a silicon wafer by UV-lithography process using manufacturer's recommendation and used as a mold master for soft lithography [2]. Figure 3 shows the fabricated device with an enlarged view of advanced combination multiplexer. In order to facilitate the visualization of channel flow, DI water was dyed by ink and injected to the channel layer in the multiplexer. There were no leaks of sample at the valves over time during the entire experiments.

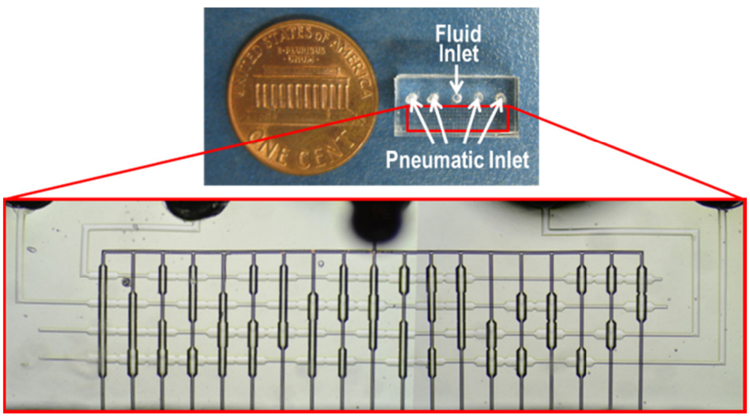


Figure 3. The fabricated multiplexer having one fluid inlet and four pneumatic inlets for flow control, with an enlarged view of the control lines and valve combination.

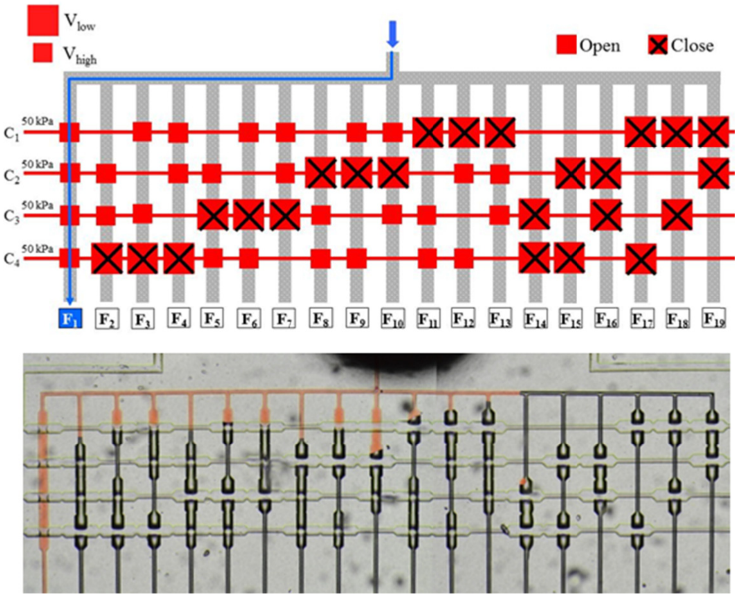


Figure 4. Fluidic channel addressing using the advanced combinational multiplexer: (a) F1 channel addressing where all control lines were pressurized to 50 kPa; (b) F18 channel addressing where only two control lines were pressurized to 100 kPa.

When we apply control pressure of 50 kPa in all control lines, all $V_{50\,kPa}$ were closed, as shown in Fig.4. For example, F_2~F_4, F_{14}, F_{15}, F_{17} channels were blocked by $V_{50\,kPa}$ valves in the control line C_4. C_3 blocked F_5~F_7, F_{16}, F_{18}. The remaining F_8~F_{13}, F_{19} were also blocked by C_1 or C_2. Since F_1 was the only channel having $V_{100\,kPa}$ in all control lines, it was the only channel which was not blocked by the control pressure of 50 kPa in all control lines. Therefore, the solution was supplied from the inlet flowed through F_1.

4. Conclusion

As a proof-of-concept, we had verified the advanced combinational multiplexer could address up to 19 fluidic channels using four control lines, which is the largest number of channels so far. The present advanced combinational multiplexer having the high efficiency and simple structure will be used in the application areas of the integrated microfluidic systems.

Acknowledgements

This research was supported by the Converging Research Center Program funded by the Ministry of Education, Science and Technology (Project No. 2013K000273), and by the Korea Research Institute of Standards and Science (Project Grant 13011045).

References

[1] Unger M A, Chou H-P, Thorsen T, Scherer A and Quake S R 2000 Monolithic Microfabricated Valves and Pumps by Multilayer Soft Lithography *Science (80-.).* **288** 113–6

[2] Lee D W and Cho Y-H 2009 High-radix microfluidic multiplexer with pressure valves of different thresholds. *Lab Chip* **9** 1681–6

[3] Hua Z, Xia Y and Srivannavit O 2006 A versatile microreactor platform featuring a chemical-resistant microvalve array for addressable multiplex syntheses and assays *J. Micromechanics Microengineering* **16** 1433–43