Supplementary Material (ESI) for Lab on a Chip
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Supplementary Text of High-radix Microfluidic Multiplexer

Combination and operation of high-radix multiplexer

Figure 1 compares the performance of ternary multiplexer and quaternary multiplexers, the high-radix multiplexers, with that of a binary multiplexer. The ternary and the quaternary multiplexers address $3^{n/2}$ and $4^{n/2}$ flow channels by using two (V_1 and V_2) or three (V_1, V_2 and V_3) pressure values of different thresholds in n control lines. When the ternary and quaternary multiplexers use the same control lines as the the binary multiplexer, they can address $(3/2)^{n/2}$ and $(4/2)^{n/2}$ times more flow channels, respectively. For example, with eight control lines, the binary multiplexer addresses 16 flow channels whereas the ternary multiplexer addresses 81 flow channels and the quaternary multiplexer addresses 256 flow channels. When the ternary and quaternary multiplexers address the same flow channels as the binary multiplexer, they successfully reduce the number of control lines by up to 64% and 50%, respectively. Table 1 shows the state of pressure valves in ternay and quaternary multiplexers according selection of the flow channel(F)

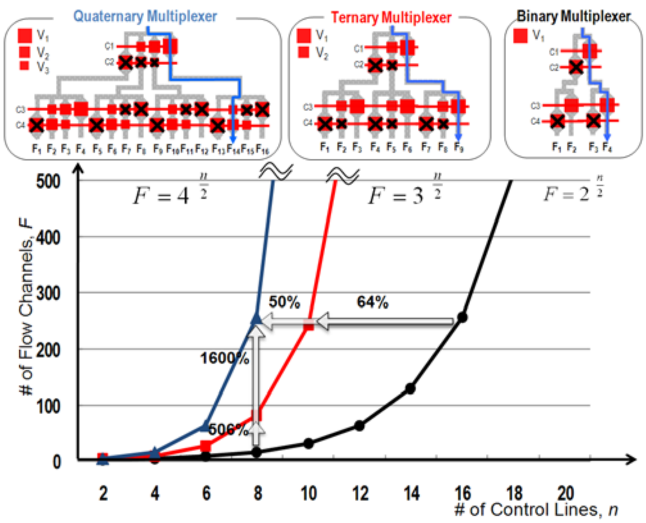


Fig. 1 Comparison of the number of addressable flow channels in relation to the number of control lines for the binary, ternary, and quaternary multiplexers. The top figures show examples of the binary, ternary, and quaternary mulitplexers with the four control lines that serially connect each of the multiplexer units.

Table 1 True table of the 3×3 well array with the ternary multiplexer and the 4×4 well array with the quaternary multiplexer

	Ternary Multiplexer					Quaternary Multiplexer				
	F	Closing valves in control lines				F	Closing valves in control lines			
		C_1	C_2	C_3	C_4		C_1	C_2	C_3	C_4
Group 1	F_1	V_1, V_2	-	V_1, V_2	-	F_1	V_1, V_2, V_3	-	V_1, V_2, V_3	-
	F_2	V_1, V_2	-	V_1	V_1	F_2	V_1, V_2, V_3	-	V_1, V_2	V_1
	F_3	V_1, V_2	-	-	V_1, V_2	F_3	V_1, V_2, V_3	-	V_1	V_1, V_2
	-	-	-	-	-	F_4	V_1, V_2, V_3	-	-	V_1, V_2, V_3
Group 2	F_4	V_1	V_1	V_1, V_2	-	F_5	V_1, V_2	V_1	V_1, V_2, V_3	-
	F_5	V_1	V_1	V_1	V_1	F_6	V_1, V_2	V_1	V_1, V_2	V_1
	F_6	V_1	V_1	-	V_1, V_2	F_7	V_1, V_2	V_1	V_1	V_1, V_2
	-	-	-	-	-	F_8	V_1, V_2	V_1	-	V_1, V_2, V_3
Group 3	F_7	-	V_1, V_2	V_1, V_2	-	F_9	V_1	V_1, V_2	V_1, V_2, V_3	-
	F_8	-	V_1, V_2	V_1	V_1	F_{10}	V_1	V_1, V_2	V_1, V_2	V_1
	F_9	-	V_1, V_2	-	V_1, V_2	F_{11}	V_1	V_1, V_2	V_1	V_1, V_2
	-	-	-	-	-	F_{12}	V_1	V_1, V_2	-	V_1, V_2, V_3
Group 4	-	-	-	-	-	F_{13}	-	V_1, V_2, V_3	V_1, V_2, V_3	-
	-	-	-	-	-	F_{14}	-	V_1, V_2, V_3	V_1, V_2	V_1
	-	-	-	-	-	F_{15}	-	V_1, V_2, V_3	V_1	V_1, V_2
	-	-	-	-	-	F_{16}	-	V_1, V_2, V_3	-	V_1, V_2, V_3

Fabrication of high-radix multiplexer

Figure 2 shows the fabrication process along the AA' lines of Fig. 4a in the manuscript. The well arrays were fabricated with PDMS (10:1 mixing ratio of the monomer and a curing agent, Sylgard 184, Dow Corning, MI) molding technology in the three steps shown in Fig. 2. First, we made the PDMS fluidic layer for the flow channels. Second, we made a PDMS control layer for the control lines. Finally, we bonded two layers with a 20 μm thick PDMS elastomer membrane, which was spin-coated with 4000 rpm for 60 sec and cured at 85℃ for 2 hours.

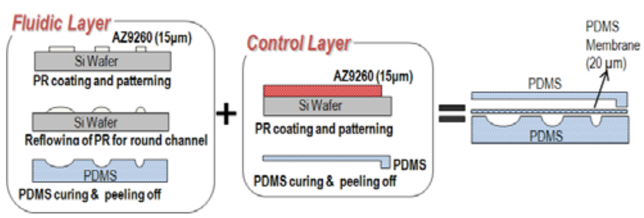


Fig. 2 Fabrication process along the A-A' of Fig. 5a of the manuscript.

The master molds for the fluidic and control layers are made by spin-coating a positive photoresist (AZ9260) at 2000 rpm for 20 sec to make 15 μm thick photoresist molds on silicon. We then pattern them with high-resolution (1 μm) transparency masks. The flow channels on the mold of fluidic layer are rounded at 120℃ for 5 hours to create a round geometry that enables full valve closure. The two PDMS layers (fluidic and control layers) are cured for 2 hours at 85□. After that, we separate the photoresist molds. When the control layer and the 20 µm thick PDMS membrane are bonded by a plasma treatment with a low-pressure plasma system (V6-G, Plasma Finish), we punch the control layer bonded with the PDMS membrane for interconnection from the chip to the world. Next, using plasma treatment with the same low-pressure plasma system, we make the final prototypes by bonding a fluidic layer with another side of the PDMS membrane bonded with the control layer. In this paper, we made prototype with PDMS material. For commercializing microfluidic multiplexer, mass-product methods of the devices using PDMS or alternative materials which have no solvent absorption are required in the future.

Control of pressure valves having different thresholds

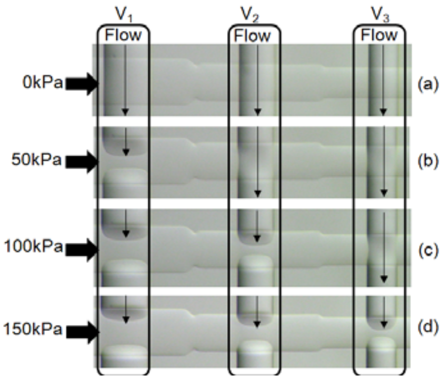
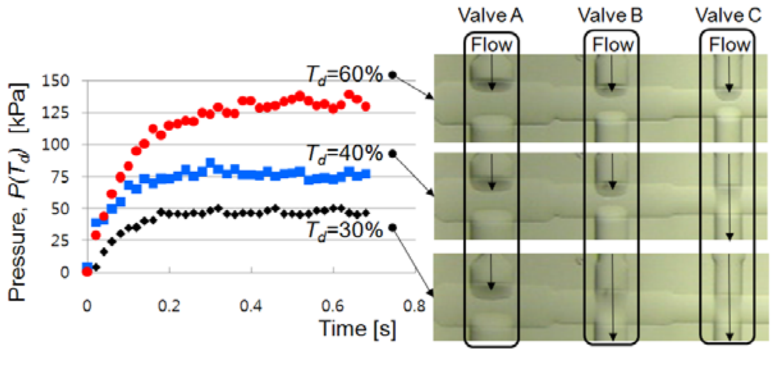


Fig.3 State of the valves in relation to the static pressure: (a) all the valves open at 0 kPa; (b) Only V1 closes at 50 kPa; (c) the V1 and V2 valves close at 100 kPa; and (d) all the valves close at 150 kPa



(a) (b)

Fig.4 The mean pressures and the state of the valves in the dynamic pressure control method: (a) different mean pressures due to the duty ratios: that is, duty ratios of 30%, 40%, and 60% correspond to the static pressure of 50, 75, 135 kPa, respectively; and (b) only V_1 is closed for a duty ratio of 30%; the V_1 and V_2 valves are closed for a duty ratio of 40%; and all the valves are closed for a duty ratio of 60%

Figure 3 shows the state of the valves in relation to the static pressure. Initially, when the pressure is zero in the control line, all the valves are opened and the sample passes through all the flow channels. A threshold pressure of 50 kPa closes only the V_1 valve; a threshold pressure of 100 kpa closes the V_1 and V_2 valves; and a threshold pressure of 150 kPa closes all the valves. By controlling the static pressure in the control lines, we can successfully control the pressure valves of diverse thresholds.

Figure 4 shows the mean pressures in the control lines and state of the valves for the dynamic pressure control method. With an oscillating pressure of 150 kPa at 50 Hz, which is faster than the response times of the valves(≈5Hz) , the measured pressure in the control line increases and saturates some of the values, as shown in the graph in Fig.4a. The fluid in the control lines do not follow the 50 Hz frequency of the oscillating pressure; thus, the pressure in the control line acts like static pressure. In Fig.4b, the mean pressure related to the duty ratio can control the pressure valves of diverse thresholds, namely the V_1, V_2, and V_3 valves. A duty ratio of 30% (≈50 kPa) closes only the V_1 valve; a duty ratio of 40% (≈75 kPa) closes the V_1 and V_2 valves; and a duty ratio of 60% (≈135 kPa) closes all the valves.