Ultra-Compact Microfluidic Valves Using Magnetorheological Fluid Patterned on an Elastomeric Membrane

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We present a novel method for magnetically actuating microfluidic valves while maintaining an ultra-compact system footprint. Our magnetically actuated valves use Magnetorheological (MR) fluids patterned on elastomeric PDMS membranes, and are capable of dynamically opening and closing microchannels with a applied magnetic fields. We performed a comprehensive study on the effects of channel dimension and valve shape. This approach can be extended to fabricate on-chip peristaltic pumps and enable portable and wearable Micro Total Analysis Systems.

Fig. 1 shows a side view and Fig. 2 a 3-D view of the valve structure, consisting of a patterned MR fluid on top of a thin PDMS membrane. The valve, fabricated using soft-lithography, consists of three PDMS layers: 1) The top substrate layer has a micro-patterned through hole confining the MR fluid (i.e. channel control layer), 2) A spin coated thin PDMS membrane to be deformed, and 3) the microfluidic channel flow layer. The magnetic particles in the MR fluid (layer 1) cover and adhere to the membrane, thus moving downward in the presence of a magnetic field, thus applying a strong force to the membrane (layer 2), deforming it and closing the flow channel (layer 3).

Figure 3A shows a combination of magnetically opened and closed valves in parallel with each other and also a close up image of a microfabricated valve (Fig. 3B). We demonstrated the ability to repeatedly open and close the valves by applying and removing magnetic field (Fig. 4). We studied the performance of various valve shapes both theoretically using COMSOL (Fig. 5) and also experimentally by testing microfabricated devices. We tested major factors influencing performance including channel width, valve shape, and valve size (Fig. 6). We experimentally characterized the influence of channel flow rate on the ability to magnetically close the valves (Fig. 7). Circular valves have better performance in lower flow rates, while rectangular shaped valves impede flow more effectively in higher flow rates. To obtain an accurate measure of the applied flow rate in the channel and also take into account hysteresis effects on the flow rate due to an external pump, we use particle image velocimetry rather than relying on the reading provided by the syringe pump. In lower pressure ranges, circular shaped valves with 700 µm diameter in a 300 µm width channel, while in higher pressures rectangular shaped valves with 700 µm width in a 300 µm width channel show optimum performance in valve closing with fastest response time among the various examined valves.

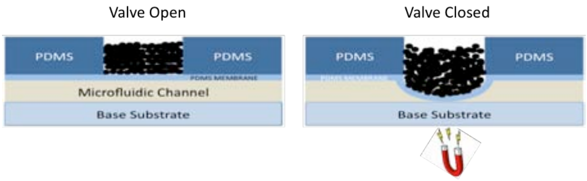

Figure 1: Side-view schematic of the concept of MR fluid integrated with elastomeric PDMS membrane valves with permanent magnet. Application of magnet applies force on MR fluid and it cause deformation of thin layer of PDMS that can close the channel in push down method.

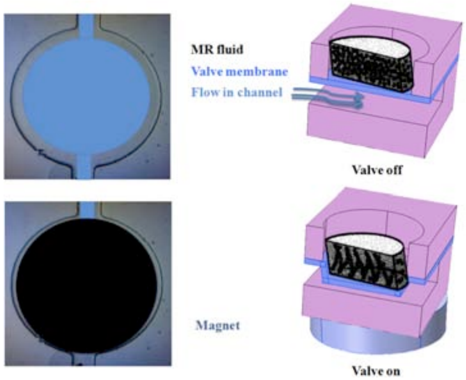

Figure 2: (Left) Bird's-eye view of microfabricated valve. (Right) 3-D schematic of closed and open valve. Application of magnetic field pulls down membrane.

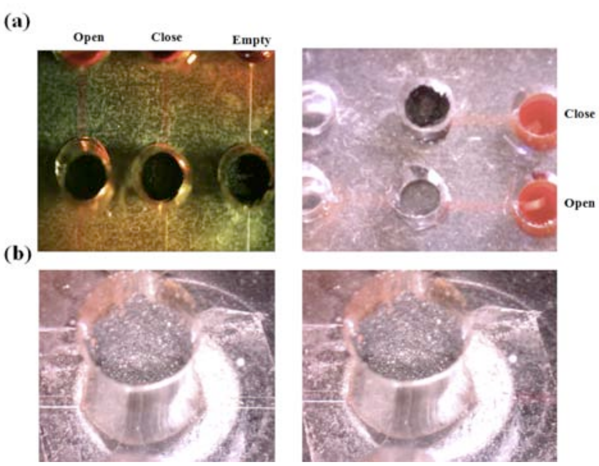

Figure 3: a) top view open and closed valves. b) cross section view of two different valves.

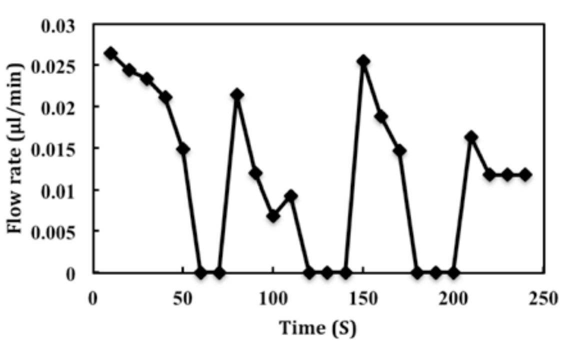

Figure 4: On-Off cycles for circular shaped valve with 700 µm diameter. Flow rate of zero indicates valve completely shut. Non-zero flow rate indicates valve open. Flow rate measured by calculating velocity of polystyrene beads travelling through the channel.

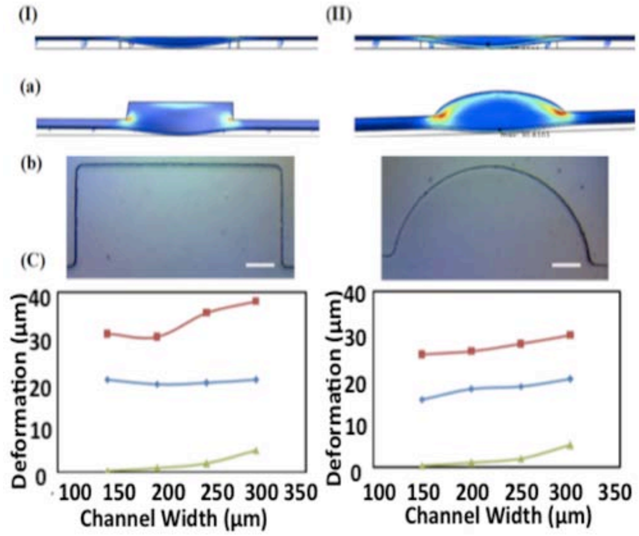

Figure 5: I) Rectangle based valve, II) Circle based valves a) simulation result for deformed valve b) image of micro-fabricated valve, c) effect of different parameters in the amount of deformation. Scale bar is 100 µm.

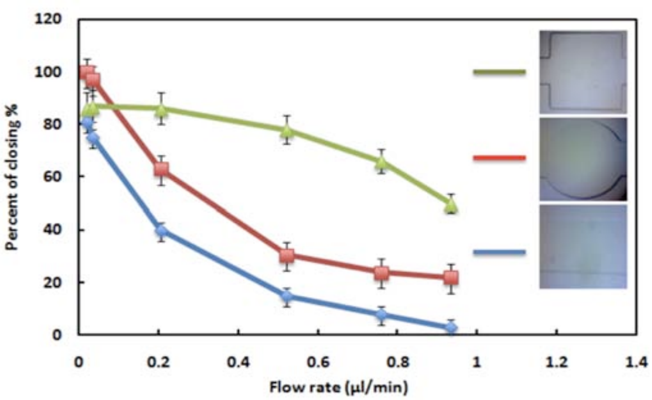

Figure 6: The response of different kind of valves to different pressure in channel. The percentage of valve closure for circlular (rectangle), and rectangular (triangle), and straight channel 300 µm valve (circle).

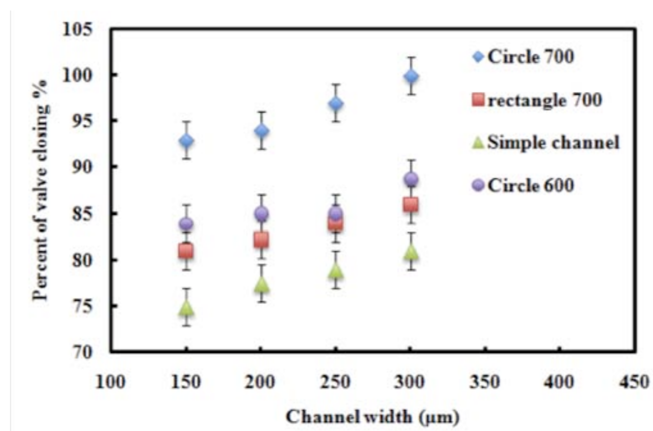

Figure 7: Effect of valve size and shape on percentage closure of valve. Each point was obtained from two different devices and averaged over five different bead velocities. Valves tested were circular 700 µm diameter (Diamond), circular 600 µm diameter (circle), rectangular 700 µm width (square) and straight channels with different channel widths (triangle). The flow rate in the channels was 0.02 µl/min.