Microvalve Architectures for High-Pressure Hydraulic and Electrokinetic Fluid Control in Microchips

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Abstract

Microvalve architectures employing mobile polymer seating elements in glass substrates are presented. These valves can operate on chip with pressures above 3000 psi, at voltages above 1 kV, and in solvents including water, acetonitrile, and acetone. The valves open and close in milliseconds, and can be used to control, inject, and rout fluids. Closing a valve in a microchannel can cause a billion-fold reduction in the flow through that microchannel; this leak rate performance, combined with pressure and voltage compatibility, makes these valves useful for controlling and integrating practical high-pressure chromatographic or electrokinetic separations on microchips.

Keywords: phase-separated polymer, polymer monolith, microvalve, fluid control

1. Introduction

Sophisticated control of both hydraulic and electrokinetic flow enables multiplexing of separation or other analysis techniques, as well as isolation of chemical reaction zones for such processes as materials fabrication, protein crystallization, or fluorescent labeling. We present techniques for rapid and inexpensive *in-situ* fabrication of microvalves suitable for control of both high-pressure-driven and electroosmosis-driven flow in a variety of solvent systems. These microvalves consist of monolithic porous polymer elements [1,2] that move in response to pressure and close or open fluid flow paths by seating or unseating against three-dimensional glass microstructures (Figure 1).

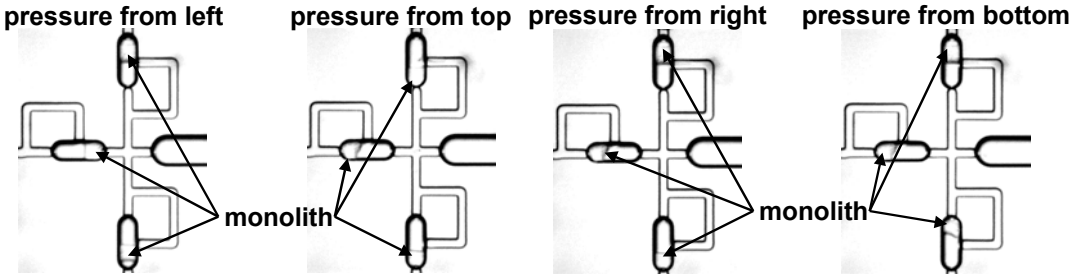

Figure 1. A system of three check valves shown with pressure applied from four different directions. The monoliths move in response to pressure, allowing inflow only at top/bottom and only outflow at left. Check valves are shown in more detail in Figure 3.

2. Microvalve Fabrication

To fabricate the valves, glass microchannels are filled with a monomer/solvent/photoinitiator mixture and phase-separation polymerization is induced by brief (10-90 s) localized exposure to the 355 nm output of a Nd:YAG laser. After exposure, the system is flushed thoroughly with acetonitrile to remove residual polymer/monomer/solvent material and then filled with a variety of solvent solutions for testing (Figure 2).

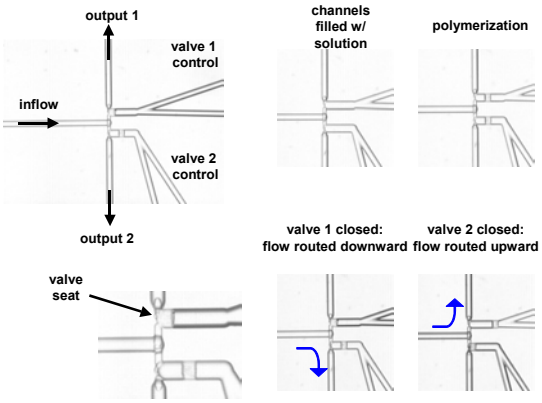

Figure 2. Polymerization and actuation of a fluid routing system comprised of two on/off valves.

3. Sample Architectures

Several microvalve architectures are shown in Figures 3 and 4; these all use mobile polymer monoliths in simple topologies to control flow. Similar topologies have been proposed for valving in other materials[3]. Figure 3 shows check and on/off valves, which serve as fundamental units for more complicated flow control systems.

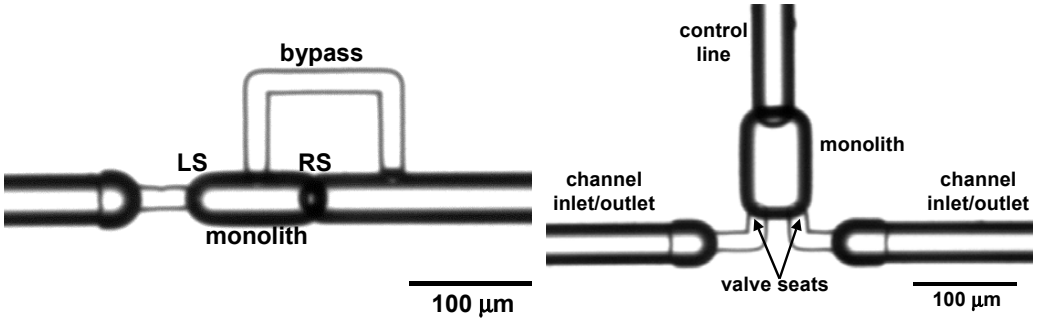

Figure 3. Basic valve architectures. Left: check valve. Pressure applied at left causes the monolith to move against the right stop (RS) and allows flow via the bypass; pressure applied at right causes the monolith to move against the left stop (LS), preventing flow. Right: on/off valve. Flow proceeds unimpeded between left and right channels when control line is at low pressure. When control line is pressurized, the monolith moves downward and closes off flow at valve seats shown.

Two techniques for metering pressure injections onto sample columns are shown in Figure 4. First, a three-port, zero-dead-volume valve architecture can be used for metered pressure injections. The input (buffer or sample) with the higher pressure is transported down the separation channel. Applying a brief overpressure at the sample line injects a controlled sample volume onto the channel. Second, on-chip reaction and injection (emulating pipette function) can be performed with several check valves and a

controlled-volume reservoir. Pressure at reagent lines injects reagents into the reaction reservoir. Pressure from a control line then injects reacted solution onto the analysis channel.

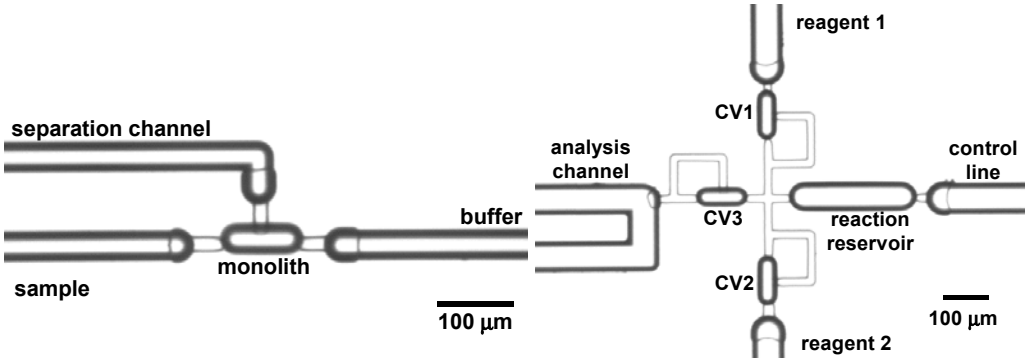

Figure 4. Valve architectures. Left: two-input, one output valve for pressure injections. Right: 1.2 nl pipette with two reagent inputs for on-chip reaction and pressure injections.

4. Microvalve Performance

Figure 5 shows leak rate data for check and on/off valves. The open/closed flow ratios for these valves range from 10^4 to 10^9 over the pressures studied. This performance shows that these valves can hold off the pressure required for high-pressure chromatographic separations on chip, with solvent compatibility that enables solvent gradient techniques. With proper control of pore size and interstitial fluid, these valves can also be used for current holdoff.

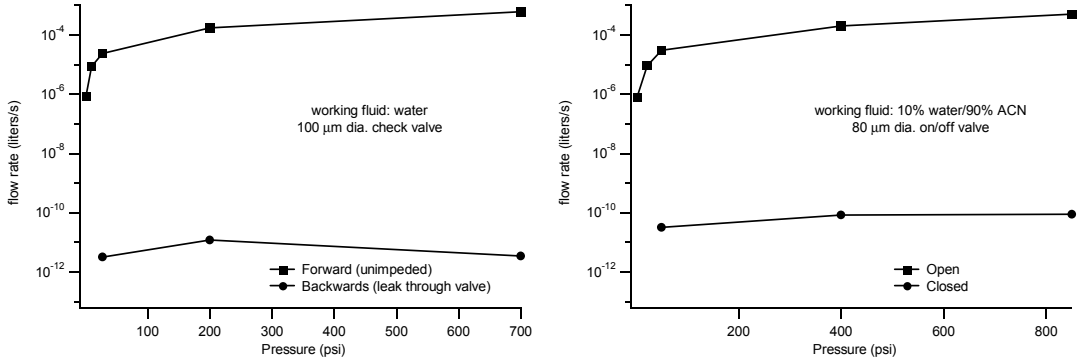

Figure 5. Leak rates for (left) check valve and (right) on/off valve. Performance is similar in water (pH 3-10), 1-propanol, acetonitrile, and acetone. Pressures as high as 3200 psi have been used on chip without valve failure.

References

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