Polymerized Poly(ethylene glycol) Diacrylate Microfluidic Membrane Valves

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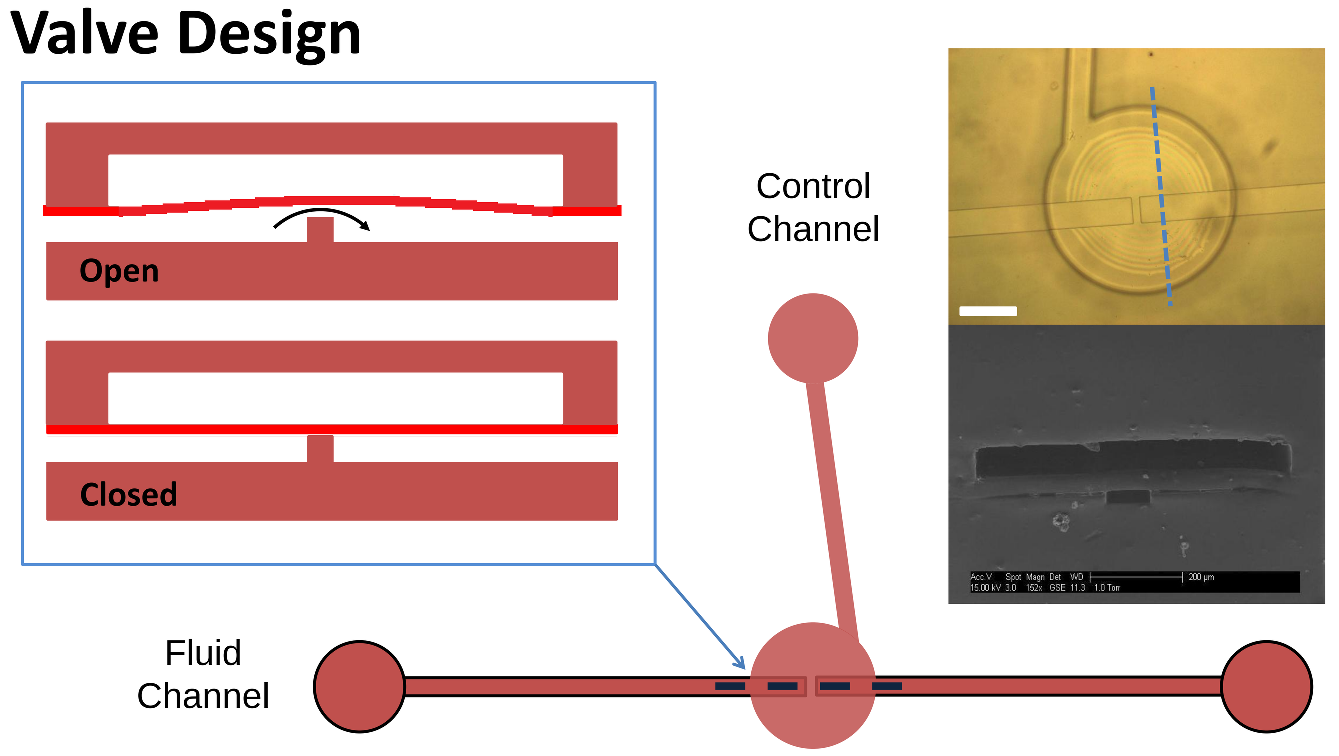
Introduction

Polymerized poly(ethylene glycol) diacrylate (poly-PEGDA) was fabricated into pneumatically controlled, non-elastomeric membrane valves as a nonspecific adsorption resistant alternative to polydimethylsiloxane valves. Temporal response, valve closure, and long-term durability of these poly-PEGDA valves were evaluated.

Valve Design

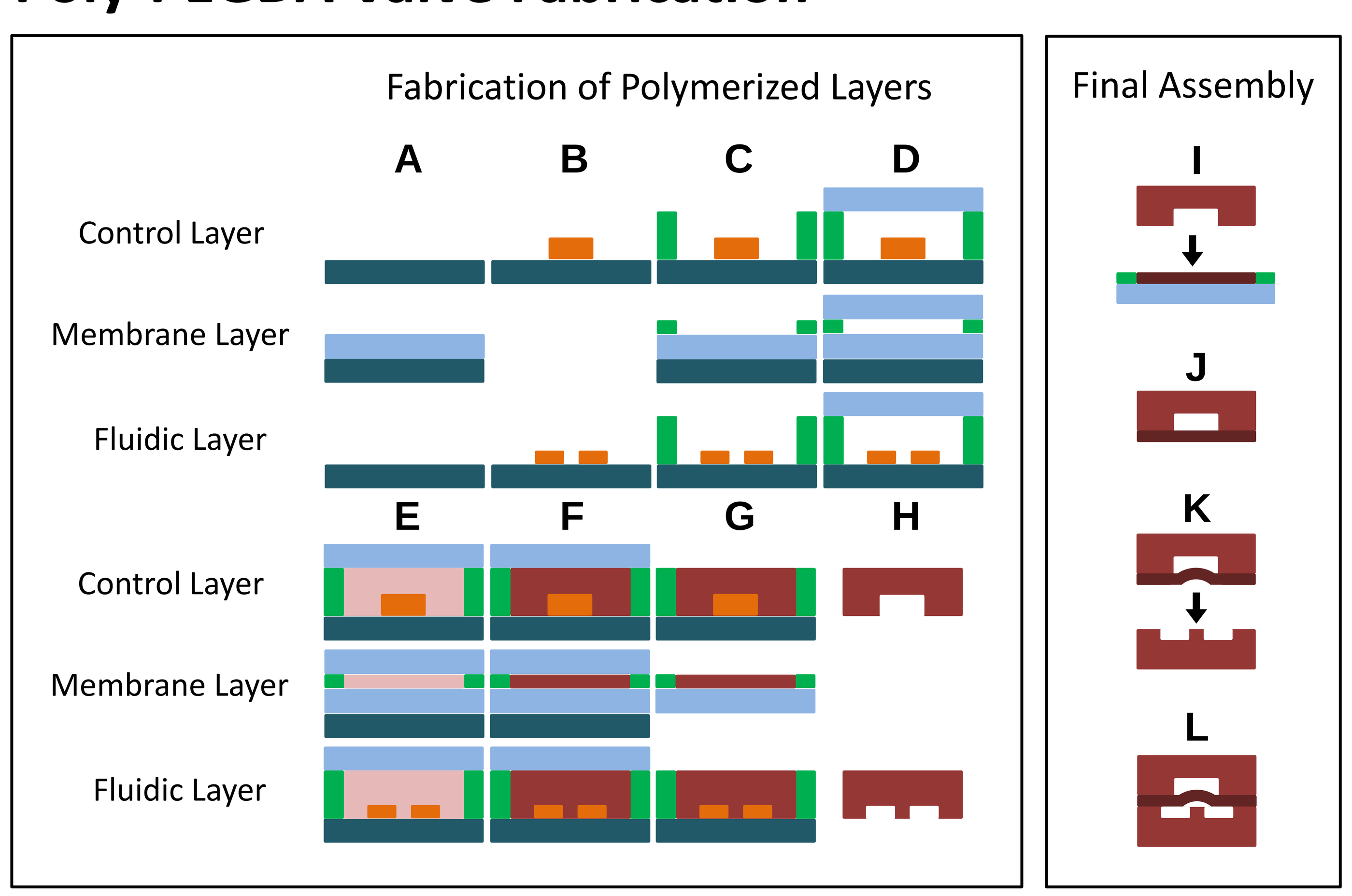


Schematic of a three-layer poly-PEGDA valve. The left inset is a cross-sectional view along the dashed line for an open or closed valve. (Right top) Top-view photomicrograph of a valve. Interference fringes indicate that the membrane is deflected upward (valve open) after the final bonding step. White scale bar is 200 µm. (Right bottom) SEM of a valve cross-section along the dashed line in the photo.

Materials and Methods

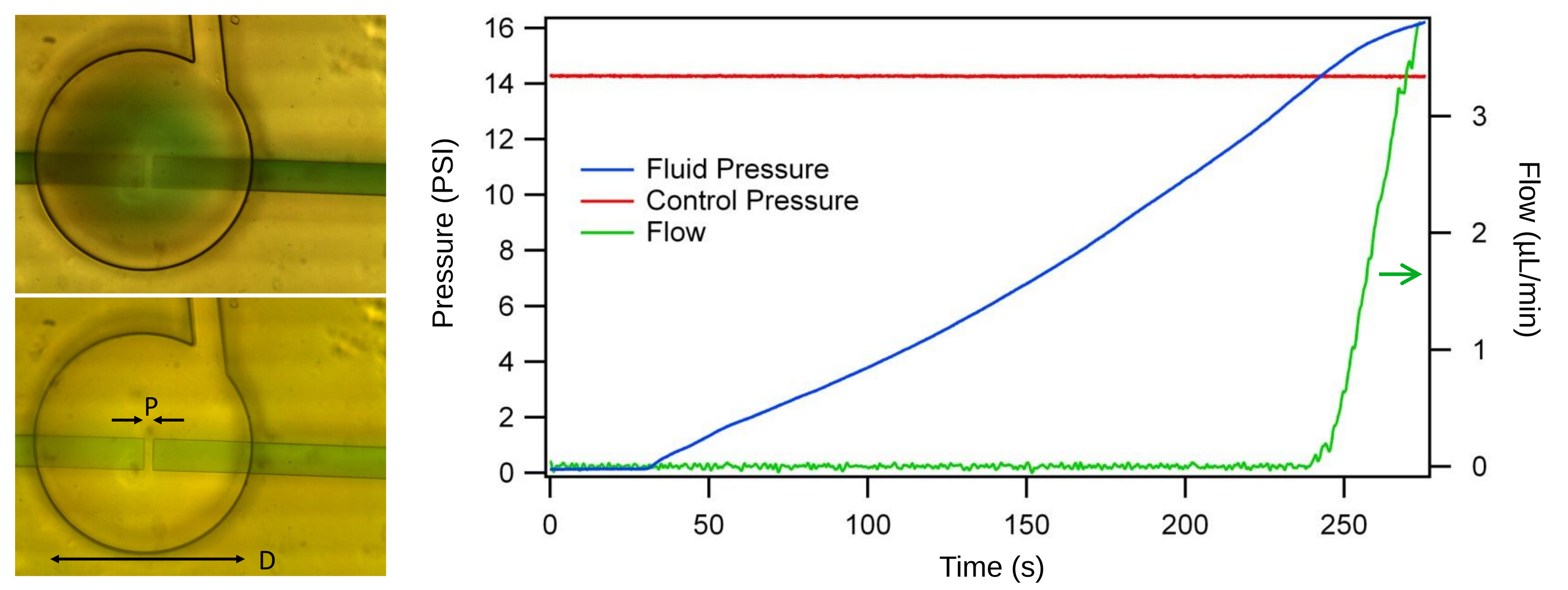
Thermal polymerization of polyethylene glycol diacrylate (PEGDA, 258 Da) mixed with azobisisobutyronitrile was used to form the control and fluidic layers. Membranes were formed using UV polymerization of PEGDA containing 2,2'-dimethoxy-2-phenylacetophenone.

Poly-PEGDA Valve Fabrication



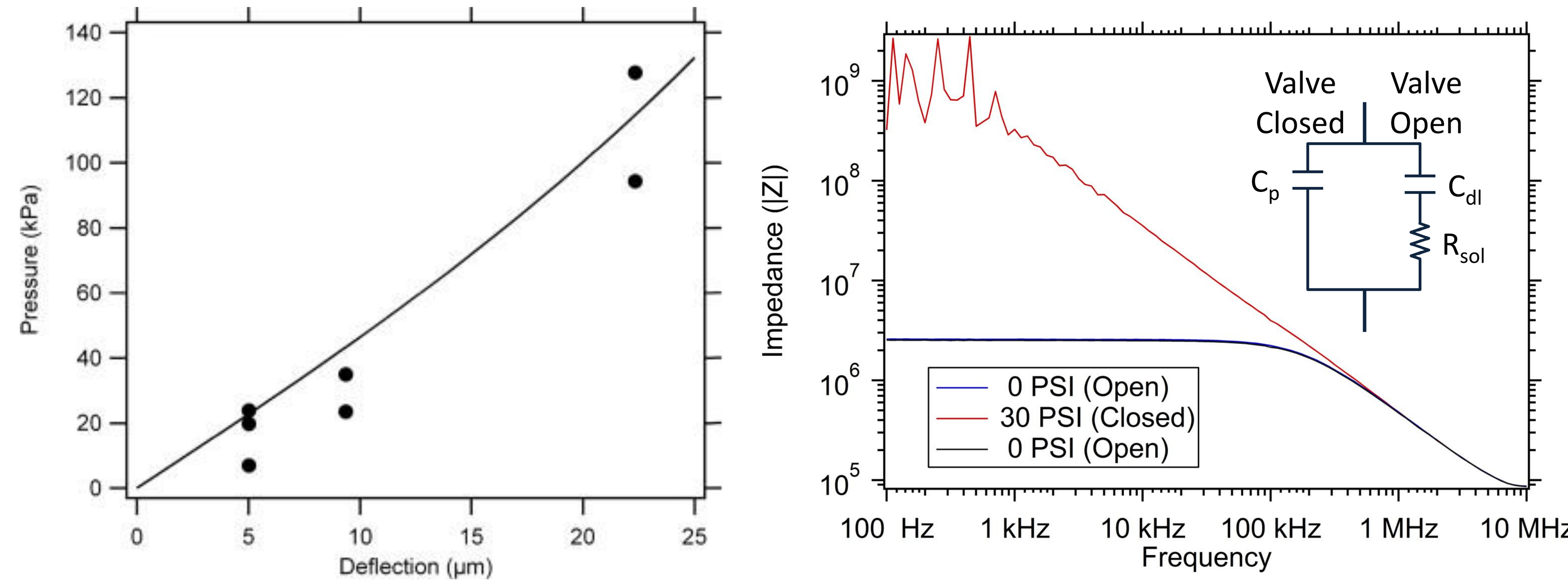
(A) Clean substrates. A glass slide on silicon forms the bottom layer of the mold for the membrane layer. (B) SU8 patterns define features. (C) Spacers define poly-PEGDA thickness. (D) Glass wafer forms top of mold. (E) Prepolymer is introduced. (F) Polymerization of poly-PEGDA. (G) Glass cover wafer is removed. (H) Finished poly-PEGDA is removed, diced, and cleaned; an input hole is cut into the control layer. (I) The just-released top surface of the membrane layer (G, middle) is bonded to the control layer (H, top). (J) The bonded control and membrane layers are removed and (K) bonded under vacuum to the fluidic layer using UV light, (L) resulting in a completed valve device.

Valve Characterization



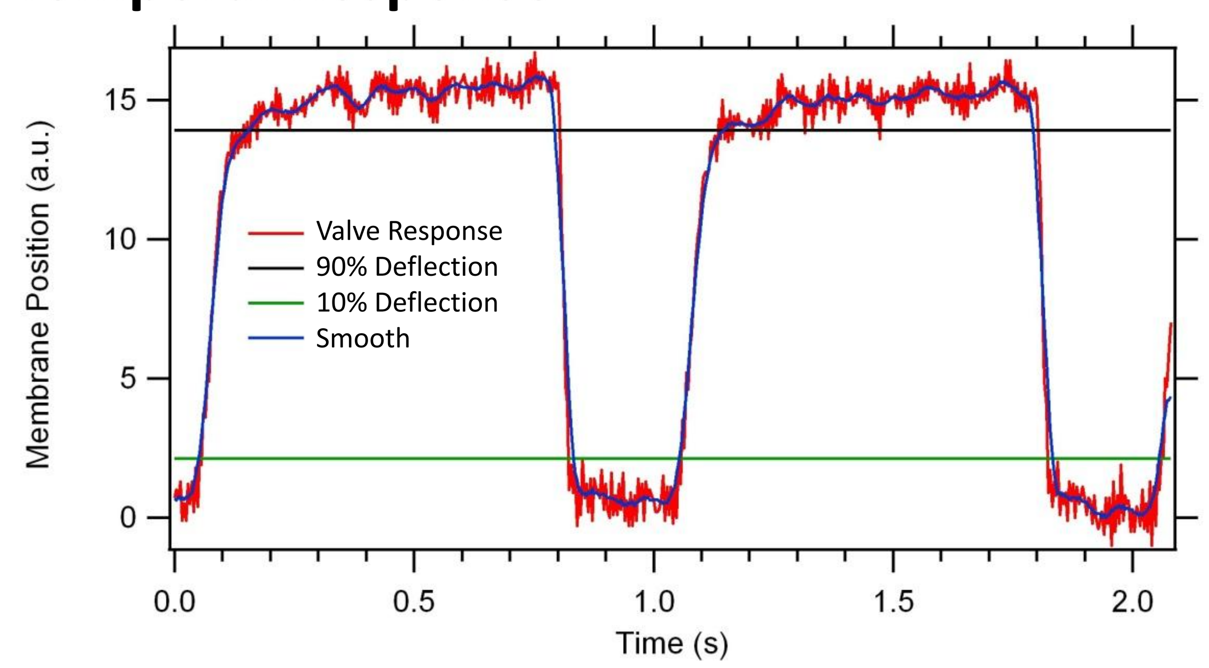
(Left) Top-view images show an open (top) and closed (bottom) valve with green dyed fluid added for contrast. Valve diameter (*D*) is 700 µm, pedestal width (*P*) is 30 µm, and the fluid channel width is 100 µm. (Right) Fluid pressure and volumetric flow rate as a function of time for a constant control pressure. Sensors in the fluid and control lines monitor pressure, and meniscus tracking on the fluid output allows for flow measurement. The flow rate increases rapidly once the fluid pressure exceeds the control pressure at ~240 s.

Evaluation of Valve Closure



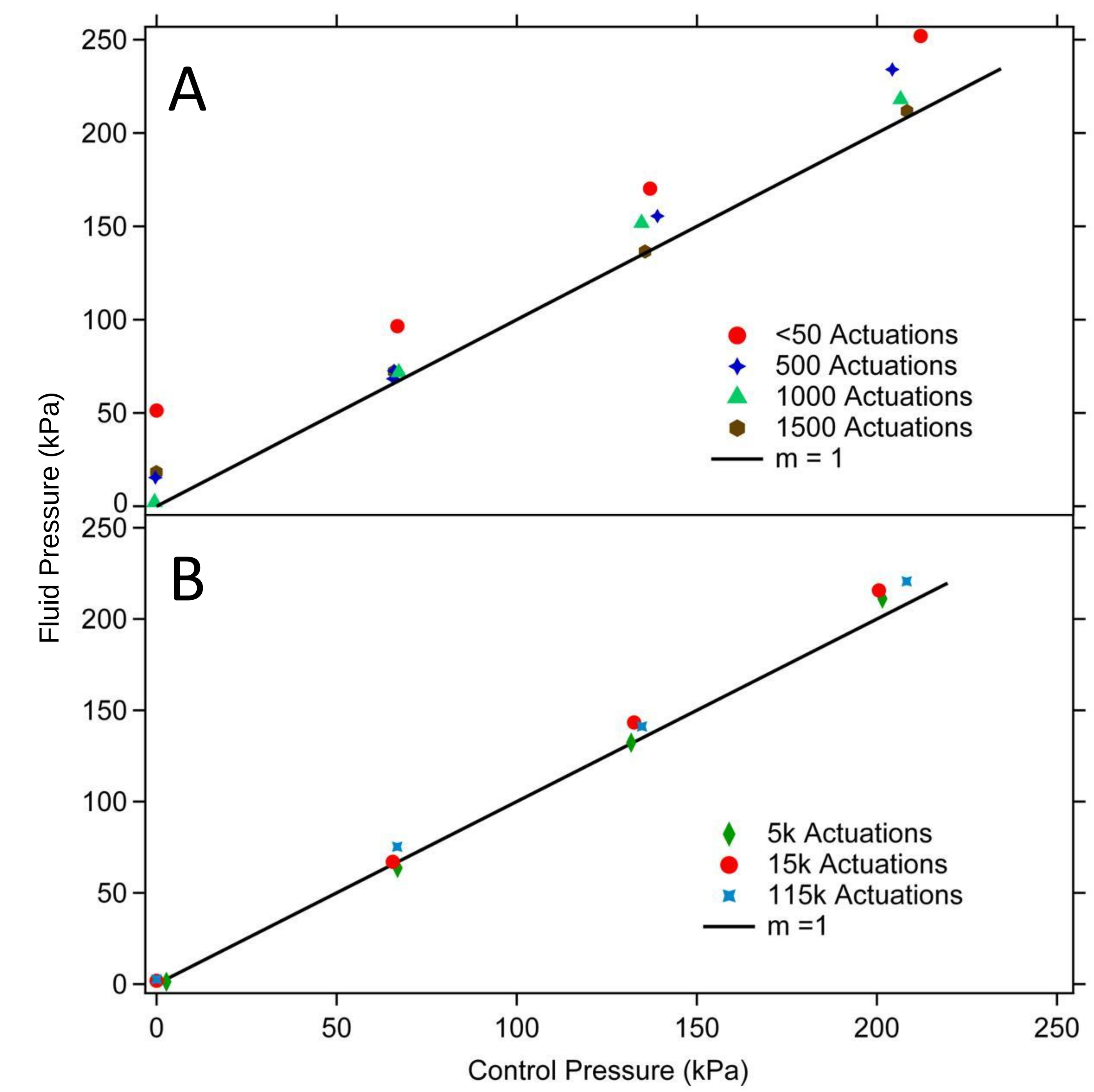
(Left) Calculated (line) and experimentally measured (circles) deflection via applied pressure, for a 45 µm thick circular membrane with an elastic modulus of 0.13 GPa, a 350 µm radius, and a Poisson's ratio of 0.35. Very low pressure (~9 kPa) is required for significant membrane deflection (>2 µm). (Right) Impedance measurements after 1000 actuation cycles demonstrating valve closure in less than 1 min. A dielectric material with a conductive solution in the fluidic channel will behave like a simple circuit (inset). When the valve is open, charge flows through the right path, consisting of two components, the double layer capacitance (C_{dl}) and the resistance through the solution (R_{sol}). When the valve is closed, charge will flow through the left path which has only one component, parasitic capacitance (C_p). An open valve shows resistive properties at frequencies below 100 kHz (blue line). When the valve is closed, the impedance increases, demonstrating parasitic capacitance (red line). When the valve is reopened (black line) it again becomes resistive at frequencies below 100 kHz.

Valve Temporal Response



A valve was actuated at 1 Hz and 30% duty cycle. Fall time (valve closure) was 0.019 s and rise time (valve opening) was 0.105 s. No vacuum was used to open the valve, and the fluid backpressure was negligible.

Valve Longevity



Valve performance after a number of actuations as a function of control pressure. (A) Initial valve testing shows a higher fluid pressure is required to open the valve for a given control pressure. After ~1500 actuations, the fluid pressure to open a valve decreases to match the control pressure. A circular valve with a 15 µm pedestal width was used for this test. (B) Valves maintain this linear fluid vs. control pressure relationship to at least 115,000 actuations. A circular valve with a 30 µm pedestal width was used for this test.

Conclusions

- Valve operation up to 8 Hz was achieved with a ~100 ms opening time (without applied vacuum) and a ~20 ms closure time.
- Less leakage occurred in geometries with a larger membrane contact area (>0.3 mm^2) and pedestals of 15 µm or greater width.
- After ~1000 actuations to reconfigure polymer chains and increase membrane elasticity, the fluid pressure needed to open a closed valve was the same as the applied control pressure.
- Valves maintained a linear relationship between the closure pressure and the opening pressure required to initiate flow, even after 115,000 actuations.

Future Work

Application of poly-PEGDA valves in microfluidic pumps and sensor integration.

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References

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2. Rogers et al. *Anal. Chem.* **2011,** *83* (16), 6418-6425