A MONOLITHIC PASSIVE CHECK-VALVE FOR SYSTEMATIC CONTROL OF TEMPORAL ACTUATION IN MICROFLUIDIC DEVICES
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ABSTRACT
This work describes the design and application of a microfluidic check-valve, made solely of poly(dimethylsiloxane), capable of passively controlling pressurized fluids. The integrated check-valve is designed to only allow forward-flow at certain threshold pressures and to negate both back-flow and diffusion when in a closed state. The required threshold pressures are directly related to the valve’s geometry and therefore can be adjusted. We demonstrate that these valves are able to act similarly to a transistor and linked-up in a specific fashion to passively switch between simultaneously infused fluids. This shows the ability to create predefined passively controlled microfluidic systems.

KEYWORDS: Microfluidic, Passive Check-valve, Transistor, Logic

INTRODUCTION
Many microfluidic analysis systems utilize soft lithography as a device platform due to its ease-of-use and cost effectiveness. Most of these systems require valves which either have cumbersome device interfacing, low fabrication fidelity, or impose limits on applicability. This paper reports an improved design of a readily constructed integrated passive poly(dimethylsiloxane) (PDMS) check-valve that enables systematic control of fluid in microfluidic devices. Typically within microfluidic devices, fluid manipulation has been controlled by active actuation using an external pressure source [1]. However, these methods require bulky equipment and superfluous interfacing, limiting its use to specialized labs. To reduce complexity, integrated passive check-valves made solely with PDMS have been designed [2, 3]. The major drawbacks of these valves are either low fabrication-fidelity and/or insufficient functionality to allow precise control of multiple fluids.

Figure 1: Schematic of device fabrication and function. A) 3-layer design with main channels in top layer, interfacing hole in middle thin layer, and cavity in bottom layer. B) Low pressure forward flow to the left is not able to deform the membrane into the cavity resulting in no net flow. As pressure increases, the membrane will deform enabling flow to bypass the gap. Back-flow is negated by fluid pressurizing the bottom cavity causing middle layer to pinch against the top layer gap.
THEORY

Our group’s design provides both high fabrication fidelity and increased performance enabling the systematic control of fluid with integrated passive valves not shown by any other group. Figure 1A shows a schematic of our 3-layer design where the limitations of the previous designs [2] are overcome by simple fabrication techniques. The check-valve is essentially an interrupted channel which can be joined together when the fluid is pressurized enough to deform the thin membrane down into the cavity of the bottom layer bypassing the gap (Figure 1B). A hole is punched into the thin middle layer after the gap which directs any back-flow to into the bottom-layer cavity pinching the membrane to the top-layer gap. Since the deflecting membrane is confined on three-sides, the elasticity of PDMS returns it to a closed position negating diffusion when unpressurized.

EXPERIMENTAL

The check-valve is fabricated by binding the three layers of PDMS with the conventional method of plasma-oxidation. First, a 30μm thick PDMS membrane is bonded to the bottom-layer and then a hole is punched (350μm biopsy punch) in the downstream region of the cavity. The top layer is then aligned and bound, however in order to keep the thin membrane from permanently binding to the gap region of the top-layer, a piece of PDMS is placed on that region during plasma-oxidation.

Figure 2 qualitatively demonstrates the check-valve’s ability to block both back-flow and diffusion. Figure 3 quantitatively characterizes the ability to control the valve’s actuation pressure based on its geometry. By varying the valve’s width (Figure 3A) or length (Figure 3B), the actuation pressure will change non-linearly or linearly, respectively; the small error bars illustrate the efficacy of the valve’s performance. Figure 3C shows the valve’s ability to facilitate normal flow dynamics after opening. All valve geometries were able to withstand back-pressures (zero back-flow) up to 45psi, which improves on previous designs by at least 16psi [3].

Figure 3. Quantitative characterization of check-valve. A) Changing length of valve linearly increases actuation pressure B) Changing width of valve non-linearly increases actuation pressure (Error bars included) C) Linear correlation between pressure and flow rate through the valve after opening.
RESULTS AND DISCUSSION

Temporal control of fluidic actuation is demonstrated in Figure 4 where three fluids being simultaneously infused are passively released into the main channel sequentially in order of decreasing valve width. A further demonstration shows how these valves can be made to act like a transistor and have fluid passively turned on and off by not punching a hole in the middle layer and having an access channel to the cavity in the bottom layer. Figure 5 demonstrates the passive switching between three solutions that are simultaneously infused by a multi-syringe pump using the systematic actuation of seven valves (five check-valves and two transistor valves). The seven valves are designated by either an “O” or “X” which represents the valve in an on or off state, respectively. A red “X” designates linked check-valves which lock in pressure causing both valves to be closed.

CONCLUSIONS

This work shows how to construct microfluidic control systems with pre-defined complex functions using integrated passive check-valves. The check-valve is designed to allow for temporal control of fluidic actuation as well as being able to act as a transistor, allowing all types of logic processes to be computed. This type of system enables enhanced implementations in microfluidic logic, bioassays, and point-of-care devices while maintaining simple user-interfacing.

REFERENCES