ON-CHIP ACTUATION OF A THERMALLY SENSITIVE HYDROGEL VALVE

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ABSTRACT

This paper reports improved response characteristics of a thermally sensitive hydrogel valve actuated via on-chip heaters on a plastic chip platform. Compared with off-chip actuation, on-chip heaters provide a 400% faster turn-off response. The device is comprised of an injection molded COC (cyclic-olefin-copolymer) chip, lithographically patterned gold heaters, and an in-situ polymerized NIPAAm (poly(*N*-isopropylacrylamide)) hydrogel valve. The valve is normally closed at room temperature. Upon heating to above the transition temperature of 32°C, the polymer valve becomes hydrophobic, shrinks while creating large pores, and permits flow. The system has been actuated reliably over 100 times with no apparent degradation.

KEYWORDS: Hydrogel, Valve, Heaters, Injection Molding

INTRODUCTION

We previously reported the NIPAAm valve in capillaries and glass chips using off-chip actuation [1]. This work uses a polymer chip and increases the level of integration by including on-chip heaters for valve actuation. Harmon et al. used on-chip heaters and NIPAAm to actuate a PDMS (polydimethylsiloxane) membrane valve, however the response time is on the order of 1 min [2]. In this work, the valve is placed directly in the channel on top of the heater, yielding a response time on the order of seconds.

THEORY

NIPAAm exhibits a sharp Lower Critical Solution Temperature (hydrophobic/hydrophilic) transition at 32°C in aqueous solutions. While the transition is sharp, a finite amount of time is required for the polymer chains to coil and uncoil. The response time of this system is dictated by both this time and the time required for heat to transfer to/from the hydrogel. By placing the valve directly on an on-chip heater, it is expected that the total response time will be faster.

EXPERIMENTAL

The chip was injection molded with a single microchannel, as previously reported [3]. Prior to enclosing the channel via controlled exposure to solvent vapor, 20 nm of chrome and 100 nm of gold were thermally evaporated onto the COC cover slide. The metal layers were then etched to define 20 µm heater traces using standard photolithographic procedures. The two parts of the chip were bonded by exposing the structured-half of the chip to solvent vapor and applying pressure, as previously reported [4]. Alignment between the channel and the heater was ob-

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tained using a custom alignment fixture under an optical microscope. The walls of the channel were surface modified to ensure covalent attachment of the valve to the channel wall. The valve was prepared *in situ* by filling the channel with a polymerization solution and exposing selected regions with UV light through a photomask. Results from fabrication are shown in Fig. 1.

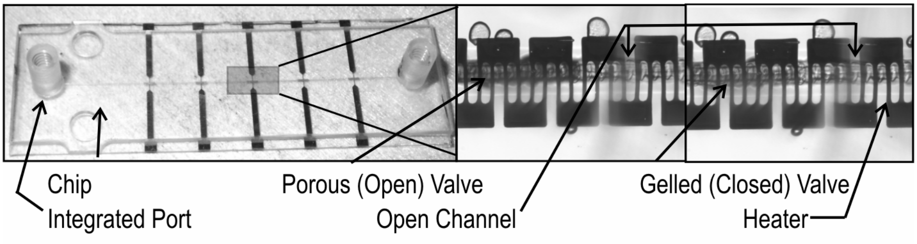

Figure 1. Left: Photograph of 25 x 75 mm plastic injection molded microfluidic chip with integrated fluidic interconnects and lithographically defined gold heaters. The channel measures 100 x 100 µm in cross-section and is 63.5 mm long. Middle: Micrograph of the channel, ~20 µm heater traces, and hydrogel valve in open state. Right: Micrograph of valve in closed state.

RESULTS AND DISCUSSION

The test set-up of the chip consisted of a syringe pump, a pressure sensor, a flow meter, and the chip. Water was pumped through the system at 10 µl/min until a pressure of 50 psi was obtained. The pump was turned off, and the pressure and flow rate response of the system was recorded as the valve was actuated. Off-chip actuation was conducted by manually shuttling the chip between a 45°C hot-plate and a room-temperature aluminum block. On-chip actuation was achieved by applying 1.1 V across the heater, generating 24 mW of heat.

Results for a single on- and off- chip actuation are presented in Fig. 2. In particular, the cooling (closing) response is significantly faster as the bulk of the chip serves as a heat sink in the case of on-chip heating. In the other case of off-chip heating, the bulk of chip serves as a heat reservoir. The system was actuated at high frequency for over 100 actuations as shown in Fig. 3. Interestingly, the time required for closing is similar for heat pulses of both 1 s and 5 s. This suggests that the closing response may be approaching the response time of the hydrogel valve itself. We are unaware of any microfluidic chip employing a hydrogel valve with a faster response.

CONCLUSIONS

These results demonstrate the capability and advantages of integrating thermally sensitive valves and heating elements onto a single microfluidic platform. This work lays the foundation for advanced applications requiring higher density of valves and greater local control of thermal environments.

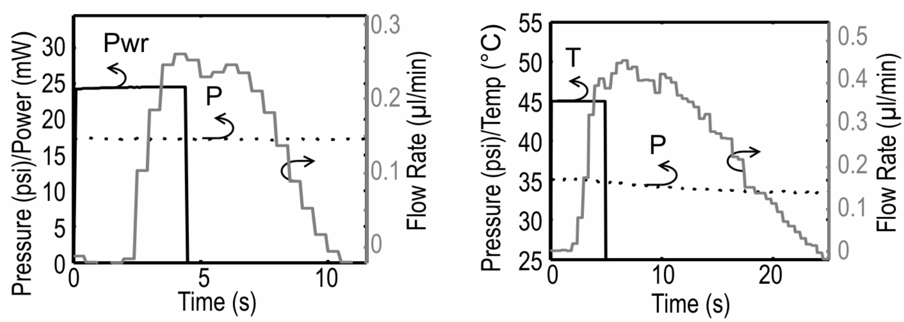

Figure 2. Typical response times for on- and off-chip valve actuation. Left: On-chip actuated valve closes in ~5 s. Right: Off-chip actuated valve closes in ~20 s. Temperature corresponds to the temperature of the plate.

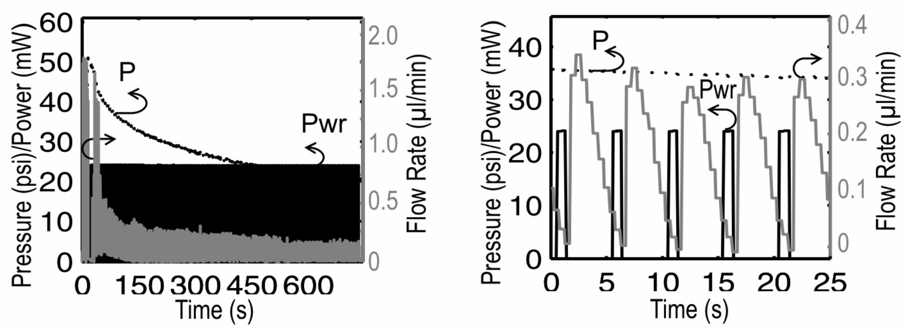

Figure 3. Left: Reliability of heater/valve system demonstrated by over 100 actuations. Right: Heater power was pulsed on and off for 1 and 4 s, respectively.

ACKNOWLEDGEMENTS

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