Polymer MEMS for Micro Fluid Delivery Systems

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Introduction

Polymer materials for microelectromechanical systems (MEMS) technology have been gaining in popularity to meet biocompatibility requirements of biological and chemical applications. Silicone rubbers have been explored extensively by many in a wide range of applications from cell sorting [1] to capillary electrophoresis [2]. However, the major drawback of using this material is the incompatibility with other microfabrication techniques and processes. Parylenes have long been used in integrated circuits and as a printed circuit board coating for its excellent electrical and mechanical properties. Much attention has now been shifted to the fabrication of biocompatible devices using parylene as a structural material. Neuroscientists have taken advantage of the biocompatibility of parylene in the form of coatings on implantable microelectrodes [3]. In addition, parylene is compatible with microfabrication techniques and forms a conformal, pinhole-free coating at room temperature.

A miniature prototype fluid delivery system incorporating polymers as structural materials is presented here using a micropump as the fluid actuator, a thermal flow sensor as a fluidic control device, and micromachined couplers as fluidic interconnects. This type of system is important in the development of micro-dispensers for lab-on-a-chip.

Experimental

Parylene Check-Valved Diaphragm Pump. Various micro mechanical diaphragm pumps have been designed to achieve the maximum flow rate possible using microfabricated parts. Typically, microfabricated pumps operate with maximum flow rates in the nL/min-µL/min range [4]. Flow rectification in these pumps was accomplished by using high-flow parylene check valves. These one-way valves consist of thin film parylene valve caps that are tethered over an orifice to a silicon substrate. Flow is only permitted when the valve cap experiences forward flow across the valve cap and seat. Operation of such a valve is shown in **Figure 1**. It has been shown that such a valve is capable of providing a four-fold improvement in flow handling capability when compared to similar microfabricated valves [5]. Bossed silicone membranes and gaskets were also used as pump components. Device fabrication details are given in [6] and additional information can be found in [7]. Using this pump, it is possible to achieve flow rates of 13 mL/min. **Figure 2** shows an assembled pump and 3D cross sectional view of a pump assembly.

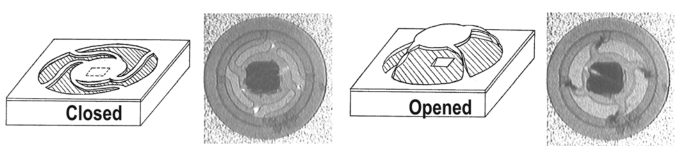
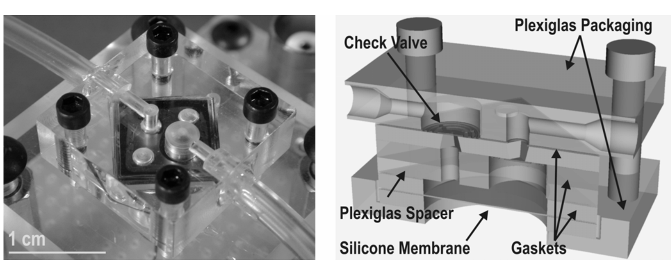


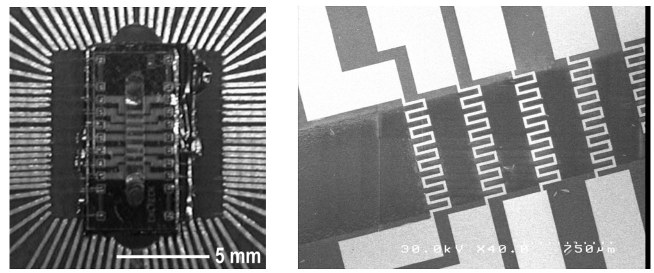
Figure 1. Diagrams and photos showing parylene check valve operations in both closed and opened modes.



(a) (b)

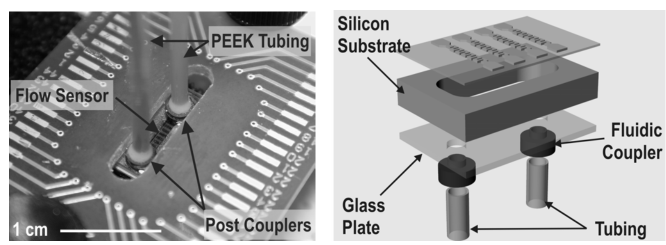
Figure 2. **(a)** Top view of an assembled micro check-valved diaphragm pump and **(b)** 3D schematic showing pump components.

Parylene Thermal Flow Sensing Array. Flow sensors based on thermal operating principles have long been popular for their ease of use and fabrication. Sensors for use with biological applications, however, require low operating temperatures and biocompatibility. A thermal flow sensing array constructed of parylene and platinum has been demonstrated [8] and satisfies both of these requirements. Various views of the sensor are seen in **Figure 3** and **Figure 4**. This device operates based on the flow rate dependent convective heat transfer from a heated sensing element to passing fluid. In addition, the sensor is capable of multiple modes of operation and can sense flows as low as 0.5 µL/min. In one operating mode, called time-of-flight, flow rate is measured by tracking a heat pulse applied to a heater at a sensor downstream. The detected signal measured in terms of resistance change over time is shown for various flow rates in **Figure 5**. The characteristic response shows that as the flow rate increases, the time at which the peak signal is detected, or "top time," decreases. Flow rates are set and supplied by a precision syringe pump (KD Scientific Inc. Model KDS 100) fitted with precision syringes (Hamilton Company 1700 Series GASTIGHT syringes).



(a) (b)

Figure 3. **(a)** Top view of packaged flow sensing array and **(b)** SEM of platinum flow sensing elements suspended on a parylene membrane.



(a) (b)

Figure 4. **(a)** Backside of packaged flow sensing array showing microfluidic couplers and **(b)** exploded 3D drawing of flow sensor components and assembly.

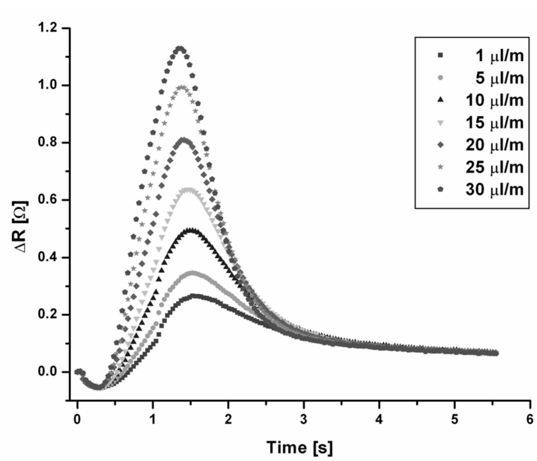
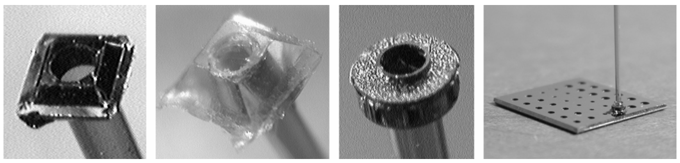


Figure 5. Sensor response at various flow rates measured in terms of resistance change over time for time-of-flight operation.

Microfluidic Couplers. Microfluidic devices require both fluidic and electrical interfaces with the outside world. While electrical interconnects are well developed, the problem of making fluidic connections to microfluidic devices with µm- or mm-scale orifices is still not completely solved. The fluidic coupling approach used here is to connect fluidic devices to the external environment using micromachined silicon and polymer couplers [9]. Several types of micromachined fluidic couplers are shown in **Figure 6**. These couplers are designed to work with conventional PEEK and fused silica capillary tubing and are constructed of silicon or polyolefin. These couplers are extremely robust and support pressures up to 10^4 kPa (1500 psi).



(a) (b) (c) (d)

Figure 6. Three types of couplers: **(a)** silicon bulk, **(b)** polymer molded, **(c)** and silicon post couplers; and **(d)** a silicon post coupler with fused silica tubing attached to a microfluidic chip.

System Assembly. The discrete microfluidic devices previously presented were joined using micromachined couplers to create a micro fluid delivery system. Here, the check-valved diaphragm pump serves as a fluid actuator and is connected to a downstream flow sensing array using silicon post couplers and PEEK tubing. The flow sensing elements are connected to a data acquisition unit (Hewlett Packard HP34970). Filtered deionized water was pumped through the system and out through a calibrated pipette where the flow rate is measured by a stop watch. The flow sensor was operated in time of flight mode using a 3 volt pulse with 1 second duration. While closed loop control is possible, it is not implemented for simplicity. A schematic diagram detailing the system components and data acquisition setup is shown in **Figure 7**.

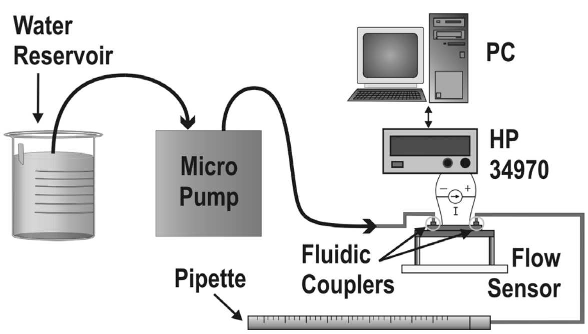


Figure 7. Schematic diagram of flow delivery system layout and experimental testing setup.

Results and Discussion

A working microfluidic system composed of mostly polymer components has been successfully assembled and tested. Performance os the system can be seen in **Figure 8** which shows the sensor output in time-of-flight mode for flow driven by the micro diaphragm pump. The 0 Hz trace corresponds to 0 µL/min flow and the 10 Hz trace corresponds to a flow rate of 46 µL/min. The frequency refers to the actuation frequency of the micro pump actuator. Values for top times and peak response are indicated. Compared to typical time-of-flight sensor response curves, there is noticeable roughness in the 10 Hz signal. This is attributed to the non-continuous flow produced by the reciprocating actuator in the diaphragm pump. In a typical pumping cycle, only the pump mode contributes to the overall flow while the supply mode replenishes fluid in the pump in preparation for the next pumping cycle. At lower flow rates, and thus lower actuation frequencies, this pulsed flow effect on the sensor output is much more pronounced [7].

This system demonstrates the feasibility and usefulness of an integrated dosing system. A further refinement to this system would be to scale the entire system down to chip level. This is ideal in applications where small flow rates (µL/min to nL/min) are desired. Parylene-based MEMS technology can be used to make reservoirs, valves, pumps, and other components all within a surface micromachined channel for performing various fluidic functions. This multi-layer parylene technique has been demonstrated in [10] in which a continuous flow micro fluid delivery system was fabricated.

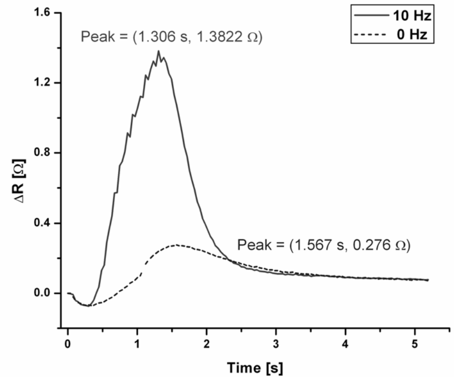


Figure 8. Flow sensor response to pumped fluid flow in time-of-flight operation.

Conclusions

Polymer materials have been readily incorporated into MEMS devices. Various polymer components such as parylene check valves, silicone membranes, and parylene supported sensors have been fabricated using MEMS technology. In turn, these discrete devices have been successfully integrated into a functional microfluidic system capable of delivery fluids in the mL/min to µL/min range. Integrated approaches to making completely functional surface-micromachined parylene based fluidic systems have been proven feasible and are being investigated.

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