

## POLYMERIC STACK-ASSEMBLED MICROPUMP WITH SU-8 CHECK VALVES

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This paper presents a new concept of designing and fabricating polymeric micropumps. The micro pump is made of SU-8 photoresist and polymethylmethacrylate (PMMA). The key elements of the micropump are the micro check valves, which are fabricated in a 100- $\mu\text{m}$ -thick SU-8 film. The SU-8 part is designed as a disc with 10-mm diameter. The check valves are 1-mm discs suspended on a compliant orthoplanar spring with 4 arms. The cross section of the spring beam has a dimension of 100  $\mu\text{m} \times 100 \mu\text{m}$ . The pump is designed as a stack of different layers, which are made of PMMA and SU-8. The low spring constant of the SU-8 check valves allows the use of relatively low drive voltages on the order of several 10 volts for the piezodisc, which works as the pump's actuator. Pump rates up to 1 ml/min and back pressures up to 200 mm water have been achieved. The pump design shows the feasibility of our current effort to make microfluidic systems based on the lamination of different polymeric materials.

*Keywords:* Microfluidics; Micropumps; Polymeric micromachining; SU-8; PMMA.

### 1. Introduction

The development of micropumps is part of the emerging microfluidics [1]. Simple pump designs are required for integration in miniaturized chemical analyzers. The trend of disposable plastic test cartridges leads to the need of simple polymeric micropumps.

Micropumps can be categorized as mechanical and nonmechanical pumps [1, 2]. The first applies conventional concepts in microscale, the latter utilizes effects, dominating in microscale such as surface tension and electrokinetics. Since the size of the above mention test cartridges is in mesoscale, mechanical pumps are still relevant.

With the need of polymeric microdevices, polymeric micromachining techniques such as thick resist lithography, polymeric surface micromachining, and soft lithography, have been established recently as new alternatives in microtechnology [1]. The advantage of polymeric micromachining is the possible use of different polymeric materials, which may offer good biocompatibility and chemical resistance.

Polymer materials are 50 to 100 times softer than silicon. Thus, polymeric check valves require less pressure for opening and offers much better sealing characteristics. Several check valves fabricated in polymers such as polyimide [3], and polyester [4], were reported. SU-8, a negative thick photoresist, has been widely used for making microchannels [1]. This paper reports a piezo-actuated micropump with novel SU-8 check valves as movable structures, fabricated with the polymeric surface micromachining [1].

## 2. Micropump Design

The pump consists of 6 material layers, Fig. 1. The first PMMA plate has an opening at the center for fixing the piezodisc. The piezodisc, a commercial buzzer, acts as both actuator and pump membrane. The pump chamber is defined by the piezodisc and a second PMMA plate, having two access holes for inlet and outlet. The next two layers are two identical SU-8 check valve discs, whose design and fabrication are discussed in the next section. The PMMA parts are fabricated with conventional cutting and milling techniques. The 6 layers are fixed with 4 bolts. The assembled device is shown in Fig. 2.

This assembly concept combines different fabrication techniques. While precision elements such as check valves are fabricated with photolithography of SU-8, others can be fabricated with conventional techniques such as cutting, milling.

## 3. Design and Fabrication of the SU-8 Check Valves

### 3.1. Design

Fig. 3 depicts the geometry parameters of the SU-8 disc. The disc is 100  $\mu\text{m}$  thick and has a diameter of 10 mm. The check valve consists of a 1-mm circular plate suspended on 4 folded springs. The spring design is called the compliant orthoplanar spring [5]. The valve springs are folded beams with a cross section of 100  $\mu\text{m} \times 100 \mu\text{m}$ . The circular hole next to the spring structures works as a spacer for the check valve on the other SU-8 disc as shown in Fig. 1.

Fig. 4 shows the simulation results of FEM analysis with ANSYS. Because of the relatively low Young's modulus, a drag pressure of 1 mbar is able to displace the valve disc by 3  $\mu\text{m}$ . The hole on the SU-8 disc works as a spacer, which limits the maximum deflection to 100  $\mu\text{m}$ . The small deflection assures the linear spring behavior, Fig. 4.

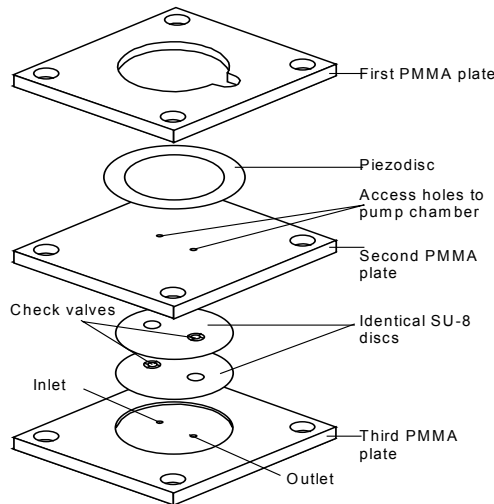


Fig. 1. Stacked concept of the micropump.

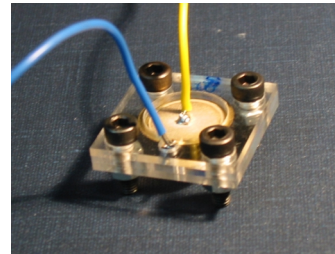


Fig. 2. The assembled micropump.

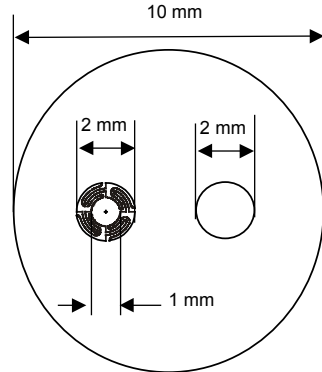


Fig. 3. Geometry of the SU-8 disk containing the valve and a hole.

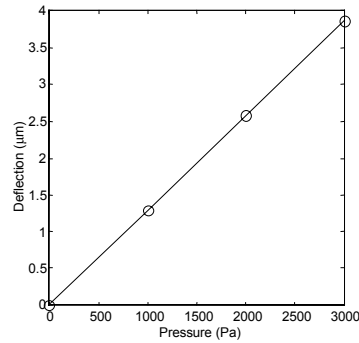


Fig. 4. Deflection of the valve disc versus applied drag pressure.

### 3.2. Fabrication

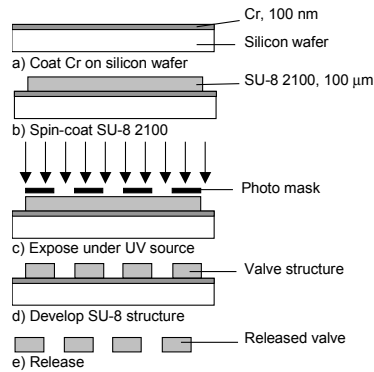


Fig. 5. Fabrication process for the SU-8 check valve.

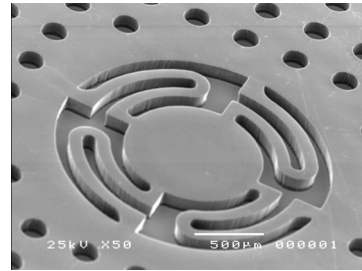


Fig. 6. The fabricated SU-8 check valve.

The SU-8 valves were fabricated with polymeric surface micromachining technique [1]. First, SU-8 was directly coated on a silicon wafer. After developing and hard bake, the SU-8 part was released by dissolving the silicon wafer in a 30% KOH solution. This method requires etching time up to 10 hours, causing curling of the SU-8 disc and difficulties in the subsequent assembly process.

To avoid the long etching time, a 100-nm thick chromium layer was sputtered on the silicon wafer acting as the sacrificial layer. SU-8 was then coated and developed. The valve was released by chromium etchant in 2 hours. Access holes in the SU-8 disc helped to reduce etching time and to arrest microcracks. The process is depicted in Fig. 5.

### 4. Characterization Results

The pump was characterized using a simple setup described in a previous paper [6]. The pump was tested with DI water. Fig. 7 shows the flow rates versus the actuating frequencies at different peak voltages and Fig. 8 shows the flow rates versus back pressures. The pump characteristics are similar to those of diffuser/nozzle pumps using the same type of piezodisc as actuator [6]. However, for the same peak voltage, the SU-8 check valve mi-

cropump achieves twice the flow rates, and half the back pressures of the diffuser/nozzle pump [6]. Thus, the two pumps, using similar actuator, deliver almost the same pump power, which is calculated as,

$$P_{\text{pump}} = 0.5 \times p_{\text{max}} \times Q_{\text{max}}, \quad (1)$$

where  $P_{\text{pump}}$  is the pump power,  $p_{\text{max}}$  and  $Q_{\text{max}}$  are maximum back pressure and maximum flow rate, respectively.

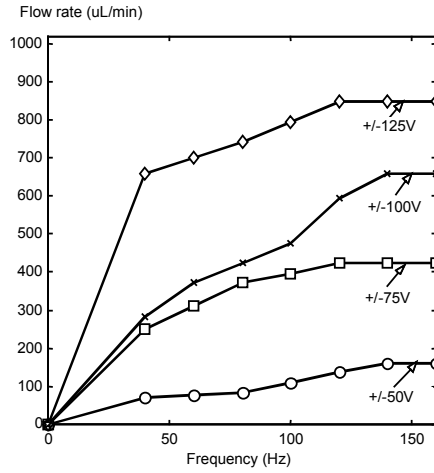


Fig. 7. Flow rates versus frequencies.

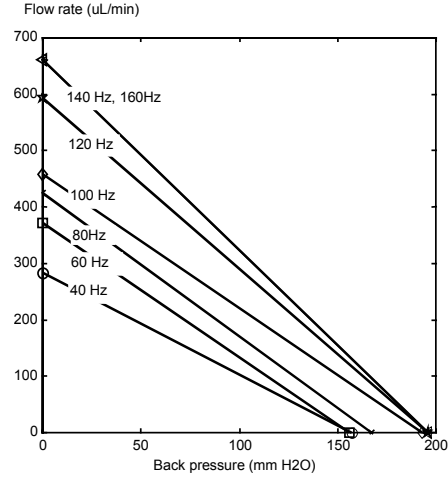


Fig. 8. Flow rates versus back pressures ( $V = \pm 100V$ ).

## 5. Conclusion and Future Works

We have designed, fabricated and characterized a piezo-actuated polymeric micropump, in which the two SU-8 check valves are the key components. The other parts are machined with conventional techniques. The pump achieves flow rates and back pressure up to 1 ml/min and 200 mm water, respectively. It works with voltage as low as 50 volts. To further reduce material cost, assembly cost, and device size, we are working on lamination techniques to assemble the pump.

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