Supporting Information

Squeeze-chip: A finger controlled microfluidic flow network device and its application to biochemical assays

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1. Supporting Experimental Section

Chip fabrication. High-resolution transparency masks (Feiling Feida, Beijing, China) for each layer were printed according to the layout design. The patterns were transferred to a silicon wafers with SU-8 2050 photoresist (MicroChem, USA) by photolithography. The photoresist was spin-coated on the wafers at 3000 rpm for 1 min, resulting a ~ 50 mm thick film. PDMS (RTV 615, GE Advanced materials, CT, USA. A:B=5:1, 4mm) was casted onto the photoresist mold followed by curing in an oven at 80 ^{o}C for 15 min. PDMS slabs were peeled off to get the top layer and the bottom layer. The thin PDMS membrane was made by spin-coating a procured PDMS mixture (RTV 615, A:B=20:1, 1000 rpm for 1min) on a plastic transparency sheet, and curing in at 80 ^{o}C for 15 min. The pressure-balance holes in the membrane were punched using a biopsy puncher (2 mm in diameter). Punching was guided through the patterns on the plastic transparency sheet. To make sure holes in the membrane layer were far from main channels to prevent leaking, we designed branched channels and punched on the branched channel, as in Fig. 3a. When hole punching is finished, the bottom layer and the membrane were bonded by curing at 80 ^{o}C for 20min. We then peeled off this bonded monolithic piece from the plastic sheet (Fig. S1a, step 1a), and punched holes in the top layer (Fig. S1a, step 1b). These two pieces of PDMS slabs were covered with physical masks made from two other PDMS slabs with holes for exposing the gap positions of the valves (Fig. S1a, steps 2a and 2b). We treated the PDMS slabs with masks in air plasma (power ~ 4W, Model PR-4, Chuangweina, Beijing, China) for 20 min and then removed the PDMS masks (Fig. S1a, step 3). Finally, the three layers were aligned (Fig. S1a, steps 4a and 4b) to form the whole device completely by curing at 80 ^{o}C for 2 h (Fig. S1a, step 5). For the squeeze chips,

bigger holes (5~10 mm in diameter) were punched in the top layer to form the reservoirs.

Plasma treatment of PDMS surface. The structure of a check valve was presented in Fig. S1b. the interface between the top layer and the thin membrane had been processed so that the two could not be bonded at that part. The whole device is a monolithic piece after bonding, as shown in Fig. S2, except the pre-treated part that was not bonded. This unbonded part of the membrane, well attached to the break point of the upper channels when no forward pressure is applied, is the most critical part of the check valve. Through a small hole in this membrane, the upper channel and the lower channel are connected. This tunnel balances the pressures between the outlet port and the lower channel. When the liquid is driven forward (Fig. S2a,b) the membrane will deflect downward to open the valve, while driven backward (Fig. S2c,d) the membrane will deflect upward and block the liquid flow. The surface modification has been realized by a longtime air-plasma treatment using masks (made by PDMS) to protect the untreated region. Extremely overdosed oxygen plasma treatment would destroy PDMS surface's flatness, generate cracks, and make the material crispy and fragile (Fig. S3). To bond two PDMS blocks, we usually treat two PDMS surface with 4W air plasma for 30 sec. When the treatment lasts more than 2 min, the bonding strength will dropped quickly. When the treatment lasts more than 10 min, nanometer-size cracks start forming on the surface, making it not bond to each other.

Performance test of check valves. We designed check valves with different gap length and channel width. The valves were linked to compressed air with Tygon tubing. The pressure of compressed air was controlled with a needle-valve. We applied pressure from 1 to 10 psi to the inlet of each passive valve, and collect the DI water passed valves within 1 min. All the tubes were in the same height level to make sure no extra pressure difference between inlet and outlet. Each data in Fig S4a is the mean from three different devices with identical values of L and M.

Performance test of the squeeze-pumps. The performance of the pump was tested with a homemade apparatus shown in Fig. S5. A stepped motor was used to drive a post to push/squeeze the pump. The diameter of the reservoir is 10 mm and the height is 3 mm. The inlet and outlet of a pump were connected to water containers with Tygon tubing. The liquid levels in both containers were kept the same. We use a computer to control the squeezing displacement, frequency, and dwell time of each action. We squeezed and released the pump for 100 times and collect the water passed through the pump. Each data in Fig. S4b is obtained from three independent measurements. During the measurement, we drove out all air bubbles from the channels and the reservoir to avoid the affection from different compressibility between air and water.

Glucose and uric acid detection. Glucose and uric acid were purchased from Alfa Aesar. The test kits for glucose and uric acid were purchased from Beijing shouyi clinical scientific center. The kit includes phosphate buffer, 4-amino-antipyrine, uricase, 2,4,6-tribromo-3-hydroxy acid, peroxidase, and stabilizers. The uric acid reaction was based on an uricase end-point method. This

solution-based reaction generates hydrogen peroxide that can be further converted to chromophore with the help of peroxidase. The similar principle has also been applied to the chromogenic reactions for test glucose. The hydrogen peroxide produced from glucose by glucose oxidase action will lead to chromophore formation.

2. Supporting Figures

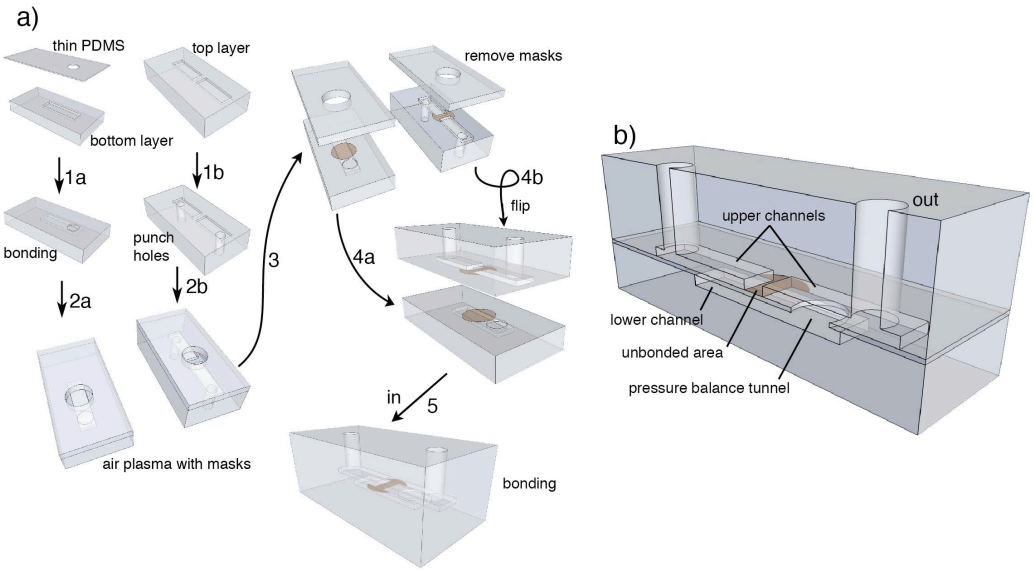


Fig. S1 The monolithic PDMS check valves. a) Fabrication of a check valve. b) Structure of a check valve. A deformable membrane section, created by oxidization of the PDMS surface through air plasma treatment, is the key component of the valve.

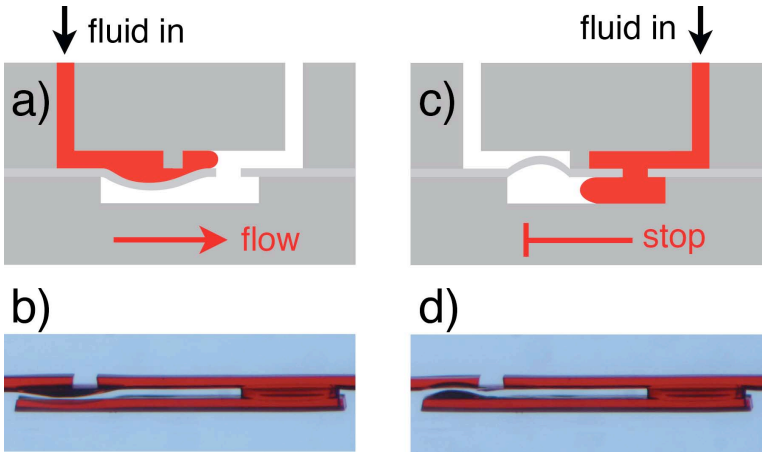


Fig. S2 The function of a monolithic PDMS check valve. a) The valve status under forward hydrodynamic pressure (side view). The valve is open for forward direction (left to right). b) The microscopic photograph of a valve under forward pressure. The channels are filled with red solution and the deformation of the thin PDMS membrane is clearly observed. c) The valve status under backward hydrodynamic pressure (side view). The valve is closed for backward direction (right to left). d) The microscopic photograph of a valve under backward pressure.

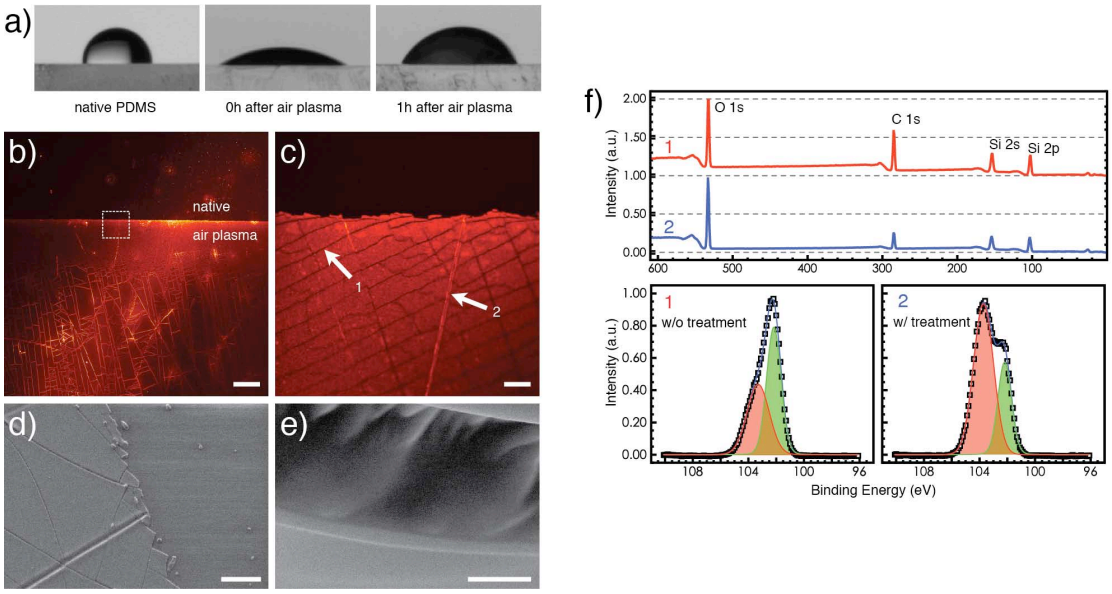


Fig. S3 Surface deactivation of PDMS. a) Contact angels of PDMS surface before and after air plasma treatment. b) Confocal image of the PDMS surface, with and without air plasma treatment. We stain the PDMS by soaking a slab in Rhodamine B solution. Scale bar is 100 μm. c) The high magnification image shows the cracks with different width (arrows). Scale bar 10 μm. d) and e) are SEM pictures of the cracks on PDMS surface. Scale bars 15 μm and 250 nm, respectively. f) XPS spectra of PDMS surfaces before (1) and after (2) the air plasma treatment. The fitted results of the Si 2p peaks show the composition of silica (red) and polymer (green) forms.

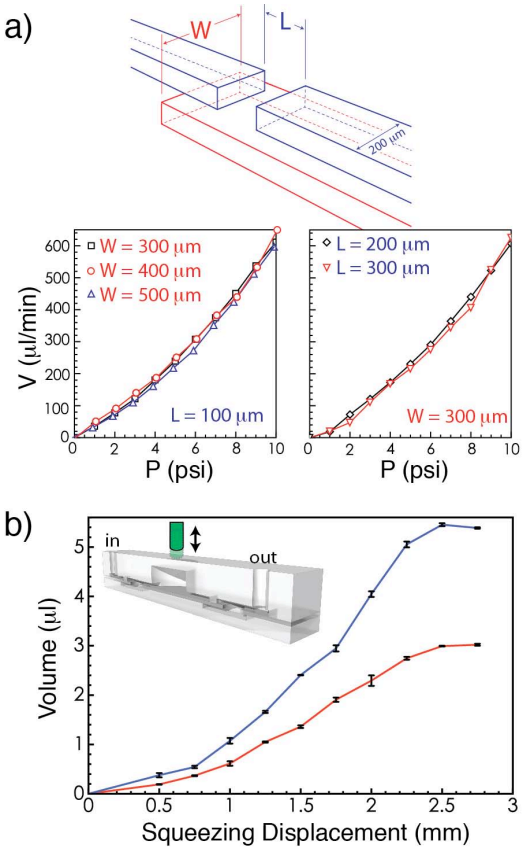


Fig. S4 a) The flow velocity of water through the valves is not sensitive to structure variation. b) Volume per squeeze measured from a chip (reservoir is 1 cm in diameter and 3 mm thick). 1s dwell time between the squeezes (blue line) offers better pump efficiency than continuous squeezes (red line).

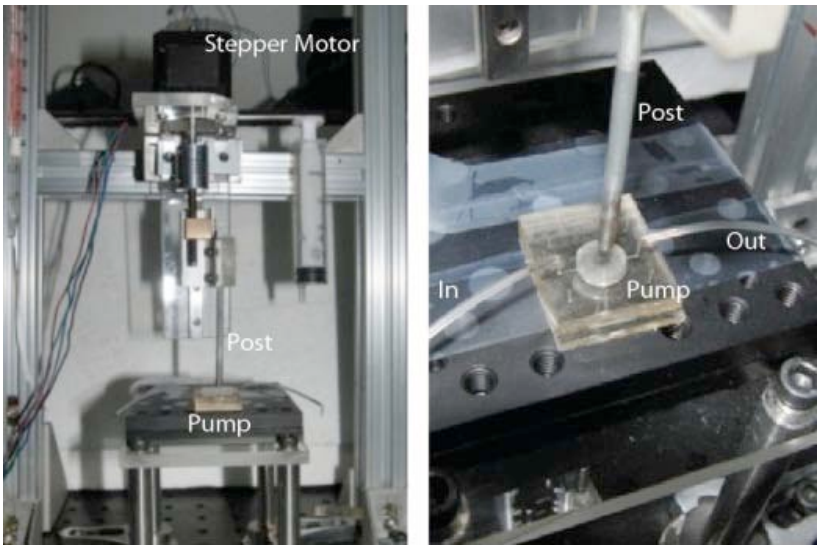
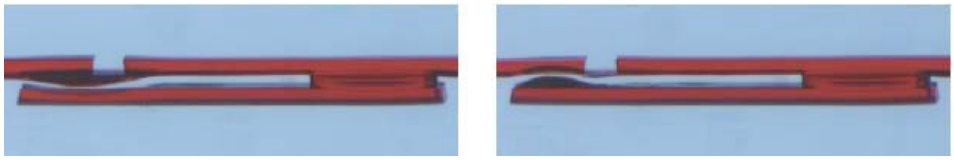


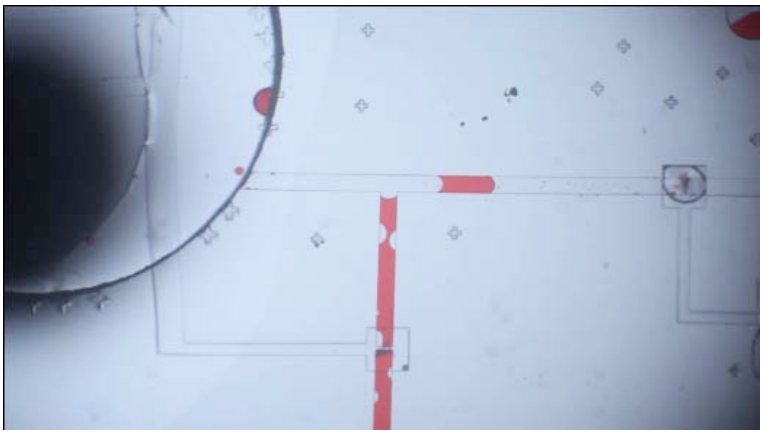
Fig. S5 The homebuilt apparatus for performance test of a pump. A computer was used to control the stepper motor, which drove the dome-headed post to push the chip. The diameter of the metallic post is 2mm, and the squeezing/releasing speed is 1.2 mm/s.

3. Supporting Movies

(1) Side view of the open and close statuses of a check valve under the forward and backward pressures, respectively.



(2) Nanoliter range aqueous plugs (red) are transferred by squeezing an oil-filled reservoir (left) connected with two check valves through a T-junction (also see Fig. 4b).



(3) Operation of a squeeze chip. Dyes are used to demonstrate the liquid flow driven by the pump actuations.