Electronic Supplementary Material (ESI) for Lab on a Chip


# Electronic Supplementary Information

## Unveil the Missing Transport Mechanism inside the Valveless Micropump

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## Materials and Methods

To make clear flow visualization inside the micropump, the experimental model was scaled up. The chamber diameter of micropump was magnified to be 25mm and the corresponding Reynolds number (at throat of rectifier) was kept less than 1 in this study. The experimental system is shown in **Fig. S1(a)** and includes mainly four parts: (I) Main body, (II) PZT driving subsystem, (III) Flow visualization subsystem and (IV) Flow measurement and data acquisition subsystem.

(I) Main body of micropump:

The main body has a sandwich structure that was made from three transparent Plexiglas (PMMA) plates, as shown in **Fig. S1(b)**. At the top is the cover layer of 1 mm in thickness. The microchannels, including one vibrator chamber and a pair of nozzle/diffuser, were in the middle layer (1 mm in thickness). The bottom plate has thickness of 0.175mm. The PMMA plates were fabricated by a laser engraving system (LaserPro Mercury II 25W, with 1000 DPI resolution) and then firmly bonded together. The PZT-plate (Eleceram, 20mm-diameter- and 200 μm-thick-PZT material on a 25 mm- diameter- and 200 μm-thick-bronze plate) was carefully fixed on the bottom layer of test model. Two Polypropylene tubes (10cm-long, 2mm-outer diameter and 1mm-inner diameter) were then connected to the inlet and outlet of micropump at the bottom plate, respectively. Detailed parameters of the micropump model can be found in **Fig. S2** and **Table S1**.

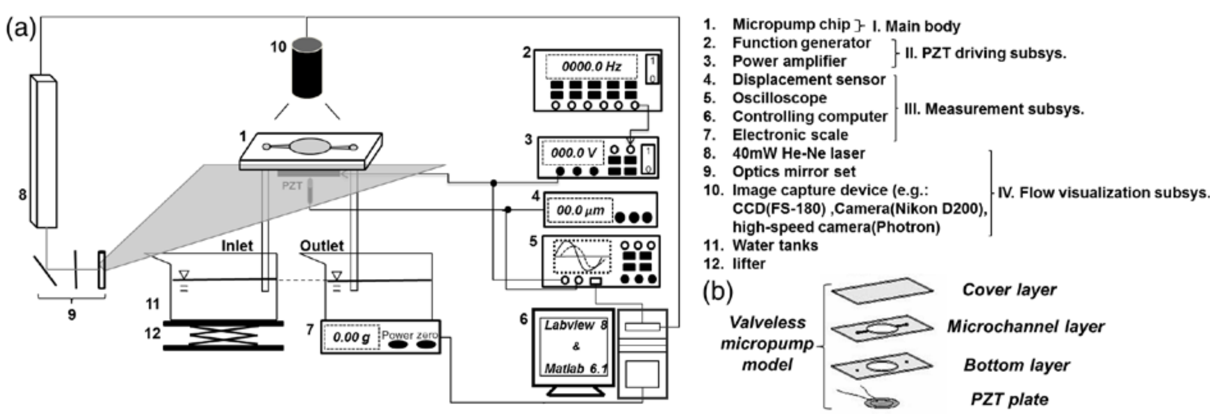


**Fig. S1 (a)** Experimental setup, **(b)** Exploded view of micropump main body & PZT plate

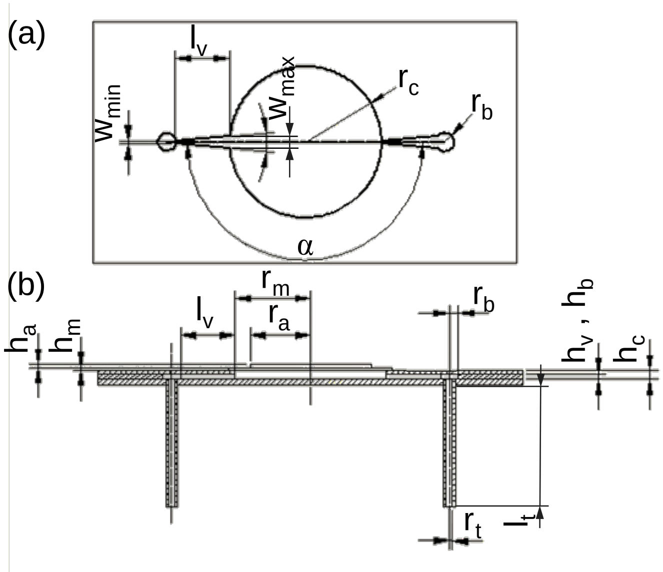


**Fig. S2** Characteristic parameters of micropump design **(a)** Top view and **(b)** Side view.

**Table S1** Parameters of valveless micropump

| Component | | Nomenclature | Value (in SI unit) |
|---|---|---|---|
| Membrane & Actuator (PZT) | Membrane radius | $r_m$ | $1.35*10^{-2}$ m |
| | Membrane thickness | $h_m$ | $2*10^{-4}$ m |
| | Density | $\rho_m$ | $8.4*10^3$ kg/m$^3$ |
| | Actuator density | $\rho_a$ | $7.7*10^3$ kg/m$^3$ |
| | Actuator radius | $r_a$ | $1*10^{-2}$ m |
| | Actuator thickness | $h_a$ | $2*10^{-4}$ m |
| Chamber | Chamber height | $h_c$ | $1.175*10^{-3}$ m |
| | Chamber radius | $r_c$ | $1.25*10^{-2}$ m |
| Rectifier | Valve length | $l_v$ | $9*10^{-3}$ m |
| | Valve minimum width (throat) | $w_{min}$ | $5*10^{-4}$ m |
| | Valve maximum width | $w_{max}$ | $2.04*10^{-3}$ m |
| | Valve height | $h_v$ | $1*10^{-3}$ m |
| | Diffuser/nozzle angle | $2\theta$ | $10^o$ |
| | Intersection angle | $\alpha$ | $180^o$ |
| Buffer | Buffer radius | $r_b$ | $1.5*10^{-3}$ m |
| | Buffer height | $h_b$ | $1*10^{-3}$ m |
| Tube | Tube length | $l_t$ | $1*10^{-1}$ m |
| | Tube inner radius | $r_t$ | $5*10^{-4}$ m |
| Working fluid | fluid density (water) | $\rho_f$ | $1*10^3$ kg/m$^3$ |
| | Water dynamic viscosity | $\mu$ | $1*10^{-3}$ m$^2$/s |

(II) PZT driving subsystem:

A function generator (NF, WF1946B) and a power amplifier (Kaohn-Hite Corp., Model 7602M) were utilized to supply the periodic signal and driving voltage for the piezoelectric actuator.

(III) Flow visualization subsystem:

Distilled water was used as the working fluid with added seeding particles (Dantec, 50μm diameter and 1.03 g/cm$^3$ density). To get long-time exposed pathlines of the flow field (actually seeded particles) inside the micropump, a camera (Nikon, D200) was utilized, the illuminating light sheet was generated by a He-Ne laser (Spectra Physics, 40mW) through a specially designed mirror set and one second exposure time was commonly used. A high speed camera (Photron, Fastcam 10K) and a higher power (1,000 mW) diode laser (UrMap, 532 nm wavelength) were used to catch the instantaneous images of pathlines for further analysis. The frame rate was 1,000 fps and exposure time was 1/1,000 second. A particle tracking analysis program by Matlab 7.1 and MatPIV6.1 was used to analyze the flow field inside the micropump. The image size was 240×256 pixels and interrogation window was set as 32×32 pixels with 50% overlap.

(IV) Flow measurement and data acquisition subsystem:

To minimize the appearance of microbubbles in the microfluidic channels to influence experimental repeatability, the carbon dioxide priming method[17] was adopted to fill the channels before the working fluid was pumped into the system. The net flowrate ($Q_{net}$) was measured by an electronic micro-balance (Mettler, PBS3002-fact, accuracy: 0.01g) based on the weight change of outlet container within the measuring period. Typically three minutes was measured by using a stopwatch. Instantaneous weight variation was also recorded in computer for further analysis. Besides, the displacement of PZT actuator was measured by a capacitance displacement sensor (JDC-III, with 0.01μm accuracy, 5‰ linearity and 0~2.7 kHz dynamic range). The data sampling rate of digital oscilloscope (Agilent, DSO6A052) was 1000Hz.