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PASSIVE CONTINUOUS PARTICLE FOCUSING IN A MICROCHANNEL WITH SYMMETRIC SHARP CORNER STRUCTURES

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ABSTRACT
We report a continuous passive particle focusing method using a novel microchannel with symmetric sharp corners which induce curved streamlines and large centrifugal force on particles. At appropriate flow rate, the centrifugal force generated on particles exceeds the inertial lift force; particles driven by the centrifugal force migrate toward the center of the microchannel, achieving continuous particle focusing. With simple structure and operation, this method can be potentially used in particle focusing and extraction processes in a variety of lab-on-a chip applications.

KEYWORDS: particle focusing, sharp corner, inertial force, centrifugal force, microfluidic

INTRODUCTION
Particle focusing is important for flow cytometry and fluorescence-activated cell sorting where suspended particles are needed to be focused into a tight stream before subsequent detection and sorting [1]. In comparison with the active focusing methods, passive methods require no external force; hence they need less power consumption, and have simpler structures. To date most existing passive methods typically have low throughputs (<4µL/min) because of the use of laminar flows [2]. In addition, particles cannot be sufficiently focused in a narrow steam [3], making the device unsuitable for the subsequent applications. In this paper, we report a new microchannel with symmetric sharp corner structures, which enables efficient particle focusing in a narrow stream at a flow rate of 240µL/min.

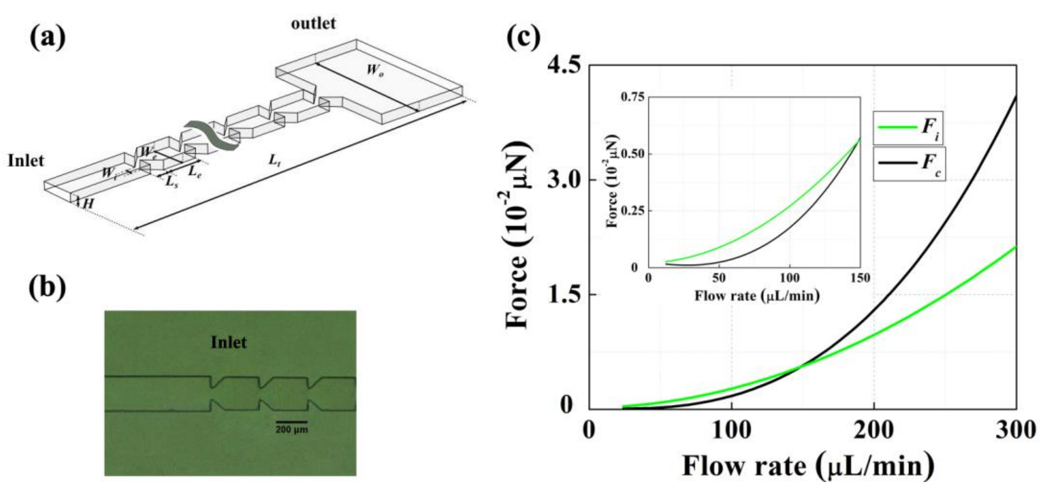

Figure 1: (a) Schematic diagram of the present microchannel with repeated symmetric sharp corner structures. (b) Microscopic pictures showing sharp corner structures. (c) Dominant forces exerted on 7.32µm particles at flow rates ranging from 20 to 300µL/min.

THEORY
The present microchannel is illustrated in Figure 1a and 1b, and the calculated major forces exerted on particles are shown in Figure 1c. The inertial lift force (F_i) drives particles toward the side equilibrium positions near the channel walls while the centrifugal force (F_c) drives particles toward the center. When the low flow rate is lower than ~150µL/min, the centrifugal force is smaller than the inertial lift

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force (shown in Figure 1c); particles migrate toward the two side equilibrium positions near walls. When the flow rate is higher than ~150µL/min, the centrifugal force exceeds the inertial lift force (shown in Figure 1c); particles will be centrifuged to the center of the channel, achieving particle focusing in a narrow stream at an appropriate flow rate. In comparison with the multi-orifice microchannel [3], the sharp corners induce more curved streamlines and larger centrifugal force on particles, which will efficiently focus particles in a narrower stream.

EXPERIMENTAL

The present microchannel was made up of polydimethylsiloxane (PDMS) and glass, fabricated with standard soft lithography techniques. 100 segments of repeated symmetric sharp corner structures were designed in the microchannel. The inlet width between the two symmetric sharp corner structures (W_i) is 40-45µm. The length of sharp corner structures in the flow direction (L_s) is 80µm. The length (L_e) and the width (W_e) of the expansion structure are both 200µm. At the channel outlet, the width of the microchannel expands to 800µm to observe particle separation behaviors. The height of the microchannel is 50µm. Fluorescent polystyrene particles 7.32µm (FS06F/9559, Dragon green, 480/520nm) in diameter were used in the experiments (Bangs Laboratories, Inc.). The sample was injected into the microchannel using a syringe pump (KDS LEGATO270; KD Scientific Inc.) equipped with a 10mL BD syringe at flow rates ranging from 40 to 260µL/min. An inverted optical microscope (IX-71, Olympus Co.) and a mono color CCD camera (Qimaging fast 1394, Qicam) were used to capture the images of particle trajectories. For clarity, green color was added to the captured images.

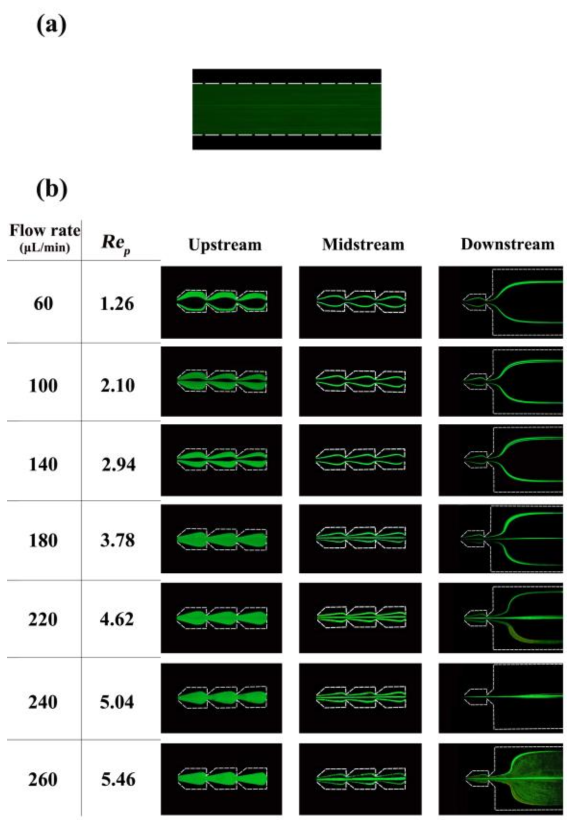

Figure 2: Fluorescence images showing particle distributions in the microchannel at various flow rates. (a) The inlet distribution of particles in the microchannel at the flow rate of 140µL/min. (b) Particle distributions at upstream, midstream and downstream of the microchannel at various flow rates from 60 to 260µL/min.

RESULTS AND DISCUSSION

Figure 2a shows 7.32μm particles were randomly distributed at inlet of the present microchannel at the flow rate of 140μL/min. Note that the inlet distributions of particles at various flow rates used in the experiments were similar. When the flow rate ranged from 40μL/min to 140μL/min (particle distribution at the flow rate of 40μL/min is not shown here), the inertial lift force is larger than the centrifugal force; particles driven by the inertial lift force migrate toward the two side equilibrium positions (Figure 1c), generating two particle streams at the outlet of the microchannel (shown in Figure 2b). When the flow rate further increased to the range from 160μL/min to 220μL/min (particle distribution at the flow rate of 160μL/min is not shown here), three particle streams were generated at outlet of the microchannel (shown in Figure 2b) because of the increase of the centrifugal force; some particles originally located near the center were centrifuged toward the center, generating the third particle stream.

At the flow rate of 240μL/min, all 7.32μm particles driven by the strong centrifugal force were focused at the center of the present microchannel in a narrow stream (shown in Figure 2b). The tightly focused particle stream at the center is suitable for the subsequent particle detection and sorting. When the flow rate increased to 260μL/min (shown in Figure 2b), the focused particle stream at the center was broken due to the turbulence induced at high flow rate in the microchannel with contraction and expansion structures [3].

CONCLUSION

A microchannel with a series of symmetric sharp corner structures for particle focusing was tested with 7.32μm fluorescent polystyrene microparticles at various flow rates from 40 to 260μL/min. Based on the inertial lift force and the centrifugal force, particles were focused in two streams at the flow rate from 40 to 140μL/min, and in three streams from 160 to 220μL/min. All particles were tightly focused at the center of the designed microchannel with a small bandwidth at a flow rate of 240μL/min. The tightly focused particle stream is beneficial for a variety of lab-on-a-chip applications, such as flow cytometry and high-throughput particle/cell extraction.

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