Fall 10-26-2014

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Recommended Citation

Fan, Liang-Liang; He, Xu-Kun; Han, Yu; Du, Li; Zhao, Liang; and Zhe, Jiang, "A New Microfluidic Device For Complete, Continuous Separation Of Microparticles" (2014). *Mechanical Engineering Faculty Research*. 1010.
http://ideaexchange.uakron.edu/mechanical_ideas/1010

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A NEW MICROFLUIDIC DEVICE FOR COMPLETE, CONTINUOUS SEPARATION OF MICROPARTICLES

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ABSTRACT

A microchannel with symmetric sharp corners is reported for particle separation, based on the interplay between the inertial lift force and the centrifugal force induced by sharp corners. At an appropriate flow rate, the centrifugal force is larger than the inertial lift force on large particles, while the inertial lift force is dominant on small particles. Hence large particles are centrifuged to the center, while small particles are focused at side streams, achieving complete particle separation. The device requires no sheath flow, avoiding the dilution of analyte sample and complex operation, and can be potentially used for many lab-on-a-chip applications.

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

INTRODUCTION

Separation of micro particles in suspension, such as cell separation, has been a critical task in many important areas including biomedical research, food industry and clinical applications. Passive particle separation methods have attracted many attentions because of the advantages of requiring no external force field, low power consumption, simple structures and simple fabrication. However, most passive separation methods have low throughput and low separation efficiency [1-3]. The present device, containing a series of repeated symmetric sharp corners, enables complete particle separation at a relatively large flow rate, based on the inertial lift force and the centrifugal force induced by the sharp corners.

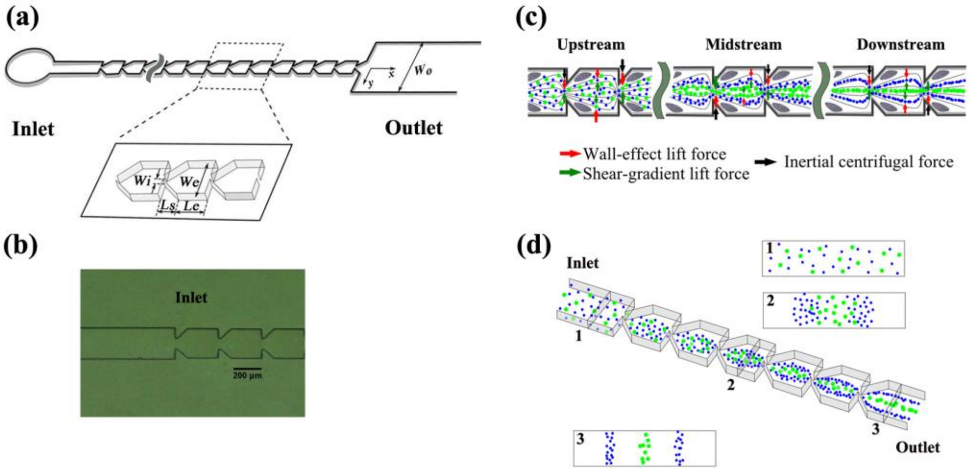

Figure 1: (a) Schematic diagram of the microchannel with symmetric sharp corner structure. (b) Microscopic picture of sharp corner structures. (c) Dominant forces exerted on the suspended particles. (d) 3-D illustration of particle separation in the present microchannel.

THEORY

The present microchannel is shown in Figure 1a and 1b, and its working principle is illustrated in Figure 1c and 1d. In the present microchannel, micro particles are subjected to the two major forces, *i.e.* the inertial lift force (F_i, driving particles toward the side equilibrium positions near the walls) and the centrifugal force (F_c, driving particles toward the centerline). At low flow rates, the centrifugal force is weak; particles tend to migrate toward the two side equilibrium positions near the channel walls. At high flow rates, the centrifugal force becomes large due to high flow velocity; particles are centrifuged to the center of the channel. At the same flow rate, the centrifugal forces on large particles are stronger than those on small particles. Therefore by selecting an appropriate flow rate, large particles are eventually focused at the center of the microchannel and small particles are focused in the two side equilibrium positions. In comparison with the microchannel with contraction and expansion structures [2, 3], the sharp corners induce more curved streamlines and larger centrifugal forces on particles. As a result, complete particle separation can be achieved in the present microchannel.

EXPERIMENTAL

The present microchannel for particle separation was fabricated using standard soft lithography techniques. It consists of 100 segments of repeated symmetric sharp corner structures. 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 outlet of the channel, the width of the microchannel is designed to be 800µm to observe particle separation. The microchannel has a uniform height everywhere (50µm). Fluorescent polystyrene particles 7.32µm (FS06F/9559, Dragon green, 480/520nm) and 15.5µm (FS07F/9277, Dragon green, 480/520nm) in diameter were used in the experiments (Bangs Laboratories, Inc.). The solutions were individually 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 160µL/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. The images of 7.32 and 15.5µm particle at outlet of the present microchannel were merged together to obtain the particle separation images. Experiments were also conducted by mixing the 7.32 and 15.5µm particles in bright light field at selected flow rate to demonstrate the particle separation.

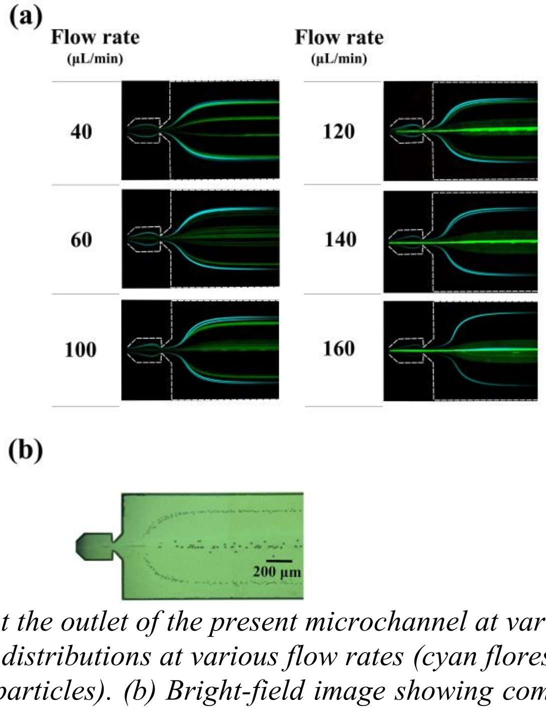

Figure 2: Particle separation at the outlet of the present microchannel at various flow rates. (a) Fluorescence images showing particle distributions at various flow rates (cyan florescence for 7.32µm particles, green florescence for 15.5µm particles). (b) Bright-field image showing complete particle separation at the flow rate of 140µL/min.

RESULTS AND DISCUSSION

Figure 2a shows 7.32 and 15.5μm particles were partly separated at the outlet of the present microchannel when the flow rate ranged from 40 to 120μL/min. When the flow rate was low (from 40 to 120μL/min), centrifugal forces induced by the sharp corner structures were not sufficient enough to push all 15.5μm particles toward the center of the microchannel; hence 15.5μm particles were distributed with a wide bandwidth.

The complete particle separation was achieved at the flow rate of 140μL/min (shown in Figure 2a). All the 15.5μm particles were focused in one single stream at the center while small particles were still focused at two side streams. This is because at this flow rate, the centrifugal force is larger than the inertial lift force on large particles, while on small particles, the inertial lift force is still dominant. Hence after passing a series of symmetric sharp corner structures large particles were completely focused at the center under the strong influence of centrifugal force while small particles mainly driven by the inertial lift force were located at two side equilibrium streams due to the dominance of the inertial lift force. The bright-field image of the complete particle separation at the flow rate of 140μL/min is shown in Figure 2b. The result demonstrated that using the microchannel with a series of symmetric sharp corner structures, two-size particles can be completely separated and collected at the outlet of the microchannel.

When the flow rate was increased to 160μL/min or higher (shown in Figure 2a), some small particles moved to the center of the present microchannel due to the increase of the centrifugal force, causing the mixing of the two types of particles; the complete particle separation becomes infeasible.

CONCLUSION

A microchannel with repeated symmetric sharp corner structures for passive microparticle separation was designed and fabricated. At appropriate flow rate (140μL/min) and Reynolds number (*Re*= 51.8), 15.5μm particles were focused at the center of the microchannel while 7.32μm particles were focused at two side particle streams, achieving complete particle separation. No sheath flow is required, avoiding the dilution of analyte sample and complex flow control. With these advantages, this passive particle separation device can potentially benefit a variety of lab-on-a-chip applications.

ACKNOWLEDGEMENTS

This study was supported by the National Natural Science Foundation of China (No.: 51128601) and the Fundamental Research Funds for the Central Universities (No.: xjj2014114). J. Zhe and Y. Han acknowledge the partial support from National Science Foundation of USA via the research grants CMMI-1129727 and ECCS-1200032.

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