CONTINUOUS SEPARATION OF PARTICLES USING INERTIAL LIFT FORCE AND VORTICITY VIA MULTI-ORIFICE MICROCHANNEL

Jae Sung Park and Hyo-il Jung
Yonsei University, South Korea

ABSTRACT
This paper describes a microfluidic separation of particles through hydrodynamic lateral forces exerted on particles migrating along a non-circular microchannel. The mechanism of separation is based on the combined use of inertial lift force and turbulent secondary flow generated in a topographically patterned microchannel.

KEYWORDS: Microfluidics, Separation, Microchannel, Hydrodynamic force

INTRODUCTION
Recently, a few hydrodynamic methods for particle separation were reported under a pinched flow condition [1], a 3-D flow motion [2] and Dean flow [3]. The hydrodynamic method is very useful for a high throughput and continuous separation. Here, we present a new scheme of particle separation using an inertial lift force and a turbulent flow generated in a multi-orifice microchannel. Our method is different from the previous works in the specific application of the secondary vortex flow and in the geometry of the microchannel design.

THEORY
This microfluidic separation is based on the hydrodynamic forces which are composed of wall effect and inertial lift force. The former induces particles to move away from walls and the other causes a lateral migration from a centerline in the Poiseuille flow (Fig. 1a). These forces make particles distributed in a shape of tube in a normal straight channel. In addition, we use a multi-orifice microchannel to make a change in the tubular particle distribution. The topographically patterned channel generates a vorticity in each expansion region and causes particles experiencing the secondary turbulent flow (Fig. 1b). All particles are laterally focused at two positions in the outlet channel as if they look like two bands (Fig. 1c).

EXPERIMENTAL
The microchannel is fabricated using usual soft-lithography techniques, i.e., rapid prototyping of master, PDMS replica molding and plasma bonding. Dry polymer microspheres (No. 35-2, Duke Scientific Corp.) are used for this experiment, which are made of polystyrene divinylbenzene (PS-DVB) and have a density of 1.05 g/cm$^3$ and the measured mean diameter of about 7 μm. We made two different shapes of microchannel, i.e., a straight square channel (width: 40 μm) and a multi-orifice channel (contraction: 40 μm and expansion: 200 μm). The particle image can be captured using a high speed CCD camera with a frame rate of 500 fps and a shutter speed of 1/10,000 sec, which is mounted on an inverted optical microscope.
RESULTS AND DISCUSSION

Figure 2 shows the various patterns of particles distribution obtained with a straight square channel. We found that the square channel longer than 1.5 mm could generate a particle focusing using the high inertial lift forces. But the straight channel could not avoid the existence of particle in the central region of outlet channel. Figure 3 illustrates that microspheres migrate through a multi-orifice microchannel with a flow rate of 100 μL/min. Note that the microspheres at the inlet are distributed randomly across the cross-section of the channel. As particles travel through orifices, the paths of particles are laterally and symmetrically focused on both sides of the microchannel. The particle distribution is influenced by the inertial lift force and the secondary turbulent flow simultaneously. We studied the effect of flow rate on focusing in the multi-orifice microchannel. Figure 4 shows the different particle distribution at the outlet of the multi-orifice channel according to various Reynolds numbers. From these images, we found that the most effective particle focusing could be generated under Re ~ 30. The lower Reynolds number results in the wide band in focusing, and the higher Reynolds number makes a part of particles focused at both sides come back to the centerline of channel.

CONCLUSIONS

An axisymmetric geometry of multi-orifice microchannel induces particles to be ordered at the channel’s exit with relatively low Reynolds number of ~30. This hydrodynamic separation method has features in continuous, biocompatible and high-speed separation without using any external potential fields. It is expected that this method can be applied for the separation of biological sample like blood cells.
Figure 2. Different particle distributions generated by a microchannel system composed of planer inlet and outlet, and a straight square channel whose length varies as (a) 0.5mm, (b) 1mm, and (c) 1.5mm.

Figure 3. Particles are focused in a multi-orifice microchannel.

Figure 4. Influence of flow rate on the inertial focusing.

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REFERENCES