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Focusing and Sorting of Particles in Spiral Microfluidic Channels

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Abstract

We present a microfluidic device for focusing and separation applications of large particles exploiting inertial migration in curved microchannels. Due to the curvilinear geometry of the microchannel particles experience a combination of inertial lift and Dean drag forces causing a lateral equilibration at a position near the inner wall. Depending on the ratio of lift and Dean drag forces particles with different sizes occupy distinct equilibrium positions resulting in individual particle streams. For testing the principle, a 5 loop spiral microchannel was used. Channel width and spacing between successive loops were fixed to 500 μm and the height to 220 μm . To evaluate the device for sorting large insect cells, particle focusing and separation was carried out using fluorescently labeled 40 μm and 60 μm polystyrene beads.

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1. Introduction

Focusing and sorting of micro particles or biological cells in microfluidic systems for analysis applications is a process of great importance [1]. Various techniques employing external forces, such as dielectrophoresis, acoustic waves, and optical interference have been used on the microscale [2]. However, these techniques show integral limitation including modification of particles or cellular properties and reduced sample volumes due to the low operating flow rates [2]. Recently, high throughput passive particle separation based on inertial migration in curved microchannels has been described [3]. This method avoids the disadvantages of conventional techniques needing externally applied forces since only fluidic forces and particle size influence the particle separation. The reported technique was used to separate small to medium-sized particles with the largest diameter fixed to 20 μm [3]. In this paper, we applied a spiral microchannel for focusing and separation of a mixture of large-sized particles with a diameter of 40 μm and 60 μm .

2. Working principle

Due to inertial lift forces arising from the parabolic nature of the laminar velocity profile in a Poiseuille flow, suspended particles migrate across the streamlines to an equilibrium position away from the channel centre. They

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equilibrate into focused streams along the perimeter of the microchannel. For a low aspect ratio rectangular microchannel, the lift force defined by the channel height is dominant resulting in two laterally broad focusing positions at the top and the bottom of the microchannel [2]. Focusing of particles occurs for $a_p/D_h \geq 0.07$, where a_p is the particle diameter and D_h the hydraulic diameter ($D_h = 4A/P$ for a microchannel with cross-sectional area A and perimeter P) [3]. For rectangular microchannel geometry equilibration depends on the smallest channel dimension rather than on D_h . Therefore, the criterion for particles focusing is $a_p/H \geq 0.07$, where H is the channel height [3].

Adding curvature to the channel introduces a transverse Dean flow. This secondary rotational flow is perpendicular to the main flow direction and consists of two symmetric counter-rotating vortices in the top and bottom of the cross-sectional plane of the microchannel. Particles dispersed in a spiral microchannel experience a drag force introduced by these Dean vortices resulting in a movement along the Dean flow. Depending on the position in the microchannel particles migrate towards the inner wall or continue to flow along the Dean vortices. Near the inner wall inertial lift forces and Dean drag forces act in opposite directions leading to equilibration and focusing of particles into a single stream. Thus, the combination of inertial lift force and Dean drag reduces the equilibrium positions to a single one introducing a continuous inertial focusing [4].

Since the ratio of the lift force F_L to the Dean drag force F_D depends on particle size, particles with different diameter equilibrate at distinct positions resulting in a continuous separation of multi-sized particle mixture. Large particles equilibrate at a position close to the inner wall while small particles move away from it, see Fig. 1.

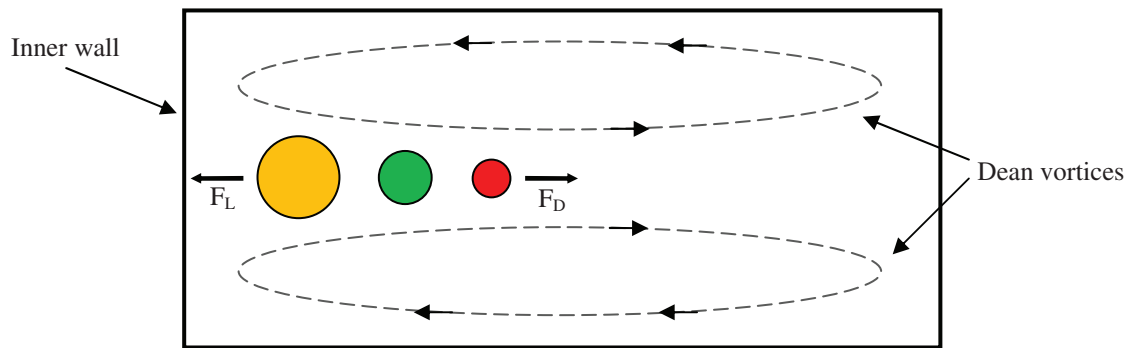


Fig. 1. Schematic cross-section of a curved microchannel illustrating focusing positions of particles of different size. Lift force F_L and Dean drag force F_D are highlighted.

3. Methods

3.1. Microchannel design and fabrication

The spiral design consists of a 5 loop microchannel with spacing of 500 μm between the successive loops. The channel width was fixed to 500 μm . The height was fixed to 220 μm to satisfy the criterion $a_p/H \geq 0.07$ for each particle size tested in this work. The outlet opened into a 1 mm wide segment and split into eight outlet ports where the particles streams were collected. The microchannels were fabricated in polydimethylsiloxane (PDMS) (Wacker Chemie AG, Germany) using standard soft lithography methods. A thick layer of SU-8 100 photoresist (Microchem Corp.) was structured to form a negative silicon master. Subsequently, PDMS polymer was cast onto the fabricated master wafer to replicate the microchannel features. After curing in convection oven at 60°C for 45 minutes, the PDMS molds were peeled from the silicon master and bonded to a glass slide using O_2 plasma pre-treatment. After each bonding process, the device was baked at 60°C for 2 hours. Input and output ports were pored using a syringe needle prior to bonding. Figure 2 shows the fabricated microchannel.

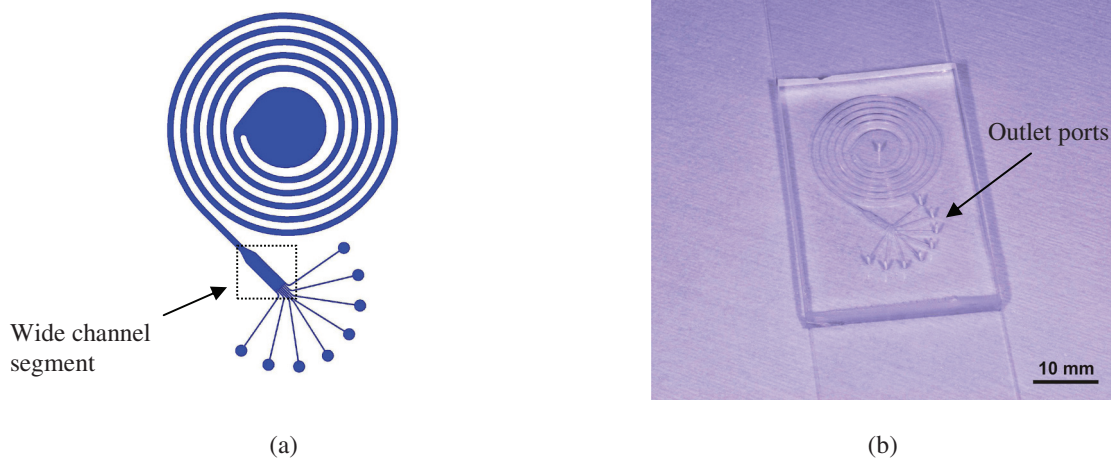


Fig. 2. Schematic of the spiral microchannel. The wide channel section prior to the outlet ports is highlighted; (b) Photograph of the spiral microchannel device fabricated in PDMS

3.2. Particle focusing

To demonstrate focusing and separation of large particles in the spiral microchannels fluorescently labeled polystyrene beads with a diameter of $40\ \mu\text{m}$ and $60\ \mu\text{m}$ were tested (microparticles GmbH, Germany). The particles were labeled with green and red fluorophores, respectively. A syringe pump LA-100 (Landgraf Laborsysteme GmbH, Germany) was used to pump the particle solution through the microchannel. To confirm particle focusing images at the microchannel outlet were captured using a fluorescence microscope (Axioplan 2, Zeiss) equipped with a CCD camera (AxioCam HR, Zeiss).

4. Results

To identify suitable flow rates for particle focusing in the spiral microchannel the two particle types were first tested individually. For both particles sizes $60\ \mu\text{m}$ and $40\ \mu\text{m}$ ($a_p = 60\ \mu\text{m} / H = 0.27$ and $a_p = 40\ \mu\text{m} / H = 0.18$, respectively), focusing occurred at flow rates greater than 1 ml/min. Increasing the flow rate resulted in an increasing lateral displacement of the focused particle stream away from the inner channel wall. This behavior agrees well with results obtained from focusing small particles [3].

After identifying the suitable flow rate range for particle focusing a particle mixture was injected in the microchannel. Figure 3 shows the two focused parallel streams at a flow rate of 3 ml/min in the last turn prior to the wide channel segment.

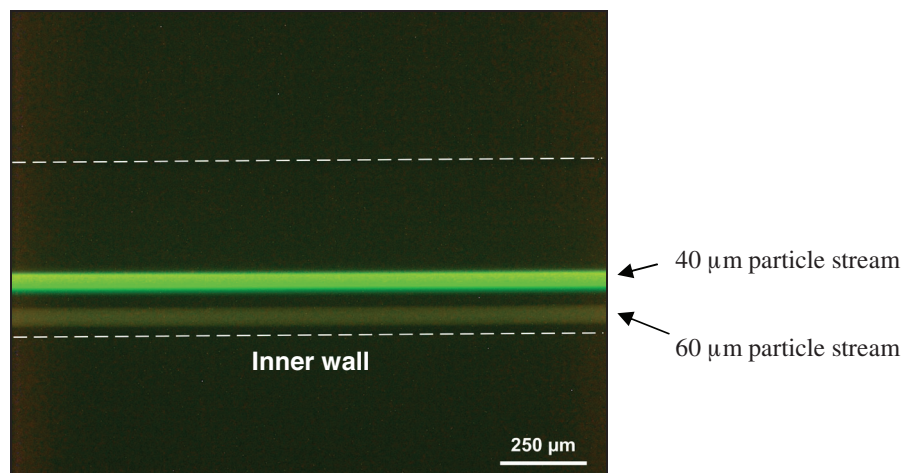


Fig. 3. Fluorescent image illustrating the two focused particle streams at a flow rate of 3 ml/min. The walls are highlighted with dotted lines.

The 60 μm particles stream equilibrated at a position closer to the inner wall as predicted from the theoretical considerations of the spiral microchannel separation principle. The flow rate can be adjusted so that the single particle streams can be directed directly into the bifurcated outlet ports, as shown in Figure 4.

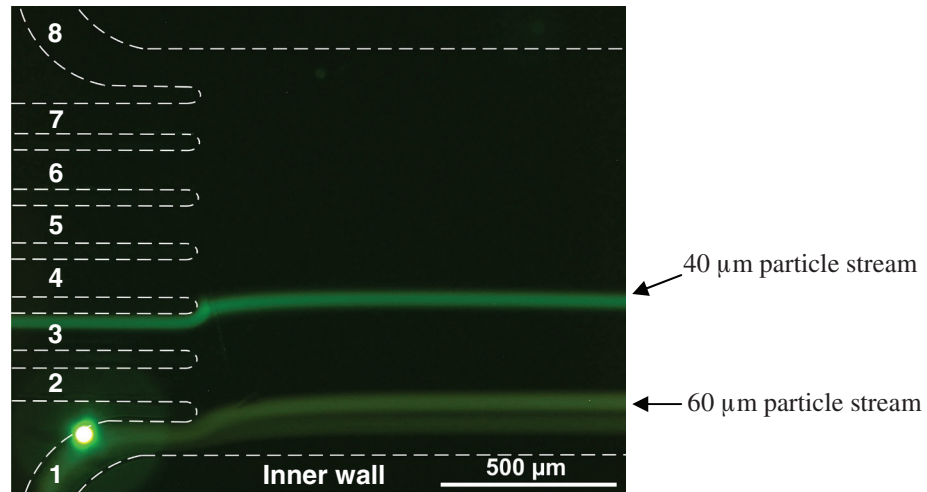


Fig. 4. Collection of the focused particle streams at outlets 1 and 3. The walls are highlighted with dotted lines.

5. Conclusions

We demonstrate a successful particle focusing and separation of large sized (40 μm and 60 μm) microparticles in a spiral microchannel. Current activities adopt and evaluate the principle for sorting large neuronal insect cells to show the potential of the device.

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References

- [1] X. Xuan, J. Zhu, and C. Church, "Particle focusing in microfluidic devices," *Microfluidics and Nanofluidics*, vol. 9, Mar. 2010, pp. 1-16.
- [2] A. Russom, A.K. Gupta, S. Nagrath, D. Di Carlo, J.F. Edd, and M. Toner, "Differential inertial focusing of particles in curved low-aspect-ratio microchannels.," *New journal of physics*, vol. 11, Jul. 2009, p. 75025.
- [3] S.S. Kuntaegowdanahalli, A.A.S. Bhagat, G. Kumar, and I. Papautsky, "Inertial microfluidics for continuous particle separation in spiral microchannels.," *Lab on a chip*, vol. 9, Oct. 2009, pp. 2973-80.
- [4] D.R. Gossett and D. Di Carlo, "Particle focusing mechanisms in curving confined flows.," *Analytical chemistry*, vol. 81, Oct. 2009, pp. 8459-65.