Particle motion in PDMS microchannels driven by surface acoustic waves

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This summer school presentation is based on a collaborative project set to investigate the fundamental physics of poly-dimethylsiloxane (PDMS) microchannels acoustically actuated by surface acoustic waves (SAW). Such microfluidic systems are currently, together with the entire acoustofluidics research field, receiving an increasing interest due to their use within the separation and manipulation of biological material and particles [1]. A typical SAW-driven PDMS device is shown in Fig. 1 and consists of a liquid-filled PDMS microchannel bonded to a piezoelectric lithium niobate ($LiNbO_3$) substrate. The substrate is patterned by so-called interdigitated electrodes (IDTs), that when exposed to a harmonically oscillating electric field generate a standing SAW in the substrate below the PDMS microchannel. The standing SAW radiates into the microchannel and creates an oscillatory pressure field which leads to two second-order effects, namely an acoustic streaming as well as an acoustic radiation force acting on suspended particles. As a result, the motion of suspended particles are affected by the viscous drag from the acoustic streaming as well as the radiation force which tends to push particles towards pressure nodes and antinodes.

However, the exact motion of particles suspended in such systems lacks understanding. Among the open questions are the precise bulk acoustic fields and associated acoustic streaming, the critical particle size for which the drag from the streaming dominates the particles motion rather than the force from the acoustic radiation, and the mechanism behind the reported focusing of particles perpendicular to the substrate plane. There are already several numerical studies on such systems, but their validation and further development require more quantitative measurements of the full three-dimensional particle behavior.

In this project we continue the development of our existing numerical model, see Ref. [2], by comparing to 3D velocity measurements using the general defocusing particle tracking (GDPT) method [3]. The GDPT method is illustrated and explained in Fig. 2. The experimental SAW device investigated is shown in Fig. 1, contains a microchannel of cross section 600 µm × 125 µm, and is driven at frequencies around 6 MHz corresponding to a full standing wave at the interface between the liquid and the substrate. The acoustophoretic trajectories are measured for microparticles of diameters 0.5 µm, 5 µm, and 8 µm. The motion of the 0.5 µm particles are clearly dominated by the viscous drag from the acoustic streaming with a distinct four-roll pattern, whereas the motion of the 5-µm and 8-µm particles are dominated by the acoustic radiation force. Both experiments and model will be presented.

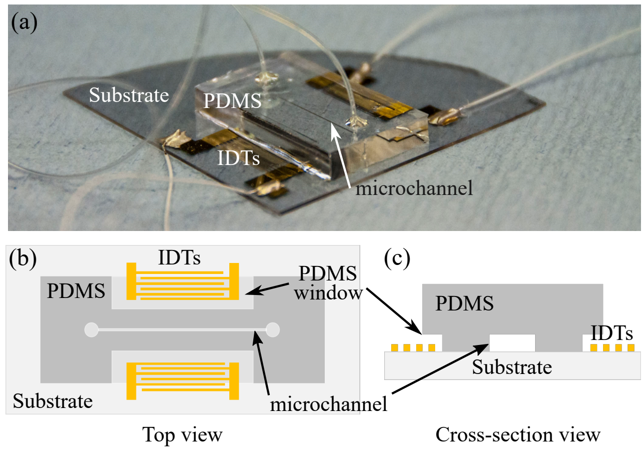

FIG. 1. Microfluidic device used for the investigations. (a) Photograph showing the liquid-filled PDMS microchannel bonded on the transparent and piezoelectric substrate which is acoustically-actuated by IDTs. The microchannel has a 600 µm × 125 µm cross section. Panel (b) and (c) show a schematic top view and cross-section view, respectively.

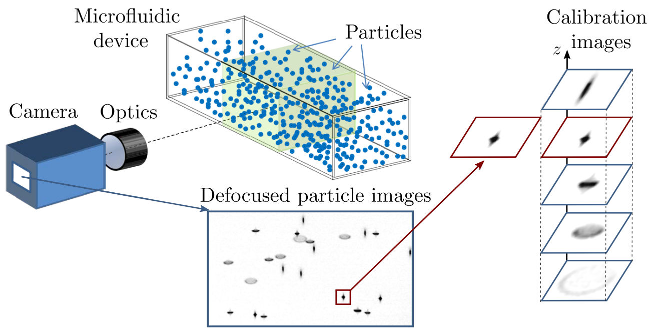

FIG. 2. The GDPT method is based on a single-camera setup for determining the 3D particle positions via defocused particle images, where the particle images change as function of the depth coordinate. To get a target particle position, the particle image is compared to a set of calibration images by use of the normalized cross-correlation. The out-of-plane coordinate for the target particle is found where the maximum correlation is highest.

Collaboration: The presented work is carried out as a collaboration between the PhD students Nitesh Nama and Liqiang Ren in the group of Professor Tony Huang at Penn State University, PA, USA, and with postdoctoral researcher Rune Barnkob at the Institute of Fluid Mechanics and Aerodynamics, Unibw, Germany, headed by Professor Christian J. Kähler.

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