Size-independent separation of vertically focused particles...

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Background studies

- Particle’s lateral migration inside a microchannel using travelling surface acoustic waves (SAW)

Destgeer et al., Lab Chip, 2014, 14, 4665
Collins et al., Lab Chip, 2016, 16, 471
Behrens et al., Lab Chip, 2015, 15, 43
Wu et al., Adv. Func. Mat., 2017, 27, 1606039

SSAW
Lateral particle migration and limitations

- **Limitations**
  - Rayleigh angle and vertical force component
  - Microchannel anechoic corner (MAC) formation
  - Sheath flows on both sides of sample
  - PDMS wall and wave attenuation

\[
\theta_t = \sin^{-1} \frac{c_f}{c_s}
\]

\[
\tan \theta = \frac{F_h}{F_v} \rightarrow \frac{F_h}{F_v} = \tan 22^\circ
\]

\[
F_v = 2.5 F_h
\]

Destgeer et al., Lab Chip, 2014, 14, 4665

\[
F_v = \frac{F_h}{22^\circ} \approx 2.5 F_h
\]

Destgeer et al., Anal. Chem., 2015, 87, 4627
Particle concentration using vertical migration

- On-demand particle trapping and release using PDMS membrane

*Collins et al., Appl. Phys. Lett., 2014, 105, 033509*

- Simple microchannel design and multiple traps

*Ahmed et al., in preparation*
Particle traps using a straight microchannel

- Size-dependent particle trapping and release

- Particle concentration

Ahmed et al., in preparation
Particle concentration and size-based separation

- A pumpless device for the concentration and separation of particles

(a) Power on (During process)
(b) Power on (After process)
(d)

12 µm 4.8 µm 2.1 µm
(c)

750 µm
140 MHz
73 MHz

Ahmed et al., in preparation
Continuous particle separation

- A schematic diagram of the proposed particle separation device.
Vertical hydrodynamic focusing

- Microchannel design simulation

Diameters of the inlet/outlet ports are equal to the width of the microchannel / Ideally not possible

Diameters of the inlet/outlet ports are smaller than the width of the microchannel / Not suitable

Diameters of the inlet/outlet ports are larger than width of the microchannel / Most suitable case

Ahmed et al., submitted
Results and discussion

- Experimental conditions
  - Frequency = 140 MHz
  - Power input = 11 mW
  - Flow ratio:
    - $Q_1: Q_2 = 1:9$
    - $Q_3: Q_4 = 2:3$
  - Particles diameter
    Green 4.8 µm $\kappa > 1$
    Red 2.0 µm $\kappa < 1$

\[ \kappa = \frac{\pi df}{c_f} \]

- $d$ = Diameter of a particle
- $f$ = Frequency of TSAW
- $c_f$ = Speed of sound in water

Destgeer et al., Anal. Chem., 2015
Ahmed et al., submitted
Separation efficiency

- A side view graphic with experimental images of outlets micro pipes.

(a) Power off

(b) Power on

Power on (Movie)

(a) Collection

- Green fluorescent particles 4.8 μm: 99.1%
- Red fluorescent particles 2.0 μm: 0.9%

(b) Waste

- Green fluorescent particles 4.8 μm: 0.1%
- Red fluorescent particles 2.0 μm: 99.9%

Ahmed et al., submitted
Size-independent separation

(A) PS
PMMA
FS
Inlets
Outlets
PDMS
LN
TSAW
IDT

(B) Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>PS</th>
<th>PMMA</th>
<th>FS</th>
<th>Water</th>
<th>Aqua-glycerol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density $\rho_p, \rho_f$ (g/cm³)</td>
<td>1.05</td>
<td>1.18</td>
<td>2.21</td>
<td>0.998</td>
<td>1.09</td>
</tr>
<tr>
<td>Speed of sound $c_l, c_f$ (longitudinal) (m/s)</td>
<td>2,350</td>
<td>2,757</td>
<td>5,950</td>
<td>1,495</td>
<td>1,665</td>
</tr>
<tr>
<td>Speed of sound $c_s$ (shear) (m/s)</td>
<td>1,120</td>
<td>1,400</td>
<td>3,750</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poisson's ratio $\sigma$</td>
<td>0.35</td>
<td>0.35</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Acoustic impedance $Z_p, Z_f$ (MRayls)</td>
<td>2.47</td>
<td>3.25</td>
<td>13.15</td>
<td>1.49</td>
<td>1.81</td>
</tr>
</tbody>
</table>

Destgeer et al., RSC Adv., 2017, 7, 22524

Ma et al., Anal. Chem., 2016, 88, 11844
Flip-flop sorting

(A) Microchannel

(B) Outlet zone (iii)

(C) 140 MHz

Intensity (a.u.)

Normalized channel width

(D) Frequency (MHz)

125 140 155 170 185 200

135 MHz 388 mW \( \kappa \approx 1.22 \)

140 MHz 136 mW \( \kappa \approx 1.27 \)

145 MHz 136 mW \( \kappa \approx 1.31 \)

150 MHz 26 mW \( \kappa \approx 1.36 \)

155 MHz 5 mW \( \kappa \approx 1.40 \)

160 MHz 34 mW \( \kappa \approx 1.45 \)

165 MHz 136 mW \( \kappa \approx 1.49 \)

170 MHz 213 mW \( \kappa \approx 1.54 \)

175 MHz 652 mW \( \kappa \approx 1.58 \)

180 MHz 1330 mW \( \kappa \approx 1.63 \)

185 MHz 1916 mW \( \kappa \approx 1.68 \)

190 MHz 2608 mW \( \kappa \approx 1.72 \)

Destgeer et al., RSC Adv., 2017, 7, 22524
Vertical migration and size-independent separation

**(A) Power off**

- **Q₁**: 500µL/hr
- **Q₂**: 4500µL/hr
- **Q₃**: 500µL/hr
- **Q₄**: 4500µL/hr

**(B) Power on**

- **Q₁**: 500µL/hr
- **Q₂**: 4500µL/hr
- **Q₃**: 500µL/hr
- **Q₄**: 4500µL/hr

**Destgeer et al., RSC Adv., 2017, 7, 22524**

**Destgeer et al., RSC Adv., 2017, 7, 22524**

<table>
<thead>
<tr>
<th>Material</th>
<th>κ</th>
<th>f (MHz) / d (µm)</th>
<th>(\kappa (\pi d f_{\text{TSAW}}/c f))</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>4.8±0.1</td>
<td>137-147</td>
<td>1.29±0.07</td>
</tr>
<tr>
<td>PMMA</td>
<td>4.9±0.2</td>
<td>170-195</td>
<td>1.31±0.10</td>
</tr>
</tbody>
</table>

Ahmed et al., submitted
Summary

- Presented the pumpless acoustofluidic device for the concentration and separation of different diameter particles.
- Separated the mixture of particles (12 µm, red; 4.8 µm, green; & 2.1 µm, blue) by making use of both horizontal and vertical component of ARF.
- Presented highly efficient SAW device for the trapping of particles from extremely low concentrated particles solution (10 particles/ml).
- The trapping, concentration and separation can be visualized without microscope.
Thank you for your attention!

Questions or comments are welcomed.