Topic No. 1. Fundamentals in Microfluidics and Nanofluidics

CONTROLLING AC-ELECTROOSMOTIC VORTEX FLOWS BY SHAPING THE CHANNEL CROSS SECTION

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Summary

This work demonstrates the ability to control lateral AC-electroosmotic flow (AC-EOF) by changing channel wall shapes. AC-EOF is generated by a tangential E-field component at the electrodes, causing a Coulomb force on the ions in the electrode double layers. When the electrode polarity changes, both E-field and ionic charge change polarity, maintaining a constant direction of AC-EOF. Classically, AC-EOF is generated by shaping the electrode geometry [1,2]. However, AC-EOF is also generated for example when a dielectric particle levitates above an electrode surface, causing locally curved E-field lines [3,4,5,6]. Here we show that a similar phenomenon occurs when field lines are shaped by nonconducting walls. We designed channels with electrodes at top and bottom and variously shaped insulating side walls and show we can create differently shaped vortices by AC-EOF.

Materials and Methods

Conducting and transparent ITO layers [7] (70 nm) were sputter-deposited on fused silica wafers in 1% O_2/99% Ar using an applied DC voltage of 240 V with 50 W power. After sputtering, the ITO electrodes were annealed at 400^{o}C for 30 min to increase the conductivity. A microchannel structure (40 µm wide, 20 µm high) was developed either in NC-epoxy foil (negative photoresist) of 20 µm thickness (structure with imperfect corners), or by using liquid SU-8 (parallelogram channel wall shape). For the parallelogram shape, inclined UV exposure at 13^{o} angle was done with the wafer connected to the mask by glycerol. Inlets and outlets were made in the glass wafers by powder-blasting. For flow visualization, 0.5 µm diameter melamine resin particles were used with Tween 20 coating (ζ-potential -4.7 mV) and polystyrene particles with PVA-coating (ζ-potential -22 mV) both as 0.0025% w/v suspension in unbuffered KNO_3 solution (0.1 mM, pH 6.2). Sinusoidal AC-potentials with 2 V peak-peak amplitude and 1 kHz frequency were applied by a function generator. Microscopic movies of the particle movements were recorded and analyzed by general defocusing particle tracking (GDTP) [8] to characterize the vortex profiles.

Results

Simple geometric considerations as well as COMSOL simulations show that the direction of the AC-EOF vortices is oriented towards sharp corners and away from obtuse corners (Figures 1-3). We experimentally validated this theoretically expected flow behaviour. Particle trajectories observed in a rectangular shaped channel with imperfect corners showed 2 vortices (Figure 4), while particle trajectories in the parallelogram shaped channel showed a single vortex (Figure 5). The flow direction in all cases was towards sharp corners and out of obtuse corners. The average particle velocity measured for the parallelogram was 15 µm/s, which is of the order of magnitude of the simulated values.

The presented approach can for example be used in applications where mass transport needs to be enhanced to achieve a better lateral distribution of chemical components along the microfluidic channel.

458 words

References:

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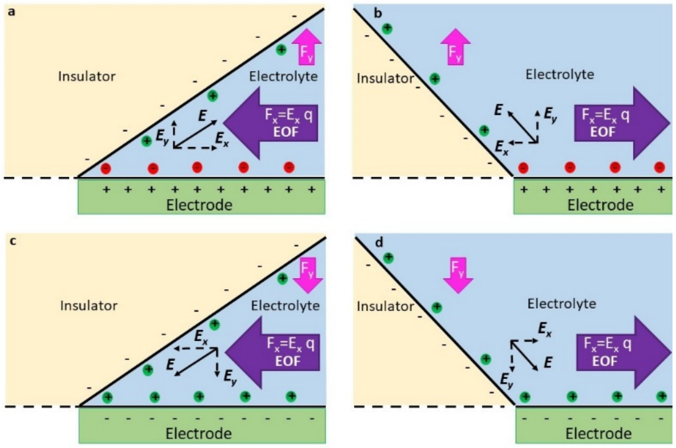

Figure 1. AC-EOF direction a) and c) for sharp corner and opposite polarities. b) and d) For obtuse corner and opposite polarities. For full cycle, $F_y=0$.

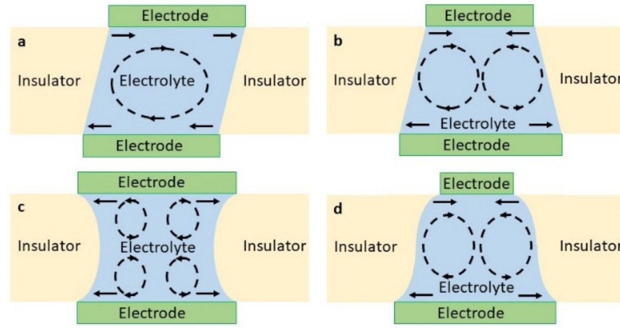

Figure 2. Several channel shapes and the EOF direction at each corner based on the theory of Figure 1.

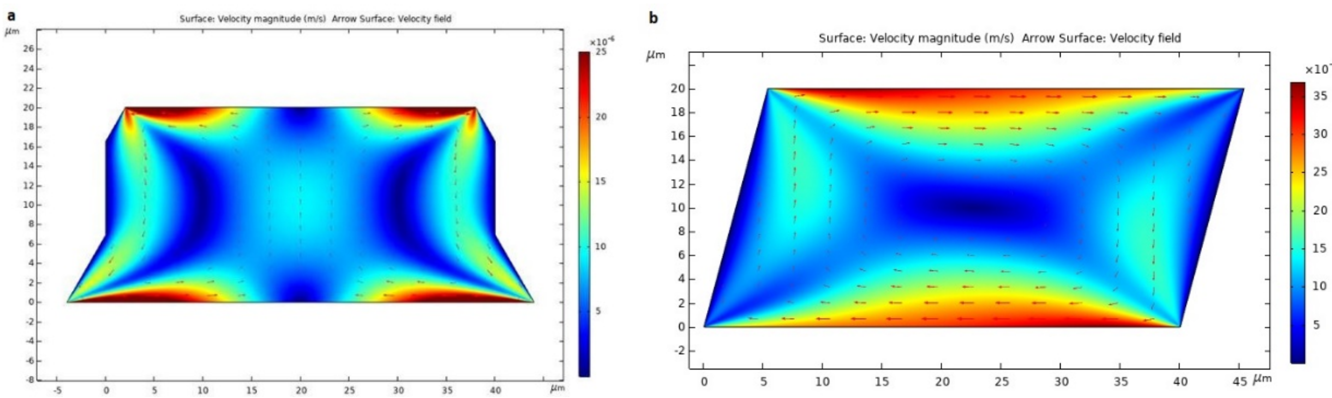

Figure 3. 2-dimensional COMSOL simulations of AC-EOF a) for rectangular shape with imperfect corners and b) for a parallelogram shape, both with a potential amplitude of 0.5 V peak-peak.

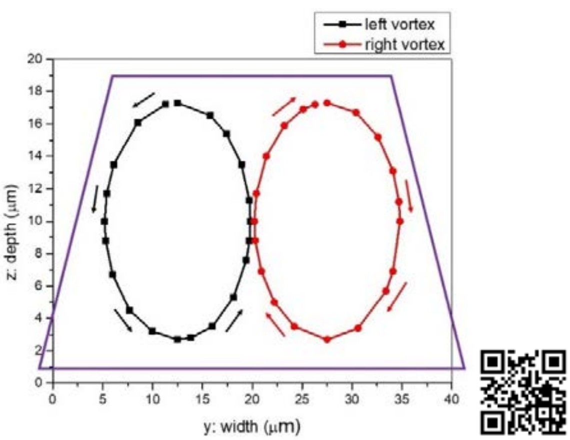

Figure 4. Schematic shape of counter rotating vortices for rectangular shape with imperfect corners, (effectively creating a trapezoid) and a QR code of the experimental recording. Particle focusing at the stagnation point between the vortices was previously reported (µTAS, Taiwan 2018).

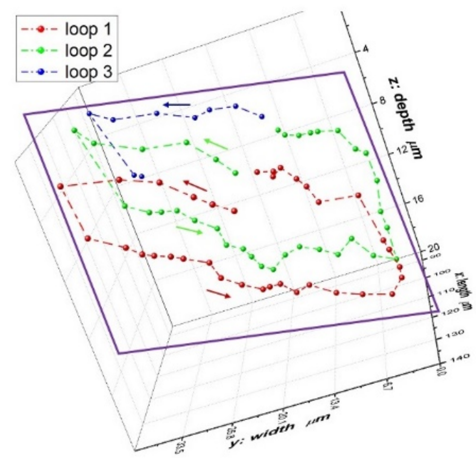

Figure 5. Melamine resin particle (0.5 µm diameter) trajectory in parallelogram-shaped microfluidic device. 2 V peak-peak applied potential and 1 kHz frequency.