Micro-pumping induced by AC electro-osmosis

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DC electro-osmosis

0.01M NaCl

Debye length $\lambda_d \approx 10\text{nm}$

Zeta-potential $\zeta \approx -0.1\text{V}$

External electric field $|E| = 20\text{V/cm}$

$U = \frac{\varepsilon \zeta E}{\eta} = 100\mu\text{m/s}$

- Too high voltage $\rightarrow$ chemical reaction, bubble generation
- The channel should be straight as possible.
Electro-osmosis

Practical micro-pumps require:

(1) Low voltage operation (less than 3.0 V) for preventing air-bubble generation and chemical reaction.

(2) Tangential external electric field to the arbitrarily shaped wall
**AC Electro-osmosis**

Fluid flow induced by AC electro-osmosis

**Streamlines of particles**
(Captured by a video camera)

**Slip velocity vs frequency**
(manual detection of particle position, Not PIV)

(Green et al. 2002)
**AC Electro-osmosis**

Why does not the flow direction change?

\[ \rho_f \frac{D\vec{V}}{Dt} = -\nabla p + \eta \nabla^2 \vec{V} + \rho_e \vec{E} \]

Body force

\( \rho_e \): Charge density of the fluid
Theoretical slip velocity

Assumptions

(1) Thin double-layer approximation (like a boundary layer flow)
(2) Linear approximation of governing equations (low applied voltage)
(3) Symmetry electrolyte (\(D_+ = D_-, |z_+| = |z_-| = 1\))
(4) Ideally polarizable electrode (no charge flow across the electrodes)
(5) Convection current \(<\ll\) conduction current

\[
<V> = -\frac{\varepsilon}{4\eta} \frac{\partial}{\partial x} (|\Delta V|^2) = -\frac{\varepsilon V_0^2}{16\eta} \frac{\partial}{\partial x} F\left(\frac{\varepsilon \omega x}{\sigma \lambda_d}\right)^2
\]

(Gonzalez et al. 2000, Ramos et al. 2003, Olesen et al. 2006)
Pump using AC electro-osmosis

Asymmetric electrodes

(Brown et al. 2002)

(Ramos et al. 2003)
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(Mpholo et al. 2003)
Pump using AC electro-osmosis

Advantages

(1) Low voltage operation (1~5V) : Order of 0.1mm/s flow velocity
(2) Tangential electrical field along the wall
Forward and backward pumping

Voltage and frequency effects

The reasons for this have not been explained yet qualitatively and quantitatively.

(Studer et al. 2004, Ramos et al. 2006)
What are needed further?

Objectives of this work

1. Experimental visualization and numerical simulation of fluid structure over symmetric electrodes at low voltages and low frequency (lack of quantitative flow pattern)
2. Investigation into backward pumping of asymmetric electrodes through experimental flow pattern at high voltages or high frequency.
Experimental set-up

2D micro particle image velocimetry

Acquisition of particle images

Image processing based on the cross-correlation

Velocity field
(spatial resolution: 1~2 μm)
Experimental set-up

3D defocusing PIV
Preliminary test

Asymmetric electrodes

Gold electrode

glass

Top view

Side view

L=10  G=2  S=2  G1=6μm
Preliminary test

$V_{\text{rms}} = 2.0\text{V}, \ f=10\text{kHz}$

Moving of particles near the surface (top view, KCl 0.011M)
(flow by an open channel + AC electro-osmosis flow)
Future works

Plans

(1) Side view measurement for look into flow structure
(2) 2D or 3D flow velocity fields measurement
(3) Numerical simulation