AC FIELD EFFECT FLOW CONTROL OF EOF IN COMPLEX MICROFLUIDIC SYSTEMS WITH INTEGRATED ELECTRODES

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ABSTRACT

This paper presents a novel method to control Electro Osmotic Flow (EOF) with AC electrical fields. It is shown that with a single potential the zeta potential at a solid liquid interface and the channel potential that drives the EOF can be controlled in a synchronized matter to create a net flow with zero average potential. The frequency regime in which the EOF can be controlled is bound by the capacitive charging of the Electrical Double Layer (EDL) as an upper limit and the formation of bubbles at the open channel electrodes by electrolysis as a lower limit.

KEYWORDS: Microfluidics, FEFC, PIV

INTRODUCTION

EOF is widely employed as a pumping method in Lab on a chip systems. Although conventional EOF pumping has some major disadvantages. Particularly when applied to fluidic networks, addressing of individual branches is challenging. Field Effect Control of the zeta potential at the solid liquid interface solves some of the associated drawbacks. Although, conventionally devices are operated with DC potentials. The resulting electrolysis reactions of the electrolyte and consequential bubble formation can result in channel blockage. This drawback can be solved by switching both the zeta potential and the channel potential in a synchronized matter. With sufficiently large actuation frequencies, electrodes can be placed within the fluidic channels. This allows for flow control in individual channel branches in fluidic networks.

THEORY

For an AC channel potential the EOF velocity is given by formula 1 In which \( \varepsilon_o \) and \( \varepsilon_r \) respectively the permittivity of vacuum and that of water, \( \zeta \) the zeta potential at the solid liquid interface, \( \eta \) the viscosity and \( E_x \) the electric field.

\[
v_{EOF} = \frac{\varepsilon_0 \varepsilon_r \zeta}{\eta} E_x \cos(\omega t) \quad (1)
\]

With a DC zeta potential the time average flow will be zero. By locating a gate electrode underneath the channel wall and covering it with an insulating layer the zeta potential can be controlled capacitively [1]. For moderate and low electrolyte concentrations the influence of the applied gate potential on the zeta potential is
given by formula 2, with $C_{\text{EDL}}$ and $C_{\text{ins}}$ respectively the EDL and insulation layer capacitance, $\zeta_0$ the natural zeta potential and $V$ the potential.

$$\zeta = \zeta_0 + \frac{C_{\text{ins}}}{C_{\text{EDL}}} E \sin(\omega t)$$

(2)

Combination of formula 1 and 2 and rearranging the terms yields formula 3. It can be seen that the EOF is composed of an oscillating term due to a natural zeta potential plus a DC and $2\omega$ term due to a coupling between the oscillating zeta and channel potential.

$$v_{\text{EOF}} = \frac{e_0\varepsilon_x\zeta_0}{\eta} E_x \cos(\omega t) + \frac{e_0\varepsilon_x\zeta}{2\eta} E_x (1 + \cos(2\omega t))$$

(3)

EXPERIMENTAL

Figures 1 and 2 show a drawing and picture of the chip. It is composed of a meandering channel with in each branch 2 open electrodes to drive the EOF and an insulated gate electrode to control the zeta potential. The rectifying mechanism for the EOF is illustrated for the positive cycle of the AC signal. In the negative cycle of the AC signal the effect is shifted a branch leading to a net flow velocity from left to right.

![Figure 1](image1.png)

**Figure 1.** Left: schematic overview of the meandering FEFC device. Yellow indicates electrodes, blue channels and reservoirs. Flow rectifying mechanism is indicated for the positive cycle of the AC signal. Gate voltage is half the applied voltage with respect to the local channel potential. Leading to flow reversal in the regions with arrows pointing up and flow enhancement for arrows pointing down. Right: Picture of the device.

The device shown in figure 1b consists of a Pyrex wafer with patterned Ti/Pt electrodes covered with 1 μm PECVD silica insulations. The insulating layer is partially etched to create open channel electrodes. Fluid reservoirs and channels are patterned in PDMS. Channels are 100 μm in width and 20 μm height. Sodiumacetate buffers of pH 3 with various concentrations were used. Flow velocities were measured by analyzing the movement of polystyrene beads with PIV [2] in matlab.

RESULTS AND DISCUSSION

Figure 2 shows the flow velocities for different concentrations measured as a function of the applied AC frequency for a amplitude of 220 Volts. The change in flow velocity is governed by 2 main mechanisms. For higher concentration the EDL capacitance increases. Secondly, as the concentration decreases the channel resistance increases. Since the time constant for the double layer charging is controlled...
by the series of the channel resistance and insulating layer capacitance lower concentrations will lead to reduced flow at higher frequencies [3]. Figure 2b shows an exponential growth in flow velocity as the applied potential is increased, since the applied potential leads to an increase in both zeta potential and channel potential.

![Figure 2. Left: Flow velocity as a function of the frequency. Right: Flow velocity as a function of the applied potential for a 1 kHz signal with 5 mM concentration.](image)

Figure 3a shows the net flow from the device as a function of time both theoretically and experimentally with a frequency of 1 kHz and potential of 220V amplitude. Data is in good agreement with theory, with a correlation factor of 0.77. Theoretical curves were calculated with the aid of formula 3. A Fast Fourier Transform (FFT) of the data indicates that higher order frequencies participate as well, possibly due to the coupling of the different channel branches.

![Figure 3. Left: Measured flow velocity as a function of the time for a 1 Hz signal of 200V amplitude as shown in blue. Red curve shows the theoretical expected flow behavior. Right: power spectrum of the FFT of the flow velocity vs. time.](image)

CONCLUSION

The presented measurements show that with the application of AC potentials at an insulated gate and open channel electrodes a net flow can be induced with relatively low potential due to the parallel alignment of the channel electrodes. While this design consists of a single meandering channel structure, the presented results indicate that this method could be applied to more complex fluidic networks allowing control over flow velocities in each channel branch.

REFERENCES