Electroosmotic Flows in Microfluidic Chips

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Abstract

Understanding the physics of electroosmotic flow is important to the optimum design and operation of microfluidic systems. Recent development on the topic in our group is summarized in this presentation. Applications to the variable-volume-Injection, micro flow switch, electrokinetic focusing, and flow cytometer will be presented with our novel design and control.

Keyword: *Microfluidics, Electroosmosis*

1. Introduction

There has been significant interest in the use of microfluidic devices for small-scale bio-analytical instruments, for example, the electrophoretic separation of fluid components using microchannels. As the characteristic dimensions of these channels decrease to micro ranges, resulting in large surface-to-volume ratio, the liquid fluid flow behavior in these microchannels is increasingly influenced by interfacial effects such as the electrical double layer (EDL). Because of channel wall influence, the microchannel flow behavior deviates from the predications of the traditional Navier-Stokes equations.

2. Governing Equations and Numerical Method

In this work, we simulate the electroosmotic flows in microfluidic chips by including the interfacial effect between the fluid and solid surface using the so-called zeta potential. The following set of differential equations is solved in this work:

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = \kappa^2 \sinh(\psi) \tag{1}$$

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0 \tag{2}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{3}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + Gx \cdot \sinh\psi\left(\frac{\partial \psi}{\partial x} + \frac{\partial \phi}{\partial x}\right) \tag{4}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} + \frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + Gx \cdot \sinh\psi\left(\frac{\partial \psi}{\partial y} + \frac{\partial \phi}{\partial y}\right) \tag{5}$$

where ψ is the EDL potential, ϕ is the applied electrical potential used to drive the liquid, Re is the Reynolds number, $Gx = 2\xi\ zen_0 / \rho_f U^2$, ξ is the zeta potential on wall surface, and e is the electron charge.

The above governing equations are solved numerically. We add an artificial time derivative term to Eqs. (1) and (2). These two equations can be efficiently solved by the alternative direction implicit (ADI) method. Similarly, the modified Navier-Stokes equations in Eqs. (3-5), we apply the artificial compressibility method by adding a time derivative pressure term to the continuity equation. Briefly, the governing equations are replaced by an implicit time difference approximation (backward difference). Non-linear numerical fluxes at the implicit time level are linearized by Taylor expansion; then, spatial difference approximations (central-difference) are introduced. The result is a system of multidimensional, linear, coupled difference equations for the dependent variables at the implicit time level. To solve these equations, the approximate-factorization or ADI scheme is used. The resulting system of equations can be written in narrow block-banded matrix structures and be solved efficiently by a standard LU decomposition method.

3. Results and Discussion

Examination of the governing equations reveals that the characteristic forces in the electroosmotic microchannel flow are determined by the non-dimensional parameters Re and Gx. The driving force of the flow is due to the interaction of the EDL and the applied electrostatic potential ϕ. With the above mentioned values and the equations developed above, it is quite straight-forward to calculate the flow characterizing parameters such as the EDL distributions near the wall, velocity distribution, pressure drop and skin friction.

Understanding the physics of electroosmotic flow is important to the optimum design and operation of microfluidic systems. Recent development on the topic in our group is summarized in this presentation. Applications to the variable-volume-Injection (Fig.1), micro flow switch (Fig.2), electrokinetic focusing (Fig.3), and flow cytometer (Fig.4) will be presented with our novel design and control.

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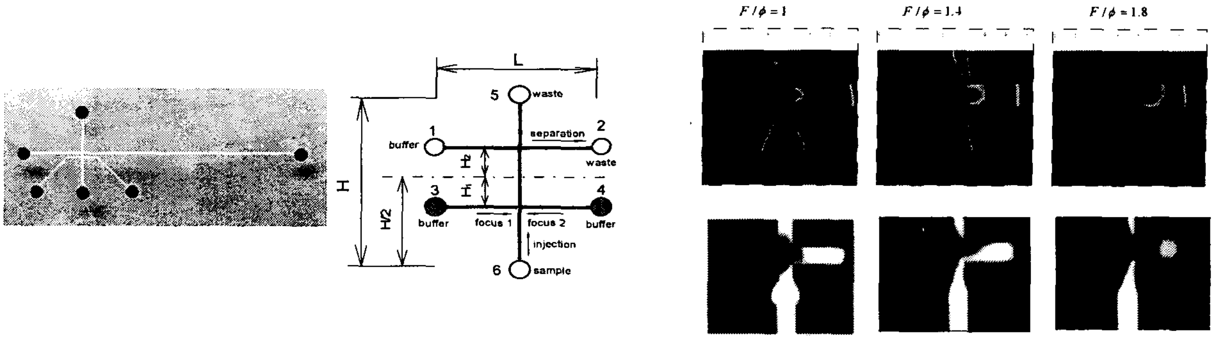

Figure 1 Variable-Volume-Injection Method

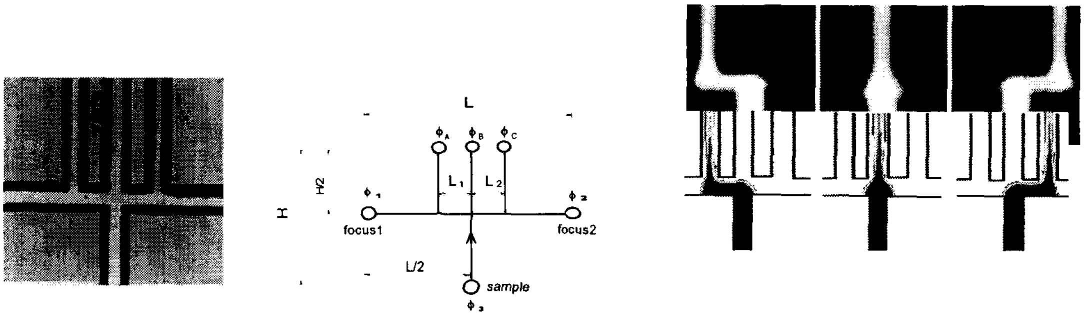

Figure 2 Micro Flow Switch Method

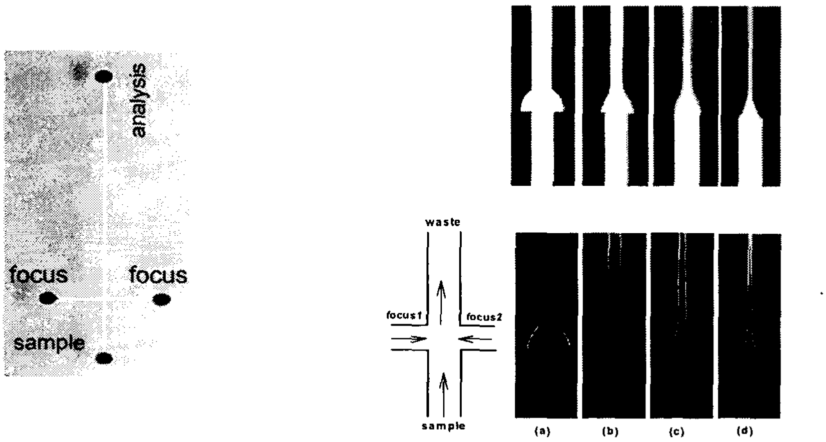

Figure 3 Electrokinetic Focusing Method

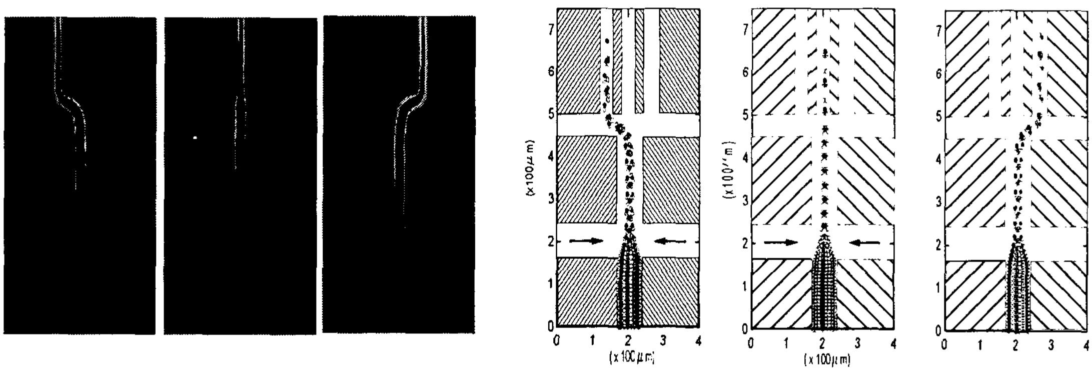

Figure 4 Electrokinetic Focusing + Flow Cytometer Method