ELECTROKINETIC TRANSPORT THROUGH NANOMETER DEEP CHANNELS

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Abstract

Electroosmotic flow was evaluated in fluidic devices with channel depths of 98 nm, 300 nm, and 10.4 µm. At each channel depth electric double layer thicknesses of 21.5, 6.80, 2.15, and 0.78 nm were examined. For the 21.5 nm double layer thickness, a 35% decrease in the electroosmotic mobility was observed with the 98 nm deep channel relative to the 300 nm and 10.4 µm channel depths. These results were in good agreement with theoretical predictions.

Keywords: nanochannel, electrokinetic transport, double layer thickness

1. Introduction

A common method for moving materials through the channels of microfabricated fluidic devices (microchips) is electrokinetic transport. When the channel dimensions are large, e.g. 10-100 µm, the electric double layer thickness is negligible compared to the channel dimensions, and the flow profile is planar normal to the axis of flow. However, when channel dimensions begin to approach the double layer thickness, flow rates are expected to decrease with cross-sectional area in a non-linear fashion [1, 2]. To test this theory, we fabricated devices with channels that were confined to the nanometer range in one dimension (depth), measured the electroosmotic mobilities over a range of double layer thicknesses, and compared the results to theory.

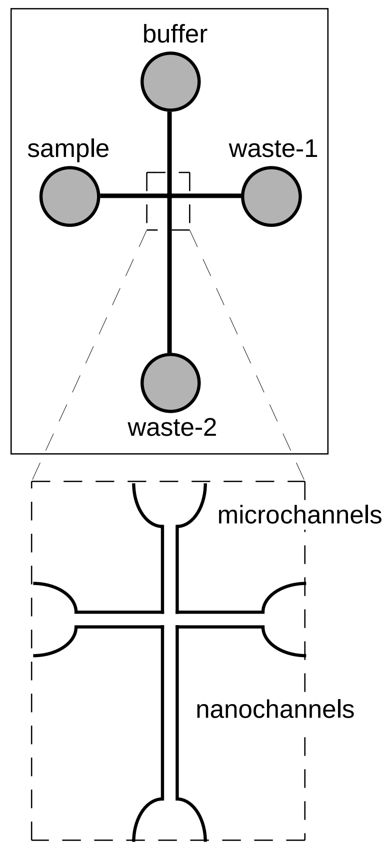

Figure 1. Schematic of the chip with nanochannels.

2. Experimental

Figure 1 shows a schematic of the fluidic chip with nano- and microchannels. The channels were fabricated using standard photolithographic and wet chemical etching techniques. The substrates with nanometer deep channels were initially etched to ≈100 or 300 nm deep. The nanochannels including the cross intersection were then coated with photoresist to prevent further etching, and the uncoated portions of the channels were etched to 5 µm deep. The 10.4 µm deep channels were etched in a single step. Cover plates were then thermally bonded to the substrates

The double layer thickness was controlled by changing the buffer concentration. Sodium tetraborate buffers of 0.20, 2.0, 20, and 150 mM with 50% (v/v) methanol were used and corresponded to calculated double layer thicknesses ($1/\kappa$) of 21.5, 6.80, 2.15, and 0.78 nm, respectively [3]. The electro-osmotic mobilities were measured by injecting a neutral dye, rhodamine B, and monitoring the arrival time 1 mm downstream from the injection cross by confocal fluorescence detection.

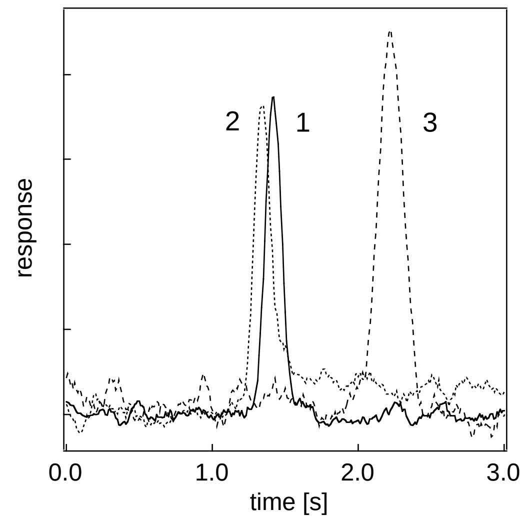

Figure 2. Temporal profiles measured with the 98 nm deep channel for (1) 21.5, (2) 6.80, and (3) 2.15 nm double layer thicknesses. The electric field strength

3. Results and Discussion

The electroosmotic mobilities were measured in three microchips with channel depths of 98 nm, 300 nm, and 10.4 µm. The 10.4 µm channel served as a control because the double layer thickness was assumed to be negligible relative to the channel depth. Figure 2 shows a series of temporal profiles obtained with the 98 nm deep channels for double layer thicknesses of 21.5, 6.80, and 2.15 nm. The electroosmotic mobility was expected to increase with increasing double layer thickness (decreasing buffer concentration). However, when the double layer thickness extends significantly into the channel, the electroosmotic flow decreases. This is seen in Figure 2 where profile 1 eluted after profile 2, and the 21.5 nm double layer was 44% of the 49 nm half-depth of the channel. Figure 3 shows the variation of the electroosmotic mobilities with the reciprocal of the double layer thickness (κ). For double layer thicknesses ≤ 6.80 nm, the electroosmotic mobility was independent of channel depth. For the 21.5 nm double layer thickness, the electroosmotic mobility in the 98 nm deep channels was 35% lower than the electroosmotic mobility in the 300 nm and 10.4 µm deep channels.

Equation 1 was used to calculate the electroosmotic mobility for different channel depths and double layer thicknesses [2].

$$\frac{u_{eo}}{E}(y) = \frac{\varepsilon\varepsilon_0\zeta}{\eta}\left[1 - \frac{\cosh[\kappa(h-y)]}{\cosh(\kappa h)}\right] \qquad (1)$$

where u_{eo}, E, h, y, ζ, η, ε, and ε_0 are the electroosmotic velocity, electric field strength, 1/2 channel height, distance from channel wall, zeta potential, viscosity, dielectric constant, and permittivity of vacuum, respectively. The zeta potentials at different double layer thicknesses were calculated from a fit to the experimental values obtained using the 10.4 µm deep channel. The dielectric constant was 59.24 [4], and the viscosity 168 mPa·s. The calculated electroosmotic mobilities are plotted in Figure 3 as the solid curve.

These experiments showed reduced electroosmotic mobilities in fluidic channels where the double layer thickness was a significant fraction of the channel depth. The results compared well with calculated mobilities from Equation 1. However, theory predicted that a slightly greater reduction in the mobility should be observed.

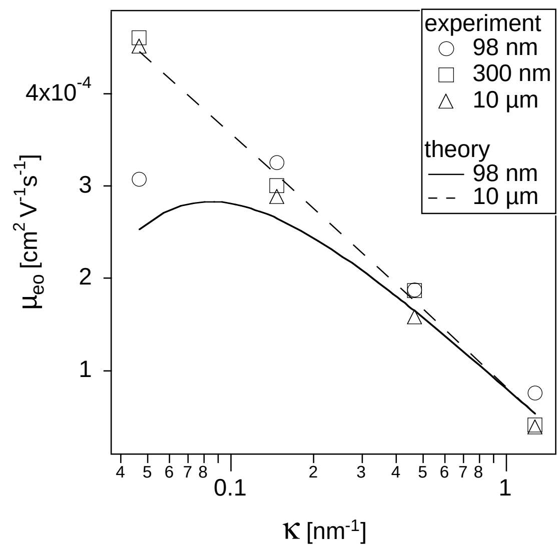

Figure 3. Variation of electroosmotic mobility (μ_{eo}) with the reciprocal of the double layer thickness (κ). Equation 1 was used for the theoretical calculations.

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