ELECTROKINETIC PARTICLE SEPARATION
S. Devasenathipathy¹, J. G. Santiago¹
T. Yamamoto², Y. Sato², K. Hishida²

¹ Department of Mechanical Engineering, Stanford University, U.S.A.
² Department of System Design Engineering, Keio University, Japan

ABSTRACT
An electrokinetic process for the separation or filtering of charged colloidal particles in solution is demonstrated. Two buffered particle-laden streams of different ionic conductivities are introduced into a T-channel system. The fluid is driven by both pressure and a DC electric field. Upon application of an electric field, the particles are extracted from the lower conductivity stream and stacked into the higher conductivity stream. Both particle density (scalar) imaging and quantitative velocity fields using micron-resolution particle image velocimetry (micro-PIV) are presented. Numerical simulations of the process capture the generation of a transverse electric field.

Keywords: Conductivity, Electrokinetic, Particle, Velocimetry

1. INTRODUCTION
Electrokinetically driven flows have been applied successfully in microfluidic devices to achieve separation, pre-concentration and mixing.¹ Heterogeneous electrolyte systems with gradients in electrical conductivity are employed in various processes including field amplified sample stacking (FASS) and two dimensional assay systems.²,³ In this work, we report a method to separate charged particles using transverse conductivity gradients.

2. EXPERIMENTS
The functional component of the device consists of a simple T-shaped microchannel system. The channel structure is fabricated from poly(dimethylsiloxane) using soft lithography and sealed with a glass cover slip. The experimental setup is shown in Figure 1a and the T-channel geometry is shown in Figure 1b. Platinum electrodes submerged in end-channel reservoirs provide electrokinetic control so that no internal channel electrodes (or other complex fabrication procedure) are needed for operation. Both liquid streams are composed of a 5 mM HEPES buffer at pH=7.2. KCl was added to Stream B to achieve a conductivity ratio of 10. The conductivities were 270 and 2650 μS/cm.

The seed particles were negatively charged 1-μm diameter carboxylate modified polystyrene spheres. Particle-based measurements offer high-resolution velocity measurements with a depth-resolved measurement volume.⁴ The particle velocities measured by micro-PIV are a superposition of the particle electrophoretic velocity and the velocity of the local fluid (including pressure and electroosmotic components).
Figure 1: (a) Experimental setup including continuous Nd:YAG laser (1); CCD camera (2); optical fiber (3); dichroic filter cube (4); objective lens (40X, oil, 1.30 NA) (5); high voltage power supply (6); and T-shaped channel system (7). (b) Schematic of T-junction geometry and voltage scheme. Velocimetry measurement areas shown as rectangles.

### 3. RESULTS AND DISCUSSION

On the application of a DC electric field from the horizontal inlets to the vertical outlet of the device, a net flux of polystyrene spheres from Stream A (low conductivity) to Stream B (high conductivity) is observed, with particles stacking just to the right of the midline as shown in Figure 2. This stacking is accompanied by a depletion of particles in a region to the left of the midline. Measurements were conducted at three locations along the streamwise direction (shown as Regions A, 1 and 2 in Figure 1b) and two depths (the mid-plane and the wall at \( z = 5 \) \( \mu \text{m} \)).

The steady state measured particle velocity field in Region A and \( z = 25 \) \( \mu \text{m} \) is shown in Figure 3a. A significant horizontal drift component occurs only in the presence of a DC electric field from the horizontal inlets to the vertical outlet of the device.
of strong conductivity gradients in the microchannel. Figure 3b shows spanwise velocity \((u)\) profiles at four measurement locations. These measurements quantify DC electrokinetic drift velocity due to a transverse electric field.

The conductivity gradients in this flow couple to produce a transverse electric field that causes particle drift across fluid flow streamlines, leading to a non-uniform distribution of spheres. Numerical simulations were performed with FEMLAB (Stockholm, Sweden). The coupled fluid and species transport equations were solved to yield approximations of velocity and electric fields assuming a net-neutral bulk flow formulation that neglects body forces in the fluid momentum equation.

Figure 4a shows nearly symmetric liquid flow streamlines, and Figure 4b shows the asymmetric electric field. Calculated particle pathlines are plotted in Figure 4c and show transverse particle drift. Figure 5 demonstrates particle filtering at higher electric fields. At 750 V, particles are completely depleted from the low conductivity stream.
Figure 5: Particle concentration images (a) Uniformly seeded flow downstream of T junction (b) Non-uniform, steady-state seed particle density at same location on application of 500 V and (c) 750 V

4. CONCLUSIONS

An on-chip T-channel design for filtering or buffer-exchange of colloidal particles using transverse conductivity gradients was demonstrated. Quantitative particle velocity field information was obtained using micro-PIV and scalar imaging. A numerical model with a net neutral formulation qualitatively captures the stacking effect. The data demonstrates the importance of conductivity gradients in electrokinetic flows and provide important benchmark data for modeling. Future work will explore the use of H-shaped channel configurations to extract two independent buffer streams from the device.

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6. REFERENCES