CONTINUOUS-FLOW DIELECTROPHORETIC PARTICLE SORTING IN RIDGED POLYMERIC MICROCHANNELS

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ABSTRACT

This work presents continuous-flow particle sorting at low applied fields (as low as 30 V/cm) using electrodeless dielectrophoresis [2-7] in ridged polymeric microstructures. Particle manipulation and sorting is critical in the analysis of cellular systems and subpopulations, water monitoring, soil analysis, and colloidal synthesis. This technique is developed with a view toward sorting of cellular systems, and offers advantages over other particle processing techniques in its ability to sort particles over small (~100 μm) spatial scales and rapid (<1s) time scales while operating under the low electric fields required when using solutions of physiological salinity.

INTRODUCTION

The microchannel geometry in this system sorts particles by transducing particle dielectric properties to transverse spatial position in a continuous flow. Two lithographic steps overlay raised ridges onto an otherwise uniform channel (Figure 1). The raised ridges lead to constrictions in the microchannel and therefore increase the local electric field (Figure 2a). The local electric field variation leads to a dielectrophoretic force away from the constriction, causing particle-dependent deflection. Curvilinear ridge structures are designed such that the dielectrophoretic forces vary spatially along the cross-sectional area (due to variation in the current flux normal to the ridge). Particles incident on the curvilinear ridge experience dielectrophoretic forces that steer the particles to the right until the angle of incidence of the bulk electric field becomes small enough for the dielectrophoretic forces

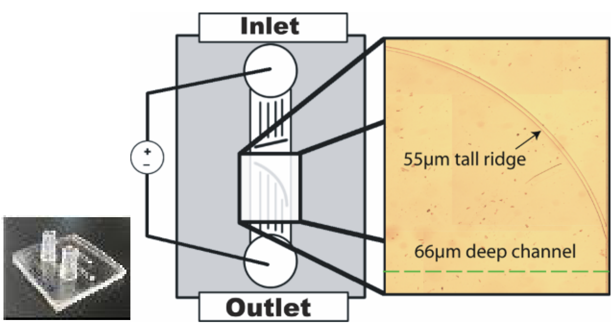

Figure 1. Overview of microdevice. Left: picture of device. Middle: schematic of device with location of electrodes. Right: blowup of region with curvilinear ridge.

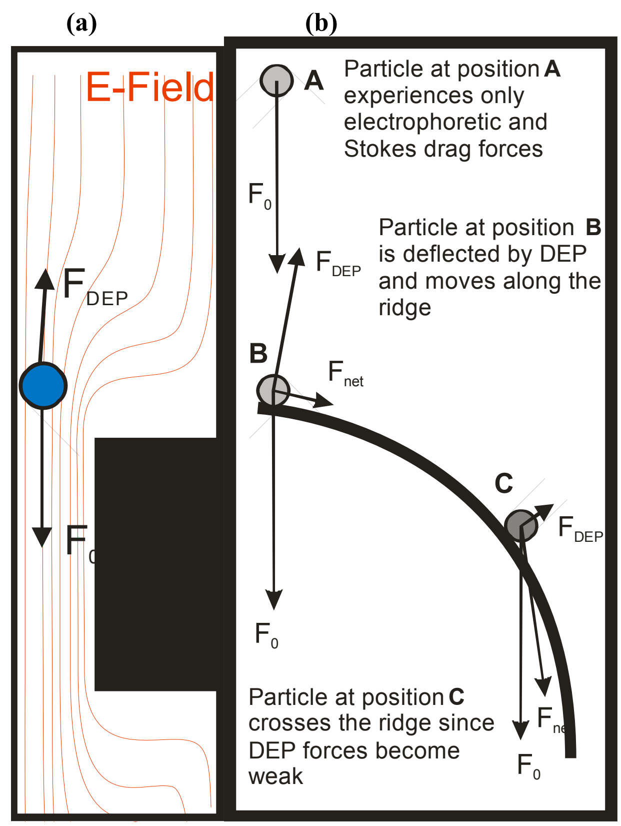

Figure 2. (a) Side view of ridge, showing constriction and attendant increase in local electric field. F_0: motive force on particle in absence of DEP. F_{DEP}: DEP force away from high electric field region. (b) Top view of microdevice, showing forces on a particle as it approaches and moves

to be overcome (Figure 2b). Since this position is a function of the dielectrophoretic properties of the particle, the resulting downstream flow thus consists of a distribution of particles in which the particle dielectrophoretic mobility varies continuously across the channel cross-sectional area. This distribution can then be routed to multiple outlets, and specific subpopulations can be analyzed.

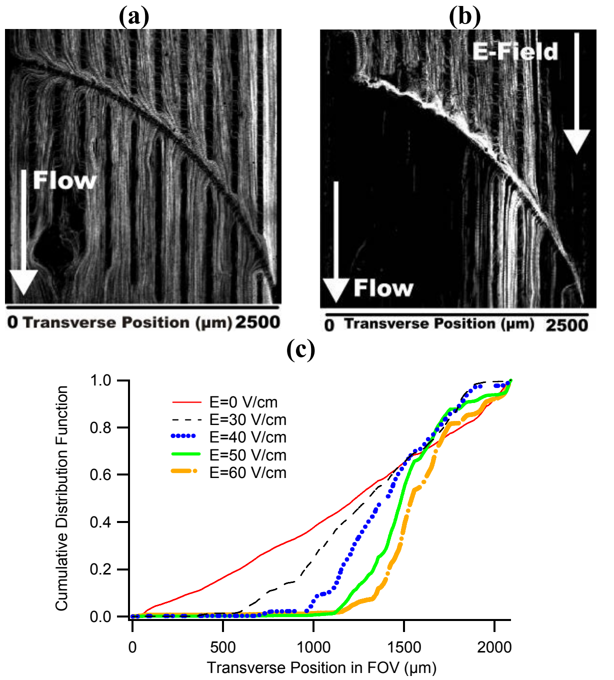

Figure 3. Effect of electric field on particle distributions. (a): uniform distribution at E=0. (b) Electric field (E=50 V/cm) causes particles to be deflected to right. (c) Cumulative distribution functions for particles as a function of electric field show a continuous shift of particles as electric field is increased.

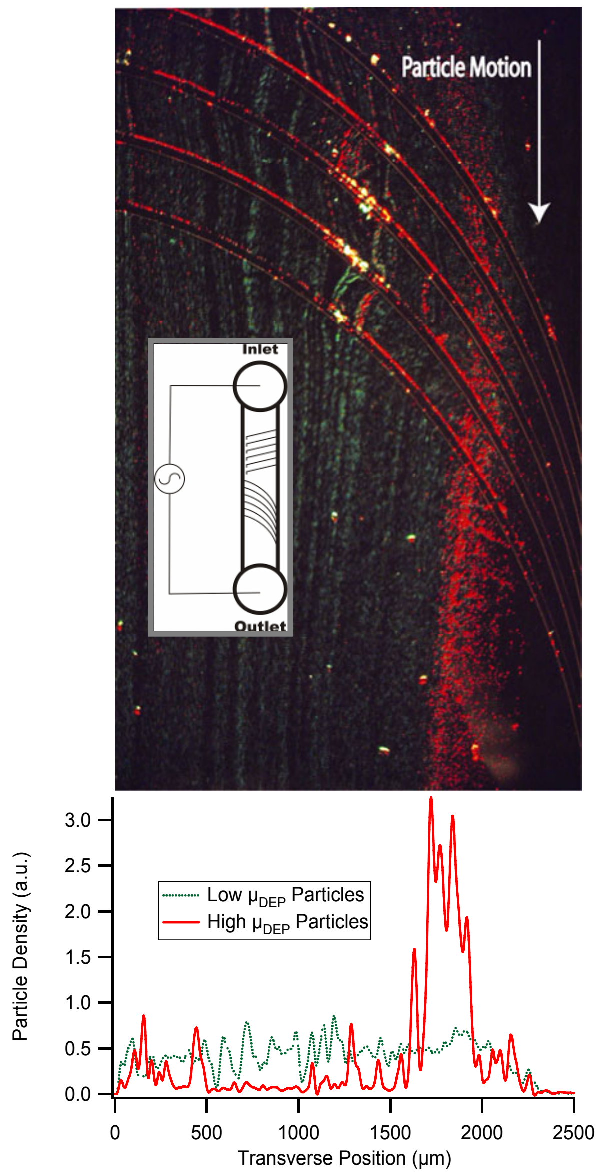

Figure 4. Particles sorted by DEP mobility. Fluorescence micrograph (top) shows deflection of particles with high DEP mobility along the curvilinear ridges (18V/cm DC + 600V/cm AC). The inset diagram illustrates the redundant ridge layout. Time averaged particle density scans (low pass filtered) show the deflection dependence on dielectrophoretic mobility.

RESULTS AND DISCUSSION

Tuning of the externally-applied electric field was used to precisely control particle deflection and distribution in flow-through systems. Inverted microscopy was used to monitor particle distributions during their flow over a curvilinear ridge (Figure 3). In the absence of an electric field, pressure driven particle distributions are uniform (Figure 3a). However, when a potential is applied between the system reservoirs, particles are deflected to the rightmost region of the field of view (Figure 3b). Precise control of this deflection is demonstrated by varying the electric field and monitoring the changes in the particle distribution (Figure 3c). These experimental results indicate that particle deflection can be controlled continuously by tuning the applied electric field.

Dielectrophoresis can be used to sort a mixed input stream into its constituents (Figure 4). In contrast to the previously presented results, which utilized pressure driven flow, this experiment transported the particles through the device using a small DC offset to an AC signal. It also made use of a redundant ridge design that minimizes the impact of individual ridge defects have on particle deflection. A mixed input stream of particles with different dielectrophoretic mobilities was introduced, and the DC-biased AC field was used to induce deflection in one of the two particle types. Thus the particles with high dielectrophoretic mobility are deflected to the right side of the field of view while the particles of low dielectrophoretic mobility are unaffected.

CONCLUSIONS

This electrodeless device design has been shown effective in both DC and DC-biased AC applied fields. As has been noted previously [2,4], electrodeless configurations eliminate micro-fabricated electrodes and the fouling attendant with their use. In the DC case, it is shown that particle deflection is controlled at fields as low as 30 V/cm, presenting the potential use of cell growth media as the running buffer without concern for Joule heating. In the AC case, it is shown that particles can be sorted in continuous-flow by their dielectrophoretic mobilities. AC fields effectively decouple the electrokinetic and dielectrophoretic particle response (accomplished in the DC case through electroosmotic flow suppression combined with pressure-driven flow). This capability, coupled with the ability to vary frequency, enables the future sorting of particles by their frequency dependent dielectrophoretic mobilities. Both cases transduce DEP mobility to position, using DC or AC fields, effectively demonstrating the viability of this design for a variety of applications.

ACKNOWLEDGMENTS

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REFERENCES

[1] G. Fuhr et al, , Biochimica et Biophysica Acta, 1201, 3 (1994).
[2] C.F. Chou and F. Zenhausern, IEEE Eng. in Medicine and Biology Magazine, 22, 6 (2003).
[3] B.H. Lapizco-Encinas, et al, Analytical Chemistry, 76, 6 (2004).
[4] E.B. Cummings and A.K. Singh , Analytical Chemistry, 75, 18 (2003).
[5] C.F. Chou et al, Biophysical Journal, 83, 4 (2002).
[6] L.M Barrett, Micro Total Analysis Systems, Boston, MA, October 9-13, 2005, Transducer Research Foundation, Inc. (2005), 1404-1406.
[7] E.B. Cummings, Ieee Engineering in Medicine and Biology Magazine, 22, 6 (2003)