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Bipolar electrode depletion: membraneless filtration of charged species using an electrogenerated electric field gradient

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6 pages

Experimental Section

Chemicals. Poly(dimethylsiloxane) (PDMS) channels were prepared using a Sylgard 184 elastomer kit obtained from K. R. Anderson, Inc. (Morgan Hill, CA). Au-coated glass slides (100 nm thick, no adhesion layer) were purchased from EMF Corp. (Ithaca, NY). The fluorescent tracers were 4,4-difluoro-1,3,5,7,8-pentamethyl-4-bora-3a,4a-diaza-s-indacene-2,6-disulfonic acid, disodium salt ($BODIPY^{2-}$, Invitrogen Corp., Carlsbad, CA) and Rhodamine B (RhB, Sigma-Aldrich, Milwaukee, WI). Photoresist (AZ 4620) and developer (AZ 421 K) were purchased from AZ Electronic Materials (Somerville, NJ). All chemicals were used as received. Deionized water having a resistivity greater than 18 MΩ-cm was used for all experiments (Milli-Q gradient system, Millipore, Bedford, MA).

Microfluidic device fabrication. Device fabrication has been described previously.[1,2] Briefly, the driving electrodes and bipolar electrodes (BPEs) were patterned onto the glass base of the microfluidic device using standard photolithographic techniques. The driving electrodes consisted of microfabricated Au disks located at the bottoms of the two reservoirs. They were connected to a power supply via external contacts. The microchannel contained an array of 16 gold microband electrodes consisting of 30 μm-wide lines evenly spaced throughout the 6 mm long microchannel. These were used to form the BPEs and measure

the electric field gradient. The microbands had external contacts so that any two could be connected to form a BPE.

Microchannels were fabricated in PDMS using a previously described replica molding procedure.[2,3] Briefly, a microfluidic channel (6 mm long, 100 μm wide, and 21 μm high) spanning two 5.0-mm diameter reservoirs was fabricated from PDMS. The PDMS was rinsed with ethanol and dried under N_2, and next both the PDMS and the glass slide supporting the Au electrodes were exposed to an O_2 plasma (60 W, model PDC-32G, Harrick Scientific, Ossining, NY) for 30 s on the medium power setting. After joining the PDMS replica and the glass slide, the entire assembly was placed in an oven at 65° C for 5 min to promote irreversible adhesion.

Instrumentation and data acquisition. Fluorescence images were obtained using a Nikon AZ100 microscope (Nikon Co., Tokyo, Japan) equipped with a mercury lamp (Nikon) and a CCD camera (Cascade, Photometrics Ltd., Tucson, AZ). Micrographs were processed using V++ Precision Digital Imaging software (Digital Optics, Auckland, New Zealand). Images were captured using 1:1 binning with 512 x 290 pixels and a 1000 ms exposure time.

BPE depletion/filtration experiments. Prior to each depletion experiment, the microfluidic channel was rinsed by introducing 80.0 μL of deionized water into the anodic reservoir and 15.0 μL into the cathodic reservoir. Deionized water was

allowed to flow through the microchannel for 20 min in response to the solution height differential (pressure-driven flow, PDF). Next, the rinsing solution in each of the reservoirs was replaced with 80.0 μL of 100 μM $BODIPY^{2-}$ in deionized water.

The depletion experiments themselves were carried out as follows. First, two microband electrodes having the desired center-to-center separation (2,000 μm) were connected via a conductive wire. Second, a driving voltage (E_{tot} = 20.0 V) was applied across the microchannel using a high-voltage power supply (LLS9120, TDK-Lambda Americas, Inc., San Diego, CA) connected to the microfabricated gold driving electrodes. Fluorescence micrographs were obtained as a function of time. The BPE filtration experiments were carried out in the same manner as the depletion experiments except that the anodic reservoir was filled with a mixture of 100 μM $BODIPY^{2-}$ and 100 μM Rhodamine B in deionized water, the cathodic reservoir was filled with deionized water only, and the microscope filter was alternated between the $BODIPY^{2-}$ and RhB filter every 10 s so that the transport of each dye could be selectively imaged.

Electric field profile measurements. The axial electric field profile within the channel was monitored using a scanning digital multimeter (SDMM, Model 2700, Keithley Instruments, Inc., Cleveland, OH) equipped with a multiplexer module (Model 7701, Keithley) connected to all the microband electrodes except

those defining the BPE. The SDMM was controlled with Microsoft Excel via the software provided by the SDMM manufacturer (ExceLinx, Keithley). The SDMM was interfaced to the microband electrodes through a breakout board (screw terminals). The SDMM reads the voltage difference between pairs of microbands in sequence. The acquisition time for each voltage measurement was ~0.1 s, and the voltage between pairs of microbands was read every 2.0 s. Electric field monitoring experiments proceeded as follows. First, the two halves of the BPE were connected via a conductive wire. Second, the SDMM was placed into scan mode. Third, a driving voltage (E_{tot} = 20.0 V) was applied across the microchannel via the driving electrodes. The captured data were stored and plotted as voltage differences between each microband pair vs. time in real-time using Excel.

Movie Files

Two movies are provided. Movie S1 shows the entire experiment from which the data in Figure 1a (main text) were extracted. This movie shows depletion of $BODIPY^{2-}$ from the microchannel during the first 60 s after application of E_{tot} = 20.0 V. A 2.0 mm-long BPE was situated in the center of the microchannel, and the initial $BODIPY^{2-}$ concentration was 100 μM. Movie S2 shows an experiment performed under the same conditions as Movie S1,

except E_{tot} = 120.0 V. The higher value of E_{tot} resulted in the channel depleting in 15 s.

References

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