The 2014 Colin G. Fink Summer Research Fellowship – Summary Report

Advanced Microfluidic Pumping at Poly(3,4-ethylenedioxythiophene)-Modified Electrodes via AC-Magnetohydrodynamics

by Christena K. Nash

A paradigm shift in microfluidic pumping using redox-magnetohydrodynamics (MHD) that preserves its advantages and resolves problems that previously slowed its application in analytical chemistry (for pumping small volumes and sustaining fluid flow) is demonstrated herein. Miniaturization of chemical analysis for lab-on-a-chip (LOAC) devices offers portability and automation with less power, reagent and waste volumes, and analysis time. A crucial feature is the programmable manipulation of fluid within the device. MHD microfluidics can provide continuous pumping without channels or moving parts and can stop or reverse fluid flow without the need for valves by switching off *or* changing the sign of the ionic current, respectively.[1] The magnetohydrodynamic force, $\mathbf{F_B}$ ($N \cdot m^{-3}$), and therefore fluid flow, is generated by the ionic current density, $\mathbf{j}$ ($C \cdot s^{-1} \cdot m^{-2}$), when perpendicular to a magnetic field, $\mathbf{B}$ (T), and follows the right-hand rule according to the cross-product relationship, $\mathbf{F_B} = \mathbf{j} \times \mathbf{B}$.[2-5] In previous studies, we have shown that electrodes modified with poly(3,4-ethylenedioxythiophene) (PEDOT) are capable of high currents while limiting the interaction with the sample, thus improving compatibility. However, use of PEDOT-modified electrodes limits redox-MHD pumping to short times because it cannot sustain the current once charge transfer in the film is completed, unlike diffusion-limited redox species in solution. The device used in this study takes advantage of the highly reversible nature of PEDOT to sustain redox-MHD over indefinitely long periods by recycling PEDOT in real time.

This study used an array chip with microband and microdisk-ring electrodes (Fig. 1) and a solution confined over them with a gasket and lid. Polystyrene latex beads (10 μm) added to the electrolyte solution allowed visualization of fluid movement using video microscopy. The chip was placed on an electromagnet with a magnetic field (0.033 T RMS) perpendicular to the chip. The electrodes were modified with a conducting polymer, PEDOT, instead of redox species added to solution, to generate an ionic current from the electrochemical reaction at the films, avoiding bubble formation and electrode corrosion. Synchronized sinusoidal potential waveforms applied to PEDOT-modified electrodes (producing an AC current) and the electromagnet (producing an AC magnetic field) allowed continuous pumping in a single direction while charging and discharging the films. Only 10 Hz was needed, drastically minimizing heating compared to prior AC MHD studies, while generating high currents. The resulting fluid velocity (115 $\mu m\ s^{-1}$) and flat flow profile between the PEDOT-modified band electrodes are comparable to those under DC conditions, when redox species are present in solution.[6] Spiraling fluid flow with a speed as high as 350 $\mu m \cdot s^{-1}$ (Fig. 2) at PEDOT-modified concentric disk-ring electrodes attained 10 times the speed achieved with redox species in solution previously, and holds promise for mixing applications.[7]

In this study, a new microfluidic technique, AC redox-MHD, was investigated that sustains linear and rotational microfluidic pumping through synchronized variations in ionic current, generated by PEDOT-modified electrodes, and the magnetic field, generated by an electromagnet. Future work will focus on using AC redox-MHD in lab-on-a-chip applications.

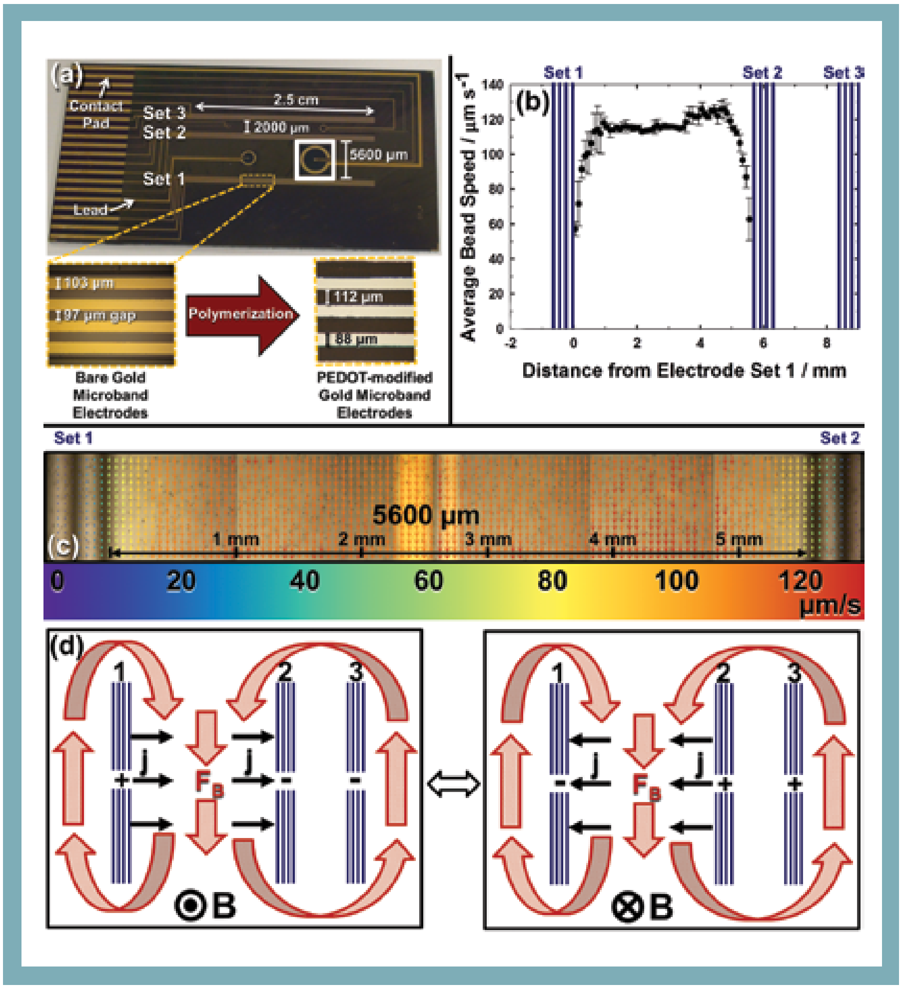

Fig. 1. *(a) Photograph of the microelectrode array chip showing electrode features and dimensions. Expanded images show unmodified gold and PEDOT-modified gold band electrodes as viewed under a microscope. During the AC MHD experiments, electrode set 1 (working), and sets 2 and 3 (combined auxiliary/quasi-reference) were active. Set 1 was oppositely biased from sets 2 and 3. (b) Fluid flow profile based on bead speeds in the 5600 μm gap between PEDOT-modified microband electrodes. Error bars represent ± one standard deviation. (c) Particle image velocimetry (PIV) data from which points in (b) were obtained. (d) Vectors involved in AC-MHD for synchronized electrical and magnetic fields to maintain flow in a single direction.*

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About the Author

Christena Nash recently defended her dissertation, *Modified-Electrodes for Redox-Magnetohydrodynamic (MHD) Pumping for Microfluidic Applications*. She received her doctorate from the University of Arkansas under the direction of Ingrid Fritsch. She may be contacted at cknash5@gmail.com.

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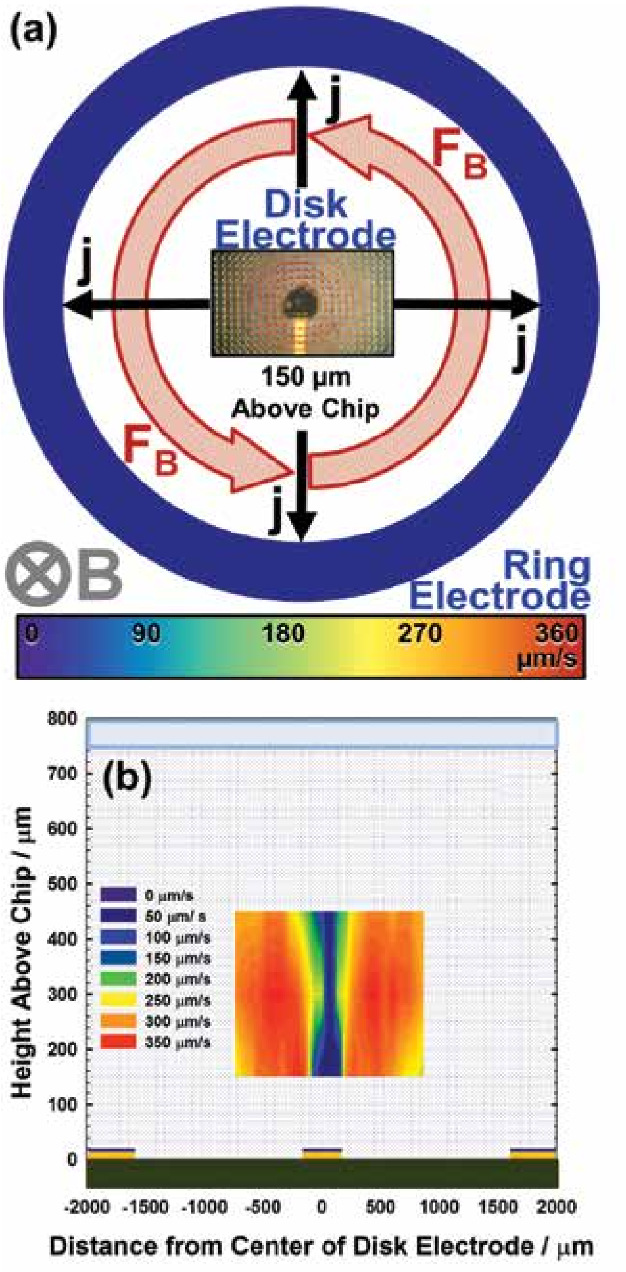

Fig. 2. *(a) Schematic of the rotational flow concept with a PIV image of fluid flow recorded around the disk electrode at 150 µm above the chip. During AC MHD experiments, the disk and ring electrodes were both active, but oppositely biased. (b) Contour plot of magnitude of velocity (its direction is shown in (a)) reveals the flow profile around the disk electrode throughout the height of the cell.*