Ionic Transportation through DNA-based Nanochannels

Paul Bertani[1], Corey Beck[2], Xi Zhao[3], L. James Lee[3], Sherwin Singer[2], Wu Lu[1,4]
[1]Department of Electrical and Computer Engineering, [2]Department of Chemistry, [3]Department of Chemical Engineering, The Ohio State University, Columbus, OH 43210; [4]Department of Nanobio Materials and Electronics, Gwangu Institute of Science and Technology, Korea. lu@ece.osu.edu

Nanofluidic devices offer great promise for development of rapid, specific, and portable sensors to detect chemical and biological threats. Electrokinetic manipulation of aqueous electrolytes can be used to control intake of environmental or biological fluids, and achieve separation of target analytes. Despite many technological achievements, however, electrokinetic processes are still understood using effective models that, while very useful for organizing experimental data, do not reflect underlying atomic reality. Here we present a polymer-based nanochannel array for ionic transport study at the nanometer scale. The nanometer scale channels are fabricated via a DNA stretching technique utilizing Polydimethylsiloxane (PDMS) stamps[1-2]. DNA bundles are stretched into nanowires across ridges between micron scale "feeder" channels, and a low-viscosity polymer is cured around them, embedding the DNA nanowires within the polymer matrix (Figure 1). This forms a device with an array of microchannels converging into nanochannels between them with reservoirs feeding the microchannels at both ends (Figure 2). A bias can then be applied to evaluate changes in conductivity. While common ions are able to translocate through the nanochannel, other larger molecules (> 1.4 nm) cannot pass or are slowed nearly indefinitely. Ion translocation is facilitated and verified a bias and conductivity change respectively. Figure 3 illustrates electrical measurements showing an approximate current level of 3 pA that is stable for a long period of time (indicating stable ion translocation), while background current levels remain at the femto-ampere scale (no translocation). Prior to measurements, the device is saturated with solution via a vacuum process in order to ensure all viable channels are completely filled with liquid. For the shown case (Figure 3), low ionic levels are used.

Navier-Stokes approximations using modeling software indicate that ion velocity approaches zero as radius approaches 1.08 nm, where as molecular dynamics simulations show a non-zero ion velocity (approximately 1 m/s) at smaller radii (Figure 4). Based on DNA bundle dimensions[1] and biological geometry, we calculate our actual channel dimensions to be approximately .75 nm. It should be noted however, that this is an indirect channel due to the serpentine nature of DNA. Using simulation ion velocities and charge concentrations, the theoretical current value falls at approximately 7-8 pA, compared to the experimental value of 3 pA.

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[1] J. Guan, L. J. Lee, PNAS **102**, 18321 (2005).
[2] J. Guan, B. Yu, L. J. Lee, Adv. Mater. **19**, 1212 (2007).

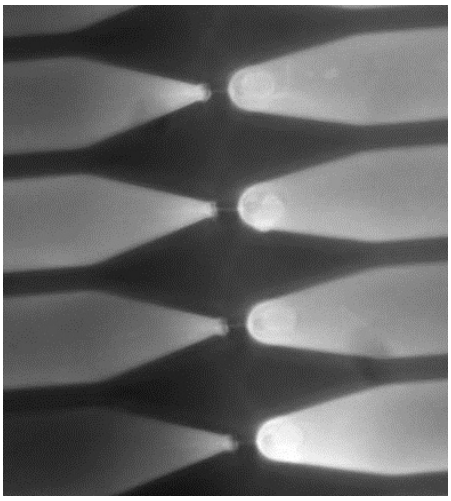


Figure 1: Micro and Nanochannel Array: Shown is the microchannel array feeding into the DNA nanochannel array via optical microscope. Nanochannels are highlighted via fluorescence.

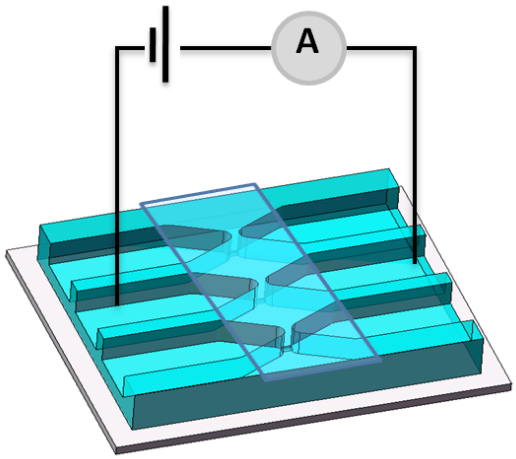
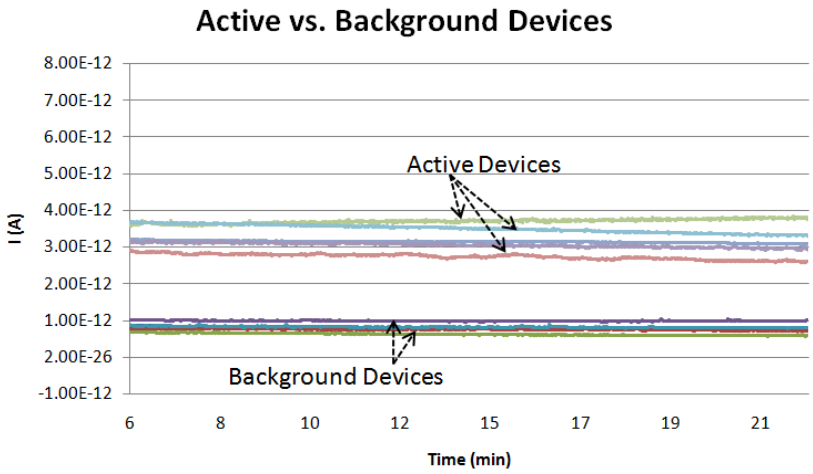


Figure 2: Device Layout: The nanochannels are embedded in the polymer matrix while the microchannels are sealed off from each other using a PDMS seal.



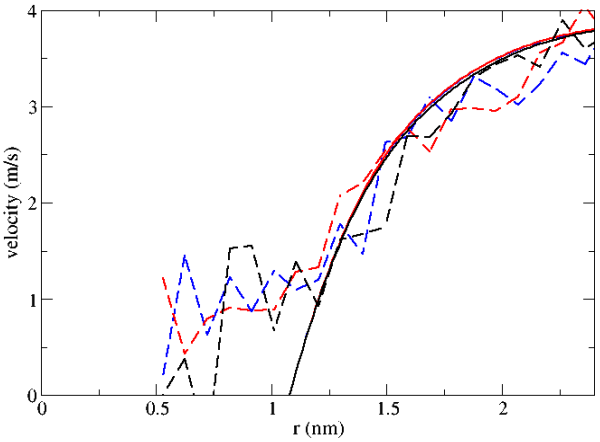


Figure 3 (above): Current Measurements: "Active Devices" correspond to devices actively translocating ions, while "Background Devices" correspond to devices not translocating ions. The bias used is 10 V.

Figure 4 (left): Molecular Dynamics Simulation: The solid lines represent standard Navier-Stokes and the dashed lines represent molecular dynamics simulations noting non-zero ion velocity at $r < 1.08$.