Actively Controlled Ionic Current Gating in Nanopores

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Abstract

Introduction: It is necessary to understand and control nanopore behavior in order to develop biosensors for a variety of applications including DNA sequencing. The fluidics of nanopore devices we fabricated exhibits a range of interesting phenomena, such as enhanced conductance and current rectification. Typical rectifying nanopore devices must be chemically modified to produce characteristic behavior. The conductance of a device is usually a fixed function of the nanopore geometry, materials, and the fluid. By electrically biasing nanopores, we were able to actively control the nanopore conductance in real time and induce a gated, non-conducting state.

Use of COMSOL Multiphysics®: A conical nanopore model consisting of Si3N4 and gold layers in an aqueous solution was constructed (Figure 1) using COMSOL Multiphysics®. The Poisson equation was solved of the pore and solution. The Si3N4 layer carried a constant surface potential due to the material work function while the potential on the gold layer swept was through a range of biases. The fluid was modeled with the Nernst-Planck and Navier-Stokes equations as a KCl solution. The Nernst-Planck and Navier-Stokes equations were coupled by a volume force.

Results: The modeled pore behavior closely approximated the analogous experimental results (Figure 2). The ionic conductance was proportional to the bias applied to the gold layer. Under a positive bias, the pore current was gated and a non-conducting state was reached. The conductance of the pore in the on-state was dependent on the pore geometry and applied bias.

The differences in potential between the biased and unbiased surfaces of the nanopore are responsible for the characteristic behavior of the nanopore. In the conducting state, the potential difference creates an internal electric field that drives conductance through the pore. When the surfaces have opposite polarity, opposing screening charges in the double layer lock the pore in a non-conducting state.

Conclusion: A nanopore with externally modifiable and gateable conductance was produced and analyzed. An internally generated electrical field modulated the conductance of the pore independently of the cross-membrane potential. Opposing charge selective regions in the diffuse layer created a non-conducting state. Active electrical modification of the pore will allow pore conductance to be controlled in spite of physical variations between pores. Such control is desirable where conductance may influence sensitivity and acquisition rate in biosensors. The

ability to gate the pore electrically suggests the possibility of creating valves and electrofluidic logic gates in nanofluidic systems.

Figures used in the abstract

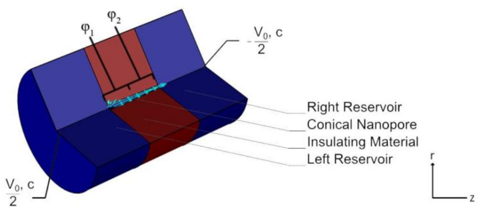

Figure 1: The rotated axisymmetric pore/solution geometry. The potentials V0 and were held constant while was varied.

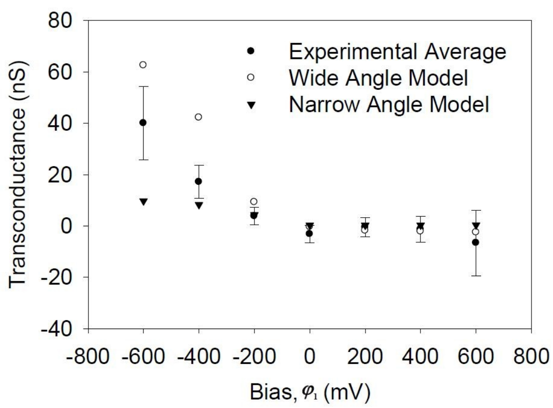

Figure 2: The conductance of the pore system from numerical and experimental studies. Under negative bias, the conductance is proportional to the applied bias while a positive bias induces a non-conducting state.

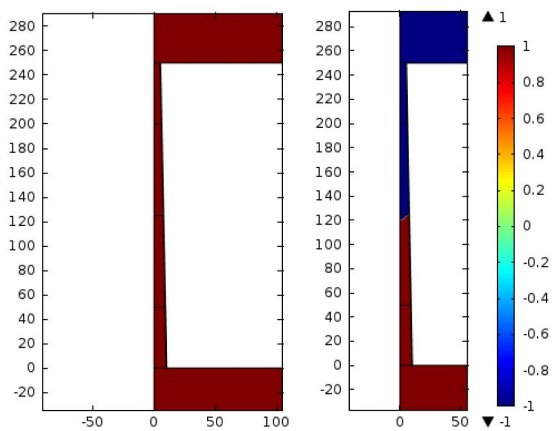

Figure 3: polarity of the electrolyte solution in the conducting (left) and non-conducting (right) configurations.