Fabrication and Characterization of Field Effect Reconfigurable Nanofluidic Ionic Diodes: Building Blocks Towards Digitally-Programmed Manipulation of Biomolecules

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With applications ranging from biosensing to the control of molecular transport, synthetic nanopores and nanochannels are the focus of growing scientific interest. [1] Analogous to a solid-state semiconductor diode for regulating the flow of electrons/holes to one preferential direction, nanofluidic diodes are being developed to achieve the rectified ionic transport. Such rectification effect is of great importance due to its relevance to biological ion channels. Moreover, ionic diodes, together with ionic transistors represent the key building blocks for ionic circuits, mimicking voltage-gated ion channels in a variety of biological systems.

Several nanofluidic platforms based on nanopores and nanochannels were reported to produce ionic current rectification. Nevertheless, it has not been possible to change the predefined rectifying properties obtained by these approaches once the devices are made. Although several externally tunable methods have been proposed so far, most of them aim to alter the nanochannel wall property by introducing external chemical stimuli, for example, hydronium ions (pH), enzymes and polyvalent cations. All these methods require changing the native environment of the solution being transported. Contrary to the chemical stimuli-responsive schemes, an electric field normal to the nanochannel walls is able to enhance or diminish the ionic concentrations near the surface in situ, resembling the carrier number modulation in a metal-oxide-semiconductor field effect transistor (MOSFET).

Here we report a field effect reconfigurable ionic diode by asymmetrically modulating the cation/anion ratios along the nanochannel. A key feature of our device is that it allows the post-fabrication reconfiguration of the diode functions, such as the forward/reverse directions as well as the rectification degrees. These results may lead to the creation of reconfigurable ionic circuits, an ionic counterpart of the electronic field-programmable gate array (FPGA).

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[1] van den Berg, A., Craighead, H. G. & Yang, P. D. From microfluidic applications to nanofluidic phenomena. Chem. Soc. Rev. 39, 899-900 (2010).

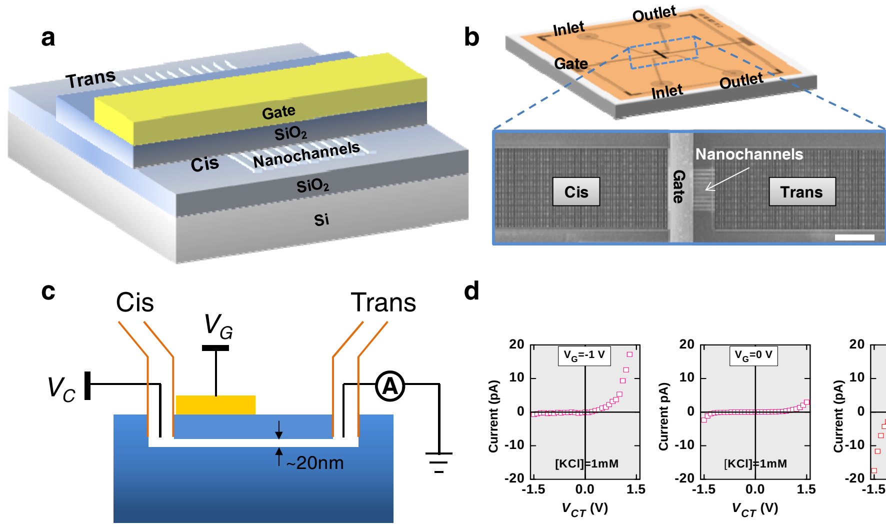

Figure 1: Device structure and experimental setup. (a) Schematic of the nanofluidic field effect reconfigurable diodes (FERD). (b) Sketch of the planar layout for the assembled device. Two microfluidic channels deliver the electrolyte solutions to the Cis and Trans reservoirs, formed by SiO_2 trenches with supporting pillars, as shown in the magnified scanning electron microscope image. The scale bar in the SEM image is 100 µm. There are 11 parallel nanochannels connecting Cis and Trans reservoirs. The supporting pillars prevent the PDMS from collapsing into the reservoirs. (c) Schematic of the electrical and fluidic connection configurations. The electrical contacts are made of Ag/AgCl electrodes and are integrated with the connecting tubes, serving as a low resistive loss contact. V_G and V_C denotes the voltage on the gate and Cis, respectively. The Trans side is referenced as ground in all measurements in this study. The whole setup is placed in a Faraday cage to shield the electrostatic noise. (d) Typical I_{CT}-V_{CT} curves at different gate voltages V_G (-1V, 0V, +1V), for a given ionic concentration (1mM) with a dual gate device.