LiCl), pores conduct no current at low voltages, but finite current above a voltage threshold for negative polarities. However, ion solutions with large anions (KBr and KI) display finite current for all probed voltages. This finding provides evidence that the enhancement of $Br^-$and I^- at the hydrophobic end facilitated pore wetting. The experimental observations were supported by first-principles simulations that revealed a weaker solvation shell of the large anions, Br^- and I^-, compared to that of Cl^-. The weaker solvation made the large anions more prone to migrate to a hydrophobic surface from the aqueous solution. Our findings are crucial for constructing nanoporous materials that show ion-size selectivity.

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Ionic Amplifying Circuits Inspired by Electronics and Biology

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Biological ion channels are a fundamental component of all cells and enable an immense amount of processes which are essential for life. Some of these channels possess inherently low conductance, producing currents below the shot noise limit that cannot be measured with current electronic technology. Sodium glucose cotransporters (SGLTs), in particular, play a key role in the dietary uptake of glucose transports in the small intestine. A single SGLT produces currents on the order of 10^{-2} fA. One possibility to measure this miniscule current is to ionically amplify biological channel output before measuring it electronically. Thus through electronics and biology, we were inspired to create an abiotic, fully ionic, nanoscale bipolar junction transistor. To further increase amplification, a circuit known from electronics as the Darlington amplifier is then employed. In this arrangement the amplified output of one transistor is used as the input for a second transistor. Through this usage, the amplification can be increased to more than the product of the individual device amplifications. The circuits we report function at gate voltages < 1 V, respond to sub-nA gate currents, and offer ion current amplification with a gain up to $\sim$300. Ionic amplifiers will enable probing new biochemical processes, and mimicking of physiological amplification processes, among others.

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Biomimetic Signal Propagation in a Two-Pore Solid-State System

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A key characteristic of excitable ion channels is the ability to interact with neighboring pores so that localized environmental stimuli can initiate complex large-scale responses, such as an action potential propagating along a neuron. In the case of a nerve signal, this is accomplished through local changes in the membrane voltage and ion concentration inducing nearby pores to change conductance states. The replication of this behavior in synthetic nanopore platforms has the potential to enable new responsive materials useful for biomimetic componentry, drug delivery and filtration technologies. While gating has been demonstrated in synthetic nanopores, previous fabrication methods make it difficult to incorporate such pores into more complex systems due to lack of control over key attributes such as pore location. Here, we fabricate two neighboring nanochannels with controlled spacing such that the transport through one pore can induce a change in conductance of a neighboring pore which has been chemically modified to be ion concentration responsive. The two-pore system is made using focused ion beam nanomachining followed by ion-beam-controlled deposition of SiO_x around one pore entrance. Chemistry selective for SiO_x is then used to graft single stranded DNA only to the regions where the local deposition was performed providing a final platform that enables local control over the location, size, shape and surface chemistry of each pore in the system. The pore-pore interaction is measured through a step-like increase of the total current passing through the SiN_x membrane vs time following a change in applied voltage. We explore the effects of voltage and bulk ionic concentration on the way the inter-pore signal behaves. This successful demonstration of a signal passed from one man-made pore to another is an important step towards the integration of nanopore technology into more complex multi-component systems.

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Electrode-Free Nanopore Sensing by Diffusioptophysiology (DOP)

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A wide variety of single molecules can be identified by nanopore sensing. However, all reported nanopore sensing applications result from the same measurement configuration adapted from electrophysiology. Electrophysiology measurements, which provide a superior temporal ($\sim$10 μs) and amplitude resolution ($<$0.1 pA), satisfy the need of single channel recording based applications but are disadvantageous in the throughput. Though urgently needed in nanopore sequencing and drug screening, simultaneous readout from 1 million channels has not been achieved without a significant sacrifice in the cost or the size of the device. Inspired by spontaneous transmembrane transports in nature, we present the first electrode-free nanopore sensing method defined as DiffusiOptoPhysiology (DOP), in which single molecule events are monitored optically without any electrical connections. Single molecule sensing of small molecules, macromolecules and biomacromolecules was subsequently demonstrated. As a further extension, a finger-tip sized, multiplexed chip has been introduced with a cost of less than $1 in consumables for a single use, which suggests a new concept of clinical diagnosis using disposable nanopore sensors. DOP, which is universally compatible with all types of channels and a variety of fluorescence imaging platforms, may benefit diverse areas such as nanopore sequencing, drug screening and channel protein investigations.

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Direct Observation of Single Biomolecule Hidden Behaviors by an Electro-Optical Nanopore

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Nanopores act as excellent single-molecule sensors which are capable of rapidly acquiring information of single molecules from the significant statistics. Plenty of pervious experimental and theoretical nanopore researches illustrated diverse single molecules motions and behaviours based statistical analysis and modelling. However, the challenge still remains in resolving and classification of each single molecules signals to uncover the precise motion behind the electrical response. Here, we employ a simultaneous electro-optical readout approach to interrogate each single molecule behaviours in confined spaces. By virtue of the high performance electron-multiplying charge coupled device camera (EMCCD) and the ultralow current amplifier, it could be easily achieved to record synchronous images of fluorescent dye labelled double stranded DNA (dsDNA) with current signatures of each single molecule interacting with the quartz nanopore in real-time. Different from conventional cognition for electrical read-outs, our results show that bumping events could contribute significant voltage-dependent current oscillation with a long dwell time, which usually hardly discriminates from the translocation events in conventional electric readouts. By real-time tracking the single-molecule motion, we further observed a cluster of distinct signals in several hundred microseconds originates from only one molecule repeatable blocked at the tip of the quartz nanopore instead of corresponding successive molecules translocation events. This result suggests that the DNA molecule undergoes complex conformation transitions at the opening of the nanopore to overcome the translocation barrier. By utilizing this simultaneous electro-optical readout strategy, around 5 types of different single molecule conformations could be distinguished from the current signals and the fluorescent images. This method paves a new path for nanopore sensing of individual single molecules motion which could also provide the visible evidence for further investigation.

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Dynamics of Laser-Assisted Silicon Nitride Dielectric Breakdown for Deterministic Fabrication of Solid-State Nanopore

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While the controlled dielectric breakdown approach has been demonstrated to be effective for various solid-state thin-film materials and provided an accessible nanopore fabrication for ordinary labs, considerable reliability challenges remain, particularly in controlling the number and location of the formed nanopore(s). The localized breakdown for nanopore fabrication often requires additional lithography patterning process, thus limiting its flexibility and tunability. Optical beams can be easily manipulated and tightly focused into a diffraction-limited spot size, offering an alternative approach for solid-state nanopore localization. In this work, we explored the laser-assisted deterministic dielectric breakdown. In particular, we studied the laser-assisted etching dynamics, and investigated the competitive effects of laser etching enhanced electric field and laser etching itself. We developed a physical model for projecting the confidence level of forming a single nanopore in the laser-assisted dielectric breakdown method. With this model, we studied and validated the impact of membrane thickness, membrane absorption coefficient and randomness of the system at different laser power and voltage on the confidence of deterministic fabrication. We anticipate our study would provide useful and practical insight for deterministic nanopore formation in dielectric breakdown.