Solid-state nanopore easy chip integration in a cheap and reusable microfluidic device for ion transport and polymer conformation sensing

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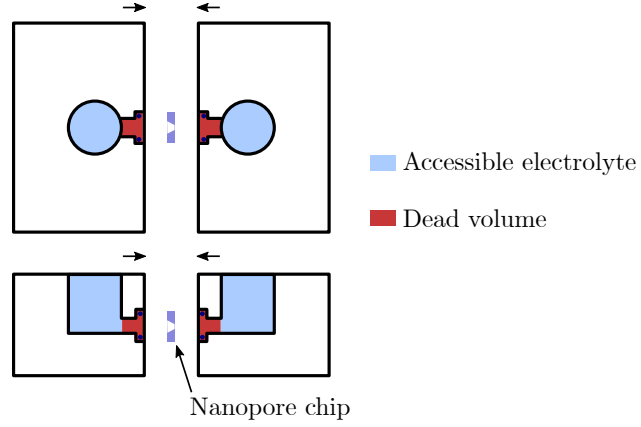
Traditional flow-cell

Figure S1: Schematic top and left view of a traditional solid-state nanopore chip integrating device.

Roughness measurement

We used a DekTak profilometer to obtain the shape and rugosity of the 3D-printed molds. We calculate both the average deviation R_a and the root mean square R_q of the profile height, calculated as:

$$R_a = \frac{1}{n} \sum_{i=0}^{n} |y_i|,$$
$$R_q = \sqrt{\frac{1}{n} \sum_{i=0}^{n} y_i^2}$$

(1)

, with y the height of the profile.
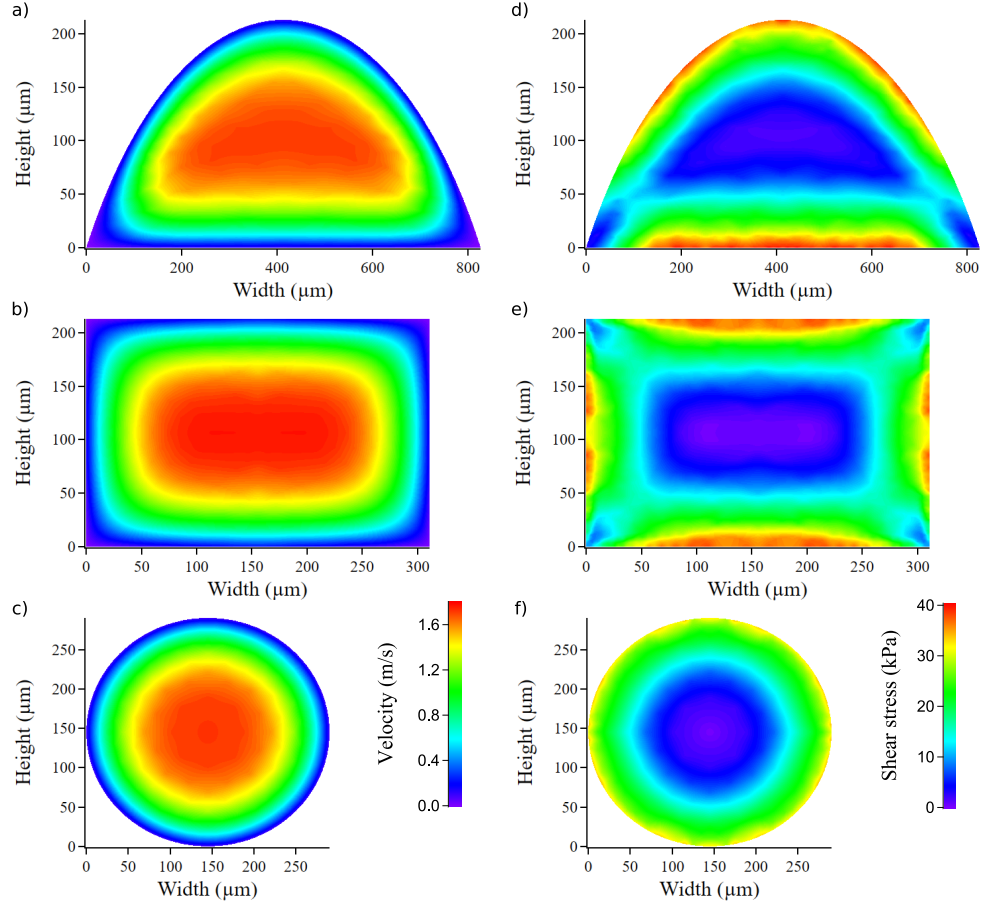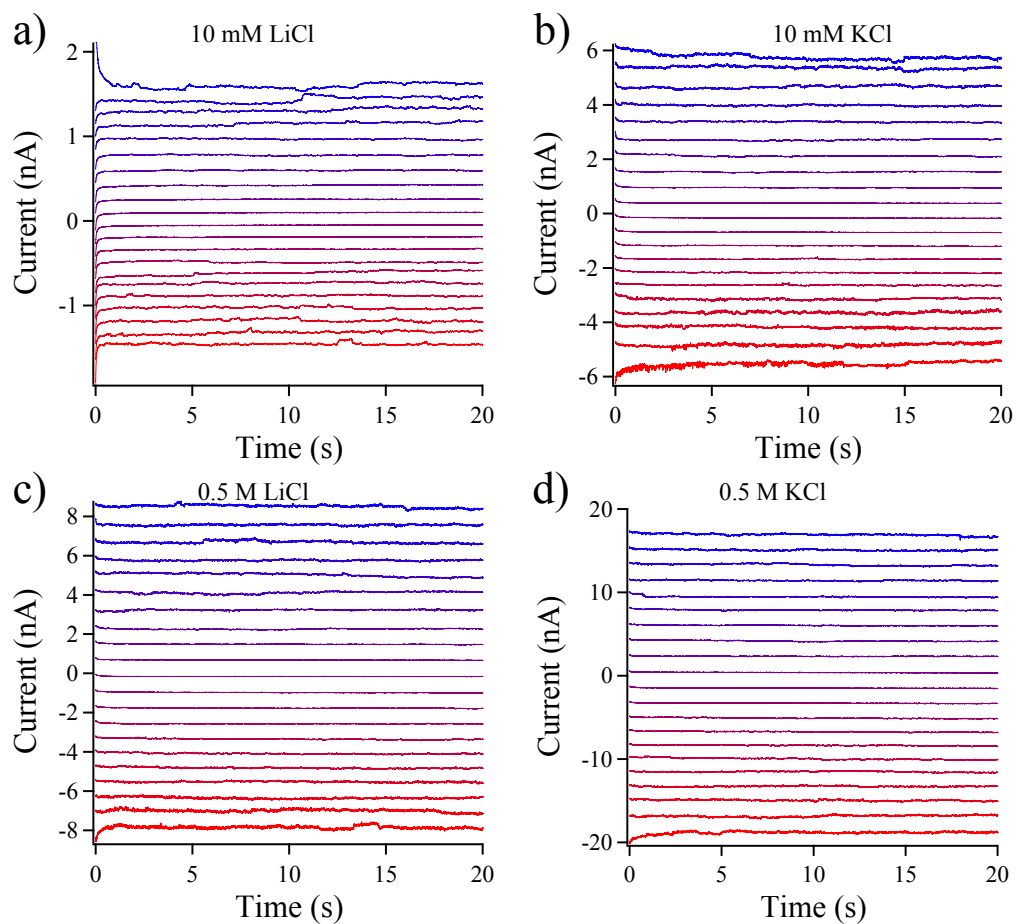
Flow simulation in microfluidic channels

Figure S2: Simulated flows in rectangular, hemicylindrical and cylindrical channels. a), b) and c) Flow speed in a section of, respectively, a rectangular, hemicylindrical and cylindrical channel. d), e) and f) Shear stress in a section of, respectively, a rectangular, hemicylindrical and cylindrical channel. In all simulations, the flow rate is kept constant to 0.68 mL/s as well as the section to 0.68 mm^2.

Nanopore polymer grafting

We follow a three step protocol to graft the polymer chains on the membrane.[1,2] Briefly, the first step is an UV/O_3 exposure to activate the surface of the Si_3N_4 membrane. Then, 3-chloropropyltrichlorosilane (Merck, Germany) is added as a precursor. Its small size ensures the homogeneity and high density of the grafting. Finally, the polymer is added. The second and third steps have to be done in anhydrous conditions to avoid any reaction between water and the chlorinated end of the precursor. The treated chips are then abundantly rinsed with water to evacuate non-grafted PEG chains off the membrane.

Current fluctuations with hairy nanopores

In figure 5a, we observe long fluctuations of the current in 10 mM LiCl. We obtain similar current traces with 10 mM KCl and 0.5 M LiCl or 0.5 M KCl (Figure S3). We plot the amplitude of these variations according to the voltage (Figure S4 a, b) in 10 mM LiCl/KCl and in 0.5 M LiCl/KCl. The height of these fluctuations increases linearly with the voltage. In Figure S4 c,d, we plot the relative variations of current versus the voltage. They are independent of the voltage at 10 mM LiCl/KCl and 0.5 M LiCl/KCl. They are larger in LiCl (1.2 ± 0.05 %) than in KCl (0.56 ± 0.02 %) at 10 mM. We observe the same behavior at 0.5 M in LiCl (0.42 ± 0.01 %) and in KCl (0.27 ± 0.01 %). These variations are very small and could be due to the grafted polymer chains.[3] At 10 mM, the deformation of these chains could be due to the counterion flow at the surface of the nanopore, considering that the Debye length controls the thickness of the electric double layer (3 nm at 10 mM).[4] At 0.5 M, the flow through the nanopore is governed by the ionic flow, which leads to smaller fluctuations than in 10 mM. As these variations are two times smaller in KCl than in LiCl, we could suppose that grafted chains are more attracted by the surface in KCl than in LiCl.

Figure S3: Current traces used versus voltage. Each trace in this graph corresponds to a voltage ranging from -200 mV (blue) to 200 mV (red) in a) 10 mM LiCl buffer, b) $10\,mM$ KCl c) $0.5\,M$ LiCl c) d) $0.5\,M$ KCl. The nanopore is 31 nm large and is grafted with PEG-7 kDa chains. All the solutions are buffered with 5 mM Hepes at pH 7.
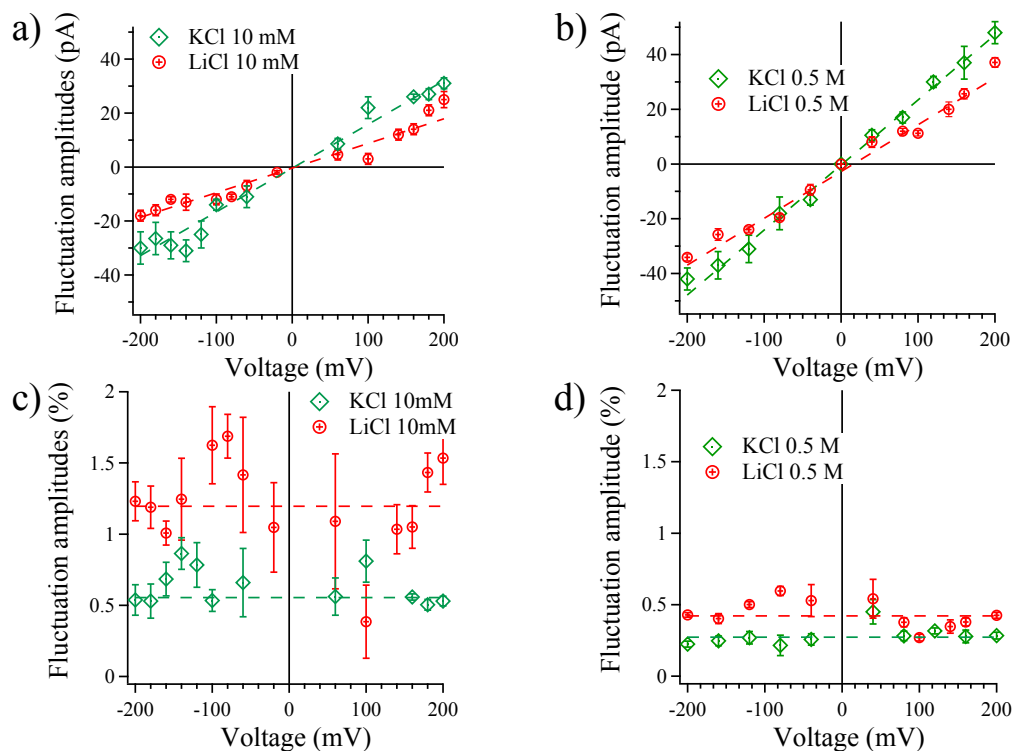
Figure S4: Fluctuations of current traces versus voltage. Amplitude of fluctuations in LiCl (red circles) or KCl (green diamonds) versus voltage a) at 10 mM, b) 0.5 M. Relative amplitudes of fluctuation in LiCl (red circles) or KCl (green diamonds) versus voltage c) at 10 mM, d) 0.5 M. The dotted lines correspond to linear fits. The nanopore is 31 nm large and is grafted with PEG-7 kDa chains. All the solutions are buffered with 5 mM Hepes at pH 7.
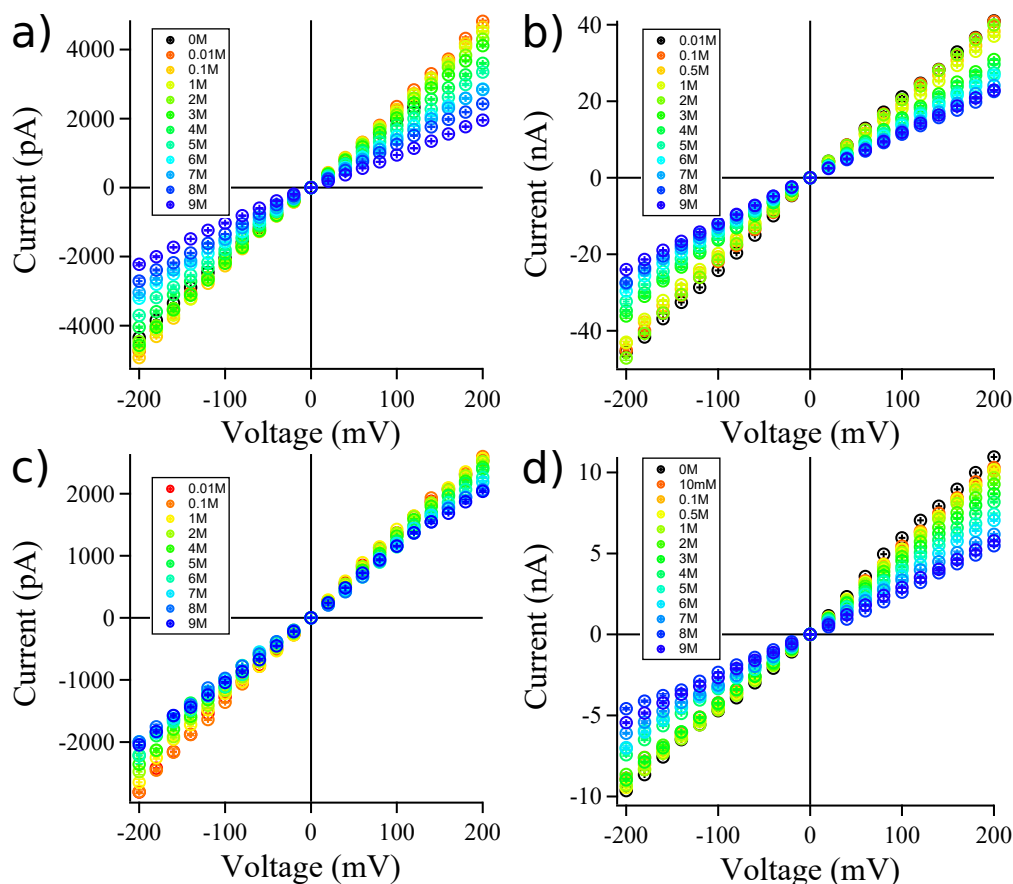
Conductance measurement in urea

Figure S 5: IV curves for different concentrations of KCl or LiCl and Urea. a) $10\,mM$ KCl b) $0.5\,M$ KCl c) $10\,mM$ LiCl d) $0.5\,M$ LiCl

References

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