SOLID-STATE NANOPORES

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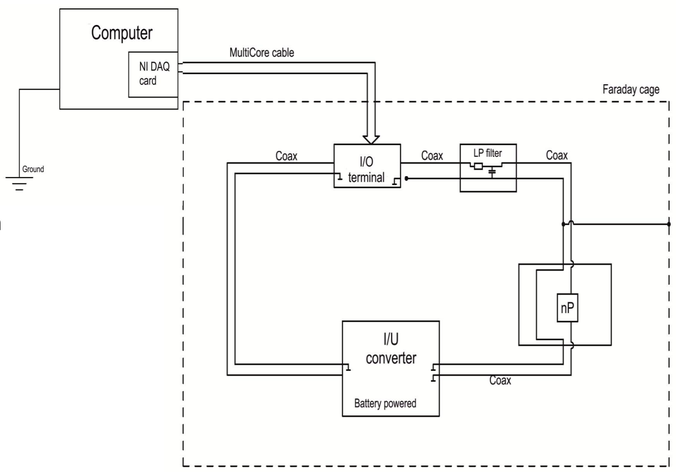
MOTIVATION

Solid-state nanopores have become a new single-molecule tool in biophysics. In comparison to biological nanopores, they offer many advantages due to their robustness, high stability, tunable pore size and potential for integration into devices. A precursor in the preparation of a nanopore is a thin, solid supported membrane of e.g. SiN (thinner than 20 nm) or ultrathin 2D materials like graphene or MoS2. Translocation of a macromolecule, e.g. DNA through a nm sized pore in such a thin membrane influences the ionic current of the surrounding electrolyte through the pore and electrical properties of the membrane itself. Both these transduction mechanisms provide single-molecule sensing capability and are being tested for an even finer role: DNA sequence readout - next generation DNA sequencing. Conventionally, nanopores are drilled in these membranes within a transmission electron microscope which is a tedious and resource intensive procedure. A latest development in this research field is a simple method of pore formation by the controlled dielectric breakdown of a membrane immersed in an electrolyte solution. We constructed a setup for nanopore characterisation and translocation measurements based on a commercial current preamplifier and some analog devices built in-house. It is also capable of performing the dielectric breakdown. We present the initial results on lambda DNA translocation events through a nanopore made in 20 nm SiN membrane by dielectric breakdown.

NANOPORE RECORDING SETUP

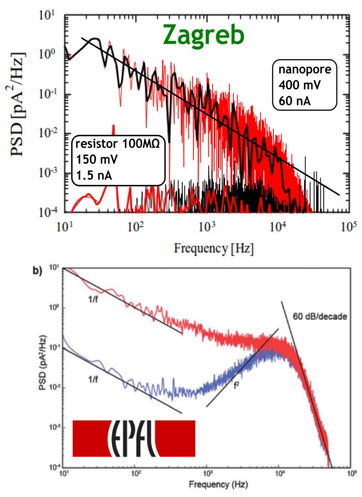


DAQ card: voltage source and readout, sampling rate 100 kHz
I/U converter - low noise current preamplifier SR570; 30kHz bandwith lowpass filter - passes only translocation events >0.1ms.
Low Pass filter for DAQ intrinsic noise
Vibrations isolation table to minimize triboelectric noise
battery powered setup
Faraday cage enclosure

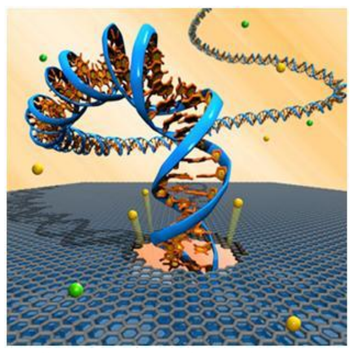
The noise power spectrum
(FFT of the time trace)

$$\frac{I_{RMS}^2}{BW} = \frac{4k_BT}{R}$$

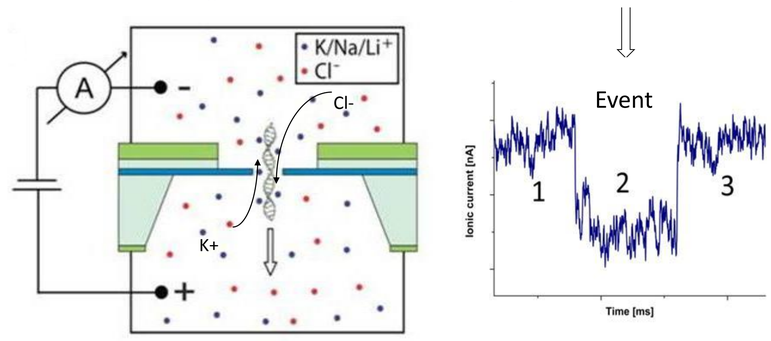
Resistor - frequency independent thermal noise
Nanopore - 1/f dependence
(Smeets *etal.* PNAS105; 417 (2008)



DNA TRANSLOCATIONS


[http://www.physics.upenn.edu/~robertjo/]

DNA „translocation“→ drop in ionic current

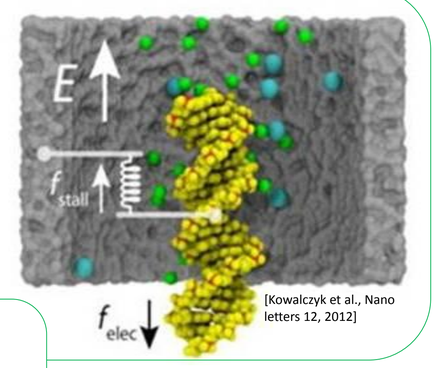


$$G = \sigma\left[\frac{4L}{d^2\pi} + \frac{1}{d}\right]^{-1}$$

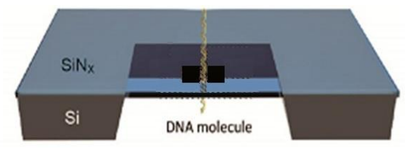
nanopore conductance, *G*
nanopore diameter, *d*
membrane thickness, *L*
ionic conductivity, *σ*

Conductance change, *ΔG,* caused by DNA translocation (d_{DNA}=2.2nm) can be predicted

$$\Delta G = \sigma\frac{d_{DNA}^2\pi}{4L}$$



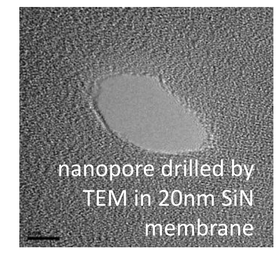
[Kowalczyk et al., Nano letters 12, 2012]



4 x 8 mm2 silicon chip

SiN-SiO_2-SiN membrane 50x50µm²

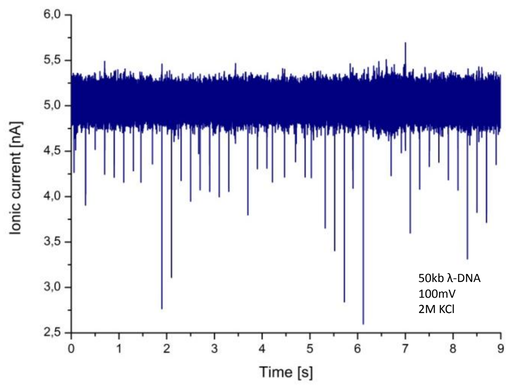
20 nm thin SiN membrane 500x500nm²

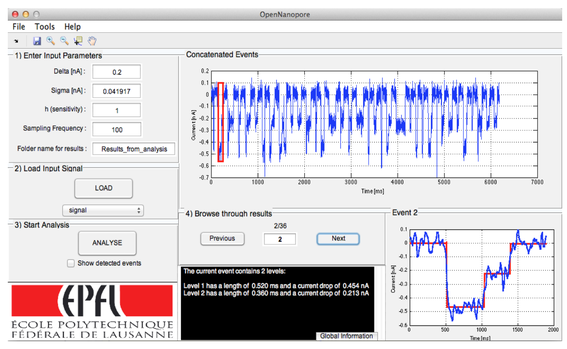


The chip is sealed by silicone o-rings between two reservoirs of a PMMA fluidic cell . Ag/AgCl electrodes are immersed into both reservoirs, filled with electrolyte, and connected to the instruments.

EVENT IDENTIFICATION AND STATISTICAL ANALYSIS

Current trace of translocation events is loaded to event-fitting algorithm OpenNanopore



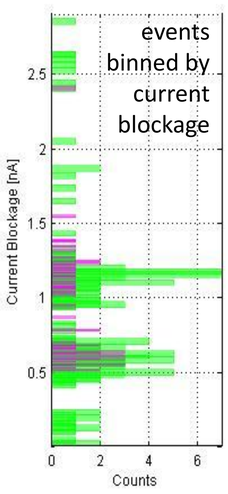


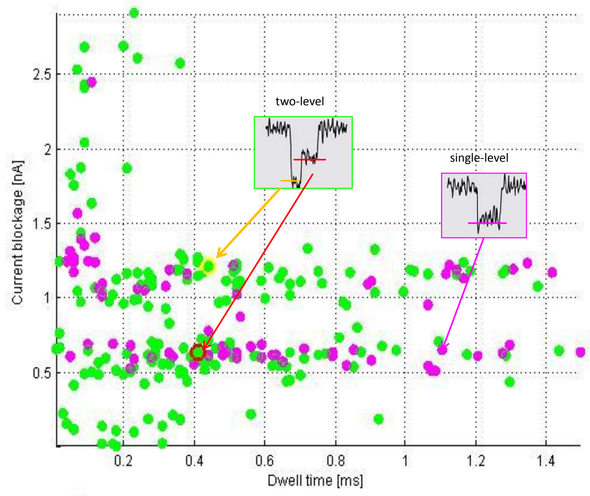
Events identified by the algorithm

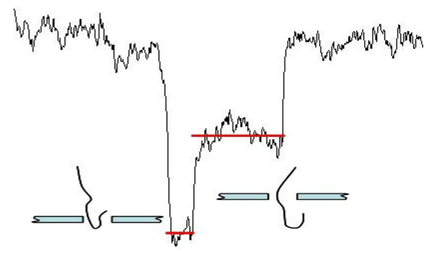
Algorithm identifies multilevel (1-6) events.

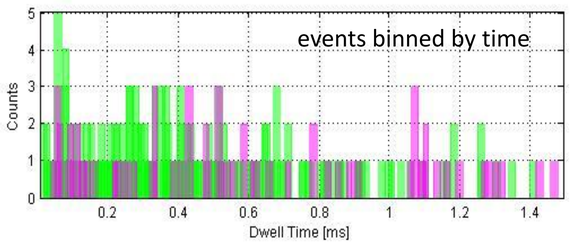
We present only single and two-level events (80% of total events)

The current blockages are bit higher then predicted. Presumably, this is due to pore geometry deviating from an ideal cylinder and a thinner membrane.

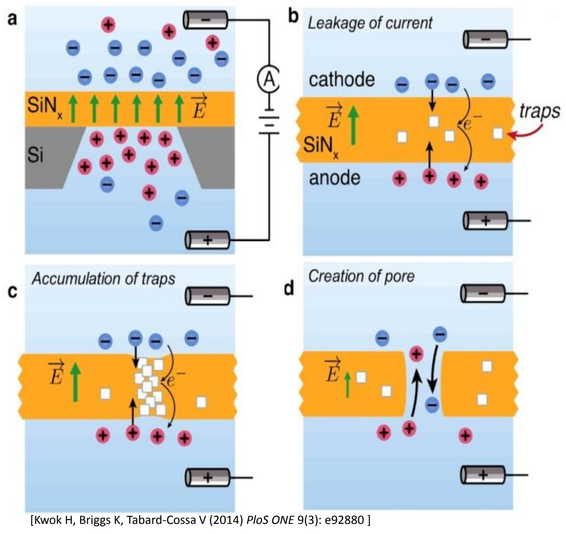








“DRILLING” BY DIELECTRIC BREAKDOWN



[Kwok H, Briggs K, Tabard-Cossa V (2014) *PloS ONE* 9(3): e92880]

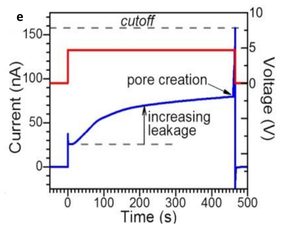
Charge accumulation→ capacitive spike

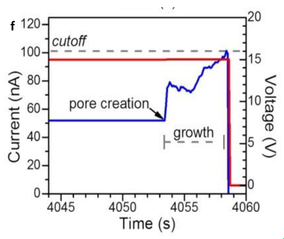
Surface redox reaction→
free charges (electrons or holes)

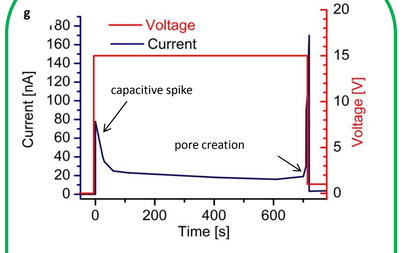
The number of traps (structural defects) → magnitude of the observed leakage current

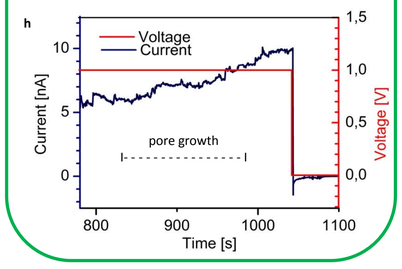
Accumulation of charge traps→ highly localized conductive path; dielectric breakdown event

A nanopore is formed
following removal of the defects.

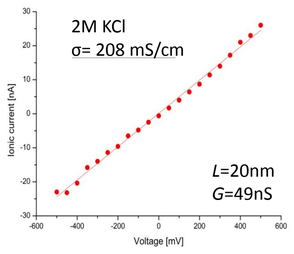








Nanopore characterization ohmic conductance



Nanopore diameter
d = 9nm
Current blockage
ΔG = 3.8nS
ΔI = 0.4nA at 100mV

CONCLUSIONS AND FUTURE WORK

Our in-house designed (thus low-cost) setup works at the same level as the commercial one used at EPFL and those used by other groups working on nanopores. We plan to adjust our setup in order to improve dielectric breakdown tehnique and test the influence of solvent viscosity in order to reduce DNA translocation time.