

# YESWECAN : SYnthetic MEmbranes With VErtilically Aligned Long CARbon Nanotubes for Noiseless miRNA Screening/Sequencing

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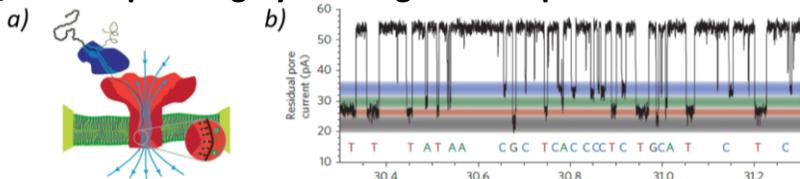
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## DNA/RNA sequencing by a biological nanopore

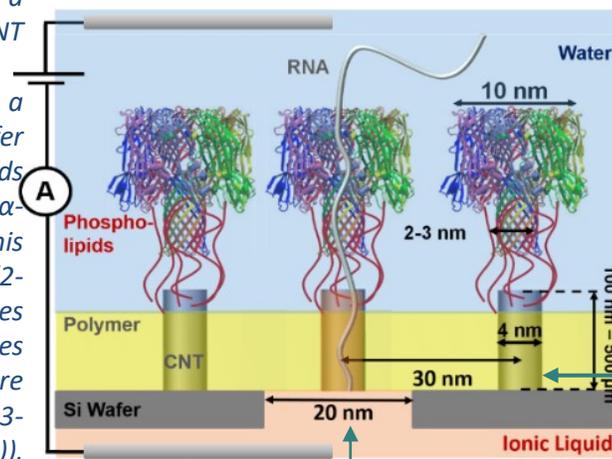


**Figure 1. nanopore sensing:** **a)** An external imposed electric field (blue arrows) forces a single DNA strand through a natural nanopore i.e. a transmembrane transport protein (in red, the membrane is in green). **b)** The real-time Nucleic Acid sequencing method consists in measuring the time dependance of the ionic current of the buffer salt (typically KCl) going through the nanopore. During the translocation process, this intensity is controlled by the sequential transient interaction of the NA bases (T, C, G, A) with the interior channel of the transmembrane protein. The electrical resistive pulses are a direct coding of the succession of bases going through the pore. An artist animated view of the process can be found [here](#).

**Figure 2. Final outcome of YESWECAN:** a single-tube  $\alpha$ -hemolysin (HL) decorated CNT membrane for miRNA screening/sequencing.

**Making of:** the single tube is obtained by a Focused Ion Beam (FIB) etching of the Si wafer basal side of the CNT membrane. Phospholipids are chemically grafted onto the CNT tips. An  $\alpha$ -HL rich solution is poured on the top of this membrane. Driven by its hydrophobic moiety (2-3 nm diameter), the  $\alpha$ -HL locates and stabilizes onto the CNT tips. The interior of the CNT tubes (4 nm diameter), where the miRNA flows, are impregnated with [BMIM-TFSI](#) (1-Butyl-3-methylimidazolium bis(trifluorosulfonyl)imide), an Ionic Liquid (IL). Only the  $\alpha$ -HL side of the membrane is left under buffer conditions.

## A porous polymer composite CNT-based membrane:



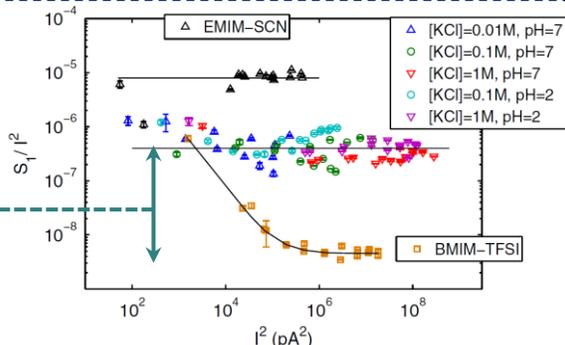
- Stable
- Long-lived

**Paradigm Change:** a  $\mu$ m-long tube and not a nm thin pore as on Fig.1.

20 nm diam. hole by FIB etching to open a 4 nm diameter single-tube. NB: the inter CNT-distance is 30 nm.

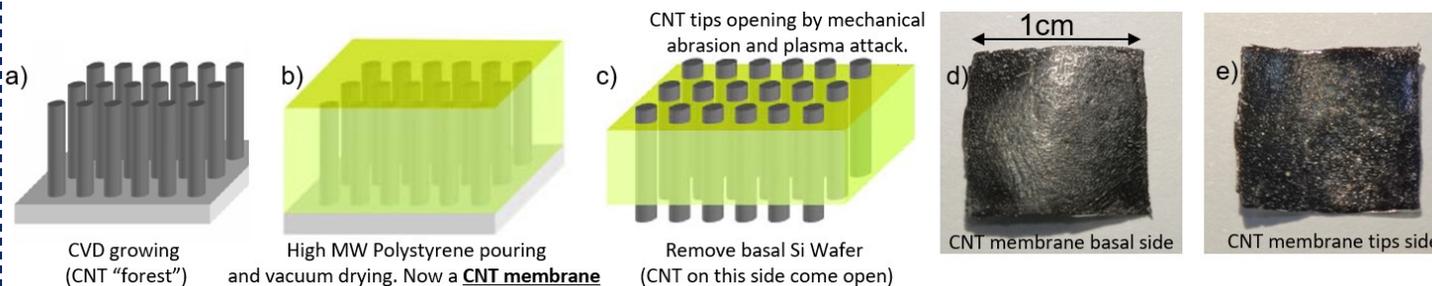
## The route to noiseless: IL confinement in a tube

Under nanometric confinement within a  $\mu$ m-long tube, the [BMIM-TFSI](#) ionic liquid (yellow) conduction noise drops by one order of magnitude compared to KCl.



**Figure 3. a)** Relative "pink noise" amplitude vs electric current for a single nanotube filled with ionic liquids or KCl. Here, a single-tube Kapton membrane (pore diameter: 20 nm, [7](#)). The chemical nature of the ionic liquid is the driving parameter of the ionic noise. Taking KCl as a reference, [EMIM-SCN](#) (Ethyl-3-methylimidazolium thiocyanate, in black) shows a noise one order of magnitude higher than KCl while for [BMIM-TFSI](#) (in yellow) it is one order of magnitude lower ([7](#)). We will therefore use [BMIM-TFSI](#).

## A porous polymer composite 1D CNT-based membrane: a processed already mastered



**Figure 4.** Aligned CNT membrane making process ([Berrod et al.](#)). The CNT interior imbibition by ionic liquids is achieved under vacuum. 250 of such membranes are already on hand. Grafting of the CNT tips has been already achieved ([pdf](#)).

2 PhD defended in December 2022:

Transport properties of Ionic Liquids under 1D CNT confinement for Li Batteries (EIS, Neutrons, RMN, MD simulations):

Camille Pinchart: CFR Phare Thesis ([pdf](#)) DRF/LLB – LITEN/DTNM.

Nino Modesto: 80 | Prime Thesis ([pdf](#)) CNRS DRF/LLB+SyMMES and Institut de Chimie Radicalaire.