Water Confinement in Individual Single-Walled Carbon Nanotube: Structure and Phase Diagram

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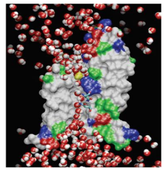
https://nanomechanics.fr/

Motivations

Confined water ubiquitous in nature and applications

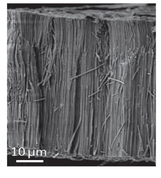
Field of Interest

Nature



[Marbach *Chem. Soc. Rev.* 2019]

Application-Purification



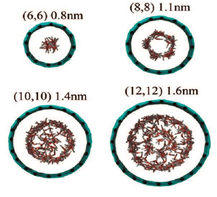
[Siria *Nature Rev.* 2017]

Water in the NT

NTs as the best matrix:

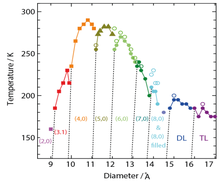
- ❖ CNT diameter & molecule size – Confinement
- ❖ Smooth surface – Friction
- ❖ High aspect ratio – Diffusion/Resistance

Structure



[Pascal *PNAS* 2011]

Phase diagram



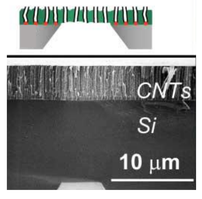
[Takaiwa *PNAS* 2008]

Methods

State of the art:

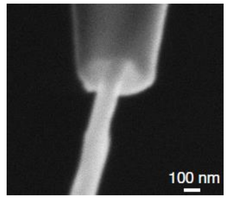
- ➢A lot of MD Simulations
- ➢Few experiments

❑Many NT ⟶ dispersion:
(quality, diameter, length)



[Holt SCIENCE 2006]

❑Large diameter NTs



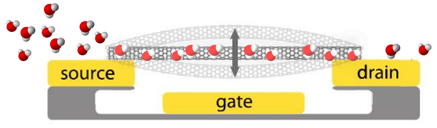
[Secchi NATURE 2016]

Lack of studies:

- individual NT
- small diameter(d<1.4nm) NT

Our Approach:

Coupling nanomechanics & nanofluidics



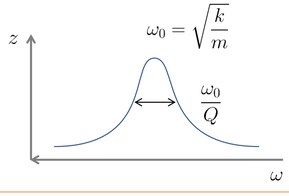
- ➢ New physical parameters accessible:
  ⟶ mass, spring, dissipation
- ➢ Works on individual NT: any diameter
- ➢ Exquisite sensitivity: single proton [Chaste NatNano 2012]
- ➢ Perfectly suited for nanofluidics

Resonance characterization

δm ⟶ structure *via* density

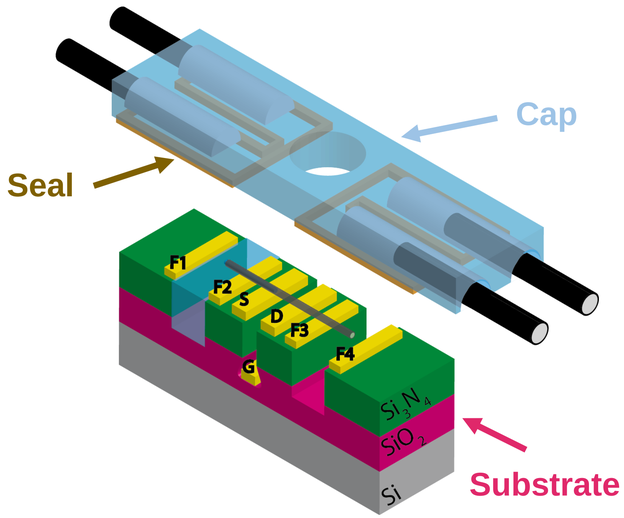
δk ⟶ phase transition

δQ ⟶ dissipation

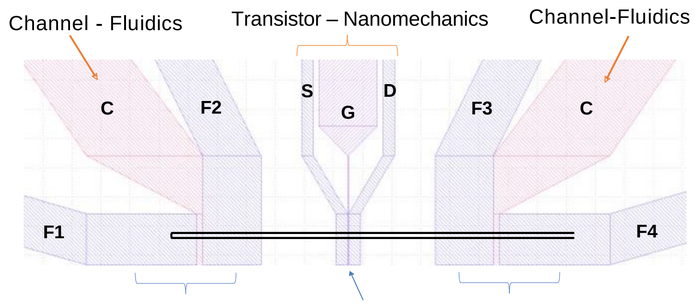


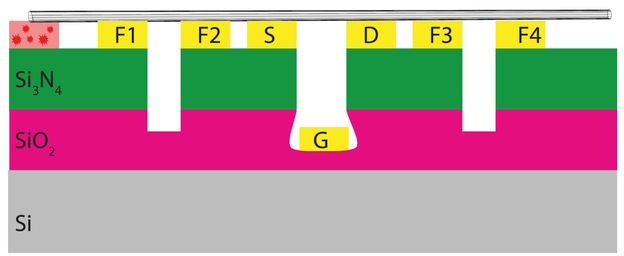
EXPERIMENTAL APPROACH

Full device

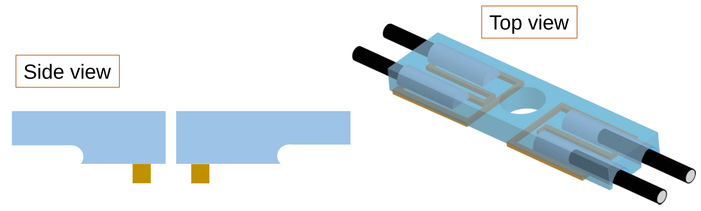


Substrate Design



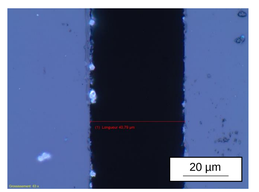


Cap Design

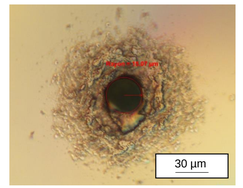


- Etching of the hole for nanomechanics & vacuum
- Etching of the inserts for capillaries

Clean room: dicing



Femto-ST: laser ablation



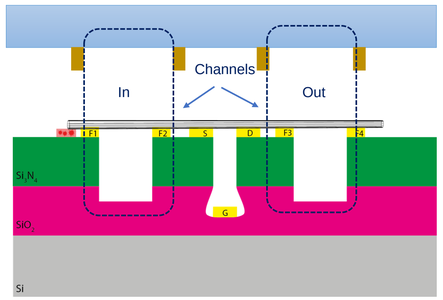
Sealing Technology

- Fluidics ⟶ impermeable & chemically inert
- Vacuum ⟶ not volatile
- Cryogenics ⟶ resistant to temperature changes
- Electronics ⟶ no parasitic effect
- CNT ⟶ seal width ≪ CNT length ≲ 1 mm

Our choice: SU-8 3000

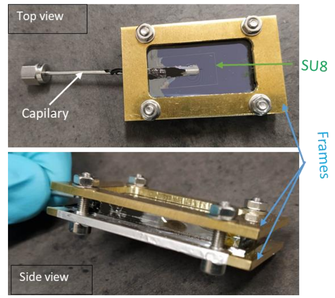
❑Compatible with water
❑Compatible with vacuum
❑Processable to micrometric scale
❑Compatibility with electronics?
❑Compatibility cryogenics?
❑Minimal dimension?

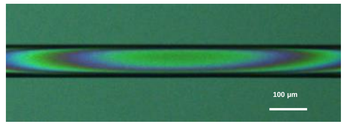
Separately substrates fabrication



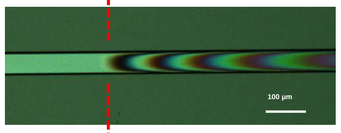
Mechanical assembly

Permanent pressing

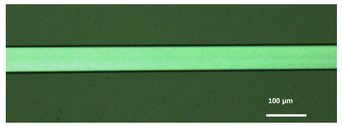




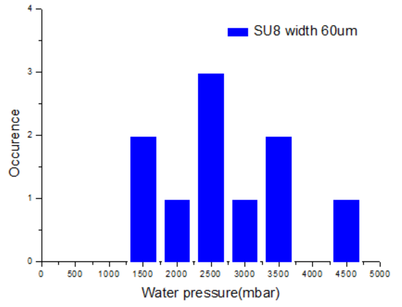
Soft contact

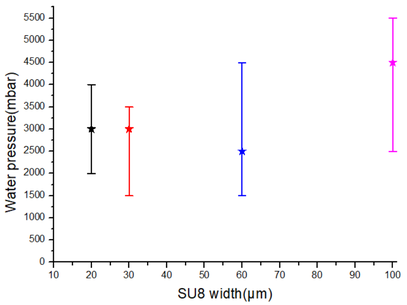


Hard press



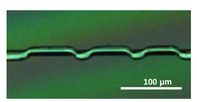
Hard bake: 2h 200°C





Open Questions

- **Minimal SU8 dimension**
- **Cryogenic performance**



Perspectives

- **Assembling full device**
- **Water filled NT vibration**
- **Structure and Phase Diagram**

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