Supervisor: Theo Emmerich, CRCNRS (theo.emmerich@ens-lyon.fr)

Hosting institution: ENS Lyon physics laboratory (LPENSL-UMR5672)

Toward the origin of ionic memory

In this internship, the student will do experimental work on the topic of nanofluidic memory for brain-inspired ionic computing. While current computing architectures rely on electronic components, biology uses solvated ions flowing through nanofluidic channels to process information with extraordinary energy efficiency. Replicating these principles with artificial nanofluidic systems could open a disruptive path toward biomimetic liquid hardware and direct interfacing with living organisms[1]. The discovery of ionic memory and synapse-like plasticity in nanofluidic devices has launched this emerging field[2]. In particular, recent optical observations in asymmetric channels and two-dimensional slits showed that memory arises from voltage-induced conformational change, akin to biological channels[3,4]. However, the physics governing these deformations remains poorly understood hindering the design of efficient ionic memories because the devices used are not suitable for rigorous characterization.

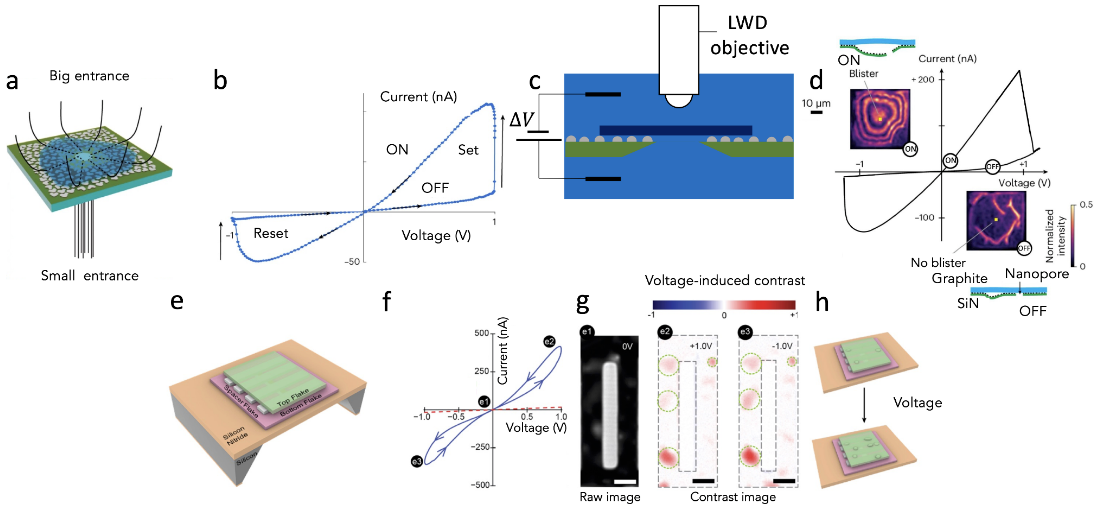

Figure: **Mechano-ionic memory observed via direct imaging. a,** Sketch of highly asymmetric channels (HAC). A pierced silicon nitride (SiN) window (in green) is covered with palladium islands (in grey) and capped with a graphite crystal (in blue). Lines indicate the fluidic/ionic path. **b,** Current/voltage characteristics of HACs. The bistable system exhibits a loop-shaped characteristics as a signature of memory. **c,** Direct imaging measurement setup. A water dipping, long working distance objective is submerged in the top reservoir and chlorinated silver electrodes are placed across the device. Electrokinetic and optical data are obtained simultaneously. **d,** Direct observation of mechano-ionic memory in HAC. Adapted from Ref 3. In black squares, microscopy images show interference patterns in the ON state as a signature of blister formation. **e,** Sketch of two-dimensional channels made by van der Waals assembly. An array of thin nanoribbons (spacers) separates two-dimensional crystals. **f,** Memristive IV of two-dimensional nanochannels. **g,** Optical image. The background at 0 V applied is subtracted from images obtained with applied voltage to obtain voltage-induced contrast maps showing the appearance of local blisters as sketched in **h.** Adapted from Ref 4.

The goal of the internship is the design and study of model nanofluidic devices in order to reach a better understanding of the ionic memory. In particular, the electrostatic pressure overcoming interlayer adhesion has to be measured precisely, enabling quantitative modeling. The student will fabricate the devices and measure them through a coupled optical and electrokinetic approach. The student will gain a wide experimental knowledge in 2D material exfoliation and nanofabrication, electrokinetic and optical measurements as well as theoretical knowledge of the exotic fluidic phenomena occurring at the nanoscale. **The internship may continue into a Ph.D. funded by an ANR grant.**

References

1. Emmerich, T. *et al.* Nanofluidics. *Nat. Rev. Methods Primer* **4**, 1–18 (2024).
2. Robin, P. *et al.* Long-term memory and synapse-like dynamics in two-dimensional nanofluidic channels. *Science* **379**, 161–167 (2023).
3. Emmerich, T. *et al.* Nanofluidic logic with mechano–ionic memristive switches. *Nat. Electron.* **7**, 271–278 (2024).
4. Saurav, K. V. *et al.* Direct imaging reveals electromechanical ionic memory in 2D nanochannels. *Nat. Mater.* In press. Preprint at https://doi.org/10.48550/arXiv.2509.11637.