Physics and Nanosciences - PhD XXXVII cycle - Annual report - 09/2024 - German Lanzavecchia

Tutors: Roman Krahne, Denis Garoli

Research activity

Continuing the work outlined in last year's report on the fabrication of 3D conical nanopores, we developed an optimized procedure to remove the photoresist and anneal the sample at 650°C. This process ensures the complete removal of organic residues, as confirmed by energy-dispersive X-ray spectroscopy, and significantly improves the mechanical properties and resistance of the nanopores compared to samples cleaned with UV and reactive ion etching. This cleaning strategy proved effective for conical nanopores made of SiO_2, Al_2O_3, TiO_2, and HfO_2. We characterized three different geometries (convex, straight, and concave) in two materials: SiO_2 and Al_2O_3, with nanopore diameters ranging from 70 to 7 nanometers. Staircase shaped cyclic voltammetry was performed to evaluate the Ionic Current Rectification (ICR) due to the asymmetrical geometry, which varies according to size, surface properties, and wall angle of the nanopores. These experimental results were consistent with simulations based on the Poisson-Nernst-Planck model. To validate the nanopores' ability to detect single molecules, we conducted λ-DNA translocation experiments, observing significant differences in signal-to-noise ratios and translocation frequencies when the direction was switched from tip-to-base versus base-to-tip. Finally, we evaluated the nanopores' performance as memristors, showing characteristic I-V hysteresis suitable for potential applications in neuromorphic computing. [1,2]

Following the addition of an extra gold layer, these nanostructures can also function as plasmonic antennas, as confirmed by enhanced Raman spectroscopies. The electromagnetic field enhancement was shown to vary according to the antenna geometry.[3] In order to measure the enhancement at various distances from the nanopore, we attach different-length DNA oligos functionalized with a thiol group on one end and a fluorophore on the other, to the tip of the gold-coated nanopores. We further advanced the fabrication by developing 3D nanopores made of silicon, fabricated via physical vapor deposition. However, removing the photoresist from these silicon nanopores is more challenging, as annealing at high temperatures oxidizes the silicon to form SiO_2. Additionally, we adapted the fabrication method to create structures composed of half gold and half silicon, to explore the potential coupling of resonant modes of gold and silicon and different functionalization chemistries.

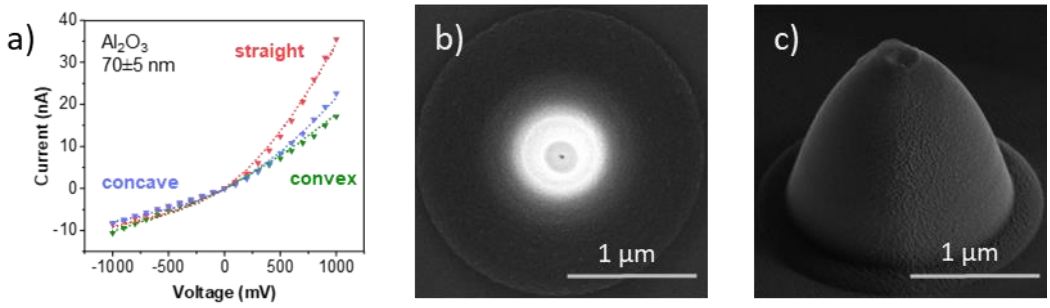

Fig. 1: a) ICR measurements in the different geometries proposed for Al_2O_3 pores of 70 nm in 10 mM KCl, b) SEM image of a concave nanopore fabricate in silicon, and c) SEM image of a convex nanopore made of silicon (left half) and gold (right half). (a) Reprinted with permission from [1] Copyright 2024 American Chemical Society.

Aside from the main research activities, I trained visiting and new students in cleanroom techniques, particularly in nanopore fabrication and characterization, with thin film magnetic materials, and in the preparation of samples for UV SERS applications,[4] I also collaborated in fabricating Ni-based MIM

structures for ultrafast opto-acoustics. We rebuilt the optical setup for single-molecule translocation experiments of fluorescent molecules, calibrated the e-beam evaporator for Ni, Al_2O_3, and Si deposition, among other activities.

Publications

(1) Lanzavecchia, G.; Sapunova, A.; Douaki, A.; Weng, S.; Momotenko, D.; Paulo, G.; Giacomello, A.; Krahne, R.; Garoli, D. Tailored Fabrication of 3D Nanopores Made of Dielectric Oxides for Multiple Nanoscale Applications. *Nano Lett* **2024**. https://doi.org/10.1021/acs.nanolett.4c02117.

(2) Sapunova, A.; Lin, L.; Weng, S.; Lanzavecchia, G.; Douaki, A.; Krahne, R. Investigation of Ion Transport in Solid-State Nanopores with Different Properties Using COMSOL Modeling. In *Proc.SPIE*; 2024; Vol. 12990, p 129900T. https://doi.org/10.1117/12.3022400.

(3) Lanzavecchia, G.; Sapunova, A.; Douaki, A.; Weng, S.; Krahne, R. Nanopores with Customized 3D Shape: Tailored Structures for Nanoscale Applications; SPIE-Intl Soc Optical Eng, 2024; p 73. https://doi.org/10.1117/12.3022456.

(4) Banerjee, S.; Mattarozzi, L.; Maccaferri, N.; Cattarin, S.; Weng, S.; Douaki, A.; Lanzavecchia, G.; Sapunova, A.; D'Amico, F.; Ma, Q.; Zou, Y.; Krahne, R.; Kneipp, J.; Garoli, D. Porous Aluminum Decorated with Rhodium Nanoparticles: Preparation and Use as a Platform for UV SERS. *Mater Adv* **2024**. https://doi.org/10.1039/d4ma00203b.

Courses

Biosensing – Course and exam passed

Microscopic and spectroscopic techniques for the analysis of surfaces and interfaces

Introduction to the Foundations of Quantum Mechanics and Applications

Advanced Imaging Course – Super-resolution microscopy techniques (SBL.00419) – University of Fribourg, Fribourg, Switzerland

Summer School

18th International Summer Schools "N&N, Organic Electronics & Nanomedicine" (ISSON24), June 29 - July 6, 2024, Thessaloniki, Greece
Poster presentation: "3D-Nanopores tailored for optical and electrical applications"

Conferences

SPIE PHOTONICS EUROPE, 7-12 April 2024, Strasbourg, France.
Oral presentation: "Nanopores with Customized 3D Shape: Tailored Structures for Enhanced Optical and Electrical Applications."

21st International Conference on Nanosciences & Nanotechnologies (NN24), July 2-5, 2024, Thessaloniki, Greece
Poster presentation: "3D-Nanopores tailored for optical and electrical applications"

Other

Unige Senior, February 27, 2024 – Seminar: "Pori nanometrici e come utilizzarli"