



Internship Proposal 2026-2027 – Master 2

Microfluidics and Electrochemiluminescence for the Study of Single-Vesicle Membrane Rupture

A) FACT SHEET

Host Laboratory

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Field: Electrochemistry ; Analytical Chemistry ; Microfluidics

Level: M2

Scientific background:

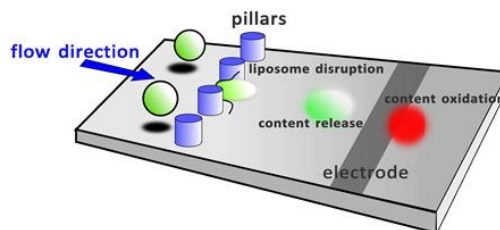
Electrochemiluminescence (ECL) is the emission of light from an excited-state luminophore generated through an electrochemical reaction. Typically, a luminophore such as tris(2,2'-bipyridine)ruthenium(II) reacts with a co-reactant (e.g., tri-n-propylamine) following electrochemical oxidation, producing an excited state that emits light at a characteristic wavelength (~620 nm for $[\text{Ru}(\text{bpy})_3]^{2+}$). By combining electrochemical stimulation with optical detection, ECL offers high sensitivity and excellent spatial and temporal resolution, making it a powerful tool for medical diagnostics [1] and bioanalytical imaging of individual biological objects and dynamic cellular or membrane processes [2].

We recently developed an ECL-based method for real-time imaging of membrane permeabilization in micrometer-sized liposomes. Membrane disruption can be induced electrochemically through electrode polarization [3–5] or through antimicrobial peptide–membrane interactions [6]. However, the current approach does not allow controlled or quantitative characterization of individual rupture events. Moreover, phospholipids released upon rupture may adsorb onto the electrode surface, progressively passivating its surface and reducing detection efficiency and reproducibility [7]. Developing a strategy for controlled and quantitative analysis of single-vesicle rupture events would provide new opportunities to investigate molecular transport across lipid membranes, with potential applications in drug delivery, artificial cells, and membrane permeabilization mechanisms.

B) PROJECT DESCRIPTION

1. Presentation and description of the project

The aim of this internship is to develop a microfluidic platform for the controlled mechanical rupture of individual giant unilamellar vesicles (GUVs, 50-100 μm) under well-defined flow conditions, coupled with quantitative ECL detection of the species released upon membrane disruption. The microfluidic device will incorporate an array of microfabricated pillars across the channel (see Figure). As GUVs are transported through the constricted region, interactions with the pillars will mechanically deform and rupture their membranes. A working electrode positioned downstream of the pillar array will detect the ECL reagents released after membrane rupture, providing an optical readout of individual rupture events and, ultimately, of the amount of material released. This project combines microfluidics, electrochemistry, ECL, and membrane biophysics to establish a new methodology for studying membrane disruption at the single-vesicle level. The main parameters to be optimized will include device geometry, flow conditions and mass transport [8], as well as vesicle size and membrane composition.



2. Techniques / methods used

- Cleanroom microfabrication,
- Cyclic voltammetry, chronoamperometry,
- Optical microscopy, fluorescence imaging and ECL imaging.

3. Expected results

The internship is expected to establish and optimize a microfluidic platform enabling reproducible single-GUV rupture and quantitative ECL detection. The project will specifically:

- identify microfluidic geometries and flow conditions enabling controlled GUV rupture;
- determine the influence of hydrodynamic conditions and pillar architecture on membrane rupture and mass transport;
- optimize the electrode operating conditions while minimizing phospholipid-induced passivation;
- correlate current and ECL responses with the amount of material released from individual GUVs;
- investigate shadow ECL imaging as a complementary approach.

Overall, this project will provide a multimodal microfluidic/electrochemical methodology for investigating membrane permeabilization and molecular transport at the single-vesicle level. It will also provide interdisciplinary training at the interface of microfluidics, electrochemistry, optical imaging, and membrane biophysics.

4. References

- [1] More than 150 ECL-based immunoassays are currently on the market, primarily from two companies: Roche Diagnostics and Mesoscale Discovery.
- [2] J. Zhang, S. Arbault, N. Sojic, D. Jiang, *Annu. Rev. Anal. Chem.* 12 (2019) 275–95.
- [3] F. Ben Trad, V. Wieczny, J. Delacotte, M. Morel, M. Guille-Collignon, S. Arbault, F. Lemaître, N. Sojic, E. Labbé, O. Buriez. *Anal. Chem.* 94 (2022) 1686-1696.
- [4] F. Ben Trad, J. Delacotte, F. Lemaître, M. Guille-Collignon, S. Arbault, N. Sojic, E. Labbé, O. Buriez. *Analyst*. 149 (2024) 3317-3324.
- [5] F. Ben Trad, E. Labbé, O. Buriez. *Chem. Biomed. Imaging*. 4 (2026) 1004-1017.
- [6] F. Ben Trad, J. Delacotte, M. Guille-Collignon, F. Lemaître, S. Arbault, N. Sojic, F. Burlina, E. Labbé, O. Buriez. *Chem. Biomed. Imaging*. 1 (2023) 58–65.
- [7] A. Pensieri, J. Delacotte, F. Lemaître, M. Guille-Collignon, A. Yamada, N. Sojic, L. Thouin, E. Labbé, O. Buriez. *Anal. Chem.* 98 (2026) 17288-17299.
- [8] Y. M. Ma, C. Sella, T. Delahaye, L. Thouin. *Electrochem. Commun.* 165 (2024) 107759.