2 PhD positions in:

PhD thesis 1

Architecting health-devoted microcapsules via non-Newtonian in-air microfluidics and dynamic chemistry

Context. **In-air microfluidics** (IAMF) is an emerging technique that enables the preparation of functional microdroplets in open air without the need for traditional microfluidic chips [1]. By precisely controlling the impact of fluid jets and their chemical interactions mid-flight, this approach allows for high-throughput droplet formation, mixing, and encapsulation with remarkable speed. In the example presented here, droplets from Jet 1 collide with Jet 2. Given the difference in surface tension between the liquids of Jets 1 and 2 (i.e., $\sigma_1 > \sigma_2$), the encapsulation of the droplet is driven by the Marangoni effect. The **solidification of the droplet** is achieved by incorporating **chemical components** with complementary functions in the fluid of the jets — for example, a functional **polymer** in Jet 1 and a **cross-linker** in Jet 2.

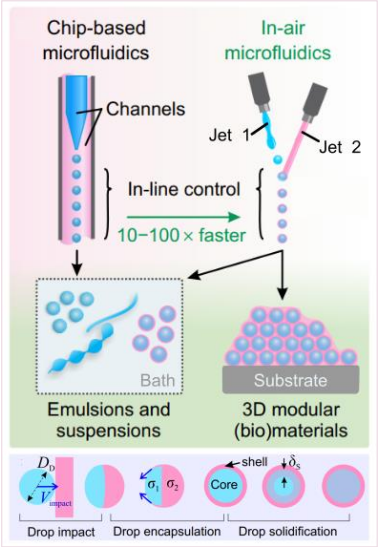

Figure adapted from [1]

IAMF offers significant advantages over traditional microfluidic methods: 1) it generates droplets at a frequency 10–100 times faster; 2) it requires relatively simple equipment that is accessible to a broad range of users; and 3) it does not require a non-solidifying carrier flow (e.g., oil), which simplifies droplet isolation and minimizes waste. These key features make IAMF ideal for applications in **bio-material synthesis**, **drug delivery**, and **3D printing of tissues**.

Key challenges. The pioneering work that introduced IAMF has prompted many intriguing questions from both a physics and chemistry point of view [1]. For instance, the fabrication of **health-devoted microparticles** via IAMF involves the stretching and subsequent breakup of non-Newtonian fluids at very high strain-rate levels ($\approx 10^4 s^{-1}$-$10^5 s^{-1}$), a problem of fluid mechanics that remains unresolved. Control over these fluids under such conditions is generally based on trial and error [2], limiting the ability to rationally design the system. In terms of chemistry, relatively simple hydrogel formulations have been reported to be used with IAMF thus far. **Elaboration of the chemical structure of the hydrogel** and **controlling its nanostructural assembly, all in the context of the processing conditions of IAMF,** are exciting routes to access biomaterials with advanced functions [3].

Objective (PhD thesis 1). The goal of this PhD project is to **implement new dynamic covalent and non-covalent motifs** [4] **into the formulation of the hydrogel generated upon drop solidification**. These new functional groups are predicted to bring new properties to the microcapsules, such as **shape changing, hierarchical assembly, and temporal modulation of viscoelasticity**. Collaboration with physicists will be essential to harness the non-Newtonian flow properties to direct the assembly of these new chemical motifs. Formulations will be developed to be compatible with IAMF, which will entail rheological characterization of the fluids. The assembly within the droplets will be studied by a combination of physicochemical characterization techniques. The morphology and assembly of the microdroplets will be assessed by a combination of optical and electron microscopic techniques.

Participants. We are seeking a **highly motivated researcher who has recently completed a master's degree interested in polymer and supramolecular chemistries**. Experience with physicochemical characterization, microscopy, and/or rheology are highly appreciated. This PhD candidate will be based at the **Laboratory of *Chimie Moléculaire, Macromoléculaire, Matériaux*** (C3M) **at the ESPCI Paris - PSL, and will start ideally on September/October 2025.** The candidate will have the opportunity to work with other academic and industrial partners.

Collaboration. This candidate will join a collaborative project between the **C3M Laboratory at the ESPCI Paris - PSL** and the **CFL Research Group at Cemef, Mines Paris - PSL**. The candidate will work in collaboration with another PhD student based at Cemef, Mines Paris - PSL, who will be focused on unravelling the non-Newtonian fluid mechanics of IAMF [see the PhD thesis 2 below; 5], and researchers from the ***Centre des Matériaux*** **(CMAT), Mines Paris - PSL**.

How to Apply. Please send your CV, letter of motivation, and bachelor/master transcripts before May 29 to:

- Nathan VAN ZEE (nathan.van-zee@espci.psl.eu), CNRS Researcher at the ESPCI Paris - PSL
- Laurent CORTÉ (laurent.corte@minesparis.psl.eu), Professor at Mines Paris - PSL & ESPCI - PSL
- Anselmo PEREIRA (anselmo.soeiro_pereira@minesparis.psl.eu), Associate Professor at Cemef, Mines Paris - PSL

Funding. The selected candidate will join an application to PSL University's *Appel à projets : Thèses binômées 2025*, which will be submitted on May 31. Please see the website dedicated to this program (Link) for details.

References

[1] Visser, Kamperman, and co-workers. *Sci. Adv.* **2018**, *4*, eaao1175. Link
[2] Veesler and co-workers. *Biomat. Res.* **2021**, *25*, 41. Link
[3] Yang, Pitera, Hedrick, and co-workers. *ACS Nano*, **2012**, *6*, 9191. Link
[4] Van Zee and co-workers. *Macromolecules* **2024**, *57*, 9030. Link
[5] Isukuwem and co-workers. *Journal of Fluid Mechanics* **2025**, *1002*, A32. Link