

Contrat doctoral – ED Galilée

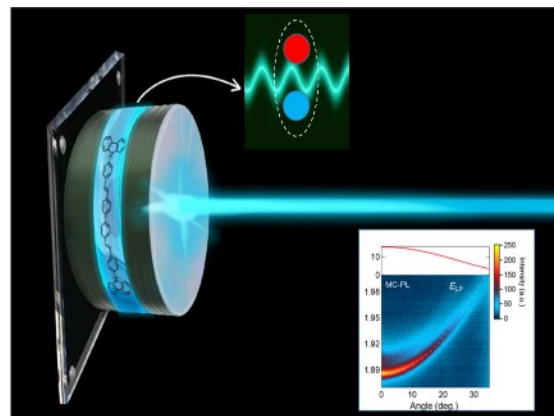
Titre du sujet : Organic exciton-polariton lasers / Lasers à polaritons à base de matériaux semiconducteurs organiques

- Unité de recherche : LPL, Institut Galilée
- Discipline : Physique
- Direction de thèse : Sébastien Chénais, Sébastien Forget
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- Domaine de recherche : Physique, Optique, Lasers
- Mots clés : polaritons, couplage fort, semiconducteurs organiques

Scientific description:

Organic photonics is an emerging domain that led to several recent breakthroughs in the fields of photovoltaics, solid-state lighting and displays. Organic Light-Emitting Diodes (OLEDs), based on luminescence of organic semiconductors, are already present in most commercial smartphone displays owing to their remarkable 100% internal quantum efficiencies. On the other hand, organic laser diodes (relying on stimulated emission instead of spontaneous emission), have just been demonstrated, at a burgeoning stage, under direct electrical pumping, which makes it a much more exploratory topic. They represent both a fundamental challenge to overcome and a potential source of new applications for instance in bio-sensing. Unlike traditional inorganic semiconductors whose emission wavelengths are fixed to a small set of available fixed energy bandgaps, organic semiconductors are excitonic materials that can be easily tuned by chemical design to cover the whole visible spectrum. Furthermore, while traditional diode lasers are based on epitaxial techniques, organic diode lasers can be made from solution or low-temperature evaporation techniques. This enables a fabrication process at lower energy costs and with limited usage of non-renewable resources, and guarantees an easy pairing with all existing technological platforms.

In this context, **Organic exciton-polariton lasers** have been the focus of many very recent promising investigations. Polaritons are light-matter eigenstates that form when electronic transitions are strongly coupled to the electro-magnetic field in an optical cavity. This occurs when the light-matter interaction rate is faster than both the photon decay rate and the exciton lifetime. In this strong coupling regime, exciton-polaritons can form a condensate whose leakage from the resonator yields coherent light that is nearly indistinguishable from conventional laser emission but without relying on stimulated emission, which may unlock some of the greatest challenges remaining unsolved with organic semiconductor lasers, that is obtaining a continuous-wave regime, or reaching the “grail” of the organic laser diode.



In our group, we have developed an expertise in organic lasers in general¹, and specifically in organic vertical resonators which are the basis for the future development of exciton-polariton lasers. We have recently published a study on this topic with colleagues at Kyushu University, Japan, with all experiments being performed by us but in the Japanese lab within the framework of an international research program². During this PhD, we want to set up a similar experiment, as well as developing numerical tools, that will serve as a basis for all our future investigations on microcavities in the strong coupling regime.

During the first part of the thesis, the selected candidate will work on three complementary projects:

- 1) Development of numerical tools to calculate optical modes in VCSEL (Vertical Cavity Surface Emitting Laser) using Transfer-Matrix and/or RCWA (Rigorous Coupled Wave Analysis) codes and understanding organic polariton behavior in such cavities using for instance the Python QuTiP package.
- 2) Fabrication of reliable VCSEL cavities encapsulating organic gain media. For such precise operation, fabrication development will involve the USPN clean room facility specialized in organic devices. So, the selected student would have the opportunity to develop clean room fabrication skills.
- 3) Setting up the Fourier-plane spectral microscope, which enables obtaining maps of the emission spectrum versus angle from the device. The work will include optical design and alignment, interfacing the spectrometer software (with Python). The setting-up of a g^2 experiment might also be involved for instance to study organic polariton laser thresholds.

These preliminary works will be the cornerstones for the second part of the thesis, where topics focused on the development of diode-pumped organic exciton-polariton lasers and the study of their temporal dynamics will be tackled. A major objective is to head towards continuous-wave operation that has never been observed yet. In this context, a collaboration with the group of Prof. Stefan Reizenstein in Berlin³ (Technische Universität Berlin) is planned to take advantage of their established expertise in strong coupling and nanolasers with inorganic materials. The PhD student will play a crucial role in this collaboration, and several stays in Berlin are expected during the 3-years thesis.

Context of the PhD

The PhD is proposed within the framework of an **international project** aiming at developing organic lasers and organic semiconductor-based quantum devices. The project gathers chemists, physicists and nanofabrication specialists. In particular, an International Research Project (IRP funded by CNRS) between our team, French chemists partners and a world-leading laboratory in Japan (the Adachi group at Kyushu university), enables a full access to state-of-the-art facilities, materials, and characterization tools. At least one stay in Japan are foreseen during the PhD within this project.

Applicant skills: A strong background in optics and general physics, and notions in quantum physics and lasers are needed. No specific skills in organic electronics or chemistry are required, but the candidate needs being open-minded and curious as numerous interactions with our partners are foreseen (both in Germany and in Japan). Given the pluridisciplinarity and international character of the project, the candidate (during the PhD) will play a central role between partners and consequently good communication skills are required. It is expected that the candidate participates in all aspects of research, including (at the PhD level) simulation work and paper writing.

PhD supervisor(s): Sébastien Chénais, Sébastien Forget (co-supervision : Arnaud Jollivet)

¹ S. Forget and S. Chénais : Organic Solid-state Lasers, Springer Series in Optical Science, Vol. 175, Springer. 169 pages, ISBN 978-3-642-36704-5. (2013)

² T. Ishii, F. Bencheikh, S. Forget, S. Chénais, B. Heinrich, D. Kreher, L. Sosa Vargas, K. Miyata, K. Onda, T. Fujihara, S. Kéna-Cohen, F. Mathevet, and C. Adachi : "Enhanced light-matter interaction and polariton relaxation by the control of molecular orientation" Advanced Optical Materials 2021, 9, 2101048. (2021) <https://doi.org/10.1002/adom.202101048>

³ <https://www.tu.berlin/agquantumdevices/ueber-uns>