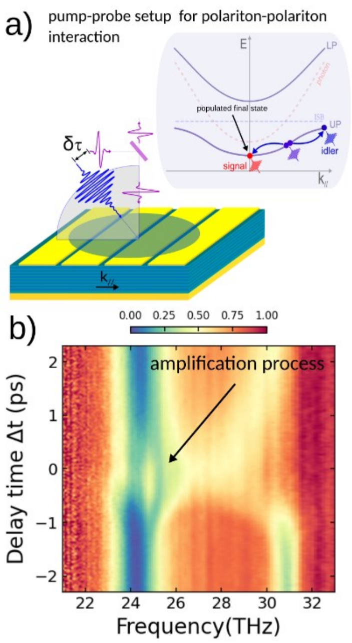
Departement/Team: Photonique/ODIN
Person in charge of the internship: Jean-Michel Manceau

Email : jean-michel.manceau@universite-paris-saclay
***Tél :* 01 70 27 06 73**

Novel Mid-InfraRed Polaritonic Architectures

Non-equilibrium Bose-Einstein condensation of exciton-polaritons have become a vast playground for fascinating phenomena previously reserved to ultracold atomic gases. In particular, it has lead to the demonstration of superfluidity, hydrodynamic soliton nucleation, topological lasing and non-Hermitian effects. In these polaritonic systems the fundamental energy scale is intrinsically fixed by the interband transition of the underlying material, constrained to the VIS/Near-IR range, limiting flexibility and also the magnitude of the Rabi splitting. **Conversely**, the transition energy of **intersubband (ISB) polaritons** in doped semiconductor quantum well (QW) structures can be freely tuned by varying the QW width and doping to reach the **mid-IR and Far-IR** range of the electromagnetic spectrum. As their excitonic counter-part, it has been predicted that they can show exotic quantum behavior such as final state stimulation and condensation. This would open interesting perspectives of a condensate operating at much lower energy scale and interacting with a 2D gas of electrons to form Fermi-Bose mixtures.



Our team has made major progresses towards that goal in the recent years. Starting with dispersion engineering [1], we developed a clear roadmap towards condensation [2] and confirmed the existence of a spontaneous process based on ISB polariton - LO phonon scattering [3]. More recently, in the frame of an international collaboration, we demonstrated for the first time polariton-polariton interaction in the regime of **final state stimulation** (see figure) [4]. In this pump-probe experiment, we have shown an amplification process ocurring on an ultrafast time scale; **this is the key ingredient towards condensation**. We further developped a numerical tools to simulate such experiment and investigate in details the key parameters behind this amplification process.

This internship aims at establishing the **fundational bricks** for the demonstration of ISB polaritons condensation. In particular we aim at developing novel polariton architectures to either increase the polaritonic non-linearities or the scatering rate. Prior to the internship, several QW structures will be designed and grown by our partners. The first task of the candidate will be to characterize the spectral absorption of the structure as function of the temperature (from 300 K down to 4 K) using the existing experimental apparatus. The candidate will then numerically design the microcavities that will host the strong coupling regime. The fabrication of the devices will be led in C2N cleanroom by the supervisor and she/he will be invited to follow the different steps of the process. The candidate will then perform the optical characterization of the polaritonic band-structure and extract several key parameters. Finally, the candidate will use an in-house numerical code to simulate the polaritons scattering dynamic and amplification process within the novel polaritonic architectures that she/he has characterized earlier on.

The project offers a global view of the different activities led in our team from the numerical design, the fabrication in cleanroom and the optical characterization. Furthermore and if time allows, the candidate will also have the opportunity to contribute to the implementation of a pump-probe experiment based on an ultrafast laser chain recently purchased. This will be the key tool for a potential PhD thesis on ISB polariton condensation.

[1] J.-M. Manceau et al., *Mid-Infrared Intersubband Polaritons in Dispersive Metal-Insulator-Metal Resonators*, Appl. Phys. Lett. **105**, 8 (2014).

[2] R. Colombelli and J.-M. Manceau, *Perspectives for Intersubband Polariton Lasers*, Phys. Rev. X **5**, 1 (2015).

[3] J.-M. Manceau et al., *Resonant Intersubband Polariton-LO Phonon Scattering in an Optically Pumped Polaritonic Device*, Appl. Phys. Lett. **112**, 19 (2018).

[4] M. Knorr, J.-M. Manceau et al., *Intersubband Polariton-Polariton Scattering in a Dispersive Microcavity*, Phys. Rev. Lett. **128**, 247401 (2022).

Methods and techniques: Optical characterization of the QW at cryogenic temperatures (FTIR absorption); EM numerical modelling of the microcavities; Optical characterization of the polaritonic band-structure (angle-resolved FTIR spectroscopy); Numerical modelling of the polaritons scattering dynamic and amplification.

Possibility to go on a PhD: yes
Funding: research grant or doctoral school grant