PhD thesis proposal

Ultrafast dynamics of the strong coupling in a plasmonic-photonic microcavity for novel biosensing pathway

Laboratory: Lumière, Matière et Interfaces (Univ. Paris-Saclay, CentraleSupélec - ENS Paris-Saclay - CNRS).
Supervisor: Bruno Palpant

- **Background.** When coupling two oscillators it is possible to reach the strong coupling regime where new resonance modes appear. We develop a collaborative research project, recently awarded and funded by the French Research Agency (ANR), aiming at investigating and exploiting the ultrafast dynamics of such modes at the nanoscale. For this, **we associate plasmonic nanoparticles (NPs) with a photonic resonance in a microcavity**. Triggered by ultrashort laser pulses, the NP optical properties are modified in a fast transient way.[1] By coupling them with an electromagnetic cavity, one may conceive optically controlled photonic functions.[2,3] We have recently shown by calculation that **it is possible to switch, within a subpicosecond timescale, from the ultrastrong regime to the weak coupling regime** (Fig. 1). Our objective is to demonstrate this experimentally. With our collaborators at L2n lab., UTT, we **design and fabricate anisotropic plasmonic-photonic hybrid microcavities** (Fig. 2). We will demonstrate the coupling switch by **time-resolved ultrafast laser spectroscopy**.[4] An implementation in a microfluidic environment will be considered for **designing innovative optical biosensors** (collab. LBPA, ENS Paris-Saclay).

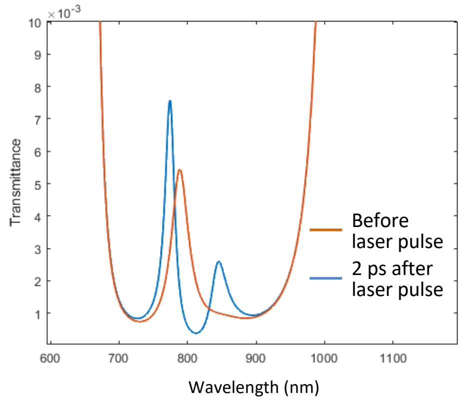

Fig. 1. Ultrafast transition from ultrastrong to weak coupling: effect on the hybrid cavity optical transmittance. *Preliminary calculations at LuMIn show that an anisotropic hybrid microcavity can undergo an ultrafast transition, induced by a pump laser pulse, from the ultrastrong coupling regime between the localized plasmonic mode and the cavity photonic mode (before the pump pulse, blue curve) to the weak coupling regime (after the pulse, red).*

- **Work plan.** Measurement of the broadband ultrafast transient optical response of hybrid cavities by the femtosecond laser pump-probe technique. Simulation combining a finite element approach and our model for ultrafast plasmonics. Demonstration of the optically-driven efficient and ultrafast switch between two coupling regimes. Investigation of the development of an innovative optical sensor in a microfluidic environment.

- **Required student profile.** The student has a **background in physics** (Master 2 level). An experience in **optical spectroscopy** and **nanophotonics** will be appreciated. Depending on the candidate's preference, the work will focus more on theoretical or experimental aspects.

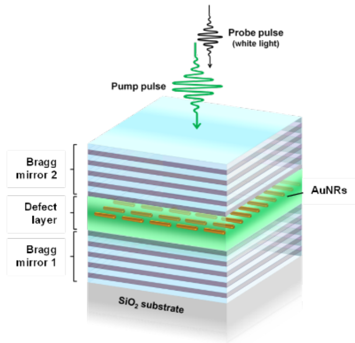

Fig. 2. Anisotropic hybrid microcavity*, filled with gold NPs. The pump-probe experiment is schematized.*

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1. *Absorption of ultrashort laser pulses by plasmonic nanoparticles: not necessarily what you might think*, X. Hou, N. Djellali and B. Palpant, *ACS Photonics* **5** (9), 3856–3863 (2018). DOI
2. *Ultrastrong coupling between nanoparticle plasmons and cavity photons at ambient conditions*, D. G. Baranov, B. Munkhbat, E. Zhukova *et al.*, *Nat. Commun.* **11,** 2715 (2020). DOI
3. *Coupling localised plasmonic and photonic modes tailors and boosts ultrafast light modulation by gold nanoparticles*, X. Wang, R. Moreira, J. Gonzalez and B. Palpant, *Nano Letters* **15**, 2633–2639 (2015). DOI
4. *Sharp spectral variations of the ultrafast transient light extinction by bimetallic nanoparticles in the near-UV*, T. O. Otomalo, L. Di Mario, C. Hamon, D. Constantin, K.-V. Do, P. O'Keeffe, D. Catone, A. Paladini, and B. Palpant, *Adv. Opt. Mater.* **9**, 2001778 (2021). DOI