INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: ANR

Quantum devices in the ultra-strong light-matter coupling regime

The absorption and emission of light in an optoelectronic device are often considered as *perturbative phenomena*, which are treated in a single-particle picture. When the light-matter coupling energy, $\hbar\Omega_R$, exceeds the dissipation rates of the system then the light-matter interaction is no longer a perturbative process, but instead energy is periodically exchanged with the microcavity at a frequency Ω_R. The system enters the *strong coupling regime*, where the cavity mode is split into two light-matter coupled (polariton) states separated by energy $2\hbar\Omega_R$. The last decade has seen the emergence of yet stronger interaction regime, where the coupling constant Ω_R becomes comparable to the frequency of the matter excitation, ω_m. This regime with $\Omega_R/\omega_m \sim 1$ is known as "ultra-strong" light-matter coupling and sets new frontiers for cavity quantum electrodynamics [1]. This regime can be realized with quantum heterostructures that interact with far infrared photons (TeraHertz, λ = 30μm-300μm and Mid-Infrared, λ = 3μm-30μm domains) [2]. A very interesting topic is the possibility of observing the signatures of ultra-strong coupling in the electronic transport of devices such as infrared detectors [3] and tunnel junctions [4]. Such devices could enable the readout of the quantum properties of light in the MIR and THz frequencies, thus opening a new field of application for quantum technologies.

As an intern, the candidate will characterize optoelectronic devices that have been already fabricated in clean room. She/he will thus acquire advanced training in infrared spectroscopy and electrical measurements of quantum devices, including in cryogenic conditions.

This activity will be followed by a PhD project, where the aim is to explore non-linear quantum devices operating in the ultra-strong light-matter coupling regime. We will study devices where semiconductor quantum wells are integrated into optical resonators featuring deep sub-wavelength electromagnetic confinement [5] (Figure). This activity will be guided by recent theoretical work from our group which studies non-linear optical conversion in the ultra-strong coupling regime [6]. For this project, the Ph.D. student will actively participate in the conception and fabrication of the nano-devices, starting from 3D numerical modeling, through clean-room processing and optical characterization of the structures. She/he will acquire not only strong scientific expertise in solid state devices and quantum optics, but also in nanofabrication techniques. The PhD project will be funded by an ANR project which is experimental collaboration with IEMN Lille.

References

[1] C. Ciuti, G. Bastard, and I. Carusotto, Phys. Rev. B **72**, 115303 (2005).
[2] Y. Todorov, et al., Phys. Rev. Lett. **105**, 196402 (2010).
[3] F. Pisani et al., Nature Comm. **14**, 3914 (2023).
[4] U. Iqbal, C. Mora, Y. Todorov, Phys. Rev. Research **6**, 033097 (2024).
[5] M. Jeannin et al. ACS Photonics **6**, (5) 1207-1215 (2019).
[6] T. Krieguer, Y. Todorov, Phys. Rev. B **111**, 165304 (2025).

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: YES Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: NO