Optical Generation of Force and Motion in the Strong Coupling Regime of Light-Matter Interaction

Keywords: *polaritons, excitons, phonons, quantum fluids, nonequilibrium thermodynamics, semiconductor optical microcavity*

Exciton-polaritons (polaritons) are the elementary excitations of semiconductor microcavities, in which the excitonic transition[1] of an embedded quantum well is in the strong-coupling regime with photons from the cavity mode. Polaritons thus have a half-light, half-exciton hybrid nature, which is an extraordinary resource. For instance, their photonic fraction provides them with a low effective mass that makes them "behave" like photons, while their excitonic fraction provides them with the ability to interact with each other, a property which is absent in regular photons. The resulting physics is so rich that, a new class of quantum fluids has been defined after them, and known as "quantum fluids of light" [a,1,2].

This excitonic fraction also opens up striking perspectives in the domain of optomechanics: indeed, while photons cannot interact directly with phonons[2], polaritons do via their excitonic fraction. As a result, we have shown recently that polaritons can be used to cool down solids [3], or to excite THz acoustic wave [4]. In this project, our goal is to take one-step further in this direction, and **develop a prototype of four-stroke autonomous engine that converts light into mechanical work, using polaritons as an intermediate coherent working fluid**. Being neither classical, nor at equilibrium, the efficiency of this engine is not bounded by Carnot's limit. We will thus investigate its performance and efficiency in the various possible regimes of operation. Equivalently, the non-thermal entropy which is produced alongside mechanical work will be quantified, and its physical origin identified. With the support of the theory group, the experimental results will be modelled, and we will try to understand how such a class of engine compares with engines defined in classical equilibrium thermodynamics.

In a second part of this project, we will **set intracavity nano-objects in motion by dragging them with a polariton flow**. This drag force, which is of similar nature to that used in the first part of this work, will be measured and compared with regular radiation pressure. In a more fundamental approach, we will measure how this force varies, vanishes, and even changes sign as suggested theoretically [b], across the various quantum states of the fluid such as the normal-to-superfluid transition [c].

This work will be of mostly experimental nature, with day-to-day theoretical support provided by the group of A. Minguzzi (LPMMC, CNRS). Frequent collaborations with other groups worldwide will also take place, in the formal context of the French ANR project "Quantum Fluids of Light", and otherwise. The experimental work will consist in high-resolution optical spectroscopy experiments in a laboratory fully equipped with adequate state-of-the-art instruments (located at Institut Néel, and owned by the supervisor).

Profile: The candidate must have a taste in experimental photonics, numerical data analysis, and the physics of light in general. Notion in the relevant subjects, and/or experimental spectroscopy are a plus. A good academic record of accomplishment is required.

Bibliography

[a] I. Carusotto et al. *Rev. Mod. Phys.* **85**, 299 (2013)
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[1] S. Klembt et al. *Phys. Rev. Lett.* **120**, 035301 (2018)
[2] P. Stepanov et al. arXiv:1810.12570 (2019)
[3] S. Klembt et al. *Phys. rev. Lett*. **114**, 186403 (2015)
[4] K. Rojan et al. *Phys. Rev. Lett.* **119**, 127401 (2017)

Funding : 36 months grant via the "Quantum Engineering Grenoble" Network.

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[1] A semiconductor exciton is an electron-hole pair bound by Coulomb interaction.
[2] Phonons are the elementary excitation of a mechanical vibration of the semiconductor crystalline structure.