Scientific Project for Master 2 Internship and PhD thesis

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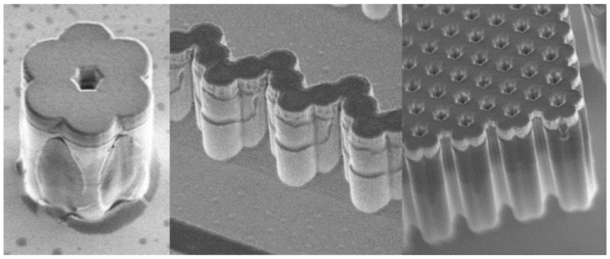
Artificial quantum materials with photons

Quantum systems containing many interacting particles are particularly hard to comprehend: when the number of particles increases, the size of the Hilbert space diverges and calculations based on classical computers become intractable. One way to learn about quantum many-body systems is to realize experiments in a well-controlled environment, as originally proposed by Richard Feynman [1]. Pioneering experiments have been realized using cold atoms, trapped ions or superconducting circuits. A promising approach nowadays is to use photons in order to implement photonic quantum materials. In this case, quantum properties are directly imprinted on a light field, which is a great advantage as it provides optical access to the observables of the system. Moreover, photonic quantum materials may be useful for realizing practical devices (quantum light sources for instance).



Scanning electron microscopy image showing lattices of coupled microcavities (diameter of each cavity is around 3.5 microns) emulating (left) a benzene molecule, (center) a topological lattice, (right) a graphene layer.

Our group at C2N has developed a unique expertise in designing photonic materials using lattices of coupled microcavities [2]. For example, we have recently realized the first topological laser in a 1D lattice [3], and explored exploring Dirac physics in 2D honeycomb lattices [4].

To progress toward the implementation of multi-photon quantum phases, we need to create strong photon-photon interactions. To do so, we mix the cavity photons with electronic excitations (excitons) created in quantum wells located in the cavity. The resulting exciton-photon state, named cavity polariton, shows significant interactions which have allowed demonstrating many fascinating such superfluidity of light [5].

The challenge we propose now is to engineer interactions that are strong enough (at the single photon level) to enter the quantum regime. The work will start with the development and characterization of novel active materials based on coupled quantum wells, which are expected to give rise to much stronger interactions. Photon-photon interactions will be characterized by low temperature spectroscopy and by photon correlations. The smoking gun evidence for the quantum regime will be the demonstration of single photon emission in a single lattice site. We will then build larger and larger lattices that will enable implementing and studying many-body Hamiltonians of increasing complexity.

We are looking for a candidate with skills and interest in experimental work, as well as solid knowledge in quantum optics and solid state physics. The work will be mainly experimental (low-temperature quantum optical spectroscopy), and the student will be introduced to sample processing in unique technological environment offered by the C2N clean room. Finally, this research being part of a large international collaboration, the student will directly interact with scientists from other laboratories and particularly with theoreticians.

References

[1] *Simulating Physics with Computers*, R. Feynman, International Journal of Theoretical Physics **21** (1982); **[2]** *Exciton-polaritons in lattices: A non-linear photonic simulator*, A. Amo and J. Bloch, Comptes Rendus Phys. **17** (2016); **[3]** *Lasing in topological edge states of a 1D lattice*, P. St-Jean *et al.*, Nature Photonics 11, 651 (2017); **[4]** *Orbital Edge States in a Photonic Honeycomb Lattice*, M. Milićević *et al.*, Physical Review Letters 118, 107403 (2017); **[5]** *Quantum Fluids of Light*, I. Carusotto and C. Ciuti, Rev. Mod. Phys. **85** (2013).