Scientific Project for Master 2 Internship and PhD thesis

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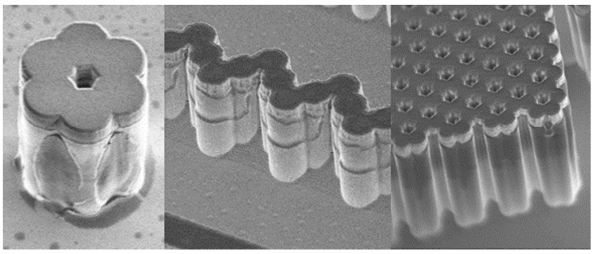
Manybody physics with light in semiconductor microcavities

Quantum simulation, first discussed by Richard Feynman [1], is an emerging experimental research field, which aims at understanding the eigenstates of quantum systems with many interacting particles. When the number of particles increases, the Hilbert space size diverges and the eigenstates are impossible to calculate with a classical computer. Richard Feynman proposed to learn about these eigenstates by realizing the experiment with a well-controlled artificial quantum system. While the most advanced platforms are cold atoms, trapped ions or superconducting loops, a very promising approach is to use photons in microcavities to realize such manybody quantum states. One advantage would be that multi photon entanglement could be imprinted on photons leaking out of the system, thus realizing a new source of quantum light.

Our group at C2N has developed a unique expertise of designing lattices of coupled microcavities and pioneered the emulation of different Hamiltonians with these lattices [2]. We have realized the first topological laser with a 1D lattice [3], we are exploring Dirac physics with 2D honeycomb lattices [4], to name just a few examples.



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

To induce photon-photon interactions and progress toward the simulation of manybody physics, we mix the cavity photons with electronic excitations, named excitons, created in quantum wells located in the cavity. The resulting exciton-photon state, named cavity polaritons, shows significant interactions which have allowed demonstrating many fascinating properties such as superfluidity of light [5].

The challenge we propose now is to increase interactions to enter the strong quantum regime with single photon non-linearities. 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. These interactions will be measured by detailed low temperature spectroscopy and photon correlations. The smoking gun evidence for the quantum regime will be the measure of single photon emission. Then we will implement manybody Hamiltonians of increasing complexity building larger and larger lattices, and we will probe their quantum properties

The work will be essentially experimental, with low temperature optical spectroscopy on microcavities. The PhD student will participate to the processing of the samples, profiting from the unique technological environment that will be able in the new C2N clean room.

This work is part of a large international collaboration and the PhD 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)