INTERNSHIP PROPOSAL

(One page maximum)

Laboratory name: Laboratoire de Physique de l’ENS (LPENS)
CNRS identification code: UMR 8023
Internship director’surname: Yannick Chassagneux
e-mail: yannick.chassagneux@phys.ens.fr Phone number:
Web page: https://www.lpens.ens.psl.eu/recherche/quant/equipe-01/nanotubes/
Internship location: 24 rue Lhomond 75005 Paris

Thesis possibility after internship: YES/~~NO~~
Funding: YES/~~NO~~ If YES, which type of funding: ANR

Deep sub-wavelength dielectric cavities coupled to nano-emitters in the cavity quantum electrodynamics regime.

The scientific project involves coupling nano-emitters to optical micro-cavities, which has a multitude of potential applications. These applications include modifying "natural" properties, such as the Purcell effect; characterized by the acceleration of the spontaneous decay rate and the efficient funneling of photons into a single optical mode. This has useful applications for quantum telecommunication. Coherent superposition of light and matter states (polaritons) can be generated using this technique. This offers various advanced photonic functionalities, including few photon non-linearity, quantum gates, etc. The strength of light-matter coupling is dependent on the ratio Q/V where V denotes the cavity mode volume and Q denotes the quality factor of the system. Two main approaches are possible to maximize this figure of merit in quantum photonics: the plasmonic route, which is restricted by Ohmic losses in the metal, yet with the mode volume being significantly sub-wavelength, and the dielectric resonator route, which can attain very high 'Q', yet with a mode volume not smaller than ~λ^3 due to the diffraction limit.

In this project, we propose to take the best of both approaches by designing and fabricating modified dielectric cavities (high Q) with deep sub-wavelength volumes, using a near field approach. These cavities will be used to couple solid-state nano-emitters (organic color centers in carbon nanotubes, graphene or perovskite quantum dots [3]) that behave like artificial atoms, for quantum technologies applications. In fact, by utilizing the discontinuities of the electric field at the center of a particular dielectric bow-tie antenna, it is possible to generate an anomaly in the E field resulting in an extremely small effective mode volume, with virtually no lower limit [1]. The price to pay is a limited extension of the mode in the z direction which puts this approach at the border of near-field optics.

Coupling the nano-emitter to the cavity requires two additional conditions: the emitter has to be in the cavity field maximum (spatial matching), and the cavity has to be resonant with the emitter (spectral matching). To fulfill these requirements, we have been working for several years with open-cavities, where one mirror is fabricated on the tip of an optical fiber [2,4]. The spatial and spectral matching are naturally obtained by moving this fiber. In this project, the bow-tie antenna will be fabricated on the tip of this fiber. All the necessary experimental equipments to conduct the experiments is readily available in our team. The core focus of this internship is to design, nanofabricate and benchmark the dielectric antennas. Subsequent developments within the PhD project involve coupling the antennas to an appropriate quantum emitter whilst investigating advanced quantum optics effects.

[1] Choi *et al*, PRL 118 223605 (2017) .
[2] Jeantet *et al*, PRL 116 247402 (2016).
[3] He *et al*, Nat. Mat. 17 663 (2018).
[4] Borel et al, ACS photonics,10, 2839 (2023).

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

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