Coherent coupling of quantum emitters on a nanofiber

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Context of the project:

Despite demonstrations of quantum advantage, photonic quantum computing is currently limited by the type of operations it can carry out. Linear operations, such as beam splitters or phase shifters, are easily implemented, in a scalable way, on a photonic chip [1–3]; however application range is limited. Adding nonlinear operations is considered as an ideal way to outperform classical computing and to achieve universal quantum computing, however they are so far mainly available on large footprints optical setup (such as atoms in cavities) or, by using probabilistic protocols, which makes scalability harder. The project aims at tackling this essential challenge head-on by using waveguide-Quantum electrodynamics (w-QED) in a nanophotonic system.

Scientific Objective of the PhD Project:
The objective of the current PhD project is to implement the team's first waveguide QED setup through the original use of a nanofiber and a single quantum emitter.

Scientific approach

The team at LKB is one of the world's experts on nanofiber fabrication using a heating and pulling process [4]. Additionally, the team has developed a technique to deposit single quantum emitters on those nanofibers to study their single photon emission properties [5].
The team recently acquired Germanium vacancy center diamond nanocrystals, a type of color centers, that exhibit excellent coherence and stability properties [6], similar to their counterparts in bulk, where they have been used for waveguide QED experiments, and in particular for the demonstration of single photon level nonlinearities [7], an asset for photonic quantum computing. The goal of the present PhD project is to use GeV-nanocrystals coupled to nanofibers to observe waveguide QED effects. To achieve this objective, highly coherent emission, have to be obtained from the color center, requiring cold temperatures (<5K). A cryostat is to be very soon ordered from the LKB team for this purpose. The PhD student will firstly examine the properties at room temperature of the GeV and select the best single photon emitters. Then the emitters will be analyzed at cold temperature to determine their optical properties. In particular, the student will scan the GeV centers transitions at resonance to measure precisely their emission linewidth and its evolution with temperature. Then the emitters will be deposited on optimized nanofibers. Secondly the PhD Student will be in charge of designing and implementing a method to integrate the nanofiber-emitter platform into a cryostat to collect single photons more efficiently and characterize the resulting light matter coupling.
Finally, the PhD student will perform resonant transmission measurement through the waveguide, with a highly attenuated laser beam (less than one photon per emitter lifetime) to measure few photons level sensitive nonlinearities.

Position in the QICS initiative

The proposed project is at the frontier of condensed matter, nanophotonics and quantum optics using continuous variable encoding. It proposes to explore a new approach to solve the issue faced in current photonics computing schemes, hindered by the lack of applications, as most schemes either rely on linear operations, or face scalability problems as using probabilistic quantum operations or large footprint setups. For example, in machine learning using quantum neural networks, several schemes for molecule simulation, require nonlinearities [8,9] (equivalent to hidden layers in classical networks) for efficient operation; remarkably it has been demonstrated that even moderate amount of nonlinearities can be very useful to boost up protocols [10]. The nanophotonic waveguide approach we chose here, is very flexible and versatile, providing already scalability and interconnectivity with quantum networks. Additionally, the waveguide approach makes it compatible with machine learning schemes as it can directly be integrated in large depth interferometer based photonic circuits.

Supervision :

Alberto Bramati is the LKB team leader and has developed the nanofiber pulling technique and emitter deposition to study the single photon emission of variety of single emitters at room temperature [11–14]. He recently established a collaboration with Christophe Couteau (Université Technique de Troyes) and Viatcheslav Agafonov (Université de Tours), on highly stable GeV nanodiamonds and their coupling to nanophotonic structures.

Hanna Le Jeannic recently joined the team at LKB and brings her waveguide QED expertise with single quantum emitters in waveguides, as assessed by her track record [15–19]. She has expertise on cryogenic and giant non linearities and will be the daily supervisor in the lab.

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