Multimode Quantum Electrodynamics with Atom-Photon Bound states

Master project

General Information

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Starting date: Summer 2023
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Motivation

Analog quantum simulators offer the opportunity to simulate quantum systems by the mean of another experimentally controllable quantum system [1,2]. These systems are of particular interest for the study of many-body physics. One can engineer such platforms by coupling one or several two-level systems to a multimode environment. At HQC laboratory, we have developed a high-quality multimode environment to which we can couple qubits. These multimode environments are implemented with disordered thin-film NbN, as an array of ultra-compact high impedance superconducting resonators, which form a band in frequency space. By coupling a qubit in the vicinity of this photonic band, one can generate atom-photon bound states. Such states form a photonic cloud around the qubit, the extent of this photonic cloud can be tuned by pushing the qubit closer or further away from the photonic band. It is possible to engineer interactions between two-atom photon bound states from the overlap of their photonic cloud, enabling the possibility for in-situ tunable coupling [3,4]. In this project, we investigate the properties of giant atoms, quantum emitters breaking the dipole approximation by coupling to a waveguide in multiple discrete points, and their behaviour when coupled to structured multimode environments[5,6].

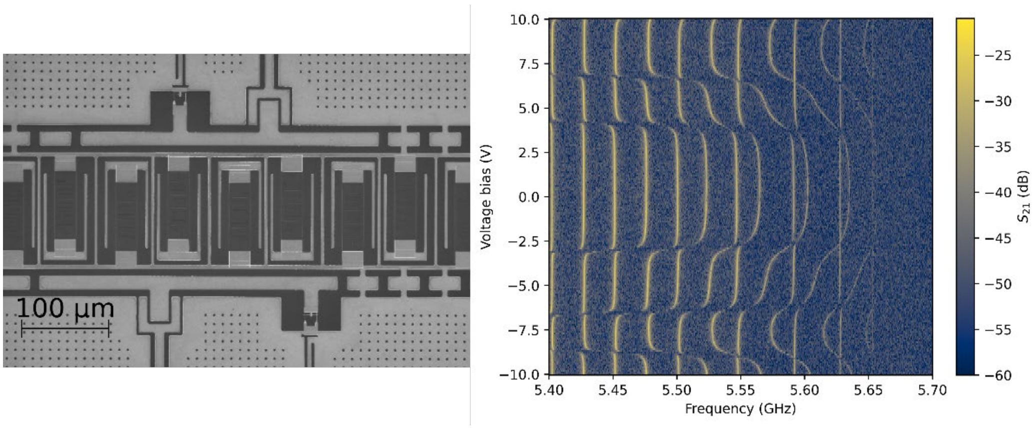

Fig 1 (Left) Image of two giant atoms coupled to a metamaterial. (Right) Upper pass band of the metamaterial measured in transmission vs the bias voltage applied to the flux line.

Description

The project is going to aim to model, design and perform measurements on the platform. The project will consist of three main phases:

1. **Modelling and Simulation**. In the first months, the student will learn about multimode quantum electrodynamics and atom photon bound states. The student will then simulate the platform.
2. **Design and Fabrication**. The student will learn how to design and fabricate the device.
3. **Measurements**. The device will then be measured in a LD250 dilution refrigerator, a cryogenic system capable of reaching temperatures in the range of 10 mK.

Tasks

- Literature search
- Devices modeling on SONNET and/or ANSYS
- Design and fabrication
- Experimental characterization of quantum systems

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[2] I. M. Georgescu et al., *Rev. Mod. Phys.* **86.1**, 153 (2014).
[3] X. Zhang et al., *Science*. 379.6629, 278-283 (2023).
[4] M. Scigliuzzo et al., *Phys. Rev. X* **12.3**, 031036 (2022).
[5] A. Soro et al, *Phys. Rev. A* **105.2**, 023712 (2022).
[6] A. Soro et al., *Phys. Rev. A* **107.1**, 01370 (2023)