Dynamical Coulomb blockade with NbN metamaterial resonators

Laboratoire de Physique et d'Étude des Matériaux, ESPCI Paris -PSL

Contact : yanko.todorov@espci.fr, cheryl.feuilletpalma@espci.psl.eu

The ability to confine light within very small volumes is of paramount importance for enhancing light-matter interactions, both for devices and fundamental studies [1]. The Terahertz (THz) and sub-THz spectral domains are particularly prominent for building metallic resonators with ultra-subwavelength mode volumes. Indeed, the corresponding wavelengths are large (λ = 1mm – 100µm), one can leverage from nanofabrication techniques with nanometer scale resolution. Moreover, metals exhibit low losses, and even superconducting materials such as NbN are available [2], with no losses below corresponding critical temperature. The resonant architectures of choice are typically either double-metal cavities [3] or metamaterial resonators, which can be engineered into 3D geometries [4], that are well mastered by our group.

In the present project, we will fabricate NbN-resonators to realize and study an elementary system for both electronic transport and light-matter interaction: a semiconductor tunnel junction coupled with an ultra-subwavelength metamaterial resonator. This structure can operate in the Dynamical Coulomb Blockade regime, where the electron tunneling transport is coupled to the electromagnetic fluctuations of the resonator, thus providing a probe for the its quantum state. This concept, pioneered by M. Devoret, 2025 Nobel prize winner [5], can even be extended to explore light-matter coupling systems in the extreme interaction regime known as Ultra-strong coupling [6].

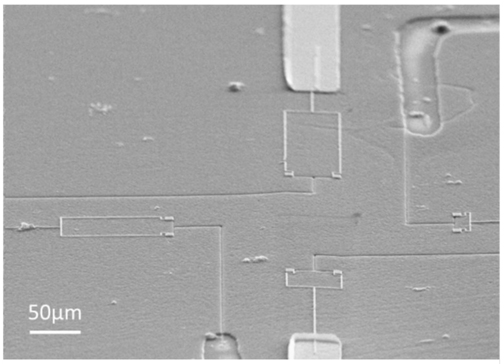

Figure: Metamaterial resonators combined with semiconductor tunnel junctions realized in the CMQED team.

As an intern, the candidate will model, fabricate and characterize electromagnetic resonators in the 100 GHz range made from NbN thin films. The internship will then be pursued as a PhD project funded by the ANR project HyQD100 where the resonators will be integrated with semiconductor tunnel junctions for the study of the regime of Dynamical Coulomb Blockade, (Figure), for various applications both in the THz and sub-THz ranges. In particular, these junctions will be used for non-demolition quantum measurements of the 100 GHz Qbits that will be produced in HyQD100. These studies open exciting possibilities for new types of devices which benefit from both concepts of semiconductor optoelectronics and superconducting quantum circuits.

The PhD candidate will receive a full training on nanofabrication techniques in the Paris Center cleanroom, and will acquire strong experience in the domains of quantum technologies and condensed matter physics, as well as advanced electromagnetism.

References:

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[3] C. Feuillet-Palma et al., “Extremely sub-wavelength THz metal-dielectric wire microcavities”, Optics Express Vol. 20, Issue 27, pp. 29121-29130 (2012).
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[5] M. H. Devoret, et al., “Effect of the electromagnetic environment on the Coulomb blockade in ultrasmall tunnel junctions”, Phys. Rev. Lett. **64**, 1824 (1990).
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