Thesis

ESPCI - PSL - PARIS
Physics and Materials Laboratory
(LPEM)

Local THz photons for coherent light-matter interaction

Condensed matter systems are the center of many game-changing technologies: superconductivity for example has allowed quantum-limited amplifiers for more sensitive detection schemes, and ferromagnetic material holds the promise for energy-efficient computation with the development of spintronics. The detection of these collective states requires energies in the meV range, which corresponds to THz frequencies. Unfortunately, at such high frequencies, dielectric and metallic losses will attenuate the information conveyed by an electromagnetic signal. Recent development in the time domain spectroscopy techniques [1] suggests the possibility of addressing single lumped resonators [2]. Combining the near-field capabilities of optical tools and the recent advances in circuit-quantum electrodynamics, we propose to build a THz spectroscopy platform to probe coherent excitations in condensed matter systems.

To reach mesoscopic lengths and increase the coupling with the collective excitations, a THz signal will be conveyed to a lumped resonator coupled capacitively or inductively to the system of interest, depending on the nature of the collective mode. In parallel, the non-linearity induced by a thin superconducting film can be harnessed to realize four-wave parametric frequency conversion [3]. Developing this technology is key to creating an integrated THz detection platform. Finally, to convey the signal from the converter to the resonator, an all-silicon topological metamaterial will be designed. These metamaterials have already been used to strongly attenuate the losses due to radiation [4]. This will unlock the main problems inherent in the THz frequency range by bringing coherent sources, low-loss LC resonators, and dissipation-free waveguides in this key frequency range. The realization of this light-matter interaction between THz photons in the circuit and many-body systems opens up the possibility of discovering new states of matter that have never been observed. One can think of magnon in graphene [5] for example.

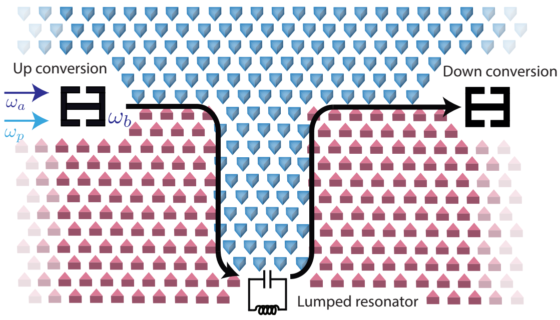

Figure 1: Schematic of a THz local sensing platform. On-chip frequency conversion allows for a short distance over which the THz signal will propagate. A lumped resonator coupled to the system under study is probed using a coherent excitation.

Objectives: The goal of this PhD is to design and fabricate a frequency converter based on NbN superconducting thin films [6], and topological waveguides in Silicon to guide THz signals towards a lumped resonator.

Prerequisite: A strong background in quantum mechanics and a taste for simulations and Python coding are recommended. If you are interested: please contact **alexis.jouan@espci.fr**

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[3] A. Anferov, A. Suleymanzade, A. Oriani, J. Simon, and D. I. Schuster, "Millimeter-wave four-wave mixing via kinetic inductance for quantum devices," *PRA*, vol. 13, no. 2, p. 024056, 2020.

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[6] M. Pechal and A. H. Safavi-Naeini, "Millimeter-wave interconnects for microwave-frequency quantum machines," *PRA*, vol. 96, 2017.