Spin-based magnetic imaging of superconducting microwave metamaterials

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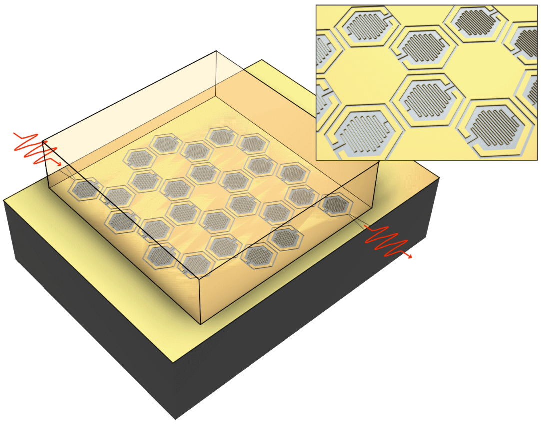
Start date:	*Spring 2025*		
Deliverables:	*Thesis / final report and defense / presentation*		

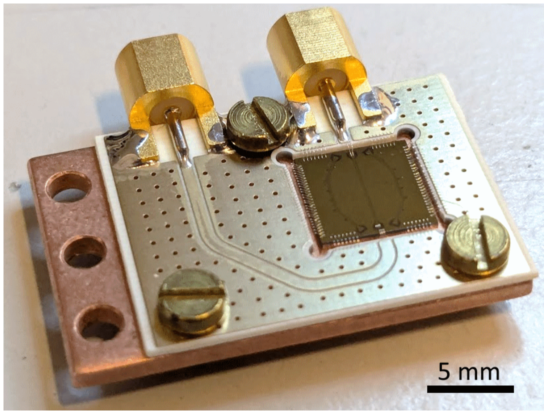
Motivation

Quantum simulation is based on the idea of using a well-controlled quantum system to reproduce the behaviour of complex and strongly correlated systems that would otherwise be impossible to simulate with a classical computer [1]. Superconducting quantum circuits serve as powerful tools for solid-state quantum simulation, as they allow excellent control over the propagation of microwave (MW) photons and offer robust nanofabrication processes.

In the proposed project, our goal is to develop an integrated hybrid quantum system for quantum simulation. We employ nitrogen-vacancy (NV) centers in diamond as microwave detectors to image the MW field amplitude and direction in compact niobium titanium nitride superconducting resonators [2]. This will provide direct insights into the spatial profile of photonic eigenmodes in a 1D / 2D array of subwavelength cavities. The freedom in designing the resonators and the couplings, combined with the relatively small footprint allows us to study interesting MW photonic metamaterials exhibiting flat bands or topologically protected states [3].



(a) Sketch of the system: an array of superconducting resonators in a hexagonal lattice, with a diamond containing NV centers on top.



(b) Photograph of a sample with coplanar waveguides (without diamond) mounted on the sample holder.

Tasks

The student will participate in the process of design, fabrication, and characterization of hybrid spin-superconducting quantum devices. Main tasks include:

- **Literature overview.** The student will familiarize themselves with the background literature and will identify how the proposed project could fill a research gap.
- **Modelling devices in Python, Sonnet, Ansys.** The student will learn the governing physics of the system: tight-binding and circuit models for the resonator lattices, and the Tavis-Cummings model for the NV spin-MW field interaction. The student will implement these models, and design and simulate new and interesting device geometries.
- **Cleanroom nanofabrication.** The student will learn how to fabricate the devices with the help of the scientific assistant.
- **RF and optical characterization.** The student will characterize the devices with a cryogenic NV magnetometry setup built in an Attodry800 4K cryostat.

[1] Changsuk Noh and Dimitris G Angelakis. Quantum simulations and many-body physics with light. *Reports on Progress in Physics*, 80(1):016401, 2017.

[2] Patrick Appel et al. Nanoscale microwave imaging with a single electron spin in diamond. *New Journal of Physics*, 17(11):112001, 2015.

[3] Vincent Jouanny et al. Band engineering and study of disorder using topology in compact high kinetic inductance cavity arrays. arXiv:2403.18150, 2024.