Superinductor-based Quantum Technologies with Ultrastrong Couplings (SiUCs)

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Introduction

Superconducting qubits have become one of the most promising platforms on which to build the entire span of quantum technologies. The success of this technology lies in the mastering of the interaction between light and matter, framed in field named circuit quantum electrodynamics (circuit QED), where microwave photons play the role of light, while qubits effectively behave as artificially man-made atoms.

The **light-matter models used by the community of superconducting quantum circuits are inherited from atomic physics,** where interaction strengths are very small and the rotating-wave approximation (RWA) is fully justified. This **unavoidably represents a limitation** when the whole physical model is required to accurately explain the results of experiments. The general light-matter interaction model is the quantum Rabi model (QRM):

$$\hat{\mathcal{H}}_{\mathrm{QRM}} = \frac{\hbar\omega_q}{2}\hat{\sigma}_z + \hbar\omega_r\left(\hat{a}^\dagger\hat{a} + \frac{1}{2}\right) + \hbar g\hat{\sigma}_x(\hat{a} + \hat{a}^\dagger)$$

containing much richer physics, but a very large interaction strength **-also known as ultrastrong coupling (USC)-** is required. Very few experiments have so far attained such levels of light-matter interaction [Forn-Diaz2010, Niemczyk2010, Yoshihara2017]. Despite this, **the interest in USC physics has grown worldwide** in the last decade.

Goals of project SiUCs

SiUCs aims to answer the following questions:

1. Can non-RWA effects be completely disregarded in conventional experiments of superconducting circuits exploring quantum computation and quantum simulation applications?*

2. Are there novel physics beyond the RWA that would significantly contribute to the advancement of quantum technologies with superconducting circuits?

Project goals:

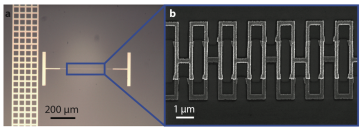
1. Deployment of **superinductorbased** technology to achieve USCs.
2. Engineer **novel qubits** with USC physics.
3. Study of **applications** of USC physics in quantum technologies.
4. Develop applications for superinductors such as **photodetectors**.

* **Recent results** in the readout of transmon qubits using resonators **clearly point in this direction** [Sank2016] in the context of quantum computation and qubit state readout.

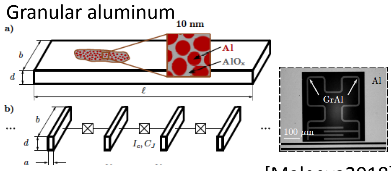
Superinductor enabling technology

A superinductor exhibits **an impedance exceeding** the quantum of impedance,
Two strategies exist to build superinductors:

Josephson junction arrays



Granular aluminum

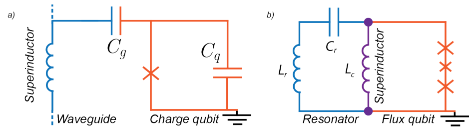


[Krupko2018]
$$Z_J = \hbar/(2e)^2\sqrt{2E_c/E_J}$$
[Maleeva2018]

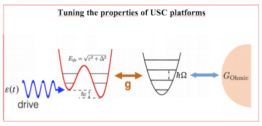
Novel qubits for USC physics

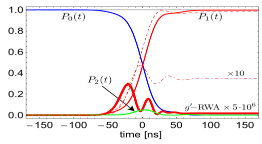
Key point in SiUCs: Employ superinductors to obtain USCs both in open (a) and closed (b) systems.

Circuit implementations for qubit-waveguide (a) and qubit-resonator (b) systems in the USC regime using superinductors.



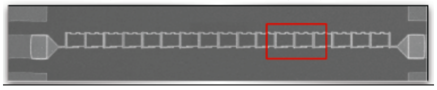
Theoretical models will be developed to define new experimental platforms for USC physics for dynamical control and switching.



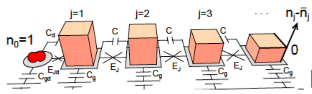


Applications of superinductor-based circuits

Microwave photodetectors using superinductors

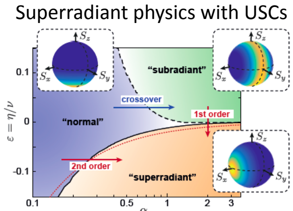


Condensed-matter physics simulation (Kondo)



[Znyman2015]

Superradiant physics with USCs



[De Bernardis2018]

The SiUCs consortium

-6 partners: 4 experiment/2 theory.
-33% Women PIs.
-50% Young researchers.
-1 widening country.
-Execution times: 04/20-03/23.
-Total budget: 1.29B€, 70% experiment.

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