SiUCs-QUCOS QuantERA workshop

Report of Contributions

Contribution ID : **1** Type : **not specified**

Pol Forn-Díaz, IFAE (SiUCs coordinator) - Welcome

Thursday, 23 February 2023 09:15 (15)

Contribution ID : **2** Type : **not specified**

Alba Torras, IFAE (SiUCs) - Ultrastrong coupling regime in superconducting circuits using superinductor materials

Thursday, 23 February 2023 09:30 (30)

Superconducting circuits offer a versatile platform to control and study light-matter interaction beyond the strong coupling regime. In this context, qubits play the role of artificial atoms, LC resonators act as cavities and the shared capacitance or
inductance between elements define the level of coupling.
From a circuit design point of view, the coupling coefficient can be engineered to take values of the order of the bare frequencies of the qubit and the resonator ($0.1 < g/\omega < 1$), allowing the study of the so-called ultrastrong coupling (USC) regime.
The challenge of obtaining large inductive couplings can be overcome by using either shared Josephson junctions or superinductor materials showcasing large kinetic inductances such as granular aluminium.
In this study, we report the first experimental steps in building a light-matter platform in the USC regime using superinductors. In particular, we will present an experimental qubit-resonator platform that incoroporates superinductances as coupling elements. We will also show our parallel efforts investigating a novel superinducting material, nitridized aluminum (NitrAl), which may become an important qubit circuit element.

Contribution ID : **3** Type : **not specified**

Gerhard Kirchmair, University of Innsbruck (QuCoS coordinator) - Coupling Fluxonium to a 3D circuit QED architecture - towards a dissipative cat qubit

Thursday, 23 February 2023 10:00 (30)

The aim of QuCoS is to encode a quantum bit in the fundamental bosonic mode of a weakly non-linear coaxial cavity[2] and protect it from decoherence with engineered two-photon dissipation [1]. In the case of this sub-project, the cavity non-linearity is inherited from a fluxonium qubit[3], which allows us to tune the memory-ancilla interaction in situ. As recently shown, in contrast to the conventional transmon ancilla, this qubit possesses higher protection against pump/readout induced decoherence. Furthermore, the larger anharmonicity of the fluxonium allows for faster gate operations on the qubit. Together with the engineered dissipation, this setup could be utilized as an improved building block for a fully protected logical qubit.
More specifically, in this talk I will present progress of coupling a fluxonium qubit to a high coherence cavity. I will talk about the coherence properties of the high-coherence cavity, the design and fabrication of the Fluxonium qubit and how to get magnetic flux into a 3D circuit QED architecture.

References

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[3] D. Gusenkova, M. Spiecker et al, Phys. Rev. Appl. 15 (2021) 064030
[4] O. Gargiulo, S. Oleschko et al, APL 118 (2021) 012601
[5] D. D. Bai, J. Du et al, J. Appl. Phys. 114 (2013) 133906
[6] P. Groszkowski, J. Koch, Quantum 5 (2021) 583

Contribution ID : **4** Type : **not specified**

Ioan Pop, KIT (SiUCs) - About AlOx interfaces and Aluminum superconducting device performance

Thursday, 23 February 2023 10:30 (30)

It is already well established that amorphous AlOx can host a zoo of spurious of two level systems, from positional defects to spin impurities. In this talk I will focus on other effects which can occur at the interface of AlOx with the Al electrodes in an SIS junction, or at the interface between a superconducting resonator and an in-situ grown para-Hydrogen crystal. The main conclusion of my talk is that we need to learn how to grow perfect dielectric crystals for junctions and custom dielectric layers for the capping of superconducting devices.

Contribution ID : **5** Type : **not specified**

Antoine Marquet, École Normale Superieure de Lyon (QuCoS) - Passive two-photon dissipation for bit-flip error correction of a cat code

Thursday, 23 February 2023 12:00 (30)

Demonstrating Quantum Error Correction is a key step toward the realization of a large-scale quantum computer. In contrast to strategies using a register of physical qubits to store the protected logical qubit, bosonic codes offer a resource-efficient alternative to reach the same goal. In these codes, the large ensemble of physical qubits is replaced by the many energy levels of a harmonic oscillator. Various bosonic codes have been proposed and implemented in superconducting circuits [1] and trapped ions [2]. Of particular interest, some implementations enable an autonomous error correction without resorting to measurement-based feedback. Recently, such autonomous schemes were successfully demonstrated for cat codes [3–6], where the logical $|0\rangle$ and $|1\rangle$ states are coherent states of opposite amplitudes $|\alpha\rangle$ and $|-\alpha\rangle$ in a superconducting resonator with single-photon loss rates κ1 as low as possible. They are able to correct bit-flip errors by either using the non-linearity of the oscillator or parametrically pumping couplers to activate a swap interaction between 2 photons of the resonator and 1 photon of the environment, a.k.a. two-photon dissipation at a rate κ2. This bit-flip correction comes at the expense of additional phase-flip errors, but importantly, the bit-flip time Tbf increases exponentially with |α|2 while the phase-flip rate only increases linearly with |α|2. This drastically lowers the number of components that are needed to design the additional layer of repetition code that protects against phase flips [7], or of the tailored surface code when the noise bias is not strong enough [8, 9]. As the ratio between two-photon and single-photon dissipation rates κ2/κ1 gets larger, the exponent λ in Tbf ∝ eλ|α|2 is expected to get larger. Previous works managed to demonstrate Tbf as high as several minutes but only for dozens of photons in the resonator owing to a low value of $\lambda < 2$, and without an ancillary transmon qubit to perform the tomography [5]. In this work, we introduce and experimentally demonstrate a new superconducting circuit designed to correct for bit-flip errors of cat codes. Crucially, the two-photon dissipation does not require any pump, so that a single drive is required to stabilize the qubit manifold. This is obtained by non-linearly coupling the cat qubit to a buffer mode that resonates at twice the frequency of the cat qubit. We experimentally demonstrate unprecedented ratios κ2/κ1, leading to reaching exponents $\lambda > 3$ so that bit flip times well over a ms can be reached with a few photons only. We also demonstrate quantum gates on this corrected cat qubit.

This work was partly supported by the QuantERA grant QuCos ANR-19-QUAN-0006.

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[2] B. de Neeve, T.-L. Nguyen, T. Behrle, and J. P. Home, Nature Physics 18, 296 (2022).
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Contribution ID : **6** Type : **not specified**

Luca Magazzù, University of Regensburg (SiUCs) - Transmission spectra of a strongly driven, dissipative Rabi model in the USC regime

Thursday, 23 February 2023 12:30 (30)

We present theoretical transmission spectra of a strongly driven, damped flux qubit coupled to a dissipative resonator in the ultrastrong-coupling regime. Such a qubit-oscillator system, described within a dissipative Rabi model, constitutes the building block of superconducting circuit QED platforms. The addition of a strong drive allows one to characterize the system properties and study novel phenomena, leading to a better understanding and control of the qubit-oscillator system. In this work, the calculated transmission of a weak probe field quantifies the response of the qubit, in frequency domain, under the influence of the quantized resonator and of the strong microwave drive. We find distinctive features of the entangled driven qubit-resonator spectrum, namely resonant features and avoided crossings, modified by the presence of the dissipative environment. The magnitude, positions, and broadening of these features are determined by the interplay among qubit-oscillator detuning, the strength of their coupling, the driving amplitude, and the interaction with the heat bath. This work establishes the theoretical basis for future experiments in the driven ultrastrong-coupling regime.

Contribution ID : **7** Type : **not specified**

Erwan Roverc'h, École Normale Superieure de Paris (QuCos) - Cooper-pair pairing: a resource for nonlocality and qubit protection

Thursday, 23 February 2023 14:30 (30)

The Josephson junction as a source of nonlinearity for superconducting circuits has become ubiquitous in quantum science and engineering. Introducing exotic circuit elements that only allow pairs of Cooper pairs to tunnel allows new properties to be uncovered, sparking interest for metrology and qubit protection. We present novel circuits obtained with an effective implementation of such an element. First, we show experimental progress on an alternative species of weakly-anharmonic oscillator where the nonlinearity comprises large displacements in phase space. In this experiment, we explore the new regime of large phase fluctuations, where the Josephson cosine potential is dominated by mixing terms even higher than fourth order. We expect peculiar effects in this extreme limit, such as the alternation of the sign of the oscillator frequency shift for each added photon, and even nonlocal quantum dynamics. Then, we discuss the design of a qubit based on the Cooper-pair pairing property [1] and its protection against various decoherence mechanisms.

[1] W.C. Smith et al., npj Quantum Inf 6, 8 (2020)

Contribution ID : **8** Type : **not specified**

Miroslav Grajcar, Slovak Academy of Sciences (SiUCs) - The quantum-limited detectors based on superconducting weak links

Thursday, 23 February 2023 15:00 (30)

In my talk I will present the design of two types of quantum-limited detectors of microwaves: a) travelling waves parametric amplifier and b) itinerant microwave photon detectors. Both designs are based on an array of superconducting nonlinear weak links.
The traveling wave parametric amplifiers are designed as coplanar waveguides with a central wire consisting of i) a high kinetic inductance superconductor, and ii) array of 2000 Josephson junctions. The standard coupled modes theory is modified by considering reflections due to impedance mismatches. This modification provides a simple analytical formula for gain and bandwidth for both 3-wave and 4-wave mixing. Predictions of the model are experimentally demonstrated on both types of TWPA.
Similarly, the design of an itinerant microwave photon detector is based on coplanar waveguide with a central wire consisting of an array of antiferromagnetically coupled superconducting flux qubits. The magnetization of such metamaterial, which can be simulated by Ising model, exhibits rapid transition to antiferromagnetic state driven by external magnetic field. The itinerant microwave photon could trigger this transition if the external magnetic field is set close to the phase transition of the metamaterial.

Contribution ID : **9** Type : **not specified**

Ramon Szmuk, Quantum Machines (QuCoS) - Pound locking for resonator frequency tracking and noise analysis

Thursday, 23 February 2023 15:30 (30)

The Pound technique is a powerful method for determining the relative detuning between a driving oscillator and a microwave resonator, allowing to lock one to the other and perform high bandwidth characterisations of resonator noise spectra, quality factors, and other parameters.
We present resonator frequency tracking with >10kHz lock bandwidth using Quantum Machine's Octave and OPX devices, allowing one to lock the controller to the resonator's frequency and vice versa for tunable resonators.
Power spectral densities of frequency noise can be extracted with >MHz bandwidths by calculating the autocorrelation, FFT, and averaging in real time, saving on data throughput and allowing for longer integration times.
We will also present the use of the Allan deviation as a statistical tool for studying long term drifts of resonators and will conclude by presenting ideas for scaling such techniques to many qubit systems.

Contribution ID : **10** Type : **not specified**

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Contribution ID : **11** Type : **not specified**

Giuseppe Falci, CNR (SiUCs) - Detecting virtual phothons in ultrastrongly coupled superconducting quantum circuits

Friday, 24 February 2023 10:30 (30)

Light-matter interaction, and understanding the fundamental physics behind, is essential for emerging quantum technologies. Solid-state devices may explore new regimes where coupling strengths are “ultrastrong”, i.e. comparable to the energies of the subsystems. New exotic phenomena occur the common root of many of them being the fact that the entangled vacuum contains virtual photons. They herald the lack of conservation of the number of excitations which is the witness of ultrastrong coupling breaking the U(1) symmetry.
Despite more than a decade of research, the detection of ground-state virtual photons still awaits demonstration. In this work, we provide a solution for this long-standing problem. Facing the main experimental obstacles, we find a design of an unconventional “light fluxonium”-like superconducting quantum circuit implemented by superinductors and an advanced control protocol of coherent amplification which yields a highly efficient, faithful and selective conversion of virtual photons into real ones. This enables their detection with resources available to present-day quantum technologies.

Contribution ID : **12** Type : **not specified**

Luiza Buimaga-Iarinca, ITIM (QuCoS) - Computational assessment of aluminium-based materials

Friday, 24 February 2023 10:00 (30)

In material manufacturing it is usually impossible to discriminate between the role and weight of each factor that may affect the structure composition at nanoscopic scale. This gap can be filled by computational modeling techniques and methods. One of the most powerful is the molecular dynamics (MD), which provides detailed information on the effect of substitutional disorder, defects, vacancies, pressure or temperature onto the manufacturing process, and allows to isolate and control the parameters and conditions for manufacturing.

We will present here our data on Al2O3 and grAl structures that resulted from the QuCos project activities.

Contribution ID : **13** Type : **not specified**

Dorian Fraudet, Néel Institute CNRS (SiUCs) - Spontaneous three photon generation in multi-mode circuit-QED

Friday, 24 February 2023 09:30 (30)

The coupling of a single quantum system to a large number of independent degrees of freedom can display very rich physics when pushed to extreme regimes. Such a setup can be implemented using the tools of circuit-QED where an artificial atom made out of Josephson junctions is coupled to a multi-mode microwave cavity. When the coupling strength between the quantum system and the modes becomes comparable to the bare transition energy of the artificial atom (ultra strong coupling USC), modes of the cavity start to interact together via their one to one interaction with the artificial atom. Such interactions lead to processes that do not conserve the number of excitations, which is a hallmark of USC. In this work we report the direct observation of such a process, namely the spontaneous generation of three photons where an incoming photon is spontanously converted into three outgoing photons.

Contribution ID : **14** Type : **not specified**

Closing session

Contribution ID : **15** Type : **not specified**

IFAE´s lab tour

Friday, 24 February 2023 12:00 (30)

Contribution ID : **16** Type : **not specified**

Lunch (end)

Contribution ID : **17** Type : **not specified**

Free Time

Thursday, 23 February 2023 18:00 (120)

Contribution ID : **18** Type : **not specified**

Workshop dinner

Thursday, 23 February 2023 20:00 (-1200)

Contribution ID : **19** Type : **not specified**

Departure

Friday, 24 February 2023 13:00 (20)