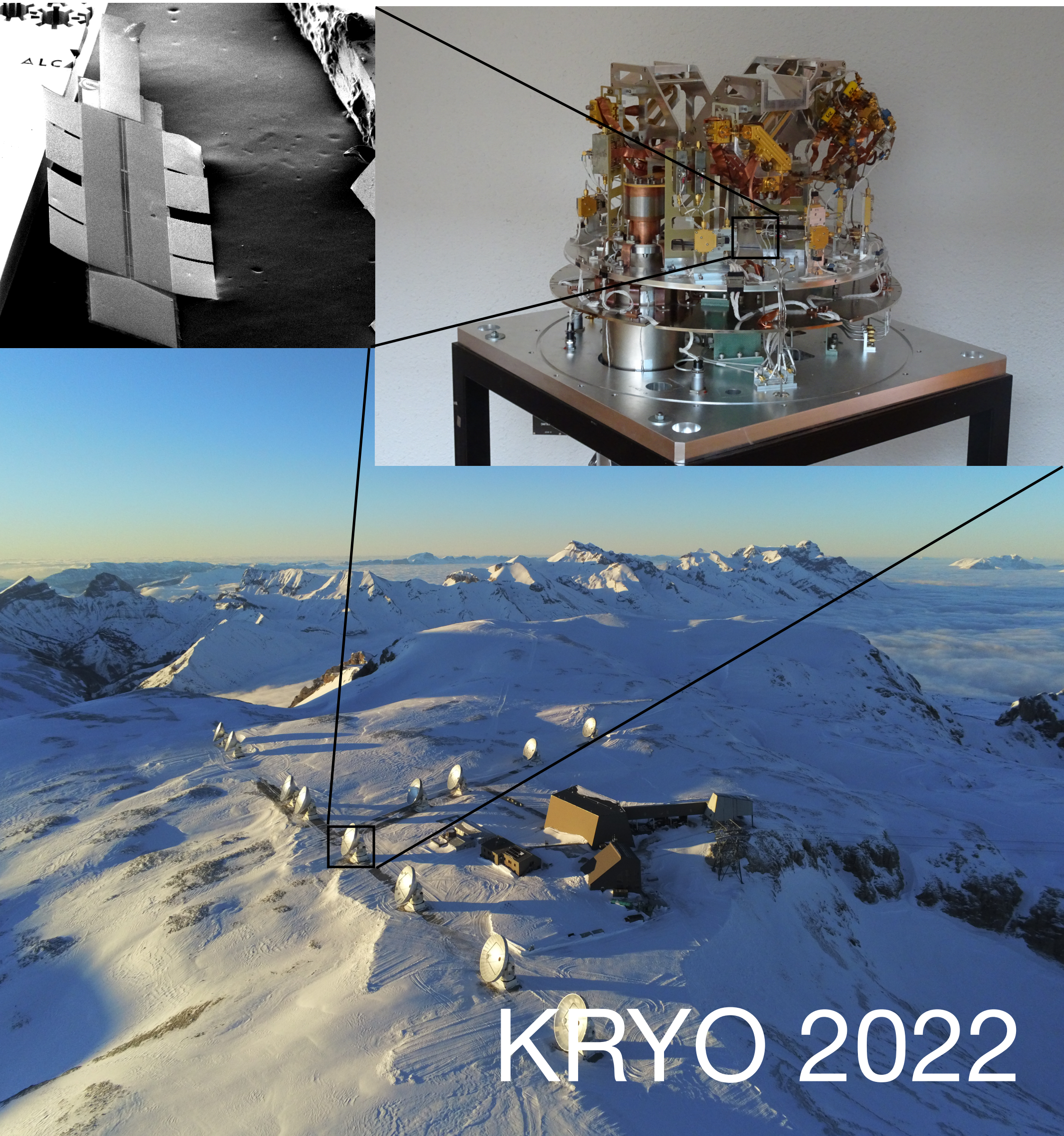
40th Workshop

Kryoelektronische Bauelemente

9-11 October 2022



Sunday		
15:00		Arrival
16:15	A Monfardini	Kinetic Inductance Detectors for (sub)millimeter wave Astronomical Instruments
17:15	G Le Gal	Superconducting parametric amplifiers for quantum measurements
19:00		Dinner
Monday		
08:50		Opening remarks
SESSION 1 - Instruments and Instrumentation		
09:00	M Schmelz	Passive magnetic exploration using a SQUID based vector magnetometer
09:30	P Serres	GERAR - a multi-pixel HEMT receiver for astronomical observations at 100 GHz
10:00	T Schönau	Towards a highly sensitive and robust SQUID-based charged particle beam monitor for accelerator facilities
10:30		Coffee break
11:00	C Risacher	Techniques for achieving cryogenic temperatures for radioastronomy
SESSION 2 - Superconducting circuits I		
11:30	F Vigneau	Preparation of maximally entangled states with digital-analog quantum computing (DAQC)
12:00		Lunch break
SESSION 3 - Microwave circuits		
14:00	K Uhl	Superconducting niobium microwave circuits with monolithic 3D constriction-type Josephson junctions
14:30	I Pop	Fano Interference in Microwave Resonator Measurements
15:00	U Chowdhury	OMKID, a horn-coupled millimeter-wave on-chip spectrometer based on LEKIDs
15:30		Coffee break

SESSION 4 - Fabrication		
16:00	J Goupy	Recent developments in Kinetic-Inductance Detector technology in Grenoble
16:30	T Griner	Nb an NbN constriction Josephson junctions and nanoSQUIDs patterned by He and Ne focused ion beams
17:00	S Linzen	Ultra-thin superconducting niobium nitride films for quantum devices
17:30		**POSTER SESSION**
19:30		Dinner
20:30		Scientific committee meeting
Tuesday		
SESSION 5 - Device physics		
09:00	A Semenov	Multiphoton effect in conditional count probability in superconducting single-photon detectors
09:30	A Murani	Assessing phonon traps efficiency through on-chip spatial and energy resolved detection of high energy impacts
10:00	S Wolter	Static and dynamic transport properties of multi-terminal, multi-junction microSQUIDs realized with Nb/HfTi/Nb Josephson junctions
10:30		Coffee break
SESSION 6 - Superconducting circuits II		
11:00	C Schuster	Monte-Carlo method based simulation framework for microwave SQUID multiplexers
11:30	F Feldhoff	Using bio-inspired principles in Digital Superconducting Electronics
12:00		Closing remarks
12:15		Lunch
13:30		Transport to Grenoble
14:30		Lab tours Institut Néel or IRAM

TUTORIALS

KINETIC INDUCTANCE DETECTORS FOR (SUB)MILLIMETER WAVE ASTRONOMICAL INSTRUMENTS

Alessandro Monfardini
Institut Néel, CNRS and Université Grenoble-Alpes, Grenoble

Since their first implementations, Kinetic-Inductance Detectors have been a game changer in millimeter-wave astronomical detection. In this tutorial, I will give an quick overview of their working principle, and an historical overview of their utilisation for millimeter astronomy following the evolution of the four instruments that we have developed in Grenoble: NIKA (2009-2015), NIKA2 (2015-), KISS (2018-2021) and CONCERTO (2021-). With these instruments, we have or we are carrying out imaging, polarimetry and spectroscopy over large instantaneous field-of-view. For example, since the installation in 2015, NIKA2 has been the largest millimeter-wave camera operating on a single dish and available to the astronomers via competitive calls.

SUPERCONDUCTING PARAMETRIC AMPLIFIERS FOR QUANTUM MEASUREMENTS

Gwenael Le Gal
Institut Néel, CNRS and Université Grenoble-Alpes, Grenoble

Over the last decades, circuit quantum electrodynamics (cQED) experiments in the microwave regime at cryogenic temperatures have started to be widespread, mostly based on superconducting circuits for the development of quantum computers. In such experiments, where quantum measurements are ubiquitous, one looks for the precise determination of low amplitude signals, where the carried energy is usually lower than a thousand photons. In order to reliably measure such signals at room temperature, one needs to amplify them while adding a minimal amount of noise. Up to now, the most widely used amplifiers for cryogenic measurements are based on semiconductors and can provide high gains (~40 dB), but their noise temperature remains limited to about 4-10 K because they are dissipative devices operated at 4 K. To overcome such limitations and try to obtain quantum-limited amplification, i.e. adding the minimum amount of noise allowed by quantum mechanics, a lot of effort has been put in the development of amplifiers based on parametric processes in superconducting circuits.

In this presentation, we will review the key processes leading to microwave signals amplification in superconducting circuits. We will present the current state of the art, focusing on devices known as travelling-wave parametric amplifiers. We will finally discuss some research directions offered by these devices beyond their use for amplification, such as the generation of multimode entanglement, or their use for nondestructive microwave photons counting.

ORAL CONTRIBUTIONS

PASSIVE MAGNETIC EXPLORATION USING A SQUID BASED VECTOR MAGNETOMETER

Ronny Stolz[1, 2], Vyacheslav Zakosarenko[1, 3], Markus Schiffler[1], Matthias Schmelz[1], Marco Schulz[3], Michael Schneider[3], Jürgen Kunert[4], Andreas Chwala[1], Jens Kobow[3], Matthias Meyer[3]
[1] *Dept. of Quantum Systems, Leibniz Institute of Photonic Technology, Jena*
[2] *Advanced Electromagnetics Group, Technische Universität Ilmenau, Helmholtzplatz 2, D-98693 Ilmenau, Germany*
[3] *supracon AG, Jena*
[4] *Competence center of Micro- and Nanotechnologies, Leibniz Institute of Photonic Technology, Jena*

In this work we present our advanced 3D vector magnetometer based on LTS Superconducting QUantum Interference Devices (SQUIDs) which enable to measure the full vector of the Earth's magnetic field in mobile operation. It is used in the passive geomagnetic exploration e.g. of minerals.
The SQUIDs are designed as multi-loop structure implementing sub-μm sized niobium Josephson junctions. The magnetometers have voltage swings of > 130 μV and a low intrinsic white noise floor of about 2 fTRMS/Hz1/2. Within the instrument the three orthogonally oriented magnetometers are read out by a flux counting electronics which provides a large dynamic range of > 32bit, a slew rate exceeding 3 MF0/s or equivalently 0.54 mT/s, and a bandwidth ranging from DC to 32 kHz.
We will present a series of laboratory and ground-based test results used to optimize the performance of the instrument. Compared to the predecessors, the new instrument has better linearity and slew rate. However, the main limiting factor is still the electromagnetic noise of the digital electronics mounted on top of the cryostat.
Finally, we will present the first results of airborne testing. A general data processing scheme is introduced which mainly incorporates the calibration of the vector magnetometer channels and the reduction of motional noise. The horizontal and vertical components show noise amplitudes for high altitude lines of 22 nTRMS and 9.7 nTRMS for the full 32 kHz bandwidth, respectively. In terms of spectral noise, it is lower than 1 pTRMS/sqrt(Hz) and well below 100 fTRMS/Hz1/2 for frequencies above 40 Hz. The processing scheme provides on the one hand the dc magnetic field related to magnetization of the underlying rocks and on the other hand the transfer functions in frequency domain between the vertical magnetic field component and the horizontal components. These transfer functions are used for deriving electrical conductivity anomalies by a 3D inversion tool for exploration depth exceeding 1km. The results are correlated to the recorded signal of a ground based SQUID EM receiver.

We will provide an outlook on the next development steps, the optimization of the instrument, and the outreach into the geophysical community.

We gratefully acknowledge the teams at Supracon AG (Germany) and DIAS Geophysical Ltd. (Canada) for their continuous and valuable aid. This work was supported in the framework of QMAG project under grant No. 01QE1710 by the Eurostars program which is powered by EUREKA and the European Community.

GERAR - A MULTI-PIXEL HEMT RECEIVER FOR ASTRONOMICAL OBSERVATIONS AT 100 GHZ

Patrice Serres
Institut de Radioastronomie Millimétrique, Grenoble

As part of AETHRA radionet project, a 75-116 GHz dual polarization 3x3 multibeam demonstrator was developed and tested at the Pico Veleta telescope. The design consists on 50nm gate length cryogenic "mHEMT" amplifiers linked to integrated frequency downconverters working at room temperature. In this presentation the system aspects will be discussed as well as details on the integration and performances of major components. To finish, the mains measurements results obtained including the observations made on the sky will be exposed.

TOWARDS A HIGHLY SENSITIVE AND ROBUST SQUID-BASED CHARGED PARTICLE BEAM MONITOR FOR ACCELERATOR FACILITIES

Thomas Schönau[1], Vyacheslav Zakosarenko[1], Matthias Schmelz[1], Jürgen Kunert[1], Volker Tympel[2]
[1] *Dept. Quantum Systems, Leibniz Institute of Photonic Technology*
[2] *Friedrich-Schiller University*

The nondestructive measurement of the current of the particle beam is a diagnostic tool of utmost importance for accelerator facilities. Recently, the concept of cryogenic current comparators (CCC) is used for implementation of a beam intensity monitor. The concept is based on two principles: a) the measurement of the super-current exited by the magnetic field of the particle beam in the superconducting pickup torus surrounding the beam using a sensitive SQUID current sensor, and b) designing a screening structure which enables the CCC to be only sensitive for an azimuthal magnetic field but not for disturbances from external sources in the very noisy environment of the accelerator. In contrast to a conventional CCC, the beam current monitor cannot be housed in a closed superconducting screen. Therefore, a sophisticated structure of a superconducting screen for the beam current monitor is required.

In order to increase the magnetic coupling of the beam to the pickup coil, often a core with high magnetic permeability is used. It allows to gain relatively high current sensitivity, but introduces additional 1/f noise due to motion of domain walls in the core. For this reason, we developed a coreless version of the current beam monitor using a SQUID based on the cross-type Josephson junctions developed at Leibniz IPHT (Jena, Germany). Herein, we present the development during the last three years resulting in the novel screening concept based on the axial meander structure allowing operation without degradation in a noisy environment. We achieved a screening factor of more than 200 dB and a white noise level of better than 5 pA/Hz1/2. The signal bandwidth of about 100 kHz is limited currently by the data acquisition system. However, the bandwidth of the SQUID with flux locked loop electronics can be as high as a few MHz. The prototype of such a beam monitor will be installed in the upcoming Facility for Antiproton and Ion Research (FAIR) or at CERN.

The test of the beam current monitor shows, however, an increased noise in the frequency range between 10 Hz and about 500 Hz which is presumably caused by microphonic excitations. By using appropriate data filtering, a current resolution of 1 nA (peak to peak) was demonstrated with the new CCC.

Finally, we will discuss future developments and possible improvements based on the coreless design of the CCC.

This project has been performed in collaboration with the colleagues Marcus Schwickert and Thomas Sieber from GSI Helmholtzzentrum für Schwerionenforschung GmbH. This work is supported by BMBF under contract numbers 05P18SJRB1 and 05P21SJRB1.

TECHNIQUES FOR ACHIEVING CRYOGENIC TEMPERATURES FOR RADIOASTRONOMY

Christophe Risacher
Institut de Radioastronomie Millimétrique, Grenoble

Instrumentation for radioastronomy requires typically cryogenic operation to achieve best sensitivities and is mandatory when using superconducting materials. Large progress has been achieved in the techniques used to reach those cryogenic temperatures. The observatories, on ground, airborne or in space where all using originally liquid Nitrogen and sometimes liquid Helium to achieve cryogenic tempetatures in wet dewars. Nowadays, closed-cycle refrigerators are mature enough to equip all modern ground-based, airborne and space telescopes. We will present this evolution in time in selected observatories and the current state of the art for closed cycles coolers, i.e., Gifford-McMahon, Pulse tube, Stirling coolers.

USING BIO-INSPIRED PRINCIPLES IN DIGITAL SUPERCONDUCTING ELECTRONICS

Frank Feldhoff, Hannes Toepfer
Advanced Electromagnetics Group, Technische Universität Ilmenau

The implementation of classical computing paradigms always has been troublesome with superconducting electronics. The implementation of a von-Neumann like computing architecture requires the usage of memory to a larger extend. Thus, non-von-Neumann type computing architectures are a good alternative to gain computational capabilities for certain tasks. Neural networks appear to have certain advantages in clustering unknown data, in correlation of different data-sets and completion of missing data, to name a few. The modeling and realization of neural systems in hardware is challenging, especially with superconductor electronics. Thus, the encoding of information in neuronal systems will be discussed as well as the transfer into RSFQ mixed signal circuit design. Furthermore, the implementation of spiking neural networks with RSFQ cells is described.

PREPARATION OF MAXIMALLY ENTANGLED STATES WITH DIGITAL-ANALOG QUANTUM COMPUTING (DAQC)

Julia Lamprich[1], Nicola Wurz[1], Manish Thapa[1], Vicente Pina[1], Stefan Pogorzalek[1], Antti Vepsäläinen[2], Miha Papic[1], Jay Nath[1], Florian Vigneau[1], Daria Gusenkova[1], Ping Yang[1], Hermanni Heimonen[2], Adrian Auer[1], Johannes Heinsoo[2], Frank Deppe[1], Inés De Vega[1]
[1] IQM Quantum Computers, Germany
[2] IQM Quantum Computers, Finland

Digital-Analog Quantum Computing (DAQC) is a novel approach, which combines digital single qubit gates with analog multi-qubit blocks. The DAQC concept distinguishes between two variants, stepwise and banged DAQC, where the single qubit gates are placed in between analog blocks or applied simultaneously with the analog (entangling) evolution, respectively.
In IQM, have implemented the preparation protocol of a maximally entangled two-qubit state (Bell state) on IQM's 5-qubit QPU using both the stepwise and banged DAQC approach. The entangling evolution is induced by a flux-tunable coupler element, which allows for the accumulation of adiabatic conditional phase. We have identified the relevant sources of error for both DAQC protocols, and we reach similar fidelities as in the purely digital case when preparing a Bell state using either stepwise DAQC or banged DAQC.
The multi-qubit version of the implemented circuit allows us to create GHZ states by parallelizing several two-qubit interactions. For the minimum example, the case of three qubits, we have investigated infidelities arising due to the multi-qubit nature of the interaction, including parasitic and higher order couplings.

We acknowledge support from the German Federal Ministry of Education and Research via the projects DAQC (13N15686) and Q-Exa (13N16062).

SUPERCONDUCTING NIOBIUM MICROWAVE CIRCUITS WITH MONOLITHIC 3D CONSTRICTION-TYPE JOSEPHSON JUNCTIONS

Kevin Uhl, Daniel Hackenbeck, Janis Peter, Reinhold Kleiner, Dieter Koelle , Daniel Bothner
Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Superconducting microwave circuits with integrated Josephson junctions and superconducting quantum interference devices (SQUIDs) are fundamental for the development of superconducting quantum information processing and quantum sensing technologies. In most cases the junctions are Al-AlOx-Al trilayer tunnel junctions with very low critical currents. In recent years, however, there is increasing interest in microwave circuits with integrated constriction-type Josephson junctions (cJJs). These cJJs provide ideal properties for several experimental platforms such as photon-pressure circuits, flux-mediated optomechanics and dispersive quantum magnetometry. So far, most microwave devices with cJJs have been realized based on aluminum, but a successful implementation with niobium (Nb) would allow for experiments at higher magnetic fields and higher temperatures. Here, we report the fabrication and integration of three-dimensional (3D) niobium constriction-type junctions into two different types of microwave circuits. The monolithic 3D junctions themselves were patterned into a 100 nm thick Nb film by means of a focussed neon-ion-beam and exhibit critical currents on the order of 10 microA. First, one of these junctions was integrated into a specialized coplanar waveguide standing wave resonator with direct current (DC) access, which allowed for simultaneous DC and microwave characterization of the Nb cJJ properties and for an extraction of the current-phase relation for varying sample temperature. In the second type of circuits, we implemented SQUIDs with two cJJs into a superconducting lumped element microwave resonator and characterized the magnetic flux tunability and nonlinear response of the resulting interference cavity. Our results reveal the properties and the potential of neon-ion-patterned monolithic 3D niobium cJJs and pave the way for a new generation of cJJ circuits and microwave quantum experiments with magnetic nanoparticles or mechanical oscillators in large magnetic fields.

FANO INTERFERENCE IN MICROWAVE RESONATOR MEASUREMENTS

Ioan M. Pop
Institute of Quantum Materials and Technologies, Karlsruhe Institute of Technology

Resonator measurements are a simple but powerful tool to characterize a material's microwave response. The losses of a resonant mode are quantified by its internal quality factor Qi, which can be extracted from the scattering coefficient in a microwave reflection or transmission measurement. Here we show that a systematic error on Qi arises from Fano interference of the signal with a back-ground path. Limited knowledge of the interfering paths and their relative amplitudes in a given setup translates into a range of uncertainty for Qi, which increases with the coupling coefficient. We experimentally illustrate the relevance of Fano interference in typical microwave resonator measurements and the associated pitfalls encountered in extracting Qi. On the other hand, we also show how to characterize and utilize the Fano interference to eliminate the systematic error.

OMKID, A HORN-COUPLED MILLIMETER-WAVE ON-CHIP SPECTROMETER BASED ON LEKIDS

Usasi Chowdhury
Institut Néel, CNRS and Université Grenoble-Alpes, Grenoble

We have fabricated an on-chip spectrometer sensitive in the 85-110 GHz range, with twelve channels selecting a frequency band of about 0.2 GHz. A horn coupled to a slot in the ground plane collects the radiation and guides it to a mm-line placed on the other side of the substrate in a micro-strip configuration. The mm-line is coupled to a filter-bank. Each filter is coupled to a Lumped Element Kinetic Inductance Detector (LEKID). The microstrip configuration allows to benefit from the high quality, i.e. low losses, mono-crystalline substrate, and at the same time prevents direct, i.e. un-filtered, LEKID illumination. The prototype spectrometer exhibit a spectral resolution $R = \lambda/\Delta\lambda \approx 300$. The optical noise equivalent power is in the low 10−16 W.Hz−1/2 range for an incoming power of about 0.2 pW per channel. The device is polarisation-sensitive, with a cross- polarisation lower than 1% for the best channels.

RECENT DEVELOPMENTS IN KINETIC-INDUCTANCE DETECTOR TECHNOLOGY IN GRENOBLE

Johannes Goupy
Institut de Radioastronomie Millimétrique, Grenoble, and Institut Néel, CNRS and Université Grenoble-Alpes, Grenoble

Over the last decade, kinetic-inductance detectors have been the preferred choice for large field-of-view cameras for millimeter-wave astronomical observations, as witnessed by the successful deployment of the NIKA2 and Concerto instruments in 2015 and 2021 respectively. In this talk, we will give an overview of the nanofabrication technology developed in Grenoble for this purpose. We will discuss the detector arrays deployed in the current instruments, as well as technological challenges for larger and more complex arrays. New developments towards medium and low resolution on-chip spectrometry will be discussed, as well as new application fields such as neutrino detection.

Nb AND NbN CONSTRICTION JOSEPHSON JUNCTIONS AND NANOSQUIDS PATTERNED BY He AND Ne FOCUSED ION BEAMS

Timur Griner[1], Simon Pfander[1], Julian Linek[1], Oscar Kennedy[2], Jamie Potter[2], Ute Drechsler[3], Thomas Weimann[4], Reinhold Kleiner[1], Paul Warburton[2], Armin Knoll[3], Oliver Kieler[4], Dieter Koelle[1]
[1] Physikalisches Institut – Experimentalphysik II, Universität Tübingen
[2] London Centre for Nanotechnology, University College London
[3] IBM Research Europe - Zürich
[4] Physikalisch-Technische Bundesanstalt [Braunschweig]

Nanopatterning of superconducting thin film structures with focused He or Ne ion beams (He/Ne-FIB) offers a flexible tool for creating constriction-type Josephson junctions (cJJs) and strongly miniaturized superconducting quantum interference devices (nanoSQUIDs) based on cJJs for applications in magnetic sensing on the nanoscale. We present our attempts to use He/Ne-FIB for fabricating Nb and NbN cJJs and nanoSQUIDs which shall provide ultra-low noise and high spatial resolution for their application in scanning SQUID microscopy (SSM). The nanoSQUIDs are designed as sensors for magnetic flux and dissipation. They shall be integrated on custom-made Si cantilevers, which will provide the possibility of simultaneous conventional topographic imaging by atomic force microscopy (AFM). We will discuss the status of this project and challenges that have to be met on the way to combine SSM and AFM on the nanoscale.

We acknowledge the European Commission under H2020 FET Open grant ‘FIBsuperProbes' (number 892427),

ULTRA-THIN SUPERCONDUCTING NIOBIUM NITRIDE FILMS FOR QUANTUM DEVICES

Sven Linzen[1], Evgeni Il'ichev[1], Mario Ziegler[1], Rais S. Shaikhaidarov[2], Oleg V. Astafiev[2], Sebastian E. De Graaf[3], Matthias Schmelz[1], Evgenia Mutsenik[1], Gregor Oelsner[1], Ronny Stolz[1]
[1] Leibniz Institute of Photonic Technology, Jena, Germany
[2] Royal Holloway, University of London, Egham, United Kingdom
[3] National Physical Laboratory, Teddington, United Kingdom

Ultra-thin films of disordered superconductors provide an opportunity to realize nanostructures with high kinetic inductances, low flux tunneling barriers, and especially quantum phase slip (QPS) junctions. For these purposes, we developed a fabrication technology for superconducting niobium nitride (NbN) films using a plasma enhanced atomic layer deposition (PE-ALD) process. The NbN films are polycrystalline with very small grain sizes. They can be prepared homogenously up to four inches wafer size and with well-controlled film thickness of only 2-4 nanometers. For NbN films with larger thickness a critical temperature of 13 K was reached.
In very thin films, a superconductor-to-isolator transition (SIT) is observed [1]. Nanowires prepared from NbN films with thicknesses close to the SIT show coherent QPS behavior at Millikelvin temperatures [2,3]. Furthermore, quantized current steps were observed within I-V measurements under microwave irradiation [3]. Thus, they may become the base for new circuits such as a current standard. On top, potential for more application is given by a combination of NbN and aluminum thin films [4].

This work was supported by European Union's Horizon2020 Research and Innovation Program under Grant Agreement No. 862660/QUANTUM E-LEAPS.

[1] S. Linzen et al., Structural and electrical properties of ultrathin niobium nitride films grown by atomic layer deposition, Supercond. Sci. Technol. 30, 035010 (2017).
[2] S. E. de Graaf et al., Charge quantum interference device, Nat. Phys. 14, 590–594 (2018).
[3] R. S. Shaikaidarov et al., Quantized current steps due to the a.c. coherent quantum phase-slip effect, Nature 608, 45–49 (2022).
[4] E. Mutsenik et al., Superconducting NbN-Al hybrid technology for quantum devices, submitted.

MULTIPHOTON EFFECT IN CONDITIONAL COUNT PROBABILITY IN SUPERCONDUCTING SINGLE-PHOTON DETECTORS

Alexej Semenov[1], Mariia Sidorova[1, 2], Heinz-Wilhelm Hubers[1,2], Sebastian Raupach[3]
[1] *DLR Institute of optical sensor systems*
[2] *Humboldt University, Berlin*
[3] *Physikalisch-Technische Bundesanstalt, Braunschweig - Germany*

Due to the combination of extended spectral sensitivity, low dark count rate and jitter, Superconducting Nanostrip Single-Photon Detectors (SNSPDs) often provide unique solutions for various applications in quantum communication, imaging, and quantum/classical light detection. However, emerged sophisticated applications e.g. in metrology, deep-space communication or for detection of dark matter or pose new challenges for the SNSPD technology. Among others they require low, if any, level of conditional dark counts known as afterpulsing. Afterpulsing in SNSPDs is a subtle phenomenon that is usually assumed to be absent or simply ignored but is occasionally observed. It occurs for both photon- and dark count-triggered events. It has been found that the rate of conditional dark counts is strongly affected by the read-out electronics. The reason is the impedance mismatch between the detector with a large kinetic inductance and the almost real input impedance of cooled low noise amplifiers that causes signal reflections [1, 2]. In this work, we discuss another, intrinsic reasons for the occurrence of conditional counts in SNSPDs and its connection to photon count events associated with multiple photons. We describe the dynamics of a normal conducting domain in a current-currying superconducting strip and find the probability of a dark count to occur at the edge of the domain caused by local thermal fluctuations [3]. We study effects of the bias current and the number of simultaneously coexisting domains on this probability and compare our predictions with recently obtained experimental results.

[1] M. Fujiwara, A. Tanaka, S. Takahashi et al., Afterpulse-like phenomenon of superconducting single photon detector in high speed quantum key distribution system, Opt. Exp. 19, 19562 (2011).
[2] V. Burenkov, H. Xu, B. Qi et al., Investigations of afterpulsing and detection efficiency recovery in superconducting nanowire single-photon detectors, J. Appl. Phys. 113, 213102 (2013).
[3] A. D. Semenov, M. Sidorova, M. Skvortsov et al., Local thermal fluctuations in current-carrying superconducting nanowires, Phys. Rev. B 102, 184508 (2020).

ASSESSING PHONON TRAPS EFFICIENCY THROUGH ON-CHIP SPATIAL AND ENERGY RESOLVED DETECTION OF HIGH ENERGY IMPACTS

Anil Murani, Francesco Valenti, Ioan Pop
Karlsruhe Institute of Technology

High energy ionizing impacts (muons, gamma rays) on a chip convert to high energy phonons which can propagate over large distances in the substrate, breaking Cooper pairs in superconducting devices on their way. These impacts are detrimental for quantum computing as they can produce correlated errors, a critical pitfall for current quantum error correction schemes. Mitigating these impacts can be done e.g. through shielding or on-chip phonon traps [1]. Being able to detect high energy impacts and the efficiency of phonon traps is therefore of paramount importance in order to optimize the performance of a device.
In this talk I will present on-chip high energy events detection with both spatial and energy resolution in order to assess the efficiency of phonon traps. We fabricated on the same chip six resonators made of granular aluminium, a high kinetic inductance superconductor very sensitive to Cooper pair breaking. Additionally, our chips were design to host phonon traps made of aluminium, a lower gap superconductor. Using custom made electronics, we performed simultaneuous event detection with time resolution at the nanosecond scale, allowing us to reconstruct the location of the impact. Additionally, the time response of the resonators provides us information about the impact's strength, from which we can estimate their energy. In the light of these results, I will discuss the efficiency of phonon traps in reducing the impacts rate.

[1] L. Cardani, F. Valenti, et. al., Nature Comm. 12 (2021)

STATIC AND DYNAMIC TRANSPORT PROPERTIES OF MULTI-TERMINAL, MULTI-JUNCTION MICROSQUIDS REALIZED WITH NB/HFTI/NB JOSEPHSON JUNCTIONS

Silke Wolter[1], Julian Linek[2], Thomas Weimann[1], Dieter Koelle[2], Reinhold Kleiner[2], Oliver Kieler[1]
[1] *Physikalisch-Technische Bundesanstalt (PTB), Fachbereich Quantenelektronik*
[2] *Universität Tübingen, Physikalisches Institut, Center for Quantum Science (CQ) and LISA+*

During the last years superconducting quantum interference devices (SQUIDs) with deep sub-micron Josephson junctions (JJs) have received increasing attention, since they offer high spatial resolution, high spin sensitivity and insensitivity to strong external magnetic fields. This makes them suitable for magnetic imaging on the nanoscale and for the detection of the magnetic states of individual magnetic nanoparticles. However, downscaling makes it increasingly difficult to modulate the magnetic flux through the SQUID using flux-modulation lines. In [1], a solution has been presented, where a multi-terminal, multi-junction SQUID-on-tip (SOT) configuration is introduced, which offers the possibility to adjust the SQUID to optimal sensitivity for all values of an applied magnetic field by applying control currents via additional ports. Since SOT include constriction-type JJs, the analysis in [1] focused on the static behaviour and the critical current of the multi-terminal SOT. In contrast we designed (as suggested in [1]) and fabricated 4-junction, 4-terminal SQUIDs (4JJSQs) with overdamped superconductor – normal metal – superconductor (SNS) trilayer Nb/HfTi/Nb JJs using our established thin-film planar fabrication process based on the combination of electron beam lithography with chemical-mechanical polishing. Due to nonhysteretic current-voltage characteristics, this allows for an investigation of static as well as dynamic electric transport properties of our 4JJSQs [2]. Like the conventional two-junction dc SQUID, also this device can be very well modelled with numerical simulations using RCSJ-type equations, and we see that the static behaviour is similar to that of the 4-junction SOT presented in [1]. Particularly in the resistive state the dynamics of symmetric 4JJSQs can strongly differ from the dynamics of a conventional dc SQUID, involving various phase-locked and chaotic states. Since these effects have disappeared in the asymmetric 4-junction SQUID studied experimentally, as judged from the transport characteristics, the multi-terminal, multi-junction configuration is a promising geometry, allowing for a stable in-situ control by shifting interference patterns. Additionally, the direct measurement of the current-phase-relation of our SNS-JJs was performed.

This work was supported by the DFG (KI 698/3-2, KO 1303/13-2), by the European Commission under H2020 FET Open grant "FIBsuperProbes" (Grant No. 892427) and has received funding from the EMPIR programme (project ParaWave 17FUN10) co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

[1] A. Y. Meltzer, A. Uri and E. Zeldov: „Multi-terminal multi-junction dc SQUID for nanoscale magnetometry“, Supercond. Sci. Technol. 29, 114001 (2016)
[2] S. Wolter, J. Linek, T. Weimann, D. Koelle, R. Kleiner, and O. Kieler: „Static and dynamic transport properties of multi-terminal, multi-junction microSQUIDs realized with Nb/HfTi/Nb Josephson junctions“, Supercond. Sci. Technol. 35, 085006 (2022)

MONTE-CARLO METHOD BASED SIMULATION FRAMEWORK FOR MICROWAVE SQUID MULTIPLEXERS

Constantin Schuster[1], Mathias Wegner[1, 2], Sebastian Kempf[1, 2]
[1] *Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology (KIT)*
[2] *Institute of Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)*

The readout of large-scale detector arrays based on low-impedance low-temperature detectors such as transition edge sensors or magnetic microcalorimeters necessitates the use of sophisticated SQUID multiplexing schemes, such as microwave SQUID multiplexing. Here, each multiplexer channel consists of a superconducting microwave resonator capacitively coupled to a non-hysteretic, unshunted rf-SQUID that is inductively coupled to the detector. In this configuration, the detector signal is transformed into a change of amplitude of phase of a microwave signal probing the resonator close to its resonance frequency. By coupling many such channels, each with a unique resonance frequency, to a common transmission line, a large number of detectors can be operated simultaneously. Due to the periodic nature of the SQUID response, readout schemes like flux ramp modulation must be used to linearize the output signal.
So far, the performance prediction and optimization of microwave SQUID multiplexers have largely been based on simple approximate analytical models and experimental results. Advances in the theoretical description of these devices have opened the door for a more detailed theoretical analysis of their performance and optimization. However, due to the complexity arising from the combination of the underlying nonlinear Josephson junction equations, flux ramp modulated readout, dynamical resonator response and various sources of noise, an analytical approach is still unfeasible.
Within this context, we present a Monte-Carlo method based simulation framework to study the characteristics and performance of a microwave SQUID multiplexer. It employs the state-of-the-art theoretical description of unshunted rf-SQUIDs which models a single microwave SQUID multiplexer channel including the finite resonator response time of superconducting microwave resonators with high internal quality factors as well as significant noise contributions such as amplifier noise, resonator noise and SQUID noise. We showcase how this simulation framework can be utilized to predict device performance considerably better than previous simple analytical methods, and present a first step towards a full microwave SQUID multiplexer optimization. Furthermore, we discuss some additional applications of our simulation framework.

PARAMETER EXTRACTION FOR THE CREATION OF ELECTRICAL EQUIVALENT CIRCUITS REGARDING SUPERCONDUCTING PLANAR METAMATERIALS AT HIGH FREQUENCIES

Melanie Schiemer, Thomas Reum, Hannes Töpfer
Technische Universität Ilmenau

A method for an efficient lumped element determination of a periodically structured grounded coplanar waveguide in the high frequency domain is presented. The proposed modeling approach is based on a quasi-stationary simulation technique as well as on analytical calculations. Equivalent lumped element circuit models are derived to mimic the physical behavior of the planar metamaterial by applying a distinct handling of electromagnetic coupling mechanisms. In contrast to classical full-wave methods used for geometrically extended components and assemblies, the prediction of lumped element values is not possible with the usage of simulated scattering parameters. Instead of this, the presented method is premised on the electromagnetic coupling considered by the capacitance matrix in conjunction with the inductance matrix of the considered structure along with quasi-stationary simulations. Due to the particular consideration of coupling mechanisms, the computational effort is significantly reduced while the calculation accuracy is still maintained. In order to prove the validity of the presented approach, the results obtained in this way are compared to those which are determined by classical full-wave methods. A satisfactory agreement is achieved for frequency domain as well as for time domain simulations. Consequently, the demonstrated procedure provides a framework for the rigorous quantitative parametrization of spatially distributed superconducting primitives, which leads to electrical equivalent circuits.

POSTERS

CURRENT SENSING SQUID NOISE THERMOMETRY WITH THIN FILM RESISTOR ELEMENTS

Jörn Beyer, Cornelia Aßmann, Patryk Krzysteczko, Alexander Kirste
Physikalisch-Technische Bundesanstalt

Johnson noise thermometry using SQUID sensors is an increasingly employed technique to measure thermodynamic temperatures in the range below about 4 kelvin into the low millikelvin range. The method has been demonstrated to be applicable even at sub-millikelvin temperatures. In 2019, SQUID noise thermometry has been included in the mise en practique for the definition of the kelvin at low temperatures in the SI. The current sensing SQUID noise thermometer (CSNT) is a SQUID noise thermometer variant. Here, a SQUID current sensor directly amplifies the thermal current noise of a resistor element, the actual sensing element, the temperature of which is determined.

We present CSNT with resistor elements that are lithographically defined thin film structures. The resistors with values of about 1 to 10 milliohm use Au and Au:Pd as well as superconducting Nb wiring. In order to ensure constant resistance values in the temperature range of operation, superconducting proximity effects are avoided. The metal thin film resistors are combined with different types of PTB's dc-SQUID current sensors to adapt noise temperatures, uncertainties and measurement speed as well as robustness against magnetic fields to different measurement setups.

For the millikelvin range, a CSNT using a single SQUID sensor channel is typically adequate. This is because the SQUID noise contribution to the uncertainty of the temperature is practically negligible. For sub-millikelvin temperatures, the resistor's thermal current noise should be read out by two SQUID sensor channels, and the resistor's temperature is deduced from the correlated noise in both readout channels. This cross-correlation approach is necessary to diminish the SQUIDs' noise contributions. Here, so-called backaction between the two SQUID sensor channels via their input circuits has to be minimized. Backaction could, otherwise, lead to nonthermal correlated noise in both readout channels and give rise to an overestimation of the measured temperature. Reduced backaction can be achieved by using a three-resistor network instead of a single resistor as the sensing element.

Design of fabrication of the metal thin film resistors as well as simulations and experimental results for different combinationsof the resistors and SQUID sensors in terms of their frequency dependent minimum noise temperatures and, hence, achievable measurement uncertainties and speeds are presented.

FABRICATION OF SIS JUNCTIONS AT IRAM

Dominique Billon-Pierron, Arnaud Barbier, Johannes Goupy, Eduard Driessen
Institut de Radioastronomie Millimétrique, Grenoble

We present the latest developments in SIS junction fabrication for millimeter wave astronomy. SIS junctions on Silicon-on-Insulator substrates will permit a wider IF bandwidth, and allow for the fabrication of beam leads which facilitate packaging and avoid parasitic inductances due to bond wires. Moreover we will present other developments in the IRAM nanofacility, such as beam lead technology on quartz substrates, and dichroic filters which will allow for dual-band operation of our receivers.

MICROWAVE SINGLE-SHOT QUANTUM KEY DISTRIBUTION

Florian Fesquet[1, 2], Fabian Kronowetter[1, 2, 3], Michael Renger[1, 2], Achim Marx[1], Rudolf Gross[1, 2, 4], Kirill G. Fedorov[1, 2]
[1] Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany
[2] Physik-Department, Technische Universität München, 85748 Garching, Germany
[3] Rohde & Schwarz GmbH & Co. KG, Mühldorfstraße 15, 81671 Munich, Germany
[4] Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 Munich, Germany

Security of modern classical data encryption often relies on computationally hard to solve problems. A potential remedy for this problem is quantum communication, which takes advantage of the laws of quantum physics to provide secure exchange of information. Here, quantum key distribution (QKD) stands as a powerful tool, allowing for unconditionally secure quantum communication between remote parties. A demand for quantum communication at microwave frequencies has emerged due to recent tremendous progresses in quantum computation with superconducting circuits. To this end, we present an experimental realization of a continuous-variable QKD protocol based on displaced squeezed microwave states. We use a Josephson parametric amplifier (JPA) to generate squeezed microwave states at cryogenic temperatures. By implementing a single-shot quadrature readout with a second JPA in the phase-sensitive regime with quantum efficiency of 38%, we demonstrate an unconditional security of our microwave QKD protocol. We analyze these results in terms of effective losses and noise in order to map them on possible real-world scenarios.

We acknowledge support by the German Research Foundation via Germany's Excellence Strategy (EXC-2111- 390814868), the Elite Network of Bavaria through the program ExQM, the EU Flagship project QMiCS (Grant No. 820505), the German Federal Ministry of Education and Research via the project QUARATE (Grant No. 13N15380), and the project QuaMToMe (Grant No. 16KISQ036). This research is part of the Munich Quantum Valley, which is supported by the Bavarian state government with funds from the Hightech Agenda Bayern Plus.

OPERATION OF NANOSQUIDS IN LARGE MAGNETIC FIELDS FOR THE DETECTION OF THE MAGNETIZATION REVERSAL OF INDIVIDUAL MAGNETIC NANOPARTICLES

Martin Hack[1], C. Spanheimer, R. Hutt, L. Koch[1], V. Morosh, T. Weimann, O. Kieler[2], R. Kleiner, D. Koelle[1]
[1] Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, Universität Tübingen
[2] Physikalisch Technische Bundesanstalt (PTB), Fachbereich Quantenelektronik, Braunschweig

Strongly miniaturized SQUIDs (nanoSQUIDs) are promising devices for the detection and investigation of magnetization reversal processes in individual magnetic nanoparticles (MNPs), such as nanowires, nanotubes or nanospheres [1]. The magnetization hysteresis loop of a MNP can be detected via the induced change of stray field coupled to a nanoSQUID by a MNP that is placed in close vicinity to the SQUID loop. The figure of merit for this kind of SQUID application is the spin sensitivity, defined as the rms flux noise of the nanoSQUID divided by the coupling factor (flux coupled to the SQUID per magnetic moment of the MNP). In addition to the optimization of the flux noise of the nanoSQUID, key challenges for MNP measurements with nanoSQUIDs are the reliable positioning of the MNP in close vicinity to the nanoSQUID and the stable operation of the nanoSQUID in variable strong external magnetic fields, which have to be precisely aligned in the plane of the SQUID loop. In this work, we describe our attempts to address those challenges. We use piezo-driven nanomanipulators mounted in a dual-beam Ga focused ion beam (Ga FIB) / scanning electron microscope (SEM) system to place MNPs in nm-distance to nanoSQUIDs. For sweeping an external magnetic field, we implemented an algorithm that provides improved alignment of the field in the plane of the SQUID loop via two orthogonal pairs of Helmholtz coils (correction coils).

[1] M. J. Martínez-Pérez and D. Koelle, NanoSQUIDs: Basics & recent advances, Phys. Sci. Rev. 2, 20175001 (2017).

FLIP-CHIP TECHNOLOGY FOR OPTICAL PULSE-DRIVE OF AC JOSEPHSON VOLTAGE STANDARD

Oliver Kieler, Hao Tian, Luis Palafox, Jonas Herick, Marco Kraus, Alexander Fernandez-Scarioni, Silke Wolter, Shekhar Priyadarshi, Johannes Kohlmann, Ralf Behr, Mark Bieler
Physikalisch-Technische Bundesanstalt [Braunschweig]

The pulse-driven AC Josephson voltage standard (or “JAWS”: Josephson arbitrary waveform synthesizer) is nowadays used at several National Metrology Institutes for various applications in electrical quantum metrology. The optical pulse-drive is one approach to further develop the JAWS setup, in particular to increase the output voltage and/or to reduce the complexity/ costs of the JAWS setup. Within several international research projects [1, 2] first promising results have already been achieved, e. g., bipolar JAWS waveforms were synthesized using 2 photodiodes (PD) arranged in a bipolar HF configuration [3]. For this purpose, high-speed PDs were mounted by flip-chip technology to specially designed Si-carrier chips. The tiny PDs (350 μm x 350 μm) are operated at 4 K close to the JAWS array. The sophisticated flip-chip technology was established at PTB very recently too. To connect the optical fiber to the backside lensed PDs, special ferrule sleeves are mounted on that carrier chip. At the conference the flip-chip procedure by thermo-compression using Au stud bumps and the sleeve mounting by gluing will be introduced. Recent results achieved with optical pulse-driven JAWS will be presented too.

This project 20FUN07 SuperQuant has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

[1] EU-project ‘Q-Wave', JRP SIB59, Available at: https://www.euramet.org/research-innovation/search-research-projects/details/project/a-quantum-standard-for-sampled-electrical-measurements/.
[2] EU-project ‚QuADC‘, JRP 15SIB04, Available at: https://www.euramet.org/research-innovation/search-research-projects/details/project/waveform-metrology-based-on-spectrally-pure-josephson-voltages/
[3] J. Herick, et al. “Realization of an Opto-Electronic Bias for Pulse-Driven Josephson Voltage Standards at PTB”, CPEM 2020 conference, Denver, USA. DOI: 10.1109/ CPEM49742.2020.9191913

MAGNETIC MICROCALORIMETERS FOR PRIMARY ACTIVITY STANDARDIZATION WITHIN THE EMPIR PROJECT PRIMA-LTD

Michael Müller[1], Ria-Helen Zühlke[1], Peter Kähler[1], Sebastian Kempf[1, 2]
[1] *Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology (KIT)*
[2] *Institute of Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)*

Magnetic microcalorimeters (MMC) are cryogenic, energy-dispersive single-particle detectors that are nowadays used for a wide variety of applications. They consist of a paramagnetic sensor material that is in strong thermal contact with a particle absorber suited for the particles to be detected and weakly coupled to a heat bath kept at constant temperature. The sensor is magnetized by a persistent current in an underlying superconducting pickup coil. The energy input due to an absorbed particle hence leads to a change in sensor magnetization which is transduced to a readout SQUID by means of the pickup coil.
Because of their excellent energy resolution as well as the very low threshold, MMCs are ideally suited for the ongoing EMPIR-project "PrimA-LTD" aiming to measure decay spectra of several isotopes with unprecedented precision to enable activity standardization for medicine and industry. Within this project we designed three optimized MMC based detectors for measuring the spectra of alpha-, beta- and electron capture-decaying radionuclides. Each MMC aims for a different method of radioactive source preparation: implanted radioactive source fully enclosed in an on-chip absorber or composite source/absorber elements attached to chip in either a single-use or reusable manner.
For fabrication of these detectors, we developed a novel electroplating setup for the deposition of ultrahigh purity absorbers made of gold allowing for fast thermalization of the detector independently from the impact location of a particle due to the very high residual resistivity ratio. Moreover, we developed a fabrication process for densely packed, overhanging absorbers standing on stems with minimized area to prevent energy loss in the early phase of detector thermalization. As an alternative to conventionally used persistent current switches, we started to develop a passive switch for persistent current preparation made of nitrated niobium allowing for easier detector handling and improved integration density in detector arrays with high pixel count.
We summarize the present state of our detector developments for the "PrimA-LTD"-project and outline ongoing next steps.

SQUID SETUPS FOR MEASURING ANTIFERROMAGNETIC AND WEAKLY REMANENT MATERIALS

Michael Paulsen[1], Julian Lindner[2], Bastian Klemke[2], Jörn Beyer[1], Dennis Meier[3], Michael Fechner[4], Klaus Kiefer[2]
[1] Physikalisch-Technische Bundesanstalt, 7.6 Cryosensors, Berlin
[2] Helmholtz-Zentrum Berlin fuer Materialien und Energie, Sample Environment Group, Berlin
[3] Norwegian University of Science and Technology, Department of Materials Science and Engineering, Trondheim
[4] Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

In this work, novel setups for measuring antiferromagnets and generally weakly remanent samples are presented. We focus on a newly developed variable temperature magnetometer insert device. It consists of a highly sensitive Super Conducting Quantum Interference Device (SQUID) magnetometer with a magnetic field resolution ~10 fT, a thermally controlled sample space with a temperature range of 1.5K- 65 K along with a non-electric sample movement drive and a position encoder. To avoid magnetic susceptibility effects, the setups are degaussed and mostly realized with plastic materials in sample proximity. They may advantageously be used in magnetically shielded rooms. The initial measurements demonstrate that such setups are very appropriate for measuring the weak external quadrupolar external fields of certain antiferromagnetic materials, which can be deployed in spintronic devices. In this capacity, the setups offer complementary and alternative access to studying such magnetic materials, which are usually measured with high field susceptibility approaches, optical methods and neutron scattering techniques.

QUANTUM LOCAL AREA NETWORK BASED ON A CRYOGENIC MILLIKELVIN LINK

Michael Renger[1, 2], Simon Gandorfer[1, 2], Wun Kwan Yam[1, 2], Florian Fesquet[1, 2], Kedar Honasoge[1, 2], Fabian Kronowetter[1, 2, 3], Yuki Nojiri[1, 2], Achim Marx[1], Rudolf Gross[1, 2, 4], Kirill G. Fedorov[1, 2]
[1] *Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften*
[2] *Physik Department, Technische Universitat Munchen*
[3] *Rohde & Schwarz GmbH & Co KG*
[4] *Munich Center for Quantum Science and Technologies (MCQST)*

The tremendous progress in superconducting quantum technology motivates the development of quantum communication networks for purposes of distributed quantum computing and quantum communication. In order to avoid inefficient and complex frequency conversion processes, it is attractive to study prototypes of quantum local area networks (QLANs) operating in the microwave regime. Here, we demonstrate realization of a microwave QLAN, based on a cryogenic link connecting two dilution cryostats over a distance of 6.5 meters. A corresponding quantum communication channel is realized by using superconducting coaxial cables cooled to the temperatures of below 100 mK. We investigate technical and fundamental limitations of such microwave cryogenic link. In addition, we demonstrate successful distribution of propagating squeezed vacuum states across the link, which potentially allows for remote entanglement of superconducting qubits and various quantum communication applications.

We acknowledge support by the German Research Foundation via Germany's Excellence Strategy (EXC2111-390814868), the Elite Network of Bavaria through the program ExQM, the EU Flagship project QMiCS (Grant No. 820505), and the German Federal Ministry of Education and Research via the project QUARATE (Grant No. 13N15380), and the project QuaMToMe (Grant No. 16KISQ036). This research is part of the Munich Quantum Valley, which is supported by the Bavarian state government with funds from the Hightech Agenda Bayern Plus.

SCALABLE TES AND READOUT PLATFORM FOR NEXT GENERATION THz SECURITY CAMERA

Matthias Schmelz[1], Erik Heinz[2], Katja Peiselt[1], Gabriel Zieger[1], Oliver Brandel[1], Detlef Born[1], Michael Siegel[2], Jürgen Kunert[1], Vyacheslav Zakosarenko[2], Matthias Meyer[2], Ronny Stolz[1]
[1] *Leibniz-IPHT*
[2] *Supracon AG*

In this work, we report on the development of a scalable architecture for transition-edge sensors-arrays (TES) and a corresponding readout scheme based on microwave rf-SQUID multiplexer (μMUX) for an advanced THz security camera. For security gate operations with stand-off detection of up to 25 m, the camera relies on a scanning optics with a 128-pixel TES array. Aiming for a compact and cost-effective solution, the demonstrator exhibits a base temperature of about 0.9 K, enabling to omit an expensive 3He cooling while maintaining necessary noise performance of the TES. A frequency-domain microwave SQUID multiplexer is used to read out the 128 feed-horn coupled TES based on aluminum thermistors. The μMUX presents a robust and scalable technology for TES noise limited operation.
We will present detailed results on the implemented aluminum TES and μMUX using the cross-type Josephson junction fabrication process developed at Leibniz IPHT. The μMUX incorporate high-quality superconducting thin-film resonators with resonant frequencies in the range of (5-6) GHz. A FPGA-based readout electronics enables the simultaneous and continuous real-time read-out of 128 rf SQUIDs including a flux ramp modulation scheme. In operation with the aluminum TES we achieved a dark NEP of < 5fW/Hz1/2 while providing a TES readout rate of 3.75 kHz necessary for video-rate of the security camera. We will present the system architecture and figures of merit of the TES and readout chain as well as first experimental results.

The authors acknowledge funding by the Federal Ministry of Education and Research in the framework of the HiTD project under grant nos. 13N14712 and 13N14713.

A SUPERCONDUCTING MICROWAVE RESONATOR WITH A MACROSCOPIC PARALLEL PLATE CAPACITOR FOR QUANTUM HYBRID SYSTEMS WITH COLD ATOMS

Benedikt Wilde, Nicolas Albenge, József Fortágh, Dieter Koelle, Reinhold Kleiner, Daniel Bothner
Experimentalphyik II and Center for Collective Quantum Science in LISA+, Universität Tübingen

Coupling superconducting quantum circuits to ultracold atom clouds promises the possibility of exploiting the advantages of both systems, allowing new advances in both fundamental research and potential technical applications. One can realize such a hybrid quantum system using a superconducting microwave resonator that is inductively coupled to the superconducting quantum circuit and at the same time capacitively coupled to Rydberg excitations in the cold atom cloud. A major challenge in designing such a resonator is that the electric microwave field experienced by the cold atoms needs to be homogeneous over the entire cloud of atoms (about 200 x 20 x 20 μm^3) to ensure a coupling with high coherence while at the same time being sufficiently large to enable strong coupling. Thus, the resonator needs to include a capacitor creating a maximized homogeneous field over a very large volume while still having a resonance frequency of several gigahertz in order to operate with superconducting qubits.
We present a novel sandwich-like resonator design comprising a two-chip parallel plate capacitor and a small inductor which has a resonance frequency of around 10 GHz. The sandwich-like assembly allows all sensitive structures to be fabricated using optical lithography. In order to position the atoms in between the capacitor plates and to facilitate tuning the Rydberg transition frequency, respectively, laser access to the inside of the parallel plate capacitor is provided and the application of a DC voltage to the capacitor plates in addition to the microwave is facilitated.
We will discuss the results of simulations regarding the field homogeneity and the microwave resonance as well as first experimental data. Our results clearly demonstrate the potential to finally achieve high-coherence strong-coupling between a superconducting integrated resonator and Rydberg states in cold atoms.

HETEROEPITAXIAL GROWTH OF SINGLE CRYSTALLINE $YBa_2Cu_3O_7$ AND $Sr_3Al_2O_6$ THIN FILMS ON $SrTiO_3$ SUBSTRATES

Katja Wurster[1], Markus Turad[2], Reinhold Kleiner[1], Dieter Koelle[1]
[1] Physikalisches Institut – Experimentalphysik II, Universität Tübingen
[2] Center for Light Matter Interaction, Sensors and Analytics (LISA+), Universität Tübingen

Scanning SQUID microscopy (SSM) is a powerful technique for imaging magnetic fields or dissipation processes. The development of the SQUID-on-tip (SOT) [1] led to a breakthrough in spatial resolution and flux sensitivity for SSM. However, so far SOTs are based on metallic superconductors, e.g., Pb or Al, which limits their operation range to temperatures below about 10 K and magnetic fields below about 1 T.
The use of the high-Tc cuprate superconductor YBa2Cu3O7 (YBCO) could enable SSM in the Tesla range and at temperatures up to about 80 K. However, YBCO has a complex crystal structure and a small coherence length, which leads to a high sensitivity to defects on the atomic scale. High quality YBCO films can only be obtained by epitaxial growth on lattice-matched substrates. Therefore, the SOT approach is not a viable option for the realization of YBCO-based SSM.
An alternative approach to realize YBCO nanoSQUIDs for SSM with high spatial resolution is based on the fabrication of nanoSQUIDs on custom made AFM cantilevers that are fabricated from Silicon-on-oxide (SOI) wafers [2]. Here, the challenge is the integration of YBCO thin films on SOI wafers. In this work, we present our approach to address that challenge. We intend to use Sr3Al2O6 (SAO), which is lattice-matched to perovskite materials, such as SrTiO3 (STO). SAO can be dissolved in water, i.e. it can be used as a sacrificial layer for the realisation of free-standing single-crystalline perovskite thin films [3], including YBCO [4].
We present the development of an epitaxial SAO thin film growth process, based on pulsed laser deposition (PLD) and discuss the properties of the grown SAO films. Furthermore, we describe our process for the heteroepitaxial growth of YBCO/STO/SAO trilayers on STO (001) single crystal substrates and discuss the optimization of growth conditions and properties of the trilayers. And finally, we present our preliminary attempts to transfer YBCO films onto Si surfaces.

This work was supported by the European Commission under H2020 FET Open grant "FIBsuperProbes" (Grant No. 892427)

[1] D. Vasyukov et al., Nature Nanotechnology 8, 639 (2013).
[2] www.fibsuperprobes.com
[3] D. Lu et al., Nature Materials 15, 1255 (2016).
[4] Z. Chen et al., Phys. Rev. Materials 3, 060801(R) (2019).

PARTICIPANTS

Participants

LAST NAME	FIRST NAME	MAIL	INSTITUTE
Barbier	Arnaud	barbier@iram.fr	IRAM
Beyer	Jörn	joern.beyer@ptb.de	Physikalisch-Technische Bundesanstalt
Billon-Pierron	Dominique	billon@iram.fr	IRAM
Bothner	Daniel	daniel.bothner@uni-tuebingen.de	Physikalisches Institut, Universität Tübingen
Chowdhury	Usasi	usasi.chowdhury@neel.cnrs.fr	Institut Néel
Driessen	Eduard	driessen@iram.fr	IRAM
Feldhoff	Frank	frank.feldhoff@tu-ilmenau.de	Technische Universitaet Ilmenau
Fesquet	Florian	florian.fesquet@wmi.badw.de	Walther-Meissner-Institut
Goupy	Johannes	goupy@iram.fr	IRAM and Institut Néel
Griner	Timur	timur.griener@uni-tuebingen.de	University of Tuebingen
Hack	Martin	martin.hack@uni-tuebingen.de	Eberhard Karls Universität Tübingen
Kieler	Oliver	Oliver.Kieler@ptb.de	Physikliasch-Technische Bundesanstalt
Kleiner	Reinhold	kleiner@uni-tuebingen.de	Universität Tübingen
Koelle	Dieter	koelle@uni-tuebingen.de	Universität Tübingen
Kohlmann	Johannes	johannes.kohlmann@ptb.de	PTB
Le Gal	Gwenael	gwenael.le-gal@neel.cnrs.fr	Institut Néel
Linzen	Sven	sven.linzen@leibniz-ipht.de	Leibniz IPHT
Monfardini	Alessandro	alessandro.monfardini@neel.cnrs.fr	Institut Néel
Müller	Michael	michael.mueller2@kit.edu	Karlsruhe Institute of Technology
Murani	Anil	anil.mlh@hotmail.fr	KIT, Alexander von Humboldt Foundation
Paulsen	Michael	michael.paulsen@ptb.de	PTB
Pop	Ioan M.	ioan.pop@kit.edu	KIT
Renger	Michael	michael.renger@wmi.badw.de	Walther-Meißner-Institut
Risacher	Christophe	risacher@iram.fr	IRAM

Participants

LAST NAME	FIRST NAME	MAIL	INSTITUTE
Rodrigues	Matias	matias.rodrigues@cea.fr	CEA
Schiemer	Melanie	melanie.schiemer@tu-ilmenau.de	Technische Universität Ilmenau
Schmelz	Matthias	matthias.schmelz@leibniz-ipht.de	Leibniz Institute of Photonic Technology
Schönau	Thomas	thomas.schoenau@leibniz-ipht.de	Dept. of Quantum Systems, Leibniz IPHT
Schuster	Constantin	constantin.schuster@kit.edu	Karlsruhe Institute of Technology (KIT)
Schuster	Karl	schuster@iram.fr	IRAM
Semenov	Alexej	Alexei.Semenov@dlr.de	DLR Institute of Optical Sensosystems
Serres	Patrice	serres@iram.fr	IRAM
Stolz	Ronny	ronny.stolz@leibniz-ipht.de	Leibniz Institute of Photonic Technology
Toepfer	Hannes	hannes.toepfer@tu-ilmenau.de	Technische Universitaet Ilmenau
Vigneau	Florian	florian.vigneau@meetiqm.com	IQM
Wilde	Benedikt	benedikt.wilde@uni-tuebingen.de	Universität Tübingen
Wolter	Silke	silke.wolter@ptb.de	Physikalisch-Technische Bundesanstalt
Wuensch	Stefan	stefan.wuensch@kit.edu	KIT
Wurster	Katja	katja.wurster@uni-tuebingen.de	Universität Tübingen

SCIENTIFIC COMMITTEE

C. Enss, Heidelberg University
R. Gross, WMI Garching
H.W. Hübers, DLR Berlin
S. Kempf, KIT
R. Kleiner, University of Tübingen
J. Kohlmann, PTB Braunschweig
H. Kohlstedt, Kiel University
D. Kölle, University of Tübingen
H.-G. Meyer, Leibniz-IPHT Jena
P. Müller, University of Erlangen
T. Ortlepp, University of Erfurt
I.M. Pop, KIT
M. Schilling, TU Braunschweig
T. Schurig, PTB Berlin
K.F. Schuster, IRAM Grenoble
R. Stolz, Leibniz-IPHT Jena
H. Töpfer, TU Ilmenau
M. Weides, University of Glasgow

WORKSHOP CHAIR

Dr. Eduard Driessen
Institut de Radioastronomie Millimétrique
300 rue de la Piscine
Domaine Universitaire
38400 Saint-Martin-d'Hères
France
www.iram-institute.org

VENUE

Best Western Grand Hôtel de Paris
124 place Pierre Chabert
38250 Villard de Lans
France
contact@ghp-vercors.com
Tel. +33 4 76 95 10 06

SPONSORS

FOCUS
Focal Plane Array for Universe Sensing

iram
Institut de
Radioastronomie
Millimétrique