TT 7: Focus Session: Disordered and Granular Superconductors: Fundamentals and Applications in Quantum Technology II

Time: Tuesday 13:30–16:15 Location: H6

TT 7.1 Tue 13:30 H6

Granular Aluminum: a superconducting material with amenable nonlinearity for quantum circuits — •Ioan Pop — KIT, Karlsruhe, germany

The electrodynamics of granular Aluminum (grAl) can be modeled based on an effective Josephson junction array with high kinetic inductance and amenable nonlinearity[1,2]. This recommends grAl for various applications in quantum technology, including kinetic inductance detectors, parametric amplifiers and quantum bits. One illustration of grAl's utility in quantum circuit design is the remarkable resilience of grAl fluxonium qubits[3] to photons populating its dispersively coupled readout resonator. This resilience allows single shot QND measurements[4] and quantum state preparation via active feedback with fidelities exceeding 90

[1] Maleeva et al. Nature Comm. 9, 3889 (2018)
[2] Winkel et al. Phys. Rev. X 10, 031032 (2020)
[3] Grunhaupt, Spiecker et al. Nature Materials 18, 816-819 (2019)
[4] Takmakov, Winkel, et al. Phys. Rev. App. 15, 064029 (2021)
[5] Gusenkova, Spiecker, et al. Phys. Rev. App. 15, 064030 (2021)
[6] Cardani, Valenti et al. Nat. Commun. 12, 2733 (2021)

TT 7.2 Tue 14:00 H6

Novel Quantum state at the interface between graphene and disordered superconductor — •Gopi Nath Daptary, Eyal Walach, Efrat Shimshoni, and Aviad Frydman — Department of Physics, Bar-Ilan University, Ramat-Gan 5290002, Israel

Over the past decades, there have been considerable interest in electronic properties of low dimensional systems, in particular the quantum effects that manifest themselves as the dimensions of a device approaches a microscopic length scale. Two-dimensional (2D) materials, composed of single atomic layers, have attracted vast research interest since the breakthrough discovery of graphene. One major benefit of such systems is the simple ability to tune the Fermi level through the charge neutrality point between electron and hole doping. For 2D Superconductors, this means that one may potentially achieve the regime described by Bose Einstein Condensation (BEC) physics of small bosonic tightly bound electron pairs. In my talk I will describe an experiment showing that single layer graphene, in which superconducting pairing is induced by proximity to a low density superconductor, can be tuned from hole to electron superconductivity through an ultra-law carrier density regime. We have studied, both experimentally and theoretically, the vicinity of this "Superconducting Dirac point" and found an unusual situation where reflections at interfaces between normal and superconducting regions within the graphene, suppress the conductance. In addition, the Fermi level can be adjusted so that the momentum in the normal and superconducting regimes perfectly match giving rise to ideal Andreev reflection processes.

TT 7.3 Tue 14:15 H6

Impact of Kinetic Inductance on the Critical Curren Oscillations of Nanobridge SQUIDs — •Heleen Dausy, Lukas Nulens, Bart Raes, Margriet Van Bael, and Joris Van de Vondel — Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium

We study lithographically fabricated MoGe nanobridges and their current phase relation (CΦR), which is linked to the nanobridge kinetic inductance. We do this by imbedding the nanobridges in a SQUID. We observe that for temperatures far below the critical temperature, the CΦR is linear as long as the condensate is not weakened by the presence of supercurrent. Another result is that the nanobridge kinetic inductance scales with its aspect ratio. We demonstrate that the SQUID $I_c(B)$ characteristic is tuneable through lithographic control over the nanobridge dimensions. These observations can be of use for the design and operation of future superconducting devices such as magnetic memories or flux qubits.

TT 7.4 Tue 14:30 H6

Disorder-enhanced inelastic relaxation in thin NbN films — Andrey Lomakin[1,2], Elmira Baeva[1,2], Philipp Zolotov[1,2], Alexandra Triznova[2], •Anna Kardakova[1,2], and Gregory Goltsman[1,2] — [1]National Research University Higher School of Economocs, Moscow, Russia — [2]Moscow Pedagogical State University, Moscow, Russia

Disordered superconducting films is a building block for superconducting nanowire single-photon detectors. A complex physics of such detectors implies a non-equilibrium response, determined by energy relaxation of electrons, namely electron-phonon (e-ph) scattering and phonon escaping times. In practice, one prefers to reduce these values along with optimization of other detector parameters.

Here, we report on experimental study of inelastic relaxation in thin disordered NbN films by measuring of magnetoconductance in the temperature range $T_c < T < 3T_c$. The studied 2.5-nm thick NbN films are characterized by a moderate level of disorder, expressed as $3 < k_F l < 6$. From magnetoconductance data, we find out the phase-breaking rate is a sum of two terms, electron-electron (e-e) and e-ph scattering, $\tau_\phi^{-1} \sim A_{e-e}T + A_{e-ph}T^n$, where $n = 3.5 - 4$ is similar as in work of Sidorova et.al, 2020. We also observe that both e-e and e-ph rates gradually increase with film disorder. The trend for increase of e-e rate with disorder is consistent with scenario of fermionic suppression of superconductivity in NbN films.

15. min. break

TT 7.5 Tue 15:00 H6

Magnetic-field-compatible hybrid superconducting circuits — •Marta Pita-Vidal — Qutech, Delft university of Technology, The Netherlands

Hybrid superconducting circuits, which integrate semiconducting elements into a circuit quantum electrodynamics (cQED) architecture, provide new insights into mesoscopic superconductivity. Extending the capabilities of hybrid circuits to work in large magnetic fields would enable the investigation and control of spin-polarized and topological phenomena. Here, I will discuss our work on magnetic-field-compatible hybrid cQED devices based on NbTiN. In particular, we exploit the high kinetic inductance of thin NbTiN to build a fluxonium which includes an electrostatically-tuned semiconducting nanowire as its nonlinear element. We in-situ tune its Josephson energy with an electrostatic gate and demonstrate operation of the fluxonium in magnetic fields up to 1T. This combination of gate-tunability and field-compatibility demonstrates the utility of hybrid superconducting circuits for exploring mesoscopic physics and enables the use of the fluxonium as a readout device for topological qubits.

TT 7.6 Tue 15:30 H6

Disordered superconducting NbN thin films and their quantum device application — •Evgeni Il'ichev[1], Sven Linzen[1], Oleg Astafiev[2,3], Rais Shaikhaidarov[3], Kyungho Kim[3], Jacob Dunstan[3], Ilya Antonov[3], Vladimir Antonov[2,3], Mario Ziegler[1], Gregor Oelsner[1], and Ronny Stolz[1] — [1]Leibniz Institute of Photonic Technology, Jena, Germany — [2]Skolkovo Institute of Science and Technology, Bolshoy Boulevard 30, bld. 1, Moscow, Russia 121205 — [3]Physics Department, Royal Holloway, University of London, United Kingdom

Within the past years we optimized and studied the properties of superconducting niobium nitride films fabricated with plasma-enhanced atomic layer deposition (PEALD). The films are polycrystalline and consist mainly of cubic δ-niobium-nitride grains of only a few nanometers in size. A superconductor to insulator transition (SIT) can be observed within ultrathin PEALD-NbN films by reducing the film thickness from 3.1 to 2.8 nm. Well-adjusting the film thickness slightly above the SIT point the films show high values of the kinetic inductance and the normal state resistance. Such films were used to fabricate nanowires in which the coherent quantum phase slips (CQPS) can be observed. Observation of the Aharonov-Casher effect as well as the dynamics of the CQPS are discussed.

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TT 7.7 Tue 15:45 H6

High-kinetic-inductance superconducting nanowires for ultra-compact microwave devices — •Marco Colangelo[1],

Daniel F. Santavicca[2], Carleigh R. Eagle[2], Brenden A. Butters[1], Owen Medeiros[1], Maitri P. Warusawithana[2], and Karl K. Berggren[1] — [1]Massachusetts Institute of Technology, Department of Electrical Engineering and Computer Science, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA — [2]University of North Florida, Department of Physics, 1 UNF Dr, Jacksonville, FL 32224

Superconducting nanowires made of disordered thin films can achieve a kinetic inductance which is several orders of magnitude higher than their magnetic inductance. Nanowires, integrated into transmission-line architectures, feature a characteristic impedance ~kΩ, an effective phase velocity a few percent of the speed of light in vacuum, and a strong compression of the microwave wavelength. We exploit these properties to demonstrate a balanced forward coupler at 4.73GHz based on coupled nanowire stripline with < 500 μm2 footprint, more than one order of magnitude lower than traditional modules. Interfacing high-impedance nanowire devices to 50 Ω electronics requires a large matching structure, which can, in principle, spoil the miniaturization achieved with nanowires. We address this challenge by combining high-inductance nanowires with high dielectric constant substrates. We demonstrate nanoscale resonators operating natively at 50Ω featuring a wavelength compression of almost 200 times. This demonstration paves the way to 50Ω ultra-compact cryogenic microwave devices.

TT 7.8 Tue 16:00 H6

Eliminating Quantum Phase Slips in Superconducting Nanowires — •Jan Nicolas Voss[1], Yannick Schön[1], Micha Wildermuth[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2,3,4] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Quantenmaterialien und Technologien (IQMT), Karlrsruher Institut für Technologie, Karlsruhe, Germany — [3]Russian Quantum Center, Skolkovo, Moscow, Russia — [4]National University of Science and Technology MISIS, Moscow, Russia

Superconducting nanowires made from granular aluminium have unique electrical properties at low temperatures. They originate from the intrinsic network of Josephson junctions in the material and the spatial restrictions to dimensions that are of the order of the superconducting coherence length. We present a novel method, which allows changing the nanowire resistance by modifying the intrinsic junction network by electrical pulses.

At low temperatures, we have observed a transition from an insulating over a metallic to a superconducting response in about a two hundred individual resistance steps. The measurement results are compared with the quantum phase slip model for superconducting nanowires [1].

[1] J. N. Voss, Y. Schön, M. Wildermuth, D. Dorer, J. H. Cole, H. Rotzinger and A. V. Ustinov, ACS Nano 15, 4108 (2021)