# TT 18: Superconductivity: Poster

Time: Monday 15:00–18:00 Location: Poster C

TT 18.1 Mon 15:00 Poster C

**Terahertz investigations on ALD-grown superconducting NbN thin films** — •Yayi Lin[1], Frederik Bolle[1], Martin Dressel[1], Detlef Born[2], Heidemarie Schmidt[2], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology (IPHT), Jena, Germany

Niobium nitride (NbN) thin films are high-disorder superconductors, that have attracted significant interest in recent years. Due to its high critical temperature ($T_c$ up to 17 K) and large energy gap, NbN is applied in single photon detectors, microwave resonators, and superconducting quantum circuits.

As the energy gap of NbN is located in the terahertz (THz) region (3 - 100 cm$^{-1}$, 100 GHz - 3 THz), we use THz spectroscopy to directly determine the energy gap from the complex optical conductivity ($\hat{\sigma}$). By measuring the THz transmission, $\hat{\sigma}$ can be derived, which encodes various superconducting properties of NbN.

Here, we measured NbN grown by atomic layer deposition (ALD) with the nominal thicknesses of 4.5, 5.0, 10.0, and 20.0 nm on $Al_2O_3$ substrates, in both THz frequency-domain spectroscopy (THz-FDS; frequencies 3 - 40 cm$^{-1}$) and THz time-domain spectroscopy (THz-TDS; 10 - 100 cm$^{-1}$), at temperatures down to 2.7 K, revealing $T_c$, the complex optical conductivity, energy gap, and superfluid density.

TT 18.2 Mon 15:00 Poster C

**Nanoscale Characterization of Superconducting Nitrides for Qubits** — •Janine Lorenz[1,2,3], Amin Karimi[1], Yorgo Haddad[4], Sven Linzen[5], Rami Barends[4], F. Stefan Tautz[1,2,3], and Felix Lüpke[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, Germany — [3]Institut für Experimentalphysik IV A, RWTH Aachen, Germany — [4]Peter Grünberg Institut (PGI-13), Forschungszentrum Jülich, Germany — [5]Leibniz Institute of Photonic Technology, Friedrich-Schiller-Universität Jena, Germany

Superconducting nitrides like NbTiN are promising candidates for advancing the performance of transmon qubits as they offer distinct advantages compared to conventional aluminum-based quantum circuits. Notably, NbTiN thin films offer improved chemical stability, show elevated critical temperatures up to 15 K and have a higher kinetic inductance, all of which are important properties for good qubit performance.

Here, we present a comprehensive investigation of superconducting nitride thin films using scanning probe techniques. We find that our polycrystalline 5 nm and 11 nm NbTiN films show a homogeneous superconducting gap throughout the surface. Applying BCS theory we extract critical temperatures of 10 K and 11.5 K, respectively. To improve structural and superconducting properties of our films we explore different post-deposition treatment methods with a focus on thermal annealing in different gas atmospheres.

TT 18.3 Mon 15:00 Poster C

**Broadband microwave measurements on superconducting granular aluminum** — •Jan Pusskeiler, Aniruddha Deshpande, Martin Dressel, and Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Granular aluminum is an interesting superconductor because its critical temperature $T_c$ can be changed by tuning the grain decoupling, measured by the normal-state resistivity. The resulting phase diagram contains a dome-shaped superconducting phase originating from the increasing superconducting energy gap $\Delta$ for weaker coupling of the grains. Decoupling on the other hand also suppresses the superfluid stiffness $J$ due to phase fluctuations of the superfluid condensate. Hence, on the high resistivity side of the dome $J < \Delta$ and the superfluid density limits $T_c$ [1]. The height of the superconducting dome (maximum $T_c$) is determined by the grain size, which can be reduced by cryogenic cooling of the substrate during sample fabrication.

We perform broadband microwave measurements in Corbino reflection geometry in the frequency range from 100 kHz to 20 GHz at temperatures down to 1.15 K. We investigate granular aluminum thin films that are grown at different substrate temperatures and that cover different parts of the superconducting dome. We determine their impedance, which gives access to the complex conductivity. We can thus observe how the superfluid density decreases with increased grain decoupling. Furthermore, we observe absorption features that we interpret as signatures of plasmonic modes of the superfluid condensate.

[1] U. S. Pracht *et al.*, Phys. Rev. B **93** (2016) 100503(R)

TT 18.4 Mon 15:00 Poster C

**Vortex effects in a superconducting $[(SnSe)_{1+\delta}]_3[NbSe_2]_1$ Van-der-Waals superlattice** — •Wieland G. Stoffel[1], Linus Grote[1], Mahni Müller[1], Theodor Griffin[1], Olivio Chiatti[1], Danielle Hamann[2], David C. Johnson[2], and Saskia F. Fischer[1,3] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Department of Chemistry and Materials Science Institute, University of Oregon, Eugene OR 97403, USA — [3]Center for the Science of Materials Berlin, 12489 Berlin, Germany

In recent years, many materials have shown a transition between 2D and 3D superconducting behaviour [1]. Layered superconductors provide a promising framework to study those transitions. A new approach to understanding the interplay between the layers are ferecrystals, which are a Van-der-Waals bound composites of superconducting layers and spacers (here: $NbSe_2$ and SnSe) [2].

In this work we characterise the collapse of the superconducting state of a $[(SnSe)_{1+\delta}]_3[NbSe_2]_1$ ferecrystal in terms of the critical current, temperature, and magnetic field. This enables the determination of both the in-plane and out-of-plane Ginzburg-Landau coherence length, as well as the observation of effects on the IV-characteristic caused by the formation of vortices. These effects are analysed in terms of a Berezinskii-Kosterlitz-Thouless transition and the formation of phase-slip lines. The latter also explains an anomaly in the temperature dependence of the critical currents.

[1] C. Parra *et al.*, Proc. Natl. Acad. Sci. 118.16 (2021)
[2] O. Chiatti *et al.*, J. Phys. Condens. Matter **35** 215701 (2023)

TT 18.5 Mon 15:00 Poster C

**Superconductivity in quasi-2D Weyl semimetal candidate trigonal $PtBi_2$ via chemical tuning** — •Soumen Ash[1], Kilian Srowik[1], Reza Firouzmandi[1], Laura Teresa Corredor Bohorquez[1], Silke Hampel[1], Saicharan Aswartham[1], and Bernd Büchner[1,2] — [1]Institute for Solid State Research, Leibniz IFW Dresden, 01069 Dresden, Germany — [2]Institute of Solid State and Materials Physics, TU Dresden, 01062 Dresden, Germany

Novel quantum states like topological superconductors that host exotic excitations like Majorana fermions have stimulated intense research due to their fundamental physics and potential applications for quantum information technology. Recent discovery of sub-Kelvin superconductivity in quasi-2D Weyl semimetal candidate $PtBi_2$ has offered a new platform to explore the effect of chemical tuning on its superconducting and topological properties. We have carried out (i) Ir doping at Pt-site, (ii) Te and Se doping at Bi-sites, and (iii) Cu intercalation into the van der Waals layers of trigonal $PtBi_2$ via solid-state reactions and successfully grown plate-like single crystals using a stoichiometric melt growth technique. Detailed structural, electrical transport, magnetic, and thermodynamic characterizations have been conducted. Doping of chalcogen atoms at Bi-sites induces a structural phase transition from noncentrosymmetric structure (space group: $P31m$) to centrosymmetric structure (space group: $P\bar{3}m$). We report superconductivity in $Pt_{0.9}Ir_{0.1}Bi_2$, $PtBi_{1.8}Te_{0.2}$, $PtBi_{1.9}Se_{0.1}$, and $Cu_{0.1}PtBi_2$ with comparatively higher $T_c \approx 2.3 - 2.4$ K. This work opens up a new avenue to get further insights into the superconductivity in trigonal $PtBi_2$.

TT 18.6 Mon 15:00 Poster C

**3D van Hove singularities near the Fermi level in $NiTe_2$ and $PdTe_2$** — •Emily C. McFarlane[1], Jonas A. Krieger[2], Antonio Sanna[1], Camilla Pellegrini[1], Mihir Date[1], Gabriele Domaine[1], Banabir Pal[1], Pranava K. Sivakumar[1], Anirban Chakraborty[1], Stuart S. P. Parkin[1], and Niels B. M. Schröter[1] — [1]Max Planck Institute of Microstructure Physics Weinberg 2, 06120 Halle, Germany — [2]Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

The type-II Dirac semimetal $NiTe_2$ has been used as the non-superconducting barrier in devices demonstrating the Josephson diode effect (JDE) at 20mK [1]. However from the Allen-Dynes formula,

$NiTe_2$ is estimated to have a $T_c$ of 1.5K [2]. In isostructural $PdTe_2$, a saddle-point van Hove singularity (vHs) and its proximity to the Fermi level ($E_F$) is thought to be important for its type-I superconductivity with $T_c$=1.7K [3]. We investigated the electronic band structure of $NiTe_2$ and $PdTe_2$ to understand the lack of superconductivity in $NiTe_2$ and origin of the JDE.

We present soft X-ray ARPES measurements of the bulk band structure to confirm the location of this vHs in $NiTe_2$ and $PdTe_2$, and show that it is closer to $E_F$ in $NiTe_2$. We also present a new approach to superconducting-DFT calculations which suggests a magnetic instability is responsible for suppressing superconductivity in $NiTe_2$.

[1] B. Pal *et al.* Nature Physics **18** 1228-1233 (2022).
[2] J. Zhang, G. Q. Huang J. Phys.: Condens. Matter **32** 205702 (2020)
[3] K. Kim *et al.* Phys. Rev. B **97** 165102 (2018).

TT 18.7 Mon 15:00 Poster C

**Superconducting transition temperatures of V and V-Ti alloys in the presence of electronic correlations** — •Dylan Jones[1,2], Andreas Östlin[1], Andreas Weh[1], Florian Beiuseanu[3], Ulrich Eckern[4], Levente Vitos[5], and Liviu Chioncel[1,2] — [1]Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg, Germany — [2]ACIT, University of Augsburg, Germany — [3]Faculty of Science, University of Oradea, Romania — [4]Institute of Physics, University of Augsburg, Germany — [5]Department of Materials Science and Engineering, Royal Institute of Technology, Stockholm, Sweden

Ordinary superconductors are widely assumed insensitive to small concentrations of nonmagnetic impurities, whereas strong disorder suppresses superconductivity, ultimately leading to a superconductor-insulator transition. In between these limiting cases, a fascinating regime may emerge where disorder enhances superconductivity. This effect is discussed here for the $\beta$-phase of V-Ti alloys. Disorder is modeled using the CPA while local electronic interactions are treated using DMFT. The McMillan formula is employed to estimate the superconducting $T_c$, showing a maximum at a Ti concentration of around 0.33 for a local Coulomb interaction $U$ in the range of 2-3 eV. Our calculations quantitatively agree with the experimentally observed concentration dependent increase of $T_c$, and its maximal value of about 20%. We show that including local electronic correlations are a necessary extension for an improved computation of the superconducting $T_c$ even in such simple materials like V and V-Ti alloys.

TT 18.8 Mon 15:00 Poster C

**Superconductivity in noncentrosymmetric lanthanum sesquichalcogenide $La_3Se_4$** — •moumita naskar[1], soumen ash[2], debendra prasad panda[3], chandan kumar vishwakarma[4], brajesh kumar mani[4], a sundaresan[3], ashok kumar ganguli[2], rajib sarkar[1], hans-henning klauss[1], and dmytro s inosov[1] — [1]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, 01069 Dresden, Germany — [2]Department of Chemistry, Indian Institute of Technology Delhi, New Delhi 110016, India — [3]School of Advanced Materials and Chemistry and Physics of Materials Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 560064, India — [4]Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India

We have discussed the superconducting properties of lanthanum sesquiselenide $La_3Se_4$ with superconducting transition temperature $T_c$=8.5 K. It crystallizes in the noncentrosymmetric cubic $Th_3P_4$-type structure with space group I-43d. Specific heat measurement classified $La_3Se_4$ as a strongly coupled superconductor. To determine the nature of the superconducting gap symmetry of $La_3Se_4$, $^{139}$La-NMR measurements have been performed. From the density functional theory based first-principles simulations, we observe the number of states at the Fermi energy is dominated mainly by d and f electrons of La. Furthermore, we observe band crossings along the high-symmetry k lines in the vicinity of the Fermi energy. These bands are observed to split due to the removal of spin degeneracy associated with spin-orbit coupling, with the splitting energy $E_{SOC}$= 65 meV.

TT 18.9 Mon 15:00 Poster C

**Revisiting spin-orbit coupling and correlations in $Sr_2RuO_4$ by QSGW** — •Weiyi Guo[1], Christoph Friedrich[2], and Irene Aguilera[1] — [1]Institute of Physics, University of Amsterdam, 1090 GL, Amsterdam, The Netherlands — [2]Peter Grünberg Institute (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The superconductor $Sr_2RuO_4$ exhibits strong spin-orbit coupling (SOC). Extensive theoretical and experimental studies make $Sr_2RuO_4$ a good testbed for ab-initio many-body methods for the simulation of the electronic structure. We demonstrate the Fermi surface and quasiparticle band topology from QSGW+SOC, how it improves the DFT+SOC results, and the general agreement between simulation and experiments. We also discuss a possible application of GW+(E)DMFT to the system.

TT 18.10 Mon 15:00 Poster C

**The three Fermi pockets of $NbSe_2$ - Investigating a Kohn-Luttinger like mechanism in TMDC monolayers.** — •Julian Siegl, Anton Bleibaum, Magdalena Marganska-Lyzniak, John Schliemann, and Milena Grifoni — Institute for Theoretical Physics, University of Regensburg, Regensburg, Germany

We investigate a possible superconducting pairing generated by competing Coulomb repulsion processes in monolayer $NbSe_2$. The two spin-orbit split Fermi surfaces (FS) of ML $NbSe_2$ in the K and K′ valley can support a superconducting gap, with predominant f-wave symmetry, when the short-range intervalley scattering is stronger than the long-range intravalley one. Upon inclusion of the third FS centered at the Gamma point an additional competing pairing channel favoring s-wave symmetry opens for strong interpocket scattering. The competition between these two channels is governed by the relative strengths of the three processes involved, resulting either in one, two or three symmetry related values of the gaps at the FSs. We estimate the relevant interactions by calculating the dielectric susceptibility and the screened Coulomb potential in the RPA approximation for a DFT-based tight-binding model. The multi-orbital nature of the valence band results in preferential screening of short-range scattering processes, favoring the interpocket scattering. Far from being a spectator, the third Fermi pocket turns out to be a powerful player, even to the point of changing the symmetry of the order parameter.

TT 18.11 Mon 15:00 Poster C

**Real-space mapping of Yu-Shiba-Rusinov states around magnetic defects on superconducting surfaces** — •Raffaele Aliberti[1,2], David Antognini Silva[1,2], Adamantia Kosma[1], Stefan Bleugel[1], and Philipp Ruessmann[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]RWTH Aachen University,Aachen, Germany — [3]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany

Magnetic impurities on superconductors generally give rise to Yu-Shiba-Rusinov (YSR) bound states which, when coupled suitably in chains of magnetic atoms, can give rise to Majorana zero modes. We study the behaviour of YSR states at isolated magnetic impurities and focus on mapping out their spatial extent. In particular, we investigate the interplay of the electronic structure of the superconductor with the extent of resulting YSR states. A better understanding and control of such states can lead to reliably produce superconducting spin qubits, important for topologically protected quantum computers.

In our work we employ the Kohn-Sham Bogoliubov-de Gennes method within the full-potential relativistic Korringa-Kohn-Rostoker Green function method [1,2] interfaced with the AiiDA infrastructure for high-throughput automation [3].

[1] P. Rüßmann and S. Blügel, Phys. Rev. B **105**, 125143 (2022).
[2] P. Rüßmann *et al.*, Proc. SPIE 12656, Spintronics XVI, 126560S (2023); https://doi.org/10.1117/12.2678145
[3] P. Rüßmann *et al.*, npj Comput Mater **7**, 13 (2021).

TT 18.12 Mon 15:00 Poster C

**Controlling Majorana modes in magnetic adatom chains.** — •Ioannis Ioannidis — Institute for Theoretical Physics, Hamburg, Germany

Controlling impurity spins in superconductors led to the observation of promising signatures of Majorana zero modes (MZMs) but manipulating these states for quantum information processing remains an open challenge. We propose using an ancillary Yu-Shiba-Rusinov state to manipulate and fuse MZMs in topological superconductors. We demonstrate that its positioning, spin orientation, and coupling energy facilitate the efficient control of MZMs in a variety of implementations. Our approach relies on well-established techniques, such as scanning-tunneling microscopy and electron-spin resonance, opening the path towards fault-tolerant quantum computation with MZMs in adatom-superconductor systems.

TT 18.13 Mon 15:00 Poster C

**Spontaneous split of surface states in d-wave superconductors** — •Ambjörn Joki, Kevin Seja, Mikael Fogelström, and Tomas Löfwander — Chalmers University of Technology, Gothenburg, Sweden

Since the experimental discovery [1] of the split of surface states at pair-breaking edges in two-dimensional d-wave superconductors, different theories have been put forward in attempts to explain it. These theories can be grouped into two main categories, explaining the split either by spontaneous currents [2] or surface magnetisation [3]. To study the competition between these mechanisms, we are using a tJ-model [4-5] that includes strong correlation effects, as previously done without magnetism [6]. By combining a mean-field approach with the Gutzwiller approximation we can treat magnetism and superconductivity on the same footing.

[1] M. Covington et al., Phys. Rev. Lett. 79, 277 (1997)
[2] M. Håkansson et al., Nat. Phys. 11, 755 (2015)
[3] A. Potter and P. A. Lee, Phys. Rev. Lett 112, 117002 (2014)
[4] M. Ogata and A. Himeda, JPSJ 72, 374 (2003)
[5. R. B. Christensen et al., Phys. Rev. B 84, 184511 (2011)
[6] D. Chakraborty et al., npj Quantum Mater. 7, 44 (2022)

TT 18.14 Mon 15:00 Poster C

**Nematic susceptibility in heavily hole-doped iron based superconductors** — •Franz Eckelt[1], Xiaochen Hong[1], Vilmos Kocsis[2], Bernd Büchner[2], Vadim Grinenko[3], and Christain Hess[1] — [1]Bergische Universität Wuppertal, Wuppertal, Germany — [2]Leibniz-Institute for Solide State and Materials Research (IFW-Dresden), 01069 Dresden, Germany — [3]Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China

We investigate the elastoresistivity of the heavily hole doped iron-based superconductor $Ba_{1-x}K_xFe_2As_2$ in the range x= 0.68 - 0.98 using a piezoelectric measurement technique. We observe a divergent increase in elastoresistance along the [110] direction during cooling for all samples studied so far. We discuss our findings in terms of nematic fluctuations and Fermi surface effects in the vicinity of a Lifshitz transition.

TT 18.15 Mon 15:00 Poster C

**Investigating the CDW phases and structural transitions in $BaNi_2As_2$ by means of Fluctuation Spectroscopy** — •Julian Beu[1], Marvin Kopp[1], Markus König[2], Amir Haghighirad[3], Matthieu Le Tacon[2], and Jens Müller[1] — [1]Institute of Physics, Goethe-University Frankfurt, Frankfurt (Main), Germany — [2]MPI CPfS, Dresden, Germany — [3]KIT, Karlsruhe, Germany

The link between charge density waves (CDW), spin density waves (SDW) and superconductivity is of interest in the theory of unconventional superconductivity ever since these effects have been found near the superconducting transition of many unconventional superconductors, more recently in the iron-based superconductors. In this work we focus on $BaNi_2As_2$, a structurally close analogue of the 122 iron-pnictide superconductors, hosting a similar high-temperature structure and structural transitions. In contrast to the iron-pnictides however, no magnetic ordering was observed, and CDW phases replace the SDW phase. Also, there have been reports of an electronic nematic phase above the structural transitions[1], where the electronic system breaks the usual rotational symmetry. We investigate the charge carriers in $BaNi_2(As_{1-x}P_x)_2$, analyzing the resistance and noise power spectral density as a function of temperature. The samples are structured with a meander current path by a FIB process in order to increase resistance by at least two orders of magnitude, rendering noise measurements possible. Resistance noise spectroscopy often reveals hidden microscopic characteristics and can help further our understanding of the CDW phases and structural transitions. [1] Phys. Rev. B 106, 144507.

TT 18.16 Mon 15:00 Poster C

**$^{75}$As NMR investigations of the quartic-metal phase in $Ba_{1-x}K_xFe_2As_2$** — •F. Bärtl[1,2], S. Luther[1], E. Babaev[3], J. Wosnitza[1,2], H. Kühne[1], R. Sarkar[2], K. Kihou[4], C.-H. Lee[4], H.-H Klauss[2], and V. Grinenko[2,5] — [1]HLD-HZDR, Dresden — [2]IFMP-TUD, Dresden — [3]Department of Physics, KTH Royal Institute of Technology, Stockholm — [4]AIST, Tsukuba — [5]TDLI, Shanghai Jiao Tong University

$Ba_{1-x}K_xFe_2As_2$ is a hole-doped superconductor (SC), for which samples in a doping range of $0.7 \le x \le 0.8$ yield a broken-time-reversal-symmetry (BTRS) SC state ($s+is$). Recently, an electron-quadrupling state (pairing of Cooper pairs) was reported to form above $T_c$ in this doping range [1], which is not possible within the mean-field BCS theory. Instead, this is a fluctuations-stabilized phase that requires the existence of pre-formed pairs above $T_c$, which can manifest itself as a pseudogap. The indication for superconducting fluctuations well above $T_c$ in BKFA with an $s + is$ state was found in measurements of the spontaneous Nernst effect [1], but spectroscopic evidence is lacking so far. Here, we present $^{75}$As NMR measurements of $Ba_{0.25}K_{0.75}Fe_2As_2$, where we employ spectroscopy and relaxometry to probe the low-energy density of states at temperatures ranging across the presumed quartic-metal phase. We find a weak slope change of the temperature-dependent nuclear spin-lattice relaxation rate at temperatures above $T_c$ = 7 K and 8 T, indicating the manifestation of a pseudo-gap-like state below $T^* \approx 12$ K in the bulk of the sample.

[1] Grinenko, V. *et al.* Nat. Phys. **17**, 1254 (2021)

TT 18.17 Mon 15:00 Poster C

**Strain-induced structural change and diffuse scattering in $HgBa_2CuO_{4.09}$** — •Mai Ye[1], Wenshan Hong[2], Tom Lacmann[1], Mehdi Frachet[1], Igor Vinograd[1], Gaston Garbarino[3], Sofia-Michaela Souliou[1], Amir-Abbas Haghighirad[1], Yuan Li[2], and Matthieu Le Tacon[1] — [1]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]International Center for Quantum Materials, School of Physics, Peking University, 100871 Beijing, China — [3]European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex, France

We study the structural change and diffuse scattering induced by a-axis compressive strain in $HgBa_2CuO_{4.09}$ at $T_c = 78$ K, using synchrotron X-ray diffraction. The high-temperature superconductor exhibits negative Poisson ratio below 0.6% strain. Although the c-axis lattice parameter at 1% strain is 0.1% larger than its zero-strain value, the Cu-O bond length is 1.2% shorter than the zero-strain value. Strain-induced diffuse scattering appears at the two sides of Bragg peaks along the strain direction. Such diffuse scattering has a wavenumber of (0.5,0,0), corresponding to a modulation with a period of twice the a-axis lattice parameters. The diffuse-scattering features saturate at 0.2% strain and exhibit little change on cooling below $T_c$.

TT 18.18 Mon 15:00 Poster C

**Microscopic Insights into London Penetration Depth: Application to $CeCoIn_5$** — •Mehdi Biderang[1] and Alireza Akbari[2] — [1]Department of Physics, University of Toronto, 60 St. George Street, Toronto, Ontario, M5S 1A7, Canada — [2]Ruhr-University Bochum, D-44801 Bochum, Germany

We present a comprehensive theoretical framework for describing the magnetic penetration depth incorporating microscopic calculations that account for various superconducting gap symmetries. Our results underscore the pivotal influence of band structure, Fermi surface topology, and the symmetry of the superconducting order parameter. Leveraging our insights into the heavy-fermion superconductor $CeCoIn_5$, we investigate both local (London) and non-local (Pippard) responses to external magnetic fields across a range of temperatures. Our analyses in the low-temperature regime provide compelling macroscopic evidence supporting the nodal character within the superconducting state, specifically with a $d_{x^2-y^2}$ symmetry. Moreover, our findings align with the characteristics of Pippard-type superconductivity, carrying significant implications for forthcoming experimental endeavors.

TT 18.19 Mon 15:00 Poster C

**High-field torque and magnetotransport in $UTe_2$ single crystals** — •Freya Husstedt[1,2], Beat Valentin Schwarze[1,2], Jean-Pascal Brison[3], Georg Knebel[3], Motoi Kimata[4], Dai Aoki[4], Toni Helm[1], and J. Wosnitza[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL) and Würzburg-Dresden Cluster of Excellence ct.qmat, HZDR, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Centre CEA de Grenoble, France — [4]Institute for Materials Research, Tohoku University, Japan

To date, the structure of the Fermi surfaces of the heavy-fermion superconductor $UTe_2$ is strongly debated [1]. We performed angle-dependent magnetic-torque and magnetotransport measurements on high-quality $UTe_2$ single crystals with $T_c = 2$ K. We observe quantum oscillations starting at about 15 T. The de Haas-van Alphen frequencies show very good agreement with previous reports [2, 3]. We compare our results to band-structure calculations performed with the full potential-local orbital code. The hysteretic response of magnetic torque in the superconducting phase and the transition in magnetoresistance provided further details about the anisotropic $H$-$T$ phase diagram of $UTe_2$.

[1] D. Aoki *et al.*, J. Phys.: Condens. Matter **34**, 243002 (2022).
[2] D. Aoki *et al.*, J. Phys. Soc. Jpn. **91**, 083704 (2022).
[3] A. G. Eaton *et al.*, arXiv preprint arXiv:2302.04758 (2023).

TT 18.20 Mon 15:00 Poster C

**Non-linear optical effects of superconductors: light-induced vs. dc supercurrents**
— •Jakob Dolgner and Dirk Manske —
Max Planck Institute for Solid State Research, Stuttgart, Germany

It is established that the presence of supercurrent enables THz-spectroscopy Second Harmonic Generation (SHG) even in otherwise inversion symmetric superconductors which do not show this response in equilibrium [1,2]. Recently, an SHG resonance at $\Omega = 2\Delta$ was observed in $Nb_3Sn$ in the absence of a static supercurrent and accredited to dynamical symmetry breaking [3]. On the other hand, such effects have never been observed in prior experiments [4]. We analyse the possible origins for this discrepancy in observations. In particular, we illuminate the mechanism of dynamical symmetry breaking and subsequent supercurrent generation proposed in [3].
[1] Nakamura et al., PRL 122.25 (2019)
[2] Moor et al., PRL 118.4 (2017)
[3] Yang et al., Nat. Photonics 13.10 (2019)
[4] Matsunaga et al., Science 345.6201 (2014)

TT 18.21 Mon 15:00 Poster C

**Prediction of high-$T_c$ superconductivity in ternary actinium beryllium hydrides at low pressure** — •kun gao — ZGH, RUB, Bochum, Germany

Hydrogen-rich superconductors are promising candidates to achieve room-temperature superconductivity. However, the extreme pressures needed to stabilize these structures significantly limit their practical applications. An effective strategy to reduce the external pressure is to add a light element M that binds with H to form MH x units, acting as a chemical precompressor. We exemplify this idea by performing ab initio calculations of the Ac-Be-H phase diagram, proving that the metallization pressure of Ac-H binaries, for which critical temperatures as high as 200 K were predicted at 200 GPa, can be significantly reduced via beryllium incorporation. We identify three thermodynamically stable ($AcBe_2H_{10}$, $AcBeH_8$, and $AcBe_2H_{14}$) and four metastable compounds (fcc $AcBeH_8$, $AcBeH_{10}$, $AcBeH_{12}$ and $AcBe_2H_{16}$). All of them are superconductors. In particular,fcc $AcBeH_8$ remains dynamically stable down to 10 GPa, where it exhibits a superconducting-transition temperature $T_c$ of 181 K. The Be-H bonds are responsible for the exceptional properties of these ternary compounds and allow them to remain dynamically stable close to ambient pressure. Our results suggest that high-Tc superconductivity in hydrides is achievable at low pressure and may stimulate experimental synthesis of ternary hydrides.

TT 18.22 Mon 15:00 Poster C

**Collective excitations in competing phases in two and three dimensions** — •Joshua Althüser and Götz Uhrig — TU Dortmund, Otto-Hahn-Str. 4, 44227 Dortmund, Deutschland

We investigate the superconducting (SC), charge-density wave (CDW), and antiferromagnetic (AFM) phases in the extended Hubbard model at zero temperature and half-filling. We employ the iterated equations of motion approach [1,2] to compute the two-particle Green's functions and by extension, the corresponding spectral densities. This renders a comprehensive analysis of the behaviour of collective excitations possible as the model's parameters are changed across phase transitions. We identify the well-known amplitude (Higgs) and phase (Leggett) modes within the superconducting phase and observe a similar excitation in the CDW phase which shift towards zero energy as the system approaches the phase transition to the SC phase. In the CDW phase, close to the phase transition to the AFM phase, we find a collective mode which does not change significantly and another modes which becomes soft as the phase boundary is approached.
[1] P.Bleicker, G.S. Uhrig, Phys. Rev. A 98, 033602 (2018)
[2] M.Kalthoff, F. Keim, H. Krull, G.S. Uhrig, Eur. Phys. J. B 90, 97 (2017)

TT 18.23 Mon 15:00 Poster C

**Signatures of a pair-density wave state in the third harmonic generation.** — •Pascal Derendorf[1], Peayush Choubey[2], and Ilya Eremin[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany — [2]Indian Institute of Technology-Roorkee, Roorkee, India

We investigate the signatures of a unidirectional pair-density wave (PDW) state in the third harmonic generation (THG) using an effective microscopic model, developed in Refs. [1,2]. The system possesses a unidirectional PDW state in thermodynamic equilibrium ground state without extra need for an additional perturbation such as external Zeeman field. We extend this model under the non-equilibrium by including a periodic driving in the form of external ac-field. The signatures of the emerging massive modes on the THG are derived via a gauge-invariant effective action approach. We discuss the similarities and differences between the PDW's s-wave and d-wave pairing channels and study the difference between the phase modes of s- and d-wave and the phase modes between the finite momentum pairings $\Delta_q$ at $q = -Q$ and $q = Q$.
[1] F. Loder et al., Phys. Rev. B 81, 020511(R) (2010)
[2] J. Wårdh and M. Granath, Phys. Rev. B 96, 224503 (2017)

TT 18.24 Mon 15:00 Poster C

**UHV cleaving of superconducting Nb tips for scanning tunneling microscopy** — Carolina A. Marques[1], Aleš Cahlík[1], Berk Zengin[1], Tohru Kurosawa[2], and •Fabian D. Natterer[1] — [1]Department of Physics, University of Zurich, Switzerland — [2]Department of Applied Sciences, Muroran Institute of Technology, Japan

In scanning tunneling microscopy (STM), superconducting tips have been widely used because they enhance energy resolution, allow the study of Josephson tunneling, and provide an easy way to characterize and optimize the noise and energy resolution of a low-temperature experimental setup. In this work, we revisit the cleaving of superconducting wires in UHV and describe a one-step *in-situ* procedure to produce Nb tips with a well-resolved superconducting gap. We measure the superconducting gap of the Nb tip on Au(111) to prove the quality of the tips. Using a fully gapped tip, we optimize the RF filtering of our STM and determine its base temperature. We show that after coating the Nb tip with Au, suppressing the superconducting gap, the gap can be gradually recovered by sputtering with $Ar^+$ ions, allowing the tuning of the gap size.

TT 18.25 Mon 15:00 Poster C

**Optical Scanning Tunneling Microscopy at Low Temperature** — •Pegah Farahi Shandiz[1,2], Alexina Ollier[1,3], Lei Fang[1,3], Won-jun Jang[1,3], Soonhyeong Lee[1,3], Sangwon Yoon[1,3], Minsu Seo[1,3], and Andreas Heinrich[1,2] — [1]Center for Quantum Nanoscience, Institute for Basic Science, Seoul 03760, South Korea — [2]Department of Physics, Ewha Womans University, Seoul 03760, South Korea — [3]Ewha Womans University, Seoul 03760, South Korea

Advances in fabricating atomic scale structure opened up new possibilities. One of interest is the optical properties. Recent experiments on nanomaterial shows that the optical properties vary drastically from bulk to nanoscale such as absorption, reflection, and light emission. These open up new avenues for technological advancements in various fields, such as electronics, energy, medicine, and quantum communication applications. Understanding the properties of such material at atomic scale involves the development of techniques capable of atomic resolution. The STM junction reveals itself as a solution and proves advantageous. Indeed, placing the STM tip in close proximity to a specific area on the sample allows localized optical interactions .Integrating the principles of STM and optical spectroscopy gain insights into electronic, vibrational, and even photonic properties with unprecedented precision. Here, we present a home built optical STM, engineered to conduct measurements at low temperature (1K) under UHV. The optical STM is incorporated with a homebuilt Joule-Thomson refrigerator to enhance spatial resolution, stability, and reveal quantum phenomena.

TT 18.26 Mon 15:00 Poster C

**Long range triplet proximity effect in a Josephson junction with a precessing magnetization** — •Miad Mansouri — Dahlem Center for Complex Quantum Systems and Physics Department, FU Berlin, Arnimallee 14, 14195 Berlin, Germany

We calculate the current phase relation for a SFS junction with a precessing magnetization in the quantum limit. We use scattering theory to find the bound states in such a junction, by artificially connecting an ideal lead reservoir to the junction, with the role of temperature being taken by the strength of the barrier between junction and reservoir.

TT 18.27 Mon 15:00 Poster C

**Fabrication Limits and Design Rules for Fabricating Optimized In-Situ Multi-Terminal Josephson Junctions** — •Justus Teller[1,3,4], Christian Schäfer[1,3,4], Gerrit Behner[1,3,4], Abdur Rehman Jalil[2,3], Benjamin Bennemann[2,3], Peter Schüffelgen[1,3], Detlev Grützmacher[1,3,4], and Thomas Schäpers[1,3,4] — [1]Peter Grünberg Institute (PGI-9): Institute of Semiconductor Nanoelectronics, Forschungszentrum Jülich, Jülich, 52425, Germany — [2]Peter Grünberg Institute (PGI-10): Institute of Energy-efficient Information Technology, Forschungszentrum Jülich, Jülich, 52425, Germany — [3]Jülich Aachen Research Alliance, Jülich, 52425, Germany — [4]RWTH Aachen University, Aachen, 52074, Germany

In connection with topological insulator, multi-terminal Josephson junctions offer a promising platform for topological quantum computation. In-situ stencil lithography is a well-established technique for fabricating molecular-beam-epitaxy-grown high-transparency Josephson junctions. However, there is still a lack of knowledge about design limits and the corresponding reliability of the used stencil masks. This work describes the fabrication of in-situ Josephson junctions in detail and shows data of more than a thousand stencil masks from two chips examined under scanning electron microscope. The stencil masks are optimized for two-, three-, and four-terminal Josephson junctions. Design rules for fabricating reliable stencil masks are explained. Deviations between design and realized structure are discussed. The mask reliability is computer simulated by using the finite element method.

TT 18.28 Mon 15:00 Poster C

**Current phase relation of HgTe nanowire Josephson junctions in an axial magnetic field** — •Niklas Hüttner, Wolfgang Himmler, Ralf Fischer, Dmitriy Kozlov, Dieter Weiss, and Christoph Strunk — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

The band structure of Topological surface states hosted by 3D Topological insulators such as HgTe can be tuned to a Dirac shape. For this a magnetic field ($B_\parallel$) is applied axial to HgTe nanowire structures[1]. Using such nano wires as weak links in a Josephson junction allows to tune between trivial and topological supercurrents[2]. We directly probe the current phase relation (CPR) of a such a device with the asymmetric SQUID method. The nanowire junction is in the short junction regime[2] and features a strongly anharmonic CPR that can be described by the generalized Kulik-Omelyanchuk theory[3]. At $B_\parallel = 0$ a high transparency of $\bar{D} \approx 0.95$, an induced gap $\Delta^* \approx 0.15\,\text{meV}$, and an approximate number of channels $n \approx 9$ to $10$ is evaluated[3]. Varying $B_\parallel$ controls the magnetic flux $\Phi$ enclosed by the topological surface state. Even for $|\Phi| \ll \Phi_0$ the $\varphi_0$ shift can be adjusted between $\pm\pi$. In the range $0 - 1.5\,\Phi_0$ we observe a strong modulation of both the critical current and the content of higher harmonics. — The HgTe material was kindly provided by Nikolay N. Mikhailov and Sergey A. Dvoretsky, Novosibirsk.

[1] A. Cook *et al.*, Phys. Rev. B **84**, 201105 (2011)
[2] R. Fischer *et al.*, Phys. Rev. Res. **4**, 013087 (2022)
[3] A. A. Golubov *et al.*, Rev. Mod. Phys. **76**, 411 (2004)

TT 18.29 Mon 15:00 Poster C

**Superconducting Diode Effect in Josephson Junction with Altermagnet** — •Osamu Kanehira[1], Yusuke Masaki[1], and Hiroaki Matsueda[1,2] — [1]Department of Applied Physics, Tohoku University, Sendai, Japan. — [2]Center for Science and Innovation in Spintronics, Tohoku University, Sendai, Japan.

Superconducting diode effects (SDEs) refer to a non-reciprocity in a critical current of superconductors (SCs). Since diodes are key building blocks for electronic devices, the SDE can be applied to superconducting electronic devices like quantum computers. However, in many experimental reports, the SDEs require a magnetic field or a magnetization of ferromagnets (FMs), although the magnetic field can have a bad effect on the superconducting devices.

To avoid this problem, we focus on an altermagnet (AM), which has no net magnetization like an antiferromagnet but has a spin-split band structure like the FM due to its crystal structure. In addition, SC/AM junctions show transport properties like those of SC/FM junctions, and thus the SC/AM junctions are expected to exhibit the field-free SDE without the magnetization and a stray field.

In this study, we theoretically investigate the SDE in an SC/AM/SC planar Josephson junction with Rashba SOC by the numerical calculation of the Josephson current. In the poster presentation, we will compare the results of the SC/AM/SC junction with those of the SC/FM/SC junction and discuss the advantages and disadvantages of the SC/AM/SC junction.

TT 18.30 Mon 15:00 Poster C

**On-off switch and sign change for a nonlocal Josephson diode in spin-valve Andreev molecules** — •Erik Wegner Hodt and Jacob Linder — Department of Physics, Center for Quantum Spintronics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Andreev molecules consist of two coherently coupled Josephson junctions and permit nonlocal control over supercurrents. By making the barriers magnetic and thus creating a spin valve, we predict that a nonlocal Josephson diode effect occurs that is switchable via the magnetic configuration of the barriers. The diode effect is turned on, off, or changes its sign depending on whether the spin valve is in a parallel, normal, or antiparallel configuration. These results offer a way to exert complete control over a nonlocal Josephson diode effect via the spin degree of freedom.

TT 18.31 Mon 15:00 Poster C

**YBCO Josephson junction arrays and resistors made by focused Helium ion beam irradiation** — •Moritz Meichsner, Christoph Schmid, Dieter Koelle, Edward Goldobin, and Reinhold Kleiner — Physikalisches Institut, Center for Quantum Science and LISA+, Universität Tübingen, Germany

We use focused-helium-ion-beam (He-FIB) irradiation to “write” different devices in epitaxially grown $YBa_2Cu_3O_7$ thin films. The He-FIB irradiation changes the local properties of the YBCO film on the nanoscale – in particular, it can produce locally normal conducting or even insulating regions in the YBCO film. For example, by scanning with the He-FIB along a single line across a lithographically prepatterned YBCO microbridge, we can produce Josephson Junctions [1]. When irradiating a larger area, we can fabricate resistors with Ohmic behavior that can be used in resonant circuits or as load resistors. Moreover, by writing several junctions next to each other one can realize Josephson junction arrays. In this work, the interaction of Josephson junctions in such arrays is investigated. To achieve better coupling between the junctions, a He-FIB resistor was fabricated in parallel to the array. Biasing this circuit by a dc current results in an additional ac current through the array, provoking junction synchronization.

[1] B. Müller et al., Phys. Rev. Applied **11**, 044082 (2019).

TT 18.32 Mon 15:00 Poster C

**$YBa_2Cu_3O_7$ constriction-type Josephson junctions with integrated shunt resistors fabricated by focused-helium-ion-beam irradiation.** — •Christoph Schmid[1], Moritz Meichsner[1], Dominik Hanisch[2], Max Pröpper[2], Meinhard Schilling[2], Edward Goldobin[1], Dieter Koelle[1], and Reinhold Kleiner[1] — [1]Physikalisches Institut, Center for Quantum Science and LISA+, Universität Tübingen — [2]Institut für Elektrische Messtechnik und Grundlagen der Elektrotechnik, Technische Universität Braunschweig

We report on the investigation of $YBa_2Cu_3O_7$ (YBCO) Josephson junctions (JJs) fabricated by irradiation with a focused helium ion beam (He-FIB). With this method one can locally modify YBCO thin films, to write insulating or normal conducting regions, including Josephson barriers, depending on the He-FIB irradiation dose $D$. We investigated the electric properties of YBCO areas with typical lateral size of $30 \times 2000\,\text{nm}^2$, irradiated with $D \sim 40\,\text{ions/nm}^2$. Such a dose preserves the YBCO crystal structure but supresses the critical temperature $T_c$ completely. Thus, such areas can be used as shunt resistors with dose-dependent resistivity and ohmic $I-V$ characteristics (IVCs). Moreover, we created constriction-type JJs (cJJs) between resistive areas. By constricting the cJJ width down to 6 nm, we observe resistively-shunted-junction (RSJ) like IVCs with small excess currents and characteristic voltages of 3 – 60 mV, making such JJs interesting for high-frequency applications. Our fabrication method opens a way to fabricate nano-circuits with integrated nm-sized cJJs and resistors/resistive areas during a single He-FIB irradiation process.

TT 18.33 Mon 15:00 Poster C

**Antenna Structures for YBCO Josephson Junction Arrays** — •Max Pröpper[1], Dominik Hanisch[1], Christoph Schmid[2], Paul Julius Ritter[1], Marius Neumann[1], Julius Mumme[1], Edward Goldobin[2], Dieter Koelle[2], Reinhold Kleiner[2], Meinhard Schilling[1], and Benedikt Hampel[1] — [1]Institut für Elektrische Messtechnik und Grundlagen der Elektrotechnik, Technische Universität Braunschweig, 38106 Braunschweig, Germany — [2]Physikalisches Institut, Center for Quantum Science and LISA+, Universität Tübingen, Germany

High-temperature superconductors like yttrium barium copper oxide (YBCO) are promising candidates for a voltage standard working at liquid nitrogen temperatures. Their ability to function at THz frequencies is advantageous, as this significantly reduces the number of Josephson junctions (JJs) needed for an array with comparable voltage output. To achieve this, JJs with low parameter variation are necessary. A promising method for fabricating consistent JJs is the use of a helium focused ion beam (He-FIB). In this work, we present JJ arrays made from YBCO based on a direct writing He-FIB process. The arrays are positioned directly at the feed point of various antenna structures, aiming to optimize the coupling efficiency of radiation to the JJs. A DC characterization of the JJs was performed. Furthermore, the JJ arrays were irradiated with frequencies up to the THz regime using a far-infrared laser system. The I-V characteristics of the JJs are analyzed and resulting output voltages characterized. Finally, the results are compared to simulations performed with CST Studio.

TT 18.34 Mon 15:00 Poster C

**YBCO heterostructures for SQUID-on-lever** — Katja Wurster[1], •Simon Koch[1], Varun Harbola[2], Yu-Jung Wu[2], Reinhold Kleiner[1], Jochen Mannhart[2], and Dieter Koelle[1] — [1]Physikalisches Institut, Center for Quantum Science (CSQ) and LISA+, Universität Tübingen, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

Scanning SQUID microscopy (SSM) is a powerful technique for imaging magnetic fields or dissipation processes. The use of the high-$T_c$ cuprate superconductor $YBa_2Cu_3O_7$ (YBCO) combined with custom made Si AFM Cantilevers could enable SSM in the Tesla range and at temperatures up to about 80 K with a high spatial resolution. 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 challenge with this approch is the integration of YBCO thin films on Si wafers. We intend to use $Sr_3Al_2O_6$ (SAO) or $Sr_2CaAl_2O_6$ (SCAO), which are lattice-matched to perovskite materials, such as $SrTiO_3$ (STO). SAO and SCAO 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, including YBCO. We present our process for the fabrication of YBCO heterostructures based on pulsed laser deposition (PLD) and discuss the optimization of growth conditions and properties of the used materials. Finally, we present our preliminary attempts to transfer YBCO films onto Si surfaces.

TT 18.35 Mon 15:00 Poster C

**Machine Learning assisted Quantum Error Correction on the Rotated Surface Code** — •Theo Haas, Kai Meinerz, and Simon Trebst — Theoretical Physics, University of Cologne, Germany

In going beyond the current era of noisy intermediate-scale quantum (NISQ) processors, quantum error correction will be an indispensable tool to reach fault-tolerant quantum computing. However, the originally developed class of combinatorial decoders, such as minimum-weight perfect matching (MWPM) and union find, exhibit scaling behavior that will not allow to decode $O(10^5$ - $10^6)$ qubits within one clock cycle. Here we discuss refinements to a recently suggested multi-level decoder that combines machine learning and combinatorial decoder in a hierarchical manner. Simulating this 2-stage decoding for the rotated surface code of varying instances, we show that (i) we can efficiently decode $O(10^6)$ qubits, while (ii) pushing the error threshold beyond the reach of conventional decoders. We further explore the potential of multi-level machine-learning decoders and their Implementation on FPGA platforms. their Implementation on FPGA platforms.

TT 18.36 Mon 15:00 Poster C

**Topological quantum phase transitions of toric code states under weak measurement** — •Finn Eckstein, Guo-Yi Zhu, and Simon Trebst — Institute for Theoretical Physics, University of Cologne, Germany

The toric code is a paradigmatic model for topological order and robust quantum memory that has been seminal in the conceptualisation of fault-tolerant quantum computation. But while toric code states are stable to Pauli noise and exhibit a finite error threshold, they are inherently unstable when the syndrome measurements are infinitesimally tuned away from a strong (projective) measurement to weak measurements. Here we expand on this long-known observation and investigate toric code states when introducing weak measurements of individual qubits. We analytically demonstrate that, for varying the measurement angle on the Bloch sphere, the quantum problem can be exactly mapped to a classical Ashkin-Teller model subject to non-Hermitian random bond couplings (which originate from the anyon statistics of the toric code). By combining state-of-the-art hybrid tensor network / Monte Carlo numerical simulations we chart out the entanglement phase diagram and its topological quantum phase transitions.

TT 18.37 Mon 15:00 Poster C

**Stability of Nishimori cat states and non-equilibrium entanglement transitions** — •Malte Pütz, Guo-Yi Zhu, and Simon Trebst — Institute for Theoretical Physics, University of Cologne, Zülpicher Straße 77, 50937 Cologne, Germany

Shallow quantum circuits that combine unitary gates with non-unitary measurements, so-called monitored quantum circuits, can create long-range entanglement (LRE) in O(1) steps - substantially faster than local unitary circuits, where entanglement creation is bounded by an information lightcone (Lieb-Robinson bounds). An open question is the stability of such engineered LRE when the circuit itself exhibits imperfections (such as incomplete gate operations or shifted measurements). Here we build on recent work from our group discuss the preparation of 'Nishimori cat' states, which exhibit a robustness to such imperfections, and explore extensions to imperfect lattice geometries (interpolating between one and two spatial dimensions) and Gaussian coherent noise. We characterize the post-measurement quantum wavefunction by various entanglement quantities and show exotic quantum criticality induced by the inclusion of such circuit imperfections. Our work employs state-of-the-art numerical simulation techniques, including hybrid Monte Carlo / tensor network calculations.

TT 18.38 Mon 15:00 Poster C

**Many-body effects in microwave-driven gates for transmon qubits** — •Christoph Berke and Simon Trebst — Institut für theoretische Physik, Universität zu Köln

Transmon qubits arise from the quantization of nonlinear resonators systems that are prone to the buildup of strong, possibly even chaotic, fluctuations. One may wonder to what extent fast gate operations, which involve the transient population of states outside the computational subspace, can be affected by such instabilities. We here consider the eigenphases and -states of the time evolution operators describing a universal gate set, and analyze them by methodology otherwise applied in the context of many-body physics. Specifically, we discuss their spectral statistic, the distribution of time dependent level curvatures, and state occupations in- and outside the computational subspace.

TT 18.39 Mon 15:00 Poster C

**Interaction of Josephson Photonics Devices with Quantum pulses** — •Hanna Zeller[1], Lukas Danner[1,2], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Josephson photonics devices have predominantly been used to create microwave radiation in a process where a Cooper pair tunneling across a dc-biased Josephson junction creates photonic excitations in a microwave cavity connected in series. In turn, there are also situations where incoming photons are required to enable the Cooper pair transfer. In fact, this scenario has been investigated as a technology for amplifiers or single (microwave-) photon detectors [1].

To study such processes we use a recently developed formalism which can describe the incidence of generic traveling pulses of quantized radiation onto a quantum device [2,3]. In- and outgoing signals are modeled by auxiliary cavities coupled in a cascaded manner to the quantum device where the pulse shape is associated with a time dependent loss rate while the full quantum state of the corresponding mode is encoded in the auxiliary cavities. Here, we present first results demonstrating that the resulting cascaded master equation is optimally suited to study the operation of Josephson photonics devices as detectors.

[1] R. Albertet al., accepted by Phys. Rev. X, arXiv:2303.03173.
[2] A. H. Kiilerich et al., Phys. Rev. Lett. **123**, 123604 (2019).
[3] A. H. Kiilerich et al., Phys. Rev. A **102**, 023717 (2020).

TT 18.40 Mon 15:00 Poster C

**Investigation of multi-qubit architecture based on supercon-**

**ducting quarton qubits** — •Hossam Tohamy[1], Alex Kreuzer[1], Alexandru Ionita[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie (KIT) — [2]Institut für Quantenmaterialien und -technologien (IQMT), Karlsruher Institut für Technologie (KIT)

In the pursuit of optimizing superconducting qubits, significant attention has been directed toward exploring the transmon-type multiqubits architecture. A recent addition to qubit designs, the quarton, represents a flux qubit characterized by a quartic potential. This novel design offers a substantial positive anharmonicity, with a magnitude of three to five larger than that of the transmon qubit. This enhanced anharmonicity enables faster and higher fidelity gate operations. Here, we construct quarton qubits utilizing a gradiometric architecture, employing vertically stacked junctions. We present comprehensive spectroscopy and time domain measurements conducted on these qubits, and compare the experimental results with theoretical models. This work is aimed at realizing a multiqubit architecture based on quarton qubits.

TT 18.41 Mon 15:00 Poster C

**Spin Transport Simulation using Quartic Flux Qubits** — •Thilo Krumrey[1], Alex Kreuzer[1], Hossam Tohamy[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruher Institu für Technologie, 76131 Karlsruhe, Germany — [2]IQMT, Karlsruher Institu für Technologie, 76131 Karlsruhe, Germany

With the advent of the modern quantum technologies, the demand for precise measurement and control remains still a challenge, especially for large and noisy systems. On the other hand, the ability to control the state of individual or few qubits also offers new possibilities to explore entanglement and interference. For instance, the quantum version of the Wheatstone resistance bridge [1] could allow for comparative measurements of coupling energy scales using the interference of spin currents.

We propose an implementation of such a quantum measurement approach, by employing superconducting quantum circuits. In particular, we use flux qubits in which the loop and junction inductance are tailored to be equal resulting in a *quartic* potential with a large positive anharmonicity [2]. This enables us to develop a specialised integrated circuit with the required topology. The multi-qubit and multi-resonator arrangement is designed to be flexible due to the flux tuneability of the qubits and avoiding frequency crowding. We will present design considerations, simulation data as well as first fabrication and measurement results.

[1] K. Poulsen *et al.*, PRL **128**, 240401 (2022)
[2] F. Yan *et al.*, arXiv:2006.04130v1

TT 18.42 Mon 15:00 Poster C

**A mm-wave platform for superconducting qubits** — •Urs Strobel[1], Jakob Lenschen[1], Jürgen Lisenfeld[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Institut für Quanten Materialien und Technologien (IQMT), Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany

Superconducting quantum circuits which are operating at frequencies one order of magnitude larger than those demonstrated until now, e.g. at a frequency of about 100 GHz, would offer numerous new possibilities. Due to the increased qubit energy level separation, such qubits could be operated at temperatures much higher than their present counterparts, qubit logic gates can be performed faster and circuit components reduced in size thus allowing for a smaller footprint, denser packaging and better integration. These potential advantages face many challenges and pose intriguing physics questions.

We are developing a versatile experimental platform for the low temperature investigation of mm-wave resonators and qubits. This includes the mm-wave cryogenic wiring, sample holders and thin film process technology for the superconducting qubits. We explore several suitable superconducting thin film materials, which we study for a better comparison with conventional materials also at microwave frequencies.

TT 18.43 Mon 15:00 Poster C

**Quantum Coherence of Josephson Vortices in High Impedance Long Junctions** — •Julian Feiler[1], Micha Wildermuth[1], Jan Nicolas Voss[1], Maximilian Kristen[1,2], Mikhail V. Fistul[3], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [3]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany

The physics of Josephson vortices in long junctions spans from nonlinear soliton dynamics with relativistic effects to the interesting applications of coherent microwave generation. In the majority of the past experiments, the vortices are modelled as classical particles and only a small subset showed signatures of a quantum behaviour. The main reason originates in the low impedance electromagnetic environment of the vortices which was set by the geometry of the electrodes. With the advent of high kinetic inductance electrode materials, such as granular aluminium, this constraint is relaxed and Josephson vortices behaving as quantum particles are now within reach.

In the presented experiment, we employ a coupled long Josephson junction-resonator system and characterise it at milli-Kelvin temperatures. We show spectroscopic data with magnetic fields applied inplane and, to tune out residual z-components, also perpendicular to the plane of the junction. We observe indications of quantum two-level systems and present associated coherence and relaxation times.

TT 18.44 Mon 15:00 Poster C

**Waveguide QED with photon-photon interaction** — •Adrian Paul Misselwitz[1,2,3] and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In quantum optics and solid state systems, light-matter interactions are usually studied under the premise, that the quantized electromagnetic field is represented by a set of independent harmonic oscillator modes. In this work we go beyond this assumption and consider the coupling of real or artificial two-level atoms to photonic waveguides in the presence of strong photon-photon interactions. Specifically, we consider superconducting qubits that are coupled to 1D and 2D arrays of coupled microwave resonators, where the presence of Josephson nonlinearities gives rise to strong interactions between the propagating photons. We investigate the few-excitation spectra of this systems and show how the interplay between atom-photon and photon-photon interactions gives rise to different classes of multi-photon bound states. Finally, we discuss how the presence of photon-photon interactions changes the photon-mediated interactions between the atoms and results in unconventional dipole-dipole interactions, which are absent in linear electromagnetic environments.

TT 18.45 Mon 15:00 Poster C

**Design and fabrication of Niobium-trilayer based Dimer Josephson Junction Array Amplifier** — •Bhoomika R Bhat, Asen L Georgiev, Fabian Kaap, Victor Gaydamachenko, Christoph Kissling, Judith Felgner, Mark Bieler, and Lukas Grünhaupt — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Quantum computation and other applications utilizing microwave signals at powers of a few fW benefit from amplification with the smallest possible noise added. Josephson parametric amplifiers are a well-established class of devices that can meet this condition. We design a Niobium-trilayer-based Dimer Josephson Junction Array Amplifier (DJJAA) [1], a standing wave parametric amplifier, which has several pairs of modes so called dimers, in the 4 to 8 GHz range. In principle, each of these dimers can be used to achieve nondegenerate amplification using the four-wave mixing mechanism. Our device, consisting of arrays with 800-1200 dc-SQUIDs is fabricated in Nb/Al-$AlO_x$/Nb trilayer technology. We present our design flow, which employs finite element simulations and the fabrication process.

[1] P. Winkel et al., Phys. Rev. Applied 13, 024015 (2020).

TT 18.46 Mon 15:00 Poster C

**Recent insights into the low frequency excess flux noise in superconducting quantum devices** — •Anna Ferring-Siebert[1], Fabian Kaap[2], David Mazibrada[1], Lukas Münch[1], Andreas Fleischmann[1], Christian Enss[1], and Sebastian Kempf[3,4,1] — [1]KIP, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany. — [2]currently at PTB, Bundesallee 100, 38116 Braunschweig, Germany. — [3]IMS, KIT, Hertzstraße 16, 76187 Karlsruhe, Germany. — [4]IPE, KIT, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany.

In many applications low frequency excess flux noise (EFN), with a frequency dependence of $1/f^{\alpha}$, limits the performance of superconducting quantum devices such as SQUIDs and Qubits. Although it was long believed that its magnitude expressed in units of magnetic flux $S_{\Phi}(1\,\mathrm{Hz})$ and exponent $\alpha$ are fairly independent of the device material and inductance, there meanwhile exist hints for the contrary. It is also known that EFN can depend on the equipment used for device fabrication, the reason for that however remained unknown up to now.

In this contribution, we discuss origins of fabrication induced EFN and means to minimize it. We show that material layers deposited with commercial deposition equipment can contain magnetic impurities causing EFN. We also present how we have modified commercial sputtering sources to reduce EFN. Finally, measurements investigating the dependence of EFN on device inductance and material choice are discussed.

TT 18.47 Mon 15:00 Poster C

**Hybrid Qubits in Kitaev Chains** — •Tobias Kuhn, Raffael L. Klees, and Mónica Benito — Universität Augsburg

The goal of this project is to investigate superconducting quantum dot arrays integrated with superconducting circuits as possible platforms for hybrid qubits. Under the appropriate magnetic fields, the effective mechanism of superconducting pairing along such arrays was predicted to be a spinless $p$-wave type, leading to the realization of a Kitaev chain with Majorana zero modes. When two such chains are embedded in a transmon circuit, hybrid qubits are formed [2] that could harness the controllability of transmon qubits and the topological protection of Majorana modes. In particular, we derive an effective low-energy Hamiltonian of the minimal Kitaev model [3], study extensions to longer chains as well as embeddings into circuit QED architectures [4]. As a future goal, the ability to perform single-qubit operations will be a first step towards quantum computing in such hybrid devices [5,6].

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[4] A. Blais, A. L. Grimsmo, S. M. Girvin, and A. Wallraff, Rev. Mod. Phys. **93**, 025005 (2021)
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TT 18.48 Mon 15:00 Poster C

**Dc-SQUIDs with distributed lossy lines to damp LC resonances** — •Lukas Münch, Anna Ferring-Siebert, Daniel Hengstler, Sebastian Hilscher, Nicolas Kahne, Fabian Krämer, David Mazibrada, Alexander Stoll, Andreas Fleischmann, and Christian Enss — KIP, Heidelberg University

SQUIDs are sensitive superconducting magnetic flux to voltage converters, whose operation is based on the Josephson effect. In particular at mK temperatures this sensitivity can be degraded by LC-resonances in inductances and capacitances of different structures of the SQUID design. To damp the resonances and reduce their influence on the SQUID characteristics, lumped-element resistors are commonly placed into the SQUID circuitry, which need precise simulations to determine the appropriate resistance values and positions.
In this contribution we show results for a dc-SQUID with a new damping strategy, using lossy lines for the input coil and the feed lines. For the input coil we use a thin gold layer which is fabricated in a bilayer process underneath the superconducting coil. For the parallel pair feed lines, on the other hand, we damp inductively through large areas of gold on top which are galvanically decoupled by an insulating layer. We compare the different damping schemes regarding the resonance features in their SQUID characteristics and noise contributions. For future designs we also plan tests with SQUID-washers made of lossy lines.

TT 18.49 Mon 15:00 Poster C

**Optimisation Of Cross-Type Josephson Tunnel Junction Based dc-SQUIDs** — •A. Stoll[1], F. Bauer[2,1], L. Münch[1], D. Hengstler[1], A. Ferring-Siebert[1], N. Kahne[1], D. Mazibrada[1], A. Reifenberger[1], A. Fleischmann[1], S. Kempf[2,3,1], and C. Enss[1] — [1]KIP, Heidelberg University — [2]IMS, Karlsruhe Institute of Technology — [3]IPE, Karlsruhe Institute of Technology

Superconducting Quantum Interference Devices (SQUIDs) are among the most sensitive wideband detectors for magnetic flux today. Based on the Josephson effect, they are able to convert small magnetic flux changes into a measurable voltage signal. For this study, microfabricated Josephson tunnel junctions (JJs) make up the basic elements of the SQUIDs. Very often window-type JJs are used due to their reliable wafer-scale fabrication process. The JJ area in the window-type geometry is defined by openings in an insulating layer and is thus limited in its size by the alignment accuracy. To circumvent this, the cross-type geometry was introduced in which the JJ area is defined by the overlap area of two crossing stripes. The transition to cross-type JJs is motivated by reducing the junction area as well as parasitic capacitances. This will in turn relax parasitic effects, e.g. $LC$-resonances, as well as improve the energy resolution $\epsilon \propto \sqrt{LC}$ of dc-SQUIDs.
We present the characteristic properties, performance and noise spectra of different design variants of dc-SQUIDS based on cross-type JJs. These results showcase the potential of moving even closer to the quantum limit by utilising the cross-type geometry.

TT 18.50 Mon 15:00 Poster C

**A dc-SQUID flux ramp modulation multiplexer in 4x32 configuration** — •D. Mazibrada[1], A. Abeln[1], A. Ferring-Siebert[1], N. Kahne[1], D. Hengstler[1], L. Hoibl[1], L. Münch[1], D. Richter[1], A. Stoll[1], T. Wolber[3], T. Muscheid[3], N. Karcher[3], M. Weber[3], O. Sander[3], A. Fleischmann[1], L. Gastaldo[1], S. Kempf[2,3,1], and C. Enss[1] — [1]KIP, Heidelberg University, Germany. — [2]IMS, Karlsruhe Institute of Technology, Germany. — [3]IPE, Karlsruhe Institute of Technology, Germany.

Superconducting quantum interference devices (SQUIDs) are flux-to-voltage converters with high sensitivity which offer a large bandwidth. With the flux ramp modulation (FRM) multiplexing technique it is possible to read out several dc-SQUIDs through a single line.
In this contribution we discuss our first FRM dc-SQUID multiplexer to read out a 16x16 metallic magnetic calorimeter array. It relaxes the hardware requirements of a SQUID system and allows a linearized readout while achieving a large dynamic range. We installed 16 individual SQUID chips containing 2 arrays, each combining 4 dc-SQUIDs connected in series. The SQUIDs operate in open-loop mode, where each SQUID in an array is provided with a different flux ramp signal while we measure the voltage across an entire array. The flux ramp modulation signals are shared by all 32 arrays, so the entire setup acts as a 4x32 configuration. This reduces the number of wires by almost a factor of 8 compared to a brute force parallel SQUID readout of the detector. This approach allows a cost-effective, simultaneous readout with adequate energy resolution.

TT 18.51 Mon 15:00 Poster C

**Comparative Analysis of Aluminium- and Niobium-based Josephson Parametric Amplifiers** — •Felix Henrich[1], Alexander Stoll[1], Federica Mantegazzini[2], Felix Ahrens[2], Claudio Gatti[3], Andreas Fleischmann[1], Loredana Gastaldo[1], and Christian Enss[1] — [1]Kirchhoff-Institute of Physics, Heidelberg University, Germany — [2]Fondazione Bruno Kessler, Trento, Italy — [3]Laboratori Nazionali di Frascati, Frascati, Italy

Josephson Parametric Amplifiers (JPAs) are devices used to amplify ultralow-power microwave signals. Their capability to operate at or even surpass the Standard Quantum Limit (SQL) with high gain enables unprecedented possibilities in quantum information processing and detector readout.
We present the characterization of flux-driven JPA designs consisting of a Superconducting QUantum Interference Device (SQUID), based on crosstype Josephson tunnel Junctions (JJs), combined with a superconducting coplanar waveguide resonator. The JPAs were fabricated using either Nb or Al as the superconductor. The aluminium versions feature a $Al\backslash Al_2O_3\backslash Al$ tri-layer, while the niobium counterparts employ a $Nb\backslash Al\backslash Al_2O_3\backslash Nb$ tri-layer, facilitated by the planarization of the tri-layer in sputtered $SiO_2$ to avoid electrical shorts at the side wall of the JJs.
We compare the key parameters obtained from the Nb-based JPAs and Al-based JPAs and discuss our observations.

TT 18.52 Mon 15:00 Poster C

**Identification of Noise Sources in Superconducting Microstructures** — •M. Renger, D. Hengstler, M. Herbst, F. Kaiser, D. Mazibrada, L. Münch, A. Reifenberger, C. Ständer, R. Yang, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Improving the performance of a superconducting device often means identifying and eliminating noise. Many potential noise sources are independent of the specific experimental set-up and transferable across many device categories such as qubits, SQUIDs, and superconducting detectors. We have constructed a stand-alone device able to representably probe specific noise sources. The set-up consists of a Wheatstone-like bridge of microfabricated superconducting inductors and a pair of two-stage dc-SQUID read-out chains. Cross-correlation removes noise contributions from the read-out electronics giving us the sum total of all noise in the superconducting circuit. If, in comparison, the Wheatstone bridge is AC-driven, we can measure a sample material's magnetic noise via the material's complex AC susceptibility using the fluctuation-dissipation theorem. The experiment is performed at temperatures between $T = 10\,\text{mK}$ and $1000\,\text{mK}$ in the frequency range from $f = 100\,\text{mHz}$ to $100\,\text{kHz}$ on an experimental holder with excellent thermal coupling and shielding. We present new measurements of $SiO_2$ and Ag:Er thin films and an macroscopic sample of $YbRh_2Si_2$, conducted with new versions of our device with increased symmetry and coupling.

TT 18.53 Mon 15:00 Poster C

**Broadband ESR spectroscopy of** $Er:Y_2SiO_5$ **at mK temperatures** — •Jianpeng Chen[1,2], Georg Mair[1,2], Ana Strinic[1,2,3], Chiun Fu[1,2], Achim Marx[1,2], Kirill Fedorov[1,2,3], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technical University of Munich, School of Natural Sciences, Garching,Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

Crystals doped with rare-earth ions are promising for the implementation of quantum memories, which are frequency-compatible with superconducting quantum circuits operated in the microwave regime. Erbium-167 is an ideal candidate for a microwave-addressed quantum memory since it exhibits ZEro First-Order Zeeman (ZEFOZ) transitions at low magnetic fields [1], Here, we present broadband ESR spectroscopy data [2] of $Er:Y_2SiO_5$ measured at millikelvin temperatures. With a goal to identify the optimal transitions for coherent microwave storage. Our results show that $Er:Y_2SiO_5$ is promising for encoding quantum information for longer times within ZEFOZ states at microwave frequencies.

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[2] A. Strinic et al., DPG Spring Meeting (2023)

TT 18.54 Mon 15:00 Poster C

**Fabrication of over-coupled transmission line resonators for broadband microwave spectroscopy** — •Chiun Fu[1,2], Georg Mair[1,2], Niklas Bruckmoser[1,2], Jianpeng Chen[1,2], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Technical University of Munich, School of Natural Sciences, Garching, Germany — [2]Walther-Meißner-Institute, Bavarian Academy of Sciences and Humanities, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Spin ensembles are promising for the development of developing quantum memories [1]. However, coupling the spins of rare-earth ions with narrow bandwidth microwave resonators limits their operation to a narrow frequency range. We design over-coupled resonators to reduce their quality factor and thereby expand the bandwidth available for the coupled spin-photon system. Here, we introduce the over-coupled coplanar transmission line (oCPTL) resonator having an interdigital capacitor structure between the linear taper and meandered transmission line. Increasing the coupling capacitance results in an increasing bandwidth of the resonator available for coupling to the rare-earth spin ensembles. The design of the over-coupled transmission line resonators, fabrication details, and the measurement results at cryogenic temperatures will be discussed.

[1] M. Guo, S. Liu, W. Sun et al., Front. Phys. 18, 21303 (2023)
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TT 18.55 Mon 15:00 Poster C

**Broadband electron spin resonance spectroscopy of Er ions in** $CaWO_4$ **with planar waveguides** — •Georg Mair[1,2], Jianpeng Chen[1,2], Ana Strinic[1,2,3], Roman Kolesov[4], Tobias Hanke[4], Michael Stanger[2], Andreas Erb[1,2], Hans Huebl[1,2,3], Kirill Fedorov[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meissner-Institute, Bavarian Academy of Sciences, Garching — [2]Technical University of Munich, School of Natural Sciences, Physics Department, Garching — [3]Munich Center for Quantum Science and Technology, Munich — [4]3rd Institute of Physics and Center of Applied Quantum Technology, University of Stuttgart, Stuttgart

Hybrid systems comprising qubits and quantum memory units have been proposed to improve processor architecture in applications of quantum computing with superconducting circuits [1]. Suitable quantum memory candidates in the microwave regime are rare-earth ions in crystal host lattices, such as $Er:CaWO_4$. Broadband ESR spectroscopy at 12 mK reveals desired ZEFOZ (Zero First-Order Zeeman) transitions at low magnetic fields, where the longest coherence times of the hyperfine spin states are expected due to their minimized sensitivity to fluctuations of external fields [2]. We present advances in the fabrication of superconducting transmission lines utilizing a planar waveguide geometry to enhance coupling of propagating microwaves to spin systems.

[1] É. Gouzien, N. Sangouard, Phys. Rev. Lett. **127**, 140503 (2021)
[2] A. Ortu et al. Nat. Mater **17**, 671 (2018)

TT 18.56 Mon 15:00 Poster C

**Pyroelectricity in a Lithium Niobate Phase Modulator During Thermal Transition to and from Cryogenic Temperatures** — Frederik Thiele, •Thomas Hummel, Nina A. Lange, Felix Dreher, Maximilian Protte, Felix vom Bruch, Sebastian Lengeling, Harald Herrmann, Christof Eigner, Christine Silberhorn, and Tim J. Bartley — Department of Physics & Institute for Photonic Quantum Systems, Paderborn University, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate ($LiNbO_3$) is a promising platform for quantum optics, due to the high nonlinearity, electro-optic effect, and low loss waveguiding. Integrating superconducting nanowire single-photon detectors requires operation at cryogenic temperatures. The transition to and from cryogenic temperatures creates free charge carriers due to the pyroelectric effect. These charge carriers are distributed in the material, inducing electric fields. The electric fields affect the refractive index inside, and the electrical structures on top of the $LiNbO_3$. When the electric fields are too strong, charge carriers recombine causing a local electrical discharge. We measure the electrical discharges and changes in birefringence with a phase-modulator in bulk Z-cut $LiNbO_3$ with titanium in diffused waveguides. For this we connect a current meter across the electrodes to measure the electrical discharges, and put the phase modulator in the Sénarmont configuration to measure changes in the birefringence. Monitoring these properties during thermal transition shows correlations between electrical discharges and optical discontinuities, where the rate of events depends on the temperature.

TT 18.57 Mon 15:00 Poster C

**Axial Cryogenic current comparator (CCC) for FAIR** — •Lorenzo Crescimbeni[1,2], David Haider[2], Thomas Sieber[2], Frank Schmidl[1], Thomas Stöhlker[1,2,4], Ronny Stolz[3], Volker Tympel[4,2], and Vvyacheslav Zakosarenko[3,5] — [1]Friedrich-Schiller-University Jena, Germany — [2]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, Germany — [3]Leibniz Institute of Photonic Technology (Leibniz IPHT), Jena, Germany — [4]Helmholtz-Institute Jena, Germany — [5]Supracon AG, Jena, Germany

The Cryogenic Current Comparator (CCC) is a superconducting device based on an ultrasensitive SQUID magnetometer (fT range). Measuring the beam's azimuthal magnetic field, it provides a calibrated non-destructive measurement of beam current with a resolution of 10 nA or better, independent from ion species and without tedious calibrations procedure. The non-interceptive absolute intensity measurement of weak ion beams (<1 muA) is essential in heavy ion storage rings and in transfer lines at FAIR. With standard diagnostics, this measurement is challenging for bunched beams and virtually impossible for coasting beams.

To improve the performance of the detector a new type of CCC using an alternative magnetic shield geometry has been developed. The socalled "axial" geometry will allow for much higher magnetic shielding factor, an increased pick-up area, and an expected lower noise component at low frequencies. Hereby the construction process and the results of test will be discussed, together with further improvements of the detector aimed to provide the best possible CCC version to FAIR.

TT 18.58 Mon 15:00 Poster C

**Noise Thermometers for mK- and** $\mu$**K-Temperatures** — •Leo Knapp, Pascal Willer, Christian Ständer, Nathalie Probst, Andreas Reiser, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

To measure mK-temperatures is a big challenge in solid state physics labs. We developed a prototype of a cross-correlated, current sensing noise thermometer for mK-temperatures. The basic concept relies on the thermal motion of charge carriers in a bulk metal resistor. Two DC-SQUIDs detect the corresponding noise signal which is then recorded via two identical but independent amplifier chains. The method of cross correlation is used to eliminate uncorrelated noise contributions from the amplifier chains. As resistor material we use the alloy $Ag_{60}Cu_{40}$. We show that this approach towards a relative primary thermometer is able to cover the complete temperature range below 4 K. We discuss the design, the considerations that lead to it and present first experimental results down to mK temperatures.

TT 18.59 Mon 15:00 Poster C

**Material Studies for Magnetic Penetration Depth Thermometers** — •F. Kaiser, N. Grun, L. Münch, M. Herbst, M. Renger, D. Hengstler, A. Reifenberger, A. Fleischmann, L. Gastaldo, and C. Enss — KIP, Heidelberg University, Germany

Microcalorimeters are energy-dispersive particle detectors, well known for their applications in high-resolution X-ray spectroscopy. They are operated at mK temperatures and convert the energy of incoming photons into a temperature rise, which can be read out using a temperature-sensitive material. In current magnetic microcalorimeters paramagnetically doped normal-metals are a popular choice for the temperature sensor as they allow for precision X-ray spectroscopy, with their excellent energy resolution over a large energy range combined with a very good linearity.

This contribution discusses superconductors as a potential sensor material. In the form of magnetic penetration depth thermometers, we use the Meißner-Ochsenfeld effect to measure the temperature dependent London penetration depth of the superconducting film with a highly-sensitive SQUID magnetometer. This technology promises an even better energy resolution in exchange for a reduced dynamic range.

With a dedicated, wheatstone-like impedance bridge we measured the superconducting transitions of different superconducting materials (Ti, AlMn 2500 ppm, etc.) and investigated the impact of different sensor geometries.

TT 18.60 Mon 15:00 Poster C

**Metallic Magnetic Calorimeter for the Search of Alpha Decay in Os-184** — •Nathalie Probst[1], Andreas Reifenberger[1], Fedor Danevych[2], Andreas Fleischmann[1], and Christian Enss[1] — [1]KIP, Heidelberg University, Germany — [2]Institute for Nuclear Research of NASU

Excesses of the daughter nuclide W-180 found in meteorites and terrestrial rocks claim an alpha decay for Os-184 with the half-life $\tau_{1/2} = (1.1 \pm 0.2) \cdot 10^{13}$ yr which is in contradiction with the theoretical prediction $\tau_{1/2} = (2.1 - 7.5) \cdot 10^{13}$ yr. While the half-life $\tau_{1/2} = (2.0 \pm 1.1) \cdot 10^{15}$ yr of Os-186 was directly measured in laboratory experiments, for Os-184 only a lower limit $\tau_{1/2} > 2.0 \cdot 10^{13}$ yr was determined.

In this work we aim to directly measure the half-life of Os-184 for the first time and in addition reach a substantially higher precision for the value of the half-life of Os-186. Therefore, bulk superconducting osmium is used as a particle absorber for a metallic magnetic calorimeter (MMC). Compared to germanium detectors which are commonly used for particle detection, this detector stands out with a small detector volume which reduces the background of myonic and cosmic radiation to a minimum.

With the energy resolution being in the keV-range, we will answer the question whether the alpha decay in Os-184 exists. We discuss first results including the characterization with external sources.

TT 18.61 Mon 15:00 Poster C

**Towards large-area 256-pixel MMC arrays for high resolution X-ray spectroscopy** — •A. Abeln, S. Allgeier, D. Hengstler, D. Kreuzberger, D. Mazibrada, L. Münch, A. Orlow, A. Reifenberger, A. Stoll, A. Fleischmann, L. Gastaldo, and C. Enss — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Metallic Magnetic Calorimeters (MMCs) are energy-dispersive cryogenic particle detectors. Operated at temperatures below 50 mK, they provide very good energy resolution, high quantum efficiency as well as high linearity over a large energy range. In many precision experiments in X-ray spectroscopy the photon flux is small, thus a large active detection area is desirable. Therefore, we develop arrays with increasing number of pixels. For a cost-effective read-out of a growing number of detector channels we investigate different multiplexing techniques.

In this contribution we present a detector setup comprising a novel dense-packed 16 × 16 pixel MMC array. The pixels provide a total active area of 4 mm × 4 mm and are equipped with 5 $\mu$m thick absorbers made of gold. This ensures a stopping power of at least 50 % for photon energies up to 20 keV. The expected energy resolution is $\Delta E = 1.4$ eV (FWHM) at an operating temperature of 20 mK. Furthermore the detector setup features 16 in-house made SQUID chips each with 2 × 4 flux-ramp modulated dc-SQUIDs which enables us to read out 128 detector channels with 32 read-out channels. We present design considerations and discuss the detector performance.

TT 18.62 Mon 15:00 Poster C

**Large-area MMC-based photon detector operated at mK temperatures** — •Ashish Jadhav, Christian Enss, Andreas Fleischmann, Daniel Hengstler, Andreas Reifenberger, Daniel Unger, and Loredana Gastaldo — Kirchhoff Institute for Physics, Heidelberg, Germany

We present the development of a large area, high-energy resolution photon detector based on low temperature metallic magnetic calorimeters (MMCs). The detector is to be the photon detector in a combined photon-phonon (P2) detector to be coupled to molybdate scintillating crystals in the AMoRE experiment. The final P2 detector utilises a 3-inch Si wafer. A central area, weakly coupled to the rest of the wafer is defined to detect visible photons emitted by particle interactions in the scintillating crystal. The outer part of the wafer contains three double-meander MMC detectors as phonon detectors to monitor temperature changes in the crystal resting on gold spacers. The most challenging part is the photon detector based on a stripline pickup coil design. We present the R&D on a large area silicon photon detector with stripline MMC geometry. We discuss the results obtained and the implications of the photon detector for the AMoRE experiment.

TT 18.63 Mon 15:00 Poster C

**Advances in microfabrication of Metallic Magnetic Calorimeters** — •Daniel Kreuzberger, Andreas Reifenberger, Andreas Abeln, Alexander Orlow, Daniel Hengstler, Andreas Fleischmann, and Christian Enss — Heidelberg University

Metallic Magnetic Calorimeters (MMCs) are low temperature particle detectors which can reliably be produced with multilayer microfabrication techniques. Moreover, the consequent use of these techniques allows for the fabrication of thousands of virtually identical detectors as required for large, dense packed arrays. Using various examples of current MMC detectors which are actively used for high resolution x-ray spectroscopy, we present the status of our microfabrication processes. This includes the fabrication of overhanging x-ray absorbers made of gold with a thickness up to 100 $\mu$m. For this, a newly developed fabrication process is presented, preventing almost all athermal phonons from escaping in the substrate without thermalization in the sensor. We also discuss copper filled Through-Silicon-Vias (TSV) used to heatsink the detector pixels to the wafer backside.

TT 18.64 Mon 15:00 Poster C

**A dedicated 2-dimensional array of metallic magnetic microcalorimeters to resolve the 29.18keV doublet of $^{229}$Th** — •A. Striebel, A. Abeln, S. Allgeier, A. Brunold, J. Geist, D. Hengstler, D. Kreuzberger, A. Orlow, L. Gastaldo, A. Fleischmann, and C. Enss — Heidelberg University

The isotope $^{229}$Th has the nuclear isomer state with the lowest presently known excitation energy, which possibly allows to connect the fields of nuclear and atomic physics with the potential application as a nuclear clock. In order to excite this very narrow transition with a laser a precise knowledge of the transition energy is needed. Recently the isomer energy (8.338±0.024) eV [Kraemer et al., arXiv:2209.10276, 2022] could be precisely determined. To get valuable insights, we will improve our high-resolution measurement [Sikorsky et al., PRL 125, 2020] of the $\gamma$-spectrum following the $\alpha$-decay of $^{233}$U. This decay partially results in excited $^{229}$Th with a nuclear state at 29.18 keV. Resolving the doublet, that in turn results from de-excitation to the ground and isomer state, respectively, would allow an independent measurement of the isomer energy as well as the branching ratio of both transitions. To resolve this doublet, a 2D detector array consisting of 8 × 8 metallic magnetic calorimeters (MMCs) was fabricated.

MMCs are operated at mK temperatures and convert the energy of a single incident $\gamma$-ray photon into a temperature pulse which is measured by a paramagnetic temperature sensor. We discuss the detector properties, including an energy resolution of 3.1 eV (FWHM) at 5.9 keV and present first spectra of $^{229}$Th taken with this detector.

TT 18.65 Mon 15:00 Poster C

**Characterization of Photoresists for DeepUV Direct Writing Lithography** — •Niels Fiedler[1], Andreas Reifenberger[1], Lukas Münch[1], Alexander Stoll[1], Ludwig Hoibl[2], Andreas Fleischmann[1], and Christian Enss[1] — [1]KIP, Heidelberg University — [2]Heidelberg Instruments Mikrotechnik GmbH

Photoresists play a key role in the transfer of patterns as protective and structuring layers for the production of micro- and nanofabricated devices. Optical maskless lithographic systems have proven to be powerful and versatile tools in research and development environments, but their resolution is limited to $\approx 0.6\,\mu$m due to the photon wavelengths of the optical systems in use. In the framework of the SuperLSI project, Heidelberg Instruments is developing a maskless lithographic system featuring a 266 nm DeepUV optical system aiming for a resolution down to 200 nm in the patterned photoresist. At the same time, it is necessary to find and characterize suitable resists and compatible developers. Here we present first results on several resist systems (DuPont UV5-0.6 and UVN2300, micro resist technology ma-N 2400) that we used to realize sub-500 nm superconducting lines. We discuss the structural accuracy as well as etching and developer compatibilities with materials used in the production of superconducting electronics (Nb, Al). The significantly reduced linewidth allows us to work on improvements of quantum sensors like SQUIDs that benefit from smaller Josephson Junctions (JJs). We will present first characterization measurements of cross-type JJs with a junction area well below 1 $\mu$m$^2$.

TT 18.66 Mon 15:00 Poster C

**Novel Susceptibility Thermometer for mK-Temperatures Based on Au:Er Micro-Fabricated on a $Al_2O_3$ Substrate** — •Wassily Holzmann, Nathalie Probst, Andreas Fleischmann, Andreas Reifenberger, Andreas Reiser, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University

Limited options exist for thermometers at mK- and sub-mK- temperatures that combine speed, high sensitivity, and reliability. Here, we present a novel concept of a susceptibility thermometer based on the paramagnetic alloy Au:Er 2000 ppm that has the potential to meet these requirements. To ensure optimal thermal contact, the 9 $\mu$m thick Au:Er sensor sputter deposited on a copper sheet is pressed onto superconducting meander-shaped readout coils with 6 $\mu$m pitch, microfabricated on a $Al_2O_3$ wafer, using springs. Two such coils, filled with Au:Er, and two empty coils form a wheatstone-like bridge with the filled coils opposed. The inductance of the empty coils is chosen to balance the bridge at a specific temperature, where the thermometer can be operated as extremly sensitive zero-detector, fully independent of any overall gain drift. The coils have a combined length of 129 m, which results in an voltage signal that can be readout with room temperature electronics. For certain applications, this can serve as an individual fixed point for precise temperature stabilization. The imbalance due to the paramagnetic contribution of the Au:Er at all other temperatures is used to establish a temperature scale by calibration with another thermometer, in our case a noise thermometer. We will discuss the design, fabrication, readout, and operation.

TT 18.67 Mon 15:00 Poster C

**Wafer calorimeter development for the Direct Search Experiment for Light Dark Matter with Superfluid Helium (DELight)** — •Friedrich Wagner[1], Lena Hauswald[1], Michael Müller[1], Fabienne Bauer[1], and Sebastian Kempf[1,2] — [1]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology, Germany. — [2]Institute for Data Processing and Electronics, Karlsruhe Institute of Technology, Germany.

The dark matter (DM)-nucleon scattering parameter space of Light Dark Matter (LDM) has been barely probed, as it requires an energy detection threshold as low as a few eV. The "Direct search Experiment for Light dark matter" (DELight) aims investigating this challenging parameter space by using superfluid $^4$He as target material. Superfluid $^4$He provides not only a low nuclear mass and a high radiopurity level, but also various signal channels for event classification. For signal detection, DELight will use energy- and time-resolving cryogenic wafer calorimeters with eV-scale energy resolution, some of which will be located above the liquid, while others will be immersed in the superfluid. The detectors will be based on magnetic microcalorimeters (MMCs) that are operated in athermal mode, i.e. the energy of an incident particle is converted into an athermal phonon population that is sensed via normal or superconducting phonon collectors heating up a paramagnetic temperature sensor that is situated in a weak magnetic field. Here, we present our most recent R&D efforts related to detector layout and fabrication technology, both ultimately paving the way towards wafer calorimeters with $O(20\,\text{eV})$ energy threshold.

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**ELECTRON - High-resolution electron spectroscopy of a novel tritium source using next-generation microcalorimeters** — •Fabienne Bauer[1], Lena Hauswald[1], Neven Kovac[2], Marie-Christin Langer[1], Michael Müller[1], Rudolf Sack[2], Beate Bornschein[2], Markus Steidl[2], Magnus Schlösser[2], Kathrin Valerius[2], and Sebastian Kempf[1] — [1]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Astroparticle Physics (IAP), Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

Magnetic microcalorimeters (MMCs) are cryogenic single-particle detectors which are used for various challenging applications such as X-ray spectroscopy, mass spectrometry or radionuclide metrology. Due to their outstanding performance, they are considered as potential detector technology for a next-generation KATRIN-like neutrino mass experiment, ultimately aiming for investigating the ordering of the neutrino masses by performing a differential measurement of the tritium beta spectrum. To verify the suitability of MMCs for such an experiment, systematic effects potentially degrading the expected performance have to be investigated. Within this context, we present our project ELECTRON aiming to systematically study MMC-based electron detection. We will present our cryogenic set-up which can be used to measure external electrons from multiple different sources and discuss the results of our latest measurements. Finally, we present the status of our attempt to perform the world's first measurement of the tritium spectrum using an atomic tritium source and an MMC.

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**Lab::Measurement – measurement control with Perl 5** — Simon Reinhardt, Mia Schambeck, Erik Fabrizzi, and •Andreas K. Hüttel — Institute for Experimental and Applied Physics, Universität Regensburg, Regensburg, Germany

`Lab::Measurement` is a collection of object-oriented Perl 5 modules for control of test and measurement devices. It allows for quickly setting up complex tasks with diverse hardware. Instruments can be connected via GPIB (IEEE 488.2), USB, or VXI-11 / raw network sockets on Ethernet. Internally, third-party backends as, e.g., Linux-GPIB or the NI-VISA library are used, in addition to lightweight drivers for USB and TCP/IP-based protocols. This enables cross-platform portability of measurement scripts between Linux and Windows machines. Based on roles within `Moose` that provide communication standards such as SCPI, dedicated instrument driver classes take care of internal details. A high-level sweep layer allows for fast and flexible creation of nested measurement loops, where, several input variables are varied and data is logged into a customizable folder structure. Sweeps can also be retrieved directly from an instrument as, e.g., a spectrum or network analyzer. Recent enhancements include support for the Zurich Instruments HDAWG waveform generator, the Synktek MCL1-540 lock-in, the Bluefors dilution refrigerator temperature control, the American Magnetics AMI430 magnet supply, as well as many improvements for Lakeshore temperature controllers. `Lab::Measurement` is free software and available at `https://www.labmeasurement.de/` —

[1] S. Reinhardt *et al.*, Comp. Phys. Comm. **234**, 216 (2019)

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**Two-stage magnetic shielding for superconducting circuits in an adiabatic demagnetization refrigerator** — •Lino Visser[1], Marc Neis[2], Jéferson Guimarães[2], Markus Jerger[2], Pavel Bushev[2], Vincent Mourik[1], and Rami Barends[2] — [1]JARA-Fit Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany — [2]Peter Grünberg Institut 13 Institute for Functional Quantum Systems, Forschungszentrum Jülich GmbH, Jülich, Germany

Adiabatic demagnetization refrigeration (ADR) is a promising technology for future quantum technology applications. Cooling units for ADRs are cheap and reliable while enabling base temperatures comparable to those obtained in dilution refrigerators. A challenge are the residual magnetic fields originating from the magnet used for recharging the paramagnetic salts, as these lower the operation fidelity of superconducting circuits. Here, we present the design of a 4 Kelvin two-stage mu-metal and Niobium magnetic shield with ports for 4 RF wires, and 48 DC lines. The lowest temperature stage enters the magnetic shield through a feedthrough, and contains an additional Copper infrared shield around the sample space. Using finite element simulations, we quantify the magnetic shielding factor before manufacturing. To benchmark the ADRs shielding performance, we characterize a set of Niobium resonators, measuring their quality factor. First results indicate a competitive performance of these resonators in our customized set-up.

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**Cooling power on different stages of a pulse tube cryocooler depending on regenerator design** — •Xaver Herrmann[1], Jack-André Schmidt[1,2], Bernd Schmidt[1,2], Jens Falter[2], and André Schirmeisen[1,2] — [1]Instiute of Applied Physics, Justus-Liebig University, Giessen, Germany — [2]TransMIT-Center for Adaptive Cryotechnology and Sensors, Giessen, Germany

Closed-cycle cryocoolers have become a reliable and important tool for low temperature scientific research[1]. Here we focus on Gifford-McMahon (GM) type pulse tube cryocoolers (PTC), which offer low maintenance and long measurement periods[2]. A critical part in cryocoolers is the regenerator. It strongly affects the temperature and cooling power achievable with a cryocooler[3, 4]. This poster will look at various regenerator fillings and associated losses, as well as the resulting cooling power achieved for a high input power system(11 kW). For comparison REGEN 3.3 simulation results will be shown.

[1] R. Güsten, et al., Nature 568 (2019) 357
[2] R. Radebaugh, J. Phys.: Condens. Matter 21 (2009) 164219
[3] J.M. Pfotenhauer, Cryocoolers 13 (2005) 463
[4] D. Abraham, IOP Conf. Ser.: Mater. Sci. Eng 1250 (2022) 012132