TT 8: Measurement Technology and Cryogenics

Time: Monday 15:00–17:45 Location: H32

TT 8.1 Mon 15:00 H32

64-pixel Magnetic Micro-Calorimeter array to study X-ray transitions in muonic atoms — •Daniel Kreuzberger, Andreas Abeln, Christian Enss, Andreas Fleischmann, Loredana Gastaldo, Daniel Hengstler, Andreas Reifenberger, Adrian Striebel, Daniel Unger, Julian Wendel, and Peter Wiedemann — for the QUARTET Collaboration, Kirchhoff Institute for Physics, Heidelberg University

The QUARTET collaboration aims to improve the knowledge on the absolute nuclear charge radii of light nuclei from Li to Ne. We use a low temperature Metallic Magnetic Calorimeter (MMC) array for high-precision X-ray spectroscopy of low-lying states in muonic atoms. MMCs are characterized by a high resolving power of several thousand and a high quantum efficiency in the energy range up to 100 keV. Conventional solid-state detectors do not provide sufficient accuracy in this energy range. A high statistics measurement with lithium, beryllium and boron has recently been performed at the Paul Scherrer Institute. We present the experimental setup and the performance of the detector used. We discuss the first preliminary spectra and systematic effects in this measurement. The high statistics data in combination with the achieved energy resolution and calibration accuracy should allow a more precise characterization of the muonic X-ray lines. With the knowledge gained, a significant improvement in the determination of nuclear charge radii is expected.

TT 8.2 Mon 15:15 H32

Magnetocaloric upgrade for the Quantum Design PPMS® — •Marvin Klinger, Jorginho Villar Guerrero, Anna Klinger, Tim Treu, Anton Jesche, and Philipp Gegenwart — EP VI, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg

Achieving millikelvin temperatures presents significant challenges in experimental physics. While many laboratories operate liquid helium cryostats at 2 K, reaching very low temperatures traditionally requires dilution refrigeration - a technique demanding both specialized expertise and substantial resources. We developed an upgrade for the Quantum Design Physical Property Measurement System (PPMS®) that overcomes these limitations. Our system employs adiabatic demagnetization refrigeration (ADR) to achieve temperatures well below 50 mK for multiple hours. The exceptional performance stems from novel quantum ADR materials that overcome disadvantages of traditional hydrated paramagnetic salts [1]. The upgrade consists of a user-friendly insert that integrates seamlessly with existing PPMS® systems. Its modular design allows researchers to easily swap the low-temperature assembly to accommodate different experimental needs, currently supporting electrical transport, stress/strain, and heat capacity measurements. This versatility and accessibility can make sub-50 mK measurements available to a broader scientific community without the complexity of dilution refrigeration.

[1] T. Treu et al., J. Phys. Condens. Matter 37, 013001 (2025)

TT 8.3 Mon 15:30 H32

The noise-o-meter: A novel device to disentangle noise sources in superconducting devices — •Lukas Münch, Daniel Hengstler, Matthew Herbst, David Mazibrada, Andreas Reifenberger, Markus Renger, Christian Ständer, Rui Yang, Andreas Fleischmann, Loredana Gastaldo, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University

In many applications of superconducting devices, different intrinsic noise sources are limiting the ultimate performance of the device. Our new device allows to conveniently disentangle the noise of the read-out chain, and to distinguish between magnetic flux noise and other noise sources. It consists of a microfabricated Wheatstone-like bridge of four superconducting inductors, two of which are filled with a sample material, which is read out via a pair of two-stage dc-SQUID read-out chains. The device can be operated in two modes. In the passive mode, the output signals of both read-out chains are cross-correlated, which allows the measurement of the total noise of all intrinsic noise sources within a sample material. In the active mode, the bridge is driven by an AC current to measure the samples complex susceptibility and, therefore, specifically the samples magnetic noise via the fluctuation-dissipation theorem. We used this setup to characterize SiO_2, Ag:Er and Au:Er films in a large temperature range from 20 to 800 mK. We discuss our design considerations and present the results of these measurements. Furthermore, we address the current performance limits of $S_\Phi = 30\,\mathrm{n}\Phi_0/\sqrt{\mathrm{Hz}}$ in passive mode and around 10 ppm for the concentration of magnetic impurities in active mode.

TT 8.4 Mon 15:45 H32

Broadband EPR Spectroscopy of $LiYF_4$ doped with Rare-Earth Ions — •Ana Strinic[1,2,3], Patricia Oehrl[1,2,3], Georg Mair[1,2], Hans Huebl[1,2,3], Rudolf Gross[1,2,3], and Nadezhda Kukharchyk[1,2,3] — [1]Walther-Meißner-Institute, Bavarian Academy of Sciences and Humanities, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology, Munich, Germany

We report on the study of hyperfine transitions of rare-earth ions doped into the host crystal $LiYF_4$ (RE^{3+}:$^7LiYF_4$) using broadband EPR spectroscopy at millikelvin temperatures. While the studied crystals are intentionally doped with ^{167}Er or ^{143}Nd, we identify impurity traces of other rare-earth ions from their EPR-transitions, based on previously published spin Hamiltonian parameters [1]. Taking into account the electron Zeeman, the hyperfine, and the quadrupole interactions, the high resolution spectra allow for the determination of refined spin Hamiltonian parameters for ^{167}Er and ^{143}Nd, as well as for the identified impurities. Our results demonstrate the advantage of using broadband EPR for material research, not only because precise information on the interactions of the spin system can be obtained, but also because the material purity can be tested. This study is relevant for quantum memory applications, as high purity materials are associated with achieving long coherence times [2].

[1] J. P. Sattler, J. Nemarich, Phys. Rev. B 4, 1, (1971);
[2] M. Le Dantec et al., Sci. Adv. 7, eabj9786 (2021).

TT 8.5 Mon 16:00 H32

Electro-optic cavities: Towards local measurement of light-matter coupling — •Michael S. Spencer[1], Joanna M. Urban[1], Maximilian Frenzel[1], Niclas S. Mueller[1], Olga Minakova[1], Martin Wolf[1], Alexander Paarmann[1], and Sebastian F. Maehrlein[1,2,3] — [1]FHI Berlin — [2]HZDR — [3]TU Dresden

Cavity quantum electrodynamics is expected to provide a unique direction for tailoring ground- and excited-state properties in correlated materials. Bringing this together with high-field driving in the terahertz (THz) spectral range opens the door to explore low-energy, field-driven cavity electrodynamics. Despite this potential, leveraging field-driven material control in bulk cavities is hindered by the lack of direct retrieval of intra-cavity fields. Here, we demonstrate novel active cavities, consisting of a Fabry-Pérot cavity filled with an electro-optic crystal, which measure their intra-cavity electric fields on ultrafast timescales. With these, we demonstrate quantitative retrieval of the cavity modes in amplitude and phase. We furthermore design a tunable multi-layer cavity, enabling deterministic design of hybrid cavities for future field-resolved polaritonic systems. Our theoretical modeling reveals the origin of the avoided crossings embedded in the intricate mode dispersion upon cavity tuning and enable fully-switchable polaritonic effects within arbitrary materials hosted by the hybrid cavity. Electro-optic cavities will therefore serve as in-situ probes of light-matter interactions across all coupling regimes, laying the foundation for field-resolved intra-cavity quantum electrodynamics.

15 min. break

TT 8.6 Mon 16:30 H32

Two-stage Pulse Tube Cryocooler with intermediate heat exchanger for accessing regenerator cooling capacity — •Bernd Schmidt[1,2], Jack-André Schmidt[1,2], Xaver Herrmann[1,2], Jens Falter[1], Dirk Dietzel[1,2], and André Schirmeisen[1,2] — [1]TransMIT GmbH, Center for Cryotechnology and Sensors, Giessen, Germany — [2]Institute of Applied Physics, University of Giessen, Germany

Two-stage PTCs achieve minimum temperatures of 2.2 K and have found their way even into sensitive applications where they compete with conventional LHe-bath cryostats. The 1st stage of a PTC is providing quite large cooling power at higher temperatures, ideal to cool radiation shields and precool peripheral elements. In addition, the cooling capacity of the regenerator is often used for precooling. This raises the question how the cooling capacity of a regenerator can best be harnessed. We present a cryocooler design [1], where an additional heat exchanger was incorporated into the 2nd stage regenerator.

This intermediate cooling stage allows to extract 4-5 W of cooling power at temperatures of 8-9 K for a standard two-stage PTC with a cooling capacity of 1.6 W at 4.2 K. The experimental data shows that applying the additional heating power does not adversely influence the performance of the second stage cold flange. The achieved cooling powers and temperatures are, for instance, ideally suited to cool superconducting wires in current quantum systems.

[1] J. Falter et al., submitted to Cryogenics (preprint: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4814535)

TT 8.7 Mon 16:45 H32

Experimental investigations of a frequency optimized Pulse Tube Cryocooler cooldown — •Jack Schmidt[1,2], Bernd Schmidt[1,2], and Andre Schirmeisen[1,2] — [1]Justus-Liebig-Universität Gießen — [2]TransMIT GmbH

Working in research often requires lower temperatures to achieve material effects such as superconductivity. This is achieved by using cryogenic liquids or closed cycle cryocoolers. Later have sub genres of working principle and provide different positive and negative aspects. We focus on the usage of Gifford-McMahon-type pulse tube cryocoolers which provide temperatures down to 2.2 K with the usage of Helium. The cooling power at 4.2 K scales up to 5 Watts nowadays with an electrical input power of the compressor around 25 kW. [1] As for mechanical stability the cryostats often become bulky and heavy. Including temperature isolation of the cold parts the cooldown times become very large. As the cryocoolers are mostly optimized for ongoing low temperature operation the cooling process lacks adaptations for an ideal cooldown. Other findings on this topic suggest to adjust valves and frequency. [2] Here we present our findings on the cooling process of a cryocooler to reduce cooldown time while adjusting the frequency. We were able to reduce the cooling time of the cryocooler by 9 % , applying electrical heat the cooldown is reduced by 10 %.

[1] X. Hao et al., Development of a 5 W/4.2 K two-stage pulse tube cryocooler. CEC/ICMC, C2Or3A-03 (2023);
[2] R. Snodgrass et al., Nat. Commun. 15, 3386 (2024).

TT 8.8 Mon 17:00 H32

Photoelectron characterization of a Cold field emitter for Ultrafast TEM — •Tim Dauwe[1,2], Nora Bach[1,2], Rudolf Haindl[1,2], Armin Feist[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Germany

Ultrafast transmission electron microscopy (UTEM) combines high spatial resolution with capabilities to image structures in the ultrafast temporal regime. This development was substantially advanced by creating femtosecond photoelectron pulses at modified Schottky tip emitters [1]. Further progress is expected by utilizing cold field emission guns (CFEG), which offer particularly high brightness and a narrower kinetic energy spectrum. In this contribution, we present a characterization of laser-triggered photoemission from a CFEG. We use a recent gun design allowing for laser access to the emitter (see Ref. [2]) and analyze beam characteristics in the linear photoemission regime. The CFEG is shown to support sub-nanometer probes and allows for photoelectron energy widths below 0.3eV. We emphasize the characterization of the spectral shape as a function of gun settings and compare it to theoretical models. Our experiments provide new insights for implementing and understanding photoemission from a CFEG, which will promote UTEM experiments at high resolution.

[1] A. Feist et al., Ultramicroscopy, 176 (2017)
[2] A. Schröder et al., arXiv:2410.23961 (2024)

TT 8.9 Mon 17:15 H32

Erbium dopants as luminescence thermometers in nanophotonic silicon waveguides — •Kilian Sandholzer, Stephan Rinner, Justus Edelmann, and Andreas Reiserer — Technical University of Munich, TUM School of Natural Sciences, and Munich Center for Quantum Science and Technology (MCQST), Garching, Germany

The demand for fast and accurate temperature measurements in nanophotonic silicon devices grows as integrated structures for applications become more complicated and denser in classical and quantum technologies. Established approaches use sensors attached close to the components, which limits spatial resolution and increases the footprint of devices [1]. We propose and implement luminescence-based thermometry using directly integrated erbium emitters within nanophotonic silicon waveguides [2]. Coverage from 2 K to 295 K is achieved using two different effects: The thermal activation of non-radiative decay channels via impurities is used for temperatures above 200 K, and the population dynamics of crystal field and spin levels caused by phononic thermalization at lower temperatures. We achieve relative thermal sensitivities of 0.22(4) %/K at room temperature, increasing to 420(50) %/K at 2 K. Combined with spatially selective implantation, our method promises precise thermometry from ambient to cryogenic temperatures with a few-nanometer resolution.

[1] Y. Ma, B. Dong, and C. Lee, Nano Convergence 7, 12 (2020)
[2] K. Sandholzer et al., arXiv (2024)

TT 8.10 Mon 17:30 H32

Fast, accurate and local temperature control using qubits — •Riya Baruah[1], Pedro Portugal[1], Joachim Wabnig[2], and Christian Flindt[1,3] — [1]Department of Applied Physics, Aalto University, 00076 Aalto, Finland — [2]Nokia Bell Labs, Cambridge, United Kingdom — [3]RIKEN Center for Quantum Computing, Wakoshi, Saitama 351-0198, Japan

Many quantum technologies operate in the subkelvin regime. It is therefore desirable to develop practical tools and methods for the precise control of the temperature in nanoscale quantum systems. Here, we present a proposal for fast, accurate, and local temperature control using qubits, which regulate the flow of heat between a quantum system and its thermal environment [1,2]. The qubits are kept in a thermal state with a temperature that is controlled in an interplay between work done on the qubits by changing their energy splittings and the flow of heat between the qubits and the environment. Using only a few qubits, it is possible to control the thermal environment of another quantum system, which can be heated or cooled by the qubits. As an example, we show how a quantum system at subkelvin temperatures can be significantly and accurately cooled on a nanosecond timescale.

[1] P.Portugal, F.Brange, C.Flindt, Phys. Rev. Res. 4, 043112 (2022).
[2] R.Baruah, P.Portugal, J.Wabnig, C.Flindt, arXiv:2410.04796 (2024).