TT 14: Superconductivity: Properties and Electronic Structure

Time: Monday 15:00–18:15 Location: HSZ/0103

TT 14.1 Mon 15:00 HSZ/0103

Tuning the superconducting dome in granular aluminum thin films — Aniruddha Deshpande, Jan Pusskeiler, Christian Prange, Uwe Rogge, Martin Dressel, and •Marc Scheffler — 1. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

The peculiar superconducting properties of granular aluminum, which consists of nanometer-sized aluminum grains separated by aluminum oxide, are attractive for applications in quantum circuitry, and they are interesting from a fundamental materials physics view. The phase diagram of granular aluminum as a function of normal-state resistivity features a superconducting dome with a maximum critical temperature T_c well above the $T_c = 1.2$ K of pure aluminum. We show how the maximum of this superconducting dome grows if the substrate temperature during deposition is lowered from 300 K to cooling with liquid nitrogen (150 and 100 K) and liquid helium (25 K). The highest T_c that we observe is 3.27 K [1]. These results highlight that granular aluminum is a model system for complex phase diagrams of superconductors and demonstrate its potential in the context of high kinetic inductance applications, where materials properties can be carefully tuned by optimized thin-film growth [2]. This is augmented by our observation of comparably sharp superconducting transitions of high-resistivity samples grown at cryogenic temperatures and by a thickness dependence even for films substantially thicker than the grain size [1].

[1] A. Deshpande *et al.*, J. Appl. Phys. **137** (2025) 013902
[2] A. Deshpande *et al.*, Physica C **634** (2025) 1354709

TT 14.2 Mon 15:15 HSZ/0103

Two facets of kinetic inductance in Corbino reflectometry on disordered and granular superconductors — •Jan Pusskeiler[1], Martin Dressel[1], Thomas Valentin[2], Ameya Nambisan[2], Simon Geisert[2], Ioan Pop[1,2], Christoph Strunk[3], Dennis Rieger[4], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Physikalisches Institut and IQMT, KIT — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [4]Qinu GmbH, Karlsruhe

Kinetic inductance L_{kin} manifests as a linear-in-frequency contribution to the reactance, which determines the low-temperature electrodynamics of superconducting microwave circuitry. We directly probe this inductive response from MHz- to GHz-frequencies, $\mathrm{Im}(Z) = \omega \cdot L_{\mathrm{kin}}$, by broadband microwave reflectometry on superconducting granular aluminum and titanium nitride in the Corbino geometry. Furthermore, we identify an unconventional collective mode with a phase velocity governed by L_{kin}. We observe an acoustic dispersion relation for up to 10 harmonics, which enables us to obtain the kinetic inductance independently for both phenomena observed in one spectrum.

We report low-temperature kinetic inductances ranging from 20 pH/□ to 2 nH/□ for granular aluminum and up to 6.2 nH/□ for titanium nitride thin films, with critical temperatures T_c ranging from 1 K to 3 K. We calculate the low-temperature superfluid stiffness J_0 and observe its suppression with increased normal-state resistivity ρ_n. For both materials in regimes with large ρ_n, we find that J_0 converges to T_c, consistent with a phase-driven superconducting transition.

TT 14.3 Mon 15:30 HSZ/0103

Strange metals studied by EELS and RIXS — •Jörg Fink — IFW-Dresden, Dresden, Germany

Strange metal behavior, which occurs above the dome of unconventional superconductivity is characterized by a linear temperature dependence of the resistivity. This signals a breakdown of the quasiparticle concept used in normal Fermi liquids. In the phenomenological marginal Fermi liquid (MFL) theory the behavior is related to a continuum of low-energy electronic excitations. Holographic theories have predicted that this continuum causes an overdamping of plasmon excitations. On the other hand, our EELS and RIXS experiments reveal well pronounced optical and acoustic plasmons in cuprates and ruthenates. The contradiction can be explained by an energy-dependent effective mass related to a strong coupling of the charge carriers to an oscillator at about 0.4 eV also detected in ARPES experiments. Moreover, this energy is used as a cutoff energy in the MFL theory. The oscillator energy is well below the plasmon energies which leads to resilient quasiparticles at high energy. Possibly, the oscillator is related to a coupling of the charge carriers to spin fluctuations.

TT 14.4 Mon 15:45 HSZ/0103

ARPES and RIXS combined in the recently designed "TOF-PAX-RIXS" spectrometer — •Chafic Fawaz[1], Tom Lacmann[1], Olena Tkach[2], Sergii Chernov[3], Luis Filsinger[1], Yaryna Lytvynenko[2], Jan Schunck[4], Olena Fedchenko[2], Siegmar Roth[1], Harshit Agarwal[2], Markus Scholz[3], Jayjit Dey[3], Kai Rossnagel[5], Martin Beye[4], Mortiz Hoesch[3], Gerd Schönhense[2], Hans-Joachim Elmers[2], and Matthieu Le Tacon[1] — [1]Karlsruher Institut für Technologie (KIT), Germany — [2]Johannes Gutenberg Universität Mainz, Germany — [3]Deutsches Elektronen-Synchrotron DESY, Germany — [4]Stockholm University, Sweden — [5]Christian-Albrechts-Universität zu Kiel (CAU), Germany

The TOFPAXRIXS instrument, recently commissioned on the P04 beamline at DESY, offers a compact design that uniquely combines Angle-Resolved Photoemission Spectroscopy (ARPES) with a Time-of-Flight (ToF) detector and Resonant Inelastic X-ray Scattering (RIXS) using the Photoelectron spectrometry for Analysis of X-rays (PAX) approach [1]. This enables direct correlation between electronic properties measured by ARPES and collective excitations probed by RIXS, an essential step toward understanding electronic order in quantum materials, including unconventional superconductors, antiferromagnets, and van der Waals heterostructures.

In this talk, I will briefly introduce the ToF-PAX-RIXS concept and show first results combining ARPES and RIXS on the same sample.

[1] G. L. Dakovski et al., J Synchrotron Rad. 24 (2017) 1180

TT 14.5 Mon 16:00 HSZ/0103

On-site two-hole Coulomb energy in CuO and La_2CuO_4 from coincidence electron spectroscopy — •Danilo Kühn[1], Swarnshikha Sinha[1,2], Fredrik O. L. Johansson[3], Katarzyna Siewirska[1], Antonello Tebano[4], Nils Mårtensson[3], Andreas Lindblad[3], Daniele Di Castro[4], and Alexander Föhlisch[1,2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany — [2]Universität Potsdam, Potsdam, Germany — [3]Uppsala University, Uppsala, Sweden — [4]Universitá di Roma Tor Vergata, Roma, Italy

The high temperature superconductivity in layered cuprates is likely driven by strong electron correlations, though not fully understood. Here, Auger photoelectron coincidence spectroscopy (APECS) data of undoped La_2CuO_4 and CuO from the COESCA station at the BESSY II storage ring will be shown [1]. O 1s/ KVV and Cu 2p/ LVV coincidence measurements allow to disentangle the various structures in the Auger spectra and give detailed information of site specific multi-hole valence states. The Auger spectra are analysed with Cini-Sawatzky and atomic multiplet models, in order to extract electronic parameters such as on-site Coulomb energy in O 2p and Cu 3d orbitals. Dynamics of the core excited states and delocalization of the multi-hole states are investigated. Our unique setup with ARTOF 2 time-of-flight spectrometers in combination with the tailored photon-pulse structure of a soft x-ray undulator beam line enables APECS with unprecedented information rate.

[1] D. Kühn et al., Nat. Commun. 16, 9748 (2025)

TT 14.6 Mon 16:15 HSZ/0103

Signatures of the Fermi surface reconstruction of a doped Mott insulator in a slab geometry — •Gregorio Staffieri and Michele Fabrizio — International School for Advanced Studies (SISSA), Via Bonomea 265, I-34136 Trieste, Italy

In the underdoped regime of high-T_c superconductors, the Fermi surface consists of small pockets coexisting with a pseudogap at the antinodal points, while in the overdoped regime it becomes large and electron-like. Evidence for this doping-driven reconstruction has been found in the two-dimensional single-band Hubbard model using various numerical methods.

We study the reconstruction of the Fermi surface in a hole-doped Mott insulator with slab geometry using the Dynamical Cluster Approximation (DCA). We show that enhanced correlations at the surface lead to a strong layer dependence of the Fermi surface: hole-like pockets appear in the superficial layers and gradually evolve into a single electron-like surface in the innermost layers. We also investigate Friedel oscillations induced by the surface as a function of hole doping and identify clear signatures of the reconstruction in their periodicity. In addition, we introduce a computationally tractable quantity that diagnoses the same variation through a concurrent breakdown of Luttinger's theorem. Together, these observables provide reliable indicators of Fermi surface topology without requiring momentum-space periodization.

15 min. break

TT 14.7 Mon 16:45 HSZ/0103

How to activate and detect the Higgs mode in superconductors — •Dirk Manske — Max Planck Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

Higgs Spectroscopy is a new and emergent field [1-3] that allows to classify and determine the superconducting order parameter by means of ultra-fast optical spectroscopy. There are two established ways to activate the Higgs mode in superconductors, namely a single-cycle *quench* or an adiabatic, multicycle *drive* pulse. In the talk I will review and report on the latest progress on Higgs spectroscopy, in particular on the role of the third-harmonic-generation (THG) [4-6,9] and the possible IR-activation of the Higgs mode by impurities or external dc current [7,8]. Finally, I discuss recent results on Non-Equilibrium Anti-Stokes Raman Scattering (NEARS) [10,11], where the Higgs mode, for the first time, has been observed directly.

[1] L. Schwarz, D. Manske et al., Nat. Commun. 2020
[2] L. Schwarz and D. Manske, Phys. Rev. B 2020
[3] H. Chu, S. Kaiser, D. Manske et al., Nat. Commun. 2020
[4] L. Schwarz, R. Haenel, and D. Manske, Phys. Rev. B 2021
[5] H. Chu, S. Kaiser, D. Manske et al., Nature Commun. 2023
[6] M.-J. Kim, S. Kaiser, D. Manske et al., Sci. Adv. 2024
[7] M. Puviani, L. Schwarz, X.-X. Zhang, S. Kaiser, and D. Manske, Phys. Rev. B 2020
[8] R. Haenel, P. Froese, D. Manske, and L. Schwarz, Phys. Rev. B 104, 2021
[9] L.Schwarz, B. Fauseweh, and D. Manske, Phys. Rev. B 2020
[10] T. Glier, D. Manske et al., Nature Comm. 2025
[11] M. Puviani, R. Haenel, and D. Manske, Phys. Rev. 2023

TT 14.8 Mon 17:00 HSZ/0103

Probing Charge Density Wave in Superconductors via Phase-resolved Higgs Spectroscopy — •Liwen Feng[1], Igor Ilyakov[2], Jan-Christoph Deinert[2], Hao Chu[3], and Stefan Kaiser[1] — [1]TUD Dresden University of Technology, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Shanghai Jiao Tong University, China

Superconductivity (SC) and charge density wave (CDW) orders often coexist in high-Tc superconductors, and their interplay is essential for understanding these correlated systems. Using high-field terahertz radiation, we coherently drive collective modes and investigate third-harmonic generation (THG) in superconductors exhibiting both CDW amplitude fluctuations and Higgs oscillations. In 2H-$NbSe_2$ and hole-doped $La_{2-x}Sr_xCuO_4$, we identify a clear Fano interference between CDW fluctuations and Higgs oscillations [1, 2]. In contrast, electron-doped $La_{2-x}Ce_xCuO_4$ shows distinct coupling behavior, revealing not only a weak Higgs-CDW interaction but also signatures of an intrinsic, field-depinned CDW [3]. These results establish THz phase-resolved Higgs spectroscopy as a powerful method for probing CDW dynamics and intertwined orders in superconductors.

[1] H. Chu et al., Nat Commun. 14 (2023) 1343
[2] L. Feng et al., Phys Rev B 108 (2023) L100504
[3] L. Feng et al., arXiv:2504.11947 (2025)

TT 14.9 Mon 17:15 HSZ/0103

Probing the intermediate state of the type-I topological superconductor SnAs using Muon Spin Spectroscopy — •Shashank Srivastava[1], Omkar Kulkarni[1], Arushi Arushi[1], Deepak Singh[2], Adrian D. Hillier[2], and Ravi Prakash Singh[1] — [1]Indian Institute of Science Education and Research, Bhopal 462066, India — [2]ISIS Facility, STFC Rutherford Appleton Laboratory, Didcot OX11 0QX, United Kingdom

The possibility of topological superconductivity in a type-I superconductor embraces exotic physics. The topological semimetal SnAs shows superconductivity below 3.6 K, but there is ambiguity in the nature of superconductivity. Some reports claim type-I superconductivity in SnAs, but recent studies contradict it. We have resolved this enigma using a thorough microscopic analysis of the superconducting ground state.

In this work, we report the muon spin rotation/relaxation (μSR) study of the possible topological superconductor SnAs. The zero-field (ZF) μSR data reveal that this system is a time-reversal-invariant superconductor. The systematic transverse field (TF) μSR measurements unveil the type-I superconductivity and the intermediate state using the superconducting phase diagram for SnAs. Moreover, ab initio calculations of band structure and phonons were performed, which correlate with the basic experimental characterization. Our study opens a platform for understanding the underlying physics behind the origin of topological superconductivity in type-I superconductors.

TT 14.10 Mon 17:30 HSZ/0103

Layer-selective Cooper pairing in an alternately stacked transition metal dichalcogenide — Haojie Guo[1], •Sandra Sajan[1], Irián Sánchez-Ramírez[1], Tarushi Agarwal[2], Alejandro Blanco Peces[1], Chandan Patra[2], Maia G. Vergniory[1], Rafael M. Fernandes[3], Ravi Prakash Singh[2], Fernando de Juan[1], Maria N. Gastiasoro[1], and Miguel M. Ugeda[1] — [1]Donostia International Physics Center, Paseo Manuel de Lardizábal 4, 20018 San Sebastián, Spain — [2]Department of Physics, Indian Institute of Science Education and Research Bhopal, 462066 Bhopal, India — [3]Department of Physics, The Grainger College of Engineering, University of Illinois Urbana-Champaign, Urbana, Illinois 61801, USA

Multigap superconductivity occurs when different superconducting gaps form on separate Fermi surfaces. In the layered material 4Hb-TaSSe, made of alternating trigonal (H) and octahedral (T) polymorph layers, we demonstrate the presence of two weakly coupled and spatially separated superconducting condensates. Using quasiparticle tunneling and Andreev reflection spectroscopy on each polymorph layer, we identify two gaps that differ in magnitude and internal structure. Their responses to temperature and magnetic field also differ: each gap opens at a distinct temperature and shows opposite resilience to magnetic fields, enabling selective external tuning of each condensate. A theoretical model supported by ab-initio calculations reproduces these features and accounts for the unusually high critical field in the T-layer, highlighting TMD polymorphs as tunable multigap superconductors.

TT 14.11 Mon 17:45 HSZ/0103

Probing hidden vortices and geometrical effect via surface-projected quasiparticle states — •Ruijun Xi and Hao Zheng — Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China

Vortices host quasiparticle excitations such as Caroli-de Gennes-Matricon (CdGM) or Majorana states. Understanding how these states are modulated by various geometrical structures is essential for both fundamental superconductivity research and quantum device design. Yet, this relationship remains challenging to elucidate. Here, using a scanning tunneling microscope equipped with a dilution refrigerator, we clearly resolve coherent quasiparticle states from lateral vortices buried beneath the surface of $NbSe_2$ under in-plane magnetic fields. Our combined spectroscopic visualization and model calculation uncover a depth-dependent quantum coupling behavior between vortices and the superconductor surface: shallow vortices (depth of $\sim$ 1.5 coherence lengths) exhibit anomalous split quasiparticle states accompanied by a pseudogap, while deeper vortices ($>$ 4 coherence lengths) restore the conventional CdGM characteristics. Our findings establish a rescaling law of vortex bound states under geometrical effect and identify a critical length scale relevant for superconducting devices aimed to utilize intrinsic vortex quasiparticles.

TT 14.12 Mon 18:00 HSZ/0103

Crystal Structure Effects on Vortex Dynamics in Superconducting MgB_2 Films — •Clemens Schmid[1], Corentin Pfaff[2], Theo Courtois[2], Anton Pokusinskyi[3], Alexander Kasatkin[4], Karine Dumesnil[2], Stephane Mangin[2], Thomas Hauet[2], and Oleksandr Dobrovolskiy[3] — [1]Faculty of Physics and Vienna Doctoral School in Physics, University of Vienna, Austria — [2]Institute Jean Lamour, Université de Lorraine-CNRS, Vandoeuvre-lès-Nancy, France — [3]Cryogenic Quantum Electronics, EMG and LENA, Technische Universität Braunschweig, Germany — [4]G. V. Kurdyumov Institute for Metal Physics, NAS Ukraine, Kyiv, Ukraine

MgB_2 offers one of the highest critical temperatures among non-cuprate superconductors. However, its dynamic phase diagram at high vortex velocities remains unexplored, and the film structure and interface quality are expected to affect the current-driven resistive transition. Here, we investigate two different structures incorporating MgB_2 thin films sputtered on sapphire (Al_2O_3) substrates. The difference between the films is in the inclusion of an additional MgO layer between the substrate and MgB_2, resulting in a single crystal structure, as opposed to an MgO-free textured one. We find that the activation energy for vortex motion is a factor of two higher for the single-crystal film. Current-voltage measurements reveal multiple jumps, suggesting that the transition to the normal state is driven by the formation of normal domains. Additionally, a lower instability current in the textured film suggests less efficient heat removal, which agrees with the results of an HRTEM inspection of the film-substrate interface.