TT 68: Superconductivity: Properties and Electronic Structure

Time: Thursday 9:30–13:15 Location: H 3010

TT 68.1 Thu 9:30 H 3010

Annealing $Tl_2Ba_2CuO_{6+\delta}$ - a step towards the origin of cuprate superconductivity — •Ayanesh Maiti[1,2,3], Seunghyun Khim[1], Carsten Putzke[2], Philip Moll[2], and Andrew Mackenzie[1,3] — [1]MPI for Chemical Physics of Solids, Dresden, Germany — [2]MPI for Structure and Dynamics of Matter, Hamburg, Germany — [3]University of St Andrews, St Andrews, Scotland

Cuprate superconductors have attracted a lot of attention due to their high T_c's that can reach up to 130 K in ambient pressure. However, the physics underlying their properties has remained obscured by (i) multitudes of complex orders that appear near the superconducting phase, and (ii) the inseparable effects of the disorder that is introduced as they are doped.

Decades of past research have identified one promising candidate, $Tl_2Ba_2CuO_{6+\delta}$, that can be used to explore the superconductivity in the (seemingly) less complicated overdoped region of the cuprate phase diagram, using samples with minimal disorder.

We have grown high-quality single crystals of $Tl_2Ba_2CuO_{6+\delta}$ with negligible orthorhombicity (<0.1%), and can be annealed reversibly across a very wide doping range (p = 0.05-0.29). This indicates that our samples are close to having perfect cation stoichiometry and no substitutional defects - solving a major issue which was faced by the previous efforts. This puts us in a position to map out the full phase diagram of clean cuprates, and thus take the crucial first step towards resolving the origin of their high T_c superconducting order.

TT 68.2 Thu 9:45 H 3010

Tracing the Higgs-CDW interplay in coherently-driven superconductors — •Liwen Feng[1,3], Tim Priessnitz[1], Jan-Christoph Deinert[4], Sergey Kovalev[4], Stefan Kaiser[1,3], and Hao Chu[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Shanghai Jiaotong University, China — [3]Technical University Dresden, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Germany

Superconductivity (SC) and charge-density-wave (CDW) often coexist in the low temperature phase diagrams of various materials, particularly high-Tc superconductors. Exploring the interplay between SC and CDW has become crucial in understanding the physics of these complex systems. We have established Higgs Spectroscopy using phase-resolved THz-Third Harmonic Generation to study the order parameter dynamics in superconductors [1]. Our investigations of the dynamics between THz-driven CDW and Higgs amplitude modes throughout several families of superconductors ranging from 2H-$NbSe_2$, hole- and electron-doped cuprates $La_{2-x}Sr_xCuO_4$ ($x \sim 0.12$) and $La_{2-x}Ce_xCuO_4$ ($x \sim 0.1$), to bismuthate superconductors BaRbBiO. We describe the interplay of Higgs and the CDW mode in the framework of a generalized Fano model. Going beyond the amplitude and phase response [2], the time-domain reveals a dynamical interplay of a Higgs-CDW hybrid in the THz driven state [3].

[1] H. Chu et al., Nat. Commun. 11 (2020) 1793.
[2] H. Chu, et al., Nat Commun. 14 (2023) 1343.
[3] L. Feng et al., Phys. Rev. B, 108 (2023) L100504.

TT 68.3 Thu 10:00 H 3010

Tracing the dynamics of superconducting order via transient terahertz third harmonic generation — •Min-Jae Kim[1,2,3], Sergey Kovalev[4], Mattia Udina[5], Gideok Kim[2], Matteo Puviani[2], Thales de Olivera[4], Jan-Christoph Deinert[4], Dirk Manske[2], Lara Benfatto[5], and Stefan Kaiser[1,2,3] — [1]Institute of Solid State and Materials Physics, Technical University Dresden, Dresden, 01062, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, 70569, Germany — [3]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart, 70569, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, 01328, Germany — [5]Department of Physics and ISC-CNR, Sapienza University of Rome, Rome, 00185, Italy

Nonlinear THz third harmonic generation (THG) was shown to directly probe internal degrees of freedoms of the superconducting condensate and its exposure to external collective modes in the framework of driven Higgs modes. Here we extend this idea to light-driven nonequilibrium states in superconducting $La_{2-x}Sr_xCuO_4$ establishing a transient Higgs spectroscopy [1]. We perform an optical pump-THz-THG drive experiment and using 2D-spectroscopy we disentangle the driven TH response into the excited quasiparticles and condensates response. As such the light induced changes of the THG signals probe the ultrafast pair breaking dynamics and transient pairing amplitude of the condensate.

[1] Kim et. al., arXiv:2303.03288

TT 68.4 Thu 10:15 H 3010

Unusual Low-Energy Collective Charge Excitations in High-Tc Cuprate Superconductors — Vyacheslav Silkin[1], Stefan-Ludwig Drechsler[2], and •Dmitri Efremov[2] — [1]Donostia International Physics Center (DIPC), 20018 San Sebastiian/Donostia, Basque Country, Spain Departamento de Polimeros y Materiales Avanzados: Fisica, Quimica y Tecnologia, Facultad de Ciencias Quimicas, Universidad del Pais Vasco UPV/EHU, 20080 San Sebastiian/Donostia, Basque Country, Spain and IKERBASQUE, Basque Foundation for Science, 48013 Bilbao, Basque Country, Spain — [2]Leibniz Institute for Solid State and Materials Research IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

Here, we present our study investigating the low-energy charge excitations in the normal state of HTSC cuprates. Our findings demonstrate that the unique characteristics of the electronic band structure at low energies significantly influence the nature of the intraband collective modes. This effect leads to the emergence of a novel type of mode with exceptionally high intensity. The study presents a non-Lorentzian spectral function, incorporated with popular collective excitations such as conventional plasmons and spin fluctuation. The nodal and antinodal directions reveal the presence of two distinct modes exhibiting maximal spectral weight. Moreover, an antinodal direction presents the intensity of a quasi-one-dimensional plasmon, which gradually transforms into a prolonged, soft mode over an extensive momentum range.

TT 68.5 Thu 10:30 H 3010

Possible unconventional vortex lattice in LiFeAs single crystals by μSR — •G. Lamura[1], T. Shiroka[2,3], T. Winyard[4], M. Speight[5], J. Quintanilla[6], P. Gentile[7], F. Anger[8], and S. Wurmehl[8] — [1]Cnr-Spin, Genova, IT — [2]ETH, Zurich, CH — [3]Paul Scherrer Institut, CH — [4]University of Edinburgh, UK — [5]University of Leeds, UK — [6]University of Kent, Canterbury, UK — [7]Cnr-Spin, Salerno, IT — [8]IFW, Dresden, DE

Muon spectroscopy (μSR) is able to study the vortex lattice (VL) of type II superconductors: positive muons implanted in interstitial sites probe different magnetic local fields B_{loc} depending on the relative position of Abrikosov vortices: the Fourier Transform of the measured time-dependent asymmetry $FT\{A(t)\} \propto n(B_{loc})$, the local field distribution. A skyrmion-vortex chains model was recently proposed to distinguish nematic superconductors [1]. It consists of stripes of skyrmions (spatially separated half-quantum vortices) parameterized by the separation between the chains and the inter-skyrmion separation along the same chain: the resulting $n(B_{loc})$ presents a double-peak instead of the one-peak structure of the usual Abrikosov VL. Here we show our experimental results by μSR on a high-purity LiFeAs single crystal (T_c=17K) [2]. We likely found the evidence of such an unconventional mixed state: $FT\{A(t)\}$ data at 2 K shows a small splitting of the main superconducting peak up to 7 K. This could confirm the nematicity of superconductivity in LiFeAs, in agreement with previous ARPES results [3].

[1] Phys. Rev. Lett. 130 (2023) 226002.
[2] J. Cryst. Growth 627 (2024) 127473.
[3] Phys. Rev. B 102 (2020) 184502.

TT 68.6 Thu 10:45 H 3010

What scanning tunneling spectra on superconductors can tell us about the spectral density of the pairing boson — •Thomas Gozlinski[1,2], Mirjam Henn[1], Thomas Wolf[1], Matthieu LeTacon[1], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology (KIT) — [2]Ludwig-Maximilians-Universität München (LMU)

A detailed interpretation of scanning tunneling spectra obtained on superconductors enables one to gain information on the pairing boson. Decisive for this approach are inelastic tunneling events. Due to the lack of momentum conservation in tunneling from or to the sharp tip, those are enhanced in the geometry of a scanning tunneling microscope compared to planar tunnel junctions. We will introduce the theoretical framework [1] and discuss the reliability and limitations of our method by taking the examples of real scanning tunneling spectra obtained on conventional [2] and unconventional [3,4] superconductors. Especially for the d-wave cuprate superconductors [4] we propose how the boson excitation spectrum can be compared to and complement glue functions determined from optical spectroscopy or ARPES.

[1] P. Hlobil et al., Phys. Rev. Lett. **118** (2017) 167001.
[2] M. Schackert et al., Phys. Rev. Lett. **114** (2015) 047002.
[3] J. Jandke et al., Phys. Rev. B **100** (2019) 020503(R).
[4] T. Gozlinski et al., arXiv:2306.03890 (2023)

TT 68.7 Thu 11:00 H 3010

Tunneling spectroscopy on hybrid superconductor-ferromagnet bilayers made of non-centrosymmetric NbRe and Co — •Marcel Strohmeier[1], Carla Cirillo[2], Carmine Attanasio[3], Angelo Di Bernardo[1,3], and Elke Scheer[1] — [1]Universität Konstanz, Fachbereich Physik, 78464 Konstanz, Germany — [2]CNR-SPIN, c/o Università degli Studi di Salerno, 84084 Fisciano (Sa), Italy — [3]Dipartimento di Fisica 'E.R. Caianiello', Università degli Studi di Salerno, 84084 Fisciano (Sa), Italy

In recent years non-centrosymmetric superconductors have attracted increasing attention as they reveal various properties of unconventional superconductivity. With the absence of inversion symmetry and an asymmetric Rashba-like spin-orbit coupling a mixed spin-singlet and spin-triplet pairing state is predicted for these materials. In our talk we focus on polycrystalline non-centrosymmetric $Nb_{0.18}Re_{0.82}$. Studies on the upper critical field of thin-film micrometric strips have shown that the Pauli-contribution might play a minor role in terms of the underlying pair breaking mechanism. In addition, FMR measurements on NbRe/Co/NbRe trilayers suggest that the observed Gilbert damping can be explained by assuming a spin-pumping scenario across a spin-triplet S-F-S interface. However, the SC order parameter of NbRe is still under debate. We present first low-temperature scanning tunneling spectroscopy measurements on pure NbRe as well as NbRe/Co bilayers fabricated by magnetron sputtering. With a high spatial and energy resolution we probe the LDOS for different film thicknesses to get insights into the intrinsic pairing symmetry of the superconductor.

15 min. break

TT 68.8 Thu 11:30 H 3010

Control of the superconducting pairing in the van der Waals superconductor $NbSe_2$ via magnetic intercalation — •Mohammad Hemmati[1,2], Stefan Blügel[1,2], and Philipp Rüssmann[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

We investigate the superconducting properties of $NbSe_2$ using first-principles calculations within the Korringa-Kohn-Rostoker Green function method, accompanied by a description of superconductivity via the Bogoliubov-de Gennes formalism [1]. The Coherent Potential Approximation (CPA) is employed to address the effects of magnetic transition-metal impurities on the electronic structure [2]. Adding low concentrations of randomly placed magnetic atoms inside the van der Waals gap of superconducting $NbSe_2$ influences the superconducting order parameter before suppressing the superconductivity at larger impurity concentrations. This allows us to control the superconducting pairing and engineer the triplet order parameter in $NbSe_2$ with varying concentration and chemical composition of magnetic the impurities.

— This work was supported by the ML4Q Cluster of Excellence (EXC 2004/1 * 390534769).

[1] P. Rüßmann and S. Blügel, Phys. Rev. B **105** (2022) 125143.
[2] P. Rüßmann, D. Silva, M. Hemmati *et al.*, Spintronics XVI (2023) 12656.

TT 68.9 Thu 11:45 H 3010

Engineering interband coupling of a two-band superconductor by topological defects — •Qili Li[1], Thomas Gozlinski[1], Ryohei Nemoto[2], Toyo Kazu Yamada[2], Jörg Schmalian[1], and Wulf Wulfhekel[1] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Chiba University, Chiba, Japan

Two-band or multiband superconductors like MgB2, Fe-based superconductors, NbSe2 and Pb [1,2] are in great interest. Fantastic properties are predicted owing to interband coupling in multiband superconductors, such as solitons, vortices with fractional flux, non-Abrikosov vortices, topological knot and odd-frequency pairing. Here, we investigate interband coupling in the two-band superconductor Pb by scanning tunnelling microscopy at 45 mK. We find that the interband coupling is significantly changed by topological defects, i.e., stacking fault tetrahedrons widely existing in face centered cubic crystals. Intra- and interband coupling are directly spatially resolved by fitting our experimental results self-consistently with Schopohl-Scharnberg-McMillan (SSM) model [3,4]. Our findings pave the way to explore the predicted properties in multiband superconductors.

[1] Phys. Rev. Lett. 114 (2015) 157001.
[2] Sci. Adv. 9, eadh9163 (2023).
[3] Phys. Rev. 175 (1968) 537.
[4] Solid State Commun. 22 (1977) 37 1-374.

TT 68.10 Thu 12:00 H 3010

Visualizing delocalized quasiparticles in the vortex state of $NbSe_2$ — •Jian-Feng Ge[1,2], Koen Bastiaans[3], Jiasen Niu[2], Tjerk Benschop[2], Maialen Larrazabal[4], and Milan Allan[2] — [1]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Str. 40, 01187 Dresden, Germany — [2]Leiden Institute of Physics, Leiden University, 2333 CA Leiden, The Netherlands — [3]Department of Quantum Nanoscience, Kavli Institute of Nanoscience, Delft University of Technology, 2628 CJ Delft, The Netherlands — [4]Debye Institute for Nanomaterials Science, Utrecht University, 3508 TA Utrecht, The Netherlands

Bogoliubov quasiparticles play a crucial role in understanding the behavior of a superconductor at the nanoscale, particularly in a vortex lattice where they are thought to be confined to the vortex cores. Here, we use scanning tunneling noise microscopy, which can locally quantify quasiparticles by measuring the effective charge, to observe and image delocalized quasiparticles around vortices in $NbSe_2$ for the first time. Our data reveals a strong spatial variation of the quasiparticle concentration when tunneling into the vortex state. We find that quasiparticle poisoning dominates when vortices are less than four times the coherence length apart. Our results set a new length scale for quasiparticle poisoning in vortex-based Majorana qubits and yield information on the effect of vortices in quantum circuits. Finally, we can describe our findings within the Ginzburg-Landau framework, but the microscopic origin of the far-extending quasiparticles is yet to be understood.

TT 68.11 Thu 12:15 H 3010

Multi-Knob tuning of electron-phonon interactions in TMDCs — •Michael Winter, Dominik Benner, and Tim Wehling — I. Institute of Theoretical Physics, University Hamburg, Hamburg

Transition metal dichalcogenides (TMDs or TMDCs) are gaining significant interest due to their layered nature and the observation of exotic quantum phases, e.g., superconductivity and Mott physics, as well as the prediction of multi-knob tunability of these phases.

In this project, we work towards the general understanding of TMD-[hetero]bilayers from quantum-lattice models. We carry out large scale and wide parameter range ab initio calculations including plane wave density functional theory, density functional perturbation theory, and subsequent electron-phonon interaction calculations. The resulting model can incorporate effects of external electric field, pressure and there-like. With a special focus, we report on results obtained for a heterobilayer of molybdenum disulfide and tungsten diselenide.

TT 68.12 Thu 12:30 H 3010

Gate controlled switching in non-centrosymmetric superconducting devices - Comparison of fabrication methods — •Jennifer Koch[1], Leon Ruf[1], Elke Scheer[1], and Angelo Di Bernardo[1,2] — [1]Universität Konstanz, Konstanz, Germany — [2]Università degli Studi di Salerno, Fisciano (SA), Italy

Gate-controlled supercurrent (GCS) devices have become of great interest as the superconducting equivalent to complementary metal-oxide-semiconductor (CMOS) logic. The idea behind this technology stems from the recent discovery that superconducting devices can be controlled electrically with the application of a gate voltage [1-3]. We investigate gate-controlled switching devices made of the non-centrosymmetric superconductor $Nb_{0.18}Re_{0.82}$ and compare how the fabrication process influences the physical properties. We examine the differences between devices fabricated with the top-down (dry-etching) and bottom-up (lift-off) approaches, as well as how the usage of different gases in the dry-etching step affects the GCS.

[1] G. De Simoni et al., Nat. Nanotechnol. 13 (2018) 802.
[2] F. Paolucci et al., Nano Lett. 18 (2018) 4195.
[3] F. Paolucci et al., Phys. Rev. Applied 11 (2019) 024061.

TT 68.13 Thu 12:45 H 3010

Curvilinear superconducting vortices in three-dimensional nano architecture — •Elina Zhakina[1], Luke Turnbull[1], Weijie Xu[1], Markus König[1], Paul Simon[1], Wilder Carrillo-Cabrera[1], Amalio Fernandez-Pacheco[2], Dieter Suess[3], Claas Abert[3], Vladimir M. Fomin[4,5], and Claire Donnelly[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany — [2]Institute of Applied Physics, TU Wien, Vienna, Austria — [3]University of Vienna, Vienna, Austria — [4]Leibniz IFW Dresden, Dresden, Germany — [5]Moldova State University, Republic of Moldova

When one patterns superconductors into three dimensional, curvilinear nanoarchitectures, intriguing phenomena in the superconductivity, and behaviour of superconducting vortices, arise due to both geometric- and topology-induced effects. In this context, we present an innovative approach to creating superconducting 3D nanoarchitectures through focused electron-beam-induced deposition of tungsten. This method empowers the realization of 3D superconducting nanostructures featuring a critical temperature near 5 K. Our experimental work proves the existence and propagation of superconducting vortices within these 3D superconducting nanostructures. We also uncover the profound geometrical effects inherent to 3D nanoarchitectures, such as the angular dependence of the upper-critical magnetic field, which one can harness to design the local superconducting state of the system. The introduction of this technique opens up new horizons for experimental investigations into the dynamics of vortices within the superconducting order parameter in curved 3D nanoarchitectures.

TT 68.14 Thu 13:00 H 3010

Cousin of Fe-based Superconductors $SrNi_2P_2$: electronic structure, superelasticity and elastocaloric cooling — •Adrian Valadkhani[1], Seok-Woo Lee[2], Paul C. Canfield[3], and Roser Valentí[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]University of Connecticut, Connecticut, USA — [3]Iowa State University, Ames, USA

$SrNi_2P_2$ is a $ThCr_2Si_2$-structured intermetallic compound that undergoes various volume collapse transitions under strain. Recently a high recoverable compressive strain rate of 14% [1] was measured for this system. Typical values for such strain rates are less than one percent, which are limited by premature plastic deformation or fracture. This recoverable strain rate also takes place for tensile strain with a maximum of about 5%. For $SrNi_2P_2$, a double lattice collapse was proposed as the underlying mechanism. This double lattice collapse comes along with a unique elastocaloric double cooling and heating effect, which contrasts strongly to the one of conventional materials with alternating cooling and heating [2]. In this talk we present ab initio density functional theory (DFT) calculations of the electronic structure of this material under various strain conditions and discuss the microscopic origin of the various collapsed phases observed experimentally, superelasticity and the possibility of employing this class of materials as prototypes for elastocaloric cooling at low temperatures.

[1] S. Xiao et al., Nano Lett. 2021, 21, 19, 7913
[2] S. Xiao, A. Valadkhani, S. Rommel, P. C. Canfield, M. Aindow, R. Valentí, S.-W. Lee, just submitted