TT 5: Superconductivity: Properties and Electronic Structure I

Time: Monday 9:30–13:00 Location: H36

TT 5.1 Mon 9:30 H36

Superconducting properties of $[(\mathrm{SnSe})_{1+\delta}]_m[\mathrm{NbSe}_2]$ superlattices with varying NbSe_2 interlayer spacing — •Linus P. Grote[1], Wieland G. Stoffel[1], Tom Herter-Lehmann[1], Willi Vallant[1], Alina Dietrich[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 layered superconductors understanding and controlling the coupling of superconducting layers is crucial due to its strong impact on their properties [1]. We examine the properties of $[(\mathrm{SnSe})_{1+\delta}]_m[\mathrm{NbSe}_2]$ superlattices, which allow for nearly arbitrary stacking sequences due to the growth technique [2]. Given this degree of freedom we study how coupling mechanisms enable the occurance of superconductivity. Temperature-dependent resistance measurements revealed superconductivity for NbSe_2 interlayer distances of 2.4 nm or smaller. This behaviour is explained by the interplay of grain boundaries, cross-plane tunneling and systematical variation of the NbSe_2 interlayer distances. Additionally, magnetoresistance hysteresis measurements were conducted to investigate the charge carrier states and microscopic superconducting structures. The results provide new insights into the coupling mechanisms of 2D superconductors.

[1] O. Chiatti et al., J. Phys.: Condens. Matter **35**, 215701 (2023);
[2] C. Grosse et al., Sci. Rep. **6**, 33457 (2016).

TT 5.2 Mon 9:45 H36

Atomic-scale mapping of superconductivity in the incoherent CDW mosaic phase of a transition metal dichalcogenide — •Sandra Sajan[1], Haojie Guo[1], Tarushi Agarwal[2], Irián S. Ramírez[1], Chandan Patra[2], Maia G. Vergniory[1], Fernando de Juan[1], Ravi P. Singh[2], 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, Bhopal 462066, India

The emergence of superconductivity in the 1T phase of TaS_2 is preceded by the intriguing loss of long-range order in the charge density wave (CDW). Such decoherence, attainable by different methods, results in the formation of nm-sized coherent CDW domains bound by a two-dimensional network of domain walls (DW)-mosaic phase, which has been proposed as the spatial origin of the superconductivity. We report the atomic-scale characterization of the superconducting state of 1T-TaSSe, a model 1T compound exhibiting the CDW mosaic phase. We use high-resolution scanning tunneling spectroscopy and Andreev spectroscopy to probe the microscopic nature of the superconducting state in connection with the electronic structure of the DW network. Spatially resolved conductance maps at the Fermi level reveal a uniform landscape, independent of domain structure, indicating no link to superconductivity. This is confirmed at 340mK within the superconducting dome, where the gap's subtle inhomogeneity remains unconnected to DWs providing new insights into the fundamental interplay between SC and CDW in these relevant strongly correlated systems.

TT 5.3 Mon 10:00 H36

Ab-initio investigation of transition metal – superconductor interfaces — •Adamantia Kosma[1], Stefan Blügel[1], and Philipp Rüssmann[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany

The realisation of Majorana-based topologically protected qubits requires a careful design and optimization of material interfaces for superconductor (SC)/topological insulator (TI) heterostructures. To this end, we perform ab-initio simulations to investigate the superconducting properties at the interface of transition metal overlayers (M = Os, Ir, Pt, Au) deposited on a Nb(110) film. Our density functional theory calculations are based on the full-potential Korringa-Kohn-Rostoker (KKR) Green function method and its Kohn-Sham Bogoliubov-de Gennes (KS-BdG) extension [1,2]. In our study we explore the possibility to control the work function mismatch through the overlayer, and we uncover the proximity induced superconductivity. Our findings show that some of these structures might be promising material candidates for interfacing a TI with a superconductor without unwanted band bending effects at SC/M/TI interfaces.

We thank the ML4Q (EXC 2004/1 – 390534769) for funding.

[1] JuDFTteam/JuKKR (2022). doi: 10.5281/zenodo.7284738
[2] P. Rüßmann, and S. Blügel, Phys. Rev. B **105**, 125143 (2022).

TT 5.4 Mon 10:15 H36

Local limit disorder characteristics of superconducting radio frequency cavities I. Frequency shift — •Matúš Hladký, Anastasiya Lebedeva, Marcel Polák, and František Herman — Comenius University in Bratislava

Negative resonant frequency shift abnormalities in the vicinity of the critical temperature have been observed in recent experiments on Superconducting Radio Frequency cavities.

We present a simple, straightforward approach using the Dynes superconductor theory [1] and discuss its results. In the ideal dirty limit, we analytically elaborate on the width and depth of the resulting dip. Studying the sign of the slope of the resonant frequency shift at crit. temperature in the moderately clean regime reveals the role of the pair-breaking and pair-conserving disorder. Next, we compare and also fit our results with the recent experimental data from the N-doped Nb sample presented in Ref. [2]. Our analysis remarkably complies with the experimental findings, especially concerning the dip width. We offer straightforward, homogeneous-disorder-based interpretation within the moderately clean regime.

This work has been supported by the APVV-23-0515 grant and by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

[1] A. Lebedeva, M. Hladký, M. Polák, F. Herman, arXiv:2409.04203v1.
[2] M. Zarea, H. Ueki, J. A. Sauls, Frontiers in Superconducting Materials, 3: 1-7, arXiv:2307.07905v1 (2023).

TT 5.5 Mon 10:30 H36

Local limit disorder characteristics of superconducting radio frequency cavities II. Quality factor — Anastasiya Lebedeva, Matúš Hladký, Marcel Polák, and •František Herman — Comenius University in Bratislava

Nowadays superconducting radio frequency (SRF) cavities represent fundamental tools used for (Standard Model) particle acceleration, (beyond Standard Model) particle probing, and long-lifetime photon preservation. We study their Quality factor properties mainly at low temperatures within the Dynes superconductor model [1]. We scrutinize and use the local limit response to the external electromagnetic field. Assuming the same regime at low temperatures, we address details of the high-quality plateaus. This work presents (and studies the limits of) the simple effective description of the complex problem corresponding to the electromagnetic response in the superconductors combining homogeneous conventional pairing and two different kinds of disorder scattering.

This work has been supported by the Slovak Research and Development Agency under the Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

[1] A. Lebedeva, M. Hladký, M. Polák, F. Herman, arXiv:2409.04203v1.

TT 5.6 Mon 10:45 H36

THz response of ultra thin NbN films grown by atomic layer deposition — •Frederik Bolle[1], Yayi Lin[1], Heidemarie Schmidt[2], Martin Dressel[1], and Marc Scheffler[1] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Leibniz IPHT, Jena

Most elementary excitations and collective modes of superconductors lie in the THz frequency range, making THz spectroscopy an ideal tool to directly measure the superconducting energy gap and superfluid density. By combining the spectral ranges from continuous, coherent backward wave oscillators and time-domain methods we can investigate a broad frequency range from $1.6\,\mathrm{cm}^{-1}$ (0.2 meV) up to $100\,\mathrm{cm}^{-1}$ (12.4 meV). We characterize the superconducting state of grown NbN films in particular concerning the behavior of its energy scales as the film becomes increasingly two dimensional approaching the superconductor insulator transition (SIT). We investigate films with thickness ranging from 4.5 nm and 20 nm and find a continuous suppression of the superconducting energy gap and superfluid density with reduced film thickness. These results enable a quantitative device design for various applications of NbN thin films such as high kinetic inductance circuitry.

TT 5.7 Mon 11:00 H36

Superfluid stiffness in strongly disordered NbN superconducting films — •Alexander Weitel Weitzel[1], Lea Pfaffinger[1], Matthias Stosiek[2], Animesh Panda[3], Ferdinand Evers[3], and Christoph Strunk[1] — [1]Inst. of Exp. a. Appl. Phys., University of Regensburg, D-93040 Regensburg, Germany — [2]TUM Sch. of Nat. Sci., Dep. of Phys. PH-I, D-85748 Garching bei München — [3]Inst. of Theoretical Phys., University of Regensburg, D-93040 Regensburg, Germany

In BCS-superconductors, the spectral gap, E_g, the pairing amplitude, Δ, and the mean-field critical temperature T_{c0} are essentially identical. At strong disorder, close to the superconductor-insulator transition (SIT), this is no longer the case. Moreover, in BCS-theory the superfluid stiffness, J_s, is determined by Δ and normal state resistance R_N. Also this relation typically no longer holds close to SIT. Recently, we have experimentally determined $J_s(T)$ in ultra-thin NbN films by measuring kinetic inductance and found a sharp Berezinski-Kosterlitz-Thouless (BKT) transition. Our latest experimental data cover $J_s(T)$ over a wide range of disorder strength, up to normal state resistance $\sim h/e^2$. We find a sharp BKT-transition right up to the SIT and independently measure the characteristic scales E_g, J_s, T_{c0} and T_{BKT} over two orders of magnitude in R_N. We present complementary numerical calculations of the superfluid stiffness, obtained from the Boguliubov-de Gennes (BdG) theory of disordered samples in a very broad range of disorder strengths. A detailed comparison of our measurements with the computational results will be presented.

15 min. break

TT 5.8 Mon 11:30 H36

Molecular hydrogen in the N-doped LuH$_3$ system as a possible path to superconductivity — •Cesare Tresca[1], Pietro Forcella[2], Andrea Angeletti[3], Luigi Ranalli[3], Cesare Franchini[3,4], Michele Reticcioli[3], and Gianni Profeta[1,2] — [1]CNR-SPIN L'Aquila, Italy — [2]University of L'Aquila, L'Aquila, Italy — [3]University of Vienna, Vienna, Austria — [4]University of Bologna, Bologna, Italy

The discovery of ambient superconductivity would mark an epochal breakthrough long-awaited for over a century, potentially ushering in unprecedented scientific and technological advancements. The recent findings on high-temperature superconducting phases in various hydrides under high pressure have ignited optimism, suggesting that the realization of near-ambient superconductivity might be on the horizon. However, the preparation of hydride samples tends to promote the emergence of various metastable phases, marked by a low level of experimental reproducibility. Identifying these phases through theoretical and computational methods poses a considerable challenge, often resulting in contentious outcomes. In this contribution, we consider N-doped LuH$_3$ as a prototypical complex hydride: By means of machine-learning-accelerated force-field molecular dynamics, we have identified the formation of H$_2$ molecules stabilized at ambient pressure by nitrogen impurities. Importantly, we demonstrate that this molecular phase plays a pivotal role in the emergence of a dynamically stable, low-temperature, experimental-ambient-pressure superconductivity.

TT 5.9 Mon 11:45 H36

Challenges in identifying nematic superconductivity of CsV$_3$Sb$_5$ kagome metal via transport measurements — •Yu-Chi Yao[1,2], Fei Sun[1], José Guimarães[1,2], and Haijing Zhang[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany — [2]School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, UK

Nematicity refers to the spontaneous symmetry breaking beyond the crystal-imposed anisotropy in the electron wavefunction. On the other hand, understanding the interplay between nematicity and superconductivity could be crucial for determining the underlying pairing mechanism in various correlated systems, such as cuprates [1] and iron-based [2] unconventional superconductors. In this study, we focus on the recently discovered kagome metal CsV$_3$Sb$_5$, which is famous for its multiple competing or coexisting orders [3,4]. By using CsV$_3$Sb$_5$ as the prototypical system, we address the challenges of identifying nematic superconductivity in transport measurements and systematically disentangle the extrinsic factors, such as imperfections in field alignment, from intrinsic nematic superconducting behavior.

[1] R. Daou *et al.* Nature **463**, 519-522 (2010).
[2] J. H. Chu *et al.* Science, **329**(5993), 824-826 (2010).
[3] B. R. Ortiz *et al.* Phys. Rev. Lett. **125**(24), 247002 (2020).
[4] F. Sun, H. Zhang *et al.* arXiv:2408.08117.

TT 5.10 Mon 12:00 H36

Unique electronic transport characteristics in superconducting MgB$_2$ films — •Clemens Schmid[1], Markus Gruber[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, 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

Maximizing the velocity of Abrikosov vortices in superconductors and characterizing the associated energy relaxation times is essential for possible applications like single photon detectors. Here, we investigate the current-voltage curves of MgB$_2$, a material whose thin film structures remain superconducting at temperatures up to 30 K. Furthermore, capabilities of a single photon response have been observed previously in MgB$_2$ films. Our experiments reveal peculiar shapes of the current-voltage curves, showing multiple steps in their transitions to the normal state. While the microscopic mechanisms underlying these steps are a topic of current debates, one explanation could imply the occurrence of composite and fractional vortices associated with the two-band nature of the superconductivity in MgB$_2$, a property which is in-line with the presence of two slopes in the temperature-magnetic-field phase diagram. We compare our findings across multiple layered structures and for varying thicknesses of the MgB$_2$.

TT 5.11 Mon 12:15 H36

Single-crystal growth and superconducting properties of Sr$_x$Bi$_2$Se$_3$ — •Max Brückner[1], Jule Kirschke[1], Fatih Cetin[1], Sven Graus[1], Maik Golombiewski[1], Fotios Maragkos[2,3], Varvara Foteinou[2], Shibabrata Nandi[4,5], Haneen Abushammala[1], Andreas Kreyssig[1], and Anna E. Böhmer[1] — [1]Experimentalphysik IV, Ruhr-Universität Bochum, 44801 Bochum — [2]Central Unit for Ion Beams and Radionuclides, Ruhr-Universität Bochum, 44801 Bochum — [3]Department of Physics, National Technical University of Athens, 15780 Athens, Greece — [4]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science and Peter Grünberg Institut, JARA-FIT, 52425 Jülich — [5]Experimentalphysik IVc, JARA-FIT, RWTH Aachen, 52074 Aachen

Bi$_2$Se$_3$ is a topological insulator in which Sr-intercalation induces superconductivity with an unexpected two-fold anisotropy of H$_{c2}$ in the basal plane. We examine how its properties relate to different single-crystal growth conditions, including self-flux growth of free-standing single crystals from a Bi-rich melt. The Sr-content was determined by proton-induced x-ray emission spectroscopy in our as-grown crystals with a resolution of up to 30 ppm. Transport measurements in magnetic fields showed superconductivity with T$_c$ $\sim$ 2-3 K at surprisingly low Sr-content. In addition, we identified SrBi$_2$Se$_4$ as a secondary phase in our growth. Its superconducting properties were found to be similar to the ones of Sr$_x$Bi$_2$Se$_3$.

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TT 5.12 Mon 12:30 H36

Tuning superconducting properties in 3D nanoarchitectures — •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], Uri Vool[1], and Claire Donnelly[1] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Str. 40, 01187, Dresden, Germany — [2]Institute of Applied Physics, TU Wien, Wiedner Hauptstr. 8-10/134,1040 Vienna, Austria — [3]University of Vienna, Vienna, Austria — [4]Leibniz IFW Dresden, Dresden, Germany

Introducing 3D nanoconfinement into the superconducting system can open a path for local geometrical control and the possibility of going beyond intrinsic properties. However, the fabrication of such intricate nanoarchitectures remains challenging.

In this context, we present an extended approach to creating superconducting 3D nanoarchitectures through focused electron-beam-induced deposition of tungsten. This method allows the realisation of 3D superconducting nanostructures with arbitrary geometries within a wide range of critical temperatures, providing local geometrical control of critical fields and, for example, the realisation of reconfigurable weak links. With transport measurements, we demonstrate the motion of superconducting vortices within these 3D superconducting nanostructures. Therefore, three-dimensional superconducting nanostructures offer new horizons for experimental investigations of the dynamics of vortices, anisotropy and possible applications of curvilinear 3D nanoarchitectures.

TT 5.13 Mon 12:45 H36

Vortex mass observed in far-infrared circular dichroism of high-T$_c$ superconductors — •Roman Tesař[1], Michal Šindler[1], Pavel Lipavský[2], Jan Koláček[1], Christelle Kadlec[1], Wen-Yen Tzeng[3], Chih-Wei Luo[4], and Jiunn-Yuan Lin[4] — [1]Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic — [3]National Formosa University, Yunlin, Taiwan — [4]National Yang Ming Chiao Tung University, Hsinchu, Taiwan

The effective mass of the Abrikosov vortex (fluxon) in type-II superconductors remains an open and still not fully solved problem. Only a few experimental techniques are currently known to examine the fluxon mass, while numerous theoretical models have been developed that predict inconsistent values scattered over several orders of magnitude. We present an experimental method to determine fluxon mass based on the interaction with circularly polarized FIR/THz laser radiation. A rotating electric field induces the motion of fluxons along cyclotron trajectories, which leads to magnetic circular dichroism at terahertz frequencies. The modified Kopnin-Vinokur theory with experimentally established parameters provides a sufficient framework for estimating fluxon mass at low temperatures. We demonstrate the proposed method on thin films of $YBa_2Cu_3O_{7-\delta}$ with different doping levels. We also briefly mention other applications of the experimental technique used, such as probing cyclotron resonance in semiconductors and magnon modes in magnetic materials.

[1] Sci. Rep. 11, 21708 (2021).
[2] IEEE Trans. Appl. Supercond. 34, 0601005 (2024).