TT 57: Superconductivity: Properties and Electronic Structure

Time: Thursday 15:00–18:00 Location: H7

TT 57.1 Thu 15:00 H7

Phase slip lines in few-layer $NbSe_2$ superconducting devices — •Nicola Paradiso, Anh-Tuan Nguyen, Karl Enzo Kloss, and Christoph Strunk — University of Regensburg

The advent of van der Waals superconductors made it possible to study 2D superconductivity in a fascinating clean regime, so far rarely studied in conventional films. In this work we show that, owing to their low level of disorder and atomically sharp edges, few-layer monocrystalline $NbSe_2$ flakes do not switch directly to the normal phase under large current bias. Instead, a sequential nucleation of phase slip lines (PSLs) is observed in all the samples under study. We investigate the dynamic of PSL nucleation in a Au-$NbSe_2$ point contact, where the temperature and bias dependence of the PSL-induced conductance step is quantitatively described by the simple model of Skocpol, Beasley and Tinkham. In plain devices, the PSL pattern is sample dependent. However, we demonstrate that it is possible to induce an artificial PSL nucleation site by mechanically stressing a flake across its whole width.

TT 57.2 Thu 15:15 H7

High-pressure transport studies in the superconducting and charge density wave material $NbSe_2$ — •Owen Moulding[1], Takaki Muramatsu[1], Charles Sayers[2], Enrico Da Como[2], and Sven Friedemann[1] — [1]University of Bristol, Bristol, UK — [2]University of Bath, Bath, UK

The transition metal dichalcogenide 2H-$NbSe_2$ has a well-documented charge density wave (CDW) and superconducting transition at 33K and 7K at ambient pressure. The CDW transition is suppressed under high pressure and is absent beyond its quantum critical point (QCP). The effect of this QCP on superconductivity is of great interest and stimulates discussions on the relation between superconductivity and the CDW order. So far, resistivity, magnetic susceptibility, and X-ray measurements have explored the vicinity of this QCP and they indicate a weak relation between superconductivity and the CDW: either a weak competition between CDW order and superconductivity or a weak promotion of superconductivity by fluctuations at the CDW QCP.

Here, we present high-pressure Hall effect measurements as a clear probe of the CDW order and trace the CDW transition to higher pressures than previously measured with transport methods. Further, the sign-change in the Hall coefficient observed at ambient pressure is suppressed and ultimately saturates to hole-like beyond the CDW QCP. We also observe a peak in the superconducting temperature about the QCP of the CDW of 4.7GPa, which indicates an enhancement of the electron-phonon coupling at the QCP.

TT 57.3 Thu 15:30 H7

Three-dimensional collective charge excitations in electron-doped copper oxide superconductors — •Matthias Hepting[1,9], Laura Chaix[1], Edwin W. Huang[1,2], Roberto Fumagalli[3], Ying Y. Peng[3], Brian Moritz[1], Kurt Kummer[4], Nicholas B. Brookes[4], Wei Cheng Lee[5], Makoto Hashimoto[6], Tarapada Sarkar[7], Jun-Feng He[1], Costel R. Rotundu[1], Young S. Lee[1], Richard L. Greene[7], Lucio Braicovich[3,4], Giacomo Ghiringhelli[3,8], Zhi Xun Shen[1], Thomas P. Devereaux[1], and Wei Sheng Lee[1] — [1]Stanford Institute for Materials and Energy Sciences, SLAC National Accelerator Laboratory and Stanford University, USA — [2]Department of Physics, Stanford University, USA — [3]Dipartimento di Fisica, Politecnico di Milano, Italy — [4]European Synchrotron Radiation Facility (ESRF), France — [5]Department of Physics, Binghamton University, USA — [6]Stanford Synchrotron Radiation Lightsource, SLAC, USA — [7]Center for Nanophysics and Advanced Materials, University of Maryland, USA — [8]CNR-SPIN, Politecnico di Milano, Italy — [9]Max-Planck-Institute for Solid State Research, Germany

We report on three-dimensional charge collective modes observed in electron-doped copper oxides by resonant inelastic X-ray scattering (RIXS) [1]. The modes are reminiscent of acoustic plasmons predicted for layered copper oxides and suggested to play a substantial role in mediating high-temperature superconductivity.

[1] M. Hepting et al., Nature 563, 374-378 (2018)

TT 57.4 Thu 15:45 H7

Superconducting Higgs mode in cuprates — •Min-Jae Kim[1,4], Hao Chu[1,4], Kota Katsumi[2], Sergey Kovalev[3], Robert David Dawson[1], Lukas Schwarz[1], Naotaka Yoshikawa[2], Gideok Kim[1], Daniel Putzky[1], Georg Cristiani[1], Gennady Logvenov[1], Andreas Schnyder[1], Dirk Manske[1], Michael Gensch[3], Zhe Wang[3], Ryo Shimano[2], and Stefan Kaiser[1,4] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]University of Tokyo, Japan — [3]Helmholtz-Zentrum Dresden- Rossendorf, Germany — [4]4th Physics Institute, University of Stuttgart, Germany

The complex phase diagram of cuprate high-Tc superconductor is due to an intriguing interplay of different orders such as the pseudogap, or charge order. Despite intensive spectroscopic measurements of these ordered states, yet the microscopic mechanism behind high-Tc superconductivity is still lacking. In particular the collective dynamics of the superconducting order parameter, the Higgs mode, was not accessible so far. Here we report on *Higgs spectroscopy* in cuprate superconductors that we accomplished by using a high-field multicycle THz pulse, which nonlinearly couples to the superconducting condensate and leads to characteristic third harmonic generation. We identify the driven Higgs amplitude response of the superconducting order parameter in three archetypal families of cuprate thin films and we report on a novel collective mode universally exhibited by optimally doped samples. In addition, we find a finite Higgs-like response above Tc that might be interpreted as finite pairing amplitude even above Tc.

TT 57.5 Thu 16:00 H7

Optical second-harmonic generation spectroscopy of superconducting $YBa_2Cu_3O_y$ — •M.C. Weber[1], Th. Lottermoser[1], T. Loew[2], J.P. Porras[2], D. Hsieh[3], B. Keimer[2], and M. Fiebig[1] — [1]Department of Materials, ETH Zurich — [2]Max-Planck Institute, Stuttgart — [3]California Institute of Technology, Pasadena

The cuprate-family – famous for their high-T_c superconductivity – is characterized by a complex phase diagram. The understanding of competition or coexistence of the different phases represents one of the intriguing questions in the field. An important milestone in order to scrutinize these questions is the understanding of the symmetry properties of the different phases. Recently, using optical second-harmonic generation (SHG) a new study on $YBa_2Cu_3O_y$ revealed a monoclinic symmetry at RT followed by an inversion-symmetry breaking upon entering the pseudo-gap phase [1]. The introduction of this symmetry-sensitive technique into the realm of superconductivity opens new doors for the investigation of the rich phase diagram of $YBa_2Cu_3O_y$-compounds. In particular, spectroscopic SHG-studies allow for a deeper insight into the microscopic nature and electronic origin of the optical nonlinearities. In the present work, we report a thorough SHG-spectroscopy investigation on $YBa_2Cu_3O_y$-compounds. We find a strong spectral dependence of the optical non-linear response. Tracing the evolution of this spectral dependence across phase transitions, we aim to enlarge the understanding of the complex phase diagram of the cuprate-family.

[1] Zhao et al., Nat. Phys. **13**, 250 (2017)

TT 57.6 Thu 16:15 H7

Dramatic asymmetry of magnetic moment reversal in superconductor-ferromagnet thin film elements — •Manuel Bihler[1], Julian Simmendinger[1], and Joachim Albrecht[2] — [1]Max Plank Institute for Intelligent Systems, Heisenbergstr. 3, 70569 Stuttgart, Germany — [2]Research Institute for Innovative Surfaces FINO, Beethovenstr. 1, 73430 Aalen, Germany

Loss-free electric currents in superconductors create persistent magnetic moments. In case of thin-film elements, this can result in two distinct states depending on the orientation of the circulating supercurrents. The reversal of such magnetic moments can be addressed by the application of external magnetic fields. The reversal process is locally investigated in small bilayers of high-temperature superconducting $YBa_2Cu_3O_7$-$Ba_2Y(Nb,Ta)O_6$ (YBCO:BYNTO) nanocomposite and soft-magnetic permalloy using magnetic scanning x-ray microscopy at low temperatures. In case of micron-sized elements, creation and reversal by external fields becomes largely asymmetric. Already small external magnetic fields allow the preparation of a defined magnetization state. The required field to reverse the magnetic moment by inverting the supercurrent orientation is substantially increased. This effect might be used for the development of a non-volatile magnetic memory device at low temperatures.

15 min. break.

TT 57.7 Thu 16:45 H7

Pressure tuning of $CeRhIn_5$ microstructures — •Janas K. John[1], Maja D. Bachmann[1], Filip Ronning[3], Eric D. Bauer[3], Joe D. Thompson[3], Philip J. W. Moll[1,2], and Michael Nicklas[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Laboratory of Quantum Materials, EPFL, Lausanne, Switzerland — [3]Los Alamos National Laboratory, MPA-CMMS, USA

$CeRhIn_5$ orders antiferromagnetically below $T_N = 3.8$K at ambient pressure. External pressure suppresses the antiferromagnetic state and induces an unconventional superconducting state. Motivated by the study of M. Bachmann *et.al.* on $CeIrIn_5$ microstructures we revisited the pressure-temperature ($p-T$) phase diagram of its relative $CeRhIn_5$ utilizing microstructures to probe the electrical resistivity for well-defined crystalline directions, along the crystallographic *a*- and *c*-axes. The obtained $p-T$ phase diagram resembles the general results in literature. Once the antiferromagnetic state is suppressed, superconductivity appears. We noted slightly different superconducting transition temperatures T_c along both crystallographic directions, which might be attributed to strain inhomogeneities. The superconducting transition is first rather broad, but sharpens upon increasing pressure and approaching the maximum in $T_c(p)$. To our surprise the temperature dependence as well as the $I-V$ curves for in-plane measurements along the *a*-axis follows the predictions of the Berezinskii-Kosterlitz-Thouless theory. This might hint at two-dimensional superconductivity.

[1] M. D. Bachmann *et al.*, arxiv:1807.05079.

TT 57.8 Thu 17:00 H7

Spatial modulation of the superconducting order parameter: A microscopic study of the FFLO state in an all-organic superconductor — •Sebastian Molatta[1,2], H. H. Wang[3], G. Koutroulakis[3], J. A. Schlueter[4], J. Wosnitza[1,2], S. E. Brown[3], and H. Kühne[1] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), Dresden, Germany — [2]Institut für Festkörper und Materialphysik, TU Dresden, Germany — [3]Department of Physics and Astronomy, UCLA, Los Angeles, USA — [4]Division of Materials Research, National Science Foundation, Arlington, USA

The Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state was theoretically predicted in 1964. A hallmark of this state is the spatial modulation of the superconducting order parameter, caused by a strong spinpopulation imbalance of a Fermi liquid. So far, experimental signatures of this superconducting state were found in only very few materials. Recently, microscopic evidence for spatially modulated superconductivity was found by nuclear magnetic resonance (NMR) spectroscopy. We report on our latest results of a comprehensive NMR study of the all-organic superconductor β''-$(ET)_2SF_5CH_2CF_2SO_3$, focused on the spectroscopic investigation of the spatial inhomogeneous distribution of the local spin susceptibility in the FFLO phase, with related signatures in the nuclear spin-lattice relaxation rate. The inhomogeneous broadening of the ^{13}C-NMR spectra, as well as the frequencydependent distribution of spin-lattice relaxation times is consistent with a one-dimensional sinusoidally modulated superconducting order parameter in the FFLO state.

TT 57.9 Thu 17:15 H7

Unconventional Magnetic Properties of Nitrogen-doped Diamond: Coexistence of superconductivity and superparamagnetism — •Jose Luis Barzola Quiquia[1], Markus Stiller[1], Pablo Esquinazi[1], Axel Molle[1], Ralf Wunderlich[1], Sebastian Pessagna[1], Jan Meijer[1], Wilhelm Kossack[2], and Sergei Buga[3] — [1]Felix-Bloch Institute for Solid State Physics, University of Leipzig, 04103 Leipzig, Germany — [2]Peter-Debye Institute for Soft Matter Physics, University of Leipzig, 04103 Leipzig, Germany — [3]Technological Institute for Superhard and Novel Carbon Materials, 7a Centralnaya street, Troitsk, Moscow, 108840 Russia

We report on the magnetization of nitrogen-doped single crystalline diamond bulk samples. We found unconventional field and temperature hysteresis loops in the magnetization at T $<$ 25 K. The results indicate the superposition of superparamagnetism and superconductivity in eight measured samples with different nitrogen concentration ($<$ 200 ppm). At temperatures above 25 K, the samples show diamagnetic behavior similar to undoped diamond. The coexistence of superparamagnetism and superconductivity is attributed to the nitrogen doping and the existence of defective regions. To support our results and interpretation we investigated the magnetic properties of ferromagnetic/high-temperature superconducting oxide bilayers. The results obtained from those bilayers show remarkable similarities to the ones in nitrogen-doped diamond. Using a simple model based on the superposition of a superparamagnetic, a superconducting and a diamagnetic contribution, we can describe very well all results.

TT 57.10 Thu 17:30 H7

Interfaces in Graphite: A Path to Room Temperature Superconductivity — •Pablo D. Esquinazi — Division of Superconductivity and Magnetism, University of Leipzig, Leipzig, Germany

Galvanomagnetic, Magnetization and Magnetic Force Microscopy studies in different graphite samples, from twisted graphene bilayers to bulk graphite samples, indicate that interfaces (e.g., between twisted Bernal or twisted rhombohedral crystalline regions or between Bernal and rhombohedral stacking) are the reason for the superconducting and metallic-like properties of graphite. In this contribution we emphasize and discuss the similarities in the superconducting-like signals obtained in twisted graphene bilayers [1] with critical temperature $T_c \sim 1$ K, in TEM lamella [2] and in bulk graphite samples [3] with 3 K $\lesssim T_c \lesssim$ 350 K. Experimental as well as theoretical work indicate that the origin of the observed superconductivity is related to the existence of flat bands at certain interfaces.

[1] Y. Cao et al., Nature **556**, 1476 (2018)
[2] A. Ballestar et al., New Journal of Physics **15**, 023024 (2013)
[3] C. Precker et al., New Journal of Physics **18**, 113041 (2016)

TT 57.11 Thu 17:45 H7

Local Magnetic Measurements of Trapped Flux Through a Permanent Current Path in Graphite — •Markus Stiller, José Barzola-Quiquia, Pablo D. Esquinazi, and Christian E. Precker — Felix-Bloch Institute for Solid-state Physics, Universität Leipzig, Linnestr. 5, D-04103, Germany

Measurements of the electrical resistance of different natural graphite samples suggest the existence of superconductivity at room temperature in some regions of the samples. To verify whether dissipationless electrical currents are responsible for the trapped magnetic flux, we localized them using magnetic force microscopy on a natural graphite sample in remanent state after applying a magnetic field. The results indicate that at room temperature a permanent current flows at the border of the trapped flux region. The current path vanishes at the same transition temperature $T_c = 370$ K as the one obtained from electrical resistance measurements on the same sample. Magnetic coupling is excluded as origin of the observed phase signal. Time-dependent measurements of the signal show the typical behavior of flux creep of a permanent current flowing in a superconductor. The overall results support the existence of room-temperature superconductivity at certain regions in the graphite structure.