TT 16: Superconductivity: Properties and Electronic Structure II

Time: Tuesday 9:30–12:45 Location: H32

TT 16.1 Tue 9:30 H32

Layer-thickness and substrate effects on superconductivity in epitaxial FeSe films on BLG/SiC(0001) — •YONGSONG WANG[1], HAOJIE GUO[1], ANE ETXEBARRIA[2], SANDRA SAJAN[1], SARA BARJA[1,2,3,4], and MIGUEL MORENO UGEDA[1,3,4] — [1]Donostia International Physics Center, San Sebastián, Spain — [2]Department of Polymers and Advanced Materials, University of the Basque Country, San Sebastián, Spain — [3]Centro de Física de Materiales, San Sebastián, Spain — [4]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

The layered nature and simple structure of FeSe reveal this iron-based superconductor as a unique building block for the design of artificial heterostructure materials. While superconductivity develops in ultrathin films of FeSe on $SrTiO_3$ substrates, it remains unclear whether it can be developed on more chemically inert, layered materials such as graphene. Here, we report on the characterization of the structural, chemical and electronic properties of few-layer FeSe on bilayer graphene grown on SiC using low-temperature scanning tunneling microscopy/spectroscopy (STM/STS) and X-ray photoelectron spectroscopy (XPS). STM imaging of our FeSe films with thicknesses up to three layers exhibit the tetragonal crystal structure of bulk FeSe, which is supported by XPS spectra consistent with the FeSe bulk counterpart. While our STS measurements at 340 mK reveal a metallic character for few-layer FeSe on BLG/SiC, they show an absence of superconductivity, as the low-lying electronic structure exhibits a spatially anisotropic dip-like feature robust against magnetic fields. Superconductivity in FeSe/BLG/SiC, however, emerges for thicker films with T_c = 6 K.

TT 16.2 Tue 9:45 H32

Lattice dynamical studies in the unconventional superconductor: LiFeAs — •AKSHAY TEWARI[1], SABINE WURMEHL[2], BERND BÜCHNER[2], ANDREA PIOVANO[3], and MARKUS BRADEN[1] — [1]II.Physics Institute, Universität zu Köln, Zülpicher Strasse 77, 50937 Köln, Germany — [2]IFW Dresden, D-01171 Dresden, Germany — [3]ILL, 71 avenue des Martyrs, 38000 Grenoble, France

LiFeAs crystallizes in a tetragonal structure(P4/nmm) and is superconducting below T_c=18K. Unlike other iron pnictides, LiFeAs does not exhibit long-range magnetic order, but has AFM fluctuations at incommensurate positions. Studies suggest that superconductivity in LiFeAs is driven by electronic correlations but a contribution from electron phonon coupling is still debated. We have studied the phonon dispersion of LiFeAs using inelastic neutron scattering on large single crystals to search for anomalies in the dispersion which are signatures of electron phonon coupling. We could determine almost all branches along main symmetry directions by analyzing the data with force-model lattice dynamical calculations. Temperature dependencies of specific phonon modes were also examined. Our experimental results provide significant differences to the DFT calculations previously reported[1,2]. No pronounced instability was observed but strong relative energy shifts of 6% were detected for specific modes in the temperature dependent scans. The overall dispersion fits the lattice dynamical model and is also supported by more recent DFT calculations.

[1] G.Q. Huang et al. PRB 82, 014511 (2010).
[2] R.A. Jishi et al., Adv. in Cond.Mat.Phys. 804343(2010).

TT 16.3 Tue 10:00 H32

NMR evidence of pseudogap and against spin magnetism in the time-reversal symmetry breaking state of $Ba_{1-x}K_xFe_2As_2$ — •F. BÄRTL[1], F. CAGLIERIS[2,3,4], Y. LI[5], Q. HU[5], Y. ZHENG[5], C.-H. YIM[5], J. WOSNITZA[1,6], R. SARKAR[2], H.-H. KLAUSS[2], E. BABAEV[7], J. GARAUD[8], H. KÜHNE[1], and V. GRINENKO[5] — [1]HLD-EMFL, HZDR, Dresden — [2]University of Genoa — [3]CNR-SPIN, Genoa — [4]IFW, Dresden — [5]TDLI, Shanghai Jiao Tong University — [6]IFMP, TU Dresden — [7]Department of Physics, KTH, Stockholm — [8]Institut Denis Poisson, Université de Tours

Recently, we focused on the investigation of samples from the narrow doping range of $0.7 \leq x \leq 0.8$ in the hole-doped superconductor $Ba_{1-x}K_xFe_2As_2$. Here, the proximity to a Lifshitz transition results in a multiband $s + is$ superconducting state, which spontaneously breaks time-reversal symmetry (BTRS), manifested as spontaneous currents around non-magnetic impurities. This is theoretically predicted and was experimentally revealed by μ^+SR measurements, where the depolarization rate below T_c is only non-zero in the mentioned narrow doping regime. Moreover, the μ^+SR together with Nernst-effect measurements suggest the emergence of the BTRS already at a temperature $T_c^{Z_2} > T_c$, which indicates a behavior beyond mean-field approximation, described by a four-fermion order parameter, hence termed quartic metal. Here, we present ^{75}As NMR spectroscopy and relaxometry measurements of a sample with $x = 0.77$, which contradict the presence of conventional spin magnetism and hint at pseudogap behavior in the critical regime.

TT 16.4 Tue 10:15 H32

Observation of saddle point nesting driven charge order on the surface of a 122-type iron-based superconductors — •YU ZHENG — Tsung Dao Lee Institute, Shanghai Jiao Tong University, 1 Lisuo Road, Shanghai, 201210

Unconventional superconductivity is known for intertwining with other correlated states, making the exploration for new intertwined orders highly important for understanding the mechanism of unconventional superconductivity. Spin and nematic orders are widely observed in the iron-based superconductors (FeSCs). However, evidence for charge order in the phase diagrams of FeSCs is rarely found. Employing STM and DFT, here we demonstrate,through expanding the phase diagram of $Ba_{1-x}K_xFe_2As_2$ to the heavily hole doped regime by surface doping, the formation of a CDW order on the As-terminated surface of $Ba_{0.23}K_{0.77}Fe_2As_2$, whose emergence suppresses superconductivity completely, indicating direct competition between the two. Notably, the wavevector of the charge order matches with the nesting vector between the near-EF saddle points, suggesting saddle-point nesting as its driving mechanism.

TT 16.5 Tue 10:30 H32

Long-term stability of irradiation-induced defects in $YBa_2Cu_3O_{7-\delta}$ thin films — •BERND AICHNER[1], SANDRA KEPPERT[2], PHILIP ROHRINGER[1], MARIUS-AUREL BODEA[2], BENEDIKT MÜLLER[3], MAX KARRER[3], REINHOLD KLEINER[3], EDWARD GOLDOBIN[3], DIETER KOELLE[3], JOHANNES DAVID PEDARNIG[2], and WOLFGANG LANG[1] — [1]Faculty of Physics, University of Vienna, Wien, Austria — [2]Institute of Applied Physics, Johannes Kepler University Linz, Linz, Austria — [3]Physikalisches Institut, Center for Quantum Science (CQ) and LISA$^+$, University of Tübingen, Tübingen, Germany

Helium ion irradiation is the method of choice for creating sub-100 nm structures in cuprate superconductors suitable for pinning magnetic flux quanta.

In this presentation, we address the stability of irradiation-induced defects for irradiation performed in an ion implanter as well as in a helium ion microscope. Annealing experiments allow us to extract the activation energy for the diffusion of displaced oxygen atoms back to their original sites in the material's crystal structure. Additionally, a long-term study indicates that vortex-matching features caused by a regular array of irradiation-induced defect columns are still present after about six years of sample storage, a strong hint for the stability of the defects created by irradiation. These findings may be an important ingredient for future applications of helium ion irradiation in the production process of superconducting electronics.

TT 16.6 Tue 10:45 H32

Two-fluid model analysis of the terahertz conductivity of YBaCuO samples: Optimally doped, underdoped and overdoped cases — •CHRISTELLE KADLEC[1], WEN-YEN TZENG[2], CHIH-WEI LUO[3], JIUNN-YUAN LIN[3], and MICHAL ŠINDLER[1] — [1]Institute of Physics, Prague, Czech Republic — [2]National Formosa University, Yunlin, Taiwan — [3]National Yang Ming Chiao Tung University, Hsinchu, Taiwan

The conductivity of a high-quality overdoped $Y_{0.7}Ca_{0.3}Ba_2Cu_3O_{7-\delta}$ film and of underdoped and optimally doped films of its parent compound $YBa_2Cu_3O_{7-\delta}$ was measured using time-domain terahertz spectroscopy. In the normal state, the frequency dependence of the complex conductivity is described by the Drude model. Below the critical temperature T_c, the two-fluid model was successfully employed to fit all the spectra, from 5 K up to T_c. The temperature behaviour of fundamental parameters such as the scattering rate $1/\tau$, the superfluid (normal) fraction f_s (f_n) and the complex conductivity σ was investigated at given frequencies. We observed that a fifth of the electrons do not condense to the superfluid fraction even at 5 K for the optimally doped and overdoped samples. The real part of the conductivity $\sigma_1(T)$ exhibits a peak for low frequencies. It can be observed for all three compounds and its exact shape depends on the quality of the sample. A further analysis shows that this peak is a consequence of the competition between the scattering time $\tau(T)$ and the superfluid fraction $f_s(T)$.

For further details, see https://arxiv.org/pdf/2309.17408

15 min. break

TT 16.7 Tue 11:15 H32

Higgs spectroscopy on the interplay of superconductivity and charge density waves — •Liwen Feng[1,2], Tim Priessnitz[2], Thales De Oliveira[3], Jan-Christoph Deinert[3], Sergey Kovalev[3], Hao Chu[4], and Stefan Kaiser[1] — [1]TUD Dresden University of Technology, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [4]Shanghai Jiao Tong University, China

Superconductivity (SC) and charge density wave (CDW) often coexist. In the framework of Higgs Spectroscopy, we use high-field terahertz pulses to coherently drive the corresponding Higgs and CDW amplitude modes and investigate their interplay directly in the third harmonic generation (THG) signals. Our findings reveal that the interaction between CDW fluctuations and Higgs oscillations lead to a Fano resonance [1]. We will show that we can characterize the interplay by directly investigating the relative phase responses of these modes in the time-domain THG signal [1]. We will discuss competing interactions of SC with long-range CDW order in 2H-$NbSe_2$ [1] and hole-doped cuprate $La_{2-x}Sr_xCuO_4$, interaction with short-range CDW order in the electron-doped cuprate $La_{2-x}Ce_xCuO_4$, and a noninteracting scenario in the Bismuthate superconductor $Ba_{1-x}Rb_xBiO_3$.

[1] H. Chu et al., Nat Commun. 14 (2023) 1343.

TT 16.8 Tue 11:30 H32

Dynamics of non-thermal states in a cuprate superconductor revealed by mid-infrared three-pulse spectroscopy — •Angela Montanaro[1,2,3], Enrico Maria Rigoni[1,2], Giacomo Jarc[1,2], Viktor Kabanov[4], and Daniele Fausti[1,2,3] — [1]University of Trieste, 34127 Trieste, Italy — [2]Elettra Sincrotrone Trieste, 34127 Trieste, Italy — [3]University of Erlangen-Nürnberg, 91058 Erlangen, Germany — [4]Jožef Stefan Institute, 1000 Ljubljana, 25123 Brescia, Italy

Unconventional cuprate superconductors exhibit anomalous high-frequency electrodynamics compared to standard BCS systems. In BCS superconductors, spectral weight redistribution occurs only near the superconducting gap energy, but in cuprates, changes extend to energies two orders of magnitude higher. This implies that high-energy electronic excitations might influence the pairing mechanism.

In this work, we disentangle the effects of high- and low-photon energy excitations in a prototype cuprate system. We set up a technique which combines two pump pulses having substantially different photon energy: a visible pulse much more energetic than the superconducting gap and a mid-infrared pump with photon energy smaller than the gap. Our findings show that the two photoexcitations have a different effect on the condensate electrodynamics. Moreover, we found that the overall response of the system strongly depends on the time-order of the two photoexcitations. This allowed us to constrain the lifetime of photoinjected carriers and ultimately the recovery time of the condensate.

TT 16.9 Tue 11:45 H32

Hidden antiferromagnetism and pseudogap from fluctuating stripes — •Henning Schlömer[1], Annabelle Bohrdt[2], and Fabian Grusdt[1] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Theresienstr. 37, 80333 — [2]University of Regensburg, Universitätsstr. 31, 93053 Regensburg

One of the central mysteries of hole-doped cuprates is the pseudogap phase, whose unusual properties are believed to be essential for understanding high-temperature superconductivity. While a broad variety of theoretical proposals have been put forward in the past decades, a unified view connecting the pseudogap to other observed phases, like antiferromagnetic (AFM) and stripe phases, has remained elusive. In this talk, I will propose a scenario in which the the AFM, stripe, and pseudogap phases all share a common origin: The spins in the material form an ordered AFM background, on top of which fluctuating domain walls exist that can obscure long-range order. I will argue that these fluctuating domain walls are at the heart of the pseudogap phase: They hide magnetic order in real space, leaving only short-range AFM correlations detectable in experiments. Furthermore, these fluctuations can give rise to a topological phase (an odd Z2 spin liquid) that supports a small Fermi surface, consistent with experimental data. At a (hidden) quantum critical point, hidden AFM order fully dissolves, restoring spin symmetry without a divergent correlation length.

TT 16.10 Tue 12:00 H32

Direct evidence of pairing up to the pseudogap energy in cuprate high-temperature superconductors — Jiasen Niu[1,2], Maialen Ortego Larrazabal[3], Thomas Gozlinski[1,2], •Yudai Sato[1,2], Koen M. Bastiaans[4], Tjerk Benschop[1], Jian-Feng Ge[1,5], Yaroslav M. Blanter[4], Genda Gu[6], Ingmar Swart[3], and Milan P. Allan[1,2] — [1]Leiden Institute of Physics, Leiden University — [2]Fakultät für Physik, Ludwig-Maximilians-Universität — [3]Debye Institute of Nanomaterials Science — [4]Kavli Institute of Nanoscience, Delft University of Technology — [5]Max Planck Institute for Chemical Physics of Solids — [6]Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory

In cuprate high-temperature superconductors, a pseudogap state is observed in a specific region of the phase diagram. Since it exists between the Mott insulating and superconducting phases, the origin of the pseudogap is thought to be associated with electron pairing and/or a locally ordered state. Despite extensive studies, however, a definitive explanation remains elusive. Shot-noise experiments, which can directly detect electron pairing, hold the potential to resolve this long-standing debate. In this presentation, I will report on local shot-noise measurements on the unconventional superconductor $Bi_2Sr_2Ca_2CuO_{8+\delta}$ using scanning tunneling microscopy. We found that the pseudogap energy is associated with electron pairing, with pairing energies reaching up to 70 meV. Our results exclude the possibility of the pseudogap arising solely from local orders, and instead indicate a clear relation between the pseudogap state and Cooper pair formation.

TT 16.11 Tue 12:15 H32

Spin susceptibility in a pseudogap state with spiral magnetic fluctuations — •Paulo Forni[1], Pietro M. Bonetti[1,2], Henrik Müller-Groeling[1], Demerio Villardi[1], and Walter Metzner[1] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]Department of Physics, Harvard University, Cambridge MA 02138, USA

We explore the spin susceptibility in the pseudogap phase of the 2D Hubbard model by introducing spin fluctuations into a spiral magnetic state. This analysis is based on an emergent SU(2) gauge theory following the fractionalization of the electron field into a fermionic chargon, carrying charge, and a bosonic spinon, encoding its spin. Chargons are treated within the random phase approximation in a spiral state. Deep in the pseudogap phase, spin fluctuations can be captured by a gradient expansion of the spinon field, leading to a nonlinear sigma model whose stiffnesses are computed from the underlying chargon order. Our results reveal a gapped, nematic, and SU(2)-symmetric spin susceptibility with a broad spectrum of magnetic excitations. These findings align with key features of the pseudogap phenomenology in cuprates, offering a unified theoretical framework to describe its spin and charge degrees of freedom.

TT 16.12 Tue 12:30 H32

Rise and fall of the pseudogap in the Emery model: Insights for cuprates — •Mario O. Malcolms[1], Henri Menke[1,2], Yi-Tin Tseng[2], Eric Jacob[3], Karsten Held[3], Philipp Hansmann[3], and Thomas Schaefer[1] — [1]Max-Planck-Institut für Festkörperforschung — [2]University of Erlangen-Nürnberg — [3]Institute of Solid State Physics, TU Wien

The intriguing properties of layered cuprate superconductors have not lost their fascination since their discovery. The physical mechanisms behind this rich phenomenology -after almost 40 years of intense community effort- are still highly debated. The reason for the latter is deeply routed in the fact that cuprates are strongly interacting quantum many-body systems, many of whose properties cannot be explained by a simple single-particle picture: their electrons are strongly correlated in space and in time. Adding to the complexity of this material class it has been realized early on, that due to the hybridization of copper $d_{x^2-y^2}$- and oxygen $p_{x/y}$-orbitals in the relevant two-dimensional layers, the undoped parent compounds are charge-transfer, rather than (single-orbital) Mott-Hubbard insulators. The adequate minimal theoretical modellization of cuprates, hence, has to include the oxygen p-orbitals on top of the copper-d ones, enabling, among other properties, (Zhang-Rice) singlet-formation between these orbitals. In this work we make significant progress in the universal description of the cuprates' phase diagrams by extending the powerful λ-corrected dynamical vertex approximation (DΓA) to the three-band Emery model.