TT 37: Ruthenates

Time: Wednesday 15:00–18:30 Location: HSZ 201

TT 37.1 Wed 15:00 HSZ 201

Elastocaloric determination of the phase diagram of Sr_2RuO_4 — •You-Sheng Li[1], Markus Garst[2,3], Jörg Schmalian[3,4], Sayak Ghosh[5], Naoki Kikugawa[6], Dmitry Sokolov[1], Clifford Hicks[1,7], Fabian Jerzembeck[1], Matthias Ikeda[8], Zhenhai Hu[1], Brad Ramshaw[5], Andreas Rost[9], Michael Nicklas[1], and Andrew Mackenzie[1,9] — [1]Max Planck Institute for Chemical Physics of Solids — [2]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie — [3]Institut für Quantenmaterialien und -technologien, Karlsruher Institut für Technologie — [4]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie — [5]Laboratory of Atomic and Solid State Physics, Cornell University — [6]National Institute for Materials Science — [7]School of Physics and Astronomy, University of Birmingham — [8]Department of Applied Physics, Stanford University — [9]School of Physics and Astronomy, University of St Andrews

Uniaxial pressure has shown the capabilities of tuning the electronic structures of Sr_2RuO_4 across a Van Hove singularity (VHS). By performing high precision ac-elastocaloric effect (ECE) measurements under uniaxial strain along <100> direction, we mapped out the phase diagram of Sr_2RuO_4 in detail. Similar to many unconventional superconductors, Sr_2RuO_4 has a SC dome in proximity to a magnetic phase. Besides, we observe a strong reversal of the ECE around the VHS upon entering the SC state. Together with a model calculation, these results strongly suggest a node-less gap opening at the VHS and, thus, put a strong constraint on possible SC order parameters.

TT 37.2 Wed 15:15 HSZ 201

High-resolution elastocaloric effect measurement of 110-Sr_2RuO_4 — •Zhenhai Hu[1,2], You-Sheng Li[1], Fabian Jerzembeck[1], Michael Nicklas[1], Andrew P. Mackenzie[1,2], and Clifford W. Hicks[1,3] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Scottish Universities Physics Alliance, School of Physics and Astronomy, University of St Andrews, St Andrews, UK — [3]School of Physics and Astronomy, University of Birmingham, Birmingham, UK

The symmetry of the order parameter of superconducting Sr_2RuO_4 remains an undetermined question. Whether the order parameter has more than one component is still under debate. If the superconducting order parameter is degenerate and protected by lattice symmetry, the degeneracy will be lifted when the lattice symmetry is broken. Uniaxial pressure, which can continuously break the lattice symmetry, is thus a powerful tool to distinguish whether there is a degeneracy. However, the second transition was not observed in the previous heat capacity and elastocaloric effect measurements with strain applied along <100>. Although stringent constraints on the nature of superconducting states at zero strain were placed by the absence of the second transition with <100> strain, there remains a possibility that a second transition exists under <110> strain. Here we report the latest progress on elastocaloric measurement of Sr_2RuO_4 crystal with strain applied along <110>. Within our experimental precision, no signal indicating a second phase transition below T_c is observed.

TT 37.3 Wed 15:30 HSZ 201

Strain dependence of the superconducting state of Sr_2RuO_4 under <110> uniaxial pressure: No evidence for multi-component order parameter — •Fabian Jerzembeck[1], You-Sheng Li[1], Zhenhai Hu[1], Naoki Kikugawa[2], Dmitry Sokolov[1], Yoshiteru Maeno[3], Michael Niklas[1], Andrew Mackenzie[1], and Clifford Hicks[4] — [1]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany — [2]National Institute for Materials Science, Tsukuba 305-0003, Japan — [3]Department of Physics, Kyoto University, Kyoto 606-8502, Japan — [4]School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, United Kingdom

After more than 25 years of intense research, the order parameter of the unconventional superconductor Sr_2RuO_4 is still unknown. Recent experiments suggest that the order parameter is even-parity and multi-component [1,2], which would result in distinct features in the strain dependence of the superconducting state, such as a kink in the strain dependence of T_c around zero strain [3]. Here, we present uniaxial pressure results along the crystallographic <110>-axis and find no evidence for a discontinuity in T_c, predicted for a multi-component order parameter. However, we can place tight constraints on the thermodynamics of several discussed two-component order parameters.

[1] Pustogow et al., Nature 574, 72 (2019)
[2] Ghosh et al., Nat. Phys. 17, 199 (2021)
[3] Kivelson et al., npj Quantum Materials 5, 43 (2020)

TT 37.4 Wed 15:45 HSZ 201

Giant lattice softening at a Lifshitz transition in the normal state of Sr_2RuO_4 — •Hilary M. L. Noad[1], Kousuke Ishida[1], You-Sheng Li[1], Veronika Stangier[2], Naoki Kikugawa[3], Dmitry A. Sokolov[1], Bongjae Kim[4], Igor I. Mazin[5], Markus Garst[2], Jörg Schmalian[2], Andrew P. Mackenzie[1,6], and Clifford W. Hicks[1,7] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]National Institute for Materials Science, Tsukuba, Japan — [4]Kunsan National University, Gunsan, Korea — [5]George Mason University, Fairfax, USA — [6]University of St Andrews, St Andrews, UK — [7]University of Birmingham, Birmingham, UK

The interplay between lattice and electronic degrees of freedom is a central theme in condensed matter physics. In Sr_2RuO_4, the quasi-two-dimensional Fermi surface can be tuned through a Lifshitz transition—a change in its topology—with uniaxial pressure along the $\langle 100 \rangle$ direction. We investigated the influence of this electronic transition on the lattice by using a piezo-based uniaxial pressure cell to measure the stress-strain relation of Sr_2RuO_4 across the Lifshitz transition. We find a large and strongly temperature-dependent softening of the [100] Young's modulus at the Lifshitz transition. From thermodynamic arguments and comparison to a tight-binding model, we establish that the softening is indeed driven by conduction electrons.

TT 37.5 Wed 16:00 HSZ 201

Effect of superconductivity on the stress-strain relationships of Sr_2RuO_4 — •Kousuke Ishida[1], Hilary Noad[1], You-sheng Li[1], Veronika Stangier[2], Naoki Kikugawa[3], Dmitry Sokolov[1], Michael Nicklas[1], Markus Garst[2], Jörg Schmalian[2], Andrew Mackenzie[1,4], and Clifford Hicks[1,5] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]National Institute for Materials Science, Tsukuba, Japan — [4]University of St. Andrews, St. Andrews, United Kingdom — [5]University of Birmingham, Birmingham, United Kingdom

In the unconventional superconductor Sr_2RuO_4, applying uniaxial stress along a $\langle 100 \rangle$ crystalline direction induces a Lifshitz transition. Here we report on measurement of the stress-strain relationships across this transition down to temperatures below the superconducting transition. In the normal state, the Young's modulus softens by ≈ 10 % in the vicinity of the Lifshitz transition, indicating that this is a local maximum in the electronic free energy. We find that the onset of superconductivity causes a slight hardening of the lattice, though the electronic free energy remains a local maximum at the Lifshitz transition.

TT 37.6 Wed 16:15 HSZ 201

Effect of strain and momentum dependent spin-orbit coupling on the superconducting phase of Sr_2RuO_4 — •Jonas Hauck[1,2], Sophie Beck[1], Dante Kennes[2,3], Antoine Georges[1,4,5,6], and Olivier Gingras[1] — [1]Center for Computational Quantum Physics, Flatiron Institute, NY 10010, USA — [2]Institut für Theorie der Statistischen Physik, RWTH Aachen, 52056 Aachen, Germany and JARA - Fundamentals of Future Information Technology — [3]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, 22761 Hamburg, Germany — [4]Collège de France, 75005 Paris, France — [5]CPHT, CNRS, École Polytechnique, Institut Polytechnique de Paris, 91128 Palaiseau, France — [6]DQMP, Université de Genève, CH-1211 Genève, Switzerland

The nature of Sr_2RuO_4's superconducting order parameter is a long-standing puzzle. First proposed to be a triplet superconductor, the current preferred picture is that of a degenerate singlet order parameter. The main driving force behind this development is the unification of experimental measurements and theoretical predictions. In this talk, we will employ a functional renormalization group approach to firstprinciples derived tight binding models to study the behavior of the leading order parameter under strain. Additionally, we examine the influence of momentum dependent spin-orbit coupling. Our results suggest the possible pairing candidates should be restricted to combinations of a d-wave pseudospin singlet with another order parameter whose critical temperature is not influenced by strain.

15 min. break

TT 37.7 Wed 16:45 HSZ 201

Gate-controlled superconductivity in Sr_2RuO_4 — •Priyana Puliyappara Babu[1], Roman Hartmann[1], Rosalba Fittipaldi[2], Antonio Vecchione[2], Elke Scheer[1], and Angelo Di Bernardo[1] — [1]University of Konstanz, 78457 Konstanz, Germany — [2]University of Salerno, I-84084 Fisciano, Italy

The electrical field effect was believed to be inapplicable for superconductors until 2018 when it was found that the supercurrent I_c in nanowires can be controlled by the application of strong enough voltages to gate electrodes, which has been interpreted as field effect. This discovery has great potential in the future to build hybrid superconductor/semiconductor architectures which might serve reducing the increasing energy demands of modern supercomputers. The majority of observations of such gate effects have been made for BCS superconductors like Ti, Va, Nb, Al etc. Here we report gate control of I_c in transistors made of Sr_2RuO_4 flakes. Sr_2RuO_4 is an unconventional superconductor found in 1994 which has been intensively studied to understand the nature of its superconducting order parameter. Single crystals of Sr_2RuO_4 were mechanically exfoliated to produce flakes which were then patterned into gated nanodevices using a gallium focused ion beam. Total suppression of I_c was observed for gate voltages V_G above 8.3 V. The V_G dependence of I_c at different temperatures and different fields were also investigated. We will also discuss the role of leakage currents between wire and gate and possibilities to further minimize them.

TT 37.8 Wed 17:00 HSZ 201

Non-local electrodynamics and field angle dependence of the superfluid density in Sr_2RuO_2 — •Javier Landaeta[1], Konstantin Semeniuk[1], Joost Aretz[1], Ismardo Bonalde[2], and Elena Hassinger[1] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Centro de Física, Instituto Venezolano de Investigaciones Científicas, Caracas 1020-A, Venezuela

Although being extensively studied for more than 25 years, the nature of the superconducting order parameter (SOP) of the weak type II superconductor Sr_2RuO_4 is still strongly debated. To get insight into the nodal structure of the SOP, we carried out a comprehensive study of the temperature dependence of the superfluid density n_s at various field orientations. By measuring the superconducting lower critical field $H_{c1}(T)$ in a spherical sample with ac-susceptibility, we obtained the temperature dependence of $n_s = H_{c1}(T)/H_{c1}(0)$ down to $0.03\,T_c$. Our results show that follows a low-temperature power law of T^2 up to $0.7T_c$ irrespective of the field angle. The observed behavior is in excellent agreement with what is expected of a type II superconductor with vertical nodes, with a strong influence of non-local electrodynamics. The discussed mechanisms are highly relevant for all weak type II superconductors.

TT 37.9 Wed 17:15 HSZ 201

Propagating charge carrier plasmon in Sr_2RuO_4 — Martin Knupfer[1], Fabian Jerzembeck[2], Naoki Kikugawa[3], Friedrich Roth[4], and •Jörg Fink[1] — [1]Leibniz Institute of Solid State an Materials Research, Dresden — [2]MPI for Chemical Physics of Solids, Dresden — [3]National Institute for Material Science, Tsukuba, Japan — [4]Institute of Exp. Physics, TU Bergakademie Freiberg

We report on studies of charge carrier plasmon excitations in Sr_2RuO_4 by transmission Electron Energy-Loss Spectroscopy. In particular, we present results on the plasmon dispersion and its width as a function of momentum transfer. The dispersion can be qualitatively explained in the framework of RPA calculations, using an unrenormalized tight-binding band structure. The constant long-wavelength width of the plasmon indicates, that it is caused by a decay into inter-band transition and not by quantum critical fluctuations. The results from these studies on a prototypical highly correlated metal system show that the long-wavelength plasmon excitations near 1 eV are caused by resilient quasiparticles and are not influenced by correlation effects.

TT 37.10 Wed 17:30 HSZ 201

Transport and structural characterisation of the metal to insulator transition in Ca_2RuO_4 nanoflakes — •Roman Hartmann[1], Anita Guarino[2], Rosalba Fittipaldi[2], Mario Cuoco[2], Elke Scheer[1], Antonio Vecchione[2], Gerardina Carbone[3], and Angelo di Bernardo[1] — [1]Department of Physics, Universität Konstanz, Konstanz, Germany — [2]CNR-Spin, Salerno, Italy — [3]Max IV Laboratory, Lund, Sweden

The Mott-insulator Ca_2RuO_4 (CRO) has attracted considerable attention due to its insulator to metal transition (IMT) with a transition temperature of 357 K (insulating below, metallic above) and the ability to trigger the IMT using pressure, current or an electric field of just 40 V/cm [1,2]. Unfortunately, stress from a structural transition (orthorombic to tetragonal) during the IMT with an increase in unit cell volume [1] generally breaks bulk crystals. To overcome this limitation we have developed a method to fabricate CRO nanoflakes (despite it not being a layered material) that we can contact using standard lithographic methods. In these nanoflakes we can reversibly trigger the IMT thousands of times by passing current without breaking the sample. The robustness of the devices also enabled us to perform spatially resolved nano-diffraction measurements showing the current-dependent local formation of the metallic phase, confirming the reversibility and giving first insights in the timescale of the IMT.

[1] F. Nakamura et al. Sci. Rep. 3, 2536 (2013)
[2] R. Okazaki et al., JPSJ 82, 103702 (2013)

TT 37.11 Wed 17:45 HSZ 201

Tuning van Hove singularities in strontium ruthenate with isovalent Barium doping — •Caitlin I O'Neil[1,2], Maximillian T Pelly[1,2], Ben Gade[1], Alexandra S Gibbs[1,3,4], and Andreas W Rost[1,2] — [1]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK — [2]MPI for Chemical Physics of Solids, Dresden, Germany — [3]MPI for Solid State Research, Stuttgart, Germany — [4]ISIS Neutron and Muon Source, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, OX11 0QX, UK

Controlling a van Hove singularity (VHS) close the Fermi energy (E_F) of a compound allows control of the low temperature phases as shown for example in recent experiments in single layer ruthenates [1,2]. This study pursues a new direction of structural doping of $Sr_3Ru_2O_7$ by the substitution of barium onto the strontium site. Powder samples of $(Sr_{1-x}Ba_x)_3Ru_2O_7$ were synthesised from x=0.0 - 0.12. The samples were analysed with X-ray and neutron diffraction, magnetic susceptibility and heat capacity measurements. The unit cell volume changes linearly with doping with the primary structural change being an adjustment of the RuO_6 octahedral rotation mode magnitude. Using heat capacity we map the evolution of the VHS towards the E_F, crossing it at x=0.08. Intriguingly, heat capacity shows that the strength of the singularity is decreased, contrary to standard scenarios. In combination with DFT calculations we trace this back to the primary role of the rotation mode in controlling the VHS in ruthenates.

[1] Y.-S. Lie *et al.*, Nature **607**, 276 (2022)
[2] C. A. Marques *et al.*, Adv. Mater. **33**, e21005

TT 37.12 Wed 18:00 HSZ 201

Imaging of compass-like control of the electronic structure in $Sr_3Ru_2O_7$ — Masahiro Naritsuka[1], Izidor Benedičič[1], Luke Rhodes[1], Carolina Marques[1], Christopher Trainer[1], Zhiwei Li[2], Alexander Komarek[2], and •Peter Wahl[1] — [1]SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, Fife, KY16 9SS, United Kingdom — [2]Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straβe 40, 01178 Dresden, Germany

Electronic nematicity results in a surprisingly strong symmetry-breaking reconstruction of electronic states without a significant lattice distortion. An enigmatic example of a nematic state is found in $Sr_3Ru_2O_7$, where a large resistivity anisotropy is stabilized by external magnetic field. The direction of the anisotropy can be controlled by the in-plane component of the magnetic field. Recently, STM measurements have revealed symmetry breaking of the electronic structure at the surface of $Sr_3Ru_2O_7$ even in zero magnetic field. Here, we use low-temperature scanning tunnelling microscopy to study the electronic structure in $Sr_3Ru_2O_7$ in vector magnetic fields. We find that the electronic structure is strongly affected even by relatively small external field when applied in the crystallographic a-b-plane, and is evolving continuously as a function of in-plane field direction. Our result establishes compass-like control over the electronic structure in the surface layer of $Sr_3Ru_2O_7$. We can rationalise the continuous evolution of the electronic structure with field direction through the interplay of magnetism and spin-orbit coupling.

TT 37.13 Wed 18:15 HSZ 201

Optical study of domains and domain walls in $Ca_3Ru_2O_7$ as a function of temperature and uniaxial pressure tuning — •Simli Mishra[1], Fei Sun[1], Elena Gati[1], Hilary Noad[1], Andrew P Mackenzie[1,2], and Veronika Sunko[1,3] — [1]Max Planck Institute, Chemical Physics of Solids, 01187, Dresden, Germany — [2]School of Physics and Astronomy, University of St. Andrews, St. Andrews, KY16 9SS, UK — [3]Department of Physics, University of California, Berkeley, California, 94720, USA

Using optical methods to investigate a material is a powerful non-contact method to explore fundamental physics. In our experiment, we use optics as a versatile microscope to investigate birefringence as well as thermal transport with micron-scale spatial resolution. It can be combined with an in-situ controllable uniaxial pressure device, which has recently been shown to be a powerful tuning parameter to control lattice symmetries in quantum materials. In this contribution, we present the birefringence of an anisotropic material, $Ca_3Ru_2O_7$, which has structural domains at room temperature and can be tuned through a structural phase transition by lowering the temperature at ambient pressure. We will discuss the spatial evolution of its domains as a function of temperature and uniaxial pressure.