# TT 2: Superconductivity: Properties and Electronic Structure 1

Time: Monday 9:30–12:45 Location: HSZ 103

TT 2.1 Mon 9:30 HSZ 103

**Local probe study of exotic superconductivity via magnetic force microscopy** — •Dirk Wulferding[1,2], Hoon Kim[1,3], Ilkyu Yang[1,3], Eric Bauer[4], Joe Thompson[4], Ryan Baumbach[5], Leonardo Civale[4], and Jeehoon Kim[1,3] — [1]CALDES, Institute for Basic Science, Pohang, Korea — [2]IPKM und LENA, TU-BS, Braunschweig, Germany — [3]Dept. of Phys., POSTECH, Pohang, Korea — [4]MPA-CMMS, Los Alamos Natl. Lab., Los Alamos, USA — [5]NHML, Florida State Univ., Tallahassee, USA

Magnetic force microscopy has established itself as a valuable tool to uncover magnetic domain structures on the nanoscale. On the other hand, its magnetically coated tip can serve as an ideal local probe to characterize important properties of superconducting samples [1,2]. We have recently completed designing and constructing a low temperature, $^3$He magnetic force microscope operating within a three-axis vector magnet [3]. We demonstrate how to employ this system to locally investigate intrinsic properties of the heavy fermion superconductor $CeCoIn_5$, such as the London penetration depth, the pairing symmetry, as well as the pinning force of single Abrikosov vortices.

[1] Kim, et al., Supercond. Sci. Technol. 25, 112001 (2012).
[2] Wulferding, et al., Phys. Rev. B 92, 014517 (2015).
[3] Yang, et al., Rev. Sci. Instrum. 87, 023704 (2016).

TT 2.2 Mon 9:45 HSZ 103

**Unexpected rotation of the vortex lattice in the noncentrosymmetric superconductor $Ru_7B_3$** — •Alistair Cameron[1], Yuliia Tymoshenko[1], Yevhen Onykiienko[1], Aleksandr Sukhanov[1], Geetha Balakrishnan[2], Monica C. Hatnean[2], Don McK. Paul[2], and Dmytro Inosov[1] — [1]Institut für Festkörperphysik, Technische Universität Dresden, Germany — [2]Department of Physics, University of Warwick, Coventry, United Kingdom

Superconductivity in a non-centrosymmetric (NCS) system was first observed in the heavy-fermion compound $CePt_3Si$. This has led to a great deal of interest, as parity is no longer a conserved quantity in a NCS superconductor, leading to a superposition of $s$-wave and $p$-wave states. The electronic states around a vortex are strongly influenced by the $s$+$p$-wave order parameter, resulting in an anisotropic vortex, which can express itself in the bulk vortex lattice (VL) structure.

We have performed measurements of the VL in the NCS superconductor $Ru_7B_3$ using small angle neutron scattering. We observe an unusual rotation of the VL with respect to the crystal lattice with changing magnetic field. Normally, a VL selects a single orientation and coordination at any particular magnetic field. However, when changing field below $T_c$ the VL in $Ru_7B_3$ rotates to a new orientation, dependent not on the absolute field but on the change in field. It is possible that this is due to the Magnus force. However, this is universal to all type-II superconductors, whereas the rotation we observe has not been reported before despite decades of research into vortex matter. We therefore cannot rule out a more exotic origin for our observations.

TT 2.3 Mon 10:00 HSZ 103

**Surface state tunneling signatures in two-component superconductor $UPt_3$** — •Fabian Lambert[1], Alireza Akbari[2,3], Peter Thalmeier[4], and Ilya Eremin[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]Asia Pacific Center for Theoretical Physics, Pohang, Gyeongbuk 790-784, Korea — [3]Department of Physics, and Max Planck POSTECH Center for Complex Phase Materials, POSTECH, Pohang 790-784, Korea — [4]Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, Germany

Quasiparticle interference (QPI) imaging of Bogoliubov excitations in quasi-two dimensional unconventional superconductors has become a powerful technique for measuring the superconducting gap and its symmetry. Here, we present the extension of this method to three-dimensional superconductors and analyze the expected QPI spectrum for the two-component heavy fermion superconductor $UPt_3$ whose gap structure is still controversial. Starting from a 3D electronic structure and the three proposed chiral gap models $E_{1g,u}$ or $E_{2u}$, we perform a slab calculation that determines the 2D continuum Bogoliubov- de Gennes (BdG) surface bands and in addition the in-gap Andreev bound states that lead to surface Weyl arcs connecting the projected gap nodes. Both features are very distinct for the three models, in particular the most prominent $E_{2u}$ candidate is singled out by the existence of two Weyl arcs due to the double monopole nodes. The signature of these distinct surface bound and continuum states provides a fingerprint that may finally determine the true nodal structure of $UPt_3$.

TT 2.4 Mon 10:15 HSZ 103

**Scanning tunneling microscope study of MoN at the superconductor-insulator transition** — •Hong Zheng[1], Ina Schneider[2], Christoph Strunk[2], and Elke Scheer[1] — [1]Department of Physics, University of Konstanz, Konstanz, Germany — [2]Department of Physics, University of Regensburg, Regensburg, Germany

Superconductor-insulator transition is a phenomenon which has intrigued scientists for several decades. Generally the transition can be induced by magnetic field or decrease of film thickness. Numerous efforts undertaken in a variety of 2D materials reveal remarkable both in the insulating and superconducting state1-4. However, the mechanism behind the transition is still under debate since no theory can explain yet all these experimental findings.

To learn more about the nature of the transition we perform a scanning tunneling microscope study on molybdenum nitride (MoN) thin films close to the superconductor-insulator transition. The fully studied topography shows a disordered structure of MoN thin films whose typical grain size is about 25 nm regardless of the fabrication temperature. In the scanning tunneling spectroscopy of superconducting samples mostly clear gaps and pronounced coherence peaks with slight intensity fluctuations from spot to spot are observed. We will present first result of shot noise measurements of samples whose thickness is very close to the transition point and try to reveal more intrinsic properties besides the topography and spectroscopy information.

TT 2.5 Mon 10:30 HSZ 103

**Manipulation of the branching of vortex nucleation in rolled-up superconductor microstructures** — E. A. Levchenko[1], R. O. Rezaev[1,2], and •V. M. Fomin[3] — [1]Tomsk Polytechnic University, Tomsk, 634050, Russia — [2]Moscow Engineering Physics Institute, Moscow, 115409, Russia — [3]IFW Dresden, Insitute for Integrative Nanosciences, D-01069 Dresden

An inhomogeneous transport current, which is introduced through multiple electrodes in an open superconductor Nb microtube, is shown to lead to a controllable branching of the vortex nucleation period. The mechanism of this branching is revealed using the time-dependent Ginzburg–Landau equation for the applied magnetic field, which is orthogonal to the axis of the tube. The average number of vortices occurring in the tube per nanosecond can be effectively decreased using the inhomogeneous transport current, which is important for noise and energy dissipation reduction in superconductor applications [1]. The work was supported by the bilateral BMBF-Russia Grant 01DJ13009 and by the COST Action MP1201 “Nanoscale Superconductivity”.

[1] R. O. Rezaev, E. A. Levchenko, V. M. Fomin, Supercond. Sci. Technol. **29**, 045014 (2016).

**15 min. break.**

**Invited Talk** TT 2.6 Mon 11:00 HSZ 103

**The Echo of Superconductivity: Higgs Oscillations of Superconductors in Non-Equilibrium** — •Dirk Manske — Max-Planck-Institut für Festkörperforschung

Since the 1:1 analogy of superconductivity with the Higgs mechanism in high-energy physics, the Higgs mode in condensed matter attracted much interest recently [1]. Using Density-Matrix-Theory we predicted in 2008 the existence of Higgs oscillations in superconductors under non-equilibrium conditions. Recently, they have been observed in the optical conductivity of a BCS superconductor using time-resolved pump-probe experiments.

New predictions are made for 2-band superconductors [2] in which 2 Higgs oscillations can not only couple, but also are changing the dispersion of the Leggett mode. This provides a unique coupling between phase and amplitude that can occur only in non-equilibrium.

The nature of Higgs oscillations allows to determine the symmetry of the superconducting order parameter and, thus, marks the way to establish a new 'Higgs spectroscopy' of unconventional superconductors.

[1] D. Manske and M. Dressel, Physik Journal 15, 37 (Jan 2016).
[2] H. Krull et al., Nature Comm. 7, 11921 (2016).

TT 2.7 Mon 11:30 HSZ 103

**Observation of an anomalous resistive phase in a strained few-layer $NbSe_2$ crystal** — •Andreas Eller, Tobias Scharff, Nicola Paradiso, Sofia Blanter, and Christoph Strunk — Universität Regensburg

We report on an anomalous resistive reentrance in a thin exfoliated crystal of $NbSe_2$. While most of the crystal undergoes a superconducting transition at 5.75 K, a strained region in the middle of it displays a resistive transition at around 4 K. The four-terminal resistance saturates at low temperatures. Similarly to the superconducting phase, the resistive phase can be destroyed by applying a magnetic field. At high bias the superconducting phase and the resistive phase show a dual behavior: while the former is quenched by a critical current, the latter is quenched by a critical voltage. Both the critical voltage for the resistive phase and the superconducting current for the superconducting phase display a similar dependence on temperature and magnetic field.

TT 2.8 Mon 11:45 HSZ 103

**Superconducting ferecrystals: turbostratically disordered atomic-scale layered $(PbSe)_{1.14}(NbSe_2)_n$ heterostructures** — Corinna Grosse[1], Matti B. Alemayehu[2], Matthias Falmbigl[2], Anna Mogilatenko[3], Olivio Chiatti[1], David C. Johnson[2], and •Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Dept. of Chemistry, University of Oregon, Eugene, Oregon 97403, United States — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Hybrid electronic heterostructures of semi- and superconducting layers possess very different properties from their bulk counterparts. Here, we demonstrate superconductivity in ferecrystal films: turbostratically disordered single-, bi- and trilayers of $NbSe_2$ separated by PbSe layers. The turbostratic (orientation) disorder between individual layers does not destroy superconductivity. The artificial sequences of atomic-scale 2D layers are structurally independent of their neighbours in the growth direction. This opens up new opportunities of stacking arbitrary numbers of hybrid superconducting-semiconducting layers in heterostructures which are not available otherwise, because epitaxial strain is avoided. The observation of superconductivity and systematic $T_c$ changes with nanostructure make this synthesis approach of particular interest for realizing hybrid systems in the search of 2D superconductivity and the design of novel electronic hybrid heterostructures.

[1] C. Grosse *et. al*, Scientific Reports **6**, 33457 (2016).

TT 2.9 Mon 12:00 HSZ 103

**Superconductivity in $TaSnS_2$** — •Manuel Feig[1,2], Matej Bobnar[2], Walter Schnelle[2], Igor Veremchuk[2], Sergiy Medvediev[2], Andreas Leithe-Jasper[2], and Roman Gumeniuk[1,2] — [1]Institut für Experimentelle Physik, TU Bergakademie Freiberg, Leipziger Str. 23, 09596 Freiberg, Germany — [2]MPI für Chemische Physik fester Stoffe, Nöthnitzer Str. 40, 01187 Dresden, Germany

The hexagonal $TaSnS_2$ sulphide is reported to be a superconductor with $T_c = 2.8$ K [1]. However, its superconducting parameters have not been studied up to now. The powder of $TaSnS_2$ was compacted by spark plasma sintering (SPS). The measurements of magnetic susceptibility revealed a superconducting transition at $T_c = 2.9$ K in agreement with earlier report [1]. The measurements of electrical resistivity and specific heat showed different critical magnetic fields $\mu_0 H_{c2}$ = 22 mT and 200 mT, respectively. This contradiction can indicate an anisotropy of superconducting properties caused by 2H-structure of $TaSnS_2$. The specific heat jump at the transition $\Delta c_p/\gamma T_c = 0.9$ and the energy gap ratio $\Delta(0)/k_B T_c = 1.17$ are well below the values (e.g. 1.43 and 1.76) predicted by BCS theory. This can be again due to an anisotropy of properties or/and by a multigap type of superconductivity. To finally shed light on the superconducting mechanisms in $TaSnS_2$ measurements on oriented crystals are required. High pressure measurements revealed that $T_c$ for $TaSnS_2$ becomes zero for $p > 2.5$ GPa. The Raman measurements indicated a structural phase transition for $TaSnS_2$ above 7 GPa.

[1] J. Dijkastra et al., Phys. Rev. B 40 (1989) 12111.

TT 2.10 Mon 12:15 HSZ 103

**Surface reconstructions and Abrikosov lattice in the heavy electron superconductor $TlNi_2Se_2$** — •Stefan Wilfert[1], Martin Schmitt[1], Henrik Schmidt[1], Tobias Mauerer[1], Paolo Sessi[1], Hangdong Wang[2], Qianhui Mao[2], Minghu Fang[2], and Matthias Bode[1] — [1]Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Department of Physics, Zhejiang University, Hangzhou 310027, China

We report on the structural and electronic properties of the heavy electron superconductor $TlNi_2Se_2$. By using a variable-temperature STM various surface $(2 \times n)$ reconstructions were observed which, similar to Fe-based superconductors [1], strongly depend on the temperature during cleavage and the measurement process. Additionally, we performed measurements with a low-temperature STM and found the opening of a superconducting gap. The values for critical temperature and critical magnetic field are in good agreement with earlier transport measurements [2]. In the superconducting state the formation of an Abrikosov lattice was observed without any sign of a zero bias anomaly in the vortex core.

[1] F. Massee *et al.*, Phys. Rev. B **80**, 140507(R) (2009).
[2] H. Wang *et al.*, Phys. Rev. Lett **111**, 207001 (2013).

TT 2.11 Mon 12:30 HSZ 103

**Pressure-structure relationships in the 10 K layered carbide halide superconductor $Y_2C_2I_2$** — •Kyunsoo Ahn[1,2], Reinhard K. Kremer[1], Arndt Simon[1], and Alfonso Munoz[3] — [1]MPI for Solid State Research, Stuttgart, Germany — [2]Department of Chemistry, Yonsei University, Wonju 220-710, Korea — [3]Departamento de Física, Instituto de Materiales y Nanotecnología, and MALTA Consolider Team, Universidad de La Laguna, 38200 La Laguna, Tenerife, Spain

In order to investigate to what extend the superconducting and the structural properties of the 10 K layered yttrium carbide halide superconductor $Y_2C_2I_2$ can be modified by external pressure we have studied the pressure dependence of the superconducting critical temperature and the crystal structure of $Y_2C_2I_2$. Up to ∼2.5 GPa. We observe an increase of $T_c$ from 10 K to about 12 K and a structural phase transition from a 1s to a 3s stacking variant. This occurs at ∼2.5 GPa above which $T_c$ rapidly decreases to a value of ∼7.5 K at 7.5 GPa. Ab initio calculations corroborate the structural phase transition to occur at a critical cell volume of ∼270 Å$^3$ corresponding to a pressure of ∼2.4 GPa, in good agreement with the experimental findings. The pressure dependence of $T_c$ and inter-atomic distances and angles are discussed with respect to the electronic structure which is characterized by bands of low dispersion and narrow peak-valley features in the electronic density of states at the Fermi level.