TT 48: Superconductivity: Heterostructures, Andreev Scattering, Proximity Effect, Vortices

Time: Friday 9:30–13:00 Location: H 2053

TT 48.1 Fri 9:30 H 2053

Epitaxial $Fe/BaFe_{2-x}Co_xAs_2$ multilayers — •Jan Engelmann[1,2], Silvia Haindl[1], Kazumasa Iida[1], Fritz Kurth[1], Christian Behler[1], Ruben Huehne[1], Bernhard Holzapfel[1], and Ludwig Schultz[1,2] — [1]IFW Dresden, P. O. Box 27 01 16, 01171 Dresden, Germany — [2]TU Dresden, Institut für Festkörperphysik, D-01069 Dresden, Germany

Heterostructures of superconducting/ferromagnetic layers have attracted attention in controlling superconductivity by changing the magnetic state. In this work we present multilayers consisting of iron and Co-doped $BaFe_2As_2$ (Ba-122) fabricated by UHV pulsed laser deposition. We have employed the advantage of a coherent interfacial bonding between the FeAs tetrahedron of the iron pnictides and bcc Fe which enables the growth of epitaxial bi- and multilayers of Fe and the new Fe-based superconductors of high crystalline quality [1, 2] The epitaxial growth of the heterostructures was controlled in-situ by reflection high-energy electron diffraction (RHEED) and ex-situ by X-ray analysis. We discuss selected results of transport measurements with respect to the influence of additional Fe layers.

[1] T. Thersleff et al., APL 97 (2010) 022506
[2] K. Iida et al., APL 97 (2010) 172507

TT 48.2 Fri 9:45 H 2053

Transport, magnetic and structural properties of $YBa_2Cu_3O_7/La_{0.7}Ca_{0.3}MnO_3$ heterostructures grown on SrTiO3 (110) substrates — •Luqman Mustafa[1], Soltan Soltan[1,2], Gennady Logvenov[1], Hanns-Ulrich Habermeier[1], and Bernhard Keimer[1] — [1]Max Planck Institute or Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany — [2]Physics Department, Faculty of science, Helwan University, 11792-Helwan, Cairo, Egypt

YBCO/LCMO bi- and multi-layers were grown on STO (110) substrates by Pulsed Laser Deposition (PLD) technique with the goal to study the interface of an oxide ferromagnet and a cuprate superconductor where the CuO_2 planes are perpendicular to the film plane. The structure was investigated by X-ray diffractometry, transport and magnetic properties were studied by conventional four-point-probe and SQUID techniques respectively.

Depending on the preparation conditions the single layer YBCO as well as bilayers can be grown in the (110), (103)/(10-3), as well as mixed orientations. Large anisotropy of electrical conductivity in these films was observed in case of (110)-oriented YBCO layer and less pronounced anisotropy in case of (103)-oriented one. We present a detailed analysis of the anisotropy of the magnetization of such bi- and multi-layers emphasizing its relation to the orientation of the YBCO film.

TT 48.3 Fri 10:00 H 2053

Transport measurements in superconductor/Heusler bilayers — •Inga-Mareen Imort, Savio Fabretti, Patrick Thomas, Günter Reiss, and Andy Thomas — Fakultät für Physik, Universität Bielefeld, Bielefeld, Germany

Superconductivity and ferromagnetism are two contrary phenomena due to their electronic properties. The investigation of superconductor (S)/ferromagnet (F) heterostructures has attracted a lot of scientific interest since they allow studying the interplay between superconductivity and ferromagnetism. Additionally, applications seem possible such as F/S/F spin valves and S/F/S π-junctions. Using transport- and magnetotransport-measurements, we investigate the behavior of the superconducting transition temperature T_c in NbTi/Co_2FeSi bilayers as a function of different layer thicknesses and for varying magnetic moments of the Co_2FeSi layers. Using rf - magnetron sputtering, NbTi/Co_2FeSi bilayers were grown on single-crystalline MgO(001) substrates and in-situ annealed at different temperatures. The layered character of our samples has been tested by X-ray diffraction (XRD) scans. The electronic and magnetic transport measurements have been performed between 3 and 300 K with the magnetic field up to 4 T oriented in the film plane. The dependence of T_c on the NbTi- and Co_2FeSi-layer thickness enables an estimation of the interface transparency of the NbTi/Co_2FeSi barrier in the framework of recent theoretical models. This work has been supported by the NRW MIFW.

TT 48.4 Fri 10:15 H 2053

Superconductivity and Magnetism in the presence of interface-induced Rashba spin-orbit coupling — •Florian Loder, Arno P. Kampf, and Thilo Kopp — Zentrum für Elektronische Korrelationen und Magnetismus, Institut für Physik, Universität Augsburg, Deutschland

Two dimensional electron systems at oxide interfaces are often influenced by a Rashba type spin-orbit coupling (SOC), which is tunable by a transverse electric field. Ferromagnetism at the interface can simultaneously induce strong local magnetic fields. This combination of SOC and magnetism leads to anisotropic two-sheeted Fermi surfaces, on which superconductivity with finite-momentum pairing is favored. The superconducting order parameter is derived within a generalized pairing model realizing both, the FFLO superconductor in the limit of vanishing SOC and a mixed-parity pairing state with zero pair momentum if the magnetism vanishes. The nature of the pairing state is discussed in the context of interface superconductivity and ferromagnetism at LAO-STO interfaces [1,2].

[1] Lu Li, C. Richter, J. Mannhart, and R. C. Ashoori, Nature Physics 7, 762 (2011).
[2] J. A. Bert, B. Kallisky, C. Bell, M. Kim, Y. Hikita, H. Y. Hwang, and K. A. Moler, Nature Physics 7, 767 (2011).

TT 48.5 Fri 10:30 H 2053

Proximity effect in semiconductor films with spin-splitting and spin-orbit interaction — •Jens Michelsen and Roland Grein — Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

Superconducting heterostructures with spin-active materials have emerged as promising platforms for engineering topological superconductors featuring Majorana bound states at surfaces, edges and vortices. Here we present a method for evaluating, from a microscopic model, the band structure of a semiconductor film of finite thickness deposited on top of a conventional superconductor. Analytical expressions for the proximity induced gap openings are presented in terms of microscopic parameters and the proximity effect in presence of spin-orbit and exchange splitting is visualized in terms of Andreev reflection processes. An expression for the topological invariant, associated with the existence of Majorana bound states, is shown to depend only on parameters of the semiconductor film. The finite thickness of the film leads to resonant states in the film giving rise to a complex band structure with the topological phase alternating between trivial and non-trivial as the parameters are tuned of the film are tuned.

TT 48.6 Fri 10:45 H 2053

Proximity effect in noncentrosymmetric superconductors hybrid structures — •Gaetano Annunziata[1], Jacob Linder[2], and Dirk Manske[1] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany — [2]Department of Physics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

We analyze proximity effect in junctions of noncentrosymmetric superconductors (NCSs) and diffusive metals/ferromagnets within the quasiclassical theory of superconductivity. We show how by standard STM/STS measurements for LDOS in the proximate region [1] exploiting the directional dependence of pair-breaking effect of the exchange field on the triplet Cooper pairs [2,3], several superconducting scenarios for NCSs characterized by different kinds of edge states [4] can be discriminated, and that within a single scenario information on the relative magnitude of triplet and singlet gaps in NCSs can be obtained [5].

[1] T. Kontos, M. Aprili, J. Lesueur, F. Genêt, B. Stephanidis, and R. Boursier, Phys. Rev. Lett. **89**, 137007 (2002).
[2] P. M. R. Brydon and D. Manske, Phys. Rev. Lett. **103**, 147001 (2009).
[3] G. Annunziata, M. Cuoco, C. Noce, A. Sudbø, and J. Linder, Phys. Rev. B **83**, 060508(R) (2011).
[4] Y. Tanaka, Y. Mizuno, T. Yokoyama, K. Yada, and M. Sato, Phys. Rev. Lett. **105**, 097002 (2010).
[5] G. Annunziata, J. Linder and D. Manske, to be published.

TT 48.7 Fri 11:00 H 2053

Transport properties of a Josephson junction coupled to the dynamics of a nanomagnet — •Cecilia Holmqvist[1], Wolfgang Belzig[1], and Mikael Fogelström[2] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz — [2]Department of Microtechnology and Nanoscience - MC2, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

The interplay between superconductivity and ferromagnetism in nanoscale junctions may lead to interesting effects that could be utilized in spintronics devices. Here, we present a theoretical study of a superconducting point contact coupled to a nanomagnet. The magnetization of the nanomagnet is brought into precession by an external magnetic field. The coupling between the Josephson effect and the magnetization precession modifies the current-phase relation [1]. Additionally, the critical current is enhanced at finite temperatures due to coupling between the continuum of states and the Andreev levels. The spin-dependent Andreev scattering also generates an ac spin current, that decays on the length scale of the superconducting coherence length. For a voltage-biased Josephson junction coupled to a precessing spin, the interplay between spin-scattering processes and multiple Andreev reflection, characterized by the Larmor and Josephson frequencies, respectively, leads to a modification of the current-voltage characteristics as well as the spin transport properties.
[1] C. Holmqvist, S. Teber, and M. Fogelström, Phys. Rev. B 83, 104521 (2011)

15 min. break.

TT 48.8 Fri 11:30 H 2053

Characterization and electronic transport properties of nanostructured Pb/Fe point contacts — •Jörg Gramich[1], Gernot Goll[1], Christoph Sürgers[2], and Hilbert v. Löhneysen[1,2] — [1]DFG-Centrum für Funktionelle Nanostrukturen, KIT Karlsruhe — [2]Physikalisches Institut, KIT Karlsruhe

We experimentally investigate the spin-polarized transport through nanostructured Pb/Fe point contacts at low temperatures. All samples are produced by *in-situ* evaporation of the metals on either side of a Si_3N_4 membrane with a nanostructured hole, resulting in clean metal interfaces. A direct measurement of the nanocontact size allows for the first time a comparison with theoretical models for contact-size estimates of heterocontacts. The ballistic transport regime for contacts with high Knudsen ratio is demonstrated by features in the spectra such as phonon peaks and the critical pair-breaking current of Pb. The spin polarization P of the current through the superconductor-ferromagnet contact is determined by means of Andreev reflection at the S/F interface. The observed systematic dependence on the contact radius a and superconducting transition temperature T_c is compared to previous measurements on Al/Fe nanocontacts.

TT 48.9 Fri 11:45 H 2053

A Numerical Study of the Superconducting Proximity Effect in Topological Surface States — •Roland Grein[1,2], Jens Michelsen[1], and Matthias Eschrig[2] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany — [2]SEPnet and Hubbard Theory Consortium, Department of Physics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, United Kingdom

We study a microcopic model to investigate the superconducting proximity effect in the topological surface states of Bi_2Se_3 by means of the recursive Green's function technique. We find that the phenomenological Fu-Kane model, usually used to describe the proximity effect in these states, breaks down at energies close to the superconducting bulk-gap and in the case of strong coupling between the topological insulator and the superconductor[1].
[1] R. Grein, J. Michelsen, M. Eschrig, arXiv:1111.0445 (2011)

TT 48.10 Fri 12:00 H 2053

Nonlocal thermoelectric symmetry relations in ferromagnet-superconductor proximity structures — •Peter Machon[1], Matthias Eschrig[1,2], and Wolfgang Belzig[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics, Royal Holloway, University of London, Egham Hill, EGHAM, TW20 0EX, UK

The symmetries of thermal and electric transport coefficients in quantum coherent structures are related to fundamental thermodynamic principles by the Onsager reciprocity. We generalize Onsager's symmetry relation to nonlocal thermoelectric currents in a three terminal ferromagnet-superconductor heterostructur including spin-dependent crossed Andreev reflection and direct electron transfer processes. We proof this general symmetry by applying spin-dependent boundary conditions for quasiclassical Green's functions in both the clean and the dirty limit. We predict an anomalously large local thermopower and a nonlocal Seebeck effect, which can be explained by the spin-dependent spectral properties.

TT 48.11 Fri 12:15 H 2053

Driven superconducting proximity effect in interacting quantum dots — •Ali G. Moghaddam[1], Michele Governale[2], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CeNIDE, 47048 Duisburg, Germany — [2]School of Chemical and Physical Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand

We show that strong superconducting correlations can be induced in an interacting quantum dot (QD) using fast oscillations in the effective coupling between the dot and superconducting leads which drive the dot out of equilibrium. This is in contrast with the well-known equilibrium state suppression of proximity effect in interacting QDs. In fact although interaction prohibits the superposition of empty (0) and doubly-occupied (d) states, fast coherent dynamics accompanied by the fast variations in the tunnel coupling can produce a nonequilibrium finite probability for such a superposition. Subsequently the superconducting correlations are established inside the QD when the energy difference between 0 and d states coincide with the frequency of driving oscillations. Simultaneously the nonequilibrium occupation probabilities of 0 and d states cause a pumping current flowing to the normal lead connected to the dot. Finally we demonstrate coherent oscillations in both dot charge and current by applying a pulsed oscillatory field to the coupling of dot and superconductor which show the possibility of coherent manipulation in the subspace of 0 and d states by changing the pulse duration.

TT 48.12 Fri 12:30 H 2053

The role of thermal conductivity on the nucleation and propagation of magnetic flux avalanches — •Claudia Stahl[1], Sebastian Treiber[1], and Joachim Albrecht[2] — [1]Max-Planck-Institut für Intelligente Systeme, Heisenbergstraße 3, 70569 Stuttgart — [2]Hochschule Aalen, Beethovenstraße 1, 73430 Aalen

Below a certain threshold temperature the critical state of superconducting thin films can get unstable, which results in large magnetic flux avalanches. In thin MgB_2 films with an inhomogeneous current density distribution both the nucleation and propagation of magnetic flux avalanches are highly favoured [1].

Magnetization measurements and magneto - optical imaging are used to characterize inhomogeneous MgB_2 thin films.

Avalanches occur when the thermal transport gets much slower than the transport by electric conductivity. Increasing the thermal conductivity by a gold cover layer leads to a suppression of the instabilities. It is investigated how the two steps of the avalanche process, nucleation and propagation, are influenced by the thermal conductivity in inhomogeneous MgB_2 thin films. We found that the gold layer in particular influences the initial phase of the avalanche formation.
[1] S. Treiber, C. Stahl, G. Schütz, and J. Albrecht, *Physical Review B* **84**, 094533 (2011).

TT 48.13 Fri 12:45 H 2053

Superconducting vortex dynamics in cylindrical Nb micro- and nanotubes — •Vladimir M. Fomin[1], Roman O. Rezaev[1,2], and Oliver G. Schmidt[1,3] — [1]Institute for Integrative Nanosciences, IFW-Dresden, D-01069 Dresden, Germany — [2]Laboratory of Mathematical Physics, Tomsk Polytechnic University, 634050 Tomsk, Russia — [3]Material Systems for Nanoelectronics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Advancements in fabrication of rolled-up micro- and nanotubes including superconductor layers (e.g., InGaAs/GaAs/Nb) open new ways for investigation of the vortex matter in superconductors with curved geometries. Geometry determines the dynamics of vortices in the presence of transport currents in open superconductor micro- and nanotubes subject to a magnetic field orthogonal to the axis. Vortices nucleate periodically at one edge of the tube, subsequently move along the tube under the action of the Lorentz force and denucleate at the opposite edge of the tube. Characteristic times of nonequilibrium vortex dynamics in an open tube are efficiently controlled by the tube radius. The magnetic field, at which the vortices begin to nucleate at the edge

of the structure, is increased several times by rolling up a planar film in a tube. This effect is caused not only by a spatial dependence of the magnetic field component normal to the cylindrical surface, but also by correlations between the states of the superconducting order parameter in the opposite areas of the cylindrical surface.