TT 64: Superconductivity: Heterostructures, Andreev Scattering, Vortex Physics

Time: Thursday 15:00–18:15 Location: H21

TT 64.1 Thu 15:00 H21

Spin injection from a normal metal into a mesoscopic superconductor — •Michael J. Wolf[1], Florian Hübler[1,2,3], Stefan Kolenda[1], Hilbert v. Löhneysen[2,3,4], and Detlef Beckmann[1,2] — [1]Institut für Nanotechnologie, KIT, 76021 Karlsruhe, Germany — [2]Center for Functional Nanostructures, KIT, 76131 Karlsruhe, Germany — [3]Institut für Festkörperphysik, KIT, 76021 Karlsruhe, Germany — [4]Physikalisches Institut, KIT, 76128 Karlsruhe, Germany

We report on nonlocal transport in superconductor hybrid structures, with ferromagnetic as well as normal-metal tunnel junctions attached to the superconductor. In the presence of a strong Zeeman splitting of the density of states, both charge and spin imbalance is injected into the superconductor. While previous experiments [1,2] demonstrated spin injection from ferromagnetic electrodes, we show that spin imbalance is also created for normal-metal injector contacts. Using the combination of ferromagnetic and normal-metal detectors allows us to directly discriminate between charge and spin injection, and demonstrate a complete separation of charge and spin imbalance. The relaxation length of the spin imbalance is of the order of several μm and is found to increase with a magnetic field, but is independent of temperature. We further discuss possible relaxation mechanisms for the explanation of the spin relaxation length.

[1] F. Hübler *et al.*, Phys. Rev. Lett. **109**, 207001 (2012)
[2] C. H. L. Quay *et al.*, arXiv:1208.0500

TT 64.2 Thu 15:15 H21

Subgap-anomalies in 3-terminal hybrid superconductor/normal metal nanostructures — •Andreas H. Pfeffer[1,2], Hervé Courtois[3], and François Lefloch[1] — [1]CEA/INAC/SPSMS, Grenoble, France — [2]Nanoscience Foundation (RTRA), Grenoble, France — [3]CNRS/Néel Institute and UJF, Grenoble, France

We have studied the electronic transport properties of three terminal superconductor (S) - normal metal (N) - superconductor (S) nanodevices using a new SQUID-based experimental set-up working at very low temperature (30 mK) and dedicated for high sensitive conductance and current noise correlations measurements [1]. In a geometry where a T-shaped normal metal (Cu) is connected to three superconducting reservoirs (Al), new subgap anomalies appear in the differential conductance for specific values of the chemical potential applied to the superconductors. The most emphasized line appears when two superconductors (collectors) are biased at opposite voltage with respect to the third superconducting electrode (injector). This anomaly is consistent with the prediction of non-local quartets as the result of double crossed Andreev reflections (dCAR)[2]. In this particular process, a Cooper pair originating from the injector is split in two quasiparticles that recombine into Cooper pairs in each of the two collectors. Additional features appear for other integer voltage ratios and could be attributed to higher order processes of dCAR. The mechanism of non-local quartet opens perspectives toward a new generation of entanglers.

[1] PRL 107, 077005 (2011); RSI 83, 115107 (2012)
[2] PRL 106, 257005 (2011)

TT 64.3 Thu 15:30 H21

Interaction of ultra soft magnetic materials with the high-T_c superconductor YBCO — •Claudia Stahl[1], Sebastian Treiber[1], Patrick Walker[1,2], Gisela Schütz[1], and Joachim Albrecht[2] — [1]Max Planck Institute for Intelligent Systems, Heisenbergstraße 3, 70569 Stuttgart — [2]Aalen University, Beethovenstraße 1, 73430 Aalen

We have grown bilayers of optimally doped $YBa_2Cu_3O_{7-\delta}$ (YBCO) and ferromagnetic CoFeB on single-crystalline substrates by pulsed laser deposition and sputtering. These heterostructures are typically composed of about 100 nm YBCO and several 10 nm of CoFeB. Regarding the superconductor, the properties of the YBCO film change as a consequence of the vicinity of the ferromagnet. In detail we investigated the critical current density as a function of temperature, applied field and time as well as the transition temperature by SQUID magnetization measurements and quantitative magneto-optical measurements. The amorphous material CoFeB exhibits an in plane anisotropy and a very low coercivity. From magneto-optical images we find that the flux line lattice of the superconductor is mapped into the magnet and still visible as significant magnetic out-of-plane contrast at room temperature. We discuss this phenomenon as a new route to high-resolution mapping of the flux line distribution on a nanometer scale.

TT 64.4 Thu 15:45 H21

Proximity effect in ferromagnet-superconductor heterostructures with noncollinear magnetisation — •Daniel Fritsch and James F. Annett — H. H. Wills Physics Laboratory, University of Bristol, Tyndall Avenue, Bristol BS8 1TL, United Kingdom

At the interface between a normal metal and a superconductor (SC) the proximity effect allows the (singlet pair) superconducting properties to leak into the normal metal side of the interface. Replacing the normal metal by a ferromagnet (FM) it has been found that unusual triplet pairs can form, which have been shown to decay much further into the metallic side compared to the singlet pairs [1]. This is called the long-range proximity effect.

To study the effects of triplet pair generation in the vicinity of a FM/SC interface we present results based on numerical solutions of the Bogoliubov - de Gennes equations, including spin-orbit coupling and noncollinear magnetisations. We use the calculated pairing amplitude and local density of states to obtain information about relevant proximity length depending on system size and exchange fields.

[1] J. W. A. Robinson, J. D. S. Witt, and M. G. Blamire, Science **329**, 59 (2010).

TT 64.5 Thu 16:00 H21

Nonlocal thermoelectric effects and nonlocal Onsager relations in a three-terminal proximity-coupled superconductor-ferromagnet device — •Peter Machon[1], Matthias Eschrig[2], and Wolfgang Belzig[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]SEPnet and Hubbard Theory Consortium, Department of Physics, Royal Holloway, University of London, Egham, Surrey TW20 0EX, United Kingdom

We study thermal and charge transport in a three-terminal setup consisting of a superconducting and two ferromagnetic contacts. We predict that the simultaneous presence of spin-filtering and of spin-dependent scattering phase shifts at each of the two interfaces will lead to very large nonlocal thermoelectric effects both in clean and in disordered systems. The symmetries of thermal and electric transport coefficients are related to fundamental thermodynamic principles by the Onsager reciprocity. Our results show that a nonlocal version of the Onsager relations for thermoelectric currents holds in a three terminal quantum coherent ferromagnet-superconductor heterostructure including spin-dependent crossed Andreev reflection and coherent electron transfer processes.

TT 64.6 Thu 16:15 H21

Josephson current through a quantum dot coupled to a molecular magnet — •Pascal Stadler, Cecilia Holmqvist, and Wolfgang Belzig — Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany

Non-dissipative Josephson currents are carried by sharp Andreev states within the superconducting energy gap. We theoretically study the electronic transport of a magnetically tunable nanoscale junction consisting of a quantum dot connected to two superconducting leads and coupled to the spin of a molecular magnet. The exchange interaction between the molecular magnet and the quantum dot modifies the Andreev states due to a spin-dependent renormalization of the quantum dot's energy level and the induction of spin-flips. A magnetic field applied to the central region of the quantum dot and the molecular magnet further tunes the Josephson current and starts a precession of the molecular magnet's spin. We use a non-equilibrium Green's function approach to evaluate the transport properties of the junction. Our calculations reveal that the magnetic field and the exchange interaction between the molecular magnet and the electrons occupying the energy level of the quantum dot can trigger transitions from a 0 to a π state of the Josephson junction. The redistribution of the occupied state induced by the magnetic field strongly modifies the current phase relation. The critical current exhibits a sharp increase as a function of the magnetic field.

15 min. break

TT 64.7 Thu 16:45 H21

ac susceptibility investigation of vortex dynamics in nearly-optimally doped ReFeAs$O_{1-x}F_x$ (Re = La, Ce, Sm) and Ba$(Fe_{1-x}Co_x)_2As_2$ superconductors — •Giacomo Prando[1], Romain Giraud[1], Saicharan Aswartham[1], Samuele Sanna[2], Mahmoud Abdel-Hafiez[1], Matteo Tropeano[3], Hans-Joachim Grafe[1], Marina Putti[3], Sabine Wurmehl[1], Anja Wolter-Giraud[1], Bernd Buechner[1], Roberto De Renzi[4], and Pietro Carretta[2] — [1]Leibniz-Institut für Festkörper- und Werkstoff-forschung (IFW) Dresden, Germany — [2]Dipartimento di Fisica, Universitá di Pavia and CNISM, Italy — [3]Dipartimento di Fisica, Universitá di Genova, Italy — [4]Dipartimento di Fisica, Universitá di Parma and CNISM, Italy

In this contribution we will report about the dynamical features of the flux lines in both optimally-doped ReFeAs$O_{1-x}F_x$ and Ba$(Fe_{1-x}Co_x)_2As_2$ superconductors as investigated by means of ac susceptometry. The features of pinning are derived in the case of ReFeAs$O_{1-x}F_x$ powder samples for several Re ions within the framework of the thermally-activated flux-creep model. In the case of the investigated Ba$(Fe_{1-x}Co_x)_2As_2$ single-crystal, the extremely high-quality and the associated low-degree of quenched disorder in the sample allow us to enlighten the emergence of a thermodynamical phase transition between the different configuration of vortices in the $H-T$ phase diagram. Insights will be provided into the features of this phase transition and into the nature of the glassy phase, being turned into a Bragg-like glass at low values of magnetic field.

TT 64.8 Thu 17:00 H21

The relation between electrical fields and flux avalanches in MgB_2 films — •Sebastian Treiber[1], Claudia Stahl[1], Soltan Soltan[2,4], and Joachim Albrecht[3] — [1]Max-Planck-Institut für Intelligente Systeme, Heisenbergstrasse 3, 70569 Stuttgart, Germany — [2]Max-Planck-Institut für Festkörperfoschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany — [3]Hochschule Aalen, Beethovenstrasse 1, 73430 Aalen, Germany — [4]Physics Department, Faculty of Science, Helwan University, 11792-Cairo, Egypt

The critical state in superconductors with strong pinning is inherently unstable. In most metallic materials, there is a threshold temperature below which large flux jump can destroy the critical state locally or even globally. The basic mechanism is a chain reaction due to local overheating. Thus, heat capacity and conductivity are important quantities in this process. Here, we want to focus on another important parameter, namely the electrical field. Large flux jumps, which are often referred to as flux avalanches, are triggered by a threshold value of the electrical field. Basically, one would expect the change of the external magnetic field $\dot{H}_{ext}$ as a direct source for electrical fields. Though a change of H_{ext} is necessary to trigger an avalanche, the mechanism is more complex which is shown by means of magneto-optical, magnetization and transport measurements.

TT 64.9 Thu 17:15 H21

Neutron dark field imaging of domain structures in superconductors — •Tommy Reimann[1,2], Christian Grünzweig[3], Sebastian Mühlbauer[1], Michael Schulz[1,2], and Peter Böni[2] — [1]TU München, Forschungsneutronenquelle Heinz Maier Leibnitz (FRM II), 85747 Garching, Germany — [2]Physik Department E21, TU München, 85747 Garching, Germany — [3]Paul-Scherrer-Institut, CH-5232 Villigen, Switzerland

In the intermediate mixed state (IMS) of a type II superconductor (SC), the sample splits up into field-free Meissner domains and Shubnikov domains which carry the vortex lattice. The IMS is analog to the intermediate state (IS) of a type-I superconductor with normal and superconducting domains. Experiments on the topology of both states show a variety of different patterns including striped, dendritic and bubble phases, which represent typical domain morphologies also seen in various other physical contexts. A detailed investigation of domain patterns offers the possibility to study general characteristics of domain nucleation and morphology as well as the physical properties of vortex-vortex interactions. Domain structures in SC are typically investigated by surface sensitive techniques such as magneto optical imaging, but flux pinning as well as Landau branching can significantly hamper the deduction of bulk properties. In this talk we show how neutron grating interferometry (nGI) can be used as a tool for the unambiguous identification of bulk properties. The capability of this unique technique will be demonstrated on Pb and Nb single crystals, which are classical representatives of type I and type II SC respectively.

TT 64.10 Thu 17:30 H21

Vortex dynamics in superconductor micro- and nanotubes: Interplay between the effects of curvature and pinning centers — •V. M. Fomin[1], R. O. Rezaev[1,2], and O. G. Schmidt[1,3] — [1]Institute for Integrative Nanosciences, IFW-Dresden, D-01069 Dresden, Germany — [2]National Research Nuclear University “Moscow Engineering Physics Institute”, 115409 Moscow, Russia — [3]Material Systems for Nanoelectronics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Achievements in roll-up technique make it possible to fabricate cylindrical tubes of superconducting materials (e. g., Nb) of radius about 500 nm from a planar film of thickness about 50 nm, where the quasi-2-dimensionality of the film is combined with a curvature. The vortex dynamics in open tubes are significantly determined by the curvature of the superconductor at the nano- or microscale as well as by the impact of single and multiple pinning centers. The presence of the pinning centers allows for an efficient control over the threshold value of the transport current (for emergence of vortex dynamics) and the transition magnetic field (separating sparse- and many-vortex regimes).The detection of the tube curvature effects on vortex dynamics suggested in [1] stays feasible in the presence of pinning centers. This work was partly supported by the IEEE Council on Superconductivity.

[1] V. M. Fomin, R. O. Rezaev, and O. G. Schmidt, Nano Lett. 12, 1282 (2012).

TT 64.11 Thu 17:45 H21

Electrical transport and pinning properties of Nb films with washboard-like nanostructures — •Oleksandr V. Dobrovolskiy[1,2], Evgeniya Begun[1], Michael Huth[1], and Valerij A. Shklovskij[2,3] — [1]Physikalisches Institut Goethe-University, Frankfurt, Germany — [2]Department of Physics, Kharkiv National University, Ukraine — [3]Institute for Theoretical Physics NSC-KIPT, Kharkiv, Ukraine

A careful analysis of the magneto-transport properties of epitaxial nanostructured Nb thin films in the normal and the mixed state is performed. The nanopatterns were prepared by focused ion beam (FIB) milling. They provide a washboard-like pinning potential landscape for vortices in the mixed state and simultaneously cause a resistivity anisotropy in the normal state. Two matching magnetic fields for the vortex lattice with the underlying nanostructures have been observed. By applying these fields, the most likely pinning sites along which the flux lines move through the samples have been selected. By this, either the background isotropic pinning of the pristine film or the enhanced isotropic pinning originating from the nanoprocessing have been probed. Via an Arrhenius analysis of the resistivity data the pinning activation energies for three vortex lattice parameters have been quantified. The changes in the electrical transport and the pinning properties have been correlated with the results of the microstructural and topographical characterization of the FIB-patterned samples. The obtained results provide further insight into the pinning mechanisms at work in FIB-nanopatterned superconductors for fluxonic applications.

TT 64.12 Thu 18:00 H21

Enhancement of critical current in mesoscopic superconducting strips by external magnetic field — •Konstantin Ilin, Dagmar Henrich, Yannick Luck, Lea Fuchs, Johannes Maximilian Meckbach, and Michael Siegel — Institut für Mikro- und Nanoelektronische Systeme, Karlsruher Institut für Technologie, Hertzstraße 16, 76187 Karlsruhe, Germany

Current crowding in superconducting mesoscopic strips with bends results in decrease of critical current in these structures with respect to the strips without geometrical non-uniformities [1-3]. Recently it has been shown that Meissner currents induced by externally applied magnetic field of appropriate direction allow to suppress this effect so that $I_c(B)$ can exceed $I_c(0)$ [4]. Experimental dependencies of critical current in mesoscopic bended strips made from ultra-thin superconducting films on externally applied magnetic field and their comparison to the theoretical predictions will be presented and discussed.

[1] Phys. Rev. B 84, 174510 (2011)
[2] Phys. Rev. B 86, 144504 (2012)
[3] Appl. Phys. Lett. 100, 182602 (2012)
[4] Phys. Rev. B 85, 144511 (2012