TT 11 Superconductivity: Heterostructures, Andreev Scattering, Proximity Effect, Coexistence

Time: Tuesday 09:30–13:00 Room: HSZ 301

TT 11.1 Tue 09:30 HSZ 301

Observation of Andreev bound states in YBCO/Au/Nb ramp-type Josephson junctions — •B. Chesca[1], D. Doenitz[1], T. Dahm[2], R. P. Huebener[1], D. Koelle[1], R. Kleiner[1], A. Ariando[3], H.J.H. Smilde[3], and H. Hilgenkamp[3] — [1]Physikalisches Institut - Experimentalphysik II, Universität Tübingen — [2]Institut für Theoretische Physik, Universität Tübingen — [3]Faculty of Science and Technology and Mesa+ Research, Institute, University of Twente

We present [1] temperature, magnetic field, and crystallographic orientation dependencies of the quasiparticle tunneling spectra of YBCO/Au/Nb junctions. With Nb superconducting, the proximity gap induced in the Au layer appears in the spectra as well defined coherence peaks and a dip at the center of a broadened zero-bias conductance peak (ZBCP).The data are consistent with the formation of Andreev bound states (ABS) at the junction interfaces supporting a d-wave symmetry of the order parameter in YBCO. We tested both proposed models of ABS assisted quasiparticle tunneling between two superconductors: the convolution model and the series connection of two decoupled interfaces model, and proved the first one applies to our case. In high contrast to Josephson tunneling, the quasiparticle spectra are crystallographic orientation insensitive: a ZBCP is observed no matter whether the tunneling occurs in the (100) or (110) directions consistent with microscopic roughness at the junction interface. The formation of ABS is insensitive to the twinned or untwinned character of the YBCO film. [1] B. Chesca et al., submitted to Phys. Rev. B(cond-mat/0506734, 2005)

TT 11.2 Tue 09:45 HSZ 301

Multiple 0 - π - transitions of Josephson - junctions with Ni_3Al as weak ferromagnetic interlayer — •Frank Born[1], M. Siegel[1], E. Hollmann[2], H. Braak[3], C.M. Schneider[3], and M.Yu. Kupriyanov[4] — [1]Institut für Mikro- und Nanoelektronische Systeme, Universität Karlsruhe (TH) — [2]ISG2, Forschungszentrum Jülich GmbH — [3]IFF, Forschungszentrum Jülich GmbH — [4]Institute of Nuclear Physics, Moscow State University

Andreev - reflection is the central mechanism for the superconducting proximity effect. In a NS bi-layer the correlation of electron-like and hole-like quasi-particles decays exponentially with distance from the interface due to the de-phasing of its wave functions. In the case of a ferromagnetic material the Andreev - reflection picture is strongly modified: the spins of electron-like and hole-like quasi-particles are opposite orientated. This results under the influence of the exchange field in an energy shift and the creation of a nonzero momentum, leading to an additional spatially oscillation of the superconducting correlation amplitude. We report on experimental studies about superconducting coupling through a thin Ni3Al film. Depending on the deposition process the alloy is either only paramagnetic or it is magnetically ordered. In the paramagnetic regime the critical supercurrent, IC, decays exponentially over several nm, thus showing the pure proximity effect. In the ferromagnetic regime up to six damped oscillations of critical current on F-layer thickness was observed, revealing 0 - π - shifts in the ground state of Josephson junctions.

TT 11.3 Tue 10:00 HSZ 301

Triplet supercurrent through a half-metallic ferromagnet — •S. T. B. Goennenwein[1,2], R. S. Keizer[2], T. M. Klapwijk[2], G. Miao[3,4], G. Xiao[4], and A. Gupta[3] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Kavli Institute of NanoScience, Faculty of Applied Sciences, Delft University of Technology, Delft, The Netherlands — [3]MINT Center, University of Alabama, Tuscaloosa, USA — [4]Physics Department, Brown University, Providence, USA

Superconductivity and ferromagnetism usually do not coexist, as the Cooper pairs in conventional superconductors are spin singlets (pairs of electrons with antiparallel spin), while the ferromagnetic exchange interaction requires parallel spins. However, the existence of long-range superconducting *triplet* correlations in a ferromagnet in proximity to a conventional superconductor has been suggested.

Using electron-beam lithography, sputtering, and lift-off, we have patterned two NbTiN electrodes on top of a thin CrO_2 film. We find that a Josephson supercurrent flows through this weak link for electrode separations of up to 1 μm at $T = 1.7$ K. The magnitude of the supercurrent oscillates as a function of the strength of an externally applied magnetic field (Fraunhofer pattern), and characteristically depends on the magnetization orientation in the CrO_2 layer. We interpret these findings as evidence for a spin triplet supercurrent in the half-metallic ferromagnet CrO_2, and discuss possible mechanisms for the singlet to triplet conversion at the superconductor-ferromagnet interface.

TT 11.4 Tue 10:15 HSZ 301

Interplay of magnetic and superconducting proximity effects in FSF trilayers — •Tomas Lofwander, Thierry Champel, Johannes Durst, and Matthias Eschrig — Institut für Theoretische Festkörperphysik, Universität Karlsruhe, 76128 Karlsruhe

We present theoretical results on the interplay of magnetic and superconducting orders in diffusive ferromagnet-superconductor-ferromagnet trilayers. The induced triplet superconducting correlations throughout the trilayer lead to an induced spin magnetization. We include self-consistency of the order parameter in the superconducting layer at arbitrary temperatures, arbitrary interface transparency, and any relative orientation of the exchange fields in the two ferromagnets. We propose to use the torque on the trilayer in an external magnetic field as a probe of the presence of triplet correlations in the superconducting phase.

TT 11.5 Tue 10:30 HSZ 301

Influence of an inhomogeneous exchange field on the proximity effect in disordered superconductor-ferromagnet hybrid structures — •Thierry Champel, Tomas Lofwander, and Matthias Eschrig — Institut für Theoretische Festkörperphysik, Universität Karlsruhe, 76128 Karlsruhe

We investigate the effect of an inhomogeneous exchange field on the proximity effect in superconductor-ferromagnet (S/F) hybrid structures within the quasiclassical theory of superconductivity. The superconducting proximity effect induces triplet correlations in the structure that are sensitive to the local quantization axis of the exchange field in the ferromagnet. As an example, we consider an in-plane spiral order in the ferromagnet. The coexistence of pair correlations results into a sensitivity of the superconducting transition temperature on the spatial variation of the exchange field in S/F bilayers. We show that the inhomogeneity also tends to suppress the oscillating behavior of the pair amplitudes in F. Finally we investigate the influence of the exchange field inhomogeneity on the π-state in SFS junctions.

TT 11.6 Tue 10:45 HSZ 301

Odd Triplet Superconductivity in Superconductor/Ferromagnet Structure with a Spiral Magnetic Structure. — •Alexandra Anishchanka — Ruhr-Universität Bochum, Theoretische Physik III, NB 6/23, Universitätsstr. 150, 44801, Bochum

We analyze a superconductor-ferromagnet (S/F) system with a spiral magnetic structure in the ferromagnet F for a weak and strong exchange field. The long-range triplet component (LRTC) penetrating into the ferromagnet over a long distance is calculated for both cases. In the dirty limit (or weak ferromagnetism) we study the LTRC for conical ferromagnets. Its spatial dependence undergoes a qualitative change as function of the cone angle. At angles close to pi/2 the LTRC decays in the ferromagnet exponentially in a monotonic way. If the cone angle exceeds a certain value, the exponential decay of the LTRC is accompanied by oscillations with a period that depends on the cone angle. This oscillatory behavior leads to a similar dependence of the Josephson critical current in SFS junctions on the thickness of the F layer. In the case of a strong ferromagnet the LTRC decays over the length which is determined by the wave vector of the magnetic spiral and the exchange field.

TT 11.7 Tue 11:00 HSZ 301

Spin-dependent Transport Through Nanostructured S/F Point Contacts — •M. Stokmaier[1], G. Goll[1], C. Sürgers[1,2], D. Weissenberger[3], F. Pérez-Willard[2,3], and H. v. Löhneysen[1,2,4] — [1]Physikalisches Institut, Universität Karlsruhe — [2]DFG Center for Functional Nanostructures (CFN), Universität Karlsruhe — [3]Laboratorium für Elektronenmikroskopie, Universität Karlsruhe — [4]Forschungszentrum Karlsruhe, Institut für Festkörperphysik

Andreev reflection at the superconductor/ferromagnet (S/F) interface in a ballistic point contact strongly depends on the degree of spin polarization of the ferromagnetic electrode. The spin polarization of the current can be determined by analysis of point-contact spectra using a theoretical model which takes into account two spin-dependent transmission coefficients for the majority and minority charge carriers of the ferromagnet [1]. Here we study the spin-dependent transport through nanostructured Al/Fe point contacts. The samples have been fabricated by deposition of Al and Fe on either side of a thin Si_3N_4 membrane with a nanostructured hole in it. Differential conductance measurements $G(V)$ have been performed in a dilution refrigerator at temperatures $T \geq 20\,\mathrm{mK}$ and various magnetic fields. These results are compared with previous data taken on Al/Co and Al/Ni point contacts in order to determine how the current spin-polarization is related to the spin polarization of the bulk magnetic material.
[1] F. Pérez-Willard *et al.*, Phys. Rev. B **69**, 140502(R) (2004).

— 15 min. break —

TT 11.8 Tue 11:30 HSZ 301

Imaging of Domain Superconductivity in a Ferromagnet-Superconductor-Bilayer by Low Temperature Scanning Laser Microscopy — •H. Eitel[1], J. Fritzsche[2], R. Szymczak[3], V.V. Moshchalkov[2], R. Kleiner[1], and D. Koelle[1] — [1]Physikalisches Institut - Experimentalphysik II, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany — [2]Nanoscale Superconductivity and Magnetism Group, K.U. Leuven, Belgium — [3]Polish Academy of Science, Institute of Physics, Warsaw, Poland

We present a spatially resolved analysis of the electric transport properties of a superconductor-ferromagnet hybrid system. This hybrid consists of a Nb thin film micro bridge on top of a $PbFe_{12}O_{19}$ single crystal whose easy axis is perpendicular to the plane of the Nb film. We used low-temperature scanning laser microscopy (LTSLM) to image regions of Nb at the transition temperature T_c as a function of temperature T and applied magnetic field H_{app}, up to the saturation field H_s of $PbFe_{12}O_{19}$. The LTSLM images give direct evidence that so called "domain superconductivity" in Nb is induced due to the magnetic domain structure of the ferromagnet. I.e., T_c of the Nb film is larger in areas above a magnetic domain with magnetization direction opposite to H_{app}, because in those areas the Nb experiences a reduced total magnetic field. By changing H_{app} from zero up to H_s, the evolution of the magnetic domain structure can be traced by LTSLM. The correlation of the LTSLM images with integral $R(T, H)$ data obtained during LTSLM imaging and with room temperature AFM-images of the $PbFe_{12}O_{19}$ domain structure and its dependence on H_{ext} will be discussed.

TT 11.9 Tue 11:45 HSZ 301

Re-entrant superconductivity in Nb/Cu_xNi_{1-x} bilayers — •V. Zdravkov[1,2], A. Sidorenko[1,2], G. Obermeier[1], S. Gsell[1], M. Schreck[1], C. Müller[1], S. Horn[1], R. Tidecks[1], and L. Tagirov[3] — [1]Institut für Physik, Universität Augsburg, D-86135 Augsburg — [2]Institute of Applied Physics, LISES ASM, Kishinev 2028 Moldova — [3]Laboratory of Theoretical Physics, Kazan State University, Kazan, Russia

The first pronounced experimental observation of the re-entrant phenomenon in superconductor/ferromagnet $Nb/Cu_{0.4}Ni_{0.6}$ bilayers is reported. A non-monotonous dependence of the superconducting critical temperature T_c is observed, strongly depending on the ferromagnet layer thickness, with a complete disappearance of superconductivity for a narrow range of F-layer thicknesses.

The observation is a manifestation of the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) - like state and can be described by a theoretical model, based on the modified SF-boundary conditions [1].
[1] Sidorenko, A.S., Zdravkov, V.I., Prepelitsa, A.A., Helbig, C., Luo, Y., Gsell, S., Schreck, M., Klimm, S., Horn, S., Tagirov, L.R., and Tidecks, R. (2003) Oscillations of the critical temperature in superconducting Nb/Ni bilayers, Ann.Phys.(Leipzig) 12, 37-50.

TT 11.10 Tue 12:00 HSZ 301

Effect of Microwaves on the Current-Phase-Relation of diffusive SNS Junctions — •Martin Füchsle, Johannes Bentner, Peter Tranitz, Werner Wegscheider, and Christoph Strunk — Institut für experimentelle und angewandte Physik, Universität Regensburg

We investigate the current-phase-relation (CPR) of long diffusive superconductor - normal metal - superconductor (SNS) Josephson junctions under microwave irradiation. In contrast to earlier experiments that focused on the I-V characteristics of current-biased junctions, we directly measure the full CPR by means of Micro-Hall-Magnetometry. The measurements are done in the high-temperature regime $E_{Th} < k_BT \ll \Delta$, where E_{Th} is the Thouless energy and $\hbar\omega \approx E_{Th}$.
We find that the occupation of the Andreev states in the N region can be strongly affected by microwave radiation. A strong deviation of the CPR from the well-known sinusoidal $I(\Phi)$ relation is observed: depending on the applied frequency and amplitude, the supercurrent can be strongly suppressed and the maximum current can appear at phase differences smaller than $\pi/2$. At some frequencies, the $\sin(\Phi)$ term in the CPR can be completely suppressed, resulting in a dominant second harmonic. The results may be qualitatively interpreted in terms of a simple model for the spectrum of low-lying Andreev bound states.

TT 11.11 Tue 12:15 HSZ 301

Impedance and field profiles of thin ohmic or superconducting strips with applied ac current — •Ernst Helmut Brandt — Max-Planck-Institut für Metallforschung, Stuttgart

A long wire carrying an applied ac current is a standard problem in electrodynamics when the wire is cylindric. The circular symmetric solutions far away from the current contacts are easily obtained for an ohmic wire with resistivity ρ and for a superconducting wire with London depth λ. When the wire has a non-circular cross section the problem becomes much more complex. Apparently, no analytic or transparent numerical solutions are available, not even for the complex impedance of thin strips that is needed, e.g., in the theory of SQUID systems. This contribution presents the inductance, resistance, and magnetic field and current distributions of thin long ohmic or superconducting strips and their dependences on λ, ρ, ac frequency, and strip length l. Approximate analytic expressions are given for the inductance and resistance. Interestingly, the inductance per unit length of the strip depends on its length while the field and current distributions and the susceptibility and resistance are independent of l. As compared to cylindrical wires, the skin effect in thin ohmic strips is much weaker (logarithmic).

TT 11.12 Tue 12:30 HSZ 301

Superconducting surfaces under electric fields — •K. Morawetz[1,2], P. Lipavský[3], J. Koláček[4], and M. Schreiber[1] — [1]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany — [2]Max-Planck-Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [3]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 12116 Prague 2 — [4]Institute of Physics, Academy of Sciences, Cukrovarnická 10, 16253 Prague 6, Czech Republic

A boundary condition for the Ginzburg-Landau wave function at surfaces biased by a strong electric field is derived within the de Gennes approach. This condition provides a simple theory of the field effect on the critical temperature of superconducting layers [1,2]. The electric-field dependent surface energy is calculated which provides an alternative explanation of the Tao effect where one observes a formation of a macroscopic sphere out of superconducting grains due to the electric field. The electrostatic potential above the Abrikosov vortex lattice is calculated as well where we include the surface dipole. We propose an experimental measurement by NMR to access this field which can yield informations about material parameters [3].
[1] P. Lipavský, K. Morawetz, J. Kolacek, Ginzburg-Landau theory of superconducting surfaces under electric fields, PRB in press
[2] K. Morawetz, Electric field dependence of pairing temperature and tunneling, Phys. Rev. B 66, 172508
[3] P. Lipavský, K. Morawetz, J. Kolacek, J. J. Mares, E. H. Brandt, M. Schreiber, Bernoulli potential in type-I and weak type-II supercoductors: III. Electrostatic potential above the vortex lattice Phys. Rev. B 71 (2005) 024526-1-7, II. Surface dipole Phys. Rev. B 70 (2004) 104518-1-7, I. Surface charge Phys. Rev. B 69 (2004) 024524-1-7

TT 11.13 Tue 12:45 HSZ 301

Nonequilibrium magnetism with superconductors — •Fabio Taddei[1], Francesco Giazotto[1], Rosario Fazio[1,2], and Fabio Beltram[1] — [1]NEST-CNR-INFM & Scuola Normale Superiore, Pisa — [2]International School for Advanced Studies (SISSA), Trieste, Italy

Electrostatic control of the magnetization of a normal mesoscopic conductor is analyzed in a hybrid superconductor-normal-superconductor system. This effect stems from the interplay between the non-equilibrium condition in the normal region and the Zeeman splitting of the quasiparti-

cle density of states of the superconductor subjected to a static in-plane magnetic field. Unexpected spin-dependent effects such as magnetization suppression, *diamagnetic-like* response of the susceptibility as well as spin-polarized current generation are the most remarkable features presented. The impact of scattering events is evaluated and let us show that this effect is compatible with realistic material properties and fabrication techniques.