TT 54: SC: Heterostructures, Andreev Scattering, Proximity Effect

Time: Thursday 15:30–17:15 Location: HSZ 301

TT 54.1 Thu 15:30 HSZ 301

Observation of Andreev bound states at spin-active interfaces — •Florian Hübler[1,2], Michael J. Wolf[1], Detlef Beckmann[1], and Hilbert von Löhneysen[2,3] — [1]Karlsruher Institut für Technologie, Institut für Nanotechnologie — [2]KIT, Institut für Festkörperphysik — [3]KIT, Physikalisches Institut

Spin-active interfaces, for instance between superconductors and ferromagnets are characterized by spin-dependent transmission amplitudes as well as phase shifts[1]. The relative phase shift between spin-up and -down, the so-called spin-mixing angle θ_s, is an important parameter for the triplet proximity effect. So far, little quantitative information is available about θ_s. Recent theoretical models indicate that θ_s may actually be quite large in structures with ultra-thin tunnel barriers[2]. One of the consequences of finite θ_s in S/F hybrids is the presence of bound states at the interface[3], at energies which have a particularly simple relation to θ_s, $\epsilon = \pm\Delta cos(\theta_s/2)$. We report here the experimental observation of Andreev bound states induced by spin-mixing in Al/Al2O3/Fe structures. From the energy of the bound states, we can determine θ_s with great accuracy. As predicted theoretically, we find examples of $\theta_s \approx \Pi$, but also a significant spread from contact to contact, even within the same fabrication batch. The large spread indicates that spin mixing in real structures depends in a subtle way on details of the interface, and is possibly controlled by defects.

[1] Millis et al., Phys. Rev. B 38, 4504 (1988)
[2] Grein et al., Phys. Rev. B 81, 094508 (2010)
[3] Zhao et al., Phys. Rev. B 70, 134510 (2004)

TT 54.2 Thu 15:45 HSZ 301

Nonlocal conductance via overlapping Andreev bound states in ferromagnet-superconductor heterostructures — •Georgo Metalidis[1], Matthias Eschrig[1,2], Roland Grein[1], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures, Karlsruher Institut für Technologie, D-76128 Karlsruhe, Germany — [2]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

In a setup where two ferromagnetic electrodes are attached to a superconductor, Andreev bound states are induced at both ferromagnet/superconductor interfaces. We study how these states propagate through the superconductor and interact with each other. We find that the energetic positions of the Andreev states are not anymore determined solely by the magnetic properties of a single interface, but depend on the interface distance and the relative magnetization orientation of the ferromagnetic contacts as well. These bound states show up as distinct peaks in the nonlocal conductance signal and lead to marked asymmetries with respect to the applied voltage. Our results are related to nonlocal crossed Andreev and elastic co-tunneling processes.

TT 54.3 Thu 16:00 HSZ 301

Experimental Observation of the Spin Screening Effect in Superconductor/Ferromagnet Thin Film Heterostructures — •Ruslan Salikhov[1,2], Ilgiz Garifullin[2], Nadir Garifyanov[2], Lenar Tagirov[3], Kurt Westerholt[1], and Hartmut Zabel[1] — [1]Experimental Physics, Ruhr-University Bochum, 44780 Bochum, Germany — [2]Zavoisky Physical-Technical Institute, Russian Academy of Science, 420049 Kazan, Russia — [3]Kazan State University, 420008 Kazan, Russia

We have studied the nuclear magnetic resonance (NMR) of 51V nuclei in the superconductor/ferromagnet thin film heterostructures $Pd_{1-x}Fe_x$/V/$Pd_{1-x}Fe_x$ and Ni/V/Ni in the normal and superconducting state. Whereas the position and shape of the NMR line in the normal state for the trilayers is identical to that observed in a single V layer, in the superconducting state the line shape definitely changes, developing a systematic distortion of the high-field wing of the resonance line. By varying the thickness of the superconducting V layer for Ni/V/Ni trilayer samples we observed that the distortion of the high-field wing of the resonance line has an obvious trend to disappear with increasing V layer thickness. We consider this as the first experimental evidence for the penetration of ferromagnetism into the superconducting layer, a phenomenon which has been theoretically predicted recently and dubbed the spin screening effect.

TT 54.4 Thu 16:15 HSZ 301

Andreev reflection with semiconductor-valence-band carriers — •David Futterer[1], Michele Governale[2], Ulrich Zülicke[3], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg Essen and CeNIDE, 47048 Duisburg, Germany — [2]School of Chemical and Physical Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology, Victoria University of Wellington, PO Box 600, Wellington, New Zealand — [3]Institute of Fundamental Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology, Massey University

We investigate Andreev reflections through a hybrid semiconductor/superconductor interface within the Bogoliubov-de Gennes formalism. In particular we focus on valence-band carriers of p-doped semiconductors with large spin-orbit coupling, approaching the junction under an arbitrary angle.

The spin-orbit coupling leads to a mixing between the energy bands. This allows four possibilities of reflection for an injected light-hole (heavy-hole) carrier. It can be normal reflected into the light-hole (heavy-hole) band or the heavy-hole (light-hole) band as well as Andreev reflected into each of the two bands. The reflection depends strongly on the angle of injection. Though Andreev reflection of heavy-hole carriers is in general possible, these carriers can only be normal reflected into the heavy-hole band in the case of perpendicular injection.

TT 54.5 Thu 16:30 HSZ 301

Adiabatic Cooper pair pumping through quantum dots — •Bastian Hiltscher[1], Michele Governale[2], Janine Splettstoesser[3], and Jürgen König[1] — [1]Theoretische Physik, Universität Duisburg-Essen and CeNIDE — [2]School of Chemical and Physical Sciences, Victoria University of Wellington — [3]Institut für Theoretische Physik A, RWTH Aachen University

Motivated by recent experimental work [1] we investigate splitting of Cooper pairs in adiabatic pumping. We consider (i) a quantum dot with Zeeman split levels tunnel coupled to a normal and a superconductor and (ii) two quantum dots tunnel coupled to the same superconductor and each dot coupled to a normal conductor.

We combine the means of two different theories. On the one hand a systematic perturbation expansion in tunnel-coupling strength between quantum dots and superconductors [2] and on the other hand an adiabatic expansion using that the pumping period is small compared to the lifetime of a certain state [3].

We find that the pumped charge and the linear conductance show the same dependence on the average dot level position. The underlying tunneling processes are discussed. In order to figure out processes where a Cooper pair is split we compare the properties of Cooper pair pumping with single-electron pumping. The dependence on the average dot-level position turns out to be the main distinguishing feature.

[1] Hofstetter *et al.*, Nature **461**, 960 (2009); Herrmann *et al.*, PRL **104**, 026801 (2010).
[2] Governale *et al.*, PRB **77**, 134513 (2008).
[3] Splettstoesser *et al.*, PRB **74**, 085305 (2006).

TT 54.6 Thu 16:45 HSZ 301

Controlling the Conductance and Thermopower of Chaotic Quantum Dots — •Thomas Engl, Jack Kuipers, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

Transport through quantum cavities, like quantum dots, has raised much interest in physics in recent decades. When attaching superconductors to the cavity, these transport properties are substantially changed, known to be caused by Andreev reflection on the interface between the normal region and the superconductor.

Using a semiclassical framework for ballistic systems, so called Andreev billiards with chaotic dynamics, we show how Andreev reflection along with the interference due to subtle correlations between the classical paths of electrons and holes inside the system affects the conductance of the system and see how these combined cause large quantum corrections to the conductance like its reduction by a phase difference between the superconductors. Furthermore we show that the thermopower requires an asymmetry with respect to an exchange of the superconducting leads in order to be nonzero. Moreover, we are able

to see what happens if the temperature is increased or a magnetic field is applied.

TT 54.7 Thu 17:00 HSZ 301

Chain of Majorana States from Superconducting Dirac Fermions at a Magnetic Domain Wall — •Titus Neupert[1], Shigeki Onoda[2], and Akira Furusaki[2] — [1]Condensed Matter Theory Group, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland — [2]Condensed Matter Theory Laboratory, RIKEN, Wako, Saitama 351-0198, Japan

We study theoretically a strongly type-II s-wave superconducting state of two-dimensional Dirac fermions in proximity to a ferromagnet having in-plane magnetization. It is shown that a magnetic domain wall can host a chain of equally spaced vortices in the superconducting order parameter, each of which binds a Majorana-fermion state. The overlap integral of neighboring Majorana states is sensitive to the position of the chemical potential of the Dirac fermions. Thermal transport and scanning tunneling microscopy experiments to probe the Majorana fermions are discussed.