International Workshop

COHERENT SUPERCONDUCTING HYBRIDS AND RELATED MATERIALS

COST Action CA16218

Les Arcs 1800, March 26-29, 2018

Programme and Abstract Book

Funded by the Horizon 2020 Framework Programme of the European Union

The international workshop "COHERENT SUPERCONDUCTING HYBRIDS AND RELATED MATERIALS" is organized within the framework of the European Cooperation in Science and Technology projet “NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES” - Action CA16218 “.

The workshop is co-organized with Ecole Supérieure de Physique et de Chimie Industrielles de la Ville de Pairs - ESPCI-Paris PSL-Research University

The Workshop is strongly supported by:

Fonds ESPCI-Paris
https://www.espci.fr/fr/nous-soutenir/fonds-espci-paris-448/

PLASSYS Bestek: Manufacturer of equipment for thin film deposition and etching
https://plassys.com/

La Société des Amis de l’ESPCI
https://www.espci.fr/fr/espci-paris/organisation/la-societe-des-amis-de-l-espci

Funded by the Horizon 2020 Framework Programme of the European Union

PROGRAMME

COST Workshop S^iφ hybrids : Programme at a glance

	Tuesday, March 27th		Wednesday, March 28th		Thursday, March 29th
08 :15-08 :20	Opening by **H. Suderow**				
08 :20	**Sacépé**		**Brison**		**Baumans**
08 :40	**Mesaros**		**Risinggard**		**Keijers**
09 :00	**Delbecq**		**Silaev**		**Muller B.**
09 :20	**Spera**		**Aprili**		**Cordoba**
09 :40	**Kunakova**		**Martinez-Perez**		**Feuillet-Palma**
10 :10-10 :30	*Coffee break*		*Coffee break*	10:00	*Coffee break*
10 :30	**Babaev**		**Amundsen**	10:20	**Muller C.**
10 :50	**Mashkoori**		**Geshkenbein**	10:40	**Szabo**
11 :10	**Li**		**Ionescu**	11:00	**Perconte**
11 :30	**Scherubl**		**Pompeo**	11:20	**Novotny**
11 :50	**Zaikin**		**Guillamon**	11:40	**Moshopoulou**
12 :10-14 :10	*Lunch*		*Lunch*	12:00	*Lunch*
14 :10	*Networking meetings*		*Networking meetings*		*Departure*
16 :10	**Caruso**		**Caprara**		
16 :30	**Ouassou**		**Bergeal**		
16 :50	**Goldobin**		**Wissberg**		
17 :10	**Eschrig**		**Rudau**		
17 :40-18 :00	*Coffee break*		*Coffee break*		
18 :00	**Gueron** (focus lecture WG1)		**Bauch**		
18 :30	**Buzdin** (focus lecture WG2)	18:20	**Kubatkin**		
19 :00	**Anahory** (focus lecture WG3)	18:40	**Vasenko**		
19 :30	**Suderow, Gonzalez** (network)	19:00	**Super-Poster: short present.**		
20:00	*Networking dinner*	19:30	**Super-Poster session** *+ dinner*		

Programme of the workshop S^iφ hybrids

Les Arcs, March 26-29, 2018

Monday, March 26th

14:00-19:30 ***Arrivals, Registration***

19:30-20:00 Welcome session

20:00 ***Dinner***

Tuesday, March, 27th

08:15-08:20 **Hermann Suderow:** Opening of the Workshop

Morning Session 1: Novel quantum states in superconductors

Chair:

08:20-08:40 **Benjamin Sacépé**
When Joule poisons Majorana in topological Josephson junctions

08:40-09:00 **Andrej Mesaros**
In-gap excitations due to defects in topological superconductors

09:00-09:20 **Matthieu Delbecq**
Synthetic spin-orbit interaction for Majorana devices

09:20-09:40 **Marcello Spera**
Spatial and energy dependent texturing of the charge order in 1T-Cu_XTiSe_2

S^iφ hybrids

09:40-10:00 **Gunta Kunakova**
Transparent superconductor-Bi_2Se_3 nanoribbon interface hybrid devices

10:10-10:30 ***Coffee break***

Morning Session 2: Novel quantum states in superconductors

Chair:

10:30-10:50 **Egor Babaev**
Superconductivity with frustrated Josephson coupling

10:50-11:10 **Mahdi Mashkoori**
Majorana quasiparticles in atomic chain of magnetic impurities: effect of *d*-wave pairing

11:10-11:30 **Chuan Li**
Observation of 4π-periodic supercurrent and Zeeman π-junction in Dirac semimetal Josephson junctions

11:30-11:50 **Zoltan Scherubl**
Signatures of non-local coupling in Cooper pair splitter: The Andreev molecule

11:50-12:10 **Andrei D. Zaikin**
Non-equilibrium ϕ_0–junction-like behavior of multi-terminal normal-superconducting nanohybrids

12:10-14:10 ***Lunch***

14:10-16:10 ***Networking meetings and discussions***

"COHERENT SUPERCONDUCTING HYBRIDS AND RELATED MATERIALS"
COST CA16218 Workshop, Les Arcs 1800, France, March 26-29, 2018

Afternoon Session 1: Josephson junctions, networks, devices

Chair:

16:10-16:30 **Roberta Caruso**
Influence of microwaves on magnetic switching in Nb-Al/AlO_X-(Nb)-PdFe-Nb Josephson junctions

16:30-16:50 **Jabir Ali Ouassou**
Superconducting spintronics in double-barrier Josephson junctions

16:50-17:10 **Edward Goldobin**
Experiments with artificial φ-Josephson junctions

17:10-17:30 **Matthias Eschrig**
Spin supercurrents due to Fermi liquid effects in Superconductor/Ferromagnet hybrid structures

17:40-18:00 ***Coffee break***

Afternoon Session 2: Focus lectures & COST networking

18:00-18:30 **Sophie Gueron**
Focus lecture on selected topics in low-dimensional superconducting hybrids

18:30-19:00 **Alexander Buzdin**
Focus lecture on selected topics in Josephson physics

19:00-19:30 **Yonathan Anahory**
Focus lecture on selected topics in vortex matter

19:30-20:00 **Hermann Suderow, Irene Gonzalez Martin**

Presentation of the NANOCOHYBRI COST Action

20:00 ***Networking Dinner***

Wednesday, March 28th

Morning Session 1: Superconductivity vs magnetism

Chair:

08:20-08:40 **Jean-Pascal Brison**
Intrinsic p-wave ferromagnetic superconductors: insights from bulk materials

08:40-09:00 **Vetle Risinggard**
Intrinsic superspin Hall current

09:00-09:20 **Mikhail Silaev**
Coupled transport of spin, heat and charge in superconductors with Zeeman splitting

09:20-09:40 **Marco Aprili**
Spectroscopy of few-layer superconducting $NbSe_2$

09:40-10:00 **Maria Jose Martinez-Perez**
Magnetization reversal in individual nanoparticles revealed by nano-SQUID magnetometry

10:10-10:30 ***Coffee break***

Morning Session 2: Vortex matter

Chair:

10:30-10:50 **Morten Amundsen**
Geometry dependence of proximity induced vortex patterns in superconducting hybrid structures

10:50-11:10 **Vadim Geshkenbein**
Strong pinning theory of thermal vortex creep in type-II superconductors

11:10-11:30 **Marinela A. Ionescu**
Bulk pinning force analysis of MgB_2 co-added with c-BN and $Ge_2C_6H_{10}O_7$ fabricated by spark plasma sintering

11:30-11:50 **Nicola Pompeo**
Flux-flow regimes in Nb/PdNi/Nb hybrids, Nb and Nb_3Sn: unconventional vs conventional behavior

11:50-12:10 **Isabel Guillamon**
Scanning tunneling spectroscopy in pnictide superconductors: 122 and related systems

12:10-14:10 ***Lunch***

14:10-16:10 ***Networking meetings and discussions***

Afternoon Session 1: Low dimensionality, disorder, coherence

Chair:

16:10-16:30 **Sergio Caprara**
Negative electron compressibility and inhomogeneous superconductivity in ionic-liquid gated thin films

16:30-16:50 **Nicolas Bergeal**

Superfluid stiffness in oxide interfaces

16:50-17:10 **Shai Wissberg**
Scanning SQUID maps of modulated superconductivity

17:10-17:30 **Fabian Rudau**
Coherent terahertz radiation from stacks of intrinsic Josephson junctions

17:40-18:00 ***Coffee break***

Afternoon Session 2: Low dimensionality, disorder, coherence

Chair:

18:00-18:20 **Thilo Bauch**
Quasiparticle spectroscopy using a YBCO transmon

18:20-18:40 **Sergey Kubatkin**
Sources of decoherence in superconducting quantum devices

18:40-19:00 **Andrey S. Vasenko**
Suppression of the low-frequency decoherence by Bell-state motion

Super-Poster Session

19:00-19:30 ***Short presentations***

19:30-21:30 ***Session & Dinner***

Jan Aarts

Spontaneous emergence of Josephson junctions in single crystal rings of Sr_2RuO_4

Victor Barrena

Superconducting density of states and the vortex lattice close to the quantum critical point in $BaFe_2(As_{1-X}P_X)_2$

Simon Bending

Gate-controlled superconductivity in few-layer 2D materials

Annica Black-Schaffer

Topological phases and Majorana fermions from magnetic impurities in superconductors

Adrian Crisan

Pinning potential in $YBa_2Cu_3O_7$ superconducting films with nanoengineered pinning centres

Szabolcs Csonka

Non-local probing of superconducting quantum dots via Yu-Shiba-Rusinov-state in Cooper pair splitter

Oleksandr Dobrovolskiy

Microwave-stimulated superconductivity in Nb films

Abdou Hassanien

Smeared d-wave anisotropy and discrete Andreev states in monolayer organic superconudctor

Beena Kalisky

Mapping superfluid density near the superconductor insulator phase transition

Wolfgang Lang

S^iφ hybrids

Unconventional critical state in cuprate superconductors with regular topological defects

Raphaël Leriche

Looking for topological superconductivity in misfit TMD $LaNb_2Se_5$

Floriana Lombardi

Unconventional induced superconductivity on the surface states of Bi_2Te_3

Ivan Maggio-Aprile

A BCS fingerprint revealed by the vortex cores of a high Tc superconductor

Milorad V. Milosevic

Effect of "impurities" on monolayer superconductivity: Selected cases

Jason Robinson

Superspin

Mikel Rouco

Electron refrigeration in hybrid structures with spin-split superconductors

Tomas Samuely

Black diamond – effects of confinement and magnetism on superconductivity

Alejandro Silhanek

In-situ tailoring of superconducting junctions via electro-annealing

Daniela Stornaiuolo

"COHERENT SUPERCONDUCTING HYBRIDS AND RELATED MATERIALS"
COST CA16218 Workshop, Les Arcs 1800, France, March 26-29, 2018

Oxide 2DEG properties for advanced electronic applications

Daria Szewczyk
Thermal conductivity measurements for superconducting materials

Hermann Suderow
Bound states and unconventional low energy electronic behavior in superconductors

Lan Maria Tran
Switching superconducting state "on" and "off" depending on the direction of the magnetic field in the Co- and Ca-doped $EuFe_2As_2$-based magnetic superconductors

Javier Villegas
Interface effects in oxide superconducting hybrids

Joris Van de Vondel
Direct visualization of degeneracy and vortex ice in nanostructured superconductors

Thursday, March 29th

Morning Session 1: novel approaches, material, devices

Chair:

08:20-08:40 **Xavier D. Baumans**
Anti-electromigration: Restoring conventional and high-Tc ultra-narrow superconducting junctions

08:40-09:00 **Wout Keijers**
Nano-SQUIDs with controllable weak links via

electromigration

09:00-09:20 **Benedikt Muller**
Advanced nano-SQUIDs based on sub-micron trilayer Nb/HfTi/Nb Josephson junctions

09:20-09:40 **Rosa Cordoba**
Superconducting nanotubes vertically grown by He^+ focused ion beam induced deposition

09:40-10:00 **Cheryl Feuillet-Palma**
High-Tc superconducting devices

10:00-10:20 ***Coffee break***

Morning Session 2: novel approaches, material, devices

Chair:

10:20-10:40 **Clemens Muller**
A passive on-chip microwave circulator using a ring of tunnel junctions

10:40-11:00 **Pavol Szabo**
On the origin of the quasiparticle states in the superconducting gap of homogeneously disordered ultrathin films: MoC case

11:00-11:20 **David Perconte**
Tunable proximity effect in cuprate superconductor/graphene junctions

11:20-11:40 **Tomas Novotny**

Perturbation theory for a correlated quantum dot attached to superconducting leads

11:40-12:00 **Evagelia Moshopoulou**
Temperature dependence of the crystal structure of the superconductor $LiTi_2O_4$ and of the heavy fermion LiV_2O_4

12:00-12:10 ***Closing Remarks***

12:10-13:30 ***Lunch***

13:30 ***Departure***

ABSTRACTS

When Joule poisons Majorana in topological Josephson junctions

Benjamin Sacépé

[1]*Insitut Néel, CNRS & UGA, Grenoble*
Benjamin.sacepe@neel.cnrs.fr

Topological Josephson junctions designed on the surface of a 3D-topological insulator (TI) harbor a Majorana bound state (MBS) among a continuum of conventional Andreev bound states. The distinct feature of this MBS lies in the 4π-periodicity of its energy-phase relation that yields a fractional a.c. Josephson effect and a suppression of odd Shapiro steps under *rf* irradiation. In this talk we present measurements of Josephson junctions tailored on the large bandgap 3D TI Bi_2Se_3 which exhibit the fractional a.c. Josephson effect acting on the first Shapiro step only, accompanied by a residual supercurrent at the nodes between Shapiro lobes. We demonstrate with a modified RSJ model that the resilience of higher order odd Shapiro steps and the residual supercurrent at the nodes between Shapiro lobes can be accounted for by thermal poisoning of the MBS driven by Joule overheating. We will furthermore show that the residual supercurrent at the nodes between Shapiro lobes provides a novel signature of the current carried by the MBS.

In-gap excitations due to defects in topological superconductors with spin-orbit coupling

Andrej Mesaros[1], and Pascal Simon[1]

[1]*Laboratoire de Physique des Solides, Université Paris-Sud, 91405 Orsay, France*
andrej.meszaros@u-psud.fr

Recent scanning tunneling spectroscopy measurements, performed at INSP-UPMC on a superconducting monolayer of lead(Pb) with nanoscale cobalt islands, have revealed puzzling quasiparticle in-gap states [1] which demand a better understanding of two-dimensional superconductivity in presence of spin-orbit coupling and magnetism. Tantalizingly, the quasiparticle states evoke general topologically protected states which haven't yet been explored in two-dimensional superconductors. Thus motivated, we theoretically study a model of two-dimensional s-wave superconductor with a fixed configuration of exchange field and spin-orbit coupling terms allowed by symmetry.

Using analytics and exact diagonalization of tight-binding models, we find that a vortex-like defect in the Rashba spin-orbit coupling binds a single Majorana zero-energy (mid-gap) state. Importantly, in contrast to the case of a superconducting vortex[2], our spin-orbit defect does not create a tower of in-gap excitation states. Our findings match the puzzling features observed in the experiment, particularly: (1) preservation of superconducting gap, and (2) short localization length of the zero-energy state compared to the superconductor coherence length. Additionally, these properties indicate that the system realizes the coveted well-protected Majorana states, which is a key requirement for a potential realization of a topological qubit. We also discuss how the quasiparticle states of the defect relate to the states of superconductors on top of magnetic textures, such as skyrmions.

Motivated by monolayer materials on a substrate, we also study superconducting vortex defects in mixed singlet-triplet pairing, in presence of spin-orbit coupling and Zeeman field. Throughout the phase diagram we find that a single defect can bind various numbers of zero-energy bound states despite the breaking of time-reversal symmetry. We discuss the phenomenon and implications of such multiple protected Majoranas. Especially, we focus on the role of discrete symmetries, such as magnetic mirror [3], in the protection of multiple Majoranas. The symmetries and protection of bound states are relevant also for general magnetic textures.

[1] G.C. Ménard, S. Guissart, C. Brun, M. Trif, F. Debontridder, R.T. Leriche, D. Demaille, D. Roditchev, P. Simon, and T. Cren, Two-dimensional topological superconductivity in Pb/Co/Si(111), arXiv:1607.06353(2016).

[2] C. Caroli, P.G. de Gennes, and J. Matricon, Bound Fermion states on a vortex line in a type II superconductor, Physics Letters 9, 307(1964).

[3] C. Fang, M.J. Gilbert, and B.A. Bernevig, New class of topological superconductors protected by magnetic group symmetries, Physical Review Letters 112, 106401(2014).

Synthetic spin orbit interaction for Majorana devices

M. M. Desjardins [1], L. C. Contamin[1], M. R. Delbecq[1], M .C. Dartiailh[1], L. E. Bruhat[1], T. Cubaynes[1], J. J. Viennot[2], F. Mallet[1], S. Rohart[3], A. Thiaville[3], A. Cottet[1] and Takis Kontos[4]

[1]*Laboratoire Pierre Aigrain, Ecole Normale Suprieure-PSL Research University, CNRS, Universit Pierre et Marie Curie-Sorbonne Universits, Universit Paris Diderot-Sorbonne Paris Cit, 24 rue Lhomond, 75231 Paris Cedex 05, France*
[2]*JILA and Department of Physics, University of Colorado, Boulder, Colorado, 80309, USA*
[3]*Laboratoire de Physique des Solides, Universit Paris-Sud et CNRS, Bt. 510, 91405 Orsay Cedex*
matthieu.delbecq@lpa.ens.fr

The engineering of Majorana modes in condensed matter systems could allow one to study excitations with particle/antiparticle duality and non-abelian statistics. Most of the experimental setups with nanoscale circuits use semiconducting nanowires with strong spin-orbit interaction connected to superconductors, under a finite magnetic field. Theoretical proposals have suggested autonomously inducing the spin-orbit coupling through a magnetic texture. In this work, we demonstrate experimentally such a platform using a single wall carbon nanotube as a conductor, which naturally exhibit few conduction channels. It is stamped over a magnetically textured gate and coupled to two superconducting electrodes. We observe subgap states in the conductance of such device, and perform a detailed investigation of their magnetic field evolution that reveals a large synthetic spin-orbit energy. Furthermore, a robust zero energy state, the hallmark of devices hosting localized Majorana modes, emerges at zero magnetic field. Our findings could be used for advanced experiments, including microwave spectroscopy and braiding operations.

Spatial and energy dependent texturing of the charge order in 1T-Cu_xTiSe_2

Marcello Spera, Alessandro Scarfato, Enrico Giannini and Christoph Renner

Department of Quantum Matter Physics, University of Geneva, 24 Quai Ernest-Ansermet, CH-1211 Geneva 4, Switzerland

Marcello.Spera@unige.ch

The competition between ground states is a central topic in modern condensed matter physics. It is of common belief that unconventional superconductivity (SC) emerges from a precursor state, such as pseudogap or charge order, which is suppressed upon the appearance of the superconducting condensate.

Since the discovery of a Charge Density Wave (CDW) modulation (1976) and Cu doping induced SC (2006) in 1T-$TiSe_2$, this system has become prototypical for studying the interplay between these two states.

While SC in 1T-Cu_xTiSe_2 seems to follow a standard BCS s-wave behaviour, the microscopic origin of the CDW is still under debate. In order to address this issue, we performed a detailed Scanning Tunneling Microscopy and Spectroscopy study of the impact of Cu intercalation on the CDW in 1T-Cu_xTiSe_2 [1,2].

Density Functional Theory modelling allowed us to identify Cu atoms, which are found to intercalate randomly on the octahedral site in the van der Waals gap. Tunneling spectroscopy remarkably shows that the CDW gap opens below the Fermi level and follows the Cu induced band shift. The CDW modulation is found to break up in a complicated energy and position-dependent domain structure, which can be explained in terms of charge inhomogeneities induced by Cu intercalation. Under certain conditions, the CDW is visible and well developed in all the crystals investigated, including the superconducting ones. This suggests a possible coexistence of SC and CDW order, and both results are compatible with a CDW gap that is not pinned to the Fermi level. These findings further invalidate both Fermi surface nesting and excitonic pairing as the primary CDW formation mechanism in this material.

[1] A.M. Novello et al. Phys. Rev. Lett. 118, 017002

[2] M. Spera et al, arXiv:1710.04096

Transparent superconductor - Bi_2Se_3 nanoribbon interface hybrid devices

Gunta Kunakova[1,2], Luca Galletti[1], Jana Andzane[2], Donats Erts[2], Thilo Bauch[1], Floriana Lombardi[1]

[1] *Chalmers University of Technology, Department of Microtechnology and Nanoscience, Gothenburg, Sweden*

[2] *University of Latvia, Institute of Chemical Physics, Riga, Latvia*

gunta.kunakova@lu.lv

3D Topological Insulators (TIs) have been regarded as novel materials with a Dirac states on the surfaces. Bi-based chalcogenides (Bi_2Te_3, Bi_2Se_3, $(Bi_{1-x}Sb_x)_2Te_3$) are well recognized 3D TIs used to probe the topological surface states. The proximity of 3D TI and superconductor has been proposed as a platform to induce the Majorana bound states (MBS) and the topological superconductivity in the surface states [1].

Imperfections of the 3D TI material bulk, such as defects and impurities, set the Fermi level into the bulk conduction band, which makes it difficult to access the transport from topological surface states. One of the promising routes of how to exclude the bulk contribution is to study the TI nanomaterials, for example, nanoribbons. A large surface to volume ratio of TI nanoribbons and nanowires may lead to the bulk suppression and reduced number of conduction modes, particularly important for Josephson devices to probe the MBS. The hybrid devices consisting of a TI and superconducting (SC) electrodes have been studied extensively. However, difficulties to achieve a good coupling of TI/SC hinder a further progress, and, up to now, no Josephson effect on TI nanowires and nanoribbons has been reported.

Here we study transport properties of catalyst-free Physical Vapour deposition grown TI nanoribbons [2], that are *bulk-free* at thicknesses below ~30 nm. An excellent coupling between the superconductor (Al) and the 3D TI – Bi_2Se_3 nanoribbon has been achieved. The Josephson devices are characterised by a high I_cR_n product (I_c – critical current and R_n – normal resistance), that is close to the value of superconducting gap of Al. The conductance spectra of TI nanoribbon Josephson devices show a multiple Andreev reflections, pointing to a highly transparent interface of the Al/Bi_2Se_3 nanoribbon.

[1] Fu, L.; Kane, C. L. Superconducting Proximity Effect and Majorana Fermions at the Surface of a Topological Insulator. *Phys. Rev. Lett.* **2008**, *100*, 96407.

[2] Andzane, J.; Kunakova, G.; Charpentier, S.; Hrkac, V.; Kienle, L.; Baitimirova, M.; Bauch, T.; Lombardi, F.; Erts, D. Catalyst-Free Vapour-Solid Technique for Deposition of Bi_2Te_3 and Bi_2Se_3 Nanowires/nanobelts with Topological Insulator Properties. *Nanoscale* **2015**, *7*, 15935.

Superconductivity with Frustrated Josephson coupling

Egor Babaev[1], Julien Garaud[1], Mihail Silaev[2]

[1]*KTH The Royal Institite of Technology Stockholm*
2 Department of Physics and Nanoscience Center, University of Jyvaskyla,

babaevegor@gmail.com

Recently many interesting phenomena were discussed to occur in superconductors that have frustrated integrand coupling. The frustration occurs rather generically for superconductors with repulsive interband coupling: for example two-band dirty S+- superconductors have frustration between bilinear and biquadratic Josephson coupling that is tunable by impurity concentration. Coupling to more bands often yields in such system frustration at the level of bilinear interband coupling. I will talk about the consequences of that coupling that ranges from frustration-generated breakdown of time reversal symmetry, appearance of spontaneous magnetic fields, skyrmionic excitations and resulting unconventional magnetic and transport properties. I will also discuss recent experimental evidence in favor of frustration-generated s+is state in iron-based materials

Majorana quasiparticles in atomic chain of magnetic impurities: effect of d-wave pairing

Mahdi Mashkoori and Annica M. Black-Schaffer
Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala, Sweden *

Topological superconductivity in low-dimensional systems is one of the amazing quantum states that can be accompanied by Majorana quasiparticles. Atomic chains of magnetic impurities (Shiba chains) on top of a superconducting substrate is one of the promising experimental set-ups that shows topological superconductivity in one dimension.[1] Here, we address the problem of topological phase transition and emergence of Majorana bound states (MBS) at the wire end points when both conventional s-wave and unconventional d-wave superconductivity co-exist in the substrate, as there is evidence for such coexistence in high T_c superconductors.[2]

Considering first a single magnetic impurity on a substrate with both s-wave and d-wave superconductivity, we observe that the d-wave order parameter plays a crucial role in the quantum phase transition.[3] Next, we discuss how the topological phase transition in a Shiba chain is affected by d-wave order. In general, we assume Rashba spin-orbit coupling in the substrate and a gap function of the form $\Delta(k) = \Delta_d(\cos(k_x) - \cos(k_y)) + e^{i\phi}\Delta_s$ where ϕ can be either $\phi = n\pi$ or $\phi = (2n+1)\pi/2$ depending on whether time-reversal symmetry is broken or not in the superconducting substrate.

Beside the emergence and robustness of MBS, another important aspect of such a system is the localization of the MBS. As illustrated in Fig. 1, our results show that a dense Shiba chain in the presence of both the d-wave and s-wave states leads to quite robust and more localized MBS for $d+is$-wave state, independent on the relative chain orientation on the substrate. However, the MBS in the case of $d+s$-wave state are fragile due to a small mini-gap. We also note that in this case, the MBS are sensitive to the the orientation of the chain with respect to the substrate.

Furthermore, we identify an appropriate topological quantity to capture the topological phase transition for a one-dimensional chain embedded in a two-dimensional substrate. Here we necessarily have to keep the substrate to be two-dimensional, because of the d-wave order in the substrate. In particular, we find that the Berry phase (γ_B), based on a Wilson loop method for the occupied states,[4] changes abruptly from $\gamma_B = 0$ to $\gamma_B = \pi$ at the topological phase transition.

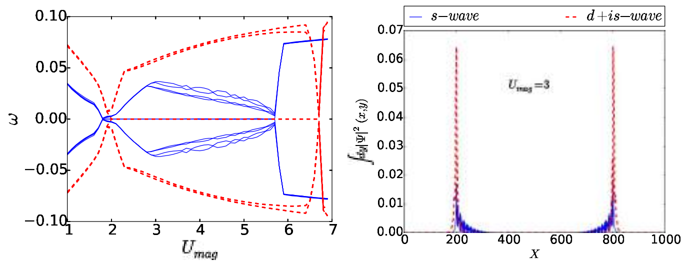


FIG. 1: Energy for a few intra-gap bound states (left) and the wave function of the MBS (right) for conventional s-wave (solid blue line) and unconventional $d+is$-wave (dashed red line) superconducting substrate. The co-existence of d-wave and s-wave order leads to a larger mini-gap and more localized MBS. Here U_{mag} is scattering matrix element from each impurity, while $\Delta_d = 1$, $\Delta_s = 0.1$, and $\lambda_R = 0.3$ in units of the hopping amplitude $t = 1$.

* Electronic address: mahdi.mashkoori@physics.uu.se / annica.black-schaffer@physics.uu.se

[1] S. Nadj-Perge et al. Science **346**, 602 (2014).
[2] J. R. Kirtley et al. Nat. Phys. **2**, 190 (2006) and D. Gustafsson et al. Nat. Nanotechnol. **8**, 25 (2013).
[3] M. Mashkoori, K. Bjornson and A. M. Black-Schaffer. Sci. Rep. **7**, 44107 (2017).
[4] A. Alexandradinata, X. Dai and B. A. Bernevig. Phys. Rev. B **89**, 155114 (2014).

Observation of 4π-periodic supercurrent and Zeeman π -junction in Dirac semimetal Josephson junctions

Chuan Li[1], **Jorrit de Boer**[1], **Bob de Ronde**[1], **Shyama V. Ramankutty**[2], **Erik van Heumen**[2], **Yingkai Huang**[2], **Anne de Visser**[2], **Alexander A. Golubov**[1], **Mark S. Golden**[2], **and Alexander Brinkman**[1]

[1]*MESA+ Institute for Nanotechnology, University of Twente, The Netherlands*
[2]*Van der Waals - Zeeman Institute, IoP, University of Amsterdam, The Netherlands*
chuan.li@utwente.nl

Dirac semimetals with chiral quasiparticles possess linear dispersion in three dimensions, and become a developing platform of novel quantum materials. A three-dimensional Dirac cone can be found in $Bi_{1-x}Sb_x$ at the Sb-induced band inversion point. Superconductivity is induced in this Dirac semimetal by making Nb-$Bi_{0.97}Sb_{0.03}$-Nb Josephson junctions and the radio frequency irradiation experiments reveal a significant contribution of 4π-periodic Andreev bound states to the supercurrent. The conditions for a substantial 4π-periodic contribution to the supercurrent are favorable because of the Dirac cone's topological protection against back-scattering, providing very broad transmission resonances and an enhanced lifetime of the 4π-periodic state due to local conservation of fermion parity.

The large g-factor of the Zeeman effect from a magnetic field applied in the plane of the junction, allows tuning of the Josephson junctions from 0 to π regimes as a consequence of the finite momentum pairing. We observe an oscillating critical supercurrent as a function of the parallel magnetic field (Fig1.b).

When this tunable π-junction is incorporated in a superconducting loop with a conventional junction, forming an asymmetric quantum interference device (SQUID), indeed π-junction behavior is observed in the SQUID modulation. The skew shape of the current-phase relation (CPR) suggests our 300 nm Dirac semimetal junction to be in the long and ballistic limit. When the parallel field along the current direction increases, the CPR alternates between 0 and π states, each time indicated by a phase shift of π. ($\Delta\varphi = 2\pi\frac{\phi}{\phi_0}$).

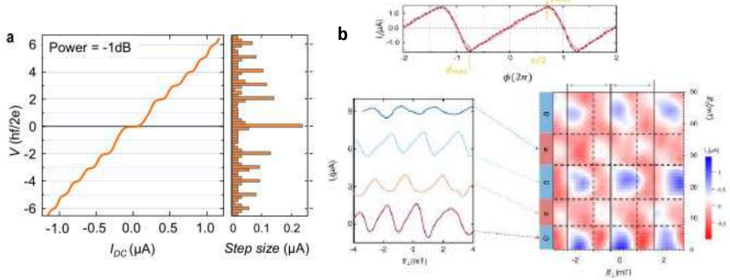


Figure 1: (a) Shapiro steps of Dirac semimetal-based junction. The first step has disappeared due the 4π-periodic supercurrent current component. (b) Current-phase relation. Upper: CPR at zero parallel field. Lower: CPR at different parallel field ($B_{//}$). The phase is shifted by π when the junction is tuned between 0 and π states.

[1] C. Li et al. *4π periodic Andreev bound states in a Dirac semimetal*. arXiv:1707.03154

Signatures of non-local couplings in Cooper pair splitter: The Andreev molecule

Zoltán Scherübl[1], **András Pályi**[2], **Szabolcs Csonka**[1]

[1]*Department of Phyiscs, Budapest University of Technology and Economics and Condensed Matter Research Group of the Hungarian Academy of Sciences, 1111 Budapest, Budafoki út 8., Hungary*
[2]*Department of Physics and MTA-BME Exotic Quantum Phases "Momentum" Research Group, Budapest University of Technology and Economics, 1111 Budapest, Hungary*
scherubl.zoltan@gmail.com

Hybrid superconductor-semiconductor devices have drawn large attention both theoretically and experimentally in the recent years. In the strong coupling limit such devices can host exotic states, like Andreev bound states [1], Majorana bound states [2-3] or parafermions [4]. In the weak coupling limit when the semiconductor hosts two quantum dots in a three terminal geometry, the device can act as a source of entangled electron pairs, it splits the Cooper pairs via crossed Andreev reflection [5-7].

Here we present the signatures of non-local couplings in the strongly coupled limit in the Cooper pair splitter geometry. The strong coupling to the superconductor gives rise to local Andreev bound states on the dots, while having non-local couplings between the dots leads to the hybridization of the Andreev bound states, forming a non-local state, the Andreev molecular state.

We distinguish three different non-local couplings, the crossed Andreev reflection, the elastic cotunneling, where an electron tunnels through the superconductor and the direct interdot tunnel coupling. We show that one can tell the dominant coupling by measuring the stability diagram of the two quantum dots simultaneously. Further we discuss the triplet blockade [8], which is usually attributed to the crossed Andreev reflection, is not exclusively present in case of finite crossed Andreev coupling.

[1] C. W. J. Beenakker and H. van Houten, in Single-Electron Tunneling and Mesoscopic Devices, edited by H. Koch and H. Lübbig, Springer, Berlin, 1992; arXiv:cond-mat/0111505.
[2] A. Yu. Kitaev, Phys. Usp. **44**, 131 (2001).
[3] V. Mourik, *el al.*, Science **336**, 1003 (2012)
[4] J. Klinovaja, *el al.*, Phys. Rev. B **90**, 155447 (2014)
[5] P. Recher, *et al.*, Phys. Rev. B **63**, 165314 (2001)
[6] L. Hofstetter, *et al.*, Nature **461**, 960 (2009)
[7] L. G. Herrmann, *et al.*, Phys. Rev. Lett. **104**, 026801 (2010)
[8] J. Eldridge, *et al.*, Phys. Rev. B **82**, 184507 (2010)

Non-equilibrium ϕ_0-junction-like behavior of multi-terminal normal-superconducting nanohybrids

Pavel E. Dolgirev[1], **Mikhail S. Kalenkov**[2], **and Andrei D. Zaikin**[3,2]

[1] *Skolkovo Institute of Science and Technology, Skolkovo Innovation Center, 3 Nobel St., 143026 Moscow, Russia*

[2] *I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, Russia*

[3] *Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany*

andrei.zaikin@kit.edu

We elucidate a non-trivial interplay between proximity-induced quantum coherence and non-equilibrium effects in multi-terminal heterostructures composed of superconducting and normal terminals interconnected by normal metallic wires and threaded by the magnetic flux Φ, as depicted in Fig. 1. We demonstrate that at low enough temperatures the corresponding SNS structure exhibits characteristic features of a novel (I_0, ϕ_0)-junction state: The current I_S in the superconducting contour is predicted to have the form [1]

$$I_S = I_0(V) + I_1(V, \phi + \phi_0(V)), \quad \phi = 2\pi\Phi/\Phi_0, \tag{1}$$

where $I_0 = \langle I_S \rangle_\phi$, Φ_0 is the flux quantum and $I_1(V, \phi)$ is a 2π-periodic function of the phase difference ϕ between two S-terminals. At low enough bias voltages $V = V_2 - V_1$ the contribution I_1 essentially coincides with the voltage-controlled Josephson current [2, 3], while at higher voltages we have $I_1 \simeq \tilde{I}_C(V)\sin(\phi + \phi_0)$ with non-zero phase shift $\phi_0(V)$ which tends to $\pi/2$ in the limit of large V, see Fig. 1. This behavior resembles that of an equilibrium ϕ_0-junction developing nonvanishing supercurrent at $\phi = 0$.

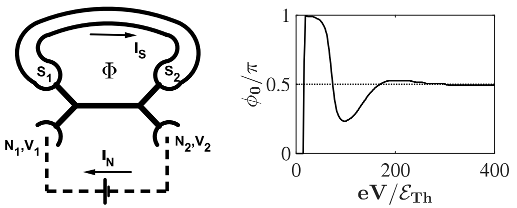


Figure 1: The system under consideration and the voltage-controlled phase shift $\Phi_0(V)$.

Applying a thermal gradient to our multi-terminal hybrid nanostructure we evaluate the flux-dependent thermopower $\mathcal{S}(\Phi)$ which turns out to exhibit features similar to those of an (I_0, ϕ_0)-junction (1). Depending on the voltage bias, $\mathcal{S}(\Phi)$ can reduce to either odd or even function of Φ and demonstrate a $0 - \pi$ phase jump with increasing V. These observations allow to resolve a number of long standing experimental puzzles regarding the flux-sensitive thermoelectric effect in Andreev interferometers [4, 5].

[1] P.E. Dolgirev, M.S. Kalenkov, A.D. Zaikin, arXiv:1711.05531v1.
[2] F.K. Wilhelm, G. Schön, A.D. Zaikin, Phys. Rev. Lett. **81**, 1682 (1998).
[3] J.J.A. Baselmans, A.F. Morpurgo, B.J. van Wees, T.M. Klapwijk, Nature **397**, 43 (1999).
[4] J. Eom, C.-J. Chien, V. Chandrasekhar, Phys. Rev. Lett. **81**, 437 (1998).
[5] A. Parsons, I.A. Sosnin, V.T. Petrashov, Phys. Rev. B **67**, 140502(R) (2003).

Influence of Microwaves on Magnetic Switching in Nb-Al/AlOx-(Nb)-PdFe-Nb Josephson Junctions

Roberta Caruso[1,2], **Davide Massarotti**[1,2], **Vitaly V. Bol'ginov**[3,4], **Aymen Ben Hamida**[4], **Liubov N. Karelina**[3], **Alessandro Miano**[1], **Igor V. Vernik**[6], **Francesco Tafuri**[1, 2], **Valery V. Ryazanov**[3,7], **Oleg A. Mukhanov**[6] **and Giovanni Piero Pepe**[1,2]

[1] *Dipartimento di Fisica, Università degli Studi di Napoli Federico II, Monte Sant'Angelo, via Cintia, I-80126 Napoli - Italy*

[2] *CNR-SPIN, Monte Sant'Angelo, via Cintia, I-80126 Napoli - Italy*

[3] *Institute of Solid State Physics (ISSP - RAS), Chernogolovka, Moscow Region, 142432 - Russia*

[4] *National University of Science and Technology MISIS, 4 Leninsky prosp., Moscow 119049 - Russia*

[5] *Leiden Institute of Physics, Leiden University, Niels Bohrweg 2, 2333 CA Leiden - The Netherlands*

[6] *HYPRES, Inc. - 175 Clearbrook Road, Elmsford, NY 10523 - USA*

[7] *Faculty of Physics, National Research University Higher School of Economics, Moscow, Russia*

caruso@fisica.unina.it

Superconducting circuits have found application in various fields, due to their high speed and high energy efficiency. However, the practical, large scale application of these circuits is limited by the lack of compatible energy-efficient, high-speed and high capacity random access memories. In 2012 Nb-Al/AlOx-(Nb)-PdFe-Nb have been proved to be random access magnetic memories compatible with RSFQ logic [1]. However, the performances of such devices can be limited by the external circuitry necessary to send the magnetic field pulses needed to switch between '0' and '1' states. Here we discuss the effect on magnetic switching of RF fields, in particular we discuss the enhancement of the separation between the '0' level and the '1' level when an external microwave field is applied, and the consequences of this enhancement on the performances of these devices.

[1] T. I. Larkin, V. V. Bol'ginov, V. S. Stolyarov, V. V. Ryazanov, I. V. Vernik, S. K. Tolpygo and Oleg A. Mukhanov *Appl. Phys. Lett.* **100**, 222601 (2012).

Superconducting Spintronics in Double-Barrier Josephson Junctions

Jabir Ali Ouassou*, Sol H. Jacobsen*, Jacob Linder*

*Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
jabir.a.ouassou@ntnu.no

This talk will summarize the results of two recent publications on Josephson junctions with multiple superconducting and magnetic interlayers [1, 2], and will present results that are directly relevant for experiments on such geometries. Based on simple analytical arguments and robust numerical simulations, we demonstrate two interesting physical predictions. The first setup we considered is a spin-valve sandwiched inbetween two superconductors to form a Josephson junction (S/F/S/F/S). We found that one can toggle magnetically between two qualitatively different current-phase relations: $I \sim \sin(\delta\varphi)$ and $I \sim \sin(\delta\varphi/2)$ [1]. The same kind of device can alternatively be used as a Josephson junction with a magnetic on–off switch. The second setup focused on inhomogeneous and strongly polarized magnetic barriers, using realistic experimental parameters for the system in Fig. 1 [2]. For this setup, we discovered that not only can one generate and inject a completely general spin supercurrent into the central superconductor, but this spin supercurrent is also conserved as a function of position inside the superconductor, even in the presence of spin-dependent impurity scattering. The same system also admitted a number of other interesting behaviours as a function of the system parameters, such as a non-monotonic behaviour as a function of the spin-flip scattering rate. All the calculations discussed above were performed using self-consistent numerical simulations in the quasiclassical and diffusive limits (Usadel equation).

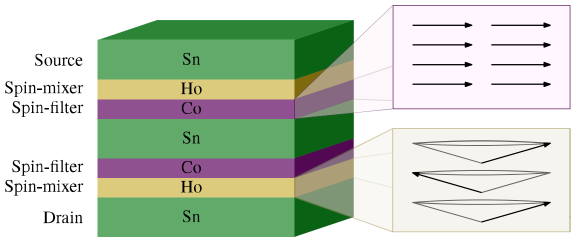


Figure 1: Example of a ferromagnetic double-barrier junction taken from Ref. [2]. The exterior superconductors (Sn) are reservoirs, the inhomogeneous magnets (Ho) generate triplets, and the strongly polarized magnets (Co) convert charge currents into spin currents. We have investigated how the resulting spin current behaves inside the central superconductor (Sn).

[1] J.A. Ouassou, J. Linder.
Spin-switch Josephson junctions with magnetically tunable $\sin(\delta\varphi/n)$ current-phase relation.
Phys. Rev. B **96**, 064516 (2017).

[2] J.A. Ouassou, S.H. Jacobsen, J. Linder.
Conservation of spin supercurrents in superconductors.
Phys. Rev. B **96**, 094505 (2017).

Experiments with artificial φ Josephson junctions

Edward Goldobin[1], Rosina Menditto[1], Michael Merker[2], Michael Siegel[2], Dieter Koelle[1], Reinhold Kleiner[1]

[1] *Physikalisches Institut, University of Tübingen. Auf der Morgenstelle 14, 72076, Tübingen, GERMANY*
[2] *Physikalisches Institut. Karlsruhe Institut für Technologie, 76128. Karlsruhe, GERMANY*
gold@uni-tuebingen.de

During the last few years our group proposed [1, 2] and experimentally demonstrated [3] a so-called φ Josephson junction (JJ) based on superconductor-insulator-ferromagnet-superconductor (SIFS) heterostructure. The φ JJ has rather unique Josephson energy profile $U(\psi)$ — a 2π periodic double-well potential with asymmetry tunable by applied magnetic field. As a result the junction has rather unusual properties, e.g., (a) non-zero degenerate ground state phase $\psi = \pm\varphi$; (b) two critical currents, corresponding to the escape of the phase from two different wells; (c) possibility to put the phase in a certain well by applying a magnetic field [4]. Several devices based on φ junctions were demonstrated [5, 6]. However, the macroscopic quantum properties remain not investigated mainly because low critical current density j_c in SIFS JJs, which results in a low thermal-to-quantum crossover temperature $T^\star$.

To investigate quantum properties we re-created a φ Josephson junction using Nb-AlO-Nb technology with high j_c, where a π discontinuity of the phase is created artificially by a pair of tiny current injectors. The mapping of a short JJ with a κ discontinuity of the phase into effective φ_0 or $\pm\varphi$ JJ was described theoretically[7] In experiment, however, we have discovered that due to finite injector size one can obtain generally asymmetric but tunable double-well potential corresponding to $\varphi_0 \pm \varphi$ JJ. In the degenerate state we have measured the statistics of both switching currents (escape from left and right wells) as a function of temperature, and saw the crossover from the thermal activation regime to the macroscopic quantum tunneling (MQT) of the phase from *both* wells of the double-well potential.

[1] E. Goldobin et al., Phys. Rev. Lett. **107**, 227001 (2011).
[2] A. Lipman et al., Phys. Rev. B **90**, 184502 (2014).
[3] H. Sickinger et al., Phys. Rev. Lett. **109**, 107002 (2012).
[4] E. Goldobin et al., Phys. Rev. B **76**, 224523 (2007).
[5] E. Goldobin et al., Appl. Phys. Lett. **102**, 242602 (2013).
[6] R. Menditto et al., Phys. Rev. E **94**, 042202 (2016).
[7] E. Goldobin et al., Phys. Rev. B **93**, 134514 (2016).

Spin supercurrents due to Fermi liquid effects in Superconductor/Ferromagnet Hybrid Structures

Matthias Eschrig and Xavier Montiel

Department of Physics, Royal Holloway, University of London, Egham, Surrey TW200EX, United Kingdom
matthias.eschrig@rhul.ac.uk

Combining spin-selectivity with phase coherence in superconductor/ferromagnet proximity devices has led to an increase in functionality due to spin-polarized Cooper pairs, which are the basic building blocks of the emerging field of superconducting spintronics [1]. Fermi liquid effects [2] are often neglected when treating normal state or superconducting transport phenomena, as they lead only to quantitative but not qualitative changes in the results. However, in superconductor-ferromagnet hybrid structures there can be important Fermi liquid parameters which can lead to qualitative changes of the spin-transport [2,3].
Recently experiments have been performed where spins are pumped from a ferromagnet into a superconductor using a ferromagnetic resonance (FMR) technique. The injected spin current into a superconducting layer is expected to decrease below T_c because singlet Cooper pairs do not carry spin, such that spin transport is entirely via excitations [4]. Here, we propose a new mechanism in which the spin current is carried by spin-triplet pairs which are created by a combination of Fermi liquid effects and spin-orbit coupling in an additional metallic layer added to the F/S structure. As a result, a new channel of spin-transport is opened in which spin is transported by Cooper pairs rather than by excitations.

[1] M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015).
[2] J.A.X. Alexander, T.P. Orlando, D. Rainer, and P.M. Tedrow, Phys. Rev. B **31**, 5811 (1985).
[3] A.G. Mal'shukv and A. Brataas, Phys. Rev. B **86**, 094517 (2012).
[4] J. Morten *et al.,* Europhys. Lett. **84**, 57008 (2008).

Superconducting proximity effect to probe the topological protection of edge states in Bismuth nanowires

Anil Murani[1], Bastien Dassonneville[1], Alik Kasumov[1,2], Shamashis Sengupta[1], Yu.A. Kasumov[2], V.T.Volkov[2], I.I. Khodos[2], F. Brisset[3], Raphaëlle Delagrange[1], Alexei Chepelianskii[1], Richard Deblock[1], Meydi Ferrier[1], Hélène Bouchiat[1], and Sophie Guéron[1]

[1] *Laboratoire de Physique des Solides, CNRS, Univ. Paris-Sud, Université Paris Saclay, 91405 Orsay Cedex, France.*
[2] *Institute of Microelectronics Technology and High Purity Materials, Chernogolovka, Moscow Region, Russia.*
[3]*Institut de Chimie Moléculaire et des Matériaux d'Orsay Bâtiments 410/420/430, Univ. Paris-Sud 11, 91405 Orsay cedex - France*
Sophie.gueron@u-psud.fr

Reducing the size of a conductor usually decreases its conductivity because of the enhanced effect of disorder in low dimensions, leading to diffusive transport and to weak, or even strong localization. Notable exceptions occur when topology provides protection against disorder, such as in the Quantum Hall effect or the recently discovered Quantum Spin Hall effect in two-dimensional Topological Insulators. In the latter, crystalline symmetry combined with high spin-orbit coupling generate band inversion and one-dimensional chiral edge states with perfect spin-momentum locking, that theoretically precludes backscattering along the edges. However, since the first evidences of edge state currents, both in the normal and superconducting-proximitised states, demonstrating the robustness of ballistic conduction and spin polarization in the one-dimensional edge states has remained a challenge. In this talk, I will present a direct signature of ballistic 1D transport along the topological surfaces of a single crystal bismuth nanowire connected to superconducting electrodes. This signature was obtained by exploiting the extreme sensitivity of the relation between the Josephson current flowing through a nanostructure and the superconducting phase difference at its ends, the "current-phase relation" (CPR). The sharp sawtooth-shaped CPR we find demonstrates that transport occurs ballistically along two edges of the nanowire, and confirms the predicted nearly perfect transmission of Cooper pairs through Quantum Spin Hall edge states. I will also describe our recent measurement of the high frequency response of the Bismuth nanowire inserted in a superconducting ring, a setup ideal to probe the topological protection of the edge states.

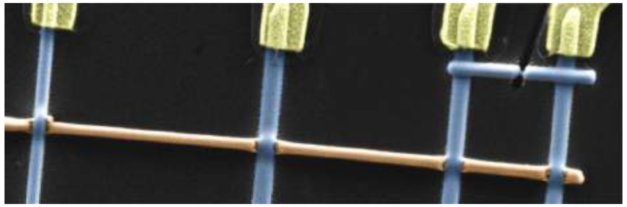


Figure 1: Bismuth nanowire (in brown) connected to superconducting electrodes (in blue), including an asymmetric SQUID configuration enabling the supercurrent-versus-phase relation measurement.

[1] Murani et al, Nature Comm. DOI: 10.1038/ncomms15941 (2017).

Long–Range Inverse Proximity Effect in Superconductor-Ferromagnet Structures

A. Buzdin[1, 2], **S. Mironov**[3], **A. Mel'nikov**[3]

[1] *University Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France*
[2] *Department of Materials Science and Metallurgy, University of Cambridge, CB3 0FS, Cambridge, United Kingdom*
[3] *Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia*
alexandre.bouzdine@u-bordeaux.fr

The spread of the Cooper pairs into the ferromagnet in proximity coupled superconductor – ferromagnet (SF) structures is shown to cause a strong inverse electrodynamic phenomenon, namely, the long-range transfer of the magnetic field from the ferromagnet to the superconductor. Contrary to the previously investigated inverse proximity effect resulting from the spin polarization of superconducting surface layer, we found a very generic orbital mechanism of the magnetic moment transfer from a ferromagnet to a superconductor which is unavoidable in S/F hybrids. It is related with the fact that the common superconducting wave function in S and F (near the interface) does not permit to exclude the vector-potential of the magnetization by gauge transformation. From the experimental point of view, this phenomenon reminds the Aharonov-Bohm effect since the current inside the attached superconductor is induced by the ferromagnetic layer which cannot create the magnetic field in the outside in the absence of such superconducting environment. At the same time, the true physical key point is that the wave function penetrating the ferromagnet is responsible for this effect. Let us stress that the characteristic length of the above proposed inverse electrodynamic effect is of the order of the London penetration depth.

Super-fast dynamics and flow instabilities of superconducting vortices

Y. Anahory[1,2], **L. Embon**[1], **Ž.L. Jelić**[3,4], **E.O. Lachman**[1], **Y. Myasoedov**[1], **M.E. Huber**[5], **G.P. Mikitik**[6], **A.V. Silhanek**[4], **M.V. Milošević**[3], **A. Gurevich**[7], **E. Zeldov**[1]

[1]*Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, Israel*
[2]*Racah Institute of Physics, The Hebrew University, Jerusalem, Israel*
[3]*Departement Fysica, Universiteit Antwerpen, Groenenborgerlaan, Antwerpen, Belgium*
[4]*Département de Physique, Université de Liège, Sart Tilman, Belgium*
[5]*Departments of Physics and Electrical Engineering, Uni. of Colorado Denver, Denver, USA*
[6]*Verkin Institute for Low Temp. Phys. & Eng., Ukrainian Academy of Sci., Kharkov, Ukraine*
[7]*Department of Physics, Old Dominion University, Norfolk, VA, USA*
yonathan.anahory@mail.huji.ac.il

NanoSQUIDs residing on the apex of a quartz tip (SOT), suitable for scanning probe microscopy with record size, spin sensitivity and operating magnetic fields are presented[1-2]. We have developed SOT made of Pb with an effective diameter of 46 nm and flux noise of $\Phi_n = 50\ n\Phi_0/Hz^{1/2}$ at 4.2 K that is operational up to unprecedented high fields of 1 T[2]. The corresponding spin sensitivity of the device is $S_n = 0.38\ \mu_B/Hz^{1/2}$, which is about two orders of magnitude more sensitive than any other SQUID to date.

We use this technique to study vortex dynamics under strong currents[3]. Quantized magnetic vortices driven by electric current determine key electromagnetic properties of superconductors. While the dynamic behavior of slow vortices has been thoroughly investigated, the physics of ultrafast vortices under strong currents remains largely unexplored. Here we image vortices penetrating into a superconducting Pb film at rates of tens of GHz and moving with velocities up to tens of km/s, which are not only much larger than the speed of sound but also exceed the pair-breaking speed limit of superconducting condensate. These experiments reveal formation of mesoscopic vortex channels which undergo cascades of bifurcations as the current and magnetic field increase (Figure 1). Our numerical simulations predict metamorphosis of fast Abrikosov vortices into mixed Abrikosov-Josephson vortices at even higher velocities. This work offers an insight into the fundamental physics of dynamic vortex states of superconductors at high current densities, crucial for many applications.

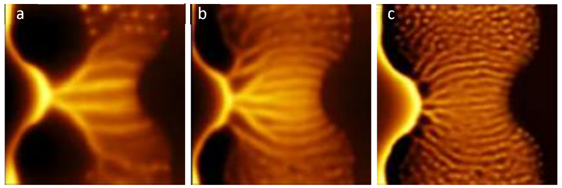


Figure 1: Magnetic imaging of fast moving vortices in Pb film at the highest sustainable current and at different applied field **a** 2.7 mT, **b** 5.4 mT and **c** 9.0 mT.

[1] A. Finkler *et al.* Nano Lett. **10**, 1046 (2010)
[2] D. Vasyukov *et al.* Nature Nanotech. **8**, 639 (2013).
[3] L. Embon *et al.* Nature Comm. **8**, 85 (2017)

Intrinsic p-wave ferromagnetic superconductors: insights from bulk materials

Beilun Wu[1,2], Gael Bastien[1,3], Daniel Braithwaite[1], Georg Knebel[1], Jacques Flouquet[1], Alexandre Pourret[1], Dai Aoki[4] and Jean-Pascal Brison[1]

[1] *Univ. Grenoble-Alpes/CEA, INAC/Pheliqs, Grenoble France*
[2] *present address: LBTUAM, Departamento de Física de la Materia Condensada, Instituto Nicolás Cabrera and IFIMAC Universidad Autónoma de Madrid, Spain*
[3] *present address: IFW Dresden, Institute for Solid State Research, Dresden, Germany*
[4] *Institute for Materials Research, Tohoku University, Oarai, Ibaraki Japan*
jean-pascal.brison@cea.fr

The first discovery of an intrinsic bulk ferromagnetic superconductor dates back from 2000, with a pressure induced superconducting phase discovered in the strongly correlated uranium-based system UGe_2 [1]. Soon after, URhGe [2] and UCoGe [3] have been found to present homogeneously coexisting ferromagnetic and superconducting orders at ambiant pressure. The amazingly robust superconducting state under high fields quickly left little doubt about the fact that they belong to the rare class of p-wave superconductors.

We will expose the progress done on the modeling of these singular materials [4], allowing to understand some of their most astonishing features, like the very strong anisotropic suppression of superconductivity [5]. Further insight has been gained recently by stress experiments, which revealed a strong boost of T_{sc} and of H_{c2} [6], shown to arise from the intrinsic "two gap" nature of the (non unitary) p-wave state. We will also discuss why these compounds are good candidates for topological superconductivity, and how we intend to probe if they keep their promise

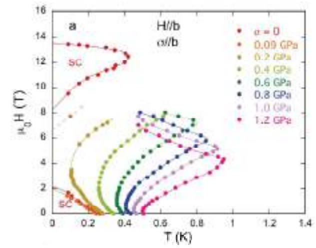


Figure 1: Upper critical field H_{c2} of URhGe under stress [6].

[1] SS Saxena, et al. *Nature*, 406(6796):587–592, 2000.

[2] D Aoki, et al. *Nature*, 413(6856):613–616, 2001.

[3] N. T. Huy, et al. *PRL*, 99(6):067006, 2007.

[4] V P Mineev. *Physics-Uspekhi*, 60(2):121, 2017.

[5] Beilun Wu, et al.. *Nature Comm.*, 8:14480, 02 2017.

[6] D. Braithwaite, et al.. *ArXiv e-prints*, October 2017.

Intrinsic superspin Hall current

Jacob Linder[1], Morten Amundsen[1], and Vetle Risinggård[1]

[1] *Center for Quantum Spintronics, Department of Physics, NTNU, Norwegian University of Science and Technology, N-7491 Trondheim, Norway*
vetle.k.risinggard@ntnu.no

We consider a Josephson junction in the ballistic limit with a normal-metal/ferromagnet/normal-metal weak link [1]. A longitudinal charge supercurrent injected by a phase difference gives rise to a transverse spin supercurrent in the presence of Rashba spin–orbit coupling in the normal metals. Due to the analogy with the conventional intrinsic spin Hall current, we refer to this as an intrinsic superspin Hall current. There is no accompanying dissipation of energy, in contrast to the conventional spin Hall effect. The transverse spin current is generated by the coexistence of two superconducting condensates: one spin-triplet p-wave condensate and one spin-singlet s-wave condensate. When the junction is phase biased, a phase mismatch arises between these two condensates that induces an antisymmetric spin density among the transverse modes k_y near the superconductor/normal-metal interface. The existence of such an antisymmetric spin density is in turn responsible for the existence of a transverse spin supercurrent. Our predictions can be tested in hybrid structures including thin heavy metal layers combined with strong ferromagnets and ordinary s-wave superconductors.

[1] J. Linder, M. Amundsen, and V. Risinggård, Physical Review B **96**, 094512 (2017).

Coupled transport of spin, heat and charge in superconductors with Zeeman splitting.

Mikhail Silaev[1]

[1]*Department of Physics and Nanoscience Center, University of Jyväskylä, P.O. Box 35 (YFL), FI-40014 University of Jyväskylä, Finland*

mikesilaev@gmail.com

The interplay of superconductivity and magnetism is known to produce many interesting phenomena. Most of the research activity in this direction has been focused on the very unusual properties of a proximity effect in hybrid systems consisting of superconductors and ferromagnets. However, more recent studies have addressed the problem of non-equilibrium spin states including spin transport and dynamics in superconducting wires. The unique properties of electronic spectrum in superconducting systems provide the possibilities of controlled interplay between spin, charge and heat degrees of freedom [1]. Such non-equilibrium states have a large potential for new discoveries. The striking phenomena of extra-large spin relaxation time and spin decay length in superconductors with Zeeman field have been observed experimentally [2,3] and explained theoretically [4].

In this talk I discuss the theoretical progress in this direction which has been gained so far based on the recent works [1,4,5,6].

[1] F. S. Bergeret, M. Silaev, P. Virtanen, Tero T. Heikkila, Nonequilibrium effects in superconductors with a spin-splitting field, arXiv:1706.08245 (submitted to Rev. Mod. Phys.)
[2] C.H.L. Quay, D. Chevallier, C. Bena, M. Aprili, Nature Phys. 9, 84 (2013).
[3] F. Hubler, M.J. Wolf, D. Beckmann, H.v. Löhneysen, PRL 109, 207001 (2012).
[4] M. Silaev, P. Virtanen, F.S. Bergeret and T.T. Heikkilä, PRL 114 (16), 167002 (2015).
[5] M. Silaev, P. Virtanen, T. T. Heikkilä, and F. S. Bergeret, PRB 91, 024506 (2015).
[6] M. Silaev, PRB 96, 064519 (2017).

Spectroscopy of few-layer superconducting NbSe2

T. Dvir[1], M.Aprili[2], F. Massee[2], M. Khodas[1], C.H.L. Quay[2], and H. Steinberg[1]

[1]*Racah Istitute of Physics, The Hebrew University of Jerusalem, Israel*
[3]*LPS-CNRS Université Paris-Sud, 91400 Orsay, France*

marco.aprili@u-psud.fr

Tunnel junctions, an established platform for high resolution spectroscopy of superconductors, require defect-free insulating barriers; however, oxides, the most common barrier, can only grow on a limited selection of materials. We show that van der Waals tunnel barriers, fabricated by exfoliation and transfer of layered semiconductors, sustain stable currents with strong suppression of sub-gap tunneling [1]. This allows us to measure the spectra of bulk (20 nm) and ultrathin (3- and 4-layer) $NbSe_2$ devices at 70 mK. These exhibit two distinct superconducting gaps, the larger of which decreases monotonically with thickness and critical temperature. The spectra are analyzed using a two-band model incorporating depairing. In the bulk, the smaller gap exhibits strong depairing in in-plane magnetic fields (see Figure1), consistent with high out-of-plane Fermi velocity to be related to 3D character of electron band associated to this gap. In the few-layer devices, the large gap exhibits negligible depairing, consistent with out-of-plane spin locking due to Ising spin–orbit coupling. In the 3-layer device, the large gap persists beyond the Pauli limit as also expected for Ising superconductors.

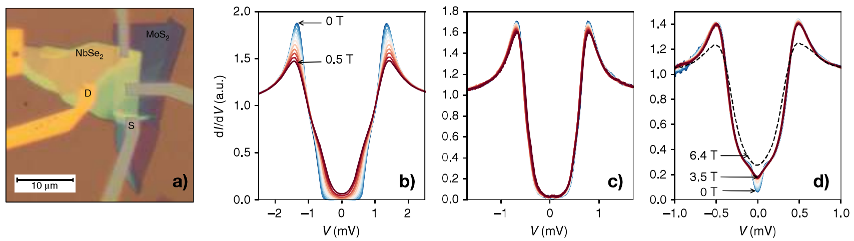


Figure 1: Response of the tunneling conductance to parallel magnetic fields. **a)** Optical image of the tunnel junction device. The yellow-green flake is a 50–20 nm thick $NbSe_2$ (20 nm at the source electrode) and the purple-blue flake is a 4–5 layer MoS_2. Au electrodes are deposited on the left to serve as ohmic contacts (yellow) and on the right to serve as tunnel electrodes (purple). **b)** dI/dV curves at increasing magnetic field parallel to the $NbSe_2$ layers ($H_{||}$) of the bulk sample, at $0 < H_{||} < 0.5$ T. **c)** Same for the 4-layer device at $0 < H_{||} < 3.5$ T, and **d)** same for the 3-layer device. Dashed line in d): dI/dV curve taken with the 3-layer device at uncompensated parallel field of 6.4 T.

[1] T. Dvir, F. Massee, L. Attias, M. Khodas, M. Aprili, C.H.L. Quay & H. Steinberg, Nature Communications 9, 598 (2018)

Magnetization reversal in individual nanoparticles revealed by nanoSQUID magnetometry

M. J. Martínez-Pérez[1,2], **J. Pablo-Navarro**[3] **B. Müller**[4], **R. Kleiner**[4], **J. M. de Teresa**[3], **J. Sesé**[3], **and D. Koelle**[4]

[1]*Instituto de Ciencia de Materiales de Aragón (ICMA-Universidad de Zaragoza), E-50009Zaragoza, Spain*
[2]*Fundación ARAID, E-50004 Zaragoza, Spain*
[3]*Laboratorio de Microscopías Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Universidad de Zaragoza, E-50018 Zaragoza, Spain*
[4]*Physikalisches Institut – Experimentalphysik II and Center for Collective Quantum Phenomena in LISA+, Universität Tübingen, D-72076 Tübingen, Germany*
pemar@unizar.es

We present recent advances made on the investigation of individual magnetic nanoparticles (MNPs) using ultra-sensitive $YBa_2Cu_3O_7$ (YBCO) nanoSQUIDs. These devices are patterned by focused ion beam milling and are based on submicron grain boundary Josephson junctions. We will show different approaches followed in order to optimize the magnetic coupling between the nanoparticle under study and the SQUID nanoloop. The impressive spin sensitivity (few $\mu_B/Hz^{1/2}$) reached with our nanoSQUIDs has enabled the detection of the tiny magnetic stray field created, for instance, by magnetic flux-closing structures in MNPs. The possibility of operating the sensors upon remarkably large in-plane magnetic fields (up to one Tesla) allows investigating different magnetization reversal mechanisms. To illustrate this, we will present results obtained on a series of cobalt nanowires in which the total cobalt concentration, degree of crystallinity and anisotropy can be tuned at will. Additionally, the nucleation, displacement and annihilation of magnetic vortices on soft magnetic nanodiscs will be presented. We have performed an in-depth investigation of these thermally assisted processes thanks to the large range of operation temperatures of the nanoSQUIDs (mK – 60 K). These studies serve to shed light on the nature and magnitude of the energy barriers separating the different magnetic states, the nucleation/annihilation fields and switching times of individual MNPs. These properties are essential for the development of magnetic memories and devices based on magnetic nanowires or vortex states.

Geometry dependence of proximity induced vortex patterns in superconducting hybrid structures

Morten Amundsen[1], Jacob Linder[1]

[1]*Norwegian University of Science and Technology*
morten.amundsen@ntnu.no

Superconducting vortices may be introduced, via the proximity effect, to nonsuperconducting materials which are coupled to superconductors. This can be done either by applying a magnetic field, or—as was recently predicted—by applying an electric current to the superconductor [1]. The arrangement of these vortices are greatly influenced by the geometry of the system considered. A numerical study of vortices in diffusive superconducting hybrid structures will be presented [2]. By solving the quasiclassical Usadel equation in two and three dimensions by means of the finite element method, with which virtually any geometry can be modelled, a rich tapestry of vortex patterns are found. Both magnetically and electronically generated vortices will be considered, and their interplay with the system geometry explored. It will be demonstrated that giant vortices, with a higher phase winding than 2π, can appear in a highly symmetric normal metal which is embedded in a current-carrying superconductor. Such a vortex is found even in the absence of an applied magnetic field. In addition, both the number and position of vortices can be controlled electronically in such a system, with both vortex nucleation, as well as the annihilation of vortex–antivortex pairs possible.

[1] D. Roditchev *et al*, Nat. Phys. **11**, 3240 (2015).
[2] M. Amundsen, J.A. Ouassou, and J. Linder, to be submitted (2017).

Strong pinning theory of thermal vortex creep in type-II superconductors

M. Buchacek[1], V.B. Geshkenbein[1], R. Willa[1,2], G. Blatter[1],

[1]*Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland*
[2]*Materials Science Division, Argonne National Laboratory, Lemont, IL 60439, USA*
dimagesh@phys.ethz.ch

Vortices in type II superconductors define a soft matter system that is prone to thermal fluctuations. We study vortex pinning and creep in type-II superconductors produced by a low density of strong defects. Extending the strong pinning theory to account for thermal effects, we calculate the current-voltage characteristic and thus provide the first quantitative treatment of vortex creep. We describe the thermally activated flux flow regime found at small driving currents, which is characterized by constant barrier. We find that the overall current-voltage characteristic keeps its shape in the form of an excess-current characteristic typical of a strong pinning material.

Bulk Pinning Force Analysis of MgB_2 co-added with c-BN and $Ge_2C_6H_{10}O_7$ Fabricated by Spark Plasma Sintering

A. M. Ionescu[1,2], A. Crisan[1], and P. Badica[1]

[1]*National Institute of Materials Physics, 77125 Bucharest-Magurele, Romania*
[2]*Faculty of Physics, University of Bucharest, 77125 Bucharest-Magurele, Romania*
alina09i@yahoo.com

Magnesium diboride is considered a promising superconductor for practical applications because of the relatively high critical temperature (39 K) and is not expensive, not toxic, etc. The coherence length is in the range of 10-20 nm making the grain boundaries transparent to the flow of Cooper pairs. This condition is very important because it allows pinning improvement through doping with different additives which can be effective pinning centers if they are comparable in size with the coherence length. Additives are introducing in the MgB_2 matrix disorder, defects, precipitates, interfaces and modifications of the grain boundaries. The pinning centers can be divided, according to dimension, in volume, surface or point pinning and according to their character in normal core or $\Delta\kappa$ pinning [1].
Many additives were added or co-added to MgB_2 [2, 3] and excellent results were obtained, in most cases, by adding carbon, supplied from different organic and inorganic compounds. Among other additions we have recently found that cubic BN [4] (c-BN) is significantly increasing the critical current density at high magnetic fields with a small suppression of J_c at low fields and of T_c. The possibility of combining the positive influences of the $Ge_2C_6H_{10}O_7$ which contains carbon and c-BN deserves attention. In this work we investigate co-addition of $Ge_2C_6H_{10}O_7$ and of c-BN into MgB_2. High density (above 90% of the theoretical density) superconducting bulks of MgB_2 co-added with cubic BN (c-BN) and $Ge_2C_6H_{10}O_7$ were obtained by *ex-situ* Spark Plasma Sintering. We determined the contributions, at various temperatures, of the types of pinning centers present in various samples on the bulk pinning force.

[1] D. Dew-Hughes, Philos. Mag. 30 (1974) 293-305.
[2] C. Buzea, T. Yamashita, Supercond. Sci. Technol. 14 (2001) R115-R146.
[3] L. Miu, G. Aldica, P. Badica, I. Ivan, D. Miu, G. Jakob, Supercond. Sci. Technol. 23 (2010) 095002.
[3] P. Badica, G. Aldica, M. Burdusel, S. Popa, R.F. Negrea, M. Enculescu, I. Pasuk, L. Miu, Supercond. Sci. Technol. 27 (2014) 095013.

Flux-flow regimes in Nb/PdNi/Nb hybrids, Nb and Nb_3Sn: unconventional vs. conventional behaviour

Nicola Pompeo[1], Kostiantyn Torokhtii[1], Andrea Alimenti[1], Rita Loria[1], Carmine Attanansio[2], Carla Cirillo[2], Tiziana Spina[3], René Flukiger[3], and Enrico Silva[1]

[1] *Dipartimento di Ingegneria, Università Roma Tre, Via Vito Volterra 62, 00146 Roma, Italy*
[2] *CNR-SPIN Salerno and Dipartimento di Fisica "E. R. Caianiello", Università di Salerno, 84084 Fisciano (SA), Italy*
[3] *European Organization for Nuclear Research (CERN), Switzerland*
enrico.silva@uniroma3.it

We present measurements of the magnetic-field variation of the surface impedance $\Delta Z_s = \Delta R_s + i\Delta X_s$ in Nb-based Superconductor/Ferromagnet/Superconductor (SFS) heterostructures, and we compare the results to similar measurements taken in Nb thin films and Nb_3Sn bulk. The SFS structures are $Nb/Pd_{0.84}Ni_{0.16}/Nb$ trilayers with $Pd_{0.84}Ni_{0.16}$ layers of thickness 1 nm < d_F < 9 nm, sandwiched between Nb layers of nominal thickness d_S = 15 nm. The microwave measurements were taken at different frequencies between 2 and 48 GHz, in magnetic fields up to 12 T, and with swept-frequency (Corbino disk) and single-tone (dielectric resonator) methods. From the measurements we obtain the vortex motion complex resistivity $\rho_{v1}(H)+i\rho_{v2}(H)$. We extract the free-flux-flow resistivity ρ_{ff} (or, alternatively, the vortex viscosity η) and the pinning constant k_p. The role of quasiparticles (in the vortex core) is reflected mainly in ρ_{ff}, while the superfluid concentration affects mostly k_p (via the condensation energy).

The superfluid concentration can be estimated from k_p in SFS and Nb. At fixed reduced temperature, a drop in the superfluid concentration with d_F is observed, by a factor of ~3 with respect to pure Nb. Moreover, a temperature-dependent reentrance exists in the sample with d_F = 2 nm, consistent with the zero-field evidence of a temperature-induced 0–π transition [1,2].

Contrary to the expectation, we find that the three materials present noticeable differences in $\rho_{ff}(H)$. In Nb_3Sn, $\rho_{ff}(H)$ can be described in terms of the usual Bardeen-Stephen model; in Nb and SFS $\rho_{ff}(H)$ evolves from a field-dependence described by the time dependent Ginzburg-Landau in pure Nb and in SFS with d_F = 1 nm, towards values well in excess of the Bardeen Stephen limit: $\rho_{ff} > \rho_n\, H/H_{c2}$ at large d_F. We investigate possible dissipation mechanisms, such as short-lived quasiparticles or excitations of different nature.

We acknowledge useful discussions with A. Buzdin, A. Mel'nikov and C. Meneghini.

[1] N. Pompeo et al., Phys. Rev. B **90** 064510 (2014)
[2] R. Loria et al., Phys. Rev. B **92**, 184106 (2015)

Scanning tunneling spectroscopy in pnictide superconductors: 122 and related systems

Isabel Guillamón

Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid

e-mail: Isabel.guillamon@uam.es

Abstract:

Quasiparticle interference and vortex imaging have both been shown to be powerful tools to investigate pnictide superconductors. Here I will review efforts in the Ca122 based materials, in the recently discovered family of 1144 materials, particularly in pure and Ni-doped $CaKFe_4As_4$ and in Ba122. Ca122 materials have a huge dependence of their properties with pressure, which provides an extreme sensitivity to strain, and leads to the formation of superconducting and normal domains [1]. In the 1144 $CaKFe_4As_4$ materials, the sensitivity to strain is released by the alternate Ca and K layers. In addition, these materials show the highest Tc among stoichiometric pnictide superconductors (35 K). We show that they are two-gap, sign-changing superconductors [2,3] and are located at optimal doping. Quasiparticle interference shows the opening of a superconducting gap in the hole bands around the zone center. Ni doping reduces Tc and induces a magnetic transition where a unique hedgehog magnetic order has been proposed [4]. I will discuss these issues from the point of view of atomic scale and vortex lattice measurements. Finally, I will mention efforts in the P-substituted Ba122 compounds [5], where we observe vortex lattices and determine the surface termination. This is the only material where we observe ultra-slow vortex creep, pointing out that there are dynamic properties specific to Ba122 compounds.

Work supported by ERC Starting Grant and Spanish MINECO.

[1] A. Fente et al., Phys. Rev. B **97**, 014505 (2018).
[2] K. Cho, A. Fente et al., Phys. Rev. B **95**, 100502(R) 2017.
[3] A. Fente et al., arXiv:1608.00605v2.
[4] W.R. Meier et al., npj Quantum Materials **3**, 5 (2018).
[5] C. Putzke et al, Nat. Comms. **5**, 5679 (2014).

Negative electron compressibility and inhomogeneous superconductivity in ionic-liquid gated thin films

Sergio Caprara[1,2], Gianluca Dezi[1], Niccolò Scopigno[3], and Marco Grilli[1,2]

[1]*Dipartimento di Fisica, Università di Roma Sapienza, piazzale Aldo Moro 5 00185 Roma, Italy*
[2]*ISC-CNR and CNISM Unità di Roma Sapienza*
[3]*Institute for Theoretical Physics 3584 CC Utrecht the Netherlands*
sergio.caprara@roma1.infn.it

Recent progress in the fabrication of highly crystalline superconducting thin films and interfaces, and the possibility of tuning the electron density both by chemical doping or ionic liquid gating, have opened a new field of research, and uncovered a wealth of interesting physical effects [1], including unconventional superconductivity, sizeable spin-orbit coupling, competition with charge-density waves (CDWs). Quite remarkably, we find a marked tendency to a negative compressibility of the electron component, giving rise to electronic phase separation and mesoscopic inhomogeneity. The mild modulation of the inhomogeneous landscape is compatible with a high electron mobility, but this intrinsically inhomogeneous character is highlighted by the peculiar behavior of the metal-to-superconductor transition in these systems. Within our model, based on a random resistor network, where superconducting *puddles* are embedded in a metallic matrix, we fit the peculiar resistance vs. temperature curves of several systems, like $TiSe_2$, MoS_2, and ZrNCl. The assessment of an intrinsically inhomogeneous character of these systems, not only is relevant *per se*, but also raises the crucial question of the general mechanisms leading to electronic inhomogeneity. We propose a mechanism based on the interplay between electrons and the countercharges of the gating ionic liquid.

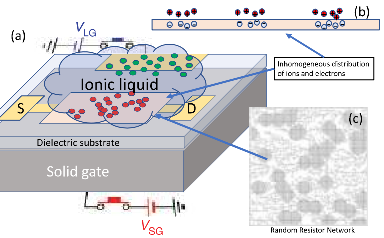


Figure 1: (a) Schematic picture of an ionic-liquid gated superconducting thin film, mounted on a dielectric substrate, with a metallic back gate. (b) Schematic profile of the inhomogeneous state. (c) 100 × 100 random resistor network, with a filamentary superconducting backbone connecting the bulky superconducting regions.

[1] Yu Saito Tsutomu Nojima and Yoshihiro Iwasa, Highly crystalline 2D superconductors, Nature Rev. **2**, 16094 (2017).

Superfluid stiffness in oxide interfaces

G. Singh[1,2] , A. Jouan[1,2], L. Benfatto[3,4] , F. Couedo[1,2], P. Kumar[5] , A. Dogra[5], R. Budhani[6] , S. Caprara[4,3], M. Grilli[4,3], E. Lesne[7] , A. Barthélémy[7] , M. Bibes[6], C. Feuillet-Palma[1,2], J. Lesueur[1,2], N. Bergeal[1,2]

[1] *Laboratoire de Physique et d'Etude des Materiaux, ESPCI Paris, PSL Research University, CNRS, 10 Rue Vauquelin - 75005 Paris, France.*
[2] *Universite Pierre and Marie Curie, Sorbonne-Universités,75005 Paris, France.*
[3] *Institute for Complex Systems (ISC-CNR), UOS Sapienza, Piazzale A. Moro 5, 00185 Roma, Italy*
[4] *Dipartimento di Fisica Universita di Roma La Sapienza, piazzale Aldo Moro 5, I-00185 Roma, Italy.*
[5] *National Physical Laboratory, Council of Scientific and Industrial Research (CSIR) Dr. K.S. Krishnan Marg, New Delhi-110012, India.*
[6] *Condensed Matter Low Dimensional Systems Laboratory, Department of Physics, Indian Institute of Technology, Kanpur 208016, India.*
[7] *Unite Mixte de Physique CNRS-Thales, 1 Av. A. Fresnel, 91767 Palaiseau, France.*

nicolas.bergeal@espci.fr

The large diversity of exotic electronic phases displayed by two-dimensional superconductors confronts physicists with new challenges. In $LaAlO_3/SrTiO_3$ heterostructures, a gate tunable superconducting electron gas is confined in a quantum well at the interface between two insulating oxides[1].

Remarkably, the gas coexists with both magnetism[2] and strong Rashba spin-orbit coupling [3], and is a candidate system for the creation of Majorana fermions. However, both the origin of superconductivity and the nature of the transition to the normal state over the whole doping range remain elusive [4]. Missing such crucial information impedes harnessing this outstanding system for future superconducting electronics and topological quantum computing. We will present resonant microwave transport experiments that enable to extract the superfluid stiffness and the superconducting gap energy of the $LaAlO_3/SrTiO_3$ interface as a function of carrier density. We show that the superconducting phase diagram of this system is controlled by the competition between electron pairing and phase coherence. The analysis of the superfluid density reveals that only a very small fraction of the electrons condenses into the superconducting state. We propose that this corresponds to the weak filling of high-energy d_{xz}/d_{yz} bands in the quantum well, more apt to host superconductivity.

[1] A. D. Caviglia et al. Nature **456**, 624 (2008).
[2] J. Bert, et al. Nature Phys. **7**, 767771 (2011).
[3] A. D. Caviglia et al. Phys. Rev. Lett. **104**, 126803 (2010).
[4] C. Richter et al. Nature **502**, 528531 (2013).
[5] G. Singh et al, arXiv:1704.03365

Large-scale modulation in the superconducting properties of thin films due to domains in the $SrTiO_3$ Substrate

Shai Wissberg and Beena Kalisky

Department of Physics and Institute of Nanotechnology and Advanced Materials
Bar-Ilan University
shaiwis@gmail.com

SrTiO3 (STO) is often used as a substrate for growing thin superconducting films. STO undergoes a structural transition at 105K, where the lattice breaks into tetragonal domains. We use a scanning Superconducting Quantum Interference Device (SQUID) to map the diamagnetic response of Nb and NbN deposited on STO, at their superconducting phase. We show that STO domains and domain walls cause large scale modulations of the superfluid density, opening possibility for better understanding of the effect of local structure on superconductivity, and a local control of the strength of superconductivity. [Phys. Rev. B 95, 144510]

References

Shai Wissberg and Beena Kalisky, Phys. Rev. B 95, 144510, (2017)

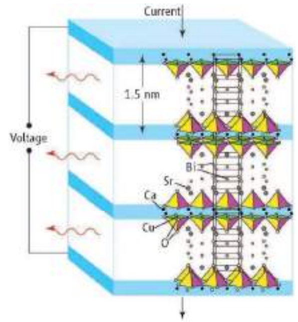
Coherent terahertz radiation from stacks of intrinsic Josephson junctions in $Bi_2Sr_2CaCu_2O_{8+\delta}$

F. Rudau[1], R. Wieland[1], J. S. Hampp[1], O. Kizilaslan[1,2], H. C. Sun[3], Y. Huang[3], X. J. Zhou[3], L. Y. Hao[3], M. Ji[3], D. Y. An[3], N. V. Kinev[4], O. S. Kiselev[4], J. Yuan[3], J. Li[3], P. H. Wu[3], V. P. Koshelets[4], H. B. Wang[3], D. Koelle[1], R. Kleiner[1]

[1]*Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Germany*
[2]*Department of Biomedical Engineering, Faculty of Engineering, Inonu University, Turkey*
[3]*Research Institute of Superconductor Electronics, Nanjing University, China*
[4]*Kotel'nikov Institute of Radio Engineering and Electronics, Moscow, Russia*
fabian.rudau@uni-tuebingen.de

In the past years, the generation of terahertz (THz) radiation attracted more and more attention due to its huge variety of potential applications. Located between the far infrared and microwave frequencies, THz radiation in the range of roughly 0.1 to 10 THz allows for new kinds of, e.g., non-destructive imaging, material testing, medical diagnosis, and high-bandwidth data communication [1].

However, the generation of THz radiation is challenging. In particular, in the range of 0.3 to 2 THz – the so-called THz gap – there is a lack of coherent, tunable, and compact devices. One way to fill this gap is based on Josephson junctions that are able to convert an applied dc voltage into an ac current. According to the Josephson relation an applied voltage of 1 mV translates into a frequency of ~483.6 GHz. However, the emission power of single junctions is rather low and the linewidth is broad.



Stacks of intrinsic Josephson junctions occurring in the high-temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) can overcome these issues and are promising candidates to build devices that, in principle, work up to 10 THz and are easy to fabricate containing hundreds of junctions in series. The main challenge is to ensure phase synchronization of the junctions to obtain high power emission. Also, due to the poor thermal conductivity of BSCCO such samples typically strongly suffer from Joule heating which limits the maximum frequency. Present devices usually work in the range of 0.3 to 1 THz at emission powers of some tens of microwatts having linewidths down to some megahertz [2].

We will present experimental results on how the emission properties of such devices can be tuned, e.g., by applying external magnetic fields or by influencing the current distribution inside the stack and show how such samples behave in general.

Three-dimensional electrothermal simulations of the system based on simultaneously solving heat diffusion equations and two-dimensional coupled sine-Gordon equations will be presented and compared to the experiment investigating the temperature and current distributions inside the samples and resonant modes excited by vortex-antivortex pairs leading to a phase-synchronized configuration that is able to emit coherent radiation.

[1] M. Tonouchi, Nature Photonics **1**, 97 (2007)
[2] L. Ozyuzer *et al.*, Science **318**, 1291 (2007), U. Welp *et al.*, Nat. Photonics **7**, 702 (2013),
I. Kakeya and H. B. Wang, Supercond. Sci. Technol. **29**, 073001 (2016)
[3] Figure from: R. Kleiner, Science **318**, 1254 (2007)

Quasiparticle Spectroscopy using a YBCO Transmon

Marco Arzeo[1], Floriana Lombardi[1], Thilo Bauch[1]

[1]*Department of Microtechnology and Nanoscience, Chalmers University of Technology, 41296 Göteborg, Sweden*

bauch@chalmers.se

We are approaching a new era in research where the fundamental aspects of quantum physics meet with nano-technology, electronics and information technology. The ability to engineer quantum systems can open up the way to new great opportunities. The experimental and theoretical investigation of superconducting artificial two level systems has developed as a rich, exciting field within the framework of quantum computing and cryptography. Far more interesting, the design of such artificial two level quantum systems (also known as quantum bits) can be used to study fundamental physics in fields ranging from quantum optics to solid-state physics in previously inaccessible regimes. One of the main challenges and unresolved problems in solid-state physics is the microscopic origin of the complex properties of High critical Temperature Superconductors (HTS). The detection of macroscopic quantum effects in HTS Josephson junctions [1, 2] and the recent observation of a fully developed superconducting gap in a HTS single electron transistor [3] could be instrumental to get new hints about the possible mechanism for HTS superconductivity redefining the role of quasiparticles in HTS systems.

In this contribution we will show first measurements of an all- $YBa_2Cu_3O_{7-x}$ (YBCO) two-level system in the form of a transmon, i.e. a capacitively shunted Josephson junction pair coupled to a coplanar wave-guide resonator [4,5]. The focus will be on material specific decoherence effects coming from the dielectrics involved in the fabrication process and the superconductor itself. In the latter case the aim is devoted to the experimental investigation of the low temperature excitation spectra of HTS by using the all-YBCO transmon.

[1] T. Bauch et al, Phys. Rev. Lett. **94**, 087003 (2005)
[2] T. Bauch et al., Science **311**, 57 (2006)
[3] D. Gustafsson et al., Nature Nanotech. **8**, 25 (2013)
[4] M. Arzeo, F. Lombardi, and T. Bauch, Appl. Phys. Lett. **104**, 212601 (2014)
[5] M. Arzeo, F. Lombardi, and T. Bauch, IEEE Trans. Appl. Supercond. **25**, 1700104 (2015)

Sources Of Decoherence In Superconducting Quantum Devices.

Sebastian de Graaf[1], Astghik Adamyan[2], Tobias Lindström[1], Donats Erts[3], Alexander Tzalenchuk[1,4], Jonathan Burnett[2] , Andrey Danilov[2], Sergey Kubatkin[2]

[1] *National physical laboratory, Teddington, TW11 0LW, United Kingdom*
[2] *Department of microtechnology and nanoscience, Chalmers university of technology, 412 96 Sweden*
[3] *Institute of chemical physics, University of Latvia, LV 1586, Latvia*
[4] *Royal Holloway University of London, Egham, TW20 0EX, United Kingdom*
sergey.kubatkin@chalmers.se

Despite the promises of superconducting qubits, their performance is presently limited by short coherence times due to defects intrinsic to materials. As a result, future quantum computers would require massive error correction circuits, which seem very challenging to build. Another more promising path would be to improve this coherence time, which would relax the constraints on the quantum error correction circuits and would thus make a quantum computer more feasible. This task is considered one of the main challenges of the field. Our recent results [1] gave vital clues to the long-standing problem of noise and decoherence in superconducting devices: a technique for on-chip Electron Spin Resonance (ESR) [2], allowed to identify, for the first time, the chemical species responsible for the flux noise in superconducting circuits [3]. Furthermore, the most recent noise measurements in superconducting resonators point to the link between charge and flux noise in superconducting circuits [4]: a mild sample treatment has lead to tenfold reduction of the surface spins, responsible for the flux noise, as evidenced by ESR, and this treatment has also led to tenfold reduction of the low frequency noise in superconducting resonator, usually associated with the charge noise. The chemical identification of the possible remaining sources of noise in superconducting devices allows for an active chemical intervention, aiming at silencing the defects and, therefore, improving the coherence in superconducting quantum devices.

[1] Phys. Rev. Lett. 118, 057703, (2017)
[2] Journ. of Appl. Phys. 112, 123905, (2012)
[3] Phys. Rev. Lett. 118, 057702, (2017)
[4] arXiv:1705.09158, NComms, under review

Suppression of the low-frequency decoherence by Bell-state motion

Andrey S. Vasenko[1] and Dmitri V. Averin[2]

[1]National Research University Higher School of Economics, 101000 Moscow, Russia
[2]Department of Physics and Astronomy, Stony Brook University, SUNY, Stony Brook, NY 11794, USA
avasenko@hse.ru

As demonstrated recently, in the realistic situation when the low-frequency noises are uncorrelated among different physical superconducting qubits, transfer of individual logical qubits in arrays of physical qubits can be used to suppress the low-frequency decoherence of quantum information encoded in the logical qubits [1]. The purpose of this work is to show that, if the quantum information is encoded in the Bell-type logical states, the transfer of these states through an array of physical qubits implements simultaneously the motion-induced and spin-echo suppression of decoherence leading to a qualitatively stronger tool against the low-frequency noise than is provided by the two approaches separately [2]. We also discuss the coexistence of the motion-induced suppression of decoherence and more complicated dynamic decoupling-schemes, like Carr-Purcell pulse sequence.

[1] D. V. Averin, K. Xu, Y. P. Zhong, C. Song, H. Wang, and Siyuan Han, Phys. Rev. Lett. **116**, 010501 (2016).
[2] D.V. Averin and A.S. Vasenko, in preparation for Phys. Rev. Lett.

Spontaneous emergence of Josephson junctions in single crystal rings of Sr_2RuO_4

Jan Aarts[1], Kaveh Lahabi[1], Yuuki Yasui[2], Shingo Yonezawa[2], and Yoshi Maeno[2]

[1]*Huygens-Kamerlingh Onnes Laboratory, Leiden University, Leiden, The Netherlands.*
[2]*Dept of Physics, Graduate School of Science, Kyoto University, Kyoto 606-8502, Japan.*
aarts@physics.leidenuniv.nl

Sr_2RuO_4 stands out among the unconventional superconductors as one of the few materials with a spin-triplet odd-parity order parameter [1, 2]. The tetragonal crystal structure allows five representations for the pairing symmetry [1, 3]. One of these is the chiral p-wave, of the form $p_x \pm ip_y$, which is strongly suggested by muon spin relaxation [4] and high-resolution polar Kerr effect measurements [5]. This equal-spin pairing state is attracting renewed attention due to the possibility that it can host Majorana bound states, which in turn are of interest for topological quantum computing. A key property of the chiral state is its double degeneracy in the orbital degree of freedom, with as possible and important consequences the emergence of domains of different chirality and the existence of an edge current. The major problem plaguing understanding of Sr_2RuO_4 is that, although the chiral state seems probable, domains or edges currents have not been observed directly. Here we present transport experiments which have been performed on microscopic rings, fabricated with Focused Ion Beam from single crystals of Sr_2RuO_4. We show that such a (homogeneous) ring show the characteristic features of quantum interference due to the presence of two weak links of similar strength in both arms of the rings , which arguably come about by the presence of two chiral domain walls.

[1] Mackenzie, A. and Maeno, Y., *The superconductivity of Sr_2RuO_4 and the physics of spin-triplet pairing*, Rev. Mod. Phys. **75**, 657-712 (2003).
[2] Maeno, Y. Kittaka, S., Nomura, T., Yonezawa, S. and Ishida, K., *Evaluation of the spin-triplet superconductivity in Sr_2RuO_4*, Jn. Phys. Soc. Japan, **81**, 011009 (2012).
[3] Rice, T. M. and Sigrist, M., *Sr_2RuO_4: an electronic analogue of ^3He*, J. Phys. Cond. Mat. **7**, L643-L648 (1995)
[4] Luke, G. M. et al., *Time reversal symmetry breaking superconductivity in Sr_2RuO_4*, Nature **391**, 558-561 (1998).
[5] Xia, J., Maeno, Y., Beyersdorf, P. T., Fejer, M. M. and Kapitulnik, A., *High resolution polar Kerr effect measurements of Sr_2RuO_4: evidence for broken time reversal symmetry in the superconducting state*, Phys. Rev. lett. **97**, 167002 (2006).

Superconducting density of states and the vortex lattice close to the quantum critical point in $BaFe_2(As_{1-x}P_x)_2$

Víctor BARRENA[1], B. WU[1], P. WALMSLEY[2], I. FISHER[2], H. SUDEROW[1] and I. GUILLAMÓN[1]

[1] Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC),
Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[2] Geballe Laboratory for Advanced Materials and Department of Applied Physics,
Stanford University, California, USA.

The isoelectronic substitution of As by P induces high T_C superconductivity in $BaFe_2(As_{1-x}P_x)_2$. The parent compound (x=0) is an antiferromagnetic metal that does not superconduct. Instead, superconductivity arises when increasing x. At the same time, the antiferromagnetic transition temperatures decreases. When antiferromagnetism disappears at x = 0.3 (and at zero temperature), thermal fluctuations are however unimportant and quantum fluctuations strongly determine the properties of the system. At this point, there is a divergence of the electronic effective mass and superfluid density, observed in quantum oscillations and penetration depth (quantum oscillations are observed with a finite x across the quantum critical point [1]). At the same time, superconducting T_C reaches its maximum. With further doping (x > 0.3), there is no antiferromagnetism and superconductivity vanishes. However, the influence of quantum fluctuations in the spatial dependence of the superconducting and electronic properties is totally unknown. For instance, the divergence in the effective mass might influence the superconducting coherence length and thus the spatial extension of the superconducting density of states around vortices and pair breaking defects.

Here we study single crystals of $BaFe_2(As_{1-x}P_x)_2$ by measuring the superconducting gap and the vortex lattice using Scanning Tunneling Microscopy and Spectroscopy (STM/STS). We show results in a sample with x = 0.44 and $T_C \approx 23$ K. We obtain atomic resolution and observe a V-shaped gap and a hexagonal vortex lattice up to 7 T. The vortex lattice is very ordered, which is highly unusual in a Fe based superconductor. We observe a zero-bias peak in the local density of states at the center of each vortex, due to Caroli-de Gennes-Matricon vortex core states. These two results confirm that substitution does not create significant disorder in the electronic properties. The tunneling conductance vs bias voltage shows a V-shaped superconducting gap evidencing nodal superconductivity. We determine the superconducting coherence length from the spatial dependence of the tunneling conductance around vortex cores and pair breaking defects. We also observe creeping vortex lattices, which is very peculiar for a Fe based superconductor, since vortex pinning is usually strong in these materials, and vortex mobility is weak. The observed creep points to weak pinning or an unexpected influence of fluctuations in the superconducting dynamics.

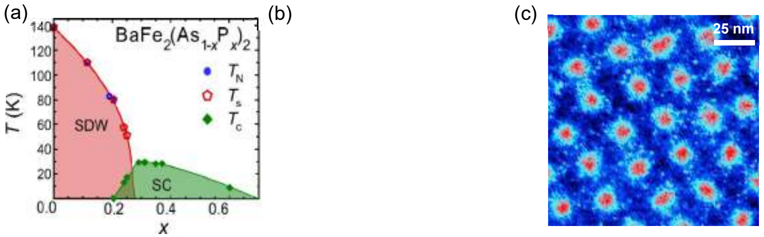


Figure (a) Phase diagram of the $BaFe_2(As_{1-x}P_x)_2$ system from reference [2] (b) Atomic resolution topography at 4.2K. (c) Vortex lattice at 3 T.

References:

[1] – P. Walmsley *et al.*; *Phys. Rev. Lett.* **110**, 257002 (2013).
[2] – J. M. Allred *et al.*; *Phys. Rev. B* **90** 90, 104513 (2014).

Gate-controlled superconductivity in few-layer 2D materials

Liam Farrar[1], Hasti Shajari[1], Sara Dale[1], Simon Bending[1], Matthew Bristow[2], Amalia Coldea[2]

[1]*Department of Physics, University of Bath, Bath BA2 7AY, UK*
[2]*Department of Physics, University of Oxford, Clarendon Laboratory, Oxford OX1 3PU, UK*
s.bending@bath.ac.uk

The isolation of graphene in 2004 has led to massively renewed interest in other van der Waals bonded materials such as the transition metal dichalcogenides which exhibit a variety of electronic ground states, e.g., superconducting, charge density wave, semiconductor and metallic. It is well established that the electronic behaviour of single molecular layer materials can differ qualitatively from that of bulk materials due to changes in their band structure and can be further controlled by electrostatic gating in field-effect structures. Initial work with solid state Si/SiO_2 back gates was only able to bring about rather small changes to the electronic properties of 2D materials because charge transfer is strongly limited by the relatively low oxide breakdown voltages [1]. Here we describe extensions of this work using ionic liquid gating whereby an applied top gate voltage induces charge separation of the anions and cations forming a compact electric double layer with a very high associated electric field. The extremely high capacitance at the surface of the 2D material (ca. 10 $\mu F/cm^2$) is typically many orders of magnitude larger than the capacitance of an SiO_2 dielectric layer (ca. 10 nF/cm^2 for 300nm SiO_2) enabling huge shifts of the chemical potential and extensive exploration of the material band structure. The power of this technique will be illustrated by an investigation of superconductivity in FeSe few-layer flakes. Discovered in 2008, bulk FeSe is a stoichiometric superconductor (T_c~8K) with a simple crystal structure and a similar electronic structure to the iron pnictides. Recently it was shown that a sharp increase in critical temperature up to 48K can be induced in FeSe flakes by ionic liquid gating, coinciding with an abrupt jump in the Hall coefficient [2]. This was interpreted in terms of a change in the topology of the multiband Fermi surface (a Lifshitz transition) arising when hole-like pockets at the zone centre of FeSe drop below the Fermi energy. Our recent measurements of few-layer FeSe flakes under ionic liquid gating will be presented and the superconducting T_c correlated with other normal state properties. The interpretation of our results is informed by DFT calculations of the sample band structure and implications for the pairing state in FeSe will be discussed.

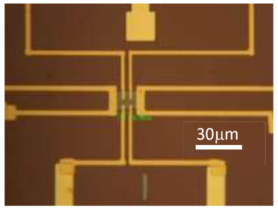


Figure 1: Optical image of a few-layer FeSe flake field effect transistor with an integrated 'top gate' for ionic liquid measurements.

[1] M.S. El-Bana, D. Wolverson, S. Russo, G. Balakrishnan, D. Mck Paul, S.J. Bending, Supercond. Sci. Technol. **26**, 125020 (2013).
[2] B. Lei *et al*., Phys. Rev. Lett. **116**, 077002 (2016).

Topological phases and Majorana fermions from magnetic impurities in superconductors

Annica Black-Schaffer[1]

[1]*Department of Physics and Astronomy, Uppsala University, Box 516, S-751 20 Uppsala, Sweden*
annica.black-schaffer@physics.uu.se

Magnetic impurities on the surface of spin-orbit coupled superconductors offer the possibility to create topological phases without having to apply an external magnetic field. I will give a short introduction to the physics of magnetic impurities in superconductors and how they give rise to Majorana fermions at the end points of one-dimensional chains of magnetic impurities. I will then present some of our recent results in modeling these types of systems. This includes an accurate treatment of the superconducting state in the underlying two-dimensional superconductor through a self-consistent approach, where the influence of the magnetic impurities on the superconducting order is explicitly taken into account.

Using fully self-consistent calculations we have shown that how the localization of the Majorana fermions at the wire end points can be understood, not as a function of the superconducting coherence length, but in terms of how the topological mass gap evolves at the boundary between the trivial and non-trivial topological phase. We have also gone beyond using conventional superconductors and shown how incorporating *d*-wave superconductivity, from proximity to a high-temperature cuprate material, can enhance the protection of the Majorana fermions.

Pinning potential in $YBa_2Cu_3O_7$ superconducting films with nanoengineered pinning centres.

Adrian Crisan[1], Alina Ionescu[1,2], Ion Ivan[1], and Lucica Miu[1]

[1]*National Institute for Materials Physics Bucharest, 405A, Atomistilor Str., 077125 Magurele, Romania*
[2]*Faculty of Physics, University of Bucharest*
acrisan652@gmail.com

We have investigated several types of nanostructured YBCO films with different architecture and types of defects in high DC magnetic fields by frequency-dependent AC susceptibility. In certain experimental windows, the dependence of the out-of-phase susceptibility on the amplitude of the excitation AC field has a frequency-dependent maximum, which can be correlated with the critical current density. Also, the dependence of the critical current density on the frequency can give precious information regarding the pinning mechanisms and the height and "shape" of the pinning potential well. We have investigated our data in the framework of Anderson-Kim model, collective pinning model, and a model proposed by Zeldov in which there is a logarithmic dependence of the effective pinning potential on the current density [1] leading to a straight line in double logarithmic plot of critical current density versus inverse frequency and a slope that can be related to the pinning potential [2]. Such analysis allowed for the estimation of critical current density and of the pinning potential of superconducting films with various architecture of pinning centres, which are shown in correlation with the types of pinning centres as revealed by TEM images.

Financial support from Romanian Ministry of Research and Innovation through POC (European Regional Development Fund, Operational Fund Competitiveness) Project P-37_697 number 28/01.09.2016 is gratefully acknowledged.

[1] E. Zeldov et al., Phys. Rev. Lett. 62 (1989) 3039.
[2] A. Crisan et al., Supercond. Sci. Technol. 22 (2009) 045014.

Non-local probing of superconducting quantum dots via Yu-Shiba-Rusinov-state in Cooper pair splitter

Zoltán Scherübl[1], Gergő Fülöp[2], András Pályi[1], Jörg Gramich[2], Péter Makk[2], Andreas Baumgartner[2], Jesper Nygård[3], Christian Schönenberger[2] and Szabolcs Csonka[1]

[1]*Department of Physics, Budapest University of Technology and Economics and Nanoelectronics 'Momentum' Research Group of the Hungarian Academy of Sciences, 1111 Budapest, Budafoki út 8., Hungary*

[2]*Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland*

[3]*Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark*

csonka@mono.eik.bme.hu

The spin-singlet Cooper-pairs formed in a superconductor (SC) are a natural source of entangled electron pairs, which are potential resources for spin based quantum architectures. The Cooper-pair splitter (CPS) serves to generate the entangled pairs via crossed Andreev reflection (CAR), with the aid of two quantum dots (QDs) placed in between the SC and two normal leads [1-4]. Depending on the ratio of relevant energy scales, several different transport regimes can be reached in the same geometry with different dominating physical phenomena. The conventional splitting process is proposed in the regime where the coupling of the QDs to the SC is weaker than to the normal leads. The opposite regime favors the appearance of the superconducting correlations on the QDs, e.g. formation of Yu-Shiba-Rusinov (YSR) states [5,6].

In this talk we give an introduction to CPS and YSR physics and present a new type non-local signal measured in an InAs nanowire based CPS device which operates in the strongly coupled SC-QD regime. Surprisingly when the coupling to one of the normal lead is turned off, the conductance of the other arm of the CPS is a sensitive tool to characterize the dot levels of the closed arm. The effect is explained with the presence of the YSR state on the dot, which couples the dot states to a subgap quasiparticle in the SC. If the SC lead is narrower than the superconducting coherence length, the quasiparticle has considerable amplitude to leave the CPS via the open arm and thereby to generate the non-local signal.

[1] P. Recher et. al., Phys. Rev. B 63, 165314 (2001).
[2] L. Hofstetter et al., Nature 461, 960 (2009).
[3] L. G. Herrmann et al., Phys. Rev. Lett. 104, 026801 (2010)
[4] G. Fülöp et al., Phys. Rev. Lett. 115, 227003 (2015)
[5] A. Eichler et. al., Phys. Rev. Lett. 99, 126602 (2007).
[6] K. Grove-Rasmussen et. al., Phys. Rev. B 79, 134518 (2009).

Microwave-stimulated superconductivity in Nb films

O. V. Dobrovolskiy[1,2], R. Sachser[1], M. Huth[1], A. Lara[3], F. G. Aliev[3], V. A. Shklovskij[2], A. I. Bezuglyj[2,4] and R. V. Vovk[2]

[1]*Physikalisches Institut, Goethe University, Frankfurt am Main, Germany*
[2]*Physics Department, V. N. Karazin National University, Kharkiv, Ukraine*
[3]*Dpto. Fisica de la Materia Condensada, Universidad Autonoma de Madrid, Spain*
[4]*Institute for Theoretical Physics, National Science Center – KIPT, Kharkiv, Ukraine*
Dobrovolskiy@Physik.uni-frankfurt.de

Stimulation of superconductivity due to the presence of vortices by a microwave (mw) excitation has been recently seen [1] in increase of T_c and H_{c2} in type II superconducting thin films. Here we report on a mw-induced enhancement of the maximal *mixed-state* dc critical current of epitaxial Nb films. The mw-stimulated flux flow is expanded up to 10% larger dc current densities and vortex velocities v^* than in the absence of mw stimulus. Here j^* and v^* correspond to an abrupt transition of the sample into the normal state because of the Larkin-Ovchinnikov (LO) instability [2]. The experimental results are discussed in comparison with the LO theory generalized for the effect of pinning on j^* and v^* [3] relying upon washboard pinning potentials deduced from combined microwave and dc voltage measurements [4]. We have also performed simulations of the time-dependent Ginzburg Landau (TDGL) equation, which reveal similar results to the ones observed in the experiments. Comparing the insertion loss by vortices at a matching field (pinned vortices) and off matching (mobile vortices), we observe a crossover, Fig. 1, from the low-power regime where pinned vortices dissipate less than the mobile ones to the high-power regime of mw-stimulated superconductivity where mobile vortices dissipate less than the pinned ones. We argue that the observed mw-induced enhancement of j^* and v^* can result in a competition between the cooling and heating of quasiparticles in the vortex cores.

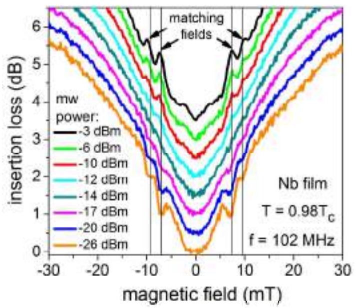


Figure 1: Crossover in the insertion loss by vortices at matching fields in a Nb film for a series of power levels of the ac stimulus at a frequency of 102 MHz at $T = 0.98T_c$. Dips at a smaller ac power turn into peaks at a larger ac power. The curves are offset by 0.5 dB.

[1] A. Lara, F. G. Aliev, A. V. Silhanek, and V. V. Moshchalkov, *Sci. Rep.* **5**, 9187 (2015).
[2] A. I. Larkin and Y. N. Ovchinnikov, *J. Exp. Theor. Phys.* **41**, 960 (1975).
[3] V. A. Shklovskij, A. P. Nazipova, and O. V. Dobrovolskiy, *Phys. Rev. B* **95**, 184517 (2017).
[4] O. V. Dobrovolskiy, M. Huth, V. Shklovskij, and R. V. Vovk, *Sci. Rep.* **7**, 13740 (2017).

Smeared d-Wave Anisotropy and Discrete Andreev States in Monolayer Organic Superconductor

K.-Z. Latt[1], Bio Zhou[2], Akiko Kobayashi[2], Saw-Wai Hla[1,3], A. Hassanien[4]

[1] *Nanoscale and Quantum Phenomena Institute, Physics & Astronomy Department, Ohio University, Athens, OH 45701, USA.*
[2]*Nihon University, Sakurajosui, Setagaya-ku, Tokyo 156-8550, Japan*
[3] *Center for Nanoscale Materials, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439, USA.*
[4]*Jozef Stefan Institute, 39 Jamova, Ljubljana, Slovenia*

Abdou.Hassanien@ijs.si

Epitaxially grown monolayer of organic superconductor, $(BETS)_2GaCl_4$ [where BETS is bis(ethylenedithio)tetraselenafulvalene], on Ag(111) form islands of uniform and mixed stacking of 2-dimensional stripes. A d-wave superconducting gap, of magnitude $2\Delta = 14$ meV, is ubiquitously measured on uniform islands while been structurally altered on the inhomogeneous islands. Mixing of intra-stripes antinodal states are manifested by smeared anisotropy of the low energy quasiparticle as well as features of multigaps in their density of states. Despite proximal convolution, the pronounced coherence peaks indicate well preserved superconducting state. Robust zero bias peaks are detected only at the edges of isolated stripes indicating tunneling into Andreev bound states. These features broaden significantly away from the edges due to quantum interference with nearby discrete states. The interplay between structural parameters and electronic properties makes single layer $(BETS)_2GaCl_4$ a unique playground to test the effect confinement and symmetry variation on the superconducting ground state.

References:

1. A. Hassanien, B. Zhou, H. Tanaka, A. Miyazaki, M. Tokumoto, A. Kobayashi, E. Zupanič and I. Musevič, Physica Status Solidi 252, 11, 2574–2579, (2015).
2. K. Clark, A. Hassanien, S. Khan, K.-F. Braun, H. Tanaka, and S.-W. Hla, Nature Nanotechnology, 5, 261 – 265 (2010).

Mapping superfluid density near the superconductor insulator phase transition

Beena Kalisky [1], Anna Kremen [1], Tatyana Baturina [2] and Aviad Frydman [1]

[1]*Department of Physics and Institute of Nanotechnology and Advanced Materials, Bar-Ilan University, Israel*
[2]*Institute of Semiconductor Physics, Novosibirsk, Russia*
beena@biu.ac.il

The behavior near the superconductor-insulator transition (SIT) is governed by quantum fluctuations. Direct experimental study of such fluctuations is challenging, and not easily probed by conventional measurements such as transport and magnetoresistance. We use scanning superconductor quantum interference device (SQUID) to simultaneously track magnetometry, susceptometry and local flow of current in a series of TiNbN samples spanning the SIT. Maps of the diamagnetic response provide information about the local superfluid density. Our measurements reveal electronic superconducting granularity which fluctuates in time and space at temperatures well below Tc. The temperature regime of these fluctuations grows as the SIT is approached indicating their quantum nature.

Unconventional critical state in cuprate superconductors with regular topological defects

G. Zechner, K. L. Mletschnig, F. Jausner, W. Lang*
University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Wien, Austria

M. Dosmailov, M. A. Bodea, and J. D. Pedarnig
Institute of Applied Physics, Johannes-Kepler-University, A-4040 Linz, Austria

The interaction of vortices with artificial defects in a superconductor is a vibrant topic in fundamental experimental and theoretical research, but also important for its prospects of technical applications. In contrast to clean metallic superconductors that were often used to study regular artificial defects, the typical average distance of random intrinsic defects in a thin film of a prototypical cuprate superconductor, namely $YBa_2Cu_3O_7$ (YBCO) is smaller than one µm. The advantage of a higher operation temperature in YBCO is opposed by the demand for advanced nanopatterning methods. To this end, YBCO thin films on MgO substrate are irradiated with He^+ ions by shadow projection through a Si stencil mask [1] to create a square array of columnar defect regions of 180 nm diameter and 300 nm lattice constant [2].

Peaks of the critical current as a function of the applied magnetic field reveal the commensurate trapping of vortices in domains near the edges of the sample. At the same magnetic fields, the magnetoresistance exhibits minima. Upon ramping an external magnetic field, an unconventional critical state emerges that is characterized by a pronounced hysteresis and different positions of the critical current peaks in virgin and field-saturated down-sweep curves, respectively. Interestingly, the distances of the various peaks or minima in a sweep remain constant and correspond exactly to the matching field [3]. Measurements of magnetoresistance at various angles of the magnetic field confirm that the columnar defects dominate the pinning. The observations are interpreted as a nonuniform, terrace-like critical state, in which individual domains are occupied by a fixed number of vortices per pinning site.

References

[1] W. Lang, M. Dineva, M. Marksteiner, T. Enzenhofer, K. Siraj, M. Peruzzi, J.D. Pedarnig, D. Bäuerle, R. Korntner, E. Cekan, E. Platzgummer, H. Loeschner, Microelectronic Engineering, **83**, 1495 (2006).
[2] J.D. Pedarnig, K. Siraj, M.A. Bodea, I. Puica, W. Lang, R. Kolarova, P. Bauer, K. Haselgrübler, C. Hasenfuss, I. Beinik, C. Teichert, Thin Solid Films **518**, 7075 (2010).
[3] G. Zechner, F. Jausner, L.T. Haag, W. Lang, M. Dosmailov, M.A. Bodea, and J.D. Pedarnig, Phys. Rev. Applied 8, 14021 (2017)

* e-mail: wolfgang.lang@univie.ac.at

Looking for topological superconductivity in misfit TMD $LaNb_2Se_5$

Leriche Raphaël[1], Brun Christophe[1], Arfaoui Imad[2], Cario Laurent[3], Sasaki Shunsuke[3], and Cren Tristan[1]

[1] *Institut des Nanosciences de Paris, Sorbonne Université, UPMC Univ Paris 6 and CNRS-UMR 7588, F-75005 Paris, France.*
[2] *MONARIS, Sorbonne Université, UPMC Univ Paris 06 and CNRS, UMR 8233, F-75005, Paris, France*
[3] *Institut des Matériaux Jean Rouxel, CNRS Université de Nantes, UMR 6502, 2 rue de la Houssinière, BP32229, 44322 Nantes, France.*
leriche@insp.jussieu.fr

Transition metal dichalcogenide (TMD) 2H - $NbSe_2$ has a layered hexagonal structure consisting in the alternation of sheets of Nb atoms sandwiched between two layers of selenium atoms. It is superconducting under the critical temperature $T_c \sim 7K$ and respects inversion symmetry. Monolayer $NbSe_2$ is also superconducting (ref 1) but contrary to bulk 2H-$NbSe_2$ it breaks in-plane inversion symmetry. The presence of large spin orbit interaction due to the 4d electrons of Nb atoms combined with this broken inversion symmetry gives rise to spin-momentum locking in the out of plane direction and unconventional Ising pairing. One of the consequences of this Ising pairing is very high in-plane upper critical fields which were measured recently (ref 2).

In the parent compound superconducting misfit TMD $LaNb_2Se_5$, which consists in alternation of bilayers of $NbSe_2$ and monolayers of insulating LaSe, very high in plane upper critical fields were also observed (ref 3). Because of this, one can assume that similar physics is at play. $LaNb_2Se_5$ is a good candidate for unconventional superconductivity and some recent ultra-high vaccum STM/STS results of our team seem to show signatures of 3D topological edge states at the surface of a cleaved *in situ* crystal of $LaNb_2Se_5$. Many studies are yet to be performed to confirm our observations.

[1] Frindt, R. F. Superconductivity in ultrathin $NbSe_2$ layers. *Phys. Rev. Lett.* **28**, 299-301 (1972).

[2] Xiaoxiang Xi, Ising pairing in superconducting $NbSe_2$ atomic layers. *Nature Phys.* **12**,139-143 (2016).

[3] Monceau, P. Anisotropy of the superconducting properties of misfit layer compounds $(MX)_n(NbX_2)_m$. *Physica B*, 194-196 (1994).

Unconventional induced superconductivity on the surface states of Bi_2Te_3

S. Charpentier[1], L. Galletti[1], G. Kunakova[1], R. Arpaia[1], A. Kalaboukhov[1], F. Tafuri[4], D. Golubev[5], J. Linder[6], T. Bauch[1] and F. Lombardi[1]

1 Department of Microtechnology and Nanoscience, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

2 Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, 865 Changning Road, Shanghai CN-200050, China

3 Department of Applied Physics, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

4 Dipartimento di Ingegneria dell'Informazione, Seconda Università di Napoli, IT-81031 Aversa (CE), Italy and CNR-SPIN

5 Department of Applied Physics, Aalto University School of Science, P.O. Box 13500, FI-00076 Aalto, Finland

6 Department of Physics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

Floriana.lombardi@chalmers.se

Topological superconductivity is currently a subject of great attention because of the possibility to study a variety of phenomena, including Majorana bound states physics. The experimental observation of topological superconductivity, however, still remains an open issue. The key ingredient is an unconventional order parameter (OP), with an orbital component assuming the form of a chiral $p_x + ip_y$ wave. In this contribution I will present phase-sensitive measurements, based on the quantum interference in a Josephson junction, realized using a Superconductor-3D Topological Insulator-Superconductor heterostructure. The experiment allows to establish that the proximity with a conventional superconductor induces an OP in the surface states of the topological insulator Bi_2Te_3, which is consistent with a chiral $p_x + ip_y$ OP. This is achieved by measuring the magnetic field pattern of the junctions which shows a dip at zero external magnetic field, which is an incontrovertible signature of the simultaneous existence of "0" and "π" coupling within the junction, inherent to an OP with a non trivial phase [1]. The nano-textured nature of the morphology of the Bi_2Te_3 flakes, and the dramatic role played by strain to tune the Dirac node, are the surprising key factors for the display of an effective induced chiral $p_x + ip_y$ OP.

[1] S. Charpentier et al NATURE COMMUNICATIONS 8: 2019

DOI: 10.1038/s41467-017-02069-z

A BCS fingerprint revealed by the vortex cores of a high T_c Superconductor

Ivan Maggio-Aprile[1], Christophe Berthod[1], Jens Bruer[1], Andreas Erb[2], and Christoph Renner[1]

[1]*Université de Genève-DQMP, 24 quai Ernest Ansermet, Geneva, Switzerland*
[2] *Walther Meissner Institut für Tieftemperaturforschung, Garching, Germany*
Email : ivan.maggio-aprile@unige.ch

For more than two decades, the electronic structure of the vortices in high-temperature superconductors (HTS) has been challenging theory. As a matter of fact, most of the observations made by scanning tunnelling spectroscopy in the vortex cores of HTS have revealed unusual features. Among these, the detection of a robust pair of electron-hole symmetric states at finite subgap energy in $YBa_2Cu_3O_{7-\delta}$ (Y123) [1] was in total contradiction with the expected signature of a d-wave superconductor vortex core, characterized by a strong zero-bias conductance peak.

In a recent series of scanning tunnelling spectroscopy experiments on Y123, we found that these subgap conductance peaks are not a specific signature of the vortices, but are part of an electronic background uniformly measured across the entire surface, whether a magnetic field is applied or not [2]. This finding led us to consider a simple model assuming that the total tunnelling current is the combination of two additive channels: one associated with the quasiparticle excitations expected for a clean *d*-wave superconductor with YBCO band structure; the other corresponding to an unknown non-superconducting background where the subgap peaks belong. According to this two-channel analysis, the superconducting condensate contributes only 15% to 20% of the total tunnelling signal, explaining the difficulty of detecting the BCS fingerprints in this material. Because the dominant background is spatially uniform and simply adds to the total tunnelling current, we can eliminate this unknown contribution by subtracting a spectrum measured away from the vortex cores from all the tunnelling spectra measured in the vortex phase. The remaining signal can be modelled in the Bogoliubov-de Gennes framework, by computing the spatial dependence of the LDOS in the presence of vortices and performing the same subtraction. We find a remarkable correspondence between the model and the data, demonstrating that the vortex cores in HTS cuprates are not exotic but present the expected quasiparticle LDOS [3]. The model provides further insight into the vortex-core structure, which is different for each vortex due to an irregular lattice and depends on the Fermi surface topology more than on the gap symmetry. The origin of this dominant background conductance remains an open question, together with the question of whether the same model applies to other HTS cuprates.

[1] I. Maggio-Aprile *et al.*, Phys. Rev. Lett. 75, 2754 (1995)
[2] J. Bruer *et al.*, Nat. Commun. 7, 11139 (2016)
[3] C. Berthod *et al.*, Phys. Rev. Lett. 119, 237001 (2017)

Effect of "impurities" on monolayer superconductivity: Selected cases

Milorad V. Milosevic

NANO Center of Excellence, University of Antwerp, Belgium
milorad.milosevic@uantwerpen.be

Superconductivity not only survives in the monolayer limit, it harbors a number of surprises. T_c name a few, electron-phonon-driven high-T_c superconductivity in monolayer FeSe on STO [1], rise of Tc by making TaS_2 thinner [2], appearance of Ising superconductivity in monolayer $NbSe_2$ [3], three-gap superconductivity in monolayer MgB_2 [4], etc.

Of course, superconductivity in the monolayer limit is intuitively fragile, and one assumes detrimental effects of possible impurities, local strain, buckling, and similar. In this presentation, I will demonstrate several opposite examples, where substitutions, vacancies or adatoms, in combination with strain actually boost superconductivity in atomically-thin samples.

[1] J.-F. Ge et al., Nat. Mater. 14, 285 (2015).
[2] E. Navarro-Moratalla et al., Nat. Commun. 7, 11043 (2016).
[3] X. Xi et al., Nat. Phys. 12, 139 (2016).
[4] J. Bekaert et al., Phys. Rev. B 96, 094510 (2017); J. Bekaert et al., Sci. Rep. 7, 14458 (2017).

Superspin

Jason Robinson

Department of Materials Science & Metallurgy, 27 Charles Babbage Road, Cambridge, CB2 1LR, United Kingdom

jjr33@cam.ac.uk

Superconducting spintronics or "superspin" is a new area of research, which involves the equilibrium coexistence of spin-polarization and superconducting phase coherence [1]. This field has emerged over the past decade following rapid developments in the understanding of unconventional superconductivity at the interface between superconductors and ferromagnetic materials. Highlights from my group include the discovery of singlet-to-triplet pair conversion at magnetically inhomogeneous superconductor / ferromagnet (S/F) interfaces [2], spin-selectivity of triplet pairs in superconducting spin-valves [3], and the inverse Meissner effect in a non-magnetic metal proximity-coupled to S/F structure [4].

In my lecture I will overview my group's recent results on coupling unconventional superconductivity and magnetism at metallic and oxide crystalline S/F interfaces. This will include triplet spin-valves and density of states measurements [5], and the interaction of d-wave superconductivity with single layer graphene [6].

[1] J. Linder and J.W.A. Robinson, ***Nature Physics*** **11**, 307 (2015).
[2] J.W.A. Robinson, J.D.S. Witt, M.G. Blamire, ***Science*** **329**, 59 (2010).
[3] N Banerjee *et al.*, ***Nature Com.*** **5**, 3048 (2014).
[4] A Di Bernardo *et al.*, ***Phys. Rev. X*** **5**, 041021 (2015).
[5] Y Kalcheim *et al.*, ***Phys. Rev. B*** **92**, 060501 (2015).
[6] A Di Bernardo *et al.*, ***Nature Com.*** **8**, 14024 (2017).

Electron refrigeration in hybrid structures with spin-split superconductors

Mikel Rouco[1], T T Heikkilä[2], and F.S. Bergeret[1,3]

[1] *Centro de Física de Materiales (CFM-MPC), Centro Mixto CSIC-UPV/EHU, Manuel de Lardizabal 5, E-20018 San Sebastian, Spain*

[2] *University of Jyvaskyla, Department of Physics and Nanoscience Center, P.O. Box 35 (YFL), FI-40014 University of Jyväskylä, Finland*

[3] *Donostia International Physics Center (DIPC),Manuel de Lardizabal 4, E-20018 San Sebastian, Spain*

mikel.mrm@gmail.com

Electron tunneling between superconductors and normal metals has been used for an efficient refrigeration of electrons in the latter [1, 2]. Such cooling is a non-linear effect and usually requires a large voltage [3]. In Ref.[4] we study the electron cooling in heterostructures based on superconductors with a spin-splitting field coupled to normal metals via spin-filtering barriers. The cooling power shows a linear term in the applied voltage [5, 6]. This improves the coefficient of performance of electron refrigeration in the normal metal by shifting its optimum cooling to lower voltage, and also allows for cooling the spin-split superconductor by reverting the sign of the voltage. We also show how tunnel coupling spin-split superconductors with regular ones allows for a highly efficient refrigeration of the latter.

[1] M. Nahum, T. M. Eiles, and J. M. Martinis, Appl. Phys. Lett. **65**, 3123 (1994)
[2] M. M. Leivo, J. P. Pekola, and D. V. Averin, Appl. Phys. Lett. **68**, 1996 (1996)
[3] F. Giazotto, T. T. Heikkila, A. Luukanen, A. M. Savin, and J. P. Pekola, Rev. Mod. Phys. 78, 217 (2006)
[4] M. Rouco, T. T. Heikkil, and F. S. Bergeret, arXiv preprint arXiv:1711.03007 (2017)
[5] A. Ozaeta, P. Virtanen, F. S. Bergeret, and T. T. Heikkila, Phys. Rev. Lett. **112**, 057001 (2014)
[6] S. Kolenda, M. J. Wolf, and D. Beckmann, Phys. Rev. Lett. **116**, 097001 (2016)

Black diamond – effects of confinement and magnetism on superconductivity.

Tomas Samuely[1], Gufei Zhang[2], Oleksandr Onufriienko[1], Pavol Szabó[1], Johan Vanacken[2], Victor V. Moshchalkov[2], and Peter Samuely[1]

[1] *Centre of Low Temperature Physics, Institute of Experimental Physics, Slovak Academy of Sciences & Faculty of Science, P. J. Safarik University, 04001 Kosice, Slovakia*

[2] *Institute for Nanoscale Physics and Chemistry, KU Leuven, Celestijnenlaan 200D, B-3001*

tomas.samuely@upjs.sk

The applications of diamond in science and technology are copious and their number increased even more after the discovery of superconductivity in boron doped diamond in 2004. Deep blue or even black in color, boron doped diamond offers new possibilities for fundamental research of superconductivity in doped insulators and in the presence of tunable disorder. Particularly, in its polycrystalline form, it represents a complex system in which the intragranular, as well as intergranular effects in superconducting condensate can be observed locally and compared to its bulk properties. Our studies of polycrystalline superconducting specimens prepared by chemical vapor deposition under various conditions revealed *e.g.* signs of ferromagnetism [1] and breaking of the global phase coherence [2]. The unique combination of experiments studying bulk properties with local investigations at the nanoscale enabled us to at least partially interpret the observed nonintuitive phenomena.

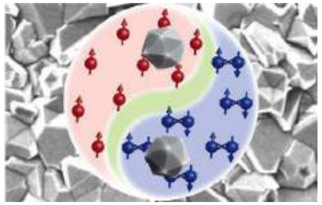


Figure 1: Our experiments on boron doped diamond imply *i.a.* the coexistence of ferromagnetism and superconductivity.

[1] G. Zhang, T. Samuely et al., ACS Nano **11** 5358 (2017), DOI: 10.1021/acsnano.7b01688
[2] G. Zhang, T. Samuely et al., ACS Nano Articles ASAP, DOI: 10.1021/acsnano.7b07148

In situ tailoring of superconducting junctions via electro-annealing

Joseph Lombardo[1], Željko. L. Jelić[1,2], Xavier D. A. Baumans[1], Jeroen E. Scheerder[3], Jorge P. Nacenta[4], Victor V. Moshchalkov[3], Joris Van de Vondel[3], Roman B. G. Kramer[4], Milorad V. Milošević[2],and Alejandro V. Silhanek[1]

[1] *Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium*

[2] *Departement Fysica, Universiteit Antwerpen, Groenenborgerlaan 171, B-2020 Antwerpen, Belgium*

[3] *Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group, K.U.Leuven, B–3001 Leuven, Belgium*

[4] *Université Grenoble Alpes, CNRS, Grenoble INP and Institute of Engineering Université Grenoble Alpes, Institut Néel, 38000 Grenoble, France*

asilhanek@uliege.be

We demonstrate the *in situ* engineering of superconducting nanocircuitry by targeted modulation of material properties through high applied current densities. We show that the sequential repetition of such customized electro-annealing in a niobium (Nb) nanoconstriction can broadly tune the superconducting critical temperature T_c and the normal-state resistance R_n in the targeted area. Once a sizable R_n is reached, clear magnetoresistance oscillations are detected along with a Fraunhofer-like field dependence of the critical current, indicating the formation of a weak link but with further adjustable characteristics. Advanced Ginzburg-Landau simulations fully corroborate this picture, employing the detailed parametrization from the electrical characterization and high resolution electron microscope images of the region within the constriction where the material has undergone amorphization by electro-annealing.

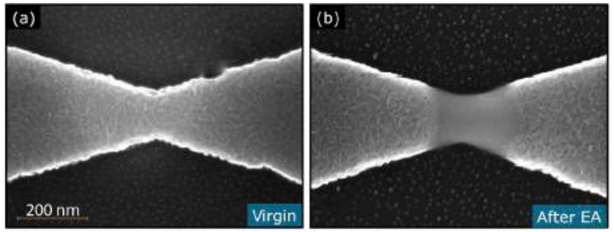


Figure 1: **Details of amorphization by electro-annealing.** (a) High-resolution SEM image of the constriction in the virgin state. (b) Constriction after several electro-annealing processes. One notices a structural change in the constriction: the initially granular structure underwent amorphization.

Oxide 2DEG properties for advanced electronic applications

D. Stornaiuolo[1,2*], D. Massarotti[1,2], B. Jouault[3], E. Di Gennaro[1,2], A. Sambri[1,2], M. D'Antuono[1], G.M. De Luca[1,2], R. Di Capua[1,2], F. Miletto Granozio[2], G.P. Pepe[1,2], M. Salluzzo[2], F. Tafuri[1,2]

[1] *Università degli Studi di Napoli "Federico II", Italy*

[2] *CNR-SPIN, UoS di Naploli, Italy*

[3] *Laboratoire Charles Coulomb, CNRS, Montpellier, France*

* stornaiuolo@fisica.unina.it

In the recent years, electron gases (2DEGs) formed at the interface between insulating transition metal oxides, like $LaAlO_3$ and $SrTiO_3$ (LAO/STO), have demonstrated extraordinary properties [1]. In this work, we review some of them, with a special focus on the possible applications to oxide electronics.

Thanks to its tunability, the LAO/STO 2DEG can be an ideal test bench for the investigation of superconductivity in reduced dimensions. Indeed, recent experimental works, carried out on LAO/STO based nanostructures, bring to light signatures of unconventional superconductivity in this system [2]. These results are of relevance for oxide quantum electronics.

Interest on possible spintronic applications of this 2DEG is also emerging. The LAO/STO system shows a large and electric field tunable Rashba spin-orbit coupling and exceptionally large spin-to-charge conversion efficiency. Moreover, a spin polarized oxide 2DES has been designed and realized using a thin layer of delta doping $EuTiO_3$ (ETO) intercalated between LAO and STO [3]. X-rays magnetic circular dichroism and transport measurements performed on LAO/ETO/STO heterostructures indicate tunable ferromagnetic properties. We will present a study of the interplay between ferromagnetism and Rashba spin-orbit coupling in LAO/ETO/STO heterostructures [4] and discuss possible implications for oxide spintronics.

[1] S. Gariglio, et al., APL Mater. 4, 060701 (2016).
[2] G.Cheng et al., Nature 521, 196 (2015); L. Kuerten et al., Phys. Rev. B 96, 014513 (2017); D. Stornaiuolo et al., Physical Review B, 95, 140502(R) (2017)
[3] D. Stornaiuolo et al., Nature Materials 15, 278-283 (2016).
[4] D. Stornaiuolo et al., submitted

Thermal conductivity measurements for superconducting materials

Daria Szewczyk, **Andrzej Jeżowski, Andrzej Zaleski**

Institute for Low Temperature and Structure Research PAS, Wrocław, Poland
d.szewczyk@int.pan.wroc.pl

The superconductor-based systems gain more and more importance when it comes to application [1]. The race for their stability and preservation from overheating and consequently falling into normal state has an essential meaning. Therefore the thermal transport investigations are of a strong interest.

Thermal conductivity κ is strongly dependent on temperature, especially below 100K, which makes the thorough experimental examination crucial for future use of a particular material. For some compounds, like high temperature superconductors, the anisotropic structure evokes specified properties suitable for designated usage.

In this work we present the possibilities of thermal transport studies in our Laboratory of Thermal Conductivity and Cryocrystals. We have two separated set-ups for κ (T) identification operating in the stationary state method using uniaxial longitudinal heat flow. The bath cryostats work in temperature range from 4.2K to RT and provide the results with accuracy of ±1.5%. The detailed description of the measuring cell can be found in [2]. We also carry out supplementary measurements of heat capacity using the standard Physical Property Measurement System (PPMS®) from Quantum Design Inc. One of the recent topics that we dealt with was about thermally actuated material, Ti-doped Cu-Zn soft ferrite, that can be used for magnetizing superconductors. The obtained thermal parameters and the low magnetic phase transition temperature make the investigated ferrite ceramic applicable as magnetic wave producer [3]. The other very recent subject was studies of melt-cast Bi2212 hollow cylinders. Thermal transport investigations show that beside the application as current leads for LTS magnets Bi2212 can also act as very efficient magnetic shields [4,5].

[1] P. Komarek, *Hochstromanwendungen der Supraleitung*. Stuttgart: Teubner Studienbücher, 1995.
[2] A. Jeżowski, J. Mucha, G. Pompe, J. Phys. D: Appl. Phys. **20** (1987) 1500
[3] P. Stachowiak, J. Mucha, D. Szewczyk, Y. Zhai, C.H. Hsu, T.A. Coombs, J.F. Fagnard, M.P. Philippe, P. Vanderbemden, J. Phys. D: Appl. Phys. **49** (2016) 125004
[4] J.F. Fagnard, S. Elschner, J. Bock, M. Dirick, B. Vanderheyden, P.Vanderbemden, Supercond. Sci. Technol. **23** (2010) 095012
[5] D. Szewczyk, J. Mucha, P. Stachowiak, P. Vanderbemden *in preparation*

Bound states and unconventional low energy electronic behavior in superconductors

Hermann Suderow

Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Spain
hermann.suderow@email.address.here

Often, perturbations of clean superconducting samples occur at very small length scales. For instance, introducing an isolated magnetic impurity causes order parameter suppression at atomic scales, or a magnetic field produces vanishing order parameter just at the center of vortex cores. Such disturbances of the order parameter lead to coherent electron-hole excitations. Magnetic impurities show Yu-Shiba-Rusinov states (or shortly Shiba states) and vortex cores Caroli de-Gennes and Matricon states. I will discuss experiments showing Shiba states in Fe impurities in the superconductor 2H-$NbSe_{1.8}S_{0.2}$ and their relation to vortex core states. Furthermore, I will show efforts in the putative chiral *d*-wave superconductor URu_2Si_2.

Switching superconducting state "on" and "off" depending on the direction of the magnetic field in the Co- and Ca-doped $EuFe_2As_2$-based magnetic-superconductors

Lan Maria Tran, Michał Babij, Zbigniew Bukowski, and Andrzej J. Zaleski

Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Wrocław, Poland
l.m.tran@int.pan.wroc.pl

In this contribution we present remarkable properties of the $EuFe_2As_2$-based magnetic-superconductors [1, 2, 3].

Our recent study focusing on the Co- and Ca-doped compounds reveal that the investigated superconductors exhibit unusual properties such as superconductivity coexisting with ferromagnetic ordering, field induced superconductivity and reentrance resistivity (and ac-susceptibility). Moreover, the properties are strongly dependent on the direction of the applied magnetic field, and in the boundary case it allows switching between superconducting and normal state.

Obtained results imply that these properties are observed due to the possibility of alerting the influence of the orbital pair breaking effect, by changing the direction of the magnetic moment on the Eu^{2+}-ions (internal magnetic field) by the external magnetic field. Due to a specific direction of the internal magnetic field (and its presence even in zero external magnetic field), we expect a spontaneous vortex state – with both Abrikosov and Josphson vortices – in the investigated Co- and Ca-doped $EuFe_2As_2$-based compounds. Our suggestion is supported by the observation of a similar spontaneous Abrikosov-vortex state in the P-doped compounds [4].

[1] Tran V.H. et al. *PRB* **85** 0525502 (2012)
[2] Tran V.H. et al. *New J. Phys.* **14** 073052 (2012)
[3] Tran L.M. *Investigation of the coexistence of magnetism and superconductivity in substituted $EuFe_2As_2$*, Wrocław 2017, eISBN 978-83-948287-1-4
[4] Vinnikov L.Ya. et al. arXiv:1709.09802

Interface effects in oxide superconducting hybrids

J. E. Villegas*

Unité Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Université Paris Saclay, 91767 Palaiseau, France
E-mail: javier.villegas@cnrs-thales.fr

Oxide superconductors and ferroics are strongly correlated electron systems that present many degrees of freedom, including different types of spin and charge order. Other key properties include that their ground state is extremely sensitive to doping and, particularly in the case of superconductors, the presence of unconventional d-wave pairing and traces of superconductivity above Tc (pseudogap phase). All of this makes oxides very interesting hybrids in which many specific interface phenomena interplay with the more classical mechanisms (proximity effects, magnetostatic coupling) present in metallic systems.

I will discuss some of our latest work along those lines, which address charge and spin accumulation effects at oxide superconducting interfaces, both in static (equilibrium) and dynamic (out-of-equilibrium) experimental conditions.

Work supported by the ERC grant Nº 64710 and French ANR grant ANR-15-CE24-0008-01 and COST "Nanoscale Coherent Hybrid Devices For Superconducting Quantum Technologies" - Action CA16218 .

***** in collaboration with V. Rouco, X. Palermo, M.-Y. Yoo, R. El Hage, A. Anane, S. D'Ambrosio, A. Sander, M. Bibes, A. Barthélémy, L. Vila, P. Noel, J. Santamaría, M. Varela, J. Lesueur, N. Bergeal, and A. Buzdin

Direct visualization of degeneracy and vortex ice in nanostructured superconductors

C. Xue [1,2], J.-Y. Ge [2], V. N. Gladilin [2,3], J. Tempere[3], A. He [4], V. S. Zharinov[2], J. T. Devreese [3], V. V. Moshchalkov [2], Y. H. Zhou [5,6], A. V. Silhanek [7] and J. Van de Vondel [2]

[1]*School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi'an 710072, China*

[2]*INPAC-Institute for Nanoscale Physics and Chemistry, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium*

[3]*Theory of Quantum and Complex Systems, U Antwerpen, Universiteitsplein 1, B–2610 Antwerpen, Belgium*

[4]*College of Science, Chang'an University, Xi'an 710064, China*

[5]*Department of Mechanics and Engineering Sciences, Key Laboratory of Mechanics on Disaster and Environment in Western China attached to the Ministry of Education of China, Lanzhou University, Lanzhou 730000, China*

[6]*School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, People's Republic of China*

[7]*Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium*

Joris.vandevondel@kuleuven.be

Artificial ice systems have unique physical properties that are promising for potential applications. One of the most challenging issues in this field is to find novel ice systems that allow precise control over the geometries and many-body interactions. Superconducting vortex matter has been proposed as a very suitable candidate to study artificial ice, mainly due to the availability of tunable vortex-vortex interactions and the possibility to fabricate a variety of nanoscale pinning potential geometries. So far, a detailed imaging of the local configurations in a vortex-based artificial ice system is still lacking. In this work we directly explore the superconducting vortex matter ground state by visualizing the vortex configurations in different nanostructured superconductors via scanning Hall probe microscopy. First, the observed vortex patterns in a Kagome lattice of elongated antidots, at specific applied magnetic fields, are in good agreement with the configurations obtained using time-dependent Ginzburg-Landau simulations. Both results indicate that the long-range interaction in this nanostructured superconductor is unable to lift the degeneracy between different vortex states and the pattern formation is mainly ruled by the nearest-neighbor interaction. This simplification makes it possible to identify a set of simple rules characterizing the vortex configurations, which can explain both the observed vortex distributions and the magnetic-field-dependent degree of degeneracy. Second, vortex-ice states can be realized in double-well pinning sites arranged into a square or Kagome lattice. Indeed, a large area with the vortex-ice ground-state configuration has been detected, which confirms the recent theoretical predictions for this ice system. Besides the defects analogous to artificial spin-ice systems, other types of unique vortex defects have been visualized and identified.

[1] C. Xue et al., Phys. Rev. B 96, 024510 (2017)
[2] J.-Y. Ge et al., Phys. Rev. B 96, 134515 (2017)

Anti-Electromigration: Restoring Conventional and High-T_c Ultra-Narrow Superconducting Junctions

Xavier D. A. Baumans[1], Joseph Lombardo[1], Jérémy Brisbois[1], Gorky Shaw[1], Vyacheslav S. Zharinov[2], Ge He[3], Heshan Yu[3], Jie Yuan[3], Beiyi Zhu[3], Kui Jin[3], Roman B. G. Kramer[4], Joris Van de Vondel[2] and Alejandro V. Silhanek[1]

[1]*Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium*

[2]*INPAC Institute for Nanoscale Physics and Chemistry, Department of Physics and Astronomy, K.U.Leuven, B3001 Leuven, Belgium*

[3]*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*

[4]*Université Grenoble Alpes, Institut NEEL, F-38000 Grenoble, France CNRS, Institut NEEL, F-38000 Grenoble, France*

xavier.baumans@uliege.be

The electromigration process has the potential capability to move atoms one by one when properly controlled. It is therefore an appealing tool to tune the cross section of monoatomic compounds with ultimate resolution or, in the case of polyatomic compounds, to change the stoichiometry with the same atomic precision. We demonstrate that a combination of electromigration and anti-electromigration can be used to reversibly displace atoms with a high degree of control. This enables a fine adjustment of the superconducting properties of Al weak links, whereas in Nb the diffusion of atoms leads to a more irreversible process[1]. In a superconductor with a complex unit cell ($La_{2-x}Ce_xCuO_4$), the electromigration process acts selectively on the oxygen atoms with no apparent modification of the structure[1]. This allows us to adjust the doping of this compound and switch from a superconducting to an insulating state in a nearly reversible fashion. We discuss the conditions needed to replace feedback controlled electromigration by a simpler technique of electropulsing. These findings have a direct practical application as a method to explore the dependence of the characteristic parameters on the exact oxygen content and pave the way towards a reversible control of local properties of nanowires.

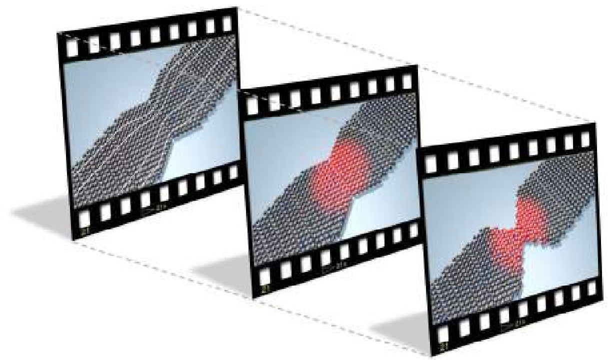


Figure 1: Sketch of electromigration process on nano-constricted compound of interest.

[1] Xavier D. A. Baumans *et al.*, Healing effect of controlled anti-electromigration on conventional and high-T$_c$ superconducting nanowires, Small **13**, 1700384 (2017)

Nano-SQUIDs with controllable weak links via electromigration

Wout Keijers[1], Xavier D. A. Baumans[2], Ritika Panghotra[1], Joseph Lombardo[2], Vyacheslav. S. Zharinov[1], Alejandro V. Silhanek[2], and Joris Van de Vondel[1]

[1]*Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group, KU Leuven, B-3001 Leuven, Belgium*
[2]*Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium*
wout.keijers@kuleuven.be

Since their discovery in 1964 [1], superconducting quantum interference devices (SQUIDs) have been extensively used in applications, mostly as magnetic field sensors. The scaling down of these devices led to low noise performance, which resulted in the flourishing of a new research area devoted to nano-SQUIDs.

This work deals with modifying the weak links of a thin film aluminum micro-SQUID beyond the limit of current lithography techniques using controlled electromigration. Since these weak links dictate the SQUID's properties, its sensitivity and working range should be gradually altered. In order to achieve this goal, a nano-SQUID is designed and fabricated using e-beam lithography (EBL) and molecular beam epitaxy (MBE) techniques (Fig 1.a). Since the design of the SQUID consists of two weak links in parallel, the next step was to experimentally verify that this design is indeed compatible with parallel electromigration. This is achieved by the, direct and in-situ, observation of the parallel electromigration process of the SQUID structure using scanning electron microscopy (Fig.1b and 1c). Hereafter, we investigated the evolution of the superconducting properties of the SQUID using low temperature measurements as function of the cross section of the weak links. The behavior of the SQUID's critical current perfectly matches the numerical calculations based on a SQUID model which takes into account the kinetic inductance and asymmetry of the device. Moreover, it is observed that when electromigration has sufficiently reduced the junction cross section, the SQUID can be operated in the dissipative state, where magnetic flux readout from voltage is possible. Hence electromigration provides a very powerful 'knob' to tune the SQUID's parameters.

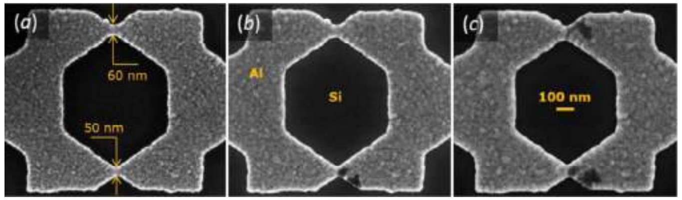


Figure 1: In-situ scanning electron microscopy snapshots of the electromigration process in parallel nanoconstrictions. Panel (a) shows the virgin device, before electromigration. An asymmetric start of the electromigration occurs at panel (b). Further electromigration leads to redistribution of the current and consequently to EM of the other constriction as seen in (c).

[1] R.C. Jaklevic *et al*. *Physical Review Letters,* 12(7); 159-160, 1964.

Advanced nanoSQUIDs based on sub-micron trilayer Nb/HfTi/Nb Josephson junctions

B. Müller[1], M. J. Martínez-Pérez[2], J. Linek[1], A. Koser[1], K. Meyer[1], D. Korinski[1], T. Weimann[3], O. Kieler[3], J. Sese[4], R. Kleiner[1], and D. Koelle[1]

[1] *Physikalisches Institut and Center for Quantum Science in LISA$^+$, Universität Tübingen, Germany*
[2] *Instituto de Ciencia de Materiales de Aragón (ICMA), Universidad de Zaragoza and Fundación ARAID, Zaragoza, Spain*
[3] *Fachbereich Quantenelektronik, Physikalisch-Technische Bundesanstalt Braunschweig, Germany*
[4] *Laboratorio de Microscopías Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Universidad de Zaragoza, Spain*
benedikt.mueller@uni-tuebingen.de

We report on the development and performance of advanced Nb nanoSQUIDs for magnetization reversal studies on individual magnetic nanoparticles (MNPs). The nanoSQUIDs are based on trilayer Nb/HfTi/Nb Josephson junctions exhibiting high critical current densities > 10^5 A/cm^2 at 4.2 K. This offers the unique advantage of combining the realization of SQUIDs with very small loop inductance, and hence extremely low flux noise, with a superconductor multilayer approach that allows for fabrication of complex devices with significantly increased functionality for various applications.

One example is the recently developed 3-axis vector nanoSQUID [1]. This device consists of three mutually orthogonal SQUID nanoloops (two magnetometers, one gradiometer; cf. Fig.1) that allow simultaneous and independent detection of the three components of the vector magnetic moment of individual MNPs at 4.2 K in applied magnetic fields up to a few 100 mT. Here, we present the design and performance of improved vector nanoSQUIDs as well as first attempts to vectorially detect the magnetization reversal of individual Co MNPs deposited onto our devices by focused electron beam deposition.

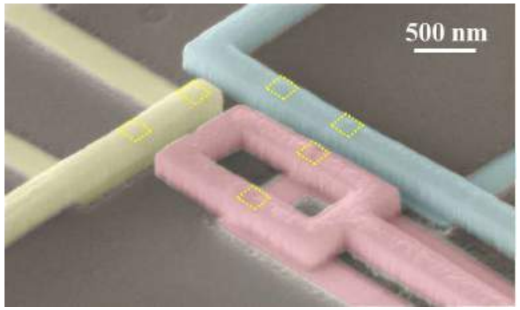


Figure 1: False-colored SEM image of a 3-axis vector nanoSQUID.

[1] M. J. Martínez-Pérez et al., ACS Nano **10**, 8308-8315 (2016).

Superconducting nanotubes vertically grown by He$^+$ focused ion beam induced deposition

Rosa Córdoba[1,2], **Alfonso Ibarra**[3] , **Dominique Mailly**[4], **and J. M. De Teresa**[1,2,3]

[1] *Instituto de Ciencia de Materiales de Aragón (ICMA), CSIC - UZ, Spain*
[2]*Departamento de Física de la Materia Condensada, UZ, 50009 Zaragoza, Spain*
[3]*Laboratorio de Microscopías Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), UZ, Spain*
[4]*Centre de Nanosciences et de Nanotechnologies, CNRS, Univ Paris Sud, Université Paris Saclay, 91120 Palaiseau, France*

rocorcas@unizar.es

Superconducting materials allow the transport of electricity without energy losses. Whereas these materials in bulk present ordinary superconducting behaviour, novel physical properties appear when their size is reduced to the nanoscale, in the range of their superconducting coherence length (ξ_0).

In the present contribution, we report for the first time the use of a He$^+$ focused-ion-beam microscope to grow in a single-step three-dimensional tungsten carbide (WC) superconducting nanotubes as small as 32 nm in diameter and with an aspect ratio (diameter/length) of as much as 200. Such extreme resolution is achieved by using a small He$^+$ beam spot of 1 nm for the growth of nanotubes.

As shown by transmission electron microscopy, they display grains of large size fitting with face-centered cubic WC_{1-x} phase, which could present a T_c up to 10 K [3]. By studying their magnetotransport properties, we have found that they exhibit superconducting properties below critical temperature (T_c)~ 6.4 K, as well as high upper critical magnetic field ($\mu_0 H_{c2}$) and critical current density (J_c) [1]. The T_c and $\mu_0 H_{c2}$ values are 1.5 times higher than those reported for WC nanowires of similar dimensions grown by Ga$^+$ FIBID [2], and the temperature dependence of $\mu_0 H_{c2}$ and the field dependence of J_c indicate that smallest nanotubes behave as quasi-one-dimensional superconductors.

The fabrication of such materials with excellent properties makes this technique at the cutting edge of nanofabrication methods based on focused beams of charged particles for the development of the broad field of 3D nano-superconductivity.

Acknowledgement:
"This project has received funding from the EU-H2020 research and innovation programme under grant agreement No 654360 NFFA-Europe."

References

[1] Córdoba R.; Mailly D.; Ibarra A. and De Teresa J. M. *manuscript submitted to Nano Letters.*
[2] Córdoba R. et al. *Nat. Commun.* 2013, 4, 1437.
[3] Kurlov A. S. and Gusev A. I. *Inorg. Mater.* 2006, 42, 121–7.

High Tc Superconducting devices

C. Feuillet-Palma[1], **P. Amari**[1], **A. Sarafiev**[1], **F. Couëdo**[1], **M. Malnou**[1], **J. Lesueur**[1] **and N. Bergeal**[1]

[1]*LPEM - ESPCI/CNRS/UPMC PSL Research University, Paris (France)*
cheryl.palma@espci.fr

In the past years, we have been developing High-Tc Josephson nano-junctions made by ion irradiation [1]. Based on commercial $YBa_2Cu_3O_{7-x}$ thin films, this versatile and highly scalable technique opens a new route towards superconducting electronics in the temperature range between 20K and 80K. DC [2,3,4] and RF applications have been explored, with very encouraging results.

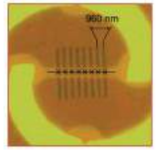


FIGURE 1 : Optical picture the array geometry with eight Jospehson junctions in series separated by 960 nm

In particular, we built a heterodyne High-Tc Superconductor (HTSc) receiver in the THz range, made of a Josephson mixer embedded in a broad-band antenna, operating at 50K-60K. High-frequency mixing properties of such device up to 420 GHz has been obtained, with interesting conversion gain [3]. Accurate modeling of the detector was made using a three-ports model.

Recently, we have reported on Josephson mixing on Giant Shapiro steps of ion-irradiated Josephson arrays [5]. Moreover, we have shown that phase locking between junctions is possible depending on the spacing of the Josephson junctions in the array, illustrated figure 1.

On the other hand, we also realize very long $YBa_2Cu_3O_{7-x}$ nanowires in a meander shape patterned in a CeO_2-capped thin film by high-energy oxygen ion irradiation, presented figure 2. DC and RF measurements outline the good superconducting properties of the nanowires whose geometry approaches the one used in single photon detector.

FIGURE 2 : AFM image of HTSc meanders made by ion irradiation embedded in a CPW line

In this presentation, we will present our recent results on ion-irradiated Josephson junctions arrays and single photon devices.

[1] N. Bergeal et al. APL 87, 102502 (2005) & JAP 102, 083903 (2007)
[2] M. Malnou et al. APL 101, 233505 (2012) & JAP 116, 074505 (2014)
[3] A. Sharafiev et al. Supercond. Sci. Technol. (2016) 29, 074001 (2016).
[4] S. Ouanani, et al. Supercond. Sci. Technol. 29, 1–9 (2016).
[5] A. Sharafiev et al. Supercond. Sci. Technol. accepted (2017)
[6] P. Amari et al. Supercond. Sci. Technol. 31, 1 (2017)

A passive, on-chip microwave circulator using a ring of tunnel junctions

Clemens Müller[1,2], Shengwei Guan[2], Nicolas Vogt[3], Jared H. Cole[3], Thomas M. Stace[2]

[1] *Institute for Theoretical Physics, ETH Zürich, Zürich, Switzerland*
[2] *ARC Centre of Excellence for Engineered Quantum Systems, The University of Queensland, Brisbane, Australia*
[3] *Chemical and Quantum Physics, RMIT University, Melbourne, Australia*
c.muller2@uq.edu.au

The unavailability of integrated microwave circulators is currently one of the major roadblocks on the way towards true scaling up of superconductor based quantum technology, with many recent proposals aimed at overcoming this capability gap. In general, these require additional microwave or radiofrequency components and therefore increase control complexity significantly. Here, I will present our recent proposal for a fully passive, on-chip microwave circulator based on a ring of superconducting tunnel junctions [1]. We investigate two distinct physical realisations, based on either Josephson junctions (JJ) or quantum phase slip elements (QPS), with microwave ports coupled either capacitively (JJ) or inductively (QPS) to the ring structure. A constant bias applied to the center of the ring provides the symmetry breaking (effective) magnetic field, and no microwave or rf bias is required. We find that this design offers high isolation even when taking into account fabrication imperfections and environmentally induced bias perturbations and find a bandwidth in excess of 500 MHz for realistic device parameters.

[1] **CM**, S. Guan, N. Vogt, J. H. Cole, and Thomas M. Stace, arXiv:1709:09826 (2017)

On the origin of the quasiparticle states in the superconducting gap of homogeneously disordered ultrathin films. MoC case.

P. Szabó,[1] M. Kopčík,[1] V. Hašková,[1] V. Vaňo,[1] T. Samuely,[1] M. Žemlička,[2] M. Grajcar,[2] and P. Samuely[1]
[1] *CLTP @ Inst. Exp. Phys. SAS, SK-04001 Košice, Slovakia*
[2] *DEP, Comenius University, SK-84248 Bratislava, Slovakia*

pszabo@saske.sk

Spectral characteristics of numerous strongly disordered ultrathin films in the proximity of the superconductor-insulator transition show signs of dissipation deep in the superconducting state [1,2]. In our previous scanning tunneling microscopy and spectroscopy (STM/STS) experiments on homogeneously disordered MoC ultrathin films we have shown, that the quasiparticle density of states of ultrathin MoC films becomes gapless and can be described by the Dynes modification of BCS density of states with a strong broadening parameter Γ accounting for the suppression of coherence peaks and increased in-gap states [1]. With reduced sample thickness the critical temperature T_c and the energy gap Δ are suppressed and the spectral broadening parameter Γ is increased. It is a paradox since the superconducting quasiparticle spectrum of standard BCS *s*-wave superconductors is characterized by a full gap. Recently, *Herman & Hlubina* assigned intrinsic microscopic explanation of the Dynes formula for a superconductor with a Lorentzian distribution of local pair breakers and arbitrary potential disorder [3]. This approach could be a clue to the detected finite DOS at the Fermi level found in many disordered systems provided the source of the pair-breaking fields is identified. For the case of ultrathin films, the interface between the film and the substrate can be such a source.

In this presentation we show that indeed, the interface strongly influences the superconductivity of the thin MoC films. We have prepared 3 nm thin MoC films simultaneously on sapphire and silicon substrates. The films exhibit the same sheet resistance indicating a similar level of scalar disorder affecting the mean free path of electrons but their superconducting properties as T_c, the energy gap Δ and the broadening parameter Γ accounting for in-gap states and suppression of coherence peaks are different. We attribute this effect to a different pair breaking at different interface.

[1] P. Szabó, et al., Phys. Rev. B 93 (1) (2016) 014505.
[2] Y. Noat, et al., Phys. Rev. B 88 (1) (2013) 014503.
[3] F. Herman, and R. Hlubina, Phys. Rev. B 94 (14) (2016) 144508

Tunable proximity effect in cuprate superconductor/graphene junctions

David Perconte[1], Fabian A. Cuellar[1], Constance Moreau-Luchaire[1], Maelis Piquemal-Banci[1], Regina Galceran[1], Piran R. Kidambi[2], Marie-Blandine Martin[2], Stephan Hoffmann[2], Rozenn Bernard[1], Christian Ulysse[3], Bruno Dlubak[1], Pierre Seneor[1], Javier E. Villegas[1]

[1]*Unité Mixte de Physique, CNRS, Thales, Univ. Paris-Sud, Université Paris Saclay, 91767 Palaiseau, France*
[2] *Department of Engineering, University of Cambridge, Cambridge CB3 0FA, United Kingdom*
[3] *Phynano team, C2N, CNRS, 91400 Orsay, France*
david.perconte@cnrs-thales.fr

Superconductivity induced by proximity effect is particularly interesting in graphene. For example, because of the conduction and valence bands touching at the Dirac point, an unusual form of the Andreev reflection (the so-called specular Andreev reflection) has been predicted theoretically to happen at a superconductor-graphene interface [1]. We have fabricated cuprate superconductor/Au/graphene planar junctions using a combination of lithography, ion irradiation and CVD graphene transfer techniques. The conductance measurements show that the interfaces are transparent such that the electrical transport is governed by the Andreev reflection. The devices allow the modulation of graphene doping via either a top or a back gate, and thus enable electrical control of the graphene's Fermi energy. This allows us to evidence superconducting electron interference effects that constitute an analogue of Klein tunneling for superconducting pairs. The interference effects periodically modulate the conductance across the junction. We perform numerical simulations based on the model developed in [1]. We compare this simulated superconductor graphene interface conductance to the experimental conductance. We will also present recent work on nanometric cuprate superconductor/Au/graphene junctions where we observe conductance oscillations with bias voltage. These oscillation period decrease when increasing the graphene channel length which indicates that the interferences happen inside the graphene channel.

[1] C. W. J. Beenakker, Phys. Rev. Lett. 97, 067007 (2007)
[2] J. Linder, A. Sudbo, Phys. Rev. Lett. 99, 147001 (2007)

Perturbation theory for a correlated quantum dot attached to superconducting leads

Tomáš Novotný[1], Martin Žonda[1], Vladislav Pokorný[2], Václav Janiš[2]

[1]*Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University in Prague, Ke Karlovu 5, CZ-12116 Praha 2, Czech Republic*
[2]*Institute of Physics, The Czech Academy of Sciences, Na Slovance 2, CZ-18221 Praha 8, Czech Republic*

Self-consistent perturbation expansion up to the second order in the interaction strength is used to study a single-level quantum dot with local Coulomb repulsion attached asymmetrically to two generally different superconducting leads [1,2]. At zero temperature and wide range of other parameters the spin-symmetric version of the expansion yields excellent results for the position of the $0-\pi$ impurity quantum phase transition boundary and Josephson current together with the energy of Andreev bound states in the 0-phase as confirmed by numerical calculations using the Numerical Renormalisation Group method. We analytically prove that the method is charge-conserving as well as thermodynamically consistent. Explicit formulas for the position of the $0-\pi$ phase boundary are presented for the Hartree-Fock approximation as well as for its variant called Generalized Atomic Limit. It is shown that the Generalized Atomic Limit can be used as a quick estimate for the position of the phase boundary at half-filling in a broad range of parameters. We apply our second order perturbation method to the interpretation of the existing experimental data on the phase boundary with very satisfactory outcome suggesting that the so far employed heavy numerical tools such as Numerical Renormalization Group and/or Quantum Monte Carlo are not necessary in a class of generic situations and can be safely replaced by a perturbative approach.

[1] M. Žonda, V. Pokorný, V. Janiš, and T. Novotný, Phys. Rev. B **93**, 024523 (2016).
[2] M. Žonda, V. Pokorný, V. Janiš, and T. Novotný, Scientific Reports **5**, 8821 (2015).

E-mail for corresponding author: tno@karlov.mff.cuni.cz

Temperature Dependence of the Crystal Structure of the superconductor $LiTi_2O_4$ and of the heavy fermion LiV_2O_4

Evagelia G. Moshopoulou

[1]*Institute of Nanoschience and Nanotechnology, National Center for Scientific Research "Demokritos", 15310 Agia Paraskevi-Athens, Greece*
e.moshopoulou@inn.demokritos.gr

The normal spinel oxide $LiTi_2O_4$ is an exotic superconductor with T_c = 11.2 K, while the isostructural neighboring LiV_2O_4, exhibits heavy-fermion behavior. The origin of their physics and the role of the spinel structure on their properties are yet unsolved issues, owing mainly to the complexity of the structure, the presence of subtle disorder and the sample dependence of the physical properties. Especially and perhaps more importantly, the enormous difference in their low-temperature properties remains an open question. This question has only been addressed theoretically but (mainly because of the above problems) there were no experimental studies that sought to understand the clearly distinct behavior of the two systems.

Here, we revise and contribute to the understanding of such distinct low-temperature behavior by comparing the temperature dependence of the main structural properties of the two systems. Because $LiTi_2O_4$ exhibits strong sample (powder, single crystal, thin film) dependence of its physical and structural properties, special attention was paid for the sample conservation and the same $LiTi_2O_4$ samples used for the structural studies, were also characterized in detail by high magnetic field magnetization and field-dependent resistivity measurements. Upon cooling from room temperature, the lattice parameter *a* decreases gradualy in about the same way for both systems. However, below 20 K, a clear decrease of *a* of LiV_2O_4 as a function of temperature contrasts strongly with the almost constant value of *a* of $LiTi_2O_4$ in the same temperature range. Therefore subtle but clearly different structural signatures are coupled with the very divergent physical properties of the two systems and suggest new directions to the theory.

List of Participants

			Institution	Contact
Prof.	Aarts	Jan	Leiden Insitute of Physics	aarts@physics.leidenuniv.nl
PhD st.	Amundsen	Morten	Norwegian University of Science and Technology	morten.amundsen@ntnu.no
Prof.	Anahory	Yonathan	The Hebrew University of Jerusalem	yonathan.anahory@mail.huji.ac.il
Dr.	Aprili	Marco	LPS-CNRS Université Paris-Sud, 91400 Orsay, France	marco.aprili@u-psud.fr
Prof.	Babaev	Egor	KTH	babaevegor@gmail.com
PhD st.	Barrena	Victor	Universidad Autónoma de Madrid	victor.barrena@uam.es
Dr.	Bauch	Thilo	Chalmers University of Technology	bauch@chalmers.se
PhD st.	Baumans	Xavier	Université de Liège	xavier.baumans@uliege.be
Prof.	Bending	Simon	University of Bath	s.bending@bath.ac.uk
Dr.	Bergeal	Nicolas	ESPCI-Paris, PSL Research University	nicolas.bergeal@espci.fr
Prof.	Black-Schaffer	Annica	Uppsala University	annica.black-schaffer@physics.uu.se
Prof.	Blatter	Johann	ETH Zurich	blatterj@phys.ethz.ch
Dr.	Brison	Jean-Pascal	Univ Grenoble-Alpes/CEA, INAC/Pheliqs	jean-pascal.brison@cea.fr
Prof.	Buzdin	Alexander	University of Bordeaux	alexandre.bouzdine@u-bordeaux.fr
Prof.	Caprara	Sergio	Dipartimento di Fisica - Università di Roma Sapienza	sergio.caprara@roma1.infn.it
Dr.	Caruso	Roberta	Universita' degli Studi di Napoli Federico II	caruso@fisica.unina.it
Dr.	Cordoba	Rosa	Instituto de Ciencia de Materiales de Aragón (ICMA)	rosa.cordoba.castillo@gmail.com
Prof.	Crisan	Adrian	National Institute of Materials Physics Bucharest	acrisan652@gmail.com
Prof.	Csonka	Szabolcs	BME Department of Physics	csonka@mono.eik.bme.hu
Dr.	Delbecq	Matthieu	Laboratoire Pierre Aigrain, Ecole Normale Superieure	matthieu.delbecq@lpa.ens.fr
Prof.	Dobrovolskiy	Oleksandr	Physikalisches Institut Goethe University	Dobrovolskiy@Physik.uni-frankfurt.de
Prof.	Eschrig	Matthias	Royal Holloway, University of London	matthias.eschrig@rhul.ac.uk
Dr.	Feuillet-Palma	Cheryl	ESPCI-Paris, PSL Research University	cheryl.palma@espci.fr
Prof.	Geshkenbein	Vadim	ETH Zurich	dimagesh@phys.ethz.ch
Dr.	Goldobin	Edward	University of Tübingen	gold@uni-tuebingen.de
Dr.	Gueron	Sophie	LPS-CNRS Université Paris-Sud, 91400 Orsay, France	sophie.gueron@u-psud.fr
Dr.	Guillamon	Isabel	Universidad Autónoma de Madrid	isabel.guillamon@uam.es
Dr.	Hassanien	Abdou	Jozef Stefan Institute	abdou.hassanien@gmail.com
PhD st.	Ionescu	Marinela Alina	National Intitute of Materials Physics	alina09i@yahoo.com
Dr.	Kakazei	Gleb	Department of Physics and Astronomy, University of Porto	gleb.kakazei@fc.up.pt
Dr.	Kalisky	Beena	Bar Ilan University	beena@biu.ac.il
PhD st.	Keijers	Wout	KU Leuven	wout.keijers@kuleuven.be

Prof.	Koelle	Dieter	Physikalisches Institut, Universität Tübingen	koelle@uni-tuebingen.de
Prof.	Kubatkin	Sergey	Chalmers University of Technology	kubatkin@chalmers.se
Dr.	Kunakova	Gunta	Chalmers University of Technology	gunta.kunakova@lu.lv
Prof.	Lang	Wolfgang	University of Vienna	wolfgang.lang@univie.ac.at
PhD st.	Leriche	Rafael	Institut des Nano-Sciences de Paris	leriche@insp.jussieu.fr
Dr.	Leridon	Brigitte	ESPCI-Paris, PSL Research University	brigitte.leridon@espci.fr
Dr.	Li	Chuan	MESA+ Institute for Nanotechnology, University of Twente	chuan.li@utwente.nl
Prof.	Lombardi	Floriana	Chalmers University	floriana.lombardi@chalmers.se
Dr.	Maggio-Aprile	Ivan	Université de Genève	ivan.maggio-aprile@unige.ch
Dr.	Martínez-Pérez	María José	Instituto de Ciencia de Materiales de Aragon	pemar@unizar.es
Dr.	Mashkoori	Mahdi	Uppsala University	mahdi.mashkoori@physics.uu.se
Dr.	Mesaros	Andrej	Laboratoire de Physique des Solides, Orsay	andrej.meszaros@u-psud.fr
Prof.	Milosevic	Milorad	Universiteit Antwerpen	milorad.milosevic@uantwerpen.be
Prof.	Mishonov	Todor	University of Sofia	mishonov@bgphysics.eu
Dr.	Moshopoulou	Evagelia	Institute of Nanoscience and Nanotechnology	e.moshopoulou@inn.demokritos.gr
Dr.	Mueller	Clemens	Institute for Theoretical Physics, ETH Zurich	c.muller2@uq.edu.au
PhD st.	Müller	Benedikt	Universität Tübingen	benedikt.mueller@uni-tuebingen.de
Dr.	Novotny	Tomas	Charles University in Prague, Faculty of Mathematics and Physics	tno@karlov.mff.cuni.cz
PhD st.	Ouassou	Jabir Ali	Center for Quantum Spintronics	jabir.a.ouassou@ntnu.no
PhD st.	Perconte	David	Unité mixte de physique CNRS/Thales	david.perconte@cnrs-thales.fr
PhD st.	Risinggård	Vetle	Dept. of Physics, Norwegian University of Science and Technology	vetle.k.risinggard@ntnu.no
Dr.	Robinson	Jason	University of Cambridge	jjr33@cam.ac.uk
Prof.	Roditchev	Dimitri	ESPCI-Paris, PSL Research University	dimitri.roditchev@espci.fr
PhD st.	Rouco	Mikel	Centro de Fisica de Materiales	mikel.mrm@gmail.com
PhD st.	Rudau	Fabian	Physikalisches Institut, Universität Tübingen	fabian.rudau@uni-tuebingen.de
Dr.	Sacépé	Benjamin	Institut Néel, CNRS	benjamin.sacepe@neel.cnrs.fr
Prof.	Samuely	Peter	Centre of Low Temperature Physics, Kosice	samuely@saske.sk
Dr.	Samuely	Tomas	Centre of Low Temperature Physics, Kosice	tomas.samuely@upjs.sk
PhD st.	Scherübl	Zoltán	Budapest University of Technology and Economics	scherubl.zoltan@gmail.com
Dr.	Silaev	Mikhail	University of Jyväskylä	mikesilaev@gmail.com
Prof.	Silhanek	Alejandro	Université de Liège	asilhanek@ulg.ac.be
Prof.	Pompeo	Nicola	University Roma Tre	enrico.silva@uniroma3.it

PhD st.	Spera	Marcello	Université de Genève	marcello.spera@unige.ch
Dr.	Stornaiuolo	Daniela	University of Naples "Federico II" and CNR-SPIN	stornaiuolo@fisica.unina.it
Prof.	Suderow	Hermann	Universidad Autónoma de Madrid	hermann.suderow@uam.es
Dr.	Szabó	Pavol	Institute of Experimental Physics, Slovak Academy of Sciences	pszabo@saske.sk
PhD st.	Szewczyk	Daria	Institute of Low Temperature and Structure Research PAS	d.szewczyk@int.pan.wroc.pl
Dr.	Tran	Lan Maria	Institute of Low Tempeature and Structure Research, PAS	l.m.tran@int.pan.wroc.pl
Prof.	Van de Vondel	Joris	KU Leuven	joris.vandevondel@kuleuven.be
Prof.	Vasenko	Andrey	National Research University Higher School of Economics	avasenko@hse.ru
Dr.	Villegas	Javier	Unité mixte de physique CNRS/Thales	javier.villegas@cnrs-thales.fr
PhD st.	Wissberg	Shai	Bar Ilan University	shaiwis@gmail.com
Prof.	Zaikin	Andrei	Institute of Nanotechnology, KIT	andrei.zaikin@kit.edu
Prof.	Zaleski	Andrzej	Institute of Low Temperature and Structure Research PAS	a.zaleski@int.pan.wroc.pl

Organizers

Dimitri Roditchev ESPCI-Paris, PSL Research University
Brigitte Leridon ESPCI-Paris, PSL Research University
Hermann Suderow Universidad Autónoma de Madrid
Irene González Martín Universidad Autónoma de Madrid