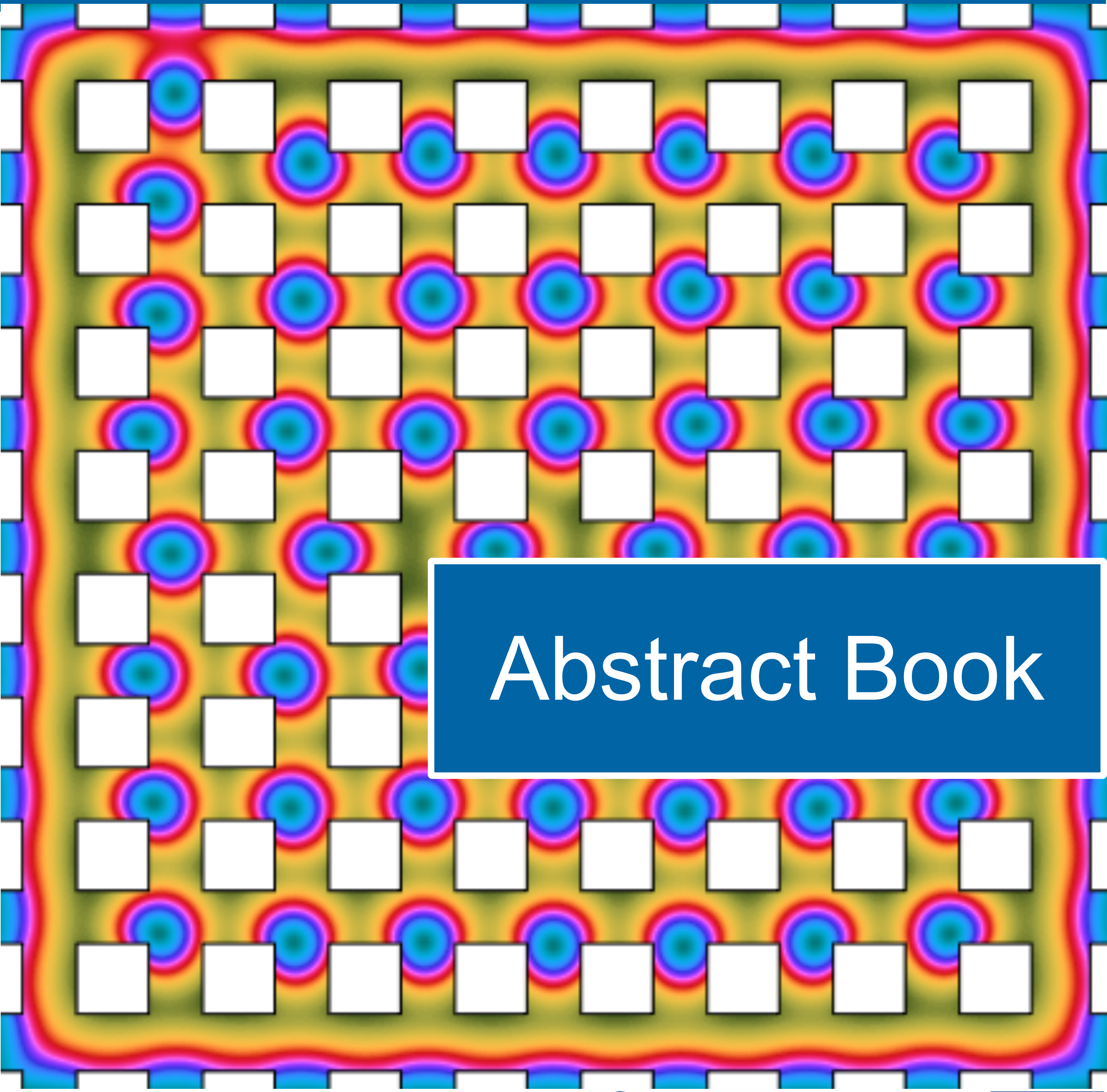
Nanoengineered Superconductors - NES21

Young Investigator's online workshop, May 10-12, 2021



Abstract Book

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NIMP SCIENTIFIC RESEARCH

NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

WELCOME

We cordially welcome you to the Young Investigator's Online Workshop on Nanoengineered Superconductors - NES21, that takes place in virtual space from May 10 to 12, 2021. The workshop is hosted by the University of Vienna in the framework of the COST Action CA16218 "Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies (NANOCOHYBRI)", which supports attendance free of charge.
The workshop aims to bring together leading experts and, especially, younger investigators on nanoengineered superconductors and vortex matter to discuss recent advances in these fields and related research domains. The workshop targets at stimulating discussions between experimentalists and theorists and should be valuable for developers of superconducting devices. The focus is on the phenomena of superconductivity, charge and flux dynamics on the micro- and nanoscale, magneto-transport properties of low-dimensional superconducting systems, as well as their applications in magnetic-field sensing, single-photon detection, and hybrid quantum circuits.

The recent advances in nanoengineered superconductors and related phenomena will be presented in 41 invited talks and 30 posters by early career investigators. Three special talks will introduce the development of superconducting single photon detectors, the helium ion microscope, and the "Physicist in Gastronomy Universe". The latter will present us a flavour of the usual conference dinner, which unfortunately is not possible in the present situation. The option to join this workshop as a "Scholar", without presenting a talk or poster, allows graduate students to get first impressions of conference life and helps to promote the research field to young minds.

We hope that the workshop NES21 triggers lively and inspiring discussions, leads to new fruitful contacts, and continues the tradition of the successful previous workshops in the frame of our COST Action.

On behalf of the programme and advisory committees,

Oleksandr Dobrovolskiy (University of Vienna)
Alina Ionescu (National Institute of Materials Physics, Bucharest)
Dieter Koelle (University of Tübingen)
Wolfgang Lang (University of Vienna)

COST-ACTION CA16218 NANOCOHYBRI

COST (European Cooperation in Science and Technology) is Europe's longest-running intergovernmental framework for cooperation in science and technology funding cooperative scientific projects called 'COST Actions'. The COST Action **Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies** (NANOCOHYBRI) started in November 2017 and will last until October 2021. Currently, 24 countries have joined the Network. The Action is guided by the Management Committee, which is formed by not more than two representatives of each country that signed the Memorandum of Understanding. This document serves as the basis for joining and implementing the Action.

NANOCOHYBRI provides instruments for networking activities, organizes meetings every year, promotes exchanges through short term visits and provides opportunities for young researchers to present work related to the Action in other conferences. The next major meetings of the Action will be "Online conference on emergent topological superconductivity, 7-9 June 2021" and "Superconducting Hybrids @ Extreme, 28th June – 02nd July 2021". We cordially invite you to participate in these meetings, by sending abstracts to the organizers or simply by registering (free), attending and discussing with us. Some of the talks are available at our youtube channel, where you can also find a popular presentation about the beauty of coherent quantum states. Further videos will be soon available.

The Action includes these objectives:

- To achieve a common ground to use superconducting quantum coherence.
- To enable a new generation of applications of superconductivity, including current carrying and quantum information devices, by controlling superconducting parameters at the nanoscale.
- To build and test new devices based on a precise control over dimensionality, geometry, and interaction with the quantum condensate.
- To develop a collaborative effort, crosscutting experiment and theory, using the full potential of European research in superconductivity.
- To bridge the gap between traditionally separated scientific communities that have complementary knowledge and a common interest in superconducting devices.
- To train the next generation of stakeholders in a growing field that will lead to the next quantum revolution.
- To educate engineers and society, making it more commonplace to think in terms of the possibilities enabled by technologies utilizing quantum coherence.
- To provide a platform for young European researchers to build an efficient network.
- To foster contribution from researchers from inclusiveness target countries and facilitate their participation in high level European calls.

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Workshop Programme

Invited talks

Time	*Monday, May 10*	Abstract
08:45-09:00	*Welcome address*	ID
	Vortex pinning, dynamics and fluxonic devices *Session Chair: Gaia Grimaldi*	
09:00-09:25	**Víctor Rouco** Vortex pinning and dynamics in mesoscopic YBCO nanowires	VP1
09:25-09:50	**Alina Ionescu** Imaging vortex-antivortex pairs in high-Tc superconductors	VP2
09:50-10:15	**Anton Bespalov** Large spectral gap and impurity-induced states in a 2D Abrikosov vortex	VP3
10:15-10:30	COFFEE BREAK	
10:30-10:55	**Lorenzo Ceccarelli** Dynamics study and imaging of superconducting vortices in MoSi thin films	VP4
10:55-11:20	**Barbora Budinská** Edge barrier effects on the flux-flow instability in superconducting MoSi thin films	VP5
11:20-11:45	**Igor Bogush** Reduction of the relativistic and non-relativistic GL models to a 2D curved surface	VP6
11:45-12:00	COFFEE BREAK	
	Layered materials and interfacial superconductivity *Session Chair: Isabel Guillamon*	
12:00-12:25	**Beilun Wu** Anisotropic superconductivity in spin-vortex AF superconductor $CaK(Fe_{0.95}Ni_{0.05})_4As_4$	LM1
12:25-12:50	**Armando Galluzzi** A precursor mechanism triggering the second magnetization peak phenomenon...	LM2
12:50-13:15	**Ondrej Šofranko** Extreme charge transfer in the misfit layered compound $(LaSe)_{1.14}(NbSe_2)$	LM3
	LUNCH BREAK	
14:35:15:00	**Roberta Caruso** Probing unconventional phenomena in $LaAlO_3$-$SrTiO_3$ and $La_{2-x}Sr_xCuO4$	LM4
	Superconducting single-photon detectors *Session Chair: Denis Vodolazov*	
15:00-15:50	**Roman Sobolewski** Superconducting single-photon detectors – twenty years	PD1
15:50-16:00	COFFEE BREAK	
16:00-16:25	**Mariia Sidorova** Vortex-assisted photon counts by a superconducting single-photon detector	PD2
16:25-16:50	**Carla Cirillo** Research perspectives on applications of NbRe and NbReN thin films in SNSPDs	PD3
16:50-17:00	COFFEE BREAK	
	Special evening talk *Chair: Wolfgang Lang*	
17:00-18:00	**Andrey Varlamov** Physicist in Gastronomy Universe	ET1

Time	*Tuesday, May 11*	Abstract ID
	Superconductors at microwave frequencies ***Session Chair: Enrico Silva***	
09:00-09:25	**Andrea Alimenti** Microwave vortex motion in superconductors in high magnetic fields	**MW1**
09:25-09:50	**Artur Romanov** Correlation between microstructure and HF properties of thick REBCO coated conductors	**MW2**
09:50-10:15	**Daniele Torsello** Interplay between ferromagnetism and superconductivity in $EuFe_2(As,P)_2$	**MW3**
10:15-10:30	COFFEE BREAK	
10:30-10:55	**Sergey Bunyaev** Whispering gallery resonators for microwave characterization of superconductors	**MW4**
10:55-11:20	**Cheryl Feuillet-Palma** Vortex dynamics in HTS nano-meanders made by ion irradiation	**MW5**
11:20-11:45	**Vasilii Vadimov** Higgs modes in proximized superconducting systems	**MW6**
11:45-12:00	COFFEE BREAK	
	Proximity effects and spin transport in S/F hybrids ***Session Chair: Andrii Chumak***	
12:00-12:25	**Matthias Althammer** Temperature-dependent spin-transport and current-induced torques in S/F heterostructures	**SF1**
12:25-12:50	**César González-Ruano** Proximity effects in epitaxial F/S hybrids: towards superconducting spintronics with SOI	**SF2**
12:50-13:15	**Sergey Mironov** Electromagnetic proximity effect in S/F heterostructures	**SF3**
	LUNCH BREAK	
	Direct-write superconductors and Josephson devices ***Session Chairs: José María De Teresa, Edward Goldobin***	
14:30-15:10	**John Notte** Precise helium ion beams for nanoscale fabrication	**DW1**
15:10-15:35	**Rosa Córdoba** Direct-writing of advanced 3D nano-superconductors	**DW2**
15:35-16:00	**Pablo Orus** Superconducting properties of in-plane W-C nanowires grown by He^+ FIBID	**DW3**
16:00-16:15	COFFEE BREAK	
16:15-16:40	**Fabrizio Porrati** Nb-C superconductor prepared by focused ion beam induced deposition	**DW4**
16:40-17:05	**Kaveh Lahabi** Direct-write printing of Josephson devices in a scanning electron microscope	**DW5**
17:05-17:30	**Jay LeFebvre** Series arrays of planar long Josephson junctions for high-dynamic range magnetic flux detection	**DW6**
17:30-19:00	**POSTER PRESENTATIONS**	

Time	*Wednesday, May 12*	Abstract ID
	Josephson junctions, SQUIDs and related phenomena ***Session Chair: Alejandro Silhanek***	
09:00-09:25	**Heleen Dausy** The impact of kinetic inductance on the critical current oscillations of nanobridge SQUIDs	**JJ1**
09:25-09:50	**Simon Collienne** Nb-based nanoscale SQUIDs tuned by electroannealing	**JJ2**
09:50-10:15	**Edoardo Trabaldo** Improving the performance of YBCO nanobridges as weak links	**JJ3**
10:15-10:30	COFFEE BREAK	
10:30-10:55	**Liam Farrar** Superconducting quantum interference in van der Waals heterostructures	**JJ4**
10:55-11:20	**Mathias Wegner** Microwave SQUID Multiplexing	**JJ5**
11:20-11:45	**Zhanna Devizorova** Effect of spin-triplet correlations on Josephson transport in structures containing half-metals	**JJ6**
11:45-12:00	COFFEE BREAK	
	Low-dimensional and topological superconductors ***Session Chair: Milorad Milosevic***	
12:00-12:25	**Jonas Bekaert** Boosting superconductivity in 2D materials by beneficial defects	**LD1**
12:25-12:50	**Nicola Poccia** Controlling strong correlations of HTSs with Van der Waals heterostructures	**LD2**
12:50-13:15	**Tosson Elalaily** Gate-controlled supercurrent in superconductor shell InAs/Al nanowires	**LD3**
13:25-13:50	**Chuan Li** Quantum devices towards 1D topological superconductivity	**LD4**
	LUNCH BREAK	
	Nano-electromechanics and hybrid quantum circuits ***Session Chair: Daniel Bothner***	
15:00-15:25	**Thomas Luschmann** Mechanical frequency control in inductively coupled electromechanical systems	**NE1**
15:25-15:50	**Ines Rodrigues** Four-wave-cooling to the single phonon level in Kerr optomechanics	**NE2**
15:50-16:15	**David Zoepfl** Coupling a magneto-mechanical oscillator to a SQUID based cavity	**NE3**
16:15-16:30	COFFEE BREAK	
16:30-16:55	**Philip Schmidt** Cavity optomechanics implemented using levitating superconductors and Josephson mw circuits	**NE4**
16:55-17:20	**Witlef Wieczorek** Levitation of micrometer-sized superconducting particles using on-chip magnetic traps	**NE5**
17:20-17:30	***Concluding remarks***	

Poster presentations

Tuesday, May 11, 17:30-19:00	
Chairs: Oleksandr Dobrovolskiy, Alina Ionescu, Dieter Koelle, Wolfgang Lang	ID
Bernd Aichner Ultradense tailored vortex pinning arrays in YBCO thin films created by He FIB irradiation	**P01**
Lu Jiang Selective triggering of magnetic flux avalanches by an edge indentation	**P02**
Krsto Invanovic Structural phase transition of the vortex lattice in bulk superconductors with low K values	**P03**
Maycon Motta Reducing the flux front penetration depth in a Nb film by cooling in an inhomogeneous field	**P04**
Vadim Plastovets Electronic structure of the vortices pinned by a planar defect of various transparency	**P05**
Filippo Gaggioli Effects of creep on the linear ac magnetic response in type II superconductors	**P06**
Benjamin McNaughton Formation and characteristic dynamics of vortex rows in superconducting nanostripes	**P07**
Xingchen Chen Towards a NbRe based fast superconducting nanowire single photon detector	**P08**
Glenn Martinez Effect of He+ ion irradiation on the performance of SNSPDs	**P09**
Michal Wyszynski Skyrmion-affected vortex dynamics in a magnet-superconductor heterostructure	**P10**
Remko Fermin Superconducting triplet edge currents in a spin textured ferromagnet	**P11**
Kumar Prateek High quality RuO_2 nanowires for dissipation-less spintronics	**P12**
Patric Holmvall Spontaneously broken time-reversal and translational symmetry at interfaces of d-wave SCs …	**P13**
Kevin Seja Charge and spin transport across mesoscopic normal metal-superconducting heterostructures	**P14**

Tuesday, May 11, 17:30-19:00	
Chairs: Oleksandr Dobrovolskiy, Alina Ionescu, Dieter Koelle, Wolfgang Lang	ID
Krzysztof Szulc Spin waves in superconductor/ferromagnet heterostructures	**P15**
Jiawei Yan Broadening of the in-gap-state energies at non-zero temperatures of the SC quantum dot	**P16**
Anna Boichenko Flux qubit as a single microwave photon counter: Exploring energy spectrum by animation	**P17**
Alexander Kopasov Geometry controlled Josephson diode based on curved proximitized nanowires	**P18**
Maria D'Antuono Nanopatterning of oxide interfaces using cold ion milling	**P19**
Niclas Wennerdal An open-source framework for mesoscopic superconductivity	**P20**
Davi Chaves Enhancing the weak-link response of Y123 nanowires prepared by solution blow spinning	**P21**
David Collomb Impact of nanoscale pinning sites in commercial 2G-HTS tapes via vortex-resolved imaging	**P22**
Lan Maria Tran Synthesis of single crystal $GdFe_{1-x}Co_xAsO$ using salt flux technique	**P23**
Michal Babij Study of the $Gd_{3-x}Ca_xIr_4Sn_{13}$ system in the form of single crystals	**P24**
Masood Rauf Khan Angular dependence on magnetic field of pinning activation energy in Fe(Se,Te) thin films	**P25**
Panch Ram In-gap states in the superconducting periodic Anderson model	**P26**
Mikhail Petrov Superconductivity and topological behaviour in gallenene	**P27**
Olivér Kürtössy Andreev molecule in parallel InAs nanowires	**P28**
Gopi Nath Daptary Superconducting Dirac point in proximetized graphene	**P29**
Elijah Abbey Magnetic flux avalanches in nanoscale wedge-shaped superconducting thin films	**P30**

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Invited talks

Vortex pinning, dynamics and fluxonic devices

Layered materials and interfacial superconductivity

Superconducting single-photon detectors

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Superconductors at microwave frequencies

Proximity effects and spin transport in S/F hybrids

Direct-write superconductors and Josephson devices

Josephson junctions, SQUIDs and related phenomena

Low-dimensional and topological superconductors

Nano-electromechanics and hybrid quantum circuits

Poster Presentations

INVITED TALKS

VP

Vortex pinning, dynamics and fluxonic devices

VP1

Vortex pinning and dynamics in mesoscopic YBCO nanowires

Víctor ROUCO[1,*], Anna PALAU[2], Teresa PUIG[2], Daniela STORNAIUOLO[1], Francesco TAFURI[1]

[1] *Università degli Studi di Napoli Federico II, Dip. di Scienze Fisiche, Napoli, Italy*
[2] *Institute of Materials Science of Barcelona, ICMAB-CSIC, Bellaterra, Spain*
[*] *Present address: Universidad Complutense de Madrid, GFMC, Madrid, Spain*

High Temperature Superconductors (HTS) can transport high current densities without dissipation at temperatures above 77K. However, this current density is well below the theoretical limit (the depairing critical current density) and its performance decreases at large magnetic fields and temperatures, where their use is more needed. The main reason for these limitations is the presence of superconducting vortices whose motion result in power losses and internal noises. To this aim several strategies have been conducted to avoid vortex flow, mainly the introduction of artificial defects into the superconducting matrix.
Here we present a different alternative that arises from the reduction of the width down to mesoscopic ~100nm $YBa_2Cu_3O_{7-x}$ nanowires. We demonstrate that critical current density close to the depairing level can be achieved, even in the presence of large magnetic fields ~1T for a wide range of temperatures. We theoretically demonstrate that this effect is related to prevention of vortex entry. Furthermore, once vortices penetrate into the superconductor and for high current densities, these mesoscopic nanowires present voltage switching up to one order of magnitude due to vortex lattice instabilities. Those effects provide a novel avenue toward achieving high values of current at high fields and temperatures, as well as to use HTS with reduced width for practical applications such as single-photon sensors.

E-mail: vrouco©ucm.es

VP2

Imaging vortex-antivortex pairs in high T_c superconductors

Alina IONESCU[1,2] Julian SIMMENDINGER[1], Manuel BIHLER[1], Markus WEIGAND[1,3], Gisela SCHÜTZ[1], Joachim Albrecht[4]

[1] Max-Planck-Institute for Intelligent Systems,Heisenbergstraße 3, D-70569 Stuttgart, Germany
[2] National Institute of Materials Physics, Atomistilor 405A, 077125, Magurele, Romania
[3] Helmholtz-Zentrum Berlin fürMaterialien und Energie GmbH, Institut Nanospektroskopie, Kekul´estrasse 5, 12489 Berlin, Germany
[4] Research Institute for Innovative Surfaces FINO, Aalen University, Beethovenstraße 1, D-73430 Aalen, Germany

Individual vortex-antivortex (V-AV) pairs in type II superconductors have been imaged using magnetic scanning transmission x-ray microscopy at low temperatures [1]. We observe that the local stray field induced by an individual superconducting flux line locally polarizes a ferrimagnetic sensor layer. We are able to visualize and analyze individual V-AV pairs far below the transition temperature with unprecedented spatial resolution of 20 nm and high contrast. We reveal V-AV pairs to nucleate spontaneously at the domain wall of the ferrimagnetic layer. Our results are the first identification of a bound and stable V-AV pair and demonstrate the potential of the x-ray method to access the properties of vortices in YBCO thin films and heterostructures.

References

[1] J Simmendinger, M Bihler, A M Ionescu, M Weigand, G Schütz, J Albrecht, New J. Phys. **22** (2020) 123035

E-mail: alina09i©yahoo.com

VP3

Large spectral gap and impurity-induced states in a two-dimensional Abrikosov vortex

Anton BESPALOV[1,2], Vadim PLASTOVETS[1,3]

[1] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia
[2] Sirius University of Science and Technology, 1 Olympic Ave, 354340 Sochi, Russia
[3] University Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France

We study the subgap quasiparticle spectrum of a 2D Abrikosov vortex in an s-wave superconductor in the absence and presence of a point impurity [1]. Within the Eilenberger equations formalism, we calculate the energy spectrum of a vortex within two models: a "coreless" vortex with a constant modulus of the order parameter, and a more realistic vortex with the order parameter profile satisfying the Ginzburg-Landau equation. Both models yield qualitatively similar results. We find multiple subgap spectral branches, the number of which can be arbitrarily large provided that the magnetic field screening length is large enough. The large number of branches appears because of the Doppler effect connected with spontaneous currents in the vortex. These currents lower the effective gap edge, creating a potential well that is large enough to accommodate many Andreev states with the same angular momentum. The quasiclassical spectrum of the vortex has a local gap (more precisely, a double-gap symmetric with respect to the Fermi energy) with a width of the order of the bulk gap and a spatial extent of several coherence lengths. The existence of such a gap is the prerequisite for the appearance of discrete impurity-induced states. Indeed, within the Gor'kov equations formalism, we find that a single impurity induces up to four discrete quasiparticle states in the vortex. The energies and wave functions of the impurity states are calculated for different parameters. In a sense, our study extends the analysis of impurity-induced states by Koulakov and Larkin [2] from the limit of low energies to the whole subgap energy range. Most of the spectral features that we have found can be observed in scanning tunnel spectroscopy experiments.

The work has been supported by Russian Foundation for Basic Research Grants No. 18-42-520037 and No. 19-31-51019.

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E-mail: bespalovaa@gmail.com

VP4

Dynamics study and imaging of superconducting vortices in MoSi thin films

Lorenzo CECCARELLI

University of Basel, Klingelbergstrasse 8, 4056 Basel, Switzerland

Nowadays superconductors are widely used in many different fields, from quantum information to engineering applications, like electromagnetic shielding for experimental setups in low loss signal transport. The magnetic field lines expulsion and the non-dissipative current transport are the two main characteristics of these materials. For type-II superconductors, the magnetic field can be trapped in form of quantized vortices of current enclosing a normal state in the middle of a superconducting medium. The motion of this quantized flux in a superconducting device can be detrimental for some applications.

We use a scanning nanometer-scale superconducting quantum interference device (SQUID) [1] to image individual vortices in amorphous superconducting MoSi thin films [2]; an alloy with properties adapt for the fabrication of single photon detectors. Local measurements of the magnetic field, generated by both vortices and Meissner screening, yield to values for the Pearl length and bulk penetration depth at 4.2 K. Flux pinning was studied under different conditions and inputs (e.g. DC and AC transport current and variation of the external magnetic field applied), allowing a classification in function the material’s pinning potential.

The high flux sensitivity and resolution of our SQUID-on-tip scanning probe [3] provides an unparalleled tool for studying vortex dynamics, potentially improving our understanding of their complex interactions. Controlling these dynamics in amorphous thin films is crucial for optimizing devices such as superconducting nanowire single photon detectors (SNSPDs), because vortices are likely involved in both the mechanism used for the detection of photons and in the generation of dark counts [4].

References

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E-Mail: lorenzo.ceccarelli©unibas.ch

VP5

Edge barrier effects on the flux-flow instability in superconducting MoSi films

Barbora BUDINSKÁ[1], Bernd AICHNER[1], Denis VODOLAZOV[2], Mikhail MIKHAILOV[3], Fabrizio PORRATI[4], Michael HUTH[4], Andrii CHUMAK[1], Wolfgang LANG[1], Oleksandr DOBROVOLSKIY[1]

[1]University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria
[2]Russian Academy of Sciences, Institute for Physics of Microstructures, Academicheskaya Street 7, Afonino, Nizhny Novgorod 603087, Russia
[3] National Academy of Sciences of Ukraine, B. Verkin Institute for Low Temperature Physics and Engineering, Nauky Street 47, 61103 Kharkiv, Ukraine
[4]Goethe University, Physics Institute, Max-von-Laue-Street 1, 60438 Frankfurt am Main, Germany

In recent years, ultra-fast vortex motion has become subject of extensive investigations, triggered by the fundamental question regarding the ultimate speed limits for magnetic flux quanta and improving the current-carrying capability of superconductors [1,2]. In external magnetic fields, near the superconducting transition temperature, the quench of the mixed state is associated with the Larkin-Ovchinnikov (LO) instability [1-5], caused by the wake of unpaired electrons left behind the moving vortex cores. At the same time, as it was pointed out in a series of recent works [2,6,7], the LO theory was developed in the continuous-medium approximation and thus care should be taken when treating experiments on systems where the instability has a strong local character. Here, by comparing the current-voltage curves (Fig. 1) for 15 nm-thick superconducting MoSi films with rough (laser cut) and smooth (focused ion beam milled) edges we demonstrate that the maximal vortex velocities can differ by more than one order of magnitude. Our findings identify MoSi as a superconductor supporting ultra-fast vortex motion at more than 10km/s velocities and emphasize the decisive role of the edge quality for the preservation of the low-dissipative state of superconductors at large transport currents.

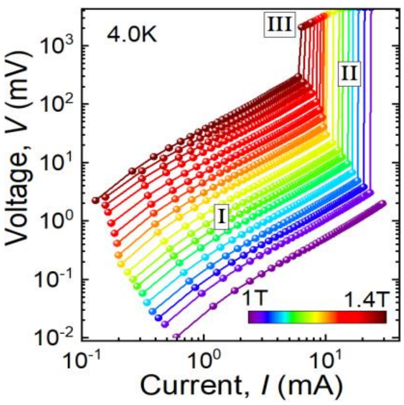

Fig.1 : Current-voltage curves at 4K and at magnetic fields as indicated in the scale bar for the laser cut MoSi film. The three different regimes are: (I) flux-flow regime, (II) instability and (III) normal state regime.

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E-mail: barbora.budinska©univie.ac.at

VP6

Reduction of the relativistic and non-relativistic GL models to a 2D curved surface

Igor BOGUSH[1,2], Vladimir FOMIN[2,3]

[1]*Theoretical Physics, Faculty of Physics, Lomonosov Moscow State University, GSP-1, 1-2 Leninskiy, Gory, 119991 Moscow, Russia*
[2]*Moldova State University, Chisinau MD-2009, Republic of Moldova*
[3]*Institute for Integrative Nanosciences, Leibniz Institute for Solid State and Material Research Helmholtzstraße 20, 01069 Dresden, Germany*

Superconductor nanoarchitectures, including self-rolled films, are highly promising for advancements in nano- and meso-scale devices for magnetic sensors, superconductor qubits and spintronics devices, single-photon detectors etc. It is a challenging technical problem to create a magnetic field with an arbitrary profile applied to a flat film. To get around this problem, one gives a complex shape to these films, in particular, just bends a flat film into a curvature-free surface. Here, we consider a theoretical model based on the time-dependent Ginzburg-Landau (GL) equation. As the surface of the film is arbitrary, we apply differential geometry, which is widely used in General Relativity, to GL equations in curved space. Effectively, a three-dimensional (3+1) GL model applied for two-dimensional ultrathin films embedded into a three-dimensional flat space with a homogeneous external magnetic field can be reduced to a two-dimensional GL model with a magnetic field normal to its surface as a scalar field. This opens the way to manipulate the effective normal component of the magnetic field, manage the superconducting properties of films and control the geometric regions with normal conductivity or superconducting state. We perform numerical calculations for different geometries using graphic processors. We discuss how the occurrence and behaviour of topological defects, such as vortices and phase slips [1], is governed by the curved film geometry for both type I and type II superconductors. Particularly, an analytically integrable model with the critical GL parameter is considered, which obeys the first-order Bogomol'nyi equations closely related to string theory and supersymmetry [2]. The present work has been partly supported by the DFG project #FO 956/6-1 and by the COST Action CA16218 (NANOCOHYBRI) of the European Cooperation in Science and Technology.

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E-Mail: bogush94©gmail.com

LM

Layered materials and interfacial superconductivity

LM1

Anisotropic superconductivity in the spin-vortex antiferromagnetic superconductor $CaK(Fe_{0.95}Ni_{0.05})_4As_4$

Beilun WU

Laboratorio de Bajas Temperaturas y Altos Campos Magnéticos, Departamento de Física de la Materia Condensada, Instituto Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid

$CaKFe_4As_4$ is a newly discovered iron pnictide superconductor which shows optimal critical temperature T_C of 38 K at the stoichiometric compound. Electron doping with Ni or Co atoms induces a decrease in T_C and the onset of a particular hedgehog antiferromagnetic order, without sign of structural instability or nematicity. The influence of this new form of magnetic order on the superconducting state has been till now poorly investigated. Here, we present quasiparticle interference study on $CaK(Fe_{0.95}Ni_{0.05})_4As_4$ using scanning tunneling microscope at dilution fridge temperature[1]. Unlike in the undoped system[2], we reveal in the Ni doped system a four-fold highly anisotropic superconducting state, in association with the hedgehog antiferromagnetic order present in this system. Finally, I will discuss recent work made in other pnictide superconductors, particularly FeSe.

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E-mail: beilun.wu©uam.es

LM2

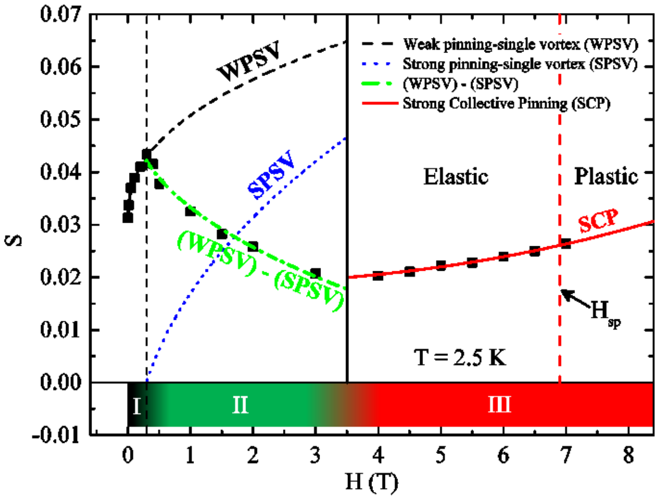
A precursor mechanism triggering the second magnetization peak phenomenon in superconducting materials

Armando GALLUZZI[1,2], Massimiliano POLICHETTI[1,2], Krastyo BUCHKOV[3,4], Vihren TOMOV[3], Elena NAZAROVA[3], Antonio LEO[1,2], Gaia GRIMALDI[2], Sandro PACE[1,2]

[1]*Department of Physics "E.R. Caianiello", University of Salerno, via Giovanni Paolo II, 132, Fisciano (SALERNO), I-84084, Italy*
[2]*CNR-SPIN Salerno, via Giovanni Paolo II, 132, Fisciano (SALERNO), I-84084, Italy*
[3]*Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee, 1784 Sofia, Bulgaria*
[4]*Institute of Optical Materials and Technologies, Bulgarian Academy of Sciences, Acad. G. Bonchev Str. Bl. 109, Sofia, 1113, Bulgaria*

The correlation in type-II superconductors between the creep rate S and the Second Magnetization Peak (SMP) phenomenon which produces an increase in J_c, as a function of the field (H), has been investigated at different temperatures by starting from the minimum in S(H) and the onset of the SMP phenomenon detected on a $FeSe_{0.5}Te_{0.5}$ sample. Then the analysis has been extended by considering the entire S(H) curves and comparing our results with those of many other superconducting materials reported in literature. In this way, we find evidence that the flux dynamic mechanisms behind the appearance of the SMP phenomenon in J_c(H) are activated at fields well below those where the critical current starts effectively to increase. Moreover, the found universal relation between the minimum in the S(H) and the SMP phenomenon in J_c(H) shows that both can be attributed to a sequential crossover between a less effective pinning (losing its effectiveness at low fields) to a more effective pinning (still acting at high fields), regardless of the type-II superconductor taken into consideration.

E-mail:agalluzzi©unisa.it



S as a function of H at T = 2.5 K. The black dashed line is the fit of the first S(H) increase with equation (1). The blue dotted line is the strong pinning single vortex behavior speculated for the vortices that enter in the twin boundaries using equation (1). The green dashed-dotted line is the fit of the decreasing S(H) data with the equation described by the subtraction of the black and blue line. The red solid line is the fit of the second S(H) increase with equation (1). In the bottom of the figure, the field intervals relative to the three S(H) portions are identified with different colours. Finally, the black vertical solid line separates the single vortex state from the collective pinning state while the red vertical dashed line, individuated by the H_{sp} value, separates the elastic regime from the plastic regime in the framework of the collective pinning theory.

LM3

Extreme charge transfer in the misfit layered compound $(LaSe)_{1.14}(NbSe_2)$

Ondrej ŠOFRANKO

Slovak Academy of Sciencies, Institute of Experimental Physics, Park Angelinum 9, 04001 Košice, Slovakia

Misfit layered materials where quasi-quadratic atomic layer(s) are alternating with quasi hexagonal one(s) while not perfectly crystallographically matching host plethora of interesting properties. Superconductivity can take various forms; e. g. 3D – 2D superconducting transition can be achieved by inserting more SnSe layers between $NbSe_2$ layers and thus $NbSe_2$ superconducting layers become decoupled [1]. Large anisotropy of B_{c2} is observed in some cases and in-plane B_{c2} can be significantly higher than upper Pauli limiting magnetic field [2,3]. Moreover, extremely high doping levels can be achieved via charge transfer between layers and this might lead to rigid band shift not achievable by other means. In the case of $(LaSe)_{1.14}(NbSe_2)_2$ this leads to a change in charge density wave order parameter and superconducting critical temperature in comparison with pure $NbSe_2$ [4]. Also in-plane critical magnetic field is strongly enhanced having a 2D character. In this work we will present observation of even larger doping from LaSe to $NbSe_2$ in the $(LaSe)_{1.14}(NbSe_2)$ compound. This can lead to $NbSe_2$ becoming insulating and LaSe layer becoming superconducting.

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E-Mail: sofranko©saske.sk

LM4

Probing unconventional phenomena in $LaAlO_3$-$SrTiO_3$ and $La_{2-x}Sr_xCuO_4$

Roberta CARUSO[1], Maria D'ANTUONO[2], Benoit JOUAULT[3], Marco SALLUZZO[4], Anthony BOLLINGER[1], Daniela STORNAIUOLO[2,4], Ivan BOZOVIC[1,5]

[1] *Brookhaven National Laboratory, Upton NY 11973-5000, USA*
[2] *Università di Napoli Federico II, Naples 80126, Italy*
[3] *Laboratoire Charles Coulomb, Université de Montpellier, Montpellier 34095, France*
[4] *CNR-SPIN, Complesso Monte Sant'Angelo, Naples 80126, Italy*
[5] *Applied Physics Department, Yale University, New Haven, CT 06511, USA*

Transition oxide metals have attracted great attention in the last few years, and in particular $LaAlO_3$-$SrTiO_3$ (LAO-STO) interfaces are widely studied to understand the properties of low dimensional systems. The transport properties of the two-dimensional electron gas (2DEG) at LAO-STO interface including superconductivity and Rashba spin-orbit coupling, are largely tuned using electrical field effect. The recently implemented delta-doping of LAO-STO with $EuTiO_3$ (ETO) has further expanded the complexity of the phase diagram of oxide interfaces, including ferromagnetism. The research group at University of Naples has recently demonstrated how a combination of gate voltage and visible light can be used to explore a wide portion of the phase diagram of LAO-ETO-STO. Here the results and the perspectives of these experiments will be discussed, as well as further studies to be conducted to investigate the nature of the superconducting state in non-conventional systems. In particular, I will discuss the similarities between LAO-STO interfaces and copper oxide superconductors such as $La_{2-x}Sr_xCuO_4$ (LSCO), the recent findings of the Molecular Beam Epitaxy group at Brookhaven National Laboratory on electron nematicity in LSCO, and the work I am carrying on in this framework.

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E-mail: rcaruso©bnl.gov

PD

Superconducting single-photon detectors

PD1

Superconducting single-photon detectors–twenty years

Roman SOBOLEWSKI

University of Rochester, Departments of Electrical and Computer Engineering and Physics and Astronomy, Materials Science Program, and Laboratory for Laser Energetics
Rochester, New York 14627-0231, USA

Since their invention in 2001 [1], superconducting single-photon detectors (SSPDs) have become the unquestioned leader in high performance single-photon detection, counting, and imaging. The detection mechanism of SSPDs is based on photon-induced hotspot formation and, subsequent, generation of a voltage transient across, typically, a superconducting nanostripe meander. The SSPDs operate at cryogenic temperatures, in the 2-5 K range, and are currently the best-performance, single-photon counters, significantly outperforming in the telecommunication wavelength *any* competing commercial or research devices, including semiconducting avalanche photodiodes and other superconducting photon detectors. This talk presents a historical overview of the physics and operation of SSPDs, as well as their practical implementations in areas ranging from quantum communication and cryptography, through medical optical tomography and LIDAR, to noninvasive testing of VLSI integrated circuits. We also comment on possible future directions of the superconducting single-photon detector technology.

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E-mail: roman.sobolewski©rochester.edu

PD2

Vortex-assisted photon counts by a superconducting single-photon detector

Mariia SIDOROVA[1,2], Alexey D. SEMENOV[1], Denis Y. VODOLAZOV[3,4]

[1]DLR, Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin
[2]Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin
[3]Institute for Physics of microstructures, Russian Academy of Science, 603950 Nizhny Novgorod, GSP-105, Russia
[4]Physics Department, Moscow State University of Education, 29 Malaya Pirogovskaya St, Moscow, 119435, Russia

Sub-micron-wide strips from disordered superconducting materials have become key elements of superconducting single-photon detectors (SSPDs or SNSPDs). The basic idea of single-photon detection by such a strip carrying a close-to-critical current is relatively simple and originates from the local destruction of superconductivity by an absorbed photon. If the photon energy is sufficient, it heats up electrons and phonons in a large area across the entire strip forming a resistive "hot belt" that is further registered. Otherwise, it locally creates a small "hot spot", which is subject to diffusion and phonon cooling rather than detection. It turned out that the detection event in this latter case is facilitated by magnetic vortices that nucleate at the photon absorption site and cross the strip forming a resistive belt. The assistance of vortices adds to the delay time elapsed between the photon absorption and the emergence of the resistive belt and manifests itself in a non-Gaussian statistical distribution of these delays [1]. While the width of the distribution determines an intrinsic temporal resolution of SSPDs, its shape reveals microscopic details of the detection mechanism.

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E-mail: mariia.sidorova©dlr.de

PD3

Research perspectives on applications of NbRe and NbReN thin films in the field of superconducting nanowire single photon detectors

Carla CIRILLO[1], Jin CHANG[2], Niels LOS[3], Sander DORENBOS[3], Iman Esmaeil ZADEH[2], Veronica GRANATA[4], Alfredo SPURI[5], Angelo DI BERNARDO[5], Carmine ATTANASIO[4]

[1]*CNR-SPIN, c/o Università degli Studi di Salerno, I-84084 Fisciano (Sa), Italy*
[2]*Optics Research Group, ImPhys Department, Faculty of Applied Sciences, TUDelft, Delft 2628 CJ, The Netherlands*
[3]*Single Quantum B.V., Delft 2628 CJ, The Netherlands*
[4]*Dipartimento di Fisica "E.R. Caianiello", Università degli Studi di Salerno, I-84084 Fisciano (Sa), Italy* [5]*Universität Konstanz, Fachbereich Physik, Universitätsstraße 10, 78457 Konstanz, Germany*

In the constant research for novel superconducting materials which could help in breaking the limits of Superconducting Nanowire Single Photon Detectors (SNSPDs) current devices, the performances of the first NbRe-based detector were recently tested [1,2]. The first results on devices, structured as meanders of wires 50-100 nm wide, demonstrate that NbRe is competitive with currently employed superconductors with a saturated internal efficiency up to λ = 1301 nm, recovery times between 8 and 19 ns and jitter of about 35 ps at T=2.8 K [2]. Inspired by these results, a new superconductor, NbReN, has been successfully synthesized with the aim of improving some of the main figures of merit of the devices made on NbRe [3]. NbReN thin films, deposited by reactive UHV dc-sputtering, present well-established superconducting ordering, as evaluated by electrical transport measurements. From the analysis of the estimated microscopic parameters the potential of NbReN thin films for the realization of high-performing SNSPDs is evaluated.

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E-mail: carla.cirillo©spin.cnr.it

ET

Special evening talk

ET1

Physicist in Gastronomy Universe

Andrey VARLAMOV

CNR-SPIN, c/o Università degli Studi di Salerno, I-84084 Fisciano (Sa), Italy

How heat propagates in media, what is the difference between pizza baking in the traditional wood oven and in the electric one, why tastes of the boiled meet and the grilled one are so different, how scientifically calculate cooking time of the soft-boiled duck egg and spaghetti, why cin-cin with crystal glasses filled by sparkling wine is not accompanied by nice canorous sound, why vodka usually contains around of 40 % of alcohol, why professional barista varies the degree of coffee beans grounding depending on weather, and many other questions of surrounding gastronomic universe are discussed in this lecture.

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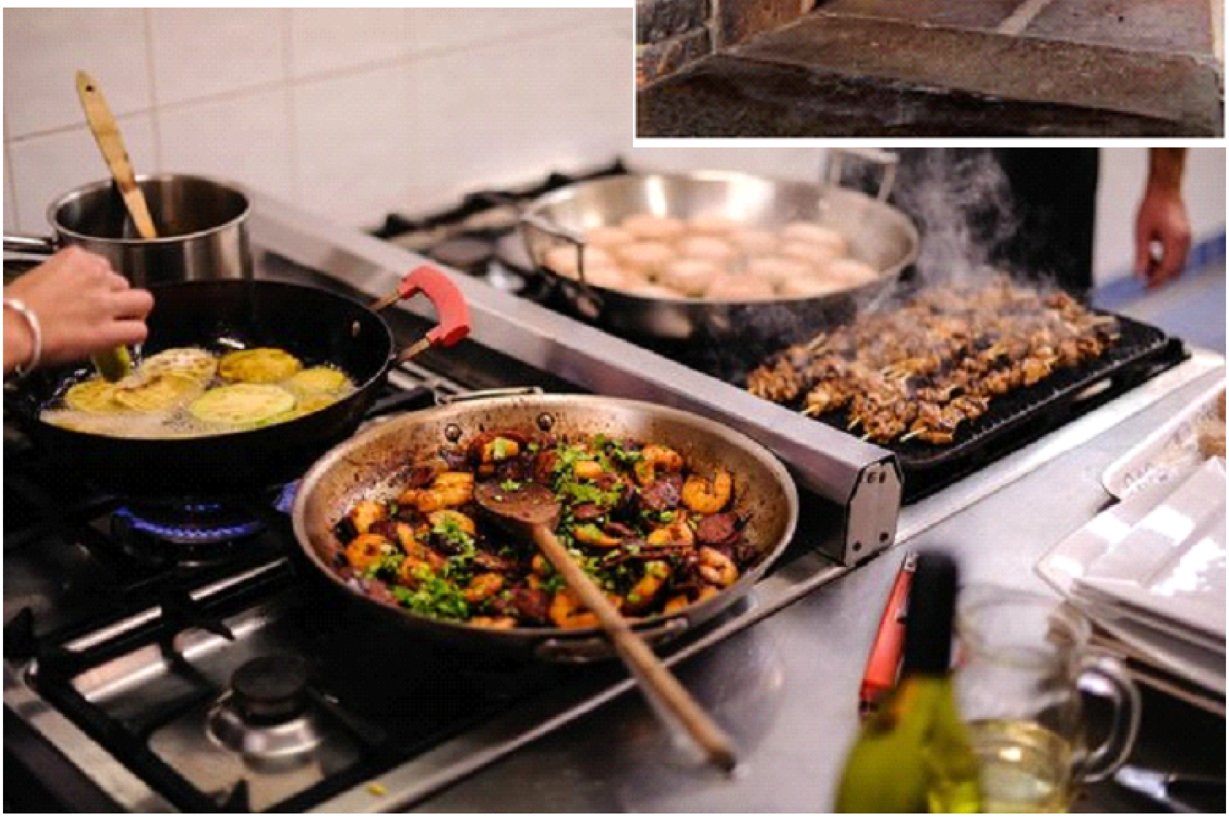
E-Mail: varlamov©ing.uniroma2.it



MW

Superconductors at microwave frequencies

MW1

Microwave vortex motion in cuprates, iron-based, and metallic superconductors in high magnetic fields

Andrea ALIMENTI[1], Nicola POMPEO[1], Kostiantyn TOROKHTII[1], Enrico SILVA[1]

[1] Università Roma Tre, Engineering Department, Via Vito Volterra, 62 – 00146 Roma, Italy

New perspective high-frequency applications of superconductors (SCs) in the mixed state for particle physics experiments, such as the coating of beam screens in large particle accelerators, or hybrid normal/superconductive cavities for galactic axions detection, are emerging in the very last years. For this reason, the interest in accurate surface impedance measurements of SCs in high magnetic fields, and the study of the vortex motion characteristics in these conditions, are suddenly revamping. In this talk, the microwave vortex motion resistivity measured at 15-27 GHz in fields up to 12 T on $REBa_2Cu_3O_{7-x}$ samples (RE = Y, Gd), grown with different techniques and with or without the inclusion of artificial nanosize pinning centers, are shown and discussed. The temperature and field dependences of the vortex motion parameters measured in these samples, such as the flux-flow resistivity ρ_{ff}, the pinning characteristic frequency f_c, the elastic pinning constant k_p and the thermal creep factor χ, allow to trace an interesting new paradigm to be followed in the nano-engineerization of SCs for high frequency applications in high magnetic fields. In fact, for these applications, materials with potentially different characteristics from those that have been optimized for dc or non-magnetic high frequency applications are required. The vortex motion parameters obtained on $REBa_2Cu_3O_{7-x}$ samples are finally compared to those measured on Nb_3Sn and $FeSe_{0.5}Te_{0.5}$ in similar conditions, to highlight fundamental differences in the high frequency pinning regime in various materials and to delimit the applicability areas and the possible room for improvements of the different SCs.

We acknowledge stimulating discussions and samples from V. Braccini (CNR-SPIN, Genova), G. Celentano, A Augieri, F. Rizzo, V. Pinto (ENEA, Frascati), M.Putti (University Genova), T. Spina (FNAL) and R. Flükiger (Geneva University). Work partially supported by EUROFusion (g.a. 633053) and PRIN "*HIBiSCUS*".

E-mail: andrea.alimenti©uniroma3.it

MW2

Correlation between the microstructure and high frequency properties of thick REBCO coated conductors

Artur ROMANOV[1], Patrick KRKOTIC[1,2,], Guilherme TELLES[1], Joan O'CALLAGHAN[3], Montse PONT[2], Francis PEREZ[2], Xavier GRANADOS[1], Sergio CALATRONI[4], Teresa PUIG[1], Joffre GUTIERREZ[1]

[1] *Institut de Ciencia de Materials de Barcelona, C.S.I.C., Campus U.A. Barcelona, E-08193 Bellaterra, Catalonia, Spain*
[2] *ALBA Synchrotron-CELLS, Carrer de la Llum 2-26, E-08290 Cerdanyola del Valles (Barcelona), Catalonia, Spain*
[3] *Universitat Politecnica de Catalunya, CommSensLab. c/Jordi Girona 1, E-08034 Barcelona, Catalonia, Spain*
[4] *European Organization for Nuclear Research (CERN), 1211 Geneva 23, Switzerland*

A thorough microwave response study of high temperature superconductors has become integral in the design decisions for CERN's future research infrastructure because they are considered as an alternative beam screen coating [1]. Here, we present the surface resistance R_s of various $REBa_2Cu_3O_{7-x}$ (RE = rare earth) coated conductors as a function of magnetic field and in a broad temperature range. The measurement device is a Hakki-Coleman type dielectric resonator [2] with resonant frequency $f \approx 8$ GHz. Analysis of the high frequency dissipation is supported by DC transport characterization and reveals vortex dynamics in thick REBCO films. The determined microscopic vortex parameters span over a wide range of magnitudes and reflect the relevance of the superconducting layer's microstructure. We demonstrate that REBCO's depinning frequency f_0 surpasses f, which confirms the operation in a high performing, low dissipation pinning regime at measurement conditions. Extrapolation of surface resistance to FCC-hh conditions point towards a significant outperformance of copper, the reference beam screen coating, by coated conductors [3]. The surface resistance margins gained by the usage of coated condutors can open up ways for a more efficient frontier circular collider.

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E-mail: aromanov©icmab.es

MW3

Interplay between ferromagnetism and superconductivity in $EuFe_2(As,P)_2$

Daniele TORSELLO[1], Laura GOZZELINO[1], Roberto GERBALDO[1], Francesco LAVIANO[1], Vasily STOLYAROV[2], Dimitry RODITCHEV[3], Tsuyoshi TAMEGAI[4], Guang-Han CAO[5], Gianluca GHIGO[1]

[1]Politecnico di Torino, DiSAT, Corso Duca degli Abruzzi 24, Torino, and INFN, Sez. Torino, Italy
[2]Moscow Institute of Physics and Technology (State University), Dolgoprudny, Moscow , Russia
[3]Laboratoire de Physique et d'Etude des Materiaux, ESPCI, PSL, Paris, France
[4]Department of Applied Physics, The University of Tokyo, Japan
[5]Department of Physics, Zhejiang University, Hangzhou, People's Republic of China

The interplay between superconductivity and magnetism is currently one of the most intriguing topics in condensed matter physics. In this respect, $EuFe_2As_2$-based systems are particularly interesting due to the proximity of superconducting and ferromagnetic transition temperatures, where the latter is connected to the Eu^{2+} magnetic subsystem. This coexistence causes the spontaneous production of vortex-antivortex pairs at low temperature, organized in intricate patterns and possibly showing complex dynamics.
We report on a microwave analysis of the interplay between magnetism and superconductivity in single crystals of $EuFe_2(As_{1-x}P_x)_2$, accomplished by means of a coplanar waveguide resonator (CPWR) technique, through a cavity perturbation approach [1]. The bulk complex magnetic susceptibility $\chi_m = \chi'_m + \mathrm{I}\ \chi''_m$ – extracted from the high-frequency characterization – is demonstrated to be highly sensitive to the magnetic structure and dynamics, revealing two distinct magnetic transitions below the superconducting critical temperature [2]. A comparison with CPWR measurements on the non-magnetic $BaFe_2(As_{1-x}P_x)_2$ [3] and with the static magnetic structure studied by µSR, help in identifying these transitions and in understanding the underlying mechanisms. In addition, a comparison with magnetic force microscopy maps of $EuFe_2(As_{1-x}P_x)_2$ allows to ascribe the χ_m peak observed at about 17 K to the transition from the ferromagnetic domain Meissner phase to the domain vortex-antivortex state, with the subsequent evolution of the domain structure at lower temperatures. The second χ_m peak observed at 11 K reflects a specific high-frequency feature, connected to vortex/antivortex dynamics. The two peaks merge and vanish upon application of an in-plane magnetic field, which is compatible with the presence of a quantum critical point below 1 T. Moreover, we studied the relative strength of the two collective phenomena by analyzing the dependence of their onset temperatures on different perturbations: magnetic fields and structural disorder. Results suggest that superconductivity and magnetism in this material are two competing orders: as the former is suppressed by irradiation or by excess P doping, the latter reinforces and manifests itself at higher temperatures [4].

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E-mail:daniele.torsello©polito.it

MW4

Whispering gallery resonators for microwave characterization of superconductors

Sergey BUNYAEV

Institute of Physics for Advanced Materials, Nanotechnology and Photonics (IFIMUP), Universidade do Porto, Rua Campo Alegre 687, Porto, 4169-007 ,Portugal

Whispering gallery mode dielectric resonators (WGR's) are of great importance for applications from microwave to optic range because they have the highest Q-factors. At microwaves, they are used in highly selective filters, power combiners/dividers, low phase-noise oscillators and sensors for material characterization.

Special focus will be given to the advantages of the developed WGR based technique for impedance measurements of high-temperature superconductors (HTS). Results of a comprehensive study and comparison of some types of microwave WGR's designed for these purposes will be presented. The resonators are made of single-crystal sapphire in the shapes of a cylindrical disc, radially-slotted disc, truncated cone and hemisphere. The features of resonance frequency spectra, electromagnetic field distribution and interaction between microwave field and a sample under test will be considered.

Additionally, the properties of a proposed K-band microstrip WGR will be discussed. This resonator demonstrates Q-factor up to 67 000 and is suitable for integration into compact circuits. Finally, the optomagnonic whispering gallery microresonators, which can be used for frequency conversion and interaction between magnons and photons, will be discussed.

E-Mail: bunyayev©fc.up.pt

MW5

Vortex dynamics in High Temperature Superconducting nano-meanders made by ion irradiation

Paul AMARI[1,2], Sergei KOZLOV[1,2], Zoé VELLUIRE[1,2], Nicolas BERGEAL[1,2], Jerome LESUEUR[1,2], **Cheryl FEUILLET-PALMA**[1,2]

[1]Laboratoire de Physique et d'Etude des Matériaux, ESPCI Paris, Université PSL, CNRS, 10 Rue Vauquelin -75005 Paris, France
[2]Université Pierre and Marie-Curie, Sorbonne-Université - 75005 Paris, France

Superconducting nanowire single photon detectors (SNSPD) have shown unrivalled performances from telecommunication wavelength up to 10 µm, including high quantum efficiency, high operating frequency, low dark count rate and low jitter [1]. Thus, SNSPD are particularly suitable for quantum optics demands and deep space to earth communications applications, among others.
Being fabricated with low temperature superconducting (LTS) thin films (Nb or NbN2), the main drawback which limits their technological applications, is their operating temperature well below 4K, which requires complex and energy consuming. It is therefore interesting to develop such detectors using high temperature superconducting (HTS) materials. This remains very challenging since superconducting properties of HTS thin films are very sensitive to nano-patterning process, which often generate oxygen out-diffusion and defects. On the physics side, HTS compounds have specificities such as a d-wave order-parameter or a fast electron-phonon scattering time, which may change the intrinsic photon detection scheme as compare to the LTS ones.
We present our last results on vortex dynamics probed in short and thin CeO_2 capped $YBa_2Cu_3O_{7-x}$ nanowires made by e-beam lithography and high-energy ion implantation[4-5]. Our nanowires whose dimensions are 500 nm in length, 100 nm in width and 12 to 30 nm in thickness, are stable in time, robust under patterning process and temperature cycling. They show high current densities, higher than 30 MA/cm2, with hysteretic I-V characteristics, and voltage switches in the volt range at 5K, which are, to our knowledge, the highest one reported to date in such small section nanowire.
We studied the dissipating branch of the hysteretic I-Vcharacteristic, as well as the stochastic behavior of the voltage switches with temperature, magnetic field, and under RF radiation. We describe the dissipating branch of I-V curves in the framework of thermally activated vortices motion [6] (TAVM) including vortex interaction in the 10 K to 70 K temperature range. These interacting vortices are responsible the large voltage switches in our short nanowires, which is a signature of the formation and the development of a self-stabilized hotspot key ingredient for a SNSPD. The study of the IV curves under magnetic field shows that a vortex instability [7,8] triggers the voltage switch. The switching current distribution widens and becomes multimodal as temperature is lowered. This behavior is interpreted as an opening of several vortex channels. This interpretation is supported by the observation, in the same temperature range, of fractional integer Shapiro steps in the I-V curves under microwave radiation (Figure 1) coming from the coherent motion of synchronized vortices in parallel rows.

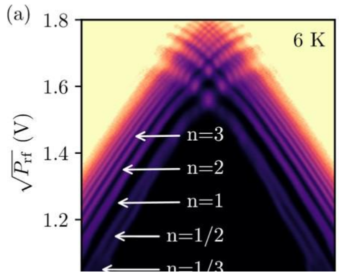

Figure 1 : Heatmaps of the dynamic resistance as a function of bias current and radiofrequency power at 18.32 GHz for a 200 nm wide ion irradiated YBCO nanowire.

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E-Mail: cheryl.palma©espci.fr

MW6

Higgs modes in proximized superconducting systems

Vasilii VADIMOV[1], Ivan KHAYMOVICH[2], Alexander MEL'NIKOV[3,4]

[1] QCD Labs, QTF Centre of Excellence, Department of Applied Physics,Aalto University, P.O. Box 13500,FI-00076 Aalto, Espoo, Finland
[2] Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany
[3] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia
[4] Sirius University of Science and Technology, 1 Olympic Avenue, 354340 Sochi, Russia

The proximity effect in hybrid superconducting–normal-metal structures is shown to affect strongly the coherent oscillations of the superconducting order parameter Δ known as the Higgs modes [1]. The standard Higgs mode at frequency 2Δ is damped exponentially by the quasiparticle leakage from the primary superconductor. Two new Higgs modes with the frequencies depending on both the primary and induced gaps in the hybrid structure are shown to appear due to the coherent electron transfer between the superconductor and the normal metal. Altogether, these three modes determine the long-time asymptotic behavior of the superconducting order parameter disturbed either by the electromagnetic pulse or the quench of the system parameters and thus are of crucial importance for the dynamical properties and restrictions on the operating frequencies for superconducting devices based on the proximity effect used, e.g., in quantum computing, in particular, with topological low-energy excitations.

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E-mail: vasilii.1.vadimov©aalto.fi

SF

Proximity effects and spin transport in S/F hybrids

SF1

Temperature-dependent spin-transport and current-induced torques in superconductor/ferromagnet heterostructures

Matthias ALTHAMMER[1,2], Manuel MÜLLER[1,2], Lukas LIENSBERGER[1,2], Luis FLACKE[1,2], Hans HUEBL[1,2,3], Akashdeep KAMRA[4], Wolfgang BELZIG[5], Mathias WEILER[1,2,6], Rudolf GROSS [1,2,3]

[1] *Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany*
[2] *Physik-Department, Technische Universität München, Garching, Germany*
[3] *Munich Center for Quantum Science and Technology (MCQST), München, Germany*
[4] *Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway*
[5] *Fachbereich Physik, Universität Konstanz, Konstanz, Germany*
[6] *Fachbereich Physik und Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany*

Proximity effects at superconductor(SC)/ferromagnet(FM) interfaces provide novel functionality in the field of superconducting spintronics. We investigate the spin current transport in NbN/Permalloy (Py) heterostructures with a Pt spin sink layer. To this end, we excite ferromagnetic resonance in the Py-layer via the microwave driving field of a coplanar waveguide (CPW) at different microwave frequencies. A phase sensitive detection of the microwave transmission signal is used to quantitatively extract the inductive coupling strength between sample and CPW as a function of temperature [1]. This approach enables the analysis of ac charge currents excited by the magnetization precession in SC/FM hybrids [2], like for example the spin pumping induced charge currents via the inverse spin Hall effect. Below the superconducting transition temperature T_c, we observe a blocking effect of pure spin current transport in the NbN layer. In addition, we show that this method enables the detection of the quasiparticle-mediated inverse spin Hall effect within a blanket thin film heterostructure. Moreover, below Tc we find a large field-like current-induced torque, which is not related to proximity effects. Last, but not least, we compare these results to our new experiments using a superconducting TaN layer [3]. Our findings reveal symmetry and strength of spin-to-charge current conversion in SC/FM heterostructures and provide guidance for future superconducting spintronics devices [2,3].

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E-mail: matthias.althammer©wmi.badw.de

SF2

Proximity effects in epitaxial ferromagnet-superconductor hybrids: towards superconducting spintronics with spin-orbit interaction

César GONZÁLEZ-RUANO[1], Diego CASO[1], Lina G. JOHNSEN[2], Coriolan TIUSAN[3,4], Michel HEHN[4], Isidoro MARTÍNEZ[5], Jaroslav FABIAN[6], Igor ZUTIC[6,7], Niladri BANERJEE[8], Jacob LINDER[2], Farkhad G. ALIEV[1]

[1]Departamento Física de la Materia Condensada C-III, Instituto Nicolás Cabrera (INC) and Condensed Matter Physics Institute (IFIMAC), Universidad Autónoma de Madrid, Madrid 28049, Spain
[2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway
[3]Department of Physics and Chemistry, Center of Superconductivity Spintronics and Surface Science C4S, Technical University of Cluj-Napoca, Cluj-Napoca 400114, Romania
[4]Institut Jean Lamour, Nancy Universitè, 54506 Vandoeuvre-les-Nancy Cedex, France
[5]IMDEA Nanociencia, 28049 Madrid, Spain
[6]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany
[7]Department of Physics, University at Buffalo, State University of New York, Buffalo, New York 14260, USA
[8]Department of Physics, Loughborough University, Epinal Way, Loughborough LE11 3TU, United Kingdom

Generation and control over long-range triplet (LRT) Cooper pairs is the key milestone for applications in superconducting spintronics. It has been commonly expected that these proximity effects require complex ferromagnetic multilayers, noncollinear magnetization or half-metals. We have studied all-epitaxial V/MgO/Fe junctions with interfacial spin-orbit coupling (SOC) and symmetry-filtering in the MgO interface, experimentally demonstrating a thousand-fold increase in tunneling anisotropic magnetoresistance below the vanadium critical temperature, which supports LRT formation depending on the magnetic configuration of the Fe layer [1]. Moreover, we report the converse effect: the transformation of the in-plane and out-of-plane magnetocrystalline anisotropies of the Fe layer driven by the superconductivity of vanadium through the SOC-bearing MgO interface [2]. We attribute this to an additional contribution to the free energy of the ferromagnet arising from the controlled generation of triplet Cooper pairs, which depends on the relative angle between the exchange field of the ferromagnet and the spin-orbit field. Our findings, supported by theoretical and numerical modelling of the ferromagnet-superconductor interaction, open pathways to active control of magnetic anisotropy in superconducting spintronics.

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E-mail: cesar.gonzalez-ruano©uam.es

SF3

Electromagnetic proximity effect in superconductor/ferromagnet heterostructures

Sergey MIRONOV[1], Zhanna DEVIZOROVA[2], Alexander MEL'NIKOV[1], Alexander BUZDIN[3]

[1] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, Russia
[2] Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia
[3] University of Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France

The spread of Cooper pairs in a ferromagnet in proximity coupled superconductor-ferromagnet structures is shown to cause a strong inverse electromagnetic phenomenon, namely, the long-range transfer of the magnetic field from the ferromagnet (F) to the superconductor (S) [1]. Contrary to the previously investigated inverse proximity effect resulting from the spin polarization of a superconducting surface layer, the characteristic length of the above inverse electrodynamic effect is of the order of the London penetration depth, which usually is much larger than the superconducting coherence length. The corresponding spontaneous currents appear even in the absence of the stray field of the ferromagnet and are generated by the vector-potential of magnetization near the S/F interface, and they should be taken into account in the design of nanoscale S/F devices. The effect can be sufficiently enhanced in superconducting spin valve structures due to the long-range spin-triplet correlations arising in the presence of noncollinear textures of magnetic moment [2]. Our results suggest a natural explanation for the puzzling enhancement of the spontaneous magnetic fields induced by the noncollinear magnetic structures observed by the muon spin rotation techniques in a wide class of layered S/F systems. We also show that the electromagnetic proximity effect causes the shift of the Fraunhofer dependence of the critical current on the external magnetic field in the Josephson junction with one superconducting electrode covered by the ferromagnetic layer. This provides an alternative way to measure both the magnitude and the direction of the spontaneous magnetic field induced in the superconductor. Finally, we demonstrate the possibility of the long-ranged superconductivity control of the magnetic state in $F_1/S/F_2$ structures.

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E-mail: svmironov©ipmras.ru

DW

Direct-write superconductors and Josephson devices

DW1

Precise Helium Ion Beams for Nanoscale Fabrication

John NOTTE

Research and Development, Carl Zeiss, SMT, 1 Corporation Way, 01960 Peabody, Massachusetts, USA

The gas field ion source (GFIS), produces a high brightness beam of helium ions which can be focused to a sub-nanometer probe size and can be directed to a substrate with sub-nanometer precision. ALIS Corporation and Zeiss conceived of and marketed this technology as an alternative microscope technology, and has found great success in this regard. Beyond this, many imaginative scientists around the globe have recognized another valuable use for this technology: the nanometer scale modification of thin film materials. This includes the introduction of lattice defects, precision sputtering, and even implanted atoms. This talk will provide an overview of the NanoFab instrument, including the historical development, the underlying physics, and the performance metrics. The interesting physics of beam sample interaction will be described. Thereafter, application examples will be presented beginning with imaging and analysis. The remainder of the talk will provide a broad survey of nano-engineering results of different materials for specific device fabrication.

E-Mail: john.notte©zeiss.com

DW2

Direct-writing of advanced 3D nano-superconductors

Rosa CÓRDOBA[1], Dominique MAILLY[2], Alfonso IBARRA[3], Roman O. REZAEV[4], Ekaterina I. SMIRNOVA[4], Oliver G. SCHMIDT[4], Vladimir M. FOMIN[4], Uli ZEITLER[5], Isabel GUILLAMON[6], Hermann SUDEROW[6], José María DE TERESA[3,7]

[1] Institute of Molecular Science (ICMol), University of Valencia, E-46980 Paterna, Spain
[2] Centre de Nanosciences et de Nanotechnologies, CNRS-Université Paris Saclay, 91120 Palaiseau, France
[3] University of Zaragoza, INA, LMA, E-50009 Zaragoza, Spain
[4] Institute for Integrative Nanosciences, Leibniz IFW Dresden, D-01069 Dresden, Germany
[5] High Field Magnet Laboratory (HFML-EFML), Radboud University, Nijmegen, 6525 ED Nijmegen, The Netherlands
[6] Universidad Autónoma de Madrid, E-28049, Madrid, Spain
[7] Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-University of Zaragoza, Spain

Nowadays, superconductors are commonly utilized in several applications such as energy generators and storage due to their unique capability of transferring electricity without energy losses. In some applications, their nanoscale patterning enhances their performance and gives rise to new physical phenomena.

Innovative schemes have taken advantage of the third dimension (3D) for the development of advanced electronic components. Thus, 3D nano-superconductors could be implemented in the next generation of energy efficient electronic devices.

In this contribution, we introduce a direct-write nanolithography method to fabricate at-will advanced 3D nano-superconductors. This specific technique called focused ion beam induced deposition (FIBID) is based on chemical vapour deposition process assisted by a charged particle beam focused to a few nanometers. Particularly, we have prepared 3D superconducting WC hollow nanowires by decomposing tungsten hexacarbonyl molecules with a highly-focused He+ ion beam, with outer diameters down to 32 nm and inner ones down to 6 nm [1, 2]. They become superconducting at 7 K and show large critical magnetic field and critical current density. In addition, we have grown nanohelices with on-demand geometries, with dimensions down to 100 nm in diameter, and aspect ratio up to 65. Given its helical 3D geometry, fingerprints of vortex and phase-slip patterns are experimentally identified and supported by numerical simulations based on the time-dependent Ginzburg-Landau equation [3].

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E-mail: rosa.cordoba©uv.es

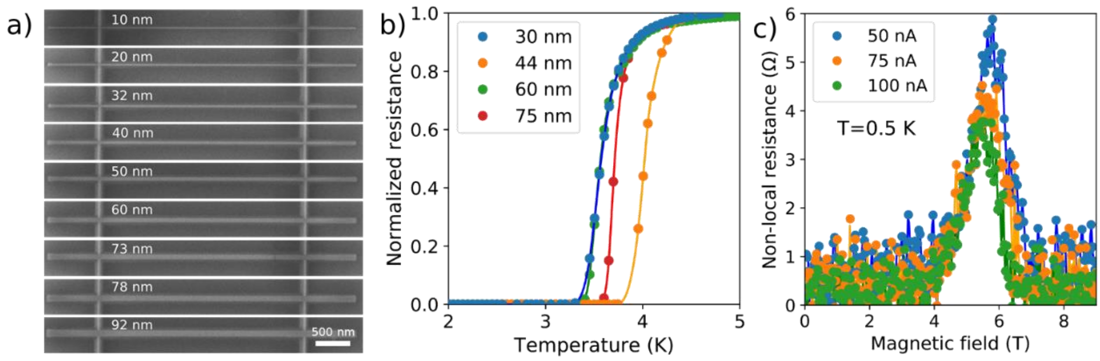
DW3

Superconducting properties of in-plane W-C nanowires grown by He^+ FIBID

Pablo ORÚS[1], Rosa CÓRDOBA[2], Gregor HLAWACEK[3], José María DE TERESA[1,4]

[1] *Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC-Universidad de Zaragoza, 50009 Zaragoza, Spain*
[3] *Instituto de Ciencia Molecular, Universitat de València, Paterna, 46980 Valencia, Spain*
[3] *Institute of Ion Beam Physics and Materials Research, Ion Beam Center, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany*
[4] *Laboratorio de Microscopías Avanzadas (LMA), Universidad de Zaragoza, 50018 Zaragoza, Spain*

Focused Ion Beam Induced Deposition (FIBID) is a nanopatterning technique that makes use of a focused beam of charged ions to decompose a gaseous precursor, yielding great versatility in the fabrication of functional nanostructures [1]. While the growth of W-C based in-plane nanostructures by Ga^+ FIBID of the $W(CO)_6$ precursor, which results in the growth of a type-II superconducting material, is widely known and studied [2-4], the usage of He^+ FIBID, which provides with enhanced patterning resolution and reduced substrate amorphization [5] for the same purpose remains relatively unexplored [6-8]. In this work, the fabrication and characterization of superconducting in-plane tungsten-carbon (W-C) nanostructures by He^+ FIBID of the $W(CO)_6$ precursor is reported. W-C nanowires with widths of 20 nm and above exhibit superconducting properties in the vicinity of 4 K, including the capability to sustain long-range non-local controlled superconducting vortex transfer [9,10], similarly to their Ga^+ FIBID-grown counterparts.



a) SEM image of the W-C superconducting nanowires grown by He^+ FIBID with varying widths. b) Temperature-induced superconducting transition. c) Non-local resistance caused by long-range vortex motion along the superconducting channel.

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E-mail: porus©unizar.es

DW4

Nb-C superconductor prepared by focused ion beam induced deposition

Fabrizio PORRATI[1], Felix JUNGWIRTH[1], Barbora BUDINSKA[2], Denis VODOLAZOV[3], Sven BARTH[1], Oleksandr DOBROVOLSKIY[2], Michael HUTH[1]

[1]*Goethe University, Institute of Physics, Max-von-Laue Str.1 60438 Frankfurt am Main, Germany*
[2]*University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna, Austria*
[3]*Russian Academy of Sciences, Institute for Physics of Microstructures, Academicheskaya Str. 7, Afonino, Nizhny Novgorod region 603087, Russia*

Nb-C prepared by focused ion beam induced deposition (FIBID) in a promising material for the fabrication of superconducting nanostructures like planar and 3D nanowires or 2D arrays of islands for studies in the field of, e.g., vortex dynamics, phase transitions, magnetic frustration and applications in, e.g., metrology, quantum information processing and nanoelectronics. In this talk, first, the fabrication method of Nb-C-FIBID nanostructures, their compositional and microstructural characterization, and the general magnetotransport properties are introduced [1]. Second, two examples are given to illustrate the potentiality of Nb-C-FIBID for the study of ultra-fast vortex dynamics in microstrips [2] and phase transitions in proximity-coupled Josephson junction arrays.

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E-mail: porrati©physik.uni-frankfurt.de

DW5

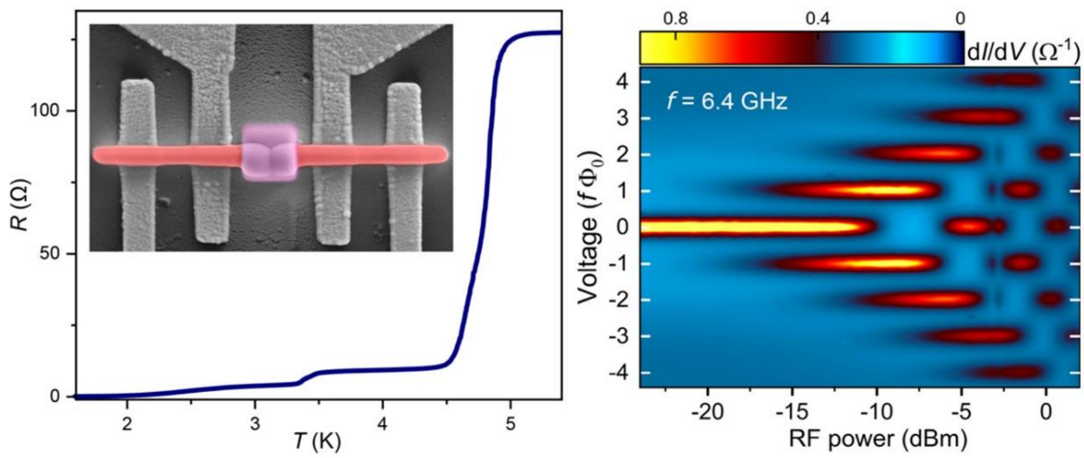
Direct-write printing of Josephson devices in an electron microscope

Kaveh LAHABI[1], Timothy Van den BERG[1], Julian LINEK[2], Dyon VAN DINTER[1], Remko FERMIN[1], Dieter KÖLLE [2], Reinhold KLEINER [2], Jan AARTS[1].

[1] Kamerlingh Onnes Laboratory, Leiden University, 2300 RA Leiden, the Netherlands
[2] Physikalisches Institut and Center for Quantum Science in LISA+, Universitat Tübingen, D-72076 Tübingen, Germany

Josephson devices are the essential building blocks of superconducting electronics. The fabrication of a Josephson device is usually a resource-intensive and multi-step procedure involving thin-film deposition and lithography. Here, we introduce a fully-additive direct-write approach based on electron beam-induced deposition (EBID), where a conventional scanning electron microscope can print complete Josephson devices in a matter of minutes.

In this talk, I will describe how we print functional proximity junctions and SQUIDs, made entirely from tungsten-carbide. The electrical conductivity of the tungsten-carbide is tuned by the scanning electron beam to produce both the superconducting and the normal-metal components of our proximity junctions. I will present the transport properties of our devices and offer an outlook for 3-dimensional printing of complex quantum circuits.



Left: False colored scanning electron microscope image of a W-C Josephson junction, fabricated using EBID. Right: Shapiro response of the junction as a function of voltage and external microwave power. The Shapiro steps appear as conductance peaks at quantized voltages.

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E-mail: lahabi©physics.leidenuniv.nl

DW6

Series arrays of planar long Josephson junctions for high-dynamic range magnetic flux detection

Jay LeFEBVRE[1], Shane CYBART[2]

[1] University of California Riverside, Department of Physics and Astronomy, 3047 Physics Building Riverside, CA 92521, USA
[2] University of California Riverside, Department of Electrical and Computer Engineering, Suite 343 Winston Chung Hall Riverside, CA 92521, USA

We recently demonstrated that series arrays of closely spaced, planar long Josephson junctions (JJs) are transducers of magnetic flux featuring high-dynamic range, wide-bandwidth and operable at cryogenic nitrogen temperatures [1]. Typical JJ-based magnetometers are superconducting quantum interference devices (SQUIDs) due to their high sensitivity (dV/dB) to magnetic flux. The dynamic range of SQUID magnetometers is limited by a magnetic flux response periodicity with the magnetic flux quantum (Φ_0) of the order 10 nT/Φ_0. This prevents unshielded operation without utilizing control electronics that limit bandwidth or alternative circuit configurations, such as SQUID arrays, that can complicate fabrication. In comparison, single JJs have much larger periodicities ~100 μT/Φ_0 and lower sensitivity. This sensitivity can be increased by chaining together in a series array a great number of JJs. These arrays of JJs are well-suited to fabrication in thins films of the high-critical temperature superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) via helium focused ion beam irradiation. Focused ion beam sources have recently been commercialized and are increasingly utilized for applications in nanotechnology. To achieve competitive magnetic flux sensitivities in our junction arrays, many JJs would have to be consistently fabricated with nanoscale resolution. For this application, we have developed a robust automated process for layout designs with feature sizes from sub-nanometer to millimeter scales, using Raith lithography software in a Zeiss Orion Plus helium ion microscope [2]. We will present efforts to optimize the JJ array's geometry and properties for magnetic flux sensing, with investigations from single junction behavior to demonstrations of large-scale series arrays of JJs. We will present a series array of long JJs fabricated in YBCO containing 2640 JJs with a critical current deviation of 30% exhibiting a sensitivity of 1.7 mV/μT and a linear response over a range of 28 μT at 40 K, resulting in a dynamic range of 125 dB.

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E-mail: Jlefe001©ucr.edu

JJ

Josephson junctions, SQUIDs and related phenomena

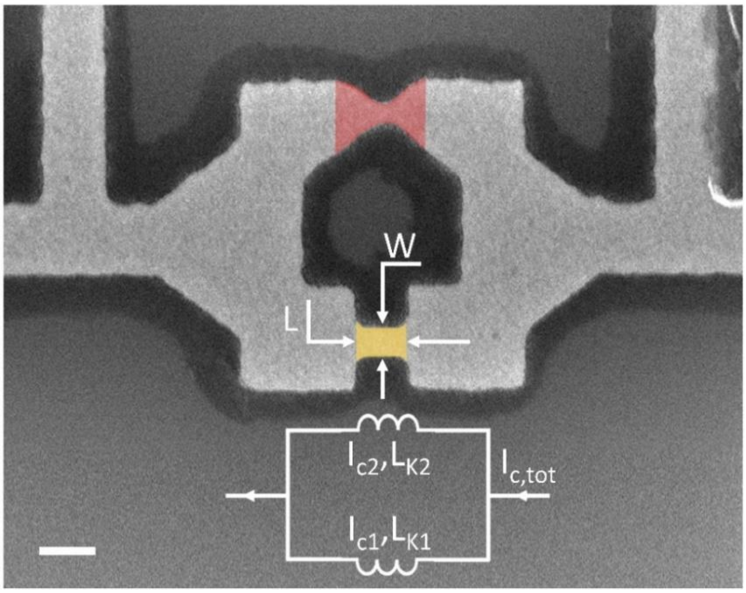
JJ1

The impact of kinetic inductance on the critical current oscillations of nanobridge SQUIDs

Heleen DAUSY[1], Lukas NULENS[1], Bart RAES[1], Margriet VAN BAEL[1], Joris Van de VONDEL[1]

[1]*KU Leuven, Department of Physics and Astronomy, Celestijnenlaan 200D, 3001 Leuven, Belgium*

We study the current phase relation (CΦR) of lithographically fabricated molybdenum germanium (MoGe) nanobridges, which is intimately linked to the nanobridge kinetic inductance. We do this by imbedding the nanobridges in a SQUID. We observe that for temperatures far below T_c, the CΦR is linear as long as the condensate is not weakened by the presence of supercurrent. We demonstrate lithographic control over the nanobridge kinetic inductance, which scales with the nanobridge aspect ratio. This allows to tune the SQUID $I_c(B)$ characteristic. The SQUID properties that can be controlled in this way include the SQUID sensitivity and the positions of the critical current maxima. These observations can be of use for the design and operation of future superconducting devices such as memory devices or flux qubits.



Scanning electron microscopy (SEM) image of a typical SQUID studied in this work. The top junction (indicated in red) is a Dayem bridge. The bottom junction is a nanobridge (shown in yellow) with width W and length L. The white scale bar represents 200 nm. The white circuit diagram presents an equivalent electronic circuit of the SQUID: L_{K1} and L_{K2} represent the inductances of each branch, while I_{c1} and I_{c2} represent the two critical currents of each branch. $I_{c,tot}$ is the total critical current of the SQUID.

E-mail: heleen.dausy©kuleuven.be

JJ2

Nb-based nanoscale superconducting quantum interference devices tuned by electroannealing

Simon COLLIENNE[1], Bart RAES[2], Wout KEIJERS[2], Julian LINEK[3], Dieter KOELLE[3], Reinhold KLEINER[3], Roman KRAMER[4], Joris Van de VONDEL[2], Alejandro SILHANEK[1]

[1]*Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, Sart Tilman, B-4000,Belgium*
[2]*Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D,B-3001 Leuven, Belgium*
[3]*Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, Universität Tübingen, Tübingen D-72076,Germany*
[4]*Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, Grenoble 38000, France*

In this work [1], we show that targeted and controlled modifications of the Josephson junction properties of a bridge-type Nb nanoSQUID can be achieved by an electroannealing process allowing to tune and tailor the response of a single device. The electroannealing consists in substantial Joule heating produced by large current densities followed by a rapid temperature quench. We report on a highly non-trivial evolution of the material properties when performing subsequent electroannealing steps. As the current density is increased, an initial stage characterized by a modest improvement of the superconducting critical temperature and normal-state conductivity of the bridges, is observed. This is followed by a rapid deterioration of the junction properties, i.e. decrease of critical temperature and conductivity. Strikingly, further electroannealing leads to a noteworthy recovery before irreversible damage is produced. Within the electroannealing regime where this remarkable resurrection of the superconducting properties are observed, the nanoSQUID can be operated in nonhysteretic mode in the whole temperature range and without compromising the critical temperature of the device. The proposed postprocessing is particularly appealing in view of its simplicity and robustness.

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E-mail: scollienne©uliege.be

JJ3

Improving the performance of YBCO nanobridges as weak links

Edoardo TRABALDO[1], Alexei KALABOUKHOV[1,2], Riccardo ARPAIA[1], Eric WAHLBERG[1], Floriana LOMBARDI[1], Thilo BAUCH

[1] *Chalmers University of Technology, Kemivägen 9, 41258 Göteborg, Sweden*
[2] *Microtechnology and Nanoscience, Chalmers University, SE-41296, Gothenburg, Sweden*

We present a summary of our work to improve the performance of YBCO nanobridges as weak links exploring two main directions: the nanoscale Grooved Dayem Bridge (GDB), and the development of an electromigration (EM) process for tuning the hole doping of nanobridges.

A GDB is a nanobridge with a groove etched across it, which acts as weak link. This is realized during one single lithography step and results in high-quality weak links with $I_C R_N$ products as high as 350 μV and differential resistances much larger than in bare Dayem bridges at T = 77 K. We have used YBCO GDBs as novel nanoscale building blocks in HTS SQUID magnetometers coupled to an in plane pickup loop, which have been characterized via transport and noise measurements at T=77 K. These devices exhibit large voltage modulations (ΔV = 30-50 μV), low values of white magnetic flux noise, 6 $\mu\varphi_0/Hz^{0.5}$, and low magnetic field noise, 63 $fT/Hz^{0.5}$, at T=77 K. GDB based SQUIDs combine the nanofabrication advantages and the device reproducibility, which are typical of Dayem bridges, with the performances, e.g. the magnetic sensitivity, of state-of-the-art SQUIDs based on grain boundary JJs.

At the same time, we developed an electromigration process to tune the superconducting properties of a nanobridge weak link by tuning its oxygen content. AC EM can be used to reduce the doping of a YBCO nanobridge, while DC EM can be conversely used to restore its oxygen content. Indeed, in a single nanowire we were able to change the hole doping in a wide parameter interval, with critical temperatures ranging from 90 K to 45 K. This technique is interesting for technological applications of YBCO weak links, where the tuning of the nanobridge properties, such as critical current and kinetic inductance, is required.

E-Mail: trabaldo©chalmers.se

JJ4

Superconducting quantum interference in van der Waals heterostructures

Liam FARRAR[1], Geetha BALAKRISHNAN[2], Simon BENDING[1], Sara DALE[1], Jieh Zhen LIM[1], Aimee NEVILL[1]

[1]University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom
[2]University of Warwick, CV4 7AL Coventry United Kingdom

Superconducting QUantum Interference Devices (SQUIDs) are commonly fabricated from either Al or Nb electrodes, with a native or artificial oxide barrier between them to create a weak link. However, such planar nano- and micro-SQUIDs generally require additional shunt resistors to suppress hysteresis in current-voltage curves, and device optimisation demands careful control of the critical currents and SQUID loop inductance. In this talk, I will discuss the formation of both Josephson junctions and SQUIDs using a dry transfer technique to stack and deterministically misalign flakes of the van der Waals bonded superconductor $NbSe_2$, opening up new control parameters for addressing these issues. The Josephson dynamics of the resulting twisted $NbSe_2$-$NbSe_2$ junctions are found to be sensitive to the misalignment angle of the crystallographic axes. A single lithographic process was then implemented to shape the Josephson junction into a SQUID geometry with typical loop areas of » 25 um^2 and weak links » 600 nm wide. In an applied magnetic field these devices display large stable current and voltage modulation depths of up to ΔIc » 75% and ΔV » 1.4 mV respectively.

E-Mail: lsf24©bath.ac.uk

JJ5

Microwave SQUID Multiplexing

Mathias WEGNER[1], Constantin SCHUSTER[1], Sebastian KEMPF[1]

[1] *Karlsruhe Institute of Technology, Institute of Micro- and Nanoelectronic Systems, Hertzstraße 16, Building 06.41, 76187 Karlsruhe, Germany*

Over the recent years microwave SQUID multiplexing has become a promising readout technique for very large arrays of low temperature detectors, e.g. transition edge sensors or metallic magnetic calorimeters. Each channel of such a multiplexer device consists of a non-hysteretic rf-SQUID which is used for detector readout and which is inductively coupled to a superconducting microwave resonator with unique resonance frequency. Due to the magnetic flux dependence of the SQUID inductance as well as the mutual interaction between the SQUID and the associated resonator, the signals of all detectors are transduced into a resonance frequency shift of the related resonators, and the subsequent change of amplitudes and phases of the resonator probing signals are simultaneously read out by a software defined radio system operating at room temperature.

In this contribution, a short overview of the state-of-the-art model of a microwave SQUID multiplexer will be presented. This model does not only allow to understand basic readout concepts on a theoretical basis, but also includes parasitic effects of non-ideal Josephson junctions, the consequences when using a flux transformer detector readout, or the multiplexer readout power dependence in general. Subsequently, typical chip designs which include different microwave resonator types and SQUID geometries, as well as one software defined radio system for the readout of metallic magnetic calorimeters will be presented. By using such a detector system, 15 metallic magnetic calorimeter pixels could be read out simultaneously, where the best achieved energy resolution was $\Delta E_{\mathrm{FWHM}} < 10$ eV. The contribution will conclude with a short overview of a recently developed hybrid Microwave SQUID multiplexer, which adds a second frequency-division readout concept to the device. This way, large arrays of low temperature detectors with low-bandwidth requirements, e.g. bolometers, can be read out by using only a fraction of readout resonators.

E-mail: mathias.wegner©kit.edu

JJ6

Effect of spin-triplet correlations on Josephson transport in atomically thin Josephson structures containing half-metals

Zhana DEVIZOROVA[1], Alexander BUZDIN[2], Sergey MIRONOV[3]

[1]Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia
[2]University of Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France
[3] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, Russia

In the recent experimental studies of spin-triplet S/F_L/S'/F_R/S device it was observed that the emergence of singlet superconductivity in the central S' layer leads to the decrease of the Josephson current [S. Komori, et al, Science Advances, 2021]. This situation is very different from one in spin-singlet S/S'/S structures, where the emergence of superconductivity in the S' layer increases the spin-singlet Josephson current. To explain this puzzling experiment we have calculated the Josephson current in atomically thin S/HM_L/S'/HM_R/S structure with spin-active S/$HM_{L,R}$ interfaces in the framework of microscopic Gor'kov formalism and tight-binding model. We managed to show that the singlet superconducting gap in the S' layer indeed suppresses the triplet Josephson current [S. Komori, et al, Science Advances, 2021] contrary to the case of singlet current in S/S'/S structure.

We also study the peculiarities of superconducting spin-triplet correlations in atomically thin S1/HM/S2 structures with spin-active S/HM interfaces. We use the combination of the microscopic Gor'kov formalism and tight-binding model allowing to obtain exact analytical results, which are valid beyond the quasiclassical approximation. In particular, we show that the spin-triplet Josephson critical current in S1/HM/S2 junction with two spin-active S/HM interfaces nonmonotonically depends on temperature. We also calculate the induced magnetic moment inside S2 layer in the S1/HM/S2 structure with spin-active S1/HM interface. Since this magnetic moment is not collinear to the spin quantization axis in HM and depends on the phase difference across the junction, one can expect the emergence of the second harmonic of the spin-triplet superconducting current in the structure. However, we show that it is not the case and the second harmonic does not appear. We suggest that some Fermi-liquid effects and/or multiband character of superconductivity should restore the second harmonics triplet current.

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E-mail: devizorovazhanna@gmail.com

LD

Low-dimensional and topological superconductors

LD1

Boosting superconductivity in 2D materials by beneficial defects

Jonas BEKAERT

University of Antwerp, Department of Physics, Groenenborgerlaan 171, B-2020 Antwerp, Belgium

The effect of disorder on superconductivity has been under much scrutiny for decades. While superconductivity is known to be robust against nonmagnetic impurities in bulk materials, in 2D materials the energy scale associated with scattering by defects can become comparable to the Fermi energy, possibly resulting in a decrease of the superconducting T_c or even a transition to an insulating state. Notwithstanding, based on advanced first-principles calculations I will demonstrate that impurities can profoundly alter the properties of a 2D superconductor beyond this simplified picture. This analysis entail the full effect of impurities on local electronic and vibrational properties, using density functional theory, combined with anisotropic Eliashberg calculations to characterize the superconducting state.

Several examples of realistic materials will be used to support these conclusions. As the first example, I will demonstrate that incorporation of oxygen into the crystal lattice of the TMD TaS_2 not only heals abundantly present sulfur vacancies, but also yields a strong enhancement of the electron-phonon coupling, and thus of the superconducting T_c. This *ab initio* prediction was experimentally confirmed by transport measurements on few-layer TaS_2, showing a marked increase in T_c as oxygen is incorporated into the crystal lattice upon sample aging [1]. Secondly, I will reveal functionalization of 2D materials by hydrogen adatoms as a new route to induce high-temperature superconductivity in 2D materials, owing to peculiar electronic and vibrational properties originating from hydrogen, such as van Hove singularities in the DOS and high-frequency phonons. Several cases will be discussed, such as hydrogenation of monolayer MgB_2 [2] and 2D gallium structures (gallenene) [3].

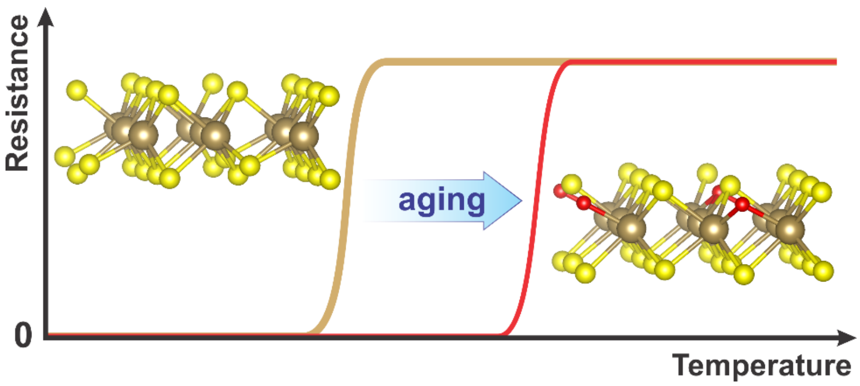

Figure: Enhancement of the superconducting T_c of TaS_2 upon aging, as a result of healing of sulfur vacancies through incorporation of oxygen (red atoms) into the lattice.

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E-mail: jonas.bekaert©uantwerpen.be

LD2

Controlling strong correlations of HTSs with Van der Waals heterostructures

Nicola POCCIA

IFW-Dresden, Institute for Metallic Materials, Helmholtzstrasse 20, 01069 Dresden, Germany

The Van der Waals (VdW) heterostructures formed by mechanically stacking layers of 2-Dimensional (2D) materials possess unique properties and new functionalities, not seen in standard materials, that make them irreplaceable platform for emergent electronics. Hindering the progress in utilizing VdW uniqueness is the fact that many of their features, especially the novel topological quantum states and related phenomena are restricted to low temperatures. This poses a challenge to create VdW heterostructures that maintain their capacity to harbor topological quantum matter physics at elevated temperatures. Employing High Temperature Superconductors (HTSCs) based 2D films for manufacturing VdW heterostructures offers the most advantageous route to increase the temperature range in which the topological states and phenomena associated with VdW devices can be studied and used. Nanofabrication and processing of these systems in a conventional clean-room facility will fail since it requires even higher standards than processing of organic semiconductors. Therefore, this methodology poses a number of formidable challenges not only in device fabrication, but also in terms of signal-to-noise ratio in spectroscopic experiments, which is essential for a true control over the properties of HTSCs VdW heterostructures. In this talk, I´ll review therefore the recent progress in this field of the last two years and I´ll show our contribution to this research.

E-Mail: n.poccia©ifw-dresden.de

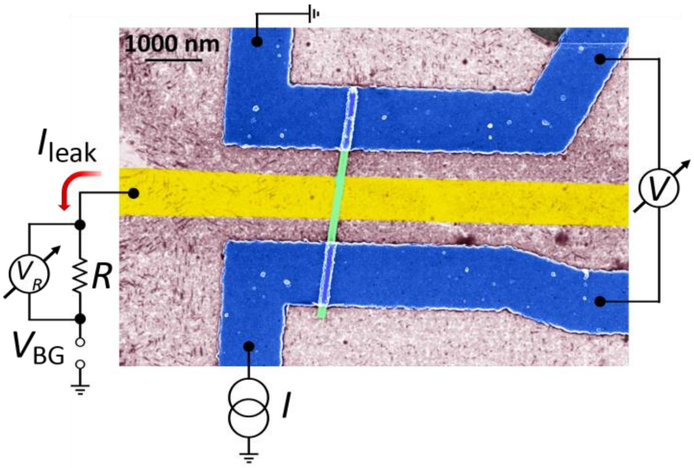
LD3

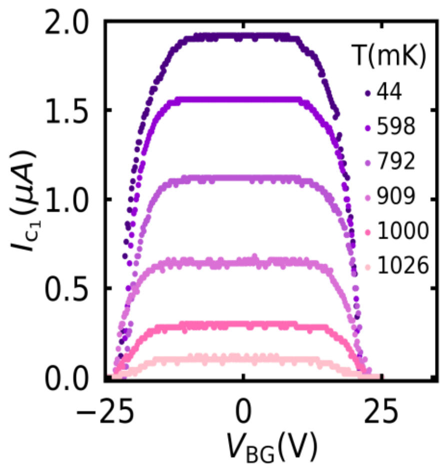
Gate-controlled supercurrent in superconductor shell in InAs/Al nanowires

Tosson ELALAILY[1], Olivér KÜRTÖSSY[1], Zoltán SCHERÜBL[1], Martin BERKE[1], István Endre LUKÁCS[2], Jesper NYGARD[3], Péter MAKK[1], Szabolcs CSONKA[1]

[1]Department of Physics, Budapest University of Technology and Economics and Nanoelectronics 'Momentum' Research Group of the Hungarian Academy of Sciences, Budafoki út 8, 1111 Budapest, Hungary.
[2]Center for Energy Research, Institute of Technical Physics and Material Science, Konkoly-Thege Miklós út 29-33., H-1121, Budapest, Hungary.
[3]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark.

Supercurrent-gating effect (SGE) has been recently realized in various polycrystalline superconductor nanostructures in which the supercurrent in the superconductor nanostructures can be switched on and off by applying voltage on a closely spaced electrode [1-3]. This surprising field effect transistor-like behaviour of superconductor nanostructures in addition to their low power and highly switching speed, could be a promising candidate for highly scalable switches in various modern architectures of classical and control circuits for quantum computers. In this work, we investigated SGE for first time in the Al shell layer epitaxially grown on InAs nanowires. We show that, the supercurrent in Al layer can be monotonically suppressed up to switching to normal state by increase the voltage on a bottom gate insulated from nanowire by hBN layer to ±23 V. Our study on SGE in InAs/Al show that the hot electron injection alone cannot explain our experimental findings.





Left: Investigated nanowire device. Right: Temperature dependence of supercurrent-gating effect

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E-mail: Tosson.elalaily©edu.bme.hu

LD4

Quantum devices towards 1D topological superconductivity

Chuan LI

University of Twente, Drienerlolaan, 5, 7522NB Enschede, Netherland

One of the main directions to realize the topological quantum bit is combining topological materials with conventional superconductors. The notion of topological phases has been extended to higher-order and has been generalized to different dimensions. Our research demonstrates the possibility of realizing the topological superconductivity in engineered 3D Dirac semimetals and their 1D hinge states in the last few years. Particularly, Cd_3As_2 is predicted to be a higher-order topological semimetal, possessing three-dimensional bulk Dirac fermions, two-dimensional Fermi arcs, and one-dimensional hinge states. These topological states have different characteristic length scales in electronic transport, allowing one to distinguish their properties when changing sample size.

E-Mail: chuan.li©utwente.nl

NE

Nano-electromechanics and hybrid quantum circuits

NE1

Mechanical frequency control in inductively coupled electromechanical systems

Thomas LUSCHMANN[1,2,3], Philip SCHMIDT[1,2], Frank DEPPE[1,2,3], Achim MARX[1], Alvaro SANCHEZ[4], Rudolf GROSS[1,2,3], Hans HUEBL[1,2,3]

[1] Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Walther-Meißner-Str.8, 85748 Garching, Germany
[2] Physik-Department, Technische Universität München, James-Franck-Str.1, 85748 Garching, Germany
[3] Munich Center for Quantum Science and Technology, Schellingstr.4, 80799 München, Germany
[4] Department of Physics, Universitat Autonoma de Barcelona, 08193 Bellaterra, Catalonia, Spain

Nano-electromechanical systems link mechanical motion to the highly successful field of superconducting quantum circuits by implementing, in the limit of weak coupling, the opto-mechanical interaction Hamiltonian at microwave frequencies. Recently, inductive coupling schemes with large coupling rates based on partially suspended superconducting interference devices (SQUID) have been demonstrated. Such systems are expected to allow for the exploration of phenomena beyond the linearized opto-mechanical interaction. We present results of an investigation into the impact of the microwave circuit on the mechanical resonance frequency. The experimental data quantitatively corroborates theoretical predictions for SQUID-based electromechanical systems. In addition, we observe a residual field dependent tuning of the mechanical resonance frequency, which we attribute to an effective coupling between the atomic lattice and the superconducting vortex lattice present the magnetic field biased nanostring.

E-mail: thomas.luschmann©wmi.badw.de

NE2

Four-wave-cooling to the single phonon level in Kerr optomechanics

Inês C. RODRIGUES [1], Daniel BOTHNER[1,2], Gary A. STEELE[1]

[1] *Delft University of Technology, Kavli Institute of Nanoscience, PO Box 5046, 2600 GA Delft, The Netherlands*
[2] *Universität Tübingen, Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, Auf der Morgenstelle 14, 72076 Tübingen, Germany*

Optomechanical systems have become the leading platform for the manipulation and exploration of mechanical motion. The field of physics where the displacement of a mechanical resonator is coupled to oscillatory optical/microwave light fields has allowed for major scientific breakthroughs. Curiously, all of these impressing results have been achieved with linear cavities and linear mechanical oscillators, and the utilization of intrinsic cavity nonlinearities has remained undesired and parasitic, as they impose limitations on the maximally achievable multi-photon coupling rates.

Recently, a new architecture has been introduced in the field of microwave of optomechanics. In this scheme, the motion of a mechanical nanobeam is transduced to the magnetic flux threading a Superconducting QUantum Interference Device (SQUID) embedded in a microwave LC circuit, resulting in an inductive optomechanical coupling. Besides providing a large and scalable single-photon coupling rate and a large single-photon cooperativity, this system naturally adds a Kerr nonlinearity to the cavity which arises from the nonlinear Josephson inductance of the SQUID. Hence, flux-mediated optomechanics is an ideal platform for the exploration of Kerr non-linearities in optomechancial systems.

In this talk we will present our latest work [1], where we actively utilize the SQUID non-linearity to cool a mechanical oscillator in a novel and counter-intuitive way. In short, we will show how a nanobeam can be cooled close to its quantum ground state (n~1.6) by using a sideband pump field that is blue-detuned from a strongly driven nonlinear microwave cavity. This surprising finding, which arises from a combination of multi tone driving and intracavity four-wave mixing, directly demonstrates the rich potential of Kerr nonlinearities as a powerful tool to manipulate phononic modes in cavity optomechanics.

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E-mail: I.C.CorveiraRodrigues©tudelft.nl

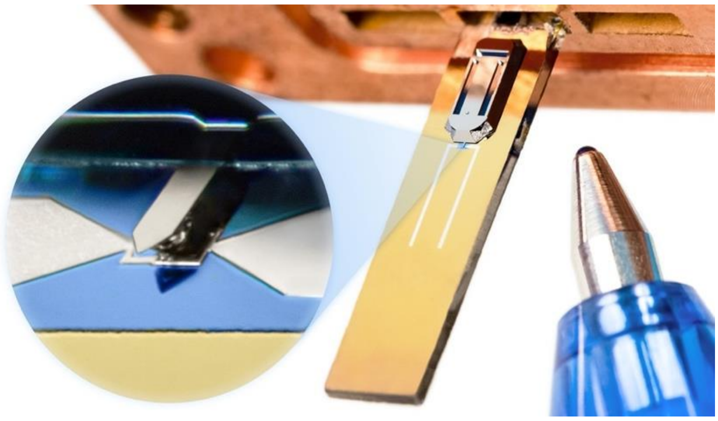
NE3

Coupling a magneto-mechanical oscillator to a SQUID based cavity

David ZOEPFL[1,2] , Mathieu L. JUAN[3], Christian M. F. SCHNEIDER[1,2], Gerhard KIRCHMAIR[1,2]

[1] *Institute for Experimental Physics, University of Innsbruck, Innsbruck, Austria*
[2] *Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Innsbruck, Austria*
[3] *Institut quantique & Département de Physique, Université de Sherbrooke, Sherbrooke, Quebec, Canada*

The possibility to operate massive mechanical oscillators in the quantum regime has become central in fundamental sciences. Optomechanics, where photons are coupled to mechanical motion, provides the tools to control mechanical motion near the fundamental quantum limits. Our setup (see Figure) consists of a magnetic field sensitive cavity coupled to a magnetic cantilever, a beam equipped with a magnet on its tip, leading to a position dependent magnetic field [1]. A SQUID embedded in our superconducting cavity provides the sensitivity to magnetic fields. As the inductance of the SQUID changes with magnetic field, the frequency of the cavity is coupled to the position of the cantilever. A measure for the interaction is the single photon coupling strength, where we achieve a value of around 6 kHz, which is among the highest in the field.



Experimental setup. Superconducting resonator (white) on top of a silicon substrate. The chip with the cantileverr (gray) is glued to this substrate. The microscope picture (zoom in) shows the cantilever above the SQUID loop.

Despite working at cryogenic temperatures, macroscopic mechanical objects (i.e. the cantilever) are in highly excited thermal states and need to be cooled close to the ground state in order to investigate quantum phenomena. One of the most common approaches is to utilize the cavity for sideband cooling. To be able to cool the ground state, usually the lifetime of the cavity has to exceed the mechanical frequency, which gets increasingly challenging working with more massive systems as their frequency decreases. We show a novel sideband cooling scheme by using the intrinsic nonlinearity of the cavity induced by the SQUID. This allows much enhanced cooling over a linear system with identical parameters and suppresses unwanted heating backaction. So far, we demonstrated cooling the cantilever down to only 11 phonons starting from around 4000 thermal phonons. While magnetic noise limits the cooling performance in the current setup, there is no fundamental limit preventing us from cooling further, possibly even to the ground state.

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E-mail: david.zoepfl©uibk.ac.at

NE4

Cavity optomechanics implemented using levitating superconductors and Josephson microwave circuits

Philip SCHMIDT[1], Markus ASPELMEYER[2], Joachim HOFER[2], Michael TRUPKE[2], Dominik ILK[2], Gerard HIGGINS[2], Stefan MINNIBERGER[2]

[1]*Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences Boltzmanngasse 3, 1090 Vienna, Austria*

[2] *Quantenoptik, Quantennanophysik und Quanteninformation, Universität Wien Boltzmanngasse 5, 1090 Vienna, Austria*

Experimental investigation of quantum mechanics with heavy objects (e.g. above Planck mass, ~20µg) has not been achieved yet, as it requires the challenging combination of decoupling the quantum object from environmental influences, while remaining a high control of the object.To achieve these, we implement the approach of superconducting microspheres in a magnetic field trap, allowingfor a mass independent levitation. To reach sufficiently high coupling rates we inductively couple the mechanicalmotion to superconducting quantum circuits to enable quantum states of motion in a completely new regime ofmasses.In my talk I will discuss prospects and challenges of the envisioned approach along with the current status of ourexperiment.

E-Mail: Philip.Schmidt©oeaw.ac.at

NE5

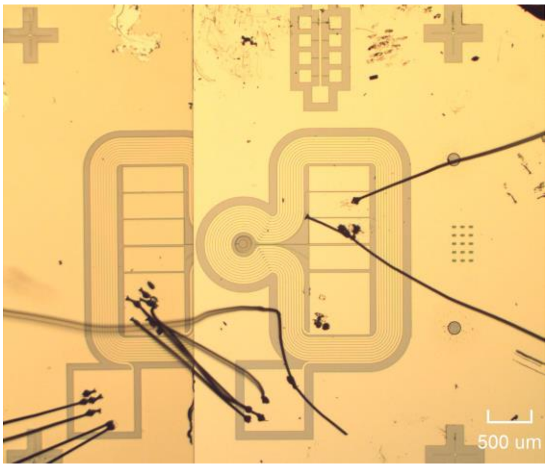
Levitation of micrometer-sized superconducting particles using on-chipmagnetic traps

Martí Gutierrez LATORRE[1], Achintya PARADKAR[1], Gerard HIGGINS[1], **Witlef WIECZOREK**[1]

[1] *Chalmers University of Technology, Department of Microtechnology and Nanoscience, Kemivägen 9, 41296 Gothenburg, Sweden*

Levitation of superconducting microparticles has been proposed as a promising approach for controlling the center-of-mass (COM) motional degree of freedom of a levitated particle in the quantum regime [1]. This approach profits from minimal mechanical dissipation along with the capability to engineer large superposition states of the COM motion. The latter would allow quantum experiments to be performed with macroscopic objects [2] and enable highly sensitive force measurements [3]. I will present our experiments in this direction, which are conducted in a low-vibration, dry4K cryostat. Our focus lies on realizing magnetic levitation of micrometer-sized superconducting particles fully on chip [4]. In our current generation of devices, we use trap structures made from 1μm thick Nb and spherical, micrometer-sized particles made from Pb. The chip trap consists of a stack of two silicon chips, each having a planar multi-winding superconducting coil that together form the magnetic trap (see Fig.1). Additionally, a pick-up and feedback loop are fabricated on the trap chip. The pick- up loop is connected to a SQUID, which facilitates the detection of the COM motion of the levitated particle. I will discuss challenges inherent to this approach and current levitation experiments. Future experiments may profit from interfacing this platform with the toolbox of superconducting circuits, when operating at Millikelvin temperatures.

Figure 1: Optical microscope image of a superconducting chip-based trap for levitating sub-100mumsuperconducting particles.



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E-mail: witlef.wieczorek©chalmers.se

POSTER PRESENTATIONS

P01

Ultradense tailored vortex pinning arrays in YBCO thin films created by focused He ion beam irradiation

Bernd AICHNER[1], Max KARRER[2], Katja WURSTER[2], Vyacheslav MISKO[3,4], Kristijan Luka MLETSCHNIG[1], Meirzhan DOSMAILOV[5], Johannes David PEDARNIG[5], Franco NORI[4,6], Reinhold KLEINER[2], Edward GOLDOBIN[2], Dieter KOELLE[2], Wolfgang LANG[1]

[1]*Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Wien, Austria*
[2]*Physikalisches Institut and Center for Quantum Science (CQ) in LISA+, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[3]*µFlow group, Department of Chemical Engineering, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium*
[4]*Theoretical Quantum Physics Laboratory, RIKEN Cluster for Pioneering Research, Wako-shi, Saitama, Japan*
[5]*Institute of Applied Physics, Johannes Kepler University Linz, Altenbergerstrasse 69, A-4040 Linz, Austria*
[6]*Physics Department, University of Michigan, Ann Arbor, Michigan 48109, United States*

Nanopatterning of the high-temperature superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) is required for many possible applications but is also demanding since conventional etching techniques are hardly useful to achieve sub-100 nm lateral resolution. With the focused He^+ ion beam of a helium ion microscope, we fabricate periodic patterns of pinning sites with spacings down to 40 nm in YBCO thin films. In such samples vortex matching effects are visible as peaks in the critical current and minima in the resistance versus applied magnetic field. In addition, in ultradense kagomé-like patterns, an unconventional commensurability effect can be observed, which is attributed to the magnetic caging of vortices. This behavior is also confirmed by molecular dynamic simulations of vortex motion [1]. Simulations of the ion-target interactions and the resulting collision cascades and the investigation of the commensurability effects in oblique magnetic fields reveal that the matching features are dominated by the artificial pinning landscape despite of the strong intrinsic pinning in thin YBCO films [2]. These findings open the path for the realization of more complex structures and thus to intriguing possibilities for the manipulation of vortices in high-temperature superconductors.

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E-Mail: bernd.aichner©univie.ac.at

P02

Selective triggering of magnetic flux avalanches by an edge indentation

Lu JIANG[1], Cun XUE[2], L. BURGER[3], B. VANDERHEYDEN[3], A. V. SILHANEK[4], You-He ZHOU[5,1]

[1] School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China
[2] School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi'an 710072, China
[3] SUPRATECS group, Montefiore Research Unit, Department of Electrical Engineering and Computer Science, University of Liege, B-4000 Sart Tilman, Belgium
[4] Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, University of Liege, B-4000 Sart Tilman, Belgium
[5] Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Department of Mechanics and Engineering Sciences, Lanzhou University, Lanzhou 730000, China

We numerically investigate the effect of an edge indentation on the threshold field of thermomagnetic instabilities in superconducting films subjected to a ramping magnetic field, applied perpendicular to the plane of the film. In particular, we are able to address the question on whether edge indentations promote magnetic flux avalanches, For the magnetic field-independent critical current density model, the triggering of the first magnetic flux avalanche systematically occurs at the edge indentation. In contrast to that, for the more realistic field-dependent critical current density model the first flux avalanche can take place either at or away from the indentation. This selective triggering of magnetic flux avalanches is shown to result from two effects. Namely, (i) the variation of the threshold magnetic field for the first flux avalanche triggered at the indentation and (ii) the reduction of the critical current density by large local magnetic fields at the tip of the indentation which translates in a lower power density dissipated near the tip. We demonstrate that this interplay can be tuned by varying the indentation size, ramp rate of applied field $\dot{H}_a$, and working temperature T_0. We build up a phase diagram in the $\mu_0\dot{H}_a - T_0$ plane with well-defined boundaries separating three distinct regimes of thermomagnetic instability. Further information can be found in Ref.[1].

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E-mail: lujiang@mail.nwpu.edu.cn

P03

Structural phase transition of the vortex lattice in bulk superconductors with low-K values

Krsto IVANOVIĆ[1], Predrag MIRANOVIĆ[1]

[1] *Faculty of Natural Sceinces and Mathematics Bulevar Džordža Vašingtona, 81000 Podgorica, Montenegro*

The behavior of the vortex lattice in bulk superconductors at low – κ limit has been investigated. It is shown by numerical calculation that at low values of magnetic induction the vortex chain structure appears. On the otherhand, with the increase of the magnetic induction a crossover to the stable hexagonal structure has been observed.These results are in accordance with the experimental observation of the attractive vortex – vortex interaction inlow – κ superconductors. The interaction energy is calculated by numerical solving of the Eilenberger equations.

E-Mail: krstoivanovic©gmail.com

P04

Reducing the flux front penetration depth in a Nb film by cooling in an inhomogeneous out-of-plane field

Maycon MOTTA[1], Antonio Marcos H. ANDRADE[2], Ítalo Moreira ARAÚJO[1], Davi CHAVES[1], Fabiano COLAUTO[1], Tom Henning JOHANSEN[3], Ana Augusta Mendonça OLIVEIRA[4], Wilson Aires ORTIZ[1], Alejandro SILHANEK[5]

[1]*Federal University of São Carlos (UFSCar) Rodovia Washington Luis, km 235 – Monjolinho, 13565-905 São Carlos, Brazil*
[2]*Universidade Federal do Rio Grande do Sul Av. Paulo Gama, 110, 91501-570 Porto Alegre, Brazil*
[3]*University of Oslo Postboks 1048 Blindern, NO-0316 Oslo, Norway*
[4]*Instituto Federal de Educação, Ciência e Tecnologia de São Paulo Rodovia Washington Luis, km 235, 13565-905 São Carlos, Brazil*
[5]*University of Liege, Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Sart Tilman, B-4000 Liege, Belgium*

In the well known Bean model framework, the penetration depth of the magnetic flux front in a type II superconductor has an intimate relation to its pinning properties, vortex dynamics, and effective current density. When thin films are nanoengineered with arrays of artificial pinning centers, such as antidots or holes, they can successfully increase the pinning capacity and more effectively shield the flux pervasion, resulting in a shorter flux penetration depth. Moreover, a gradient distribution of pinning centers can further enhance the effect[1], pronouncedly in the case of a conformal crystal arrangement[2].
Simulations within the Ginzburg Landau formalism[3] have reported that a superconducting thin film cooled under an inhomogeneous out of plane magnetic field presents vortex distributions equivalent to conformal crystals. Such a finding can be achieved experimentally by using a current loop concentric with the sample to generate the inhomogeneous field. This approach, therefore, stands to have a significant impact on the depth of flux penetration front. Thus, we have fabricated a superconducting device composed of a square 200 nm thick Nb film surrounded by a thin Nb loop with contact pads allowing current to flow through. Qualitative and quantitative analysis of magnetic optical images of our device under critical state conditions reveal the influence of different cooling routes on the flux penetration. The results show that the presence of vortices previously pinned during cooling under an inhomogeneous field with the same orientation as the applied field leads to the shortest flux front penetration depth, even when compared to a homogenous field cooling condition, therefore pointing to a hierarchy on the film's screening capacity directly influenced by either repulsive (vortex vortex) or attractive (vortex antivortex) interactions.

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E-Mail: m.motta©df.ufscar.br

P05

Electronic structure of the vortices pinned by a planar defect of various transparency

Vadim PLASTOVETS[1,2], Alexey SAMOKHVALOV[2,3], Alexander MEL'NIKOV[2,3], Alexander BUZDIN[1]

[1]University Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France
[2]Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, Russia
[3]Sirius University of Science and Technology, 1 Olympic Ave, 354340, Russia

The electronic structure of an Abrikosov vortex pinned by a high-transparency planar defect in a type-II superconductor is analyzed within the quasiclassical approach of the Bogoliubov–de Gennes (BdG) theory. The normal reflection of electrons and holes at the defect plane results in the topological transition in the spectrum and formation of a type of quasiparticle state skipping or gliding along the defect. This topological transition appears to be a hallmark of the initial stage of the crossover from the Abrikosov to the Josephson vortex type (A-J) revealed in the specific behavior of the quantized quasiparticle levels and density of states [1].

The change in the magnetic structure of the Abrikosov vortex placed near a plane defect with high transparency was also obtained using the Londons approach. As the vortex approaches to the defect the level lines of the magnetic field in the plane perpendicular to the vortex axis lines are deformed due to the change in the London penetration length in the vicinity of the barrier.

The opposite limit of the A-J vortex – pure Josephson vortex without a normal core formed on the low-transparency planar defect was also considered [2]. Such a vortex can be described as a system with quasiparticles moving in the presence of an effective potential shaped by an inhomogeneous distribution of the phase difference of the order parameter along the defect. Within the framework of the quasiclassical approximation of the BdG equations, the quantized spectrum of quasiparticles and the local density of states were obtained. The results for both different cases can be used to analyze data from experiments on measuring the electronic properties of the described systems.

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E-mail: vadim.plastovets©u-bordeaux.fr

P06

Effects of creep on the linear ac magnetic response in type II superconductors

Filippo GAGGIOLI,[1], Gianni BLATTER[1], Dima GESHKENBEIN[1]

[1] *Institut für Theoretische Physik, ETH Zürich, CH-8093, Switzerland*

We study the effect of thermal fluctuations (or creep) [1] on the penetration of an ac magnetic field into the mixed state of a type II superconductor within the strong pinning formalism, where vortices get pinned by individual defects and jumps in the energy (Δe_{pin}) and force (Δf_{pin}) between pinned and free states characterize the pinning process. The ac linear magnetic response is quantified by the so-called Campbell length $\lambda_C(t)$ [2], whose evolution as a function of time t is the result of two competing effects, the change in the force jumps Δf_{pin} (t) and a change in the trapping distance $t_{trap}(t)$ of vortices; the latter describes the distance from the defect where a nearby vortex gets trapped. During the decay of the critical state in a zero-field cooled (ZFC) experiment, the Campbell length $\lambda_C(t)$ behaves nonmonotonically, contrary to what happens in a measurement of the persistent current. The Campbell length always decreases at short times, and then increases for longer waiting times, at least for very strong pinning, and its relative change is parametrically smaller than that of the persistent current [3]. Once thermal equilibrium is reached, the magnetic field is distributed homogeneously inside the superconductor, leading to vanishing persistent current, while the Campbell length remains finite and similar to the one without relaxation. Measuring the Campbell length $\lambda_C(t)$ for different states, zero-field cooled, field cooled, and relaxed along closed temperature loops, we obtain different results, dependent on the state preparation, the temperatures and the waiting times. In this way, important information on the pinning mechanism is obtained and the pinning potential of the defects can be quantitatively characterized [4].

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E-mail: filippog©phys.ethz.ch

P07

Formation and characteristic dynamics of vortex rows in superconducting nanostripes

Benjamin MCNAUGHTON[1,2], Milorad MILOŠEVIĆ[2], Andrea PERALI[3], Nicola PINTO[1,4]

[1] School of Science and Technology, Physics Division, University of Camerino, Camerino, Italy
[2] Department of Physics, University of Antwerp, Belgium
[3] School of Pharmacy, Physics Unit, University of Camerino, Camerino, Italy
[4] Advanced Materials and Life Science Division, INRiM, Turin, Italy

Understanding and controlling the behaviour of vortices of supercurrent is of utmost importance in nanostripes based superconducting electronics such as diodes [1,2], logic devices [3,4], microwave resonators [5], and single-photon detectors [6] to name a few. To that end, we have performed numerical simulations within the Ginzburg-Landau formalism to investigate how vortex row formations stabilize in nano-stripes of different widths in the presence of an external magnetic field. We emphasise how such rows relate to observable features in the superconducting critical current and spectra of frequencies in output voltage modulations. Commensurate behaviour between the critical current and magnetic field is reinforced showing how it can help identify the presence of a number of vortex rows. Analysing the modulations in output voltages for dissipative states just above the critical current, shows a clear difference in the number of characteristic frequencies present between one row of vortices and two or more rows, related to the vortex crossings and different phases of slow and fast moving vortices [7,8].

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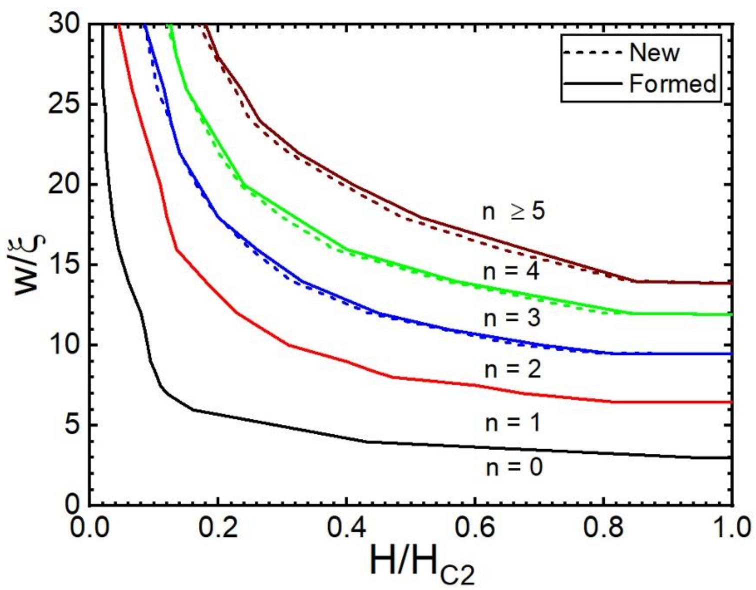
E-mail:benjamin.mcnaughton©unicam.it



Vortex-row phase transition diagram showing the stripe width, in units of ξ, against the applied magnetic field, in units of H_{C2}. Obtained using the stationary Ginzburg-Landau approach. Dashed lines represent the appearance of a new row, and solid lines depict a fully formed row. The variable n is used for the number of rows present.

P08

Towards a NbRe based fast superconducting nanowire single-photon detector

Xingchen CHEN[1], Guerino AVALLONE[1,2], Carmine ATTANASIO[2], Sense Jan Van der MOLEN[1], Michiel DE DOOD[1], Jan AARTS[1]

[1] Huygens-Kamerlingh Onnes Laboratory, Leiden Institute of Physics, Leiden University, Niels Bohrweg 2, Leiden, The Netherlands
[2] Dipartimento di Fisica "E.R.Caianiello", Universita degli Studi di Salerno, Via Giovanni Paolo II, I-84084 Fisciano (Sa), Italy

As recently demonstrated, thin-film NbRe is a promising material for Superconducting Nanowire Single Photon Detectors (SNSPDs) with low recovery and jitter times [1,2]. Both the small effective coherence length and high current density reduce the quasiparticle relaxation time. This resulting gain in single photon detection rate is expected to be further enhanced by coupling it to a thin ferromagnetic layer [3]. Our aims to realise a NbRe SNSPD, and subsequently, to build an even faster device by coupling the NbRe thin layer with a thin Co layer. For this, the polycrystalline noncentrosymmetric superconductor NbRe films (8 nm) are deposited onto a substrate by UHV sputtering. Charge transport measurements confirm the superconducting ordering in NbRe with a small coherence length of 5.2 nm. Furthermore, the electronic characteristics of a 14 nm NbRe film coupled with a 4 nm Co layer were carefully investigated at cryogenic temperatures. The data show strong coupling effects at the superconducting-ferromagnetic interface. A signature of proximity effect has been observed. The results so far validate NbRe as a highly encouraging base material for future fast SNSPDs. It is also shown that coupling it to a thin ferromagnetic film provides an exciting pathway to superconducting-ferromagnetic interface research. Indeed, a high single photon detection rate is now accessible, with comparatively simple fabrication methods.

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E-mail: chen©physics.leidenuniv.nl

P09

Effect of He+ ion irradiation on the performance of superconducting nanowire single-photon detectors

Glenn MARTINEZ[1,2], Ilya CHARAEV[1], Owen MEDEIROS[1], Marco, COLANGELO[1], Karl K. BERGGREN[1]

[1] *Massachusetts Institute of Technology, Research Laboratory of Electronics, 50 Vassar St, Cambridge, MA 02139, USA*
[2] *Boston University, Department of Electrical & Computer Engineering, 8 Saint Mary's Street, Boston, MA 02215, USA*

In this work, we present an approach to tune the device metrics of superconducting structures through local He+ ion irradiation. Due to the superconducting thin film's sensitivity to disorder when irradiated and the high collimation of the He+ ion beam, we can control the superconducting gap at specific locations on the device. We investigate the effect of He+ ion irradiation by comparing the critical current between unexposed and exposed devices. Additionally, we have explored using local He+ ion irradiation to potentially improve superconducting single-photon detectors.

E-mail: gmart©mit.edu

P10

Skyrmion-affected vortex dynamics in a magnet-superconductor heterostructure

Michał WYSZYŃSKI[1], Rai MACIEL DE MENEZES[1,2], Milorad MILOŠEVIĆ[1]

[1] Department of Physics, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium
[2] Department of Physics, Federal University of Pernambuco, Cidade Universitária, 50670-901, Recife-PE, Brazil

We show the results of time-dependent Ginzburg-Landau simulations of vortex statics and dynamics in a superconducting film coupled to a chiral magnet in a hybrid heterostructure. We discuss the conditions on the stray field of skyrmions to nucleate vortex-antivortex structures in the superconductor, and how those interact with externally applied homogeneous magnetic field – changing simultaneously both skyrmion and vortex(-antivortex) configuration. Correspondingly, in applied current simulated vortex dynamics reveals rich features due to the presence of skyrmion background. This includes successive vortex-antivortex pair creations and annihilations at the skyrmion domain walls, interacting non-trivially with other moving vortices under applied drive, and changing strongly with inverted polarity of the applied current and/or applied magnetic field. Our results are in agreement with recent experiments conducted on similar hybrids [1], and offer insights into the underlying mechanisms of measurable quantities, be it static magnetization or transport I-V characteristics. Such realizations of a strongly interacting skyrmion-vortex system could open a path towards controllable topological hybrid materials, unattainable to date.

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E-mail: michal.wyszynski©uantwerpen.be

P11

Superconducting triplet edge currents in a spin textured ferromagnet

Remko FERMIN[1], Mikhail SILAEV[2], Jan AARTS[1], Kaveh LAHABI[1]

[1] *Leiden University, Leiden Institute of Physics, Niels Bohrweg 2, 2333 CA, Leiden, The Netherlands*
[1] *University of Jyväskylä, Department of Physics, Survontie 9, C 40500, Jyväskylä, Finland*

Since the early works on long-range triplet (LRT) correlations in ferromagnets, a growing number of theoretical studies have considered the relation between spin-polarized Cooper pairs and magnetic textures, like Skyrmions, domain walls and ferromagnetic vortices. In contrast, the experiments that can establish this interaction remain scarce. Here we investigate the interplay between a ferromagnetic vortex and LRT Cooper pairs by combining micromagnetic simulations with nanostructured Josephson junctions. We show that LRT correlations can be generated by a single ferromagnet, utilizing the vortex spin texture of a disk-shaped Co/Nb bilayer (See Figure 1).

Our findings demonstrate that spin texture can lead to non-trivial distribution of triplet supercurrent, where transport tends to be highly localized at the edges of the junction. By modifying the spin texture of a single ferromagnet, we show that both zero and π channels can be realized in the same device. Here I will describe the relevant mechanisms for the LRT generation in our junction, with a particular emphasis on the role of equilibrium spin currents at sample boundaries.

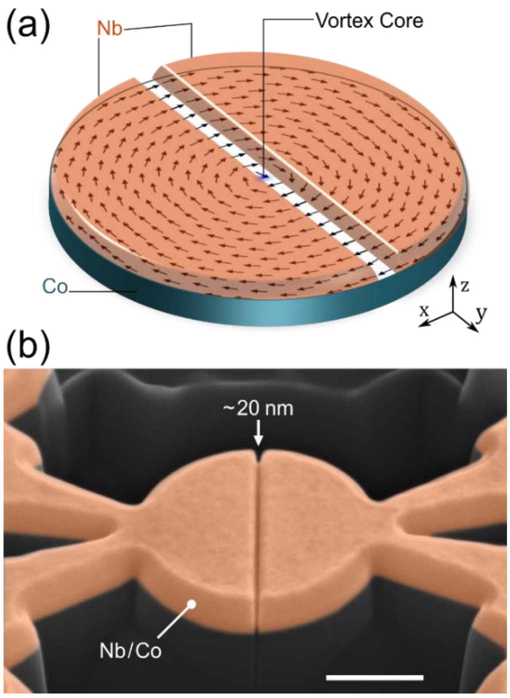

Figure 1: © Schematic of a disk device. The Nb electrodes are separated by a trench, forming a Co weak link. The pattern on the Co layer corresponds to micromagnetic texture of the ferromagnet. The arrows show the in-plane magnetization, while the out of plane component is represented by color, which only appears at the vortex core (blue region). (b) False colored scanning electron micrograph of a structured bilayer. The 20 nm gap indicates the Co weak link at the bottom of the trench. The scale bar is equivalent to 400 nm.

E-mail: fermin©physics.leidenuniv.nl

P12

High quality RuO_2 nanowires for dissipation-less spintronics

Kumar PRATEEK[1], Thomas MECHIELSEN[1], Kaveh LAHABI, Douwe SCHOLMA, Jan AARTS[1]

[1] Huygens-Kamerlingh Onnes Laboratory, Leiden University
P.O. Box 9504, 2300 RA Leiden, The Netherlands

RuO_2 has generated considerable interest in recent years due to the discovery of its anomalous antiferromagnetic order [1], crystal Hall effect [2] and its affinity with unconventional superconductivity [3,4]. This makes high quality RuO_2 nanostructures an attractive platform for antiferromagnetic spintronics and the study of highly correlated electrons. In this work, we grow single-crystal RuO_2 nanowires through chemical vapor deposition. We show that high quality metallic RuO_2 wires can be prepared in a reliable and reproducible manner using selective area growth. The RuO_2 is characterized via XRD and transport experiments, including Hall measurements. In order to explore the interplay between the superconductivity and exotic magnetic ordering of RuO_2, we proximize the nanowires using superconducting electrodes, forming a planar Josephson junction. Here, I will discuss the nature of the proximity effect in RuO_2, and provide an outlook for its potential applications in dissipation-less antiferromagnetic spintronics.

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E-mail: prateek©physics.leidenuniv.nl

P13

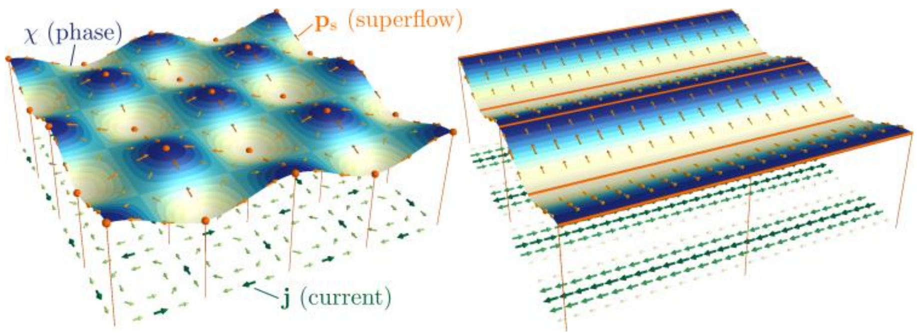
Spontaneous time-reversal and translational symmetry breaking at *d*-wave interfaces and conventional SIF junctions

Patric HOLMVALL[1,2], Niclas WENNERDAL[2], Anton B. VORONTSOV[3], Tomas LÖFWANDER[2], Mikael FOGELSTRÖM[2]

[1] *Uppsala University, Department of Physics and Astronomy, Sweden*
[2] *Chalmers University of Technology, Department of Microtechnology and Nanoscience – MC2, Sweden*
[3] *Department of Physics, Montana State University, Bozeman, USA*

Superconductivity owes its properties to the phase of the electron pair condensate that breaks the *U(1)* symmetry. In the most traditional ground state, the phase is uniform and rigid. The normal state can be unstable towards special inhomogeneous superconducting states: the Abrikosov-vortex state and the Fulde-Ferrell-Larkin-Ovchinnikov state. Here we show that the phase-uniform superconducting state can go into a fundamentally different and more ordered nonuniform ground state, referred to as a *"phase crystal"* [1]-[5]. This state breaks translational invariance through formation of a spatially periodic modulation of the phase, manifested by unusual superflow patterns and circulating currents, that also break time-reversal symmetry. Using microscopic theory, we derive an analytic expression for the superfluid density tensor for the case of a nonuniform environment in a semi-infinite superconductor [1]. We demonstrate how surface quasiparticle states enter the superfluid density and identify phase crystallization as the main player in several previous numerical observations in unconventional *d*-wave superconductors, and predict the existence of a similar phenomenon in conventional superconductor-ferromagnetic structures. The analytic approach provides a unifying aspect for the exploration of boundary-induced quasiparticles and collective excitations in superconductors. The analytic results are compared with self-consistent numerics, using both quasiclassical theory [2]-[4] and Bogoliubov-de Gennes theory [5]. These methods show qualitative agreement, and effects of size quantization and Friedel oscillations are not detrimental. Furthermore, the state shows robustness against external fields and surface disorder. The transition into the phase-crystal state is of second order and occurs at roughly 20% of T_c.

Figure 1: Spontaneous appearance of periodic phase and phase gradients, giving rise to current loops (left), and sheets (right).



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E-mail: patric.holmvall©physics.uu.se

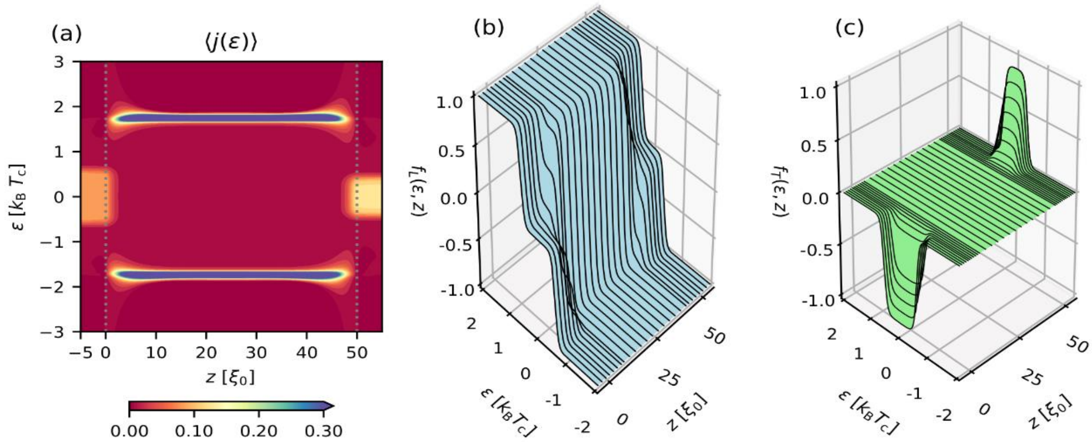
P14

Charge and spin transport across mesoscopic normal metal-superconducting heterostructures: Quasiclassical theory with current conservation

Kevin Marc SEJA[1], Tomas LÖFWANDER[1]

[1] *Chalmers University of Technology, Department of Microtechnology and Nanoscience - MC2, Kemivägen 9, 41 258 Gothenburg, Sweden*

We study mesoscopic superconducting (S)-normal metal (N) heterostructures with spin-active interfaces in steady-state nonequilibrium induced by a voltage bias in an N-S-N set-up [1]. In the case of spin-active N-S interfaces, we report results for the nonequilibrium magnetization injected into the superconductor. Our interests lie in the charge and spin transport in such systems outside of the diffusive limit that is usually considered in literature. Using full quasiclassical theory from the ballistic to diffusive case, we perform a self-consistent calculation that guarantees current conservation through the entire system. This allows us to investigate crucial phenomena such as charge imbalance, induced magnetization, the quasiparticle current-to-superflow conversion, and momentum-resolved nonequilibrium distribution functions. Extending earlier results for the diffusive case, we find a critical bias voltage *Vc* that can cause the breakdown of superconductivity at currents far below the bulk critical current. We discuss the origin of *Vc* and its dependence on the mean-free path and the interface transparency *D*. The value of *Vc* typically increases with reduced *D*, while the dependence on the mean-free path is non-monotonous.



Spectral current density *j(ε,z)* for a normal metal-insulator-superconductor-normal metal (NISN) system with asymmetric interface transparencies (D_L=0.5, D_R=1) and intermediate mean-free path l = ξ_0, where ξ_0 is the superconducting coherence length. The conversion from quasiparticle current to superflow is clearly seen. (b) Energy mode f_L of the distribution function for the same system. The mode is zero for energies less than $eV_{L/R}$ in the N region and relaxes to the equilibrium shape deep in the superconductor. (c) The charge mode f_T of the distribution function for the same system.

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E-mail: seja©chalmers.se

P15

Spin waves in superconductor/ferromagnet heterostructures

Krzysztof SZULC[1], Szymon MIESZCZAK[1]

[1] *Institute of Spintronics and Quantum Information, Faculty of Physics, Adam Mickiewicz University in Poznań, Uniwersytetu Poznańskiego 2, Poznań, Poland*

We investigated numerically the hybrid structures where a homogenous ferromagnetic (F) layer is coupled via stray field to a planar superconducting (S) pattern. The F layer forms a conduit for spin waves and the S layer affects and controls their propagation. The main mechanism behind this control is the change of the static and dynamic magnetic field in the vicinity of F by the eddy currents in a superconductor due to the Meissner effect and the modification of the boundary conditions resulting from the presence of the perfect conductor.

In the considered structures, the spin-wave transmission can be investigated experimentally by propagating spin-wave spectroscopy. For such experiments, a high group velocity of spin waves is required to minimize signal losses between the transmission and receiving antennas. Therefore, we will focused on the Damon-Eshbach geometry (magnetic field is applied in-plane, perpendicularly to the direction of the wavevector), where the foundational structure [Fig. 1©] which exhibits non-reciprocity for spin-wave propagation and demonstrates the potential of such systems, is a single F layer overlaid by a continuous S layer. By changing the distance *d* between the F and S layers, we can modify the range of the increased group velocity values in one of the directions of propagation. These features are also observed for more complex structures like magnonic crystals induced in an initially homogenous F layer by the stray field of a periodic S nanostructure [Fig. 1(b)].

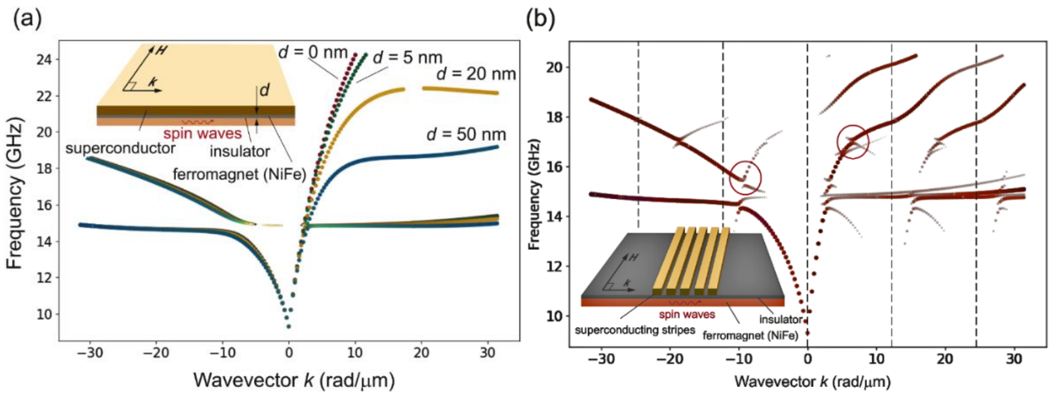

Fig. 1. Non-reciprocity of spin waves in F/S hybrid structures. The spin-wave dispersion calculated by the finite-element method (COMSOL Multiphysics) for a continuous Py layer covered with a uniform S layer © and 500 nm-spaced S stripes (b). The red circles in (b) mark the Bragg gaps observed at non-symmetric locations in the Brillouin zone for the F layer with a thickness *d* of 20 nm.

E-mail: krzysztof.szulc©amu.edu.pl

P16

Broadening of the in-gap-state energies at non-zero temperatures of the superconducting quantum dot: A Green function study

Jiawei YAN, Václav JANIŠ

Institute of Physics of the Czech Academy of Sciences, Department of Dielectronics, Na Slovance 1999/2, 182 00 Praha 8, Czech Republic

A single quantum dot attached to two superconducting leads has recently raised great interest due to its novel physics and potential application in nanoelectronics and quantum computing. Here, we employ our recently developed many-body perturbation theory [1] to study the spectral properties of the superconducting quantum dot in the weak coupling regime. We determine the dynamical self-energy on the dot from the Schwinger-Dyson equation with the two-particle vertex calculated from the reduced parquet equations of Ref. [2]. The one-particle Green function in the Schwinger-Dyson equation must be used fully self-consistently with the resulting self-energy. This is the only way to guarantee analytic properties of the Green functions and physical consistency. Consequently, the zero-temperature poles due to the in-gap states of the one-particle propagator are broadened to bands by thermal fluctuations at non-zero temperatures.

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E-mail: yan©fzu.cz

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Flux qubit as a single microwave photon counter: Exploring energy spectrum by animation

Anna BOICHENKO[1], Oleg TURUTANOV[1], Vleriy LYAKHNO[1], Alexei SOROKA[2], Vladimir SHNYRKOV[3]

[1] B.Verkin Institute for Low Temperature Physics and Engineering of NAS of Ukraine, 47 Nauky Ave., Kharkiv, 61103, Ukraine
[2]National Science Center "Kharkiv Institute of Physics and Technology", Akhiezer Institute for Theoretical Physics, 1 Akademicheskaya Str., Kharkiv 61108, Ukraine
[3] Kyiv Academic University, 36 Acad. Vernadsky Blvd, Kyiv 03142, Ukraine

The detection of single photons in microwave range needed for a number of novel quantum applications (quantum radars, quantum computing, quantum communications, astrophysical detectors, etc.) are still a challenge because of low photon energy. The experimental approaches using transitions in a quantum system with discrete spectrum [1,2] require detailed understanding of the spectrum evolution during working cycle of the counter.

Basing on the scheme we proposed earlier [3,4], we start to explore the energy spectrum of a tunable flux qubit with specified "hardware" parameters by its animation when changing the inter-well potential barrier height and external magnetic flux bias through two dedicated gates. This visualization makes much easier for one to imagine the re-arrangement of the qubit energy levels during its operational cycle. Here we report the first step in the spectrum modelling in approximation of zero dissipation and are planning to include an interaction with dissipative environment as a future model enhancement.

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E-mail: ann.boychenko199©gmail.com

P18

Geometry controlled Josephson diode based on curved proximitized nanowires

Alexander KOPASOV[1,2], Anton KUTLIN[3], Alexander MEL'NIKOV[1,2,4]

[1] Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia
[2] Lobachevsky State University of Nizhni Novgorod, 603950 Nizhni Novgorod, Russia
[3] Max Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany
[4] Sirius University of Science and Technology, 1 Olympic Avenue, 354340 Sochi, Russia

It has been recently predicted that the Josephson junctions formed by proximitized semiconducting nanowires connected with an offset angle should exhibit the anomalous Josephson effect [1-3] which is characterized by the appearance of a spontaneous phase shift in the ground state of such junctions. However, the analysis of this effect has been restricted to the limit of large Zeeman fields so that the proximitized nanowire is in the topologically nontrivial phase and realizes the spinless p-wave superconductivity. The main goal of our work is to study the key features of the Josephson transport through a curved semiconducting nanowire within the full range of the Zeeman fields covering both topologically trivial and nontrivial regions of the phase diagram.

Based on numerical simulations and analytical estimates within the framework of the Bogoliubov – de Gennes equations we reveal the magnetic-field driven crossover from the conventional to the anomalous Josephson effect as the system undergoes the topological phase transition. The distinctive features of the Josephson effect are studied for two inequivalent orientations of the spin splitting field: (i) a curved nanowire junction is placed in the external magnetic field directed perpendicular to the substrate, (ii) the spin splitting field is directed parallel and antiparallel to the nanowire axis in different parts of the system. We find that for both orientations of the spin splitting field the presence of the above-mentioned crossover reveals itself in the superconducting diode effect: the magnitude of the critical current depends on the direction of the applied current.

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E-mail: kopasov©ipmras.ru

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Nanopatterning of oxide interfaces using cold ion milling

Maria D'ANTUONO[1], Roberta CARUSO[2], Alexei KALABOUKHOV[3,4], Marco SALLUZZO[5], Daniela STORNAIUOLO[1]

[1]*University of Naples "Federico II" Cupa Cinthia, 80126 Naples, Italy*
[2]*Brookhaven National Laboratory 98 Rochester St., 11973-5000 Upton, USA*
[3]*Chalmers University of Technology, Kemivägen 9, Gothenburg, Sweden*
[4]*Microtechnology and Nanoscience, Chalmers University, SE-41296, Gothenburg, Sweden*
[5]*CNR-SPIN Complesso Universitario Monte sant'Angelo, via Cintia, 80126 Naples, Italy*

The two-dimensional electron gas (2DEG) formed at the interface between $LaAlO_3$(LAO) and $SrTiO_3$ (STO) band insulators is a very rich and complex system[1], whose properties are now being investigated also in the view of innovative quantum devices realization. This tunable 2DEG can be made spin-polarized introducing a thin layer of $EuTiO_3$ at the interface between LAO and STO [2]. In the recent years, several specific nanofabrication techniques were developed to reveal the unique fundamental properties of oxide 2DEGs, such as direct writing using a conducting-tip atomic-force microscope or creation of an amorphous template on the substrate using electron-beam lithography [3].

In this work, we present LAO/ETO/STO nano-devices with dimensions down to 160nm obtained by a top-down patterning technique based on Ar+ ion milling in combination with electron beam lithography. We realized several types of devices, including Dayem bridges and side gate devices with various gate electrodes configurations. We demonstrate that our patterning technique does not damage the oxide 2DEG, both from the structural and from the electronic transport point of view. Our devices are indeed largely tunable using electric field effect and their properties are remarkably uniform. The innovation brought by our technique is the possibility to access laterally the 2DEG, opening new exciting perspectives for the creation of hybrid devices.

We believe that 2D oxides have a great potential for new spintronic and quantum electronic applications; to this aim, the development of specific nano patterning techniques represents a fundamental requisite for the realization of functional integrated devices, of hybrid normal/superconductor structures or even to superconductor/superconductor structures, where the 2DEG could be proximized by another superconducting material.

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E-Mail: maria.dantuono©unina.it

P20

An open-source framework for mesoscopic superconductivity

Niclas WENNERDAL[1], Patric HOLMVALL[1,2], Mikael HÅKANSSON[1], Oleksii SHEVTSOV[1], Pascal STADLER[1], Mikael FOGELSTRÖM[1], Tomas LÖFWANDER[1]

[1] *Chalmers University of Technology, Department of Microtechnology and Nanoscience Address, Sweden*
[2] *Uppsala University, Department of Physics and Astronomy, Sweden*

We present an open-source framework for simulating singlet superconductors in equilibrium, confined to 2D mesoscopic grains, in an external magnetic field. It aims at being both fast and easy to use, enabling research without access to a computer cluster. The core is written in C++ and CUDA, exploiting the embarrassingly parallel nature of the quasiclassical theory of superconductivity by utilizing the parallel computational power of modern GPUs. The framework can compute the superconducting order-parameter, the induced vector potential (and flux density), the current density, and the free energy, as well as the local density of states. The simulation can be visualized in real-time with OpenGL. A user-friendly Python frontend is provided enabling simulation parameters to be defined via intuitive configuration files, or via the GUI/CLI, without requiring a deep understanding of implementation details. The framework ships with simple tools for visualizing the results, including an interactive spectroscopy tool. An overview of the theory is presented, as well as examples showcasing the framework's capabilities and ease of use.

E-mail: wennerda©chalmers.se

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Enhancing the weak-link response of Y123 nanowires prepared by solution blow spinning

Davi A. D. CHAVES[1], Ana M. CAFFER[2], Alexsander L. PESSOA[2], Claudio L. CARVALHO[2], Wilson A. ORTIZ[1], Rafael ZADOROSNY[2], Maycon MOTTA[1]

[1] *Universidade Federal de São Carlos, Departamento de Física, 13565-905, São Carlos, SP, Brazil*
[2] *Universidade Estadual Paulista, Departamento de Física e Química, 15385-000, Ilha Solteira, SP, Brazil*

There is extensive knowledge about the production and optimization of superconducting properties of several $YBa_2Cu_3O_{7-\delta}$ (Y123) structures, which are distinguishable for their high critical temperature and possible use in practical applications. However, particular information regarding the ideal heat treatment to obtain high-quality Y123 specimens in the form of one-dimensional nanostructures is still lacking at present. These Y123 nanowires may be fabricated by different techniques, but the Solution Blow Spinning technique (SBS) has been gaining attention in recent years as the most simplified and low-cost method to provide a large-scale production of nanowires.

To contribute to these efforts we have prepared polymer fiber samples with embedded metals employing the SBS technique. Such polymer composite fibers were then fired and studied by thermogravimetric analysis and precursor ceramic fibers were obtained. Then, samples were divided into batches and subjected to different heat treatments with maximum sintering temperature in the interval of 850ºC–925ºC for 1 h under oxygen flux. X-ray diffraction analysis revealed the presence of the desired Y123 phase in all samples together with small concentrations of secondary phases. Scanning electron microscopy allowed us to investigate the evolution of morphologic characteristics of the Y123 nanowires with sintering temperature, indicating a reduction in the grain boundary density for higher temperatures, i.e., an improvement in the weak-link response. These findings are then confirmed by ac susceptibility and dc magnetization measurements that demonstrate the highest weak-link critical temperature and largest diamagnetic response for the sample sintered at 925ºC/1 h.

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E-mail: davi©df.ufscar.br

P22

Investigating the impact of nanoscale second phase pinning sites in commercial 2G-HTS tapes via vortex-resolved imaging

David COLLOMB[1], Weijia YUAN[2], Min ZHANG[2] Simon BENDING[1]

[1] *University of Bath, Department of Physics, Claverton Down, United Kingdom*
[2] *University of Strathclyde, Applied Superconductivity Laboratory, Department of Electronics and Electrical Engineering, Glasgow, G1 1XQ, United Kingdom*

A high critical current density in high temperature superconducting (HTS) tapes is vital for their employment in future superconducting energy applications, such as for lossless power transmission from remote energy sources [1], superconducting magnetic energy storage systems [2], and superconducting motors and generators [3]. The critical current density is controlled by engineering the pinning force for superconducting vortices. One such pinning strategy involves the introduction and optimisation of nanoscale second phase inclusions. To better understand the pinning mechanism and evaluate the performance of this approach, we perform quantitative magnetic imaging and 'local' magnetisation measurements on commercial GdBaCuO second generation (2G)-HTS tapes hosting Gd_2O_3 second phases using scanning Hall probe microscopy. Our low magnetic field (<1mT) images reveal a low density of very strong pinning sites giving rise to repeatable but highly disordered vortex patterns. Remarkably, the peak fields and full-width-half-maxima (FWHM) of the vortices differ considerably from what is typically observed in 'cleaner' superconductors. Vortex profiles are found to be exceptionally broad, several times larger than the film thickness, with very little temperature dependence in the range 10K to 85K. This suggests that while the vortex line energy restricts the lateral wandering due to pinning by multiple sites to be less than the superconducting layer thickness, the supercurrent flow around the vortices is highly disrupted by the dense array of pinning sites, greatly extending their range as well as that of the magnetic fields associated with them. Additionally, by correlating magnetic imaging with topographic gating and SEM images, we find that CuO_z precipitates and outgrowths, which are ~1μm in size, do not represent effective pinning sites. This suggests that the nanoscale Gd_2O_3 second phases are the dominant pinning sites at low fields over a broad range of temperatures below T_c. Our 'local' magnetisation measurements reveal a noticeable deviation from the accepted 2D Bean critical state model, and irreversible M-H loops have shapes closer to those predicted by a 3D critical state model. This suggests that the critical state profiles are relaxing quite rapidly due to flux creep. Our measurements provide important new insights about the role second phase defects play in enhancing the critical current in 2G-HTS tapes.

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E-mail: dc805©bath.ac.uk

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Synthesis of single crystal $GdFe_{1-x}Co_xAsO$ using salt flux technique

Lan Maria TRAN[1], Michał BABIJ[1], Paweł GÓRNIAK[1, 2], Andrej ZALESKI[1], Masashi TANAK[3], Yoshihiko TAKANO[4]

[1] Institute of Low Temperature and Structural Research, Polish Academy of Sciences in Wroclaw, Okolna 2, 50 422 Wroclaw, Poland
[2] Wrocław University of Science and Technology, Wybrzeże Wyspiańskiego st. 27, 50-370 Wrocław, Poland
[3] National Institute for Materials Science (NIMS), 1-2-1 Sengen, Tsukuba 305-0047 Japan
[4] Graduate School of Engineering, Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata, Kitakyushu 804-8550, Japan

In this contribution we present our approach to synthesizing single crystals of $GdFe_{1-x}Co_xAsO$ superconductors using the salt flux technique.

The study performed on polycrystal $GdFe_{1-x}$CoxAsO-based samples [1-3] suggest a lot of similarities to the $Eu(Fe_{1-x}Co_x)_2As_2$ compounds [4, 5 and references therein].

Similarly as in the Eu-122-systems, the Gd-1111-systems exhibit 3d and 4f magnetism, as well as superconductivity. Moreover, the study suggests that in both cases there is an interplay between the two magnetic sublattices, and an interplay of the magnetic lattices with superconductivity. [1-5]

Our study on the Eu-122-systems have shown that due to the unique magnetic structure on the Eu-sublattice (4f-electrons) we can tune the superconducting state not only by changing the Co-concentration but also by the external magnetic field – and in extreme cases induce superconductivity. We also suggest that due to the Eu-magnetism we could witnessing a vortex state even in zero (external) magnetic field – spontaneous vortex state. [4, 5 and references therein]

Due to the similarities in Eu-122 and Gd-1111 systems we want to investigate the latter compounds to see whether the same behaviour can be induced in these compounds. Because of the anisotropic nature of these phenomena, we need single crystal samples.

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E-mail: l.m.tran©intibs.pl

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Study of the $Gd_{3-x}Ca_xIr_4Sn_{13}$ system in the form of single crystals

Michal BABIJ[1], Lan Maria TRAN[1],

[1]*Institute of Low Temperature and Structure Research PAS Okolna 2, 50-422 Wroclaw, Poland*

Among the Remeika phases – the group of stannides named after their discoverer – we found two of representatives especially interesting. $Gd_3Ir_4Sn_{13}$ compound that exhibit multiple magnetic states associated with the *3d* and *4f* electrons and $Ca_3Ir_4Sn_{13}$ (calcium analogue) which is well known superconductor. However, until now the studies on these materials were limited to the 'pure' parent compounds and did not consider its 'solid solutions' [1,2].

Therefore, these materials have promising properties, where interplay of superconductivity and *f*-electron magnetism could be observed as for the $EuFe_2As_2$-based superconductors. [3] Moreover, there are cases when only for certain directions extraordinary properties are observed (e.g., field induced superconductivity, re-entrance). [3]

In this contribution we present our approach to synthesizing single crystals of $Gd_{3-x}Ca_xIr_4Sn_{13}$ magnetic superconductors, that were used for bulk and microscopic studies.

The single crystals of the parent compounds and their mixtures were synthesized using Sn flux technique. The typical size of obtained crystals was 3 mm × 3 mm × 3 mm. XRD diffraction and EDS spectroscopy studies performed on these crystals confirm purity and chemical composition. Moreover, DC magnetization and AC susceptibility measurements revealed that our samples exhibits superconductivity and various magnetic phases such as localized magnetism and charge density wave.

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E-Mail: m.babij©intibs.pl

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Understanding the angular dependence on magnetic field of pinning activation energy in Fe (Se,Te) thin films

Masood Rauf KHAN[1], Antonio LEO[1], Angela NIGRO[1], Gaia GRIMALDI[2]

[1] Dipartimento di Fisica 'E. R. Caianiello' Università di Salerno, via Giovanni Paolo II, 132, I-84084 Fisciano (SA), Italy
[2] CNR-SPIN Salerno, via Giovanni Paolo II, 132, I-84084 Fisciano (SA), Italy

Understanding the vortex pinning mechanisms in Iron-Based Superconductors (IBS) is crucial for their practical applications. In order to understand the pinning mechanisms acting in Fe (Se,Te) thin films, we analysed the angular dependence of pinning activation energy U (H, θ) as a function of magnetic field and of the angle θ between the ab-plane and the direction of the field. The U (H, θ) curves have been evaluated from magneto-resistivity measurements acquired at different orientations between the applied magnetic fields and sample. We observed that the activation energy decreases with increasing applied magnetic fields and varying θ from 0° to 90. It can be noticed that the magnetic-field dependence of the activation energy follows a power law, $U(H) \propto H^{-\alpha}$ and it is observed a crossover in the α values. The crossover can be interpreted as a transition from a low-field single-vortex pinning to a collective-vortex pinning at higher field. Finally, it is found that in the collective pinning regime, U (H, θ) dependence is smooth and less anisotropic for the Fe (Se,Te) material if compared to other HTS materials.

Email: Mkhan©unisa.it

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In-gap states in the superconducting periodic Anderson model

Panch RAM[1], Vladislav POKORNÝ[2]

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

A magnetic impurity placed on a surface of a conventional superconductor gives rise to discrete sub-gap states in the spectral function known as Yu-Shiba-Rusinov (YSR) states. When an array of magnetic impurities is placed on a superconductor, the individual localized YSR states hybridize and form a continuous band. A recent experimental study in a system of superconducting boron-doped diamond coated with a hydrogen monolayer shows indeed this case [1].
Motivated by the experimental findings, we use the superconducting periodic Anderson model (SCPAM) at half-filling to describe the in-gap YSR bands [2, 3]. The SCPAM consists of a superconducting BCS-type band that hybridizes with a correlated localized band (impurities). We use the dynamical mean-field theory method with quantum Monte Carlo and iterative perturbation theory as impurity solvers to study the model on a square lattice [4, 5]. We find the spectral function for the localized electrons shows in-gap YSR-like bands and a transition from a singlet to doublet ground state similar to the 0-pi transition known from the superconducting impurity Anderson model.

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E-mail: panchram©karlov.mff.cuni.cz

P27

Superconductivity and topological behavior in gallenene

Mikhail PETROV

University of Antwerp, Physics department, Prinsstraat 13, 2000, Belgium

Structural simplicity combined with a rich variety of electronic properties are key signatures of elemental 2D materials and every new member of this family attracts substantial interest. By means of accurate ab initio calculations in combination with anisotropic Eliashberg theory, we reveal that two recently fabricated monolayer phases of gallium, Ga-100 and Ga-010 (also referred to as gallenenes), are conventional superconductors with sizable critical temperatures (7-10 K) surpassing that of the bulk alpha-gallium (4 K) [1]. The superconducting state of Ga-100 is represented by three distinct gaps in contrast to Ga-010 which has one anisotropic gap. Ga-100 attracts particular interest due to it being isostructural to graphene and thus representing structurally the simplest superconductor to-date. For Ga-010, we investigated the effect of hydrogenation on superconductivity, and we report that not only does the hydrogenation enhance the critical temperature up to 17 K, but also it induces two distinct superconducting gaps.

Additionally, we investigated topology of the Ga-100, and found that above the Fermi level, there is a graphene-like Dirac cone which represents highly prominent edge states and thus suggests non-trivial topology of the monolayer. Thus, we reveal Ga-100 as a promising material with superconducting and topological quantum phases in coexistence. Such mixture of phases in combination with the striking structural simplicity makes Ga-100 a promising material to consider for making heterostructures. Ga-010 shows that its superconducting properties can be significantly enhanced by chemical functionalisation.

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E-mail: Mikhail.Petrov©uantwerpen.be

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Andreev molecule in parallel InAs nanowires

Olivér KÜRTÖSSY[1], Zoltán SCHERÜBL[1,2], Gergő FÜLÖP[1], István Endre LUKÁCS[3], Thomas KANNE[4], Jesper NYGÅRD[4], Péter MAKK[1], Szabolcs CSONKA[1]

[1] Department of Physics, Budapest University of Technology and Economics and Nanoelectronics 'Momentum' Research Group of the Hungarian Academy of Sciences, Budafoki út 8, 1111 Budapest, Hungary
[2] Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG, PHELIQS, 38000 Grenoble, France
[3] Center for Energy Research, Institute of Technical Physics and Material Science, Konkoly-Thege Miklós út 29-33., H-1121, Budapest, Hungary
[4] Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

Coupling individual atoms via tunneling fundamentally changes the state of matter: electrons bound to atomic cores become delocalized resulting in a change from an insulating to a metallic state, as it is well known from the canonical example of solids. A chain of atoms could lead to more exotic states if the tunneling takes place via the superconducting vacuum and can induce topologically protected excitations like Majorana or parafermions [1]. Toward the realization of such artificial chains, coupling a single atom to the superconducting vacuum is well studied, but the hybridization of two sites via the superconductor was not yet reported. The peculiar vacuum of the BCS condensate opens the way to annihilate or generate two electrons from the bulk resulting in a so-called Andreev molecular state[3][4]. By employing parallel nanowires with an Al superconductor shell, two artificial atoms were created at a minimal distance with an epitaxial superconducting link between. Hybridization via the BCS vacuum was observed between the two artificial atoms for the first time, as a demonstration of an Andreev molecular state.

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E-mail: okurtossy©edu.bme.hu

P29

Superconducting Dirac point in proximetized graphene

Gopi Nath DAPTARY[1], Eyal WALACH[1], Efrat SHIMSHONI[1], Aviad FRYDMAN[1]

[1] *Bar-Ilan University, Department of Physics, Ramat-Gan 5290002, Israel*

Two-dimensional (2D) materials, composed of single atomic layers, have attracted vast research interest since the breakthrough discovery of graphene. One major benefit of such systems is the simple ability to tune the chemical potential by back-gating, in-principle enabling to vary the Fermi level through the charge neutrality point, thus tuning between electron and hole doping. For 2D Superconductors, this means that one may potentially achieve the regime described by Bose Einstein Condensation (BEC) physics of small bosonic tightly bound electron pairs. Furthermore, it should be possible to access both electron and hole based superconductivity in a single system. However, in most 2D materials, an insulating gap opens up around the charge neutrality point, thus preventing approach to this regime. Graphene is unique in this sense since it is a true semi-metal in which the un-gapped Dirac point (DP) is protected by the symmetries. In this work we show that single layer graphene, in which superconducting pairing is induced by proximity to regions of a low density superconductor, can be tuned from hole to electron superconductivity through an ultra-low carrier density regime where the BEC limit is effectively realized. We study, both experimentally and theoretically, the vicinity of this "Superconducting Dirac point" (SDP) (Figure 1©) and find an unusual situation where reflections at interfaces between normal and superconducting regions within the graphene, suppress the conductance (Figure 1(b)) and, at the same time, Andreev reflections maintain a large phase breaking length. In addition, the Fermi level can be adjusted so that the momentum in the normal and superconducting regions perfectly match, giving rise to ideal Andreev reflection processes.

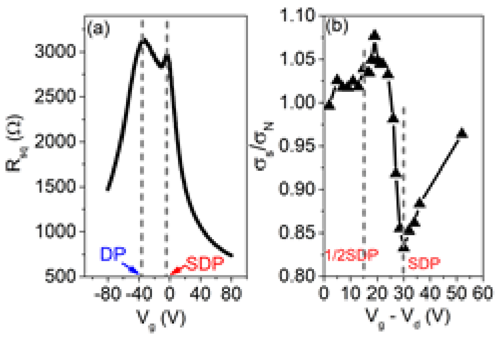

Figure 2: © Sheet resistance as a function of gate voltage of bilayer of single layer graphene and disordered indium oxide film (SLG/InO). (b) Relative conductivity σ_S/σ_N (σ_S is the differential conductivity of bilayer of SLG/InO and σ_N is the differential conductivity of bare SLG) as a function of bias voltage V_{DC}. Measurements were performed at T=0.33K and B=0T.

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E-mail: gopinathdap2011©gmail.com

P30

Magnetic flux avalanches in nanoscale wedge-shaped superconducting thin films

E. A. ABBEY[1], L. B. L. G. PINHEIRO[2], A. J. CHIQUITO[1], J. VAN DE VONDEL[3], A. V. SILHANEK, M. MOTTA[1], W. A. ORTIZ[1]

[1] *Department of Physics, Federal University of São Carlos, 13565-905 São Carlos, SP, Brasil*
[2] *Federal Institute of São Paulo, São Carlos Campus, 13565-905 São Carlos, Brasil*
[3] *INPAC, K. U. Leuven, Celestijnenlaan 200D, B–3001 Leuven, Belgium*
[4] *Department of Physics, University of Liège, B-4000 Sart Tilman, Belgium*

Vortex matter in superconductors has been the focus of research by theoretical and experimental groups around the world (1). When developing superconducting devices patterned on thin films, it should be borne in mind that flux avalanches can occur for some materials in a certain range of applied fields and temperatures. Technological applications of thin films can be threatened by the occurrence of magnetic flux avalanches of thermomagnetic origin appearing in a large part of the superconducting phase (2). Using a quantitative magneto-optical imaging technique, this work deals with thin films of Pb in the distinctive form of a wedge. The thicknesses of the wedge-shaped samples decrease almost linearly to a non-zero minimum value at the opposite edge. AC and DC magnetometry measurements were conducted to characterize the superconducting properties of the thin wedge films. Magneto-optical images revealed interesting features of the dendritic flux avalanches in the films. Wedge-shaped systems open up a new way of tuning the critical current in the film, allowing one to study the resulting changes in the flux penetration patterns throughout the films. The observation of flux avalanches reported here implies that, as usual, attention should be paid to this feature when films with variable thickness are considered for possible applications.

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E-mail: elijah@df.ufscar.br

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