NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES

Work is supported by COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

COST is supported by the EU Framework Programme Horizon 2020

Eilat, Israel • February 17-20, 2019

International Workshop

Probing Coherent Superconducting Hybrids at the Nanoscale

Cost Action CA16218

17-20 February 2019

Program and Abstract Book

COST Workshop Program

	Sunday	Monday	Tuesday	Wednesday
	Feb 17	Feb 18	Feb 19	Feb 20
		Vortices Chair: Yonathan Anahory	Coexisting order Chair: Hadar Steinberg	Tunneling experiment I Chair: Peter Samuely
9:00		Alejandro Silhanek	Deung-Jang Choi	Csonka Szabolcs
9:25		Milosevic Milorad	Jeroen Custers	Isabel Guillamón
9:50		Hermann Suderow	Alexander Buzdin	Emanuele Dalla Torre
10:15		Eylon Persky	Jonathan Ruhman	Gerbold Ménard
10:40		Coffee		
		SQUIDs and other devices Chair: Beena Kalisky	Coexisting order II Chair: Jonathan Ruhman	Tunneling experiment II Chair: Emanuele Dalla Torre
11:10		Joris Van de Vondel	Gleb Kakazei	Haim Beidenkopf
11:35		Jan-Michael Mol	Eytan Grosfeld	Hadar Steinberg
12:00		Amit Keren	Zuzana Pribulova	Hen Alpern
12:25		Nir Bar-Gil		
13:00	Arrival	Lunch		
14:00			Excursion	Departure (14:00)
		Josephson physics Chair: Amit Keren		
15:00		Shay Hacohen-Gourgy		
15:25		Maciej Zgirski		
15:50		Martin Žonda		
16:15		Coffee		
		Vortices II Chair: Hermann Suderow	Complex oxide Chair: Alexander Buzdin	
16:50		Oleksandr Dobrovolskiy	Christopher, Bell	
17:15		Adrian Crisan	Daniela Stornaiuolo	
17:45		Yoram Dagan	Lior Embon	
18:10			Super poster	
	Dinner			
20:00-22:00		MC meeting	Poster session	

The workshop “Probing Coherent Superconducting Hybrids at the Nanoscale" is organized in the framework of the COST action CA16218 and will focus on recent advances in local probes for the investigation of nanoscale hybrids.

We will bring together leading research groups in order to stimulate discussions between device developers, experimental techniques for probing quantum coherence in superconducting devices, and theoreticians. The focus will be on local probes, such as scanning tunneling microscopy, scanning SQUID microscopy, local temperature sensors, transport of nanoscale devices, specific heat measures etc. Although the focus will be set on imaging techniques which are able to probe superconductivity at the nanoscale, the workshop is also open to experimental and theoretical works which deal with systems where the superconducting condensate is confined to or interacting with nanoscale domains.

The workshop includes outstanding contributions about specific applications of probing coherent superconducting hybrids at the nanoscale and allows young researchers to present and discuss their results to their peers. The Workshop will cover all related subjects, with focus on the following topic from a local probe point of view:

1. Unconventional superconductivity and proximity phenomena in multi-band, magnetic, topological and low-dimensional materials.
2. Josephson junctions and arrays
3. Superconductor/ferromagnet hybrids.
4. Coherent phenomena at mesoscopic and nanoscale (including vortex physics).
5. Novel materials, hybrids, properties.
6. Challenges in theoretical modelling of coherent superconducting hybrids.
7. Applications benefiting from quantum coherence of superconducting hybrids.

Invited Talks – Abstracts

Statistics of thermomagnetic breakdown in Nb superconducting films

Alejandro SILHANEK[1], Sylvain BLANCO ALVAREZ[1], Jérémy BRISBOIS[1], Sorin MELINTE[2], Roman KRAMER[3]

[1] *Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium.*
[2] *Institute of Information and Communication Technologies, Electronics and Applied Mathematics (ICTM),*
Institut de la Matière Condensée et des Nanosciences (IMCN), Université catholique de Louvain, Louvain-la-Neuve, Belgium.
[3] *Institut Néel, CNRS, Université Grenoble Alpes, Grenoble, France.*

As dissimilar as they might appear, lightning during a dielectric breakdown, failure of interconnects in integrated circuits, snow avalanches on mountain slopes, or popcorn explosion share a common physics ground corresponding to the triggering of a catastrophic event when a threshold stress is exceeded. Interestingly, even if the same experience is repeated under identical environmental conditions, the event will not happen at exactly the same threshold stress. The question as to whether the statistical distribution of this threshold stress follows a universal law for all phenomena is experimentally difficult to answer, since exceeding the threshold point brings along dramatic consequences leading to irreversible changes in the system. Remarkably, superconducting materials offer a unique opportunity to investigate the statistical distribution of similar catastrophic events consisting of non-destructive magnetic flux avalanches in the same sample and thus ruling out the spreading factors associated to unavoidable uncontrollable variations in the replicas of the system.

Using the magneto-optical imaging technique to record images of the magnetic field in a superconducting Nb sample, we cycled 2000 times the same thermomagnetic breakdown experiment under identical conditions. Based on this experience, we determined the probability density function of the threshold field of thermomagnetic breakdown and tracked its temperature dependence with unprecedented resolution. Strikingly, we identified a bimodal distribution of the threshold field, with a transition from filamentary to dendritic branching avalanches, representing a unique fingerprint associated to avalanches initiated by a thermomagnetic instability, with no counterpart in other catastrophic events such as earthquakes or granular avalanches.

E-mail: asilhanek@uliege.be

Advances in Ginzburg-Landau simulations of superconductivity

Milorad V. MILOŠEVIĆ

NANO Center of Excellence, University of Antwerp
Groenenborgerlaan 171, B-2020 Antwerpen, Belgium

While modern experimental techniques are enabling increasingly multifold studies of superconductivity (from in-situ synthesis to transport and scanning-probe measurements), the community has witnessed an increasing gap between the ab initio calculations and those on mean-field levels, and even more to the desired device modelling. At present, the only tool able to address the needed multi-scale modelling of superconductors, nanopatterned into electronic circuitry, are the advanced Ginzburg-Landau simulations. We have recently developed a multiscale approach where first information about fermiology, vibrational modes, and electron-phonon coupling are obtained from first principles for the materials of interest [1], to be subsequently translated into (anisotropic) superconducting properties, that can further serve to properly parametrize mean-field models to capture the behavior of that superconductor in applied magnetic field and electric current.

In this talk, I will review our recent further breakthroughs in that respects, and show realized numerical experimentation on circuits of arbitrary shape (on advanced size and time scale), variable thickness, inhomogeneous parameters, with self-consistent account for magnetic field distribution, the electric field generated under applied current, incorporated heating effects, thus fully characterized behavior of the superconducting condensate in non-equilibrium conditions that reveals physics behind improved or worsened performance of various realistic transport devices [2-4].

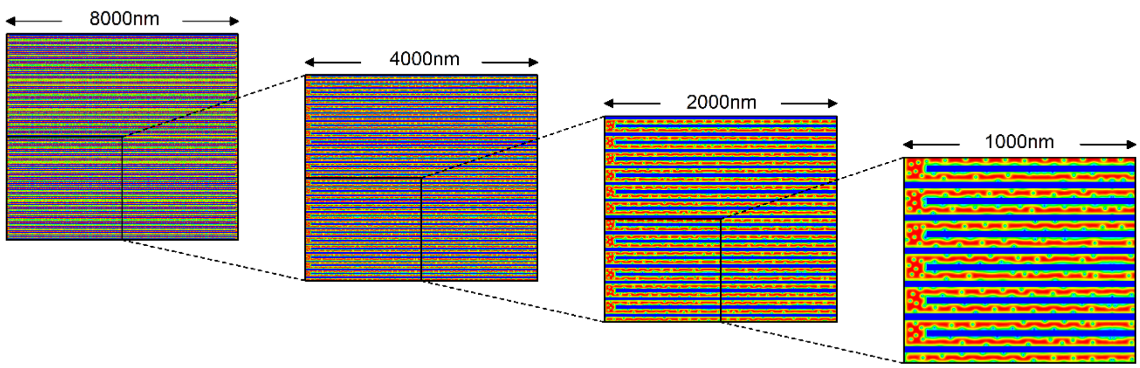


Figure 1: Snapshot of numerically simulated vortex dynamics in a NbN superconducting meander of size and geometry as typically used for single-photon detection.

References

[1] J. Bekaert et al., Phys. Rev. B 94, 144506 (2016); Phys. Rev. B 96, 094510 (2017).
[2] L. Embon et al., Nature Commun. 8, 85 (2017).
[3] J. Lombardo et al., Nanoscale 10, 1987 (2018).
[4] R. Cordoba et al., in preparation.

Email: milorad.milosevic@uantwerpen.be

Scanning probe microscopy of vortices in tilted magnetic fields

Hermann SUDEROW

[1] Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain

Many practical applications of high T_c superconductors involve layered materials and magnetic fields applied on an arbitrary direction with respect to the layers. When the anisotropy is very large, Cooper pair currents can circulate either within or perpendicular to the layers. Thus, tilted magnetic fields lead to intertwined lattices of Josephson and Abrikosov vortices, with quantized circulation across and within layers, respectively. Transport in such intertwined lattices has been studied in detail, but direct observation and manipulation of vortices remains challenging. Here, we present magnetic force microscopy experiments in tilted magnetic fields in the extremely quasi two dimensional superconductor Bi2Sr2CaCu2O8. We trigger Abrikosov vortex motion in between Josephson vortices, and that Josephson vortices in different layers can be brought on top of each other. Our measurements suggest that intertwined lattices in tilted magnetic fields can be intrinsically easy to manipulate thanks to the mutual interaction between Abrikosov and Josephson vortices.

I will further discuss recent insight on the vortex lattice at very small magnetic fields in the conventional superconductor β-Bi_2Pd, where we find we find clusters of vortices together with large vortex free locations.

References

[1] Attractive interaction between superconducting vortices in tilted magnetic fields. Accepted in Communications Physics (2019).

E-mail: Hermann.suderow@uam.es

Scanning SQUID imaging of quantum phase transitions

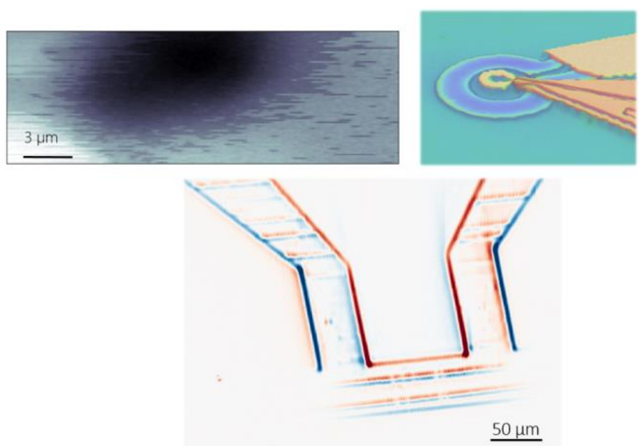
Eylon PERSKY[1], Anna KREMEN[1], Beena KALISKY[1]

[1] Bar Ilan University, Department of Physics and Institute of Nanotechnology and Advanced Materials, Ramat Gan 52900, Israel

Close to quantum critical points, systems become susceptible to small local perturbations, such as defects and disorder. Understanding how these perturbations affect the system near the transition, is key to understanding the underlying electronic phases involved.

I will describe how we use sensitive magnetic imaging to track the spatial distribution of electronic states in systems undergoing phase transitions. Near the superconductor-insulator transition in NbTiN we use scanning superconducting quantum interference device (SQUID) susceptometry to track superconducting fluctuations and detect non-trivial behavior near the quantum critical point. Near the metal to insulator transition at the 2D LaAlO3/SrTiO3 interface we use SQUID magnetometry and identify how different types of defects control the current distributions near the transition.

Collaborators: Hwang (Stanford), Caviglia (TU Delft), Frydman (Bar Ilan), Baturina (Novosibirsk), Trivedi (Ohio State), Ruhman (Bar Ilan).



Nano-SQUIDs with controllable weak links created via current-induced atom migration

Joris Van de Vondel[1], Wout Keijers[1], Xavier D. A. Baumans[2], Željko L. Jelić[3], Ritika Panghotra[1], Joseph Lombardo[2], Vyacheslav. S. Zharinov[1], Jorge P. Nacenta[4], Victor V. Moshchalkov[1], Roman B. G. Kramer[4], Milorad V. Milošević[3], Alejandro V. Silhanek[2]

[1]*Laboratory of Solid-State Physics and Magnetism, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium.*
[2]*Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, 4000 Sart Tilman, Belgium.*
[3]Departement Fysica, Universiteit Antwerpen, Groenenborgerlaan 171, 2020 Antwerpen, Belgium.
[4]Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France.

As the most sensitive magnetic field sensor, the superconducting quantum interference device (SQUID) became an essential component in many applications due to its unmatched performance. Through recently achieved miniaturization, using state-of-the-art fabrication methods, this fascinating device extended its functionality and became an important tool in nanomaterial characterization.

During the past years we have developed an accessible and yet powerful technique of targeted atom displacement in order to modify the properties of superconducting weak links. Recently, we showed that the sequential repetition of such customized electro-annealing in a single niobium (Nb) nanoconstriction can broadly tune the superconducting critical temperature T_c and the normal-state resistance R_n in the targeted area [1]. Once a sizable R_n is reached, clear magneto-resistance oscillations are detected along with a Fraunhofer-like field dependence of the critical current, indicating the formation of a weak link but with further adjustable characteristics.

In a next step we used electromigration on an Aluminium DC nano-SQUID to modify the parallel weak links beyond the limits of conventional lithography [2]. The controllability of our protocol allows us to characterize in situ the full superconducting response after each electromigration step. From this in-depth analysis, we reveal an asymmetric evolution of the weak links at cryogenic temperatures. A comparison with time resolved scanning electron microscopy images of the atom migration process at room temperature confirms the peculiar asymmetric evolution of the parallel constrictions. Moreover, we observe that when electromigration has sufficiently reduced the junction's cross section, superconducting phase coherence is attained in the dissipative state, where magnetic flux readout from voltage becomes possible.

References

[1] Joseph Lombardo, Željko L. Jelić, Xavier D. A. Baumans, Jeroen E. Scheerder, Jorge P. Nacenta, Victor Moshchalkov, Joris Van de Vondel, Roman B. G. Kramer, Milorad V. Milosevic and Alejandro V Silhanek, *Nanoscale* **10**, 1987 (2018)

[2] Wout Keijers, Xavier D. A. Baumans, Ritika Panghotra, Joseph Lombardo, Vyacheslav. S. Zharinov, Alejandro V. Silhanek, and Joris Van de Vondel, *Nanoscale* **10**, 21475 (2018)

E-mail: joris.vandevondel@kuleuven.Be

Scanning SQUID Microscopy with Dispersive SQUIDs

Jan-Michael Mol[1], Farshad Foroughi[1], Tristan Müller[1], Eugen Kammerloher[1], Jennifer Arps[1], John R. Kirtley[3], Kathryn A. Moler[3], and Hendrik Bluhm[1,2]

[1] 2nd Institute of Physics C, Quantum Technology Group, RWTH Aachen University, Germany
[2] JARA-FIT Institute Quantum Information, RWTH Aachen University and Forschungszentrum Jülich GmbH, Germany
[3] Center for Probing the Nanoscale, Stanford University, Stanford, USA

Scanning SQUID Microscopy (SSM) serves as a local probe of magnetic flux created by surface magnetic fields of solid-state materials. It is therefore particularly suitable for studies on superconductors and mesoscopic systems. In unconventional superconductors, it enables measurements of local superfluid density and magnetism [1]. Experiments on mesoscopic rings can give insight into coherent phenomena in normal metals [2]. Conventional DC SQUIDs use flux-dependent current-voltage-characteristics as readout. Here, we present a novel approach by employing SQUIDs with dispersive readout for scanning probe microscopy. The SQUID is operated as a nonlinear oscillator driven at microwave frequencies. Its resonance frequency is both flux- and power-dependent. The different sensor designs feature (sub-)micron spatial resolution with integrated superconducting coils for local application of magnetic fields and a gradiometric circuit topology for background cancellation. We extensively benchmarked our SQUIDs at 4K and reached a flux noise down to $80\,\mathrm{n}\Phi_0\mathrm{Hz}^{-1/2}$ above 10 kHz at a bandwidth of 200 MHz [3]. Our scanning SQUID microscope is housed inside a wet dilution refrigerator with a base temperature of 20 mK. Low temperature, good flux sensitivity and high measurement bandwidth make our microscope a useful platform for studies on broadband dynamics of quantum coherent processes such as Majorana quasiparticle switching in topologically superconducting mesoscopic rings [4].

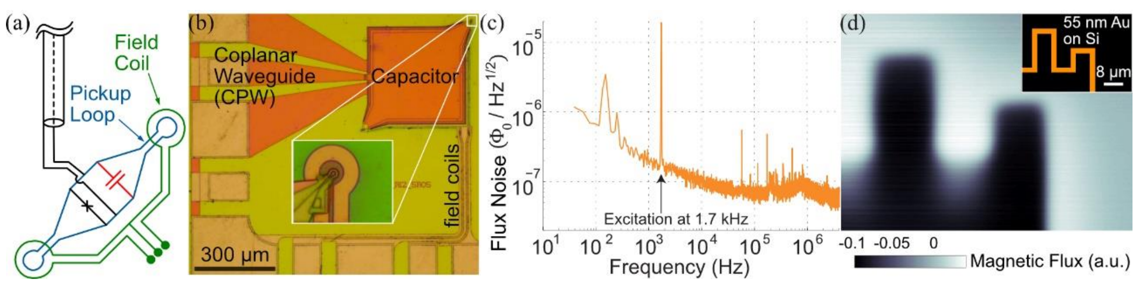


FIG. 1 (a) Schematic circuit diagram of dispersive SQUID. (b) Optical image of same chip. (c) Flux Noise at 4K (calibrated by known signal at 1.7 kHz). (d) Imaging magnetic fields created by running a current through a gold stripline (see inset).

References

[1] J.A. Bert, B. Kalisky, C. Bell, M. Kim, Y. Hikita, H.Y. Hwang, and Kathryn A. Moler, Nat. Phys. 7, 767 (2011), https://doi.org/10.1038/nphys2079

[2] H. Bluhm, N.C. Koshnick, J.A. Bert, M.E. Huber, K.A. Moler, Phys. Rev. Lett. 102, 136802 (2009), https://doi.org/10.1103/PhysRevLett.102.136802

[3] F. Foroughi, J.-M. Mol, T. Müller, J. Kirtley, K.A. Moler, and H. Bluhm, Appl. Phys. Lett. 112, 252601 (2018), https://doi.org/10.1063/1.5030489

[4] E.M. Spanton, M.Deng, S. Vaitiekėnas, P. Krogstrup, J. Nygård, C.M. Marcus, and K.A. Moler, Nat. Phys. 13, 1177 (2017), https://doi.org/10.1038/nphys4224

E-mail: mol@physik.rwth-aachen.de

The Stiffnessometer - a Magnetic-Field-Free Superconducting Stiffness Meter and it applications

Amit KEREN[1], Itzik Kapon[1], Itai Mangel[1], Nitzan Blau[1], Nir Gavish[2]

[1] *Technion-Israel Institute of Technology, Department of Physics, Haifa 3200003, Israel*

[2] *Technion-Israel Institute of Technology, Department of Mathematics, Haifa 3200003, Israel*

We present a new method to measure the superconducting stiffness tensor $\bar{\rho}_s$, without subjecting the sample to a magnetic field [1]. The method is based on the London equation $\mathbf{J} = -\bar{\boldsymbol{\rho}}_\mathbf{s}\mathbf{A}$, where $\mathbf{J}$ is the current density and $\mathbf{A}$ is the vector potential. Using rotor free $\mathbf{A}$ and measuring $\mathbf{J}$ via the magnetic moment of superconducting rings, we extract $\bar{\rho}_s$ and coherence length ξ at $T \to T_c$. The technique, named Stiffnessometer, is sensitive to very small stiffness or long ξ, which translates to penetration depth on the order of a few millimeters or ξ on the scale of few microns. We will demonstrate the application of this methods to anisotropic superconductors and films as thin as 3nm.

References

[1] Itzik Kapon, Katrine Golubkov, Nir Gavish, and Amit Keren; Cond-mat 1705.00624

E-mail: keren@physics.technion.ac.il

Toward hybrid diamond-superconducting devices

Nir Bar-Gill[1,2], Yoav Romach[2], Elad Farchi[1]

[1] *Hebrew University, Dept. of Applied Physics, Jerusalem, Israel*
[2] *Hebrew University, Racah Institute of Physics, Jerusalem, Israel*

Nitrogen Vacancy (NV) centers in diamond have emerged over the past few years as well-controlled quantum systems, with promising applications ranging from quantum information science to magnetic sensing.

In this talk, I will first introduce the NV center system and the experimental methods used for measuring them and controlling their quantum spin dynamics.

I will then present our work on using the NV centers as magnetic sensors, in the context of measuring quantitative, vectorial magnetic fields of integrated condensed-matter samples, with an example of geological samples (as a new tool for paleomagnetometry, in collaboration with Prof. Ron Shaar, [1]. I will also demonstrate the modality of studying magnetic fluctuations through advanced quantum noise spectroscopy [2,3].

Finally, I will describe our efforts toward integrating nanofabricated superconducting structures on the diamond surface in order to mediate coherent NV-NV interactions, with the goal of establishing a scheme for scalable quantum spin simulators.

References

[1] E. FARCHI, Y. EBERT, D. FARFURNIK, G. HAIM, R. SHAAR AND N. BAR-GILL, SPIN 7, 3, 1740015 (2017)
[2] Y. Romach et. al., Phys. Rev. Lett. 114, 017601(2015).
[3] Y. Romach et. al., Phys. Rev. Applied, accepted (2019).

E-mail: bargill@phys.huji.ac.il

The Josephson Parametric Amplifier – from magnetometry to quantum trajectories

Shay Hacohen-Gourgy

[1] Technion – Israel institute of technology, Department of physics, Haifa 3200003, Israel

The Josephson parametric amplifier gives the ability to probe near the quantum limit at microwave frequencies and at millikelvin temperatures. These precision devices, together with advanced microwave control, allow for magnetometry with unmatched bandwidth and precision, faithfully track the quantum trajectories of superconducting qubits, probe qubits with squeezed light, and to canonically measure the phase of a single photon. In this talk I will describe the Josephson parametric amplifier and explain its usage and imperative role in some of the above settings.

E-mail: shayhh@physics.technion.ac.il

Nanosecond thermometry with Josephson junction

Maciej ZGIRSKI[1], Marek FOLTYN[1], Alexander SAVIN[2],
Konrad NOROWSKI[1], Matthias MESCHKE[2], Jukka PEKOLA[2]

[1] Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL 02668 Warsaw, Poland
[2] Low Temperature Laboratory, Department of Applied Physics, Aalto University School of Science, P.O. Box 13500, 00076 Aalto, Finland

Thermometry is a key in studies of thermodynamics - discipline investigating heat flows arising from difference in temperature between two bodies. In our pioneering experiment we employ a superconducting weak link (Fig.1) to measure rapidly changing electron temperature in a long superconducting nanowire with nanosecond resolution [1]. Investigation of thermal properties in nanoscale is much less common than corresponding electrical and magnetic studies. Partially it is because of the lack of fast thermometers that would be able to trace thermal transients appearing when electrical circuit is driven out of equilibrium due to, say, rapidly changing current responsible for Joule heating or photons absorbed in the bolometer. Yet, a proper understanding of thermal processes is essential for failure-free functioning of quantum circuits, involving design of nanoscale calorimeters and bolometers. In our quest to measure temperature even faster we utilized the ability of current-carrying superconducting weak link to instantaneously switch from superconducting to normal state. This switching depends on temperature, thus providing a feature required for a temperature sensor. The ease of integration, true nanometer size and simplicity make our thermometer a good candidate for exploring thermodynamics of low temperature quantum circuits. The method can prove to be very attractive in determination of vanishingly small heat capacities and studying heat exchange mechanisms involving real-time visualization of hot electron diffusion in nanostructures and calorimetric counting of single microwave photons.

References

[1] M.Zgirski, M.Foltyn, A.Savin, K.Norowski, M.Meschke, J.Pekola, **Phys. Rev. Appl. 10, 044068, 2018**

E-mail: zgirski@ifpan.edu.pl

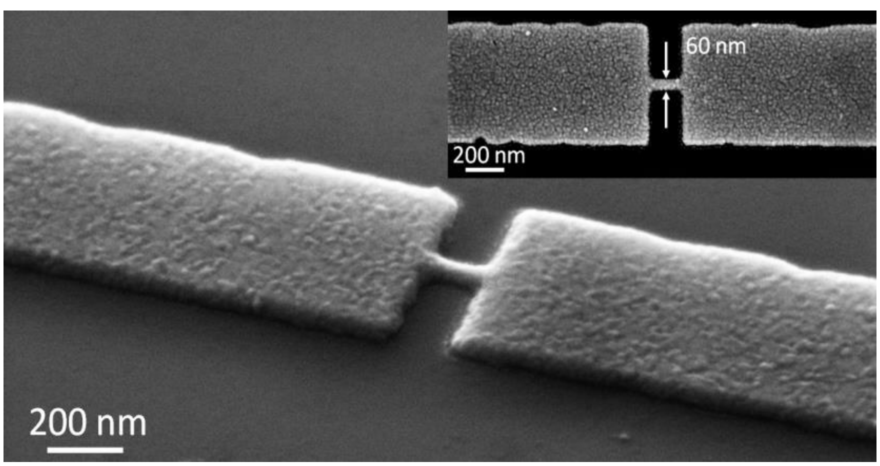


Fig.1. The nanoscale thermometer offering nanosecond resolution.

Josephson-phase-controlled interplay between correlation effects and electron pairing in superconducting quantum dot setup

Martin ŽONDA[1,2] and **Tomáš NOVOTNÝ[2]**

[1] Albert Ludwig University of Freiburg, Institute of Physics, Hermann-Herder-Strasse 3, Freiburg, Germany [2] Department of Condensed Matter Physics, Faculty of Mathematics and Physics,
Charles University in Prague, Ke Karlovu 5, CZ-121 16 Praha 2, Czech Republic

We will present a theoretical study of the subgap spectrum of the interacting single-level quantum dot coupled between two superconducting reservoirs and probed by a metallic normal lead. This hybrid nanosystem allows for the phase-tunable interplay between the correlation effects and the proximity-induced electron pairing. This interplay results in the singlet-doublet crossover and the phase-dependent Kondo effect. We have investigated the spectral function, induced local pairing, Josephson supercurrent, and Andreev conductance in a wide range of system parameters by the numerical renormalization group and quantum Monte Carlo calculations along with perturbative treatments in terms of the Coulomb repulsion and the hybridization term.

Our results address the correlation effects reflected in dependencies of various quantities on the local Coulomb interaction strength as well as on the coupling to the normal lead. We have quantitatively established the phase-dependence of the Kondo temperature. We will show that it can be read off from the half-width of the zero-bias enhancement in the Andreev conductance in the doublet phase which can be experimentally measured by the tunneling spectroscopy.

References

[1] T. Domański, M. Žonda, V. Pokorný, G. Górski, V. Janiš, T. Novotný; Phys. Rev. B **95**, 045104 (2017).

[2] A. Kadlecová, M. Žonda, T. Novotný; Phys. Rev. B **95**, 195114 (2017).

E-mail: (martin.zonda@physik.uni-freiburg.de)

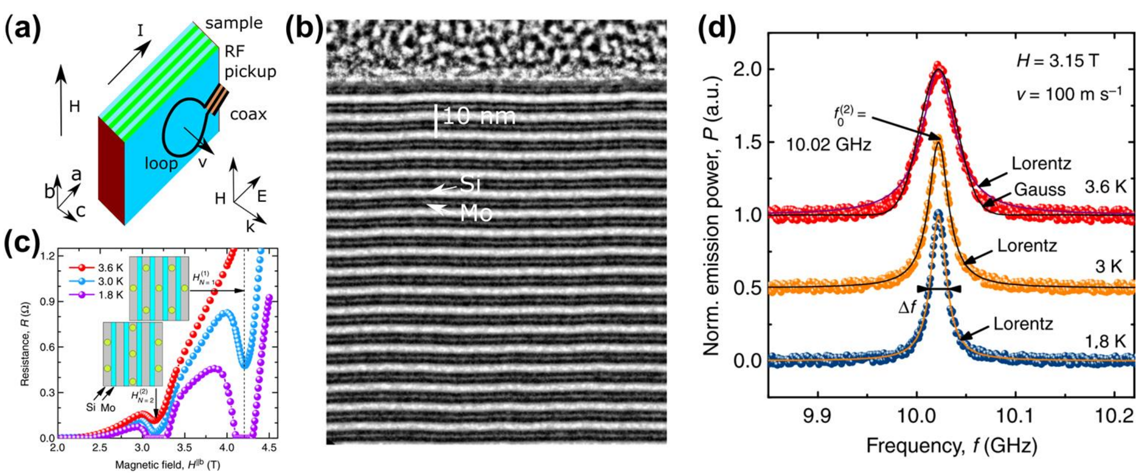
Microwave radiation from superconducting vortices in Mo/Si superlattices

O. V. Dobrovolskiy[1], V. M. Bevz[2], M. Yu. Mikhailov[3], O. I. Yuzephovich[3], V. A. Shklovskij[2], R.V. Vovk[2], M. I. Tsindlekht[4], R. Sachser[1] and M. Huth[1]

[1] *Physikalisches Institut, Goethe University, Frankfurt am Main, Germany*
[2] *Physics Department, V. N. Karazin Kharkiv National University, Kharkiv, Ukraine*
[3] *B.Verkin Institute for Low Temperature Physics and Engineering of the NAS of Ukraine, Kharkiv, Ukraine*
[4] *The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem, Israel*

Most of superconductors in a magnetic field are penetrated by a vortex lattice. In the presence of a transport current causing fluxons to cross sample edges, emission of electromagnetic (em) waves is expected due to the continuity of tangential components of the fields at the surface [1]. Yet, such a radiation has not been observed so far due to low radiated power levels and lacking coherence in the vortex motion. To recover coherence, a washboard pinning potential at matching fields can be used [3, 4]. Recently, we observed emission of em waves from vortices crossing the layers of a superconductor/insulator Mo/Si superlattice [2]. The emission spectra consist of harmonically related peaks which can be finely tuned in the 5 to 50 GHz range by the dc bias current and, coarsely, by the in-plane magnetic field value. The typical radiation linewidths at $0.5T_c$ amount to 10^{-3}, i.e. are by one-to-two orders of magnitude larger than those for intrinsic Josephson junctions in BSCCO [5] and a factor of ten smaller than for the em generation from moving fluxons in Nb/Au hybrides [6]. Our findings go beyond the theoretical model [1], requiring to theoretically address the possibility for em radiation from individual layers. In all, Mo/Si superlattices have been shown to act as dc-tunable microwave generators bridging the frequency gap between conventional rf oscillators and (sub-)terahertz generators relying upon the Josephson effect.

Fig. 1. (a) Geometry of the em detection from (b) the Mo/Si superlattice. (c) Reentrant superconductivity and resistance minima at fundamental matching fields at which (d) the em radiation has been detected.



References

[1] L. N. Bulaevskii and E. M. Chudnovsky, Phys. Rev. Lett. **97**, 197002 (2006).
[2] O. V. Dobrovolskiy *et al.* Nature Commun. **9**, 4927 (2018).
[3] N. Yu. Fogel *et al.* Phys. Rev. B **59**, 3365 (1999).
[4] O. V. Dobrovolskiy, Physica C **533**, 80 (2017).
[5] U. Welp, K. Kadowaki, K. and R. Kleiner, Nature Photon. **7**, 702 (2013).
[6] O. V. Dobrovolskiy *et al.* Appl. Phys. Lett. **112**, 152601 (2018).

E-mail: Dobrovolskiy@Physik.uni-frankfurt.de

Dynamic Liquid-like Vortex Phase and Pinning Potential in Bi:2212 Films in Low Magnetic Fields Probed by Scanning Hall Probe Microscopy

Adrian CRISAN[1], Simon BENDING[2]

[1] National Institute of Materials Physics Bucharest, 077125 Magurele, Romania
[2] University of Bath, Department of Physics, Claverton Down, Bath BA2 7AY, Bath, UK

We have used Scanning Hall Probe Microscopy (SHPM) to obtain direct evidence of a dynamic liquid-like vortex state in highly anisotropic Bi:2212 thin films at very low magnetic induction which might be related to the "re-entrant" vortex liquid phase due to long wavelength fluctuations at very low fields when the lattice shear modulus becomes exponentially small, as predicted by Blatter et.al., [1].

From the analysis of the lifetimes of trapped vortices before thermally activated depinning we were able to make a rough estimation of the pinning potential. Knowing the time needed to complete one scan (6 s), we can estimate the time τ spent by vortices on their respective pinning centres. At these low values of magnetic induction our system is approximately in the isolated vortex regime and the depinning process is expected to be a simple thermally activated one described by $\tau = \tau_0 \exp(U/k_B T)$, where τ_0 is the inverse of the macroscopic attempt frequency ($\sim 10^6$ Hz) and U is the pinning potential of the individual pinning centre.

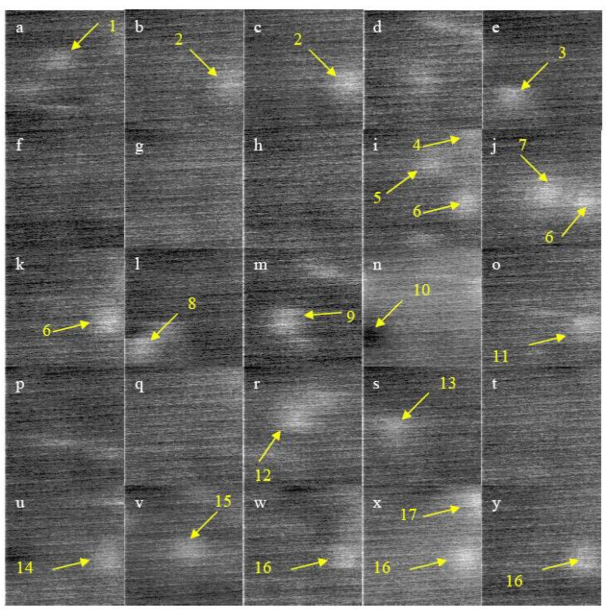


Fig. 1 Twenty-five consecutive SHPM images captured in a perpendicular applied field of 3 Oe. Scan *a* started at t=0 s, scan *b* started at t=6 s, and so on up to scan *y* that started at t=144 s. Numbers from 1 to 17 are individual vortices trapped on pinning centres indicated by arrows.

Placing upper and lower bounds on the trapping time for many vortices captured in the liquid-like phase (one example is shown in Fig. 1) we were able to estimate an average pinning potential, U_{av} = 900 ± 100 K, which is quite reasonable for strong pinning centres in a Bi:2212 film at 59 K.

References

[1] Blatter G, Geshkenbein V B, Larkin A I and Nordborg H 1996 *Phys. Rev*. B **54** 72

E-mail: acrisan652@gmail.com

Vortex excitations in the insulating state of an oxide interface

Yoram Dagan [1], Michael Mograbi, Prasanna K. Rout, Eran Maniv [1] David Graf [2]

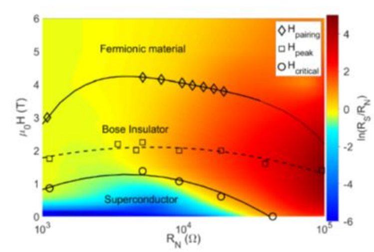
[1] *Raymond and Beverly Sackler School of Physics and Astronomy, Tel-Aviv University, Tel Aviv, 69978, Israel*
[2] *National High Magnetic Field Laboratory, Tallahassee, Florida 32310, USA.*

The two dimensional electron liquid formed at oxide interfaces is a laboratory for studying electronic properties in tunable correlated system where various degrees of freedom of the interfacial constituents can be combined. The electronic properties of such interface are sensitive to symmetry changes imposed by the interface itself and to various phase transitions in the constituent materials. In this talk I will present our recent study of various polar oxides/$SrTiO_3$-based interfaces.

The triangular lattice of the (111) $LaAlO_3$/$SrTiO_3$ interface is reflected in a six-fold anisotropic magnetoresistance [1]. Superconductivity is observed in a dome-shaped region in the carrier density – temperature phase diagram. The superconducting transition temperature follows the same behavior as the spin-orbit interaction suggesting a link between these quantities [2].

Upon removing carriers by gate voltage this interface is driven into a highly insulating regime where the sheet resistance is significantly larger than the quantum one. We use this interface to study the superconductint-to-insulator transition as a function of electrostatic gate and magnetic field. This crystalline interface surprisingly exhibits very strong features observed previously only in amorphous systems. These features persist deep into the insulating state. We identify a new magnetic field scale, $H_{pairing}$, where superconducting fluctuations are muted and find a length-scale ξ_{ins} interpreted as the size of the vortex fluctuation in the insulating state. Our findings suggest that vortex fluctuation excitations and Cooper pair localization are responsible for the observed superconductor to insulating transition and that these excitations surprisingly persist deep into the insulating state. [3]

Finally, we study the case where a small amount of Sr atoms in $SrTiO_3$ is replaced with calcium. This gives rise to a ferroelectric phase transition below a Curie temperature that increases with the level of Ca substitution. We discuss the various effects of ferroelectricity on the superocnducting state. [4].



Phase diagram of (111) $SrTiO_3$/$LaAlO_3$ interface color code represents the ratio between sheet resistance to the normal state resistance.

References

[1] P.K. Rout, I. Agireen, E. Maniv, M. Goldstein, Y. Dagan Physical Review B **95** (24), 241107 (2017)
[2] P.K. Rout, E. Maniv, Y. Dagan, Physical Review Letters **119** (23), 237002 (2017)
[3] M. Mograbi *et al.* arXiv:1805.09574
[4] G. Tuvia P. K. Rout et al. To be published.

E-mail: (yodagan@tauex.tau.ac.il)

Spin correlations of atomic chains on superconductors

Deung-Jang, Choi[1,2]

[1]Centro de Fisica de Materiales, CFM/MPC (CSIC-UPV/EHU), Paseo Manuel de Lardizabal 5, 20018 Donostia-San Sebastian

[2]Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal 4, 20018 Donostia-San Sebastian, Spain

Recently, the introduction of impurity states in the superconducting gap has received a lot of attention. Indeed, the search of a new superconducting state called topological superconductivity is strongly based in the combination of doping classical (s-wave) superconductors with magnetic impurities that arrange spins in a chiral fashion. Magnetic adatoms can be considered as impurities that weaken the binding of superconducting Cooper pairs leading to impurity levels in the gap: so-called Yu-Shiba-Rusinov (YSR) states. By using scanning tunneling microscopy (STM), we study magnetic impurities on superconducting surfaces revealing the orbital properties of the YSR states associated with them [1]. We also present the first results of controlled single-atom manipulation to assemble a chain of Cr atoms on a Bi2Pd superconductor. The influence of the atoms on the superconducting electronic structure is revealed as well as the interactions at work. The dependence of the electronic structure on the interatomic distance between two Cr atoms is thoroughly explored revealing Cr-Cr interactions mediated by the superconductor for the first time [2]. Such magnetic impurities on different substrates allow us to explore many-body effects and exotic phenomena in different experimental spin systems giving an understanding on the parameters on each system.

References

[1] Choi, D.-J. et al. Mapping the orbital structure of impurity bound states in a superconductor. Nat. Commun. 8, 15175 (2017).

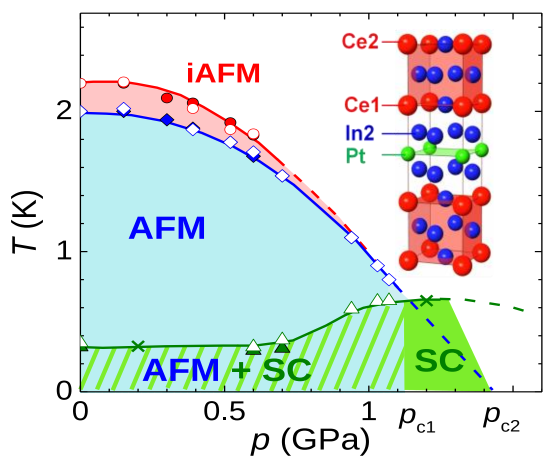
[2] Choi, D.-J. et al. Influence of Magnetic Ordering between Cr Adatoms on the Yu-Shiba-Rusinov States of the β-Bi2Pd superconductor, Phys. Rev. Lett., 120(16), 167001 (2018).

E-mail: djchoi@dipc.org

Coexistence of Superconductivity and Antiferromagnetism in the Heavy Fermion Compound Ce_3PtIn_{11}

Jeroen CUSTERS[1], Jan PROKLEŠKA[1], Marie KRATOCHVÍLOVÁ[1], Klára UHLÍŘOVÁ[1], Vladimir SECHOVSKÝ[1]

[1] *Dept. of Condensed Matter Physics, Charles University, Ke Karlovu, 5, 121 16 Praha, Czech Republic*



Pressure –temperature phase diagram of Ce_3PtIn_{11} and the unit cell of Ce_3PtIn_{11}. Red highlights the $CeIn_3$ structure.

One of the most intriguing challenge in contemporary condensed matter physics is to understand the mutual relationship magnetism and superconductivity (SC). Regarded in the past as definitive antagonists, the observation of SC in the vicinity of a quantum critical point (QCP) indicates an intimate relationship between magnetic fluctuations and SC as has been discussed in heavy fermion (HF) compounds [1], cuprates [2] and iron-pnictides [3]. In the case of the HF compound $CeCu_2Si_2$ neutron data showed that magnetic reflection disappear in the SC state [4]. Particularly puzzling is the case when magnetism and SC microscopically coexist as in the case of $CeRhIn_5$ [1]. At ambient pressure $CeRhIn_5$ orders antiferromagnetically (AFM) at T_N = 3.8 K. With applied hydrostatic pressure SC is observed while the AFM state is gradually suppressed and disappears at p_{c1} = 1.77 GPa (QCP). Neutron experiments showed that AFM order coexists with superconductivity over a wide range of pressures below p_{c1} and $T_N > T_c$, which implies that the cerium 4*f* electrons are **simultaneously** responsible for magnetism and superconductivity [5]. The observation of superconductivity emerging in the magnetic phase in Ce_3PtIn_{11} at ambient pressure (see figure) might even present a **third scenario**: The compound belongs to the same family as $CeRhIn_5$. More intriguing, Ce_3PtIn_{11} exhibits two crystallographically inequivalent Ce-sites. It has been speculated that two Kondo sublattices are formed with largely different Kondo temperatures. At present it is still an open question if those Kondo scales compete or cooperate and if such interplay can lead to the suggested Kondo breakdown or if a partially screened phase or even fractionalized Fermi liquid state is established. Nevertheless, a careful entropy analysis pointed out that one Ce-sublattice (Ce2) is responsible for the magnetic ordering while the second one (Ce1) carries the superconducting state, an **unprecedented case** in HF physics.

References

[[1] H. Hegger *et al,* Phys. Rev. Lett. **84,** 4986 (2000).
[2] M.P.M. Dean *et al.,* Nat. Mater. **12,** 1019 (2013).
[3] K.-J. Zhou, *et al.,* Nat. Commun. **4,** 1470 (2013).
[4] O. Stockert *et al.*, Nat. Physics **4,** 119 (2011)
[5] J. Prokleška *et al.*, Phys. Rev. B **92,** 16114 (2015)

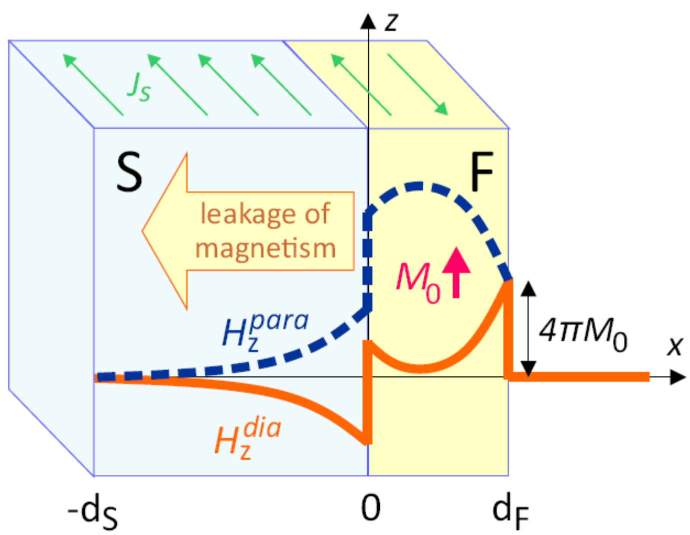
E-mail: custers@mag.mff.cuni.cz

Electromagnetic Aharonov-Bohm like proximity effect in planar superconductor-ferromagnet structures

Alexander Buzdin[1], Sergei Mironov[2], Alexander Mel'nikov [2]

[1] *University of Bordeaux, LOMA UMR-CNRS 5798, F-33405 Talence Cedex, France,*
[2] *Institute for Physics of Microstructures, Russian Academy of Sciences, 603950 Nizhny Novgorod, GSP-105, Russia*

The spread of the Cooper pairs into the ferromagnet in proximity-coupled superconductor – ferromagnet (SF) structures is shown to cause a strong inverse electrodynamic phenomenon, namely, the long-range transfer of the magnetic field from the ferromagnet to the superconductor. Contrary to the previously investigated inverse proximity effect resulting from the spin polarization of superconducting surface layer, we found a very generic orbital mechanism of the magnetic moment transfer from a ferromagnet to a superconductor, which is unavoidable in S/F hybrids [1]. It is related with the fact that the common superconducting wave function in S and F (near the interface) does not permit to exclude the vector-potential of the magnetization by gauge transformation. From the experimental point of view, this phenomenon reminds the Aharonov-Bohm effect since the current inside the attached superconductor is induced by the ferromagnetic layer, which cannot create the magnetic field in the outside in the absence of such superconducting environment. At the same time, the true physical key point is that the wave function penetrating the ferromagnet is responsible for this effect. Let us stress that the characteristic length of the proposed inverse electrodynamic effect is of the order of the London penetration depth.



References

[1] S. V. Mironov, A. S. Mel'nikov, A. I. Buzdin, Appl. Phys. Lett. **113**, 022601 (2018).

E-mail: alexandre.bouzdine@u-bordeaux.fr

Superconductivity near a ferroelectric quantum critical point in Dirac materials

Jonathan Ruhman

[1] *Bar Ilan University, Ramat Gan, 5290002 Israel*

A key ingredient in superconductivity is pairing between electrons. While electrons repel each other very strongly in free space, in the presence of a lattice they effectively attract and form bound states. This, however, requires that the lattice dynamics is much slower than the electronic one. Notwithstanding, many low-density superconductors have been discovered, where the lattice dynamics is comparable or even faster than the electronic one (e.g. SrTiO3, Bismuth or PbTe). Moreover, the electronic density of states is orders of magnitude smaller than in metals, such that the standard coupling to phonons is negligible. This raises the question: What glues electrons in low density systems?

In this talk I will discuss the possibility of electronic pairing mediated by the fluctuations a ferroelectric order parameter close to a quantum critical point in Dirac materials (such as PbTe and SnTe). I will first present the low-energy theory describing the transition, including an important coupling between the electrons and transverse ferroelectric modes. Then, using RG, I will show how electronic pairing can overcome repulsion even when the Fermi energy is much smaller than the relevant phonon frequency. Finally, I will discuss the implications of such a paring mechanism on the resulting superconducting state.

E-mail: jonathan.ruhman@biu.ac.il

Probing magnetic parameters of individual nanoelements by spin-wave spectroscopy

O. V. Dobrovolskiy[1], S. A. Bunyaev[2], N. R. Vovk[3], D. Navas[2], P. Gruszecki[4], M. Krawczyk[4], R. Sachser[1], M. Huth[1], K. Y. Guslienko[5,6] and **G. N. Kakazei[2]**

[1]Physikalisches Institut, Goethe University, Frankfurt am Main, Germany
[2]IFIMUP-IN/Department of Physics and Astronomy, University of Porto, Porto, Portugal
[3]Department of Physics, V. N. Karazin Kharkiv National University, Kharkiv, Ukraine
[4]Nanomaterials Physics Division, Adam Mickiewicz University in Poznan, Poznan, Poland
[5]Departamento de Física de Materiales, Universidad del País Vasco, UPV/EHU, San Sebastián, Spain
[6]IKERBASQUE, the Basque Foundation for Science, 48013 Bilbao, Spain

While micro- and nanosized magnetic elements are widely used in various microwave applications, the analytical description of spin waves that govern their magnetodynamic response is a complicated problem. This is because of the inhomogeneity of the internal demagnetizing field limiting finding exact eigenfrequencies to only few cases of simplest symmetry – circular disks and infinite stripes. Here, we employ a dipole-exchange spin-wave dispersion equation from Ref. [1] to deduce magnetization and exchange constant for individual Co-Fe nanodisks. The disks were directly written by focused electron beam-induced deposition [2] and studied by broadband ferromagnetic resonance spectroscopy with external magnetic field applied along the normal to sample plane. The finite disk radius leads to the quantization of the in-plane spin-wave vector and gives rise to resonance drum modes with circular Bessel-function profiles (Fig. 1 left). We were able to record spin-wave spectra with high signal/noise ratio (shapes of at least 8 peaks can be analyzed) from the individual Co-Fe disk with thickness L = 40 nm and radius R = 200 nm, but even for the disk with R = 100 nm the positions of 3 peaks were detected (Fig. 1 right). The analytical theory has been generalized for large aspect ratios $L/R \leq 0.5$ and found to agree well with numerical simulations. The proposed approach is especially valuable for the characterization of magnetic materials that are unavailable in large arrays or in bulk form.

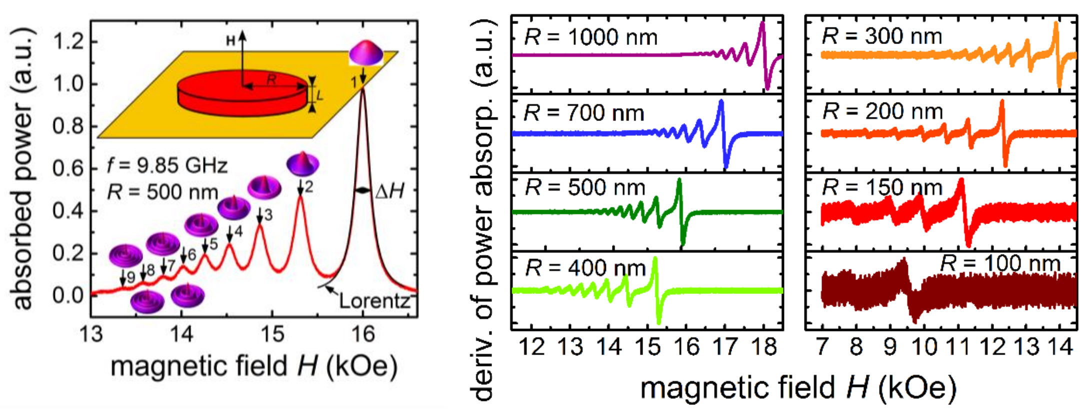


Fig. 1. Left panel: Experimental spectrum of an individual Co-Fe disk with a radius of 500nm at 9.85 GHz. Arrows indicate resonance drum modes with the shown profiles of zero-order Bessel functions. Inset: Experimental geometry. Right panel: Derivatives of the experimentally measured spin-wave resonance spectra at 9.85 GHz for a series of disk radii, as indicated.

References

[1] G.N. Kakazei et al., Appl.Phys Lett. 85, 443 (2004).
[2] M. Huth, F. Porrati, and O. V. Dobrovolskiy, Microelectr. Engin.185-186, 9 (2018).

E-mail: gleb.kakazei@fc.up.pt

Andreev and Majorana bound states in superconducting circuits

Eytan Grosfeld[1], Konstantin Yavilberg[1], Eran Ginossar[2]

[1] Department of Physics, Ben-Gurion University of the Negev, Be'er-Sheva 84105, Israel
[2] Advanced Technology Institute and Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

Coupling Majorana fermion excitaitons to coherent external fields is an important stage towards their manipulation and detection. We recently proposed that a superconducting circuit based on topological superconductors can implement a device that can be used to detect the presence of Majorana modes as well as coherently control them [1]. This generates a highly isolated qubit whose coherence time could be greatly enhanced. We investigated the quantum electrodynamics of this device and extended the conventional semiclassical method to obtain analytical derivations for strong transmon-photon coupling [2]. Using this formalism, we developed protocols to initialize, control, and measure the parity states. We show that, remarkably, the parity eigenvalue can be detected via dispersive shifts of the optical cavity in the strong-coupling regime and its state can be coherently manipulated via a second-order sideband transition. As an important implementation, we investigate the low-energy theory of a topological insulator nanowire threaded with magnetic flux and coupled in proximity to a finite capacitance Josephson junction [3]. Both Andreev and Majorana bound states are generated in the weak-link, and the hybridization between the two types of localized excitations has a significant effect on the charge transfer along the junction and the resulting dipole. This behavior is encoded in a few key spectroscopic patterns, where in conjunction with a high-Q resonator, can be used to detect and differentiate Majorana from Andreev bound states.

References

[1] Eran Ginossar and Eytan Grosfeld, Tunability of microwave transitions as a signature of coherent parity mixing in the Majorana-Transmon qubit, Nat. Commun. **5**, 4772 (2014).
[2] Konstantin Yavilberg, Eran Ginossar and Eytan Grosfeld, Fermion Parity measurement and control in Majorana circuit quantum electrodynamics, Phys. Rev. B **92**, 075143 (2015).
[3] Konstantin Yavilberg, Eran Ginossar and Eytan Grosfeld, in preparation.

E-mail: eytan.grosfeld@gmail.com

Two gaps, or not two gaps, that is the question.

Zuzana Pribulová*

Centre of Low Temperature Physics, IEP SAS, Watsonova 47, 04001 Košice, Slovakia

Two-gap superconductivity is a compelling phenomenon as it comprises novel riches of condensed matter physics. The hunt for its representatives continues since the experimental justification of two energy scales in MgB_2 in 2001. Any new member in the family of multi-gap superconductors must withstand a thorough critical appraisal of its properties. Before any definite conclusion is made, a consistent picture of multi-gap superconductivity must be assembled using a combination of techniques capable to address several aspects of the phenomenon. Here, we present two instances of supposedly two-gap superconductors that showed up to possess only one intrinsic energy gap in the k-space.

In Mo_8Ga_{41} it was suggested that Mo site-selective orbital contributions lead to existence of two energy gaps elucidating scanning tunneling spectroscopy (STS) [1] and muon spin rotation/relaxation measurements [2]. However, our detailed thermodynamic and spectroscopic experiments using ac-calorimetry and low-temperature scanning tunneling microscopy/spectroscopy exposed that the observed „two-gap" features are actually a consequence of multi-phase character of the surface [3] arising from complicated structure of Mo_8Ga_{41} formed by endohedral clusters.

The situation is different in Cu_xTiSe_2, where superconductivity co-exists with charge density waves (CDW). Studying samples with various doping we have arrived to contradictory results – single-gap superconductivity was seen in the heat capacity [4] and STS measurements, while two energy gaps were observed in the superfluid density [5]. A hint to reconcile this contradiction appeared when we found the samples to exhibit a so-called „lock-in" effect when vortices remain locked parallel to the *ab*-planes even for tilted magnetic fields. Such an effect needs a layered superstructure where superconductivity is locally suppressed, with the period on the order of the coherence length ξ. Suggested incommensurate CDW state in [7] with CDW domains separated by domain walls with spacing matching ξ could form this superstructure. Variation of the order parameter along the *c*-direction related to existence of the domain walls would lead to locally smaller energy gap(s). Thus multiple gaps observed in superfluid density of Cu_xTiSe_2 are related to a modulation of the order parameter in the real space not in the k-space as is expected for multi-gap superconductor.

References

[2] A. Sirohi et al., arXiv 1810.01914.
[5] V. Yu. Verchenko et al., Phys. Rev. B 96, 134504 (2017).
[3] Z. Pribulová et al., arXiv 1810.02556, submitted to Phys. Rev. B.
[4] J. Kačmarčík et al., Phys. Rev. B 88, 020507(R) (2013).
[5] Z. Pribulová et al., Phys. Rev. B 95, 174512 (2017).
[6] Z. Medvecká et al., Phys. Rev. B 93, 100501(R) (2016).
[7] A. Kogar et al., Phys. Rev. Lett. 118, 027002 (2017).

E-mail: pribulov@saske.sk

*The work was performed in collaboration with: Z. Medvecká, J. Kačmarčík, P. Szabó, M. Marcin, M. Kopčík, V. Paľuchová, V. Vaňo, V. Komanický, T. Klein, P. Rodiere, C. Marcenat, G. Karapetrov, V. Cambel, J. Šoltýs, D. Evtushinsky, V.Yu.Verchenko, A.V. Shevelkov, and P. Samuely

Tuning superconductivity and photoconductivity in $SrTiO_3$

Christopher BELL[1]

[1] University of Bristol, HH Wills Physics Laboratory, Tyndall Avenue, Bristol, BS8 1TL United Kingdom

$SrTiO_3$, STO, is a famous superconducting semiconductor with high electron mobility at low-temperatures. In the low density limit in both the 2D and 3D limits there are a number of important questions to be addressed, including the role of quantum sub-bands on the superconductivity [1,2], and the impact of the non-BCS character [3]. I will also discuss the intriguing possibility of a BCS-BEC crossover [4], and the use of (persistent)-photoconductivity [5-7] to access ultra-low carrier densities at dilution refrigerator temperatures.

References

[1] Y. Kozuka, M. Kim, C. Bell, B. G. Kim, Y. Hikita, and H. Y. Hwang, Nature **462**, 487 (2009).
[2] M. Kim, C. Bell, Y. Kozuka, M. Kurita, Y. Hikita, and H. Y. Hwang, Phys. Rev. Lett. **107**, 106801 (2011).
[3] X. Lin, Z. Zhu, B. Fauqué, and K. Behnia, Phys. Rev. X 3, 021002 (2013).
[4] D. M. Eagles, Sol. Stat. Commun. **60**, 521 (1986).
[5] Y. Kozuka, Y. Hikita, T. Susaki, and H. Y. Hwang, Physical Review B **76**, 085129 (2007).
[6] Y. Kozuka, T. Susaki, and H. Y. Hwang, Physical Review Letters **101**, 096601 (2008).
[7] H. Gordon-Moys & C. Bell, (unpublished).

E-mail: christopher.bell@bristol.ac.uk

Tunable oxide 2DES heterostructures for electronic applications.

Daniela STORNAIUOLO[1,2] , Benoit JOUAULT[3] , Davide MASSAROTTI[4,2], Alessia SAMBRI[2], Maria D'ANTUONO[1], Alessandro MIANO[1,2], Giovanni Piero PEPE[1,2] , Marco SALLUZZO[2] and Francesco TAFURI[1,2]

[1]*Dipartimento di Fisica Ettore Pancini, Università degli Studi di Napoli Federico II, Napoli, Italy*

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

[3] *Laboratoire Charles Coulomb, UMR 5221, CNRS, Universitè Montpellier 2, F-34095 Montpellier, France*

[4]*Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione, Università degli Studi di Napoli Federico II, Napoli, Italy*

Oxide interfaces hold a great potential for electronic applications. One of the most celebrated oxide 2 dimensional electron system (2DES) is the $LaAlO_3/SrTiO_3$ (LAO/STO) heterostructure. We will present a study of nanosclae field effect devices based on this 2DES where change in the resistance of more than 4 orders of magnitude and a voltage gain of up to 50 can be obtained with the application of a gate voltage smaller than 1V. At dilution temperatures, the nanodevices become superconducting and we demonstrate the possibility to obtain a superconductor to insulator transition applying only 200mV. We will discuss these results in the view of application to quantum electronics which could exploit the coexistence superconductivity and Rashba spin-orbit coupling in this system [1].

Recently, thanks to the introduction of a delta-doping layer of $EuTiO_3$ sandwiched between STO and LAO, ferromagnetic correlations were added to this picture [2]. We will present a study of the interplay between ferromagnetism and Rashba spin-orbit coupling in LAO/ETO/STO heterostructures performed by analyzing the magnetotransport data as a function of the carrier density and of the temperature [3]. We will show also that the ferromagnetic correlations in this system can be tuned by light illumination. Also in this case, applications to oxide electronics will be revised.

References

[1] G.Cheng et al., Nature 521, 196 (2015); L. Kuerten et al., Phys. Rev. B 96, 014513 (2017); D. Stornaiuolo et al., Physical Review B, 95, 140502(R) (2017)

[2] D. Stornaiuolo et al., Nature Materials 15, 278-283 (2016).

[3] D. Stornaiuolo et al., PRB 98, 075409 (2018)

email: stornaiuolo@fisica.unina.it

The other path

Lior Embon

Philips Healthcare, Haifa Israel

Physics grad-school students often see the pursuit of an academic career as "the right choice", although this choice might not necessarily be what they truly desire, or what they are best suited for. Switching to industry is sometimes perceived as "dropping out" or admitting failure. A notion which may result in great frustration. In this short talk, I will try to change this perception and offer a positive view of the industry, by sharing my experience as a physicist who has willingly and consciously decided to cross over to the other side. I will describe what kind of jobs are out there for physicists, how the industry views us and our abilities, and what is it like to suddenly work with non-scientists. Finally, I'll give some examples of the kind of exciting challenges I encounter nowadays, working for Philips Healthcare.

E-mail: liorembon@gmail.com

Non-local probing of Yu-Shiba-Rusinov state in superconductor- quantum dot hybrid

Zoltan SCHERÜBL[1], Gergő FÜLÖP[1], Pascu MOCA[2,3], András PÁLYI[2], Gergely ZARÁND[2], Jesper NYGARD[4], **Szabolcs CSONKA**[1]

[1] Department of Physics, Budapest University of Technology and Economics and MTA-BME "Momentum" Nanoelectronics Research Group
[2] Department of Theoretical Physics and BME-MTA Exotic Quantum Phases Research Group, Budapest University of Technology and Economics
[3]Department of Physics, University of Oradea, 410087, Oradea, Romania
[4]Center for Quantum Devices and Nano-Science Center, Niels Bohr Institute, University of Copenhagen

In this contribution we investigate how the transport properties of a superconductor (SC) is affected when an artificial impurity (quantum dot) is attached to the SC. A tunnel probe is connected to the SC at a distance from the impurity larger than the SC coherence length. We find a significant enhancement - called non-local signal - in the tunnel-probe current when the impurity is tuned to the charge degeneracy point. Direct transport measurement on the quantum dot reveals the presence of Yu-Shiba-Rusinov state. The magnitude of the non-local signal is increase with up to a factor of 20 with applied external magnetic field. We compare our experimental results with NRG simulation, which reproduce the experimental findings.

This work is supported by National Research Development and Innovation Office of Hungary (Project No. 2017-1.2.1-NKP-2017-00001).

E-mail: csonka@mono.eik.bme.hu

Anisotropic gap and vortex lattice imaging in the pnictide superconductors Ni-doped CaKFe4As4 and P-substituted BaFe2As2

Isabel GUILLAMON

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

Quasiparticle interference scattering is a powerful tools to investigate pnictide superconductivity. Here I will discuss results in the family of 1144 materials, particularly in pure and Ni-doped $CaKFe_4As_4$ and in P-substituted Ba122. We show that $CaKFe_4As_4$ is a two-gap, sign-changing superconductor [1,2] located at optimal doping. Ni doping reduces Tc and induces a magnetic transition with a unique hedgehog magnetic order. The superconducting gap and band-structure are both considerably modified [3]. In the P-substituted Ba122 compounds [4], we observe a superconducting gap consistent with nodal superconductivity and a particularly ordered vortex lattice. Surprisingly, we find ultra-slow vortex creep at very low temperatures, pointing out that there are dynamic properties specific to vortices in Ba122 compounds.

Work supported by ERC Starting Grant and Spanish MINECO.

References

[1] K. Cho, A. Fente et al., Phys. Rev. B **95**, 100502(R) 2017.
[2] A. Fente et al., Phys. Rev. B 97, 134501 (2018).
[3] W.R. Meier et al., npj Quantum Materials **3**, 5 (2018).
[4] C. Putzke et al, Nat. Comms. **5**, 5679 (2014).

E-mail: isabel.guillamon@uam.es

Probing superconducting fluctuations in tunneling experiments

David DENTELSKI[1], Aviad FRYDMAN[1], Efrat SHIMSHONI[1], and **Emanuele G. DALLA TORRE**[1]

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

Disordered thin films close to the superconductor-insulator phase transition (SIT) hold the key to understanding quantum phase transition in strongly correlated materials. The SIT is governed by superconducting quantum fluctuations, which can be revealed, for example, by tunneling measurements. These experiments detect a spectral gap, accompanied by suppressed coherence peaks, on both sides of the transition. Here we describe the insulating side in terms of a fluctuating superconducting field with finite-range correlations. We perform a controlled diagrammatic resummation and derive analytic expressions for the tunneling differential conductance. We find that short-range superconducting fluctuations suppress the coherence peaks even in the presence of long-range correlations. Our approach offers a quantitative description of existing measurements on disordered thin films and accounts for tunneling spectra with suppressed coherence peaks.

References

[1] D. Dentelski, A. Frydman, E. Shimshoni, and E. G. Dalla Torre, Phys. Rev. B 97, 100503(R) (2019).

E-mail: Emanuele.dalla-torre@biu.ac.il

Isolated pairs of Majorana zero modes in a disordered superconducting lead monolayer

Gerbold Ménard[1], Andrej Mesaros[2], Christophe Brun[1], François Debontridder[2], Dimitri Roditchev[1, 3], Pascal Simon[2], Tristan Cren[1]

[1] Institut des nanosciences de Paris, Sorbonne Universités and CNRS-UMR 7588, 75005 Paris, France
[2] Laboratoire de Physique des Solides, CNRS, Univ. Paris Sud, Université Paris-Saclay, 91405 Orsay Cedex, France and
[3] Laboratoire de Physique et d'étude des matériaux, ESPCI PSL and CNRS-UMR 8213, 75005 Paris, France

It has been predicted that Majorana quasiparticles were to appear when mixing a few simple ingredients: superconductivity, spin-orbit interaction and magnetism. During this talk I will present our implementation of these ingredients in a monolayer of Pb on Si(111) in the presence of magnetic Co nanoclusters and discuss the spectroscopic signatures obtained by scanning tunnelling microscopy in the context of topological superconductor. I will go in details into the comparison with individual impurities giving rise to individual Yu-Shiba-Rusinov [1] bound states as well as disordered clusters of magnetic atoms and other similar situations [2] in order to eliminate as many non-topological interpretations as possible.

References

[1] G. Ménard et al., Nature Physics **11** 1013-1016 (2015).
[2] G. Ménard et al., Nature communications **8** 2040 (2017).

E-mail: gerbold.menard@cea.fr

Coulomb blockade spectroscopy of superconducting aluminum islands deposited on InAs nanowires

Haim Beidenkopf[1], Jonathan Reiner[1], Abhay K Nayak[1], Amit Tulchinsky[1], Yuval Oreg[1], Hadas Shtrikman[1], Nurit Avraham[1]

[1] *Weizmann Institute of Science, Condensed Matter Department, Herzl 234 Rehovot 7610001, Israel*

Hybrid InAs/Al nanowires are studied as a platform for topological superconductivity. Here we visualize spectroscopically the Coulomb blockade regime of aluminum islands deposited in situ on InAs nanowires. We find no changes in the chemical potential before and after aluminum deposition signifying absence of charge doping and of local band bending at the immediate vicinity of the islands. On the aluminum islands we find Coulomb blockade features typical to double barrier tunneling junction. From these we characterize the resistive and capacitive properties of the nanowire-aluminum interface. We identify a finite barrier for tunneling of electrons across that interface. Our observations strongly reflect on the ability to induce robust topological superconductivity by deposition of aluminum on InAs nanowires.

Singlet ground states in barrier-defects coupled to $NbSe_2$

Hadar STEINBERG[1]

[1] *Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel*

The physics of a quantum dot coupled to a superconductor is governed by the interplay of the dot chemical potential, its charging energy and coupling to the superconductor. This interplay results in either a spin-polarized doublet ground state, when the charging energy is significant, or a spin-unpolarized singlet ground state when the coupling to the superconductor dominates. We use van der Waals semiconductors as tunnel barriers separating the superconductor $NbSe_2$ and normal counter electrodes. We find that defect states, ubiquitous to the semiconducting barrier, hybridize with the superconductor and form Andreev bound states, which are observed in tunneling experiments. By the application of magnetic field we show that these Andreev bound states have a singlet ground state, consistent with a small charging energy. We argue that the screening from electrodes is significant in the reduction of the charging energy. Finally, by tuning the ground state using a Zeeman field, we drive the system in the Kondo regime.

E-mail: hadar@phys.huji.ac.il

Unconventional superconductivity induced in singlet s-wave superconductors by adsorbed chiral molecules

Hen ALPERN[*1,2], Tamar SHAPIRA[1], Eran KATZIR[2], Tom DVIR[1], Shira YOCHELIS[2], Gad KOREN[3], Hadar STEINBERG[1], Yossi PALTIEL[2], Oded MILLO[1]

[1] The Racah Institute of Physics, Hebrew University of Jerusalem, ISRAEL
[2] The Applied Physics Department, Hebrew University of Jerusalem, ISRAEL
[3] Department of Physics, Technion - Israel Institute of Technology, ISRAEL

Following our previous results [1] that provide evidence for the emergence of a triplet-pairing chiral p-wave superconducting component in Nb upon the adsorption of chiral molecules, we turned to investigate whether such an effect can take place in other superconductor systems. First we addressed a proximal superconductor, namely, a thin Au film proximity-coupled to NbN. By applying scanning tunneling spectroscopy (STS) we found that the conventional BCS-like spectra measured on the pristine Au layer changed significantly after the adsorption of chiral polyalanine alpha-helix molecules, exhibiting now a zero-bias conductance peaks embedded inside a gap. The peak reduced in size, but did not split, upon the application of magnetic field. These results suggest the emergence of unconventional superconductivity with sign-changing order-parameter, consistent, here too, with triplet-pairing p-wave symmetry. Next, we performed conductance measurements on thin NbSe2 flakes exfoliated over Au electrodes before and after chiral molecules adsorption. Upon adsorption, the conventional differential conductance spectra change their shape markedly, exhibiting in gap structures. At large molecule densities the spectra exhibited a pronounced narrow zero bias conductance peak, while at low density a pair of peaks symmetrically positioned around zero bias appeared. The former reduced in size and vanished upon the application of magnetic field, leaving only the conventional gap, consistent with an unconventional sub-dominant superconducting components, while the latter pair of peaks shifted with magnetic field, conforming to the behavior of Shiba states.

References

[1] [1] H. Alpern, E. Katzir, S. Yochelis, N. Katz, Y. Paltiel, and O. Millo, New J. Phys. 18, 113048 (2016)

E-mail: hen.alpern@mail.huji.ac.il

Poster Abstracts

Calculations of in-gap states by Cr adatoms on Bi2Pd

Nicolás Lorente[1] , Cristina Meir[1],, Deung-Jang Choi[1]

[1]*Centro de Física de Materiales, Materials Physics Center, EHU & CSIC, 5 Paseo de Manuel de Lardizabal, E-20018 San Sebastián, Spain*

Magnetic impurities on s-wave superconductors give rise to in-gap states. Cr is a largemagnetic-moment 3d atom and induces in-gap states on Bi2Pd, which is a single-gap swave superconductor with very large Rashba coupling. We use Bogoliubov-de Gennes equations to find the interactions of single, double [1] and multiple Cr atoms on the Bi2Pd surface, studying the role of non-colinearity between Cr magnetic moments, the creation of in-gap bands and the conditions for appearance of Majorana bound states on Cr chains.

References

[1] D.J. Choi et al, Phys. Rev. Lett. 120, 167001 (2018).

E-mail: nicolas.lorente@ehu.eus

Orientation dependence of quasiparticle transport properties in d-wave superconductor-ferromagnet-d-wave superconductor trilayers

Zorica Popović[1], Radomir Zikic[2], Ljiljana Dobrosavljević-Grujić[2], and Predrag Miranović[3]

[1]University of Belgrade, Faculty of Physics, Studentski trg 12, 11001 Belgrade, Serbia

[2] University of Belgrade, Institute of Physics, Pregrevica 118, 11080 Belgrade, Serbia

[3] University of Montenegro, Faculty of Science and Mathematics, Džordža Vašingtona bb, 81000 Podgorica, Montenegro

We develop a quantitative theory describing the behavior of current-voltage characteristics (CVCs) and conductances (G) in d-wave superconductor (D)/ferromagnet (F) /d-wave superconductor (DFD) junctions. The approach of K*ü*mmel, Gunsenheimer and Nikolsky (PRB 42, 3992 (1990)), developed for s-wave superconductor(S)/normal metal (N)/s-wave superconductor (SNS) and based on solution of time-dependent Bogoliubov-de Gennes equations combined with the time-relaxation model, is generalized for DFD case [1,2]. Since the superconducting electrodes have anisotropic d-wave symmetry, the proximity effect therefore is determined by the angle θ of orientation of the d-wave electrodes with respect to F/D interface. Consequently, this orientation dependence of the proximity effect affects the quasiparticle current and zero bias conductance (ZBC) in these junctions as well. For DFD junctions with misoriented superconducting electrodes we found that at low bias the coherence in the quasiparticle transport could be enhanced by magnetic field in F. For $\theta = \pi/4$, where the proximity effect is the strongest, there is an enhancement of the current and ZBC as well, starting from $h = 0$ up to a maximum at $h \approx \Delta(T)$. We find that $G(V)$ at higher voltage have characteristic dips whose position are not influenced by the type of order parameter anisotropy and electrodes misorientation, but vary only with h in F and temperature dependent pair potential in D, according to the simple low $neV = 2\Delta(T) \mp h$, with $n = 0,1, ...$ For given h ZBC decreases with temperature, but for $h \leq \Delta$, ZBC has a distinct kink at some characteristic temperature T^* such that $\Delta(T^*) = h$, what provides reliable experimental method for measurements of small h.

References

[1] Z. Popović, R. Zikic, and L. Dobrosavljević - Grujić, Prog. Theor. Exp. Phys. **2015**,103I01 (2015).

[2] Z. Popović, P. Miranović, and R. Zikic, Phys. Status Solidi B **255**, 1700554 (2018).

E-mail: pzorica@ff.bg.ac.rs

Thermal transport in nanodiamond composites

Daria SZEWCZYK

Institute of Low Temperature and Structure Research PAS, Department of Low Temperature and Superconductivity, Okólna 2, 50-422 Wroclaw, Poland

Recent studies on possible existence of magnetism and/or superconductivity in carbon materials (like graphite, graphene or diamond) has attract a lot of attention [1-2]. The method behind this phenomena is MeV ion-beam irradiation as an inducing factor. In our studies we focused on some preliminary investigations of the nanodiamond samples prepared in high pressure / high temperature chamber. The materials appear to be a good candidate for the scheduled survey of induced magnetism / superconductivity. But the initiatory goal was to test if the thermal transport can be increased with the sintering temperature. For that reason two series of thermal conductivity measurements were carried out for samples coming from two distinct preparation procedures. The obtained results seems to confirm the assumptions. As a further step selected nanodiamond ceramics will be used as an introductory material in matrixes of a new type of nanocomposites with a relatively high thermal conductivity coefficient in order to test the co-existence of two solid phases with embedded nanoclusters. After detailed analysis the samples will be checked if and how they are prone to ion-beam irradiation.

References

[1] "Lattice damage in 9-MeV-carbon irradiated diamond and its recovery after annealing", F. Agulló-Rueda, N. Gordillo, M. D. Ynsa, A. Maira, J. Cañas, and M. A. Ramos, Carbon 123, 334-343 (2017)

[2] “Investigation of the magnetic properties of proton irradiated type Ib HPHT diamond”, N. Daya, E. Sideras-Haddad, T.N.Makgato, M. García-Hernández, A. Climent-Font, A.Zucchiatti, and M.A. Ramos, Diamond & Related Materials 64, 197–201 (2016)

E-mail: d.szewczyk@intibs.pl

Synthesis and properties of Co-doped GdFeAsO magnetic superconductors

Lan Maria TRAN[1], Michał Babij, Paweł Górniak, Andrzej J. Zaleski

[1] *Institute of Low Temperature and Structure Research, Department of Low Temperature and Superconductivity, Polish Academy of Sciences in Wrocław, Okólna 2, 50-422 Wrocław, Poland*

In this contribution we present synthesis and physical properties of newly obtained Co-doped GdFeAsO magnetic superconductors.

Similarly to the $EuFe_2As_2$-based superconductors, [1,2] these materials have promising properties, where interplay of superconductivity and Ga-magnetic moment is expected.

Belonging to the so called 11 11 family GdFeAsO-based compounds have a lot similarities to the thoroughly investigated $EuFe_2As_s$-based materials. I.e. at room temperature they crystalize in tetragonal structure; exhibit tetragonal to orthorhombic structural phase transition accompanied by a spin density wave order on iron at T_{SDW}; exhibit localized (antiferro)magnetic order associated with f-electrons. [3,4] With Co-doping it is possible to tune the T_{SDW} and introduce superconductivity in this system. [3,4]

Crystallites of $GdFe_{1-x}Co_xAsO$ (x = 0.1; 0.15, 0.2) were grown using the salt-flux method. The GdAs, Co, Fe, Fe_2O_3 and KCl in molar ratios of 1:x:2/3-x:1/3:30 were loaded into double sealed quartz ampules under vacuum. To increase diffusion, the ampules were heated slowly to 1050 ^{0}C, kept at this temperature for several hours, and then cooled down slowly to 770^{o}C with a rate of ~2^{o}C/h. The KCl flux was removed via dilution in water.

References

[1] L. M. Tran “Investigation of the coexistence of superconductivity and magnetism in substituted $EuFe_2As_2$”, Imt. Wrocław 2017, ISBN 978-83-948287-0-7, eISBN 978-83-948287-1-4 URL www.intibs.pl/locate/lmtran
[2] S. Zapf; M. Dressel, Reports Prog. Phys. 80, 16501
[3] P Wang, Z. M Stadnik, C. Wang, G-H. Cao, Z-A. Xu, J. Phys.: Condens. Matter 22 (2010) 145701.
[4] G. K. Selvan, D. Bhoi, S. Arumugam, A. Midya, P. Mandal. Supercond. Sci. Technol. 28 (2015) 015009

E-mail: l.m.tran@intibs.pl

Synthesis and properties of superconducting iridium doped NdFeAsO

Michal BABIJ[1], Lan Maria TRAN[1], Andrzej J. ZALESKI[1], Yoshihiko TAKANO[2]

[1] *Institute of Low Temperature and Structure Research, Department of Low Temperature and Superconductivity, Polish Academy of Sciences in Wrocław, Okolna 2, 50-422 Wroclaw, Poland*
[2] *MANA National Institute for Material Science, 1-2-1 Sengen, Tsukuba, Ibaraki 305-0047, Japan*

In this contribution we present synthesis and physical properties of newly obtained, by two methods, Ir-doped NdFeAsO superconductors.

REFeAsO-based compounds (where RE is rare earth metal) as a members of so called 1111 family have a lot similarities to the thoroughly investigated AFe_2As_2-based materials (where A = Ca, Sr, Ba, Eu). They crystalize in tetragonal structure; exhibit tetragonal to orthorhombic structural phase transition accompanied by a spin density wave order on iron at T_{SDW}. Additionally some of them exhibit localized magnetic order associated with f-electrons [1,2]. In case of NdFeAsO, by Ir-doping, it is possible to tune the T_{SDW} and introduce superconductivity in this system.

Crystallites of $NdFe_{1-x}Ir_xAsO$ (x = 0.05; 0.1) were grown using the Salt-flux method. The NdAs, Ir, Fe, Fe_2O_3 and KCl in molar ratios of 1:x:2/3-x:1/3:30 were loaded into double sealed quartz ampules under vacuum. To increase diffusion, the ampules were heated slowly to 1050 °C, kept at this temperature for several hours, and then cooled down slowly to 770 °C with a rate of ~2 °C/h. The KCl flux was removed via dilution in water. Polycrystalline samples of $NdFe_{1-x}Ir_xAsO$ (x= 0.05; 0.1) were grown using the High Pressure Technique. The NdAs, Ir, Fe and Fe_2O_3 in molar ratios of 1:x:2/3-x:1/3 were loaded into BN crucible with lid. After applying pressure equal 2 GPa samples were heated up to 1000 °C and kept at this temperature for 1.5 hours.

Obtained samples exhibits superconducting transitions with T_c up to 30 K.

References

[1] S. Zapf; M. Dressel, Reports Prog. Phys. 80, 16501
[2] Y. J. Cui, Y. L. Chen, C. H. Cheng, Y. Yang, J. Jiang, Y. Z. Wang, Y. Zhang, Y. Zhao, Physica C 470 (2010) 1077.

E-mail: m.babij@intibs.pl

DETERMINE THE CURRENT PHASE RELATION OF AN UNCONVENTIONAL JOSEPHSON JUNCTION

Martin ŽONDA[1,2] and Tomáš NOVOTNÝ[2]

Avia Noah[1], *Tomer Feld*[1], *Genady Devit*[1] *Hen Alpern*[1,2], *Tamar Shapira*[1], *Tom Dvir*[1], *Shira Yochelis*[1], *Hadar Steinberg*[1], *Nadav Katz*[1], *Yossi Paltiel*[2], *Oded Milo*[1], *Yonathan Anahory*[1]

[1]*The Racah Institute of Physics, Hebrew University of Jerusalem. ISRAEL*

[2]*The Applied Physics Department, Hebrew University of Jerusalem, ISRAEL*

The Josephson effect lies in the basis of superconductivity and plays a significant role in many applications of modern day technology, ranging from ultra-sensitive magnetic flux sensors, through complex signal processing circuits to quantum bits. A key element of the dc Josephson effect is the dependence of the supercurrent I_s on the phase difference across the Josephson junction. The study of this current-phase relation (CPR) may provide important information about a junction's parameters and characteristics. Chiral molecules have been shown to act as highly efficient spin selective filters and induce magnetization and triplet-pairing superconductivity. We used a three-terminal, three- junction SQUID (mSQUID) which allows a direct measurement of the CPR to examine the effect of chiral molecules attached to a Josephson junction. Although we did not find significant period changing of the CPR or major phase shifts, our data did show an increase of the critical current and an interesting phase shift of the interference pattern before and after the adsorption of chiral molecules on the mSQUID.

E-mail: avia.noah@mail.huji.ac.il

Quantum Phase Transitions in Superconducting Quantum Dots

Alžběta KADLECOVÁ [1], Martin ŽONDA[2,1], Vladislav POKORNÝ[1], and Tomáš NOVOTNÝ[1]

[1] *Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University in Prague, Ke Karlovu 5, CZ-121 16 Praha 2, Czech Republic*
[2] *Institute of Physics, Albert Ludwig University of Freiburg, Hermann-Herder-Strasse 3, 791 04 Freiburg, Germany*

Single-impurity Anderson quantum dot attached to BCS superconducting leads exhibits a $0 - \pi$ impurity quantum phase transition, which can be experimentally controlled either by the gate voltage or by the superconducting phase difference. We newly present two simple analytical formulae describing the position of the phase boundary in parameter space for the weakly correlated and Kondo regime, respectively. Furthermore, we show that the two-level approximation provides an excellent description of the low temperature physics of superconducting quantum dots near the phase transition. We discuss reliability and mutual agreement of available finite temperature numerical methods (Numerical Renormalization Group and Quantum Monte Carlo) and suggest a novel approach for efficient determination of the quantum phase boundary from measured finite temperature data.

References

[1] A. Kadlecová, M. Žonda, V. Pokorný, and T. Novotný, *arXiv:1807.07017*.

E-mail: alzbeta.kadlecova@gmail.com

Tuning the noncentrosymmetric resistance of giant Rashba spin-orbit crystal BiTeBr

Matyas KOCSIS[1], Olexandr ZHELIUK[2], Balint SZENTPETERI[1], Zoltan KOVACS-KRAUSZ[1], Endre TOVARI[1,3], Istvan Endre LUKACS[4], Peter MAKK[1], Justin YE[2], Szabolcs CSONKA[1]

[1] Department of Physics, Budapest University of Technology and Economics and MTA-BME "Momentum" Nanoelectronics Research Group, H-1111 Budapest, Budafoki út 8., Hungary
[2] Device Physics of Complex Materials, Zernike Institute for Advanced Materials, University of Groningen, 9747 AG Groningen, The Netherlands
[3] National Graphene Institute, University of Manchester, Oxford Road, Manchester, M13 9PL, UK
[4] Center for Energy Research, Institute of Technical Physics and Material Science, 1121 Budapest, Konkoly Thege Miklós út 29-33. Magyarország

Recently BiTeBr attracted considerable attention, as it is a layered polar conductor with gigantic built-in Rashba spin-orbit interaction [1][2][3], which has a great potential to engineer synthetic topological insulator in combination with graphene [4]. Recently nonreciprocal electrical signals where reported in bulk BiTeBr which is predicted to increase as the carrier density decreases [1]. So far carrier density tuning has not been reported, and the dependence of the noncentrosymmetric resistance has not been experimentally confirmed on a single flake. In this contribution we report on a novel BiTeBr based heterostructure, which is compatible with the ionic-liquid gating environment. Using these nanodevices BiTeBr was gated for the first time, and large tuning of the noncentrosymmetric resistance was observed.

This work is supported by National Research Development and Innovation Office of Hungary (Project No. 2017-1.2.1-NKP-2017-00001).

References

[1] Ideue, T. et al. Bulk rectification effect in a polar semiconductor. Nature Physics 13, 578–583 (2017).
[2] Fiedler, S. *et al.* Termination-dependent surface properties in the giant-Rashba semiconductors BiTeX (X = Cl, Br, I). *Physical Review B* **92**, (2015).
[3] Eremeev, S. V., Nechaev, I. A. & Chulkov, E. V. 2D and 3D topological phases in BiTeX compounds. *Physical Review B* **96**, (2017).
[4] Kou, L. *et al.* New Family of Robust 2D Topological Insulators in van der Waals Heterostructures. *ACS Nano* **8**, 10448–10454 (2014).

E-mail: matyilona@gmail.com

Local view of superconducting fluctuations

Shai WISSBERG[1], Aviad FRYDMAN[1], Beena Kalisky

[1] Bar Ilan University, Department of Physics and Institute of Nanotechnology and Advanced Materials, Ramat-Gan 5290002, Israel

Superconducting transitions are driven by thermal fluctuations close to the transition temperature, Tc. These fluctuations are averaged out in global measurements, leaving imprints on susceptibility and resistance measurements. We use a scanning superconducting quantum interference device to image thermal superconducting fluctuations in Nb, a conventional BCS superconductor. We observe fluctuations in both space and time which manifest themselves as grains of weaker and stronger diamagnetic response, exhibiting telegraph-like noise as a function of time. Local fluctuations are also found in the imaginary component of the susceptibility demonstrating that the local vortex dissipation can also be used as a probe of the fluctuations. An important outcome of our measurements is the observation that the decrease of susceptibility towards Tc occurs in quantized steps irrespective of the sample geometry [1].

References

[1] Appl. Phys. Lett. **112**, 262602 (2018).

E-mail: Shai.Wissberg@biu.ac.il

Defect-assisted tunneling and compressibility measurements in a Graphene-hBN device

Itai Keren[1], Hadar Steinberg[1]
[1]Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem 91904, Israel

The electronic transport through quantum dots is sensitive to the electrostatic environment. Such dots, used as single electron transistors (SET[1,2]), are a useful probe for electronic charging. In this work we report electronic transport measurements on a graphite-hBN-graphene tunneling device utilizing a few-layer hBN as a tunnel barrier. Graphene is gated via a second hBN flake. We find the graphite-graphene electronic transport to be dominated by tunneling through a dot-like defect in the hBN spacer. The bias-gate stability trace exhibits strong dependence on graphene charge density at zero magnetic field, demonstrating the utility of the dot as a probe for graphene ground-state density of states. At finite magnetic fields, these traces map the zeroth Landau level of the graphene layer. Finally, at elevated bias the dot also serves as a discrete energy current to the graphene layer, thereby providing an additional probe to the excited state spectrum. We suggest this defect-assisted tunneling as a new paradigm for sensitive device-based spectroscopy.

E-mail: itai.keren@mail.huji.ac.il

Ac losses in macroscopic thin-walled superconducting niobium cylinders

Menachem I. Tsindlekht[1], Valery M. Genkin[1], Israel Felner[1], Felix Zeides[1],

Nadav Katz[1], Stefan Gazi[2], and Stefan Chromik[2]

[1]*The Racah Institute of Physics, The Hebrew University of Jerusalem, 91904 Jerusalem, Israel*

[2]*The Institute of Electrical Engineering SAS, Dubravska cesta 9, 84104 Bratislava, Slovakia*

We report the results of measurements of ac losses in macroscopic thin-walled superconducting niobium cylinders as a function of temperature in various dc magnetic fields. Measurements were carried out while the temperature being swept at the rate of 0.1 K/min. We demonstrated that losses were localized near the $H_{c3}(T)$ line on the H-T phase diagram. The stability of the superconducting state of an infinite slab with thin films on both sides was estimated in the Ginzburg-Landau approximation. Using the result of this analysis we have shown that the magnetic flux penetrates into the sample via a sequence of small jumps random in both amplitude and time. Applied ac field produces oscillations of the magnetic moment along minor magnetization loop with small random jumps. By changing the parameters of these loops, the amplitude and width of the jumps randomly, we can fit the model to the experiment with high accuracy, Fig. 1. The model of minorl loops of magnetization, but without any jumps in the magnetic moment, was used in earlier studies to explain the experiment in bulk samples in surface superconducting states [1].

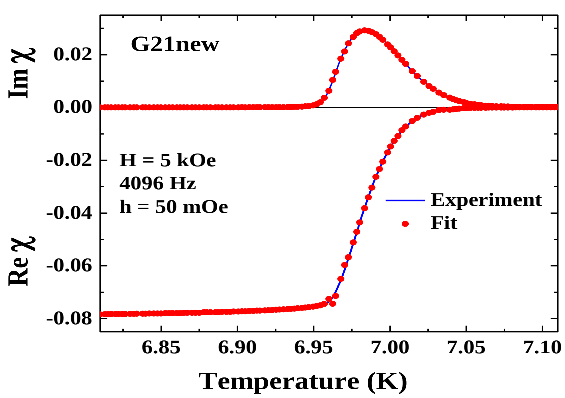


Fig. 1. AC susceptibility of the sample with wall thickness 120 nm and length 21 mm. Blue line – experiment and red circles – fit.

References

[1] H. J. Fink, Phys. Rev. Lett., 1**6**, 447 (1966); R. W. Rollins and J. Silcox, Phys. Rev., **155**, 404 (1967).

E-mail: mtsindl@mail.huji.ac.il

Extremely anisotropic $(LaSe)_{1.14}(NbSe_2)$ misfit layer superconductors

Ondrej Šofranko[1], Pavol Szabó[1], Tomáš Samuely[1] Jozef Kačmarčík[1], Shunsuke Sasaki[2], Laurent Cario[2], Raphaël. Leriche[3], Tristan Cren[3], and **Peter Samuely**[1]

[1] *Centre of Ultra Low Temperature Physics, Institute of Experimental Physics, Slovak Academy of Sciences and P. J. Šafárik University, 04001 Košice, Slovakia*
[2] *Institut des Matériaux Jean Rouxel, Nantes, France*
[3] *Institut des NanoSciences de Paris, Sorbonne Universités, UPMC, CNRS, Paris, France*

Extremely anisotropic $(LaSe)_{1.14}(NbSe_2)$ [1] and $(LaSe)_{1.14}(NbSe_2)_2$ misfit layer superconducting single crystals with the superconducting transition T_c around 1 K and 5 K, resp., are studied by means of the transport measurements and scanning tunneling microscopy and spectroscopy at very low temperatures and in high magnetic fields. The in-plane upper critical fields strongly exceed the Pauli limit reminding the Ising superconductivity in monolayer of $NbSe_2$ [2]. The tunneling density of states indicate non-conventional superconductivity. Fourier transform of the surface topography maps shows besides the Bragg peaks due to hexagonal $NbSe_2$ lattice also a long range modulation in the misfit direction and additional structures. Spectroscopy Imaging STM conductance maps at energies close to Fermi level are recorded to get quasiparticle interference patterns for study of the electronic structure in the systems.

References

[1] P. Samuely et al., Physica C 369, 61 (2002)
[2] X. Xi et al., Nature Phys. 12, 139 (2016)

E-mail: samuely@saske.sk

From a vortex gel to dense hyperuniform vortex lattices

Jose Benito, [3] Alexandre Correa,[1] Lior Embon,[2] Edwin Herrera,[3, 4] Isabel Guillamón,[3, 5] Roberto F. Luccas,[1] Jon Azpeitia,[1] Federico Mompean,[1, 5] Mar García-Hernández,[1, 5] Carmen Munuera,[1, 5] Eli Zeldov,[2] Milorad V. Milosevic,[6] Hermann Suderow,[3, 5] and Yonathan Anahory[7, 2]

[1]Instituto de Ciencia de Materiales de Madrid, Consejo Superior de Investigaciones Científicas (ICMM-CSIC), Sor Juana Inés de la Cruz 3, 28049 Madrid, Spain
[2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel
[3]Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto Nicolás Cabrera and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, E-28049 Madrid, Spain
[4]Facultad de Ingeniera y Ciencias Básicas, Universidad Central, Bogotá 110311, Colombia.
[5]Unidad Asociada de Bajas Temperaturas y Altos Campos Magnéticos, UAM, CSIC, Cantoblanco, E-28049 Madrid, Spain
[6]Theory of Functional Materials, Department of Physics, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerpen, Belgium
[7]Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel

We first discuss high-resolution imaging of the superconducting vortex lattice in β-Bi_2Pd in the limit where vortices are nearly independent and find that the variance of the distribution of intervortex distances diverges when decreasing the magnetic field. This is due to the presence of clusters of vortices separated by large vortex free areas. We suggest that this forms a vortex gel which might be present in type II superconductors at magnetic fields well below H_{c1} and consists of a scaffold of pinned vortices holding vortex free areas. The main difference with the known vortex glass found in cuprate superconductors in the same field range is that the density is not homogeneous. We then analyze vortex lattices at high magnetic fields when vortices are very close to each other, calculating the variance and the structure factor. We study four different systems and show that disordered lattices are not random but hyperuniform in the limit of dense packing. By contrast, at very low magnetic fields in vortex glasses with low but uniform density, the disorder is however random.

Local view of $BaPb_{1-x}Bi_xO_3$ near Quantum criticality

Yiftach Frenkel[1], Anthony L Edgeton[2], Chang-Beom Eom[2], Beena Kalisky[1]

[1] Bar Ilan University, Department of Physics and Institute of Nanotechnology and Advanced Materials, Ramat-Gan 5290002, Israel
[2] University of Wisconsin, Department of Materials and Engineering. Madison, Wisconsin 53706 USA

Recently we used scanning SQUID to image fluctuations in the local superfluid density near quantum phase transition between SC to insulator in a series of NbTiN samples with different thicknesses. In this work, Kremen at al. [1] presented images indicating of electronic superconducting granularity which fluctuates in time and space at temperatures well below Tc. The temperature regime of these fluctuations grew as the Superconductor to Insulator (SIT) is approached indicating their quantum nature.
Here we image a series of $BaPb_{1-x}Bi_xO_3$ samples with decreasing thickness approaching the SIT. Harris et al [2] demonstrated the existence of superconducting fluctuations above Tc and that Tc is correlated with disorder in a set of $BaPb_{1-x}Bi_xO_3$ samples with decreasing thickness. We show preliminary results of scanning SQUID measurements of this set of samples.

References

[1] A.kremen *et al*. Nat. Phys. 2018
[2] D.T. Harris *et al.* PR Materials 2018

E-mail: yiftachf@gmail.com

NOTES

NOTES

NOTES

NANOSCALE COHERENT HYBRID DEVICES FOR SUPERCONDUCTING QUANTUM TECHNOLOGIES

Work is supported by

COST
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

COST is supported by the EU Framework Programme Horizon 2020