Seventh INTERNATIONAL CONFERENCE ON
VORTEX MATTER IN NANOSTRUCTURED
SUPERCONDUCTORS

Rhodes (Greece)
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ABSTRACT BOOK

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Index

WELCOME ADDRESS 4
ESF-NES WEBPAGE AND FLYER 5
CONFERENCE COMMITTEE 19
VENUE, LOCATION, HOTEL AREA MAP AND ALDEMAR INFO SHEET 20
SOCIAL EVENTS 25
COMPANIONS PROGRAMME 26

SCIENTIFIC PROGRAMME 29
PROGRAMME MATRIX 31
PROGRAMME (IN DETAIL) 33
detailed Presentation INDEX 34

ORAL PRESENTATIONS 51
POSTER PRESENTATIONS- 131
SESSION I- 133
SESSION II- 151

PARTICIPANT INDEX 169

NOTES 173
WELCOME ADDRESS

In May 2007 the European Science Foundation launched a new Research Networking Programme “Nanoscience and Engineering in Superconductivity (NES)” for 2007-2012. Together with the JSPS-NES Programme and the research carried on in this field by the teams from the USA, this created a unique coordinated global research effort in the area of “Nanoscience and Engineering in Superconductivity”. To support this truly global activity, a series of Conferences has been organized, including the previous VORTEX IV Conference (September 3-9, 2005, Crete, EU), the MesoSuperMag (August 28-September 1, 2006, Chicago, USA), the VORTEX V Conference (September 8-14, 2007, Rhodes, EU) and the previous VORTEX VI Conference (September 17-24, 2009, Rhodes, EU). The VORTEX VII conference is a continuation in this series and it is supported by the ESF - NES Programme.

On behalf of the VORTEX VII Organizing, Programme and Local Committees it is our pleasure to welcome you to this Conference.

The main focus of the VORTEX VII Conference is on the following topics: (i) 100 years of Superconductivity, (ii) Multigap Superconductivity, (iii) Vortices in Mesoscopic Superconductors, (iv) Superconductivity at the Nanoscale, (v) Nano-engineered Pinning Arrays, (vi) Superconductor/ferromagnet Hybrids, (vii) Josephson Junctions and their Arrays, (viii) Vortex Dynamics, Driven Vortex Lattices, Ratchets, (ix) Nanoscale Imaging, (x) Vortices in Bose-Einstein Condensates, (xi) Vortices in Superfluid Helium and (xii) Nanoplasmonics and Nanophotonics

We hope that the presence of leading experts and young students, and their "confinement" by a beautiful Mediterranean "pinning centre" (Rhodes) will result in a productive and exciting event which will generate new ideas and further strengthen the research efforts in the field of “Nanoscience and Engineering in Superconductivity”.

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The European Science Foundation (ESF) is an independent, non-governmental organisation of national research organisations. Our strength lies in the membership and in our ability to bring together the different domains of European science in order to meet the scientific challenges of the future. ESF’s membership currently includes 77 influential national funding agencies, research-performing agencies and academies from 30 nations as its contributing members. Since its establishment in 1974, ESF, which has its headquarters in Strasbourg with offices in Brussels and Ostend, has assembled a host of research organisations that span all disciplines of science in Europe, to create a common platform for cross-border cooperation. We are dedicated to supporting our members in promoting science, scientific research and science policy across Europe. Through its activities and instruments ESF has made major contributions to science in a global context. The ESF covers the following scientific domains:

- Humanities
- Life, Earth and Environmental Sciences
- Medical Sciences
- Physical and Engineering Sciences
- Social Sciences
- Marine Sciences
- Nuclear Physics
- Polar Sciences
- Radio Astronomy Frequencies
- Space Sciences

Cover picture:
Vortex patterns in a superconducting square with magnetic dot.
Courtesy of Victor V. Moshchalkov, Leuven.
Summary

Confined condensate and flux in superconductors will be investigated at nanoscale by using various confinement patterns introduced artificially in the form of individual nanocells, their clusters and huge arrays. The dependence of the quantisation effects on the confinement length scale and the geometry will be studied. The boundary conditions, defining the confinement potential, will be tuned by using the hybrid superconductor/normal and superconductor/magnet interfaces.

The evolution of superconductivity at nanoscale will be revealed by determining the size dependence of the superconducting critical temperature and the gap in mass selected clusters and nanograins and also by doing comparative studies of superfluidity in different restricted geometries.

Flux confinement by arrays of magnetic dipoles and other periodic pinning arrays in superconductors will be investigated. By tailoring the confinement, physical properties of the confined condensates and flux can be designed starting from the fundamental Ginzburg-Landau equations (including their generalisation to two component order parameters) and applying them to the real samples with the boundary conditions imposed at the physical sample’s boundary.

This research will reveal the fundamental relations between quantised confined states and the physical properties of the superconducting quantum coherent systems, which will also be of importance for other scientific fields (superconducting elements for quantum computing, nanoelectronics, hydrodynamics, liquid crystals, plasmas).

The ESF-NES Programme and similar programmes in Japan and the USA together form the Global Research Networking, ‘Nanoscience and Engineering in Superconductivity – NES’.

The running period of the ESF NES Research Networking Programme is for five years from May 2007 to May 2012.
Scientific Context

Nanoscale confinement phenomena have recently become the focus of modern condensed matter physics, and very intense research on confined condensates has already begun across the world. This brings us to the main objective of the proposed programme: to investigate the effect of the nanoscale confinement of condensate and flux on superconductivity in order to reveal its nanoscale evolution and to determine the fundamental relations between quantised confined states and the physical properties of these systems, enabling 'quantum design' of their properties.

Along the line of the main objective, the proposed research will be focused on the following topics:

• Evolution of superconductivity at nanoscale, superfluidity in restricted geometries

The correlation between the nanograin size and the superconducting gap and the critical temperature $T_c$ will be investigated theoretically and experimentally. We will systematically reduce the characteristic size of superconducting grains and clusters in order to reveal the crossover between the bulk superconducting regime and the fluctuation-dominated superconductivity regime. For comparison, superfluidity in nanopores will also be studied as a function of the size of the nanopores.

• Superconductivity in hybrid superconducting, normal (SN) and superconducting magnet (SM), nanosystems with tunable boundary conditions

Confined condensate will be studied in superconducting nano-islands surrounded by normal metallic or magnetic material. The role of proximity effects and the Andreev reflection in modifying the transparency of the sample boundaries will be revealed. The variation of the superfluid density near the boundary will be mapped by using the local scanning tunnelling spectroscopy (STS) techniques. Different vortex configurations, including those with symmetry-induced antivortices, and their dynamics will be investigated in individual nanostructures of different geometries. Here we expect to find the strong effect of the specific boundary conditions on confined flux and condensate.

![Image of superconductivity](image1.png)

*Figure 1: The superconducting ($T < T_c$) and normal state ($T > T_c$) of a superconductor. At high temperatures, the material is in the normal state (right side of the figure) and the carriers are scattered. As such, a resistance is observed as can be seen from the R vs. $T$ curve (middle graph). Once the temperature drops below the critical temperature $T_c$, a transition to the superconducting state occurs. Instead of electrons, now the carriers become Cooper pairs. The resistance drops to zero, and simultaneously a diamagnetic state occurs. In this diamagnetic state, all magnetic field is expelled from the body of the superconductor as can be seen from the bottom left side of the picture.*

![Image of vortex core](image2.png)

*Figure 2: STM image of a vortex core in NbSe$_2$. The inset shows the underlying atomic wave density, visible in the vortex core (Courtesy of Hermann Suderow, Madrid).*

• Confined flux in nanostructured superconductors and hybrid SN and SM nanosystems

Three different types of nanostructured superconductors will be investigated: individual nanocells of different topology, their clusters and huge arrays. By using local probe techniques, such as STM and the scanning Hall-probe microscope, the distributions of the order
parameter density and local magnetic fields will be mapped simultaneously and then compared with the calculations of these parameters based on the solution of the GL equations with the realistic boundary conditions imposed through nanostructuring. Hybrid SN and SM arrays will be also studied. Magnetic dots will be used to generate local vortex-antivortex dipole loops, which will be strongly interacting with the flux lines in superconductors, creating a tunable magnetic periodic confinement. Different novel flux phases, including stable vortex-antivortex patterns, will be studied. Here we can anticipate a very interesting interplay between flux generated by an applied field and magnetic dipoles, which can substantially enhance flux pinning. Magnetic domains will be used to achieve vortex manipulation. Using the recent progress in nano-engineered pinning arrays in superconductors, similar structures can be made to confine flux in rotating superfluids. Keeping in mind that the coherence length for the $^3$He superfluids is much longer than for $^4$He, it seems to be much easier to fabricate periodic pinning arrays for $^3$He. Instead of antidots used in superconductors, an adequate choice here is the periodic array of nanopillars. Here we expect to discover novel flux phases, which are otherwise not stable in a reference superfluid without a periodic pinning array.

- Josephson effects and tunneling in weakly coupled condensates
  
  We shall investigate a variety of Josephson phenomena and phase shifting effects in coupled superconducting condensates, where nanoscale coupling can be provided through an insulating, metallic or magnetic layer. Hybrid structures are essential here in order to tune the coupling strength. These phenomena will be compared with Josephson effects in coupled superfluids.

- Fundamentals of fluxonics, superconducting devices
  
  We will study the devices that control the motion of flux quanta in superconductors and could address a central problem in many superconducting devices; namely, the removal of trapped magnetic flux that produces noise. The controllable vortex motion will be used in nanostructured superconductors for making pumps, diodes and lenses of quantised magnetic flux. Vortex ratchets effects will be studied and then used to achieve vortex manipulation.
Scientific Context

One of the important aspects of this work is to investigate superconducting nanostructured materials for which the confinement of the condensate inside the samples can be controlled by imposing the proper boundary conditions for the order parameter at the nanofabricated boundaries. Remarkably, the order parameter, the analogue of the wave function for normal quantum mechanical systems, obeys the Ginzburg-Landau equations, which play a role similar to that of the Schrödinger equation. This gives a theoretical background for proving the feasibility of the fundamentals of the quantum design and nano-engineering of the superconducting critical parameters. The concept of quantum design is now the backbone for developing new elements and systems for microelectronics and information technology (quantum computing, SQUIDS with improved sensitivity, sensors, etc.).

Summarising the proposed tasks, the core of the NES – ESF project will be focused on the development of the fundamental principles of the ‘quantum design’ of the superconducting critical parameters through the optimisation of the flux and condensate confinement. The nanoscale evolution of superconductivity will be investigated. In individual superconducting nanostructures, topology- and geometry-dependent critical fields, as well as symmetry-induced antivortices in single and two-component order parameter systems will be investigated. In nanostructured superconductors a rich variety of novel flux phases and patterns will be studied in order to master vortex behaviour and develop fundamentals of fluxonics. Superconducting elements for quantum computing will be designed and investigated.
Facilities and expertise which will be accessible within the ESF-NES Programme

In order to successfully carry out the planned joint research, the integration of the research facilities of the NES teams will be achieved at five different levels via a European Virtual Institute (EVI):

- Integration of modern sample preparation and nanostructuring techniques (level 0)

- Integration of local probing techniques enabling vortex visualisation and condensate wave function mapping with a nanoscale resolution (first level)
  Local techniques are a key factor for achieving the scientific objectives, since these techniques provide an important microscopic information: (Low Temperature) STM, (Low Temperature) Scanning Tunneling Spectroscopy (STS), Force Microscopy (FM), Low Temperature Laser Microscopy (LT-laserm), Low Temperature Electron Microscopy (LETM), Scanning Electron Microscopy (SEM), Micro-Raman, Scanning Hall Probe or (array) Hall micro-magnetometry, Magnetic decoration, Scanning Superconducting Quantum Interference Device (Scanning SQUID), Magneto-Optical Imaging (MOI), Low energy muon spin rotation (LE-uSR), Transmission Electron Microscopy (TEM).

- The next level of the shared research facilities is bulk integrated response (second level)
  The techniques needed for the experimental studies on nanostructured superconductors are: SQUID, Vibrating Sample Magnetoetry (VSM), Torque Magnetometry, AC-susceptibility, Noise measurements, MOKE, Thermal conductivity, Electrical transport measurements (including high frequency responses), Ultra Low Temperature Systems, Ultrasonic resonances, Specific heat, Neutron scattering, Synchrotron radiation, Far-Infrared magneto-optics (FIR-MO), Nuclear Magnetic Resonance (NMR).

- A test platform for the development of new applications (third level)

- The theoretical methods and techniques will be integrated in order to interact continuously with the experimental NES teams (fourth level)
  The most important approaches describing the physics of individual nanostructured superconductors are: Bardeen-Cooper and Schrieffer (BCS), (Time Dependent) Ginzburg-Landau (TDGL), Bogolubov-de Gennes, Richardson’s approach to the solution of the BCS Hamiltonian, Molecular dynamics simulations, Group theory and Topology, Monte Carlo simulations, bosonisation, renormalisation group calculations, Keldysh – formalisms, Sin-Gordon Equation.
Grants

The NES Programme supports two types of grants:

- **Short Visits** (There is no deadline for submitting such applications).
- **Exchange Grants**: Deadlines for submitting applications: 1 September, 1 December, 1 March, 1 June. All applications should be submitted via the online application form and using the guidelines: http://www.kuleuven.be/inpac/nes. Priority will be given to applications where the institutions involved are in countries that financially support the programme.

**Eligibility**
- Undertake work applicable to the Programme.
- Apply to stay in a European country other than the country of origin.
- Return to the institute of origin upon termination, so that the applicant’s institution may also benefit from the broadened knowledge of the scientist.
- Acknowledge ESF in publications resulting from the grantee’s work in relation with the grant

Conferences and Workshops

Within NES, the following activities are planned:

- **NES Workshops** (at least one focused workshop per year) and Conferences (1st, 3rd and 5th year).
- Organisation of Workshops/Conferences in a School format thus giving an opportunity to young researchers and PhD students to learn efficiently about the main trends and the latest achievements.
- Organisation of several Joint ESF-JSPS-USA events with support from the JSPS and the USA for the participation of scientists from those countries in the NES-ESF events.

For a regular update on these activities, please refer to our website: http://www.kuleuven.be/inpac/nes
Funding

ESF Research Networking Programmes are principally funded by the Foundation’s Member Organisations on an à la carte basis. NES is supported by:

- Fonds zur Förderung der wissenschaftlichen Forschung (FWF)
  Austrian Science Fund, Austria
- Fonds voor Wetenschappelijk Onderzoek — Vlaanderen (FWO)
  Research Foundation Flanders, Belgium
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  Academy of Sciences of the Czech Republic, Czech Republic
- Grantová agentura České republiky (GAČR)
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  Academy of Finland, Finland
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- Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO)
  Netherlands Organisation for Scientific Research, The Netherlands
- Norges Forskningsråd
  Research Council of Norway, Norway
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- Vetenskapsrådet (VR)
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For the latest information on this Research Networking Programme consult the NES websites:
www.esf.org/nes
www.kuleuven.be/lnpac/nes
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VENUE, LOCATION, HOTEL AREA MAP AND ALDEMAR INFO SHEET:

The Seventh International Conference “VORTEX MATTER IN NANOSTRUCTURED SUPERCONDUCTORS” will take place in the Aldemar Paradise Royal Mare Hotel, Kalithea, Rhodes:

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The hotel is located at 20 kilometers from Rhodes Int. airport and at 6 kilometers from Rhodes town

**Transport facilities at the hotel:**
- Daily public bus service to and from the town of Rhodes (extra charge)
- **Taxi service** (airport – hotel ~€30-€35 and hotel – town ~€12-€15, extra charge)
  Tf: 22410 / 69600
- Car, motorcycle and bicycle hire service (extra charge)
- Organized excursions (extra charge)
The conference centre is located in the main building of the hotel. Arrows and announcement posters will be indicating the lecture/poster rooms as well as the accommodation areas.
Dear Guests,

On behalf of the management and staff of the Hotels Aldemar Paradise Royal Mare and Paradise Village, we would like to take this opportunity to welcome you and wish you a pleasant holiday.

Your choice of an All Inclusive package will mean a carefree holiday for everyone. Please take a few minutes to read the services and items offered at the hotel and how you can obtain the best from your holiday. On arrival at the hotel you will be provided with an identity card and a plastic bracelet, which should be placed upon check-in. It is necessary to keep it during your whole stay with us, in order to be able to consume food and drinks from the hotel departments.

Hotel check-in time: > 14h00
Hotel check-out time: < 11h30

In case you wish to dine in our Theme Restaurants, please make a reservation two days in advance at the main restaurant Symposio from 8:00-10:00, 12:00-14:00 and 18:30-21:15 with the vouchers you received upon arrival.

Formal dressing is required in all restaurants during dinner (no shorts, sleeveless t-shirts, etc.).
Swimming suits are not allowed during lunch in the main restaurants.

Please observe that children under the age of 18 are not allowed to order and / or drink alcoholic beverages.

RESTAURANTS & SNACK-BARS

Symposio Restaurant (Paradise Mare)
Early Breakfast: to be ordered one day in advance, before 19:00
07:00 - 07:30 Continental Breakfast
07:30 - 10:00 American Buffet Breakfast
18:30 - 21:15 Dinner Buffet
18:30 - 20:00 Children's Dinner Buffet - Aldy's Children Restaurant

Special theme Buffets: Every Tuesday & Thursday
Drinks included during lunch and dinner: soft drinks, juices, local draught beer, table water and local wine.

Byzantine Restaurant (Paradise Village)
Early Breakfast: to be ordered one day in advance, before 19:00
07:00 - 07:30 Continental Breakfast
07:30 - 10:00 American Buffet Breakfast
18:30 - 21:15 Dinner Buffet
18:30 - 20:00 Children's Dinner Buffet - Aldy's Children Restaurant

Special theme Buffets: Every Tuesday & Thursday
Drinks included during lunch and dinner: soft drinks, juices, local draught beer, table water and local wine.

Thalassa Snack Bar (Paradise Village)
10:00 - 17:00 daily
10:00 - 12:00 Buffet with a variety of salads, snacks and sandwiches
12:00 - 16:00 Buffet with a variety of salads, hot and cold appetizers, main courses/grills, fruits and desserts, ice cream
16:00 - 17:00 Buffet with a variety of salads, sandwiches, fruits and desserts

Drinks included: soft drinks, juices, local draught beer, table water and local wine
Local and international alcoholic drinks, cocktails, long drinks, cold & hot beverages
Snack Bar La Pergola (Paradise Mare)
10:00 - 17:00 daily
10:00 - 12:00 Buffet with a variety of salads, snacks and sandwiches
12:00 - 16:00 Buffet with a variety of salads, hot and cold appetizers, main courses/grills, fruits and desserts, ice cream
16:00 - 17:00 Buffet with a variety of salads, sandwiches, fruits and desserts
Drinks included: soft drinks, juices, local draught beer, table water and local wine
Local and international alcoholic drinks, cocktails, long drinks, cold & hot beverages

THEME RESTAURANTS
La Pergola Italian Restaurant (Paradise Mare)
19:00 - 23:00 Five days a week dinner buffet (reservation required)

Dionysos Fine Dining (Paradise Mare)
19:00-23:00 Five days a week A la carte French restaurant (reservation required)

Greek Taverna Thalasa (Paradise Village)
19:00-23:00 Five days a week Dinner Buffet Greek restaurant (reservation required)
Live music

Golden Palm Restaurant (Paradise Village)
19.00-23.00 Five days a week Buffet with specialties from the Far East (reservation required)

BARS & BEACH BARS
Venus Bar – Main Bar (Paradise Village)
17:00-00:00 daily
Drinks included: soft drinks, juices, local draught beer, table water, local wine, local and international alcoholic drinks, cocktails, long drinks, cold & hot beverages

Chevalier - Main Bar (Paradise Mare)
17:00 - 00:00 daily
Drinks included: soft drinks, juices, local draught beer, table water, local wine, local and international alcoholic drinks, cocktails, long drinks, cold & hot beverages

Pool Bar – Delfinia 10:00-18:00 daily.
Eva Bar 17:00-00:00 daily.

Albatross Beach Bar 10:00-18:00 daily (Paradise Mare)
10:00-18:00 ice, sweets and fruits
12:00-16:30 salads, variety of grilled meat (barbecue)
Drinks included: soft drinks, juices, local draught beer, table water and local wine

Nautilus Beach Bar 10:00-18:00 daily (Paradise Village)
Soft drinks, juices, local draught beer, table water, local wine, Mexican snacks, fruits et dessert

Safari Disco 22:00 - 02:00 Sunday close (last drink order 00:00) drinks are available after 00:00, against charge.

Every evening animation program.
Drinks included: soft drinks, juices, local draught beer, table water, local wine, local and international alcoholic drinks, cocktails and long drinks.
Stage Bars 21:00-22:30 operative during shows
Mini Market 09:00 - 22:00 daily
Aldemar Shop 09:00 - 13:00 18:00 - 22:00 daily open
Art Gallery Shop 09:00 - 13:00 18:00 - 22:00 daily open
Furs Shop 09:00 - 13:00 18:00 - 22:00 daily open (Paradise Mare)
Jewellery Shop 09:00 - 13:00 18:00 - 22:00 daily open (Paradise Mare)
Fitness Centre 09:00 - 21:00 Monday - Saturday

Animation Paradise Royal Mare & Paradise Village
Water polo, darts, table games, water games, beach volleyball, beach soccer, mini golf, open chess, table tennis, water gym, sports, gymnastics, aerobic, step aerobics, dance lessons, dance competitions, bingo, games and various tournaments.
4 Tennis Courts
Internet corner (extra charge)
Wireless internet access at the reception lobby and all common areas (free of charge)
Game room (extra charge), Billiards (extra charge)
Water slide 80 m long

Children's facilities:
Supervised mini club for children from 4-12 years old, with daily program
Mini disco 20:30 - 21:00 daily
Baby cots (upon request)
Aldy's restaurant at 18:30 - 20:00 in our main restaurant Sympossio

Other Services:
Beach Towels, Tennis Rackets, Mini Golf Sticks : can be obtained from beach towel point, with a beach towel card. In case the items have not been returned upon departure, a 15,00€ penalty will be charged.
Internet Corner (extra charge), Wireless internet access (free of charge)
Laundry & Dry Cleaning (extra charge)
Daily Public bus services to Rhodes
Information for excursions
Rent a car Services, Taxi Services (upon request with extra charge )
Currency exchange
Housekeeping facilities : daily service

Remarks:
Local alcoholic drinks: raki, ouzo, brandy
International alcoholic drinks: liquor, gin, vodka, rum, tequila, whisky (except champagne)
All the drinks are mentioned on the list of each department
Juices are not freshly pressed.
Smoking is prohibited in all close areas
Wearing an all inclusive bracelet is obligatory in order to be served.
Lost bracelets must be reported immediately to the reception in order to receive a new one
Drinks and food are on self service basis. Every guest can only take 2 drinks each time.
No food or drinks may be taken outside the hotel's departments areas.
For safety reasons, drinks around the pools and at the beach, mast be in polycarbonate glasses (not glass)
Under aged children (younger than 18 years old) are not allowed to consume alcohol.
Some departments or services may operate periodically, depending on the season/weather conditions.

For any other questions, do not hesitate to contact us
We wish you a wonderful stay!
Social events

The Conference organizers offer:

- Welcome drink
- Coffee breaks
- Conference excursion
- Conference dinner
- Best poster prizes
Companions programme

There are lots of **sport and recreation facilities in the hotel**. Some of the possible activities (which are free of charge) are listed here:

- *Sandy & pebble beach*
- *Beach/pool deck Chairs & Umbrellas*
- *Club by the animation team*
- *Dance Competitions*
- *Greek Dances Lessons*
- *Aqua Aerobics*
- *Two Tennis Courts (Quartzsand)*
- *Table tennis*
- *Mini – Golf*
- *Beach Volley*
- *Beach Soccer*
- *Water Polo*

Several excursions can be attended, organized by the hotel. Some of the possible outings are described here (extra charge):

**The city of Rhodes**
Founded from the merging of the three Dorian cities of Ialyssos, Kamiros and Lindos, the town was ruled by the priest of the sun, and its coins bore images of the god Helios.

**Lindos Acropolis**
Lindos is located along two beaches in the shape of a half-moon. Trace the steps of Dorian domination in the epigraphs on the Acropolis.

**Socrates’ market**
Walk through the medieval gates of the town and let yourself be enchanted by its multicoloured window displays!

**Square with the 100 Palms (Plateia 100 Hourmadies)**
A long and narrow square flanked by rows of palm trees. Why not visit the three storey Nestorideion Melathron, the gallery run by Rhodes Town Council with over 1,000 works of art by Greek artists.

**The Colossus of Rhodes**
One of the 7 wonders of the world, the Colossus was created by the sculptor Chares of Lindos. The statue was shaped out of bronze and was 31 m tall. In the year 226 BC, it was destroyed in an earthquake and never replaced. The statue is known to all far and wide and is surrounded by many myths.

**The Thalassini Pyle or Gate to the Port**
The most popular and most impressive of the 11 gates protecting the Old Town of Rhodes. On your left is Hippocrates Square, and from here the most commercial street on the island takes you up to the Suleyman Mosque and the Islamic Library.

**Mount Smith**
Take an afternoon walk up to visit the ancient theatre and the Rhodes Acropolis before enjoying the wonderful sunset.

**The Valley of the Butterflies**
Gigantic trunks of the plane trees, arbutus, carobs, laurels, lentiscus or mastic trees, and oleanders combine with the
River Pelekanos to create a mini paradise. Millions of panaxiaquadripunctaria (pretty, named after the Roman numeral IV that can be discerned on their wings) butterflies decorate rocks and trees with their velvet beauty, quite unique.

**Rodini**
A little valley, a park to the south of the city. Take a stroll along the paths, lined with plane trees, rhododendrums, willows, little bridges, lakes and lots of green. For those with an interest in archaeology, why not take a look at the tombs dating back to the time of the Ptolemies. The Rodini was also used as a park during the time of the Turkish occupation, and at the time of the Knights this was the location for their Court of the Magistrates.

**Melekounia**
A traditional local pasteli. This sweet was traditionally made by the women of every house before important celebrations, and each stage in the process would be accompanied by the respective song. Only found in the Koskinou area.

**Anthony Quinn**
A beach with natural stone deck-chairs, pine trees growing right down to the sea and emerald green waters… Anthony Quinn fell in love with the area and bought a large estate here during the filming for the ‘Guns of Navarone’. Ever since then the beach has borne the name of the great actor.

**The Baths at Kallithea**
Famous for their healing qualities since the time of the Dorians, the baths were at their most popular during the period between the First and Second World Wars. The architectural features of the village and its buildings combine a variety of styles – the ancient Greek, the Roman, the Byzantine and Arab architecture. The village retains its old fascination and takes you back to the glories of its past.
Seventh International Conference on Vortex Matter in Nanostructured Superconductors

Rhodes 2011

VORTEX VII

Scientific Programme
<table>
<thead>
<tr>
<th>Time</th>
<th>Sun 11</th>
<th>Mon 12</th>
<th>Tue 13</th>
<th>Wed 14</th>
<th>Thu 15</th>
<th>Fri 16</th>
<th>Sat 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>08h30</td>
<td>Opening</td>
<td>Ishida</td>
<td>Silhanek</td>
<td>Kwok</td>
<td>Desyatnikov</td>
<td>Goldobin</td>
<td>Sudbo</td>
</tr>
<tr>
<td>09h00</td>
<td>Moshchalkov</td>
<td>Guillamon</td>
<td>Iavarone</td>
<td>Karpinski</td>
<td>Verellen</td>
<td>Wördenweber</td>
<td>Pedersen</td>
</tr>
<tr>
<td>10h00</td>
<td>Babaev</td>
<td>Tamegai</td>
<td>Lyuksyutov</td>
<td>Haindl</td>
<td>Wurtz</td>
<td>Aliev</td>
<td>Lang</td>
</tr>
<tr>
<td>10h30</td>
<td>Chibotaru</td>
<td>Yurchenko</td>
<td>Cy. Reichhardt</td>
<td>Zhigadlo</td>
<td>Vanacken</td>
<td>Kolacek</td>
<td>Joon</td>
</tr>
<tr>
<td>11h00</td>
<td>Gutierrez</td>
<td>Samuely</td>
<td>Coffee</td>
<td>Coffee</td>
<td>Coffee</td>
<td>Coffee</td>
<td>Coffee</td>
</tr>
<tr>
<td>11h30</td>
<td>Ch. Reichhardt</td>
<td>Van Delft</td>
<td>Zhu</td>
<td>De Groot</td>
<td>Gross</td>
<td>Takayanagi</td>
<td>Zhang</td>
</tr>
<tr>
<td>12h00</td>
<td>Carlstrom</td>
<td>Fosheim</td>
<td>Kusmartsev</td>
<td>Crisan</td>
<td>Kadowaki</td>
<td>Thompson</td>
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</tr>
<tr>
<td>12h30</td>
<td>Silaev</td>
<td>Devreese</td>
<td>Shapiro</td>
<td>Prihna</td>
<td>Welp</td>
<td>De Long</td>
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</tr>
<tr>
<td>13h00</td>
<td>Vestgarden</td>
<td>Kagan</td>
<td>Lunch</td>
<td>Lunch</td>
<td>Lunch</td>
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<tr>
<td>14h00</td>
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<tr>
<td>17h00</td>
<td>Maggio-Aprile</td>
<td>Mori</td>
<td>Andreev</td>
<td>Ortiz</td>
<td>Saarela</td>
<td></td>
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</tr>
<tr>
<td>18h00</td>
<td>Janko</td>
<td>Aladyshkin</td>
<td>Tempère</td>
<td>Anwar</td>
<td>Sardella</td>
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<tr>
<td>19h00</td>
<td>Coffee</td>
<td>Misko</td>
<td>Coffee</td>
<td>Coffee</td>
<td>Cabral</td>
<td>Coffee</td>
<td>Galperin</td>
</tr>
<tr>
<td>19h30</td>
<td>Suderow</td>
<td>Pan</td>
<td>Poster Session I</td>
<td>Poster Session II</td>
<td>Coffee</td>
<td>Klushin</td>
<td>Kornev</td>
</tr>
<tr>
<td>20h00</td>
<td>Roditchev</td>
<td>Kato</td>
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<tr>
<td>20h30</td>
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</tbody>
</table>

**Notes:**
- Coffee breaks are indicated with "Coffee.
- Lunch breaks are indicated with "Lunch.
- Poster Session I and II are scheduled for specific times.
- Conference Trip is indicated.
- Departure is indicated at 7:00 PM.
DETAINED PROGRAMME
SATURDAY 10

Saturday, September 10, 2011

ARRIVAL

16h00-22h00  REGISTRATION

18h00  WELCOME DRINK @ COCKTAIL BAR “EVA”

19h30  DINNER @ MAIN RESTAURANT “SYMPOSIO”
      - FOR GUEST ARRIVING LATE, A COLD DISH CAN BE SERVED UPON ARRIVAL
## Detailed Programme

### Sunday 11

**Sunday, September 11, 2011**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session/Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>08h30-08h40</td>
<td>Welcome Address (Sun. 01)</td>
</tr>
<tr>
<td>08h40-09h10</td>
<td><strong>Session 1: Type 1.5 Superconductors &amp; Two-gap Phenomena I</strong></td>
</tr>
<tr>
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<td>Chair: Wördenweber</td>
</tr>
<tr>
<td>08h40-09h10</td>
<td>Vortex Matter in Type-1.5 Superconductors</td>
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<tr>
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<td>Victor V. Moshchalkov (Sun. 02)</td>
</tr>
<tr>
<td>09h10-09h40</td>
<td>Type-1.5 Superconductivity in Multiband Systems: Effects of Interband Coupling and Complexity of Bound Vortex States</td>
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<td>Egor Babaev (Sun. 03)</td>
</tr>
<tr>
<td>09h40-10h10</td>
<td>Microscopic Description of Vortices in Nanoscale Superconductors: Quest of Applicability of Ginzburg-Landau Theory</td>
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<tr>
<td></td>
<td>Liviu Chiboratu (Sun. 04)</td>
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<tr>
<td>10h10-10h40</td>
<td>Scanning Hall Probe Microscopy Study of Unconventional Vortex Patterns in the Two-gap MgB2 Superconductor</td>
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<tr>
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<td>Joffre Gutierrez (Sun. 05)</td>
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<tr>
<td>10h40-11h10</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>11h10-11h40</td>
<td><strong>Session 2: Type 1.5 Superconductors &amp; Two-gap Phenomena II</strong></td>
</tr>
<tr>
<td></td>
<td>Chair: Kadowaki</td>
</tr>
<tr>
<td>11h10-11h40</td>
<td>Pinning and dynamics in Pattern Forming Systems on Random and Periodic Structures: Implications for Vortices in Type-1.5 Superconductors and Other Systems</td>
</tr>
<tr>
<td></td>
<td>Charles Reichhardt (Sun. 06)</td>
</tr>
<tr>
<td>11h40-12h10</td>
<td>Non pairwise Inter-vortex Forces in Multi-band Superconductors</td>
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<tr>
<td></td>
<td>Johan Carlstrom (Sun. 07)</td>
</tr>
<tr>
<td>12h10-12h30</td>
<td>Microscopic Theory of Type-1.5 Superconductivity in Multiband Systems</td>
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<td>Mikhail Silaev (Sun. 08)</td>
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<tr>
<td>12h30-12h50</td>
<td>Simulation of Dendritic Flux Avalanches in Superconducting Films</td>
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<td>Jørn Vestgarden (Sun. 09)</td>
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<tr>
<td>12h50-13h10</td>
<td>Anomalous Kinetic and Thermodynamic Characteristics in the Two-band Superconductor with One Narrow Band</td>
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<td></td>
<td>Maxim Kagan (Sun. 10)</td>
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<tr>
<td>13h10-17h00</td>
<td>Lunch Break</td>
</tr>
</tbody>
</table>

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*7th International Conference on Vortex Matter in Nanostructured Superconductors*
SUNDAY 11

Sunday, September 11, 2011

**SESSION 3:** STS/STM & Vortex Imaging I
*Chair: P. Samuely*

17h00-17h30  **STS MEASUREMENTS OF MULTIBAND SUPERCONDUCTORS**  
*Ivan Maggio-Aprile*  (Sun. 11)

17h30-18h00  **NOVEL ANDREEV BOUND STATES IN NANOSTRUCTURED SUPERCONDUCTORS**  
*Boldizsár Jankó*  (Sun. 12)

18h00-18h30  **Coffee Break**

**SESSION 4:** STS/STM & Vortex Imaging II
*Chair: Maggio-Aprile*

18h30-19h00  **CURRENT DRIVE SCANNING TUNNELING SPECTROSCOPY: GAP STRUCTURE AND VORTEX LATTICE OF 2H-NbSe2**  
*Hermann Suderow*  (Sun. 13)

19h00-19h30  **REVEALING SUPER-DENSE VORTEX CONFIGURATIONS IN NANO-METER-SCALE SUPERCONDUCTORS WITH SCANNING TUNNELING SPECTROSCOPY**  
*Dimitri Roditchev*  (Sun. 14)
# DETAILLED PROGRAMME

## MONDAY 12

### SESSION 5: STS/STM & Vortex Imaging III

**Chair:** Bending

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>08h30</td>
<td>Vortices configuration in superconducting MoGe networks</td>
<td>Takekazu Ishida</td>
<td>Mon. 01</td>
</tr>
<tr>
<td>09h00</td>
<td>Direct observation of the Bragg-to-Vortex Glass transition in a 2D vortex lattice</td>
<td>Isabel Guillamón</td>
<td>Mon. 02</td>
</tr>
<tr>
<td>09h30</td>
<td>Imaging of vortex penetration into superconducting square networks</td>
<td>Tsuyoshi Tamegai</td>
<td>Mon. 03</td>
</tr>
<tr>
<td>10h00</td>
<td>High Speed Magneto-Optical Imaging of Flux Dynamics in Superconductors</td>
<td>Vitaliy Yurchenko</td>
<td>Mon. 04</td>
</tr>
<tr>
<td>10h30</td>
<td>Superconducting density of states and vortex studies on SrPd2Ge2</td>
<td>Tomas Samuely</td>
<td>Mon. 05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Coffee Break</th>
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</thead>
<tbody>
<tr>
<td>10h50</td>
<td>11h20</td>
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</tbody>
</table>

### SESSION 6: Nobel Prizes for Superconductivity & Quantum Condensates

**Chair:** Moshchalkov

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>11h20</td>
<td>Heike Kameringh Onnes and the Road to Superconductivity</td>
<td>Dirk van Delft</td>
<td>Mon. 06</td>
</tr>
<tr>
<td>11h50</td>
<td>Superconductivity: From 10 Nobel Laureates’ Stories</td>
<td>Kristian Fossheim</td>
<td>Mon. 07</td>
</tr>
<tr>
<td>12h20</td>
<td>History of Superfluidity in ultracold atomic condensed systems</td>
<td>Jozef Devreese</td>
<td>Mon. 08</td>
</tr>
<tr>
<td>12h50</td>
<td>Lunch Break</td>
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</table>

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<thead>
<tr>
<th>Time</th>
<th>Lunch Break</th>
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</thead>
<tbody>
<tr>
<td>12h50</td>
<td>17h00</td>
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</tbody>
</table>

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7th International Conference on Vortex Matter in Nanostructured Superconductors
## SESSION 7: Vortex Matter at the Nanoscale I

Chair: Ishida

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>17h00-17h30</td>
<td>INFLUENCES OF MAGNETIC-FLUCTUATION, RESONANCE, AND OSCILLATION ON JOSEPHSON CURRENT IN SUPERCONDUCTOR/FERROMAGNET/SUPERCONDUCTOR JUNCTION</td>
<td>Michiyasu Mori</td>
<td>Mon. 09</td>
</tr>
<tr>
<td>17h30-17h50</td>
<td>MESOSCOPIC CROSS-FILM CRYOTRONS: LOCALIZED AND DELOCALIZED SUPERCONDUCTIVITY, VORTEX TRAPPING AND DC-JOSEPHSON-LIKE OSCILLATIONS OF THE CRITICAL CURRENT</td>
<td>Alexei Aladyshkin</td>
<td>Mon. 10</td>
</tr>
<tr>
<td>17h50-18h10</td>
<td>VORTEX MOBILITY AND GUIDED VORTEX MOTION IN SUPERCONDUCTORS WITH ANTIDOT ARRAYS IN PRESENCE OF AC AND DC DRIVING</td>
<td>Vyacheslav Misko</td>
<td>Mon. 11</td>
</tr>
</tbody>
</table>

18h10-18h40 Coffee Break

## SESSION 8: Vortex Matter at the Nanoscale II

Chair: Ch. Reichhardt

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Speaker</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>18h40-19h00</td>
<td>EVIDENCE OF TWO PERPENDICULAR ABRIKOSOV VORTEX STRUCTURES IN THIN SUPERCONDUCTORS</td>
<td>Alexey Pan</td>
<td>Mon. 12</td>
</tr>
<tr>
<td>19h00-19h20</td>
<td>VORTEX CONFIGURATION AND VORTEX-VORTEX INTERACTION IN NANO-STRUCTURED SUPERCONDUCTORS</td>
<td>Masaru Kato</td>
<td>Mon. 13</td>
</tr>
<tr>
<td>19h20-19h40</td>
<td>Bi2223 NANO SENSOR DEVICE FOR NMRI</td>
<td>Mihir Sen</td>
<td>Mon. 14</td>
</tr>
</tbody>
</table>
Tuesday, September 13, 2011

SESSION 9: Nanostructured Superconductors & S/F Hybrids I  
Chair: Weip

08h30-09h00  Microscopic Picture of the Critical State in a Superconductor with Periodic Array of Antidots  
Alejandro Silhanek  (Tue. 01)

09h00-09h30  Vortex Confinement in Planar Superconducting/Ferromagnet Hybrid Structures  
Maria Iavarone  (Tue. 02)

09h30-10h00  Controlling Superconducting Film with Magnetic Nanostructures  
Igor Lyuksyutov  (Tue. 03)

10h00-10h30  Vortex Dynamics in Periodic and Quasiperiodic Pinning Arrays  
Cynthia Reichhardt  (Tue. 04)

10h30-11h00  Coffee Break

SESSION 10: Nanostructured Superconductors & S/F Hybrids II  
Chair: Saarela

11h00-11h30  Vortex State in a Mesoscopic Flat Disk with Rough Surface  
Albino Aguiar  (Tue. 05)

11h30-12h00  Ratchet Effect of Josephson Vortex Motion in Stacked Intrinsic Josephson Junctions  
Beiyi Zhu  (Tue. 06)

12h00-12h30  Vortex Structures and Magnetization of Superconducting Pb Nanowires and Other Nano-Superconductors of Different Shapes  
Feodor Kusmartsev  (Tue. 07)

12h30-13h00  Microwave Absorption in the Core of the Abrikosov Vortex Pinned by Artificial Insulator Inclusion  
Boris Shapiro  (Tue. 08)

13h00-17h00  Lunch Break
Tuesday, September 13, 2011

SESSION 11: Helium & Superfluid Atomic Gases  

Chair: Sudbø

17h00-17h30  *Resonant Tunneling Clusters of Crystal Defects in Solid Helium: An Internal Josephson Effect*

*Alexander Andreev* (Tue. 09)

17h30-18h00  *Vortices in Two-Dimensional Superfluid Atomic Gases*

*Jacques Tempère* (Tue. 10)

18h00-18h30  COFFEE BREAK

SESSION 12: Poster Session I
Wednesday, September 14, 2011

SESSION 13: Oxypnictide & Cuprate Superconductors I

Chair: Gross

08H30-09H00 Doping and irradiation induced vortex pinning in iron-pnictide superconductors
Wai-Kwong Kwok (Wed. 01)

09H00-09H30 Direct doping and substitutions in LnFeAsO single crystals grown at high pressure: influence on superconducting properties and structure
Janusz Karpinski (Wed. 02)

09H30-10H00 New routes for epitaxial thin films of Fe-based superconductors
Silvia Haindl (Wed. 03)

10H00-10H30 Recent developments in crystal growth of LnFeAsO (Ln=rare earth) oxypnictide superconductors by high-pressure flux method
Nikolai Zhigadlo (Wed. 04)

10H30-11H00 Coffee Break

SESSION 14: Oxypnictide & Cuprate Superconductors II

Chair: Kwok

11H00-11H30 Vortex imaging in unconventional superconductors
Simon Bending (Wed. 05)

11H30-12H00 Multiple history effects near commensurate states in Y123 and Y124 single crystals
Peter De Groot (Wed. 06)

12H00-12H30 Nanoengineered pinning centres in thick superconducting films: effects on critical current and critical current anisotropy
Adrian Crisan (Wed. 07)

12H30-12H50 High-pressure effect on pinning in MgB2-based superconductors
Tatiana Prikhna (Wed. 08)

12H50-13H10 Superconducting critical fields in K0.8Fe1.25Se2 compound
Menachem Tsindlekh (Wed. 09)

12H30-17H00 Lunch Break

Conference Trip
DETAILED PROGRAMME

THURSDAY 15

Thursday, September 15, 2011

SESSION 15: Optical Vortices, Plasmonics & THz Radiation I
Chair: Anlage

08H30-09H00 Knots of quantized vortices in self-trapped optical beams
Anton Desyatnikov (Thu. 01)

09H00-09H30 Plasmonic line shaping through nanostructuring
Niels Verellen (Thu. 02)

09H30-10H00 Active nanodevices: the next challenge for plasmonics
Gregory Wurtz (Thu. 03)

10H00-10H30 Propagation of magnetic avalanches and fast emission of heat in Mn12-AC under high field sweep rates
Johan Vanacken (Thu. 04)

10H30-11H00 Coffee Break

SESSION 16: Optical Vortices, Plasmonics & THz Radiation II
Chair: Tafuri

11H00-11H30 Vortex-switched transparency window with meta-molecules utilizing superconducting dark resonators
Steven Anlage (Thu. 05)

11H30-12H00 Ultrastrong light-matter interaction in superconducting quantum circuits
Rudolf Gross (Thu. 06)

12H00-12H30 Coherent terahertz radiation phenomena from high temperature superconductor mesa structures
Kazuo Kadowaki (Thu. 07)

12H30-13H00 Tunable terahertz emission from Bi2Sr2CaCu2O8±δ mesa devices
Ulrich Welp (Thu. 08)

13H00-13H30 Lunch Break
## Detailed Programme

### Thursday, September 15, 2011

**Session 17:** Nanostructured Superconductors & S/F Hybrids III  
*Chair:* Suderow

- **17h00-17h20**  
  **Threshold Critical Current to Trigger Vortex Avalanches in Superconducting Thin Films**  
  *Wilson Ortiz* (Thu. 09)

- **17h20-17h40**  
  **Vortex Dynamics in YBCO Films with Engineered Antidots and Ferromagnetic Nanostructures**  
  *Victor Rouco* (Thu. 10)

- **17h40-18h00**  
  **Dynamics of Kinematic Vortices in a Superconducting Stripe**  
  *Edson Sardella* (Thu. 11)

- **18h00-18h20**  
  **Dynamic Phases of Vortex-Antivortex Molecules in a Corbino Disk with Magnetic Dipole on Top**  
  *Leonardo Cabral* (Thu. 12)

- **18h20-18h50**  
  **Coffee Break**

**Session 18:** Poster Session II
DETAILED PROGRAMME
FRIDAY 16

Friday, September 16, 2011

SESSION 19: Josephson Effects, Vortex Ratchets & Dynamics I
Chair: Aguiar

08h30-09h00 Performance of Deterministic Josephson Vortex Ratchet with a Load
Edward Goldobin (Fri. 01)

09h00-09h30 Microwave Vortices Matter in Nanostructured High-Tc Films
Roger Wördnweber (Fri. 02)

09h30-10h00 Flux Avalanches Triggered by Microwave Depinning of Superconducting Vortices
Farkhad Aliev (Fri. 03)

10h00-10h30 Josephson Relation and Lorentz Force
Jan Koláček (Fri. 04)

10h30-11h00 Coffee Break

SESSION 20: Josephson Effects, Vortex Ratchets & Dynamics II
Chair: Kolacek

11h00-11h30 Macroscopic Quantum Phenomena Decay in LTS and HTS Josephson Junctions
Francesco Tafuri (Fri. 05)

11h30-12h00 Transport Properties of Andreev Polarons in a Superconductor-Semiconductor-Superconductor
Junction with Superlattice Structure
Hideaki Takayanagi (Fri. 06)

12h00-12h30 Ultrathin Superconducting Alloy Films Formed from Bulk-Immiscible Elements by Quantum Stabilized
Growth
James Thompson (Fri. 07)

12h30-13h00 Observations of Extreme Magnetic Anisotropy and Multiple Superconducting Transition Signatures
in Nb/Ni Heterostructures
Lance De Long (Fri. 08)

13h00-17h00 Lunch Break
Friday, September 16, 2011

SESSION 21: Josephson effects, Vortex Ratchets & Dynamics III  
Chair: Joon

17h00-17h30  Nanoscale structures and giant Nernst effect below the pseudogap in high-Tc superconductors  
Mikko Saarela  (Fri. 09)

17h30-18h00  Spin triplet superconductivity generation with CrO$_2$ and Co based SFS junctions  
S. Anwar  (Fri. 10)

18h00-18h30  Coffee Break

SESSION 22: Josephson Effects, Vortex Ratchets & Dynamics IV  
Chair: Pedersen

18h30-18h50  Coulomb-enhanced resonance transmission of quantum SINIS junctions  
Yuri Galperin  (Fri. 11)

18h50-19h10  Room temperature detection of strong sub-terahertz emission from niobium Josephson junctions  
Alexander Klushin  (Fri. 12)

19h10-19h30  Design issues for active electrically small superconductive antenna  
Victor Kornev  (Fri. 13)
DETAILLED PROGRAMME

SATURDAY 17

Saturday, September 17, 2011

SESSION 23: Superconducting Layered & Nanopatterned Structures I
Chair: Vanacken

08h30-09h00 Simulations of a dissipative (2+1)-dimensional XY model for quantum criticality of circulating currents in cuprates
Asle Sudbø (Sat. 01)

09h00-09h30 Fluxon dynamics in stacked Josephson junctions at THz frequencies
Niels Pedersen (Sat. 02)

09h30-10h00 High-velocity vortex channeling in vicinal YBCO thin films
Wolfgang Lang (Sat. 03)

10h00-10h20 Polaron in high-Tc cuprates
Enno Joon (Sat. 04)

10h20-10h50 Coffee Break

SESSION 24: Superconducting Layered & Nanopatterned Structures II
Chair: Lang

10h50-11h10 Insulating state of a superconductor
Konstantin Arutyunov (Sat. 05)

11h10-11h30 AC-driven vortex ratchet reversal in superconducting films with asymmetric tilted washboard pinning potential
Valerij Shklovskij (Sat. 06)

11h30-11h50 Grain size dependent transport properties of superconducting nanocrystalline diamond:B
GuFei Zhang (Sat. 07)

11h30-11h40 Closure
Victor V. Moshchalkov (Sat. 08)
POSTER SESSION I
TUESDAY, SEPTEMBER 13, 2011
18H30-

GROUND STATES OF MULTI-BAND TYPE-I AND TYPE-1.5 SUPERCONDUCTORS AND INTERLACED TYPE-I/TYPE-II LAYERED SUPERCONDUCTING STRUCTURES IN EXTERNAL MAGNETIC FIELD (PSI. MB-SC-01)
JULIEN GARAUD

MULTIGAP SUPERCONDUCTIVITY – THERMODYNAMIC AND MAGNETIZATION STUDIES OF NbS₂ AND PNICTIDES (PSI. MB-SC-02)
Z. PRIBULOVÁ

TWO-GAP SUPERCONDUCTORS IN THE GINZBURG-LANDAU DOMAIN (PSI. MB-SC-03)
LUCIA KOMENDOVA

THE PATTERN FORMATION DUE TO THE NON-MONOTONIC INTERACTION (PSI. MB-SC-04)
H. J. ZHAO

PHASE FLUCTUATIONS IN PROXIMITY COUPLED SUPERCONDUCTING ARRAYS (PSI. VD-01)
SERENA ELEY

SAW-TOOTH RATCHET (PSI. VD-02)
DORIN CERBU

CURRENT-INDUCED VORTEX PINNING (PSI. VD-03)
JO CUPPENS

VORTEX LATTICE STUDIES IN CeCoIn₅ WITH \( H \perp c \) (PSI. VD-04)
P. DAS

INFLUENCE OF PINNING BY PERIODIC ARRAY OF CIRCULAR Py DOTS ON BROADBAND MICROWAVE RESPONSE OF SUPERCONDUCTING Pb FILMS (PSI. VD-05)
AHMAD A. AWAD

MAGNETORESISTIVE RESPONSE IN THIN Nb FILMS WITH UNIAXIAL RATCHET PINNING POTENTIAL (PSI. VD-06)
OLEKSANDR V. DOBROVOLSKY

DIRECT VISUALIZATION OF DYNAMICAL ORDERING EFFECTS IN NbSe₂ (PSI. VD-07)
B. RAES

FLUX AVALANCHES TRIGGERED BY AC MAGNETIC FIELDS IN SUPERCONDUCTING THIN FILMS (PSI. VD-08)
M. MOTTA
THE DYNAMICS OF VORTEX “SHELLS” IN CIRCULAR CHANNELS IN MACROSCOPIC CORBINO DISKS (PSI. VD-09)
N. S. Lin

VORTEX MOTION IN MgB$_2$ THIN FILMS (PSI. VD-10)
Sebastian Treiber

VORTEX MOTION IN Nb/PdNi/Nb TRILAYERS: NEW ASPECTS IN THE FLUX FLOW STATE (PSI. S/F-01)
Kostiantyn Torokhtii

MAGNETIC CONFINEMENT EFFECTS IN A MULTIPLY CONNECTED SUPERCONDUCTOR-FERROMAGNET HYBRID (PSI. S/F-02)
Zorro Millán

ELECTRORESISTANCE AND MAGNETORESISTANCE EFFECTS IN SUPERCONDUCTOR–INSULATOR–FERROMAGNET HYBRID STRUCTURES (PSI. S/F-03)
Sergey A. Fedoseev

DYNAMICS OF AC DRIVEN VORTEX-ANTIVORTEX MATTER IN SUPERCONDUCTOR-FERROMAGNETIC HYBRID STRUCTURES (PSI. S/F-04)
Cléssio L. S. Lima
Formation of Multi-Quanta Vortices in Mesoscopic Superconductors: Electronic, Calorimetric and Magnetic Evidence (PSII. TH-SC-01)
Ben Xu

YBCO Thin Film Critical Current Behaviour Described by Vortex Pinning on Low-Angle Domain Boundaries and Vortex Creep (PSII. TH-SC-02)
I. A. Golovchanskiy

Change of the Vortex Lattice Symmetry in the Vicinity of the Macro-to-Mesoscopic Threshold (PSII. TH-SC-03)
R. Zadorosny

Stationary States and Dynamics of Superconducting Thin Films (PSII. TH-SC-04)
Magnus Ögren

Vortices in a Mesoscopic Superconducting Disk with Surface Defects (PSII. TH-SC-05)
Sindy. J. Higuera

Bogolubov-de Gennes Solutions for the Vortex Phases in Nanoscale Superconductors (PSII. TH-SC-06)
Bart Deloof

Relaxation of Non-Equilibrium Quasiparticles in a Superconductor at Ultra-Low Temperatures (PSII. TH-SC-07)
K. Yu. Arutyunov

Angular Dependence of the High-Frequency Vortex Response in YBCO Thin Films with Self-Assembled BAZrO3 Nanorods (PSII-NEW-SC-01)
Nicola Pompeo

Penetration and de-Pinning of Vortices in Sub-Micrometer Ba(Fe,Co)2As2 Thin Film Bridges (PSII. NEW-SC-02)
D. Rall

Far-Infrared Properties of NbN Superconductor Thin Film (PSII. NEW-SC-03)
R. Tesár

Hints of Superconducting Nanowires Phenomena in Nanoperforated Nb Thin Films (PSII. NEW-SC-04)
M. Trezza

Effects of Non-Homogeneous Magnetization on the Superconducting Properties of Nb/Pt/Nb Trilayers (PSII. NEW-SC-05)
E. A. Ilyina

Thickness-Induced Crossover from Weak to Strong Vortex Pinning in YBa2Cu3O7-δ Ultra-Thin Films (PSII. NEW-SC-06)
Petra Probst

Temperature Dependence of Quasiparticle Energy Relaxation Time by Flux-Flow Instability (PSII. NEW-SC-07)
S. Pace
CRITICAL STATES GENERATED BY CURRENT AND MAGNETIC FIELDS IN THIN TaN FILM STRUCTURES (PSII. NEW-SC-08)
K. IL’IN

NON-MONOTONOUS TEMPERATURE VARIATION OF THE MAGNETIZATION RELAXATION RATE IN YBCO FILMS WITH BZO NANORODS BELOW THE MATCHING FIELD (PSII. NEW-SC-09)
L. MIU

NEAR-FIELD OPTICAL MICROSCOPY OF PLASMONIC EFFECTS IN ANISOTROPIC METAMATERIALS (PSII. OV-01)
VLADIMIR PANOV
Seventh International Conference on Vortex Matter in Nanostructured Superconductors

ORAL PRESENTATIONS
Vortex matter in type-1.5 superconductors (*)

Victor V. Moshchalkov

INPAC-Institute for Nanoscale Physics and Chemistry, University of Leuven,

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The existence of the novel superconducting state has been demonstrated in two-component high quality MgB$_2$ single crystals where a unique combination of both type-1 and type-2 conditions is realized in the same material: $\lambda_1/\xi_1<1/\sqrt{2}$ for the first and $\lambda_2/\xi_2>1/\sqrt{2}$ for the second component of the order parameter. Such materials are, in fact, neither type-1 nor type-2 superconductors (PRB 72, 180502 (2005)) and can be introduced as "type-1.5 superconductors" (PRL 102, 117001 (2009); PRB 81, 020506(R) (2010); PRB 83, 020503 (2011)), since they combine simultaneously characteristic features of both type-1 and type-2 regimes, including the combination of the repulsive and the attractive vortex-vortex interactions. This leads to an appearance of unconventional vortex arrangements such as stable vortex stripes, clusters and gossamer-like vortex patterns. We have directly visualized these novel patterns by using scanning Hall probe microscopy, Bitter decoration and scanning SQUID microscopy. The observed patterns are in a good agreement with the molecular dynamics simulations based on the vortex-vortex interaction corresponding to the type-1.5 superconductivity.

These data are also compared with the exotic vortex-vortex patterns in the so called "intermediate/mixed state" observed earlier by Bitter decoration technique in single gap superconductors in the vicinity of the special point $\lambda/\xi=1/\sqrt{2}$.


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Type-1.5 superconductivity in multiband systems: effects of interband coupling and complexity of bound vortex states

Egor Babaev\textsuperscript{1,2}, Johan Carlstrom\textsuperscript{1}, Julien Garaud\textsuperscript{2}, Mihail Silaev\textsuperscript{2,3}, Martin Speight\textsuperscript{4}

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\textsuperscript{2}University of Massachusetts Amherst, US
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\textsuperscript{4}Leeds University, GB

Single-component superconductors are described at the level of Ginzburg-Landau theory by a single Ginzburg-Landau parameter: the ratio of coherence and penetration lengths and are divided into type-I and type-II classes. In contrast multi-component systems (in particular multiband superconductors) in general should possess distinct characteristic length scales at which the two components vary. This gives rise to a new regime which falls outside the type-I/type-II dichotomy (which was recently termed "type-1.5" superconductivity). In that state there are thermodynamically stable vortex excitations which have nonmonotonic interaction as a consequence of the multicomponent nature of the condensate. Two such vortices attract one another at long range but repel at shorter ranges. As a consequence the system should possess an additional "semi-Meissner" phase in magnetic field. That phase is a macroscopic phase separation into vortex clusters where one of the components is suppressed and domains of two-component Meissner phase. Moreover in the vortex clusters the interaction forces between N vortices are non-pairwise at intermediate length scales which leads great diversity of structure formation in the semi-Meissner state.

Presenting author: Prof. Egor Babaev
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Microscopic description of vortices in nanoscale superconductors: quest of applicability of Ginzburg-Landau theory

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Vortices in mesoscopic superconductors have been thoroughly investigated in the past within the phenomenological Ginzburg-Landau theory. However, it was argued repeatedly that this approach is not suited for the treatment of mesoscopic superconductors because the spacing between vortices in the obtained vortex distributions is usually smaller than the coherence length. Another limitation of the Ginzburg-Landau approach is its formal validity only in the region close to normal/superconducting phase boundary, which raises doubts on its predictions for lower temperatures. Here we show the results of Bogolyubov-de-Gennes calculations of the vortex phase diagrams for the superconducting square of nanoscopic size. We find that the main features of the calculated diagrams compare surprisingly well with the prediction of the Ginzburg-Landau theory. In the second part of the presentation we discuss the applicability of Ginzburg-Landau theory to two-band superconductors, in particular, for the treatment of 1.5 superconductors. As an example, the effect of geometry of the boundary on the deconfinement of vortices in mesoscopic two-band superconductors will be considered.

Presenting author: Prof. Liviu Chibotaru
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Scanning Hall probe microscopy study of unconventional vortex patterns in the two-gap MgB$_2$ superconductor

J. Gutierrez$^1$, B. Raes$^1$, A.V. Silhanek$^1$, Lin-jun Li$^1$, V.V. Moshchalkov$^1$, N.D. Zhigadlo$^2$, J. Karpinski$^2$

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The low magnetic field vortex patterns nucleation and evolution in a two-gap superconductor MgB$_2$ single crystal have been investigated by Low Temperature Scanning Hall Probe Microscopy. Large areas have been imaged with single vortex resolution while changing systematically the thermodynamic parameters $H - T$. The obtained patterns have been studied and compared to that of a reference 2H-NbSe$_2$ single crystal. We found that the observed vortex patterns in MgB$_2$ correspond to that of a type-1.5 superconductor with an inter-cluster vortex-vortex equilibrium separation well described by the theory of type-1.5 vortex – vortex interaction [1].


Presenting author: Dr. J. Gutierrez
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Pinning and dynamics in pattern forming systems on random and periodic structures: implications for vortices in type-1.5 superconductors and other systems

Charles Reichhardt, Cynthia Reichhardt

Los Alamos National Laboratory, US

We consider several models for systems with competing interactions including interactions expected for vortices in type-1.5 superconductors. These systems can form stripe, bubble, and crystalline phases in the absence of pinning. In the presence of random or periodic pinning the patterns can be significantly modified. The stripe forming system can exhibit new types of matching effects with periodic pinning arrays due to the existence of two length scales in the vortex lattice at which matching effects can occur. When the system is driven, a rich variety of dynamical phases are possible that are distinct from those found previously for vortex systems. We also discuss new types of ratchet effects that could arise in the presence of a ratchet potential.

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Non pairwise inter-vortex forces in multi-band superconductors

Johan Carlstrom  
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Julian Garaud  
UMass Amherst, US

Egor Babaev  
KTH Stockholm, SE; UMass Amherst, US

Within the standard paradigm, the structure formation in superconducting and superfluid vortices is understood under the assumption that forces acting in a large group of vortices are a superposition of two-body forces. Indeed this picture emerges in the standard approaches used to calculate inter-vortex interaction which are based on linearization of the problem or on the London approximation. Here we show that in a group of more than two vortices in a two band superconductor, there are in general complicated multi-body forces present which arise from nonlinear effects associated with nontrivial interaction-induced deformations of vortices. These forces can significantly affect the ground state of type-1.5 superconductors.

Presenting author: Mr. J. Carlstrom  
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Microscopic theory of type-1.5 superconductivity in multiband systems

Mihail Silaev, Egor Babaev

Royal Institute of Technology, Stockholm, SE

Traditionally superconductors are classified as type-I or type-II according to their magnetic response. However this dichotomy is insufficient for classification of the growing family of superconductors where multiple superconducting components originate from different superconducting bands. Here we report the microscopic theory of type-1.5 superconducting state in the entire temperature regimes, in particular outside the validity of Ginzburg-Landau theory.

Presenting author: Dr. Mihail Silaev
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We do numerical simulation of dendritic flux avalanches in superconducting films. Dendritic flux avalanches is a frequently encountered instability in the vortex matter at low temperatures, and it is caused by a thermomagnetic positive feedback loop. Our simulation covers all stages of flux dynamics: flux creep dynamics before the avalanche, instability nucleation, fast propagation, and then cooling where heat is absorbed into the substrate, leaving behind a complex branched flux structure. We will explain the efficient and accurate flux dynamics simulation method and list result from runs on thermomagnetically unstable samples, i.e., discuss nucleation conditions, electric field and temperature distributions, pattern formation, the impact of sample geometry, and interactions with material defects. The material defects are either randomly distributed disorder, larger holes, or strategically patterned arrays of blind holes.
Anomalous kinetic and thermodynamic characteristics in the two-band superconductor with one narrow band

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We search for marginal Fermi-liquid behavior in the two-band Hubbard model with one narrow band. We consider the limit of low electron densities in the bands and strong intraband and interband Hubbard interactions. We analyze the influence of electron polaron effect and other mechanisms of mass-enhancement on effective mass and scattering times of light and heavy components in the clean case. We find the tendency towards phase-separation in a 3D case for large mismatch between the densities of heavy and light bands in a strong coupling limit. We also observe that for low temperatures and equal densities the resistivity in a homogeneous state R(T) ~ T² – behaves in a Fermi-liquid fashion both in 3D and 2D cases. For temperatures higher then effective bandwidth for heavy electrons T > Wₕ the coherent behavior of heavy component is totally destroyed. The heavy particles move diffusively in the surrounding of light particles. At the same time the light particles scatter on the heavy ones as if on immobile (static) impurities. In this regime the heavy component is marginal, while the light one is not. The resistivity goes on saturation for T > Wₕ in the 3D case. In 2D the resistivity has a maximum and localization tail due to weak – localization corrections of Altshuler – Aronov type. Such behavior of resistivity in 3D could be relevant for some uranium-based heavy-fermion compounds like UNi₂Al₃ and in 2D for some other mixed-valence compounds possibly including the layered manganites. We also consider the superconductive (SC) instability in the model. The leading instability is towards p-wave pairing and is governed by enhanced Kohn – Luttinger mechanism of SC at low electron density. The critical temperature is mostly governed by the pairing of heavy electrons via polarization of the light ones in 2D. However the two SC gaps in heavy and light bands are opened simultaneously below this temperature.

References


Multiband superconductivity was first proposed 50 years ago as a potential avenue for increasing critical temperatures [1], but essentially remained a theoretical concept until the discovery of superconductivity in MgB$_2$ in 2001. Since then, a number of multiband superconductors have been identified and characterized by various techniques, including scanning tunneling spectroscopy (STS). I will present and confront STS measurements performed on MgB$_2$, oxy-pnictides and Chevrel phase compounds. I will show that these materials reveal very different spectroscopic characteristics, concerning the detection of the superconducting gaps and striking electronic signatures of the vortex cores.

This work was supported by the National Centre of Competence in Research MaNEP and the Swiss National Science Foudation.

Novel Andreev bound states in nanostructured superconductors

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We investigate the electronic structure of a superconductor (SC) in proximity of nanoscale ferromagnetic (FM) disc (SC/FM hybrids) and find that the superconductor order parameter has its minimum under the edge of the disc, thus forming a sombrero-like profile. The quasiparticle dispersion for such an order parameter is calculated with quasi-classical Bogoliubov-de Gennes equations. The result shows that the energy versus angular momentum dispersion has a minimum at finite non-zero angular momentum. The low-lying superconducting excitations of this SC/FM nanohybrid are Andreev bound states that possess a large non-zero angular momentum.

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Current drive scanning tunneling spectroscopy: gap structure and vortex lattice of 2H-NbSe$_2$


Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Universidad Autónoma de Madrid, E-28049 ES

I will discuss measurements of the local electronic density of states of 2H-NbSe$_2$ under an applied current of several mA. At zero field, tunneling conductance varies when increasing the applied current, highlighting the current induced Doppler shift on the density of states. Current appears to affect differently the two main gap structures found over the Fermi surface of this material. Under magnetic fields, we observe that vortex motion sets in when we reach the critical current of the sample. Remarkably, the vortex core of pinned vortices is also strongly affected by the applied current. When current flows, the Caroli-Matricon-De Gennes localized state features inside the vortex core considerably change.

Presenting author: Prof. H. Suderow
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Revealing super-dense vortex configurations in nanometer-scale superconductors with scanning tunneling spectroscopy

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Since the pioneering work by Hess et al. [1] the Scanning Tunneling Spectroscopy is widely used to visualize the vortices in superconductors and to study their cores. In nano-scale superconductors where the confinement effects are strong, the vortex configurations are different from the Abrikosov lattice [2,3]. The vortex arrangements are complex, and the individual vortex cores may not be always easily discriminated. In order to determine the vorticity – the number of vortices sitting inside a given superconducting nano-object, we use the fact that the quasiparticle excitation spectrum of a superconductor is sensitive to the supercurrents through the pair-breaking [4] or Doppler effects [5]. Owing to this sensitivity, we probe locally the Meissner currents at the periphery of nano-superconductors subject to external magnetic field. We show that the Meissner currents flowing at the sample periphery change each time a new vortex enters and thus, the vorticity in each individual nano-superconductors may be determined with high precision for any vortex configuration. The perfect knowledge of vorticity allowed us to discover novel super-dense vortex configurations impossible in the bulk materials. In some cases, the inter-vortex distance was found up to three times shorter than the critical one at HC2.

References


Vortices configuration in superconducting MoGe networks

Ho Than Huy¹, Masahiko Hayashi², Masaru Kato¹, Tsutomu Yotsuya¹, and Takekazu Ishida¹

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²Akita University, JP

Vortices behave quite differently in a restricted geometry compared to the cases of bulk superconductor. This essentially enables possible from enhanced electronic energy due to confinement of superconducting electrons to small restricted space. We intend to investigate a local magnetic field of nanostructured superconductors. The SQUID microscope is superior in view of magnetic field sensitivity, but the spatial resolution is rather modest. One is to use a sample with weaker pinning sample. Amorphous MoGe films deposited by a sputtering method were modified in a topological structure such as networks and small plates using a lift off technique. A scale of microscopic disorder in MoGe film is much shorter than a superconducting coherence length, and hence pinning becomes weak in MoGe film. Various interesting vortex configurations in the superconducting network predicted by the nonlinear Ginzburg-Landau equation under the different combinations of field and temperature are attempted to observe by the SQUID microscope. To enhance the spatial resolution of SQUID microscope, we developed an image restoration method, where the magnetic field is properly taken into account for considering the effect of superconducting pickup SQUID coil.

Presenting author: Prof. Takekazu Ishida  
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Direct observation of the Bragg-to-vortex glass transition in a 2D vortex lattice

Isabel Guillamón¹,², Hermann Suderow¹, Sebastián Vieira¹, Rosa Córdoba³, Javier Sesé³, José M. De Teresa³, Ricardo Ibarra³

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In this talk, I will report on Scanning Tunnelling Microscopy and Spectroscopy studies of a two-dimensional (2D) vortex lattice formed in a W-based superconducting thin film and its evolution from low magnetic field up to H_C² at 100 mK. At low fields, vortices arrange forming a highly ordered lattice, completely free from topological defects. Vortex position deviations from a perfect hexagonal lattice below the intervortex distance confirm the presence of a Bragg glass. When increasing the field, disorder gradually appears in the lattice and positional and orientational order begin to decay at different pace. Positional order first disappears when a few isolated dislocations show up in the Bragg glass, creating a hexatic ordering. Further compression of the lattice increases the density of topological defects, suppressing the remaining orientational order and leading the hexatic arrangement towards a vortex glass. Here we will present vortex lattice images showing the whole process and discuss the length scales relevant to the order loss that control the crossover between the different observed phases.

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Imaging of vortex penetration into superconducting square networks

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We have reported that vortex penetration into superconducting square networks with square holes show anomalous preferential penetration along the diagonal direction depending on the size of holes and the width of superconductors [1,2]. TDGL simulation have successfully reproduced basic features of the phenomenon [3]. However, there are significant differences between the experimental situation and theoretical modeling. Namely, in the simulation, length scale is much smaller, and it completely ignores pinning and demagnetization effect. In order to get more insights into the origin of the anomalous diagonal penetration, we prepared several kinds of superconducting networks; (1) square networks with square holes with different film thicknesses, (2) square network with different shapes of holes, (3) square networks with square holes and with additional anti-dots at the center of intersections. Extensive magneto-optical imaging experiments have been performed on these networks. At the same time, we have made transport measurements in superconducting square network with two different orientations of average current flow to confirm the effect. Furthermore, to check if this phenomenon is only related to electrodynamics but not due to thermal effect, electromagnetic simulation is attempted. Based on these experimental results, we discuss the origin of anomalous diagonal penetration of vortices. [1] Y. Tsuchiya, Y. Nakajima, T. Tamegai, T. Yamamoto, Y. Nakamura, J. S. Tsai, M. Hidaka, and Z. Wang, Physica C 470 (2010) S788. [2] T. Tamegai, Y. Tsuchiya, Y. Nakajima, T. Yamamoto, Y. Nakamura, J. S. Tsai, M. Hidaka, H. Terai, and Z. Wang, Physica C 470 (2010) 734. [3] N. Nakai and M. Machida, Physica C 470 (2010) 1148.

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High speed magneto-optical imaging of flux dynamics in superconductors

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Magneto-optical imaging of magnetic flux dynamics with sub-millisecond temporal resolution can substantially improve understanding of numerous phenomena in flux line medium in superconductors. Dendritic flux avalanches is one of those. It is known that metallic coating can suppress the avalanches either by providing an additional heat sink, or due to electro-magnetic dragging of the flux that propagates through a superconductor with extremely high velocity. Which one of these mechanisms is dominant is still a subject of debate. It is also known that the avalanches are triggered by micro-jumps of flux bundles, which seems to be a generic feature of vortex medium. We report results of high speed-with frame rate more then 2000 frames per second-magneto-optical imaging of statistics and dynamic properties of micro-jumps and dendritic avalanches in NbN with partial metallic coating, which allows direct analysis of the changes in creep rates induced by the electro-magnetic drag.

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Since their discovery, iron pnictides [1] have gained considerable interest from the scientific community. One of the puzzles of these iron based superconductors is the role of magnetism and the effects of chemical and structural tuning on their superconducting properties. The recently discovered SrPd$_2$Ge$_2$ superconductor, with the superconducting transition temperature $T_c$ around 2.9 K, is isostructural with the group of “122” iron pnictides. However, it is pnictogen- and chalcogen-free and it has the magnetic metal (Fe) completely replaced by the nonmagnetic metal (Pd). Hence, determining its superconducting properties and comparing them to the ones of “122” iron pnictides might answer at least some open questions. The three-dimensional topology of SrPd$_2$Ge$_2$ Fermi surface, in contrast to basically 2D pnictides, is confirmed by experimentally measured momentum distribution maps by ARPES and supported by the LDA calculations. The temperature evolution of the superconducting density of states of SrPd$_2$Ge$_2$ down to 400 mT, determined by our homebuilt STM with Au and superconducting Pb tips, clearly indicates its s-wave single gap character. The $s^\pm$ pairing proposed for the "122" iron pnictides [2], which has been associated with the unconventional pairing mediated by magnetic fluctuations, is missing. The Ginzburg-Landau parameter $\kappa \sim (1/2)^{1/2}$, calculated from the Fermi velocity and details of the Fermi surface topology estimated by ARPES and the superconducting gap value estimated by STS, is an apparent sign of type-I superconductivity [3]. However, our recent STM/S measurements in magnetic fields indicate $\kappa > (1/2)^{1/2}$ and show that the superconducting order parameter varies across the scanned surface with periodicity approximately matching the Abrikosov lattice.


Presenting author: Dr. Tomas Samuely
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The discovery of superconductivity on 8 April 1911 came as a big surprise…

It was stumbled upon in the Leiden cryogenic laboratory of Heike Kamerlingh Onnes in a moment of serendipity. Three years before, the liquefaction of helium on the other hand had been the culmination of a long battle with nature. It was a meticulously prepared operation, ‘Big Science’ in its first appearance. Until recently, careless notebook entries by Kamerlingh Onnes and his terrible handwriting had hindered a complete view to the road to superconductivity. Even a date of the fascinating discovery was lacking. How did the discovery fit into the Leiden research program? What about the research effort Kamerlingh Onnes had to put in to be sure he had found superconductivity rather than a short-circuit? What about superfluidity? Once the right interpretation of the notebooks is clear, the real story can be told.

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Superconductivity: From 10 Nobel laureates’ stories

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Based on interviews of 10 Nobel laureates, glimpses are given into the stories of their personalities and achievements as they were recounted to the author. With one exception the interviews took place in 2001 in preparation for the book by K. Fossheim and A Sudbo: Superconductivity. Physics and Applications. Wiley 2004. In this talk I will give examples of how 10 different scientists became interested in physics at an early age, and how crucial ideas or events came to shape their scientific life and lead to the breakthroughs which gave them the Nobel award. The interviews are currently being prepared by the author for a book to be printed by Springer in 2012.

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History of superfluidity in ultracold atomic condensed systems

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This talk represents a historical overview of the superfluidity, which is one of most remarkable macroscopic manifestations of quantum mechanics. A special emphasis is given to the manifestation of superfluidity in ultracold atomic gases.

The discovery of superfluidity is related to the names by J. F. Allen, D. Misener, P. L. Kapitza, F. London, L. Tisza and L. D. Landau. In fact, the first discovery of superfluid behavior was made nearly 100 years ago, when H. Kamerlingh Onnes found that the cooled mercury sample conducted electricity without dissipation. After the experimental evidence of superfluidity, F. London suggested that superfluid helium forms a macroscopic liquid matter wave, as a consequence of Bose-Einstein condensation. When superfluidity was discovered in cold atomic gases, the experimental evidence of its relation to Bose-Einstein condensation was absolutely clear. Further, the investigation of interacting Fermi gases become one of the most stimulating areas of research in ultracold atoms.

Started from the experimental achievements of Bose-Einstein condensation in dilute alkali gases, atomic physics has transitioned from a few-body science to the study of many-body physics featuring thermodynamic phases and phase transitions. A possibility of controlled interaction in different dimensionalities has put research of ultracold fermions in harmonic traps and optical lattices at the forefront of investigations of Fermi and Bose condensates. Research on ultracold atoms can give insight into understanding of different phases of nuclear, atomic, molecular, and condensed matter.

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Presenting author: Prof. Jozef T. Devreese
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Influences of magnetic-fluctuation, resonance, and oscillation on Josephson current in superconductor/ferromagnet/superconductor junction

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Superconductivity usually competes against ferromagnetism in their ordered states. However, once those are coupled in a superconductor/ferromagnet/superconductor junction, we can see various novel phenomena such as pi-state, in which the current-phase relation is shifted by a half period. First, we will discuss effect of magnetic fluctuation on the critical current in a case of ferromagnetic metal[1]. If the superconducting transition temperature is comparable to the Curie temperature, the 0-pi transition is induced by temperature due to the magnetic scattering. In a case of ferromagnetic insulator, we can expect another interesting phenomenon [2,3]. In a superconductor/ferromagnetic-insulator/superconductor (S/FI/S) junction, it is found that the current-voltage characteristic shows two resonant peaks in a large junction with voltage bias. The voltages at the resonant peaks are given by a function of the normal modes of electromagnetic field in FI, which indicates a composite excitation of the electromagnetic field and the spin-waves in the S/FI/S junction. The stepwise current-voltage characteristics can be obtained in a small junction as well, when the magnetization in a ferromagnet is driven by the microwave irradiation, whose frequency is adjusted to a ferromagnetic resonance one. In addition to magnetic-fluctuation and resonance, we will examine an influence of magnetic oscillation, and will discuss several possible applications to electronic devices.


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Mesoscopic cross-film cryotrons: Localized and delocalized superconductivity, vortex trapping and \textit{de}-Josephson-like oscillations of the critical current

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We present the results of the theoretical and experimental investigations \cite{1} of the transport properties of the long and narrow superconducting type-II strip in the field of a current-carrying wire, oriented perpendicular to the strip. Since the width of the strip is comparable with the superconducting coherence length $\xi$, this system can be called mesoscopic unshielded cross-film cryotron. Since the magnetic field of the straight wire, $b_w(x)$, is maximal near the wire and it decays approximately as $1/x$ at large distances $x$ from the wire, one can expect that only a small part of the superconducting strip close to the current-carrying wire will be affected by the non-uniform magnetic field. Experimentally the influence of such non-uniform magnetic field with the tunable amplitude $B_0$, which linearly depends on $I_w$, was studied for a hybrid structure, consisting of a 4 μm wide and 120 nm thick superconducting Al strip on top of a 1.5 μm wide and 50 nm thick current-carrying Nb wire.

At rather low temperatures $T$ and in the absence of an external magnetic field $H$ the appearance of a vortex is accompanied by the formation of a symmetrically positioned antivortex and the number of vortex-antivortex pairs increases as $|I_w|$ increases. We demonstrate that the stability of the vortex-antivortex ensemble breaks down if the bias current $I_{\text{bias}}$ exceeds the critical current $I_c$: vortex and antivortex periodically in time enter and exit into/from the superconductor. We found out that $I_c$ decays with oscillations upon sweeping $H$ and the positions of the cusps (i.e. the $I_c$ minima) have to be attributed to the discrete change in the number of pinned vortices/antivortices. The observed oscillatory dependence $I_c(I_w)$ seems to be similar to the standard Fraunhofer pattern describing the field dependence of the critical current of a conventional Josephson junction. Indeed, the built-in field of the wire guarantees the tunable modification of the distribution of the order parameter phase in the restricted part of the strip by the trapped vortices and antivortices. This area with partly suppressed superconductivity near the control wire acts like an effective \textit{weak link}, since the vortex dynamics in this area determines the flow of the bias current and the resistance of the entire strip. The external magnetic field $H$, applied perpendicularly to the sample’s plane, breaks the symmetry between vortex and antivortex. As a results, the oscillatory dependence $I_c(I_w)$ becomes more complicated. In addition, we showed that rather close to the phase boundary $T_c(H)$ the formation of the vortex structure (i.e. delocalized superconductivity) becomes unfavorable as compared with the localized superconductivity. Depending on $T$ and $H$ the order parameter can be localized along the edges of the bridge (i.e. parallel to the bias current), or in the region with minimal magnetic field (i.e. perpendicular to the bias current).

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Vortex mobility and guided vortex motion in superconductors with antidot arrays in presence of ac and dc driving

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Controlled trapping and guided motion of vortices via special arrangements of micro-holes, or antidots, in YBa2Cu3O7 films was demonstrated [1] in experiments using resistive Hall-type measurements. A new mechanism of vortex propagation based on flux nucleation within antidots due to the redistribution of screening currents and flux quantization was proposed based on the numerical solution of the Ginzburg-Landau equations. This mechanism can be used for new device concepts. As an example, a vortex ratchet with special arrangements of antidots was experimentally demonstrated. Recently, the dynamics of vortices in antidot arrays has been studied at high frequency. In particular, high-frequency vortex ratchet in the range between 0.5MHz to 2.0GHz (and up to 8.0GHz) was measured in a superconducting film with an array of asymmetric pinning sites [2]. A micropattern induced transition in the mechanism of vortex motion and vortex mobility was demonstrated for high-Tc films [3]. We have investigated vortex guidance and vortex mobility in a superconducting film with an array of artificial pinning sites in presence of ac and dc driving currents. Depending on the ratio between the dc and ac components and between the driving and the pinning forces, we demonstrate different dynamical regimes, guided motion and mode locking effect. Using Langevin-type Molecular-Dynamics simulations of driven vortices, we propose a way of experimental measurement of vortex trajectories and mobility by analyzing the output voltage.

Evidence of two perpendicular Abrikosov vortex structures in thin superconductors

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Accurate torque measurements and theoretical modelling provide the features compatible with the presence of two different Abrikosov vortex structures in Nb-films of different thicknesses. These features associated with vortex rearrangements into rows between the main surfaces of the films and with the edge barrier for transverse vortex entry prove the co-existence of these two vortex structures which are most likely perpendicular one the other.

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Using the Bogoliubov-de Gennes equation, we have investigated the vortex structures in nano-sized conventional and unconventional superconductors. For arbitrary shaped superconductors, we use the finite element method [1]. Including the quasi-particle structures into the calculation, the vortex structures changes with decreasing the temperature from the results from the phenomenological theory. This is because the bound states around the vortices interfere each other and affect the vortex-vortex interaction. In order to clarify the vortex-vortex interaction, we developed the numerical method for treating two singularities (vortices). We use the elliptical coordinate where two vortices sit at two foci and Mathieu functions for expansion of the quasi-particle wave functions. Using this method we clarify change of the interference of the quasi-particles around two vortices with changing the distance between them. We also apply these methods to the some types of superconductors, including p-wave superconductors and multi-band superconductors. [1] H. Suematsu, T. Ishida, T. Koyama, M. Machida, M. Kato, J. Phys. Soc. Jpn. 79 (2010) 124704.

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Nuclear Magnetic source imaging is a new function diagnosis. Every activity of the brain is connected with neuronal ionic current and every beat of the heart is generated by ionic depolarization currents. These currents create magnetic fields that can be measured non-invasively outside the body. By sampling these fields by Bi2223 at many locations simultaneously a map of the field is determined from which the location of the source inside the body can be calculated. Since the body consists of different tissues with various electrical conductivities it is very difficult to determine the location of the source, The magnetic field of pT for the heart and some 100fT for the brain. Only Bi2223 sensors measuring system can reach the noise level required for valuable bio-magnetic measurements. Bio-magnetic imaging is one of the most important application of HTS nano sensor devices. Detail construction of the system is highlighted in this paper. Various type of high Tc junction has been developed is shown in this paper. The majority of junctions are prepared from Bi2223 material. The junctions can be structured with argon ion etching. The external flux entering the loop induces a current that is led almost completely around the hole consisting of a slit in a nano superconductor area. Nano particles left un-utilizes used to capture free floating cancer cells and then take them out of the body. This process used in the treatment of ovarian cancer cells released from the primary tumor into the abdominal cavity.
Microscopic picture of the critical state in a superconductor with periodic array of antidots

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The penetration of magnetic field into hard superconductors is usually described in terms of the Bean model. Within this model the slope of the field penetration consisting of a gradient in the density of quantum flux units is just determined by the critical current, very much like the slope of a sand-pile. Remarkably, in superconductors with periodic arrays of well defined pinning sites, a stratification of the classical Bean model was theoretically predicted by Cooley and Grishin (Phys. Rev. Lett. 74, 2788 – 2791, 1995) in the form of the so-called "terraced critical state". Our mental picture of this terraced critical state in superconductors is similar to the terraces in the Chinese rice fields. Up to now, however, the direct visualization of this remarkable new state has been lacking. In this talk I will present the first direct visualization of the terraced critical state by exploring the nanoscale distribution of the vortex penetration in nanopatterned superconductors with the scanning Hall probe microscope (SHPM). Seeing is believing and by analyzing the numerous SHPM images we obtained, we have directly confirmed the predictions of the Cooley-Grishin model of the quantized character of the flux penetration into superconductors with periodic pinning.

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Magnetically coupled superconductor-ferromagnet hybrids offer advanced routes for nanoscale control of superconductivity. Scanning tunneling microscopy and scanning magnetic force microscopy coupled to magneto-transport measurements reveal rich vortex phase diagram.

The magnetic stripe domain of the ferromagnet induces periodic local magnetic induction in the superconductor, creating a series of pinning and anti-pinning channels for vortices observed with scanning tunneling microscopy and magnetic force microscopy at low temperature. Such laterally confined Abrikosov vortices form chains. When the experimental parameters of the superconductor and the ferromagnet are properly tuned spontaneous formation of Vortex-Anti-Vortex (V-AV) pairs is observed in these systems. The key role for formation of V-AV is played by the out-of-plane magnetization of the ferromagnet and by the ratio of the magnetic domain width to the superconducting film thickness.

Static and dynamics of these systems will be discussed.

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We discuss different possibilities to control vortex motion in a thin superconducting film with Tesla range magnetic fields generated by magnetic nanostructures. These nanostructures can be embedded into the superconducting film (arrays of magnetic nanorods) or placed outside the film and separated from it with an insulating layer (arrays of magnetic nanostripes). Interaction of the superconducting film with the magnetic nanostructure results in a strong increase and hysteresis of the critical current, in a strong anisotropy of the critical current (in the case of magnetic nanostripes) and several other phenomena. We discuss recent experiments with magnetsuperconductor hybrids and their future development.
Using large scale simulations we examine the dynamics of individual vortex manipulation in random and periodic pinning arrays. In a sample with periodic pinning we apply a dc, rotating, or shaking drive on an individual vortex. Under the influence of the dc drive, the driven vortex moves either along the pinning sites or through the interstitial region. The effective drag force experienced by the driven vortex depends strongly on the vortex lattice density and the pinning strength. Strong pinning can reduce the effective drag since the strongly pinned vortices are unable to absorb the momentum of the driven vortex. For rotating drives, we observe a series of transitions between ordered and disordered orbits depending on the number of immobile vortices enclosed by the orbit. Finally, we also explore the dynamics of vortices driven over 5- and 7-fold quasicrystalline pinning arrays and find a variety of dynamical phases, including directional locking effects and a new ordered moving phase which we term a dynamically induced Archimedean lattice.

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Vortex state in a mesoscopic flat disk with rough surface

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The study of mesoscopic superconducting structures has attracted the attention of scientific community, both from experimental and theoretical point of view due to the possibility of obtaining a large enhancement of the critical parameters such as the critical fields and the critical superconducting current density. Once the mesoscopic regime is attained, i.e., when the sample size becomes comparable to superconducting penetration depth, $\lambda$, and/or coherence length, $\xi$, the vortex-surface interactions can become comparable to the inter-vortex interaction and the local flux density becomes intrinsically dependent on sample geometry, both shape and size. In this work we address some of these points by investigating how the roughness affects the vortex properties. To do this we use the link variable method and implemented an algorithm to solve the time dependent Ginzburg-Landau equation in a superconductor disk with rough surface. The sample is surrounded by a thin layer of a metallic material and submitted to and external magnetic field applied perpendicular to its plane. The boundary condition is taking into account via the de Gennes extrapolation length $b$. We evaluate the Gibbs free energy, magnetization, vorticity, the first and second critical thermodynamical fields as a function of the external magnetic field and $b$ parameter. We found that for this interfaces, the second critical field $H_{C2}$ and magnetization are largely increased while the first critical field remains practically unchanged. Work supported by CAPES, CNPq and FACEPE (APQ-0589-1.05/08). Keywords: vortex, link variables, rough surface, mesoscopic.

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Ratchet effect of Josephson vortex motion in stacked intrinsic Josephson junctions

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We study the Josephson vortex (JV) ratchet in a triangular-shaped stack of intrinsic Josephson junction (IJJ) in the Bi2Sr2CaCu2O8 single crystal. The experimental measurements show clearly the non-zero dc-voltage response with ac drive current along c-axis when the external magnetic field is parallel to the edge of the triangular sample in ab-plane. We explain the rectification of JV vortex motion with the anisotropic pinning effect in the triangles by solving the perturbed sine-Gordon equation. The simulation results are in good agreement to our experimental measurements. The investigation of such static asymmetric system may stimulate the development of the devices to control the JV motion and enhance the coherent in-phase mode which is desirable for the Terahertz irradiation. This work is in collaboration with H. B. Wang (NIMS, Japan), R. Kleiner (Tubingen, Germany) and V. V. Moshchalkov (Leuven, Belgium).

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Vortex structures and magnetization of superconducting Pb nanowires and other nano-superconductors of different shapes

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In present paper we have developed a new theory in which we applied the 3-D Ginzburg-Landau equations to study the vortex structures and magnetization of superconducting lead (Pb) circular nanowires for an increasing and a decreasing applied magnetic fields and different temperatures. Our results show that the magnetization curves exhibit hysteresis for some finite temperatures which are in agreement with several experimental studies. We also identify stable vortex states of nanowires along the magnetization curves with respect to the increasing and decreasing magnetic fields and show that they are associated with a particular form of the vortex-antivortex interaction in nanowires. Application of the developed methods to study vortices in other nanostructures superconductors will be described. The obtained results indicate on an appearance many nontrivial vortex structures which form depend on the shape of the superconductors.

The reason is that the shape of the nano-superconductors influences the vortex-vortex interaction and this in will lead to the formation of vortex molecules and other exotic configurations.

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Microwave absorption in the core of the Abrikosov vortex pinned by artificial insulator inclusion

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Core excitations spectrum of the Abrikosov vortex pinned by a dielectric inclusion or nano-hole is considered using the Bogoliubov – de Gennes equations beyond semi-classical approximation. Unlike that of columnar defects, the radius of the inclusion in artificially created nano-holes is not small compared to the coherence length of a type II superconductor. The spectrum of the quasiparticle excitations have been obtained numerically for different orbital moments and for various sizes of the artificial inclusions. It was predicted that the lowest excitation, mini-gap, becomes of the order of the energetic gap $\Delta$. The microwave absorption by the core quasiparticles has been calculated analytically. It was shown that both the mini-gap and the microwave absorption are significantly increased in thin films. The results are compared with that obtained by quasi-classical approach.

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Resonant tunneling clusters of crystal defects in solid helium: an internal Josephson effect

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Low-temperature anomalies of hcp $^4$He crystals (mass decoupling from a torsional oscillator, shear modulus anomaly, dissipation peaks, heat capacity peak) are explained. A simple model based on the concept of resonant tunneling clusters of crystal defects is proposed. Resonant tunneling clusters are degenerate two-level systems in which the bare (with no tunneling) energy difference of two localized states is zero. The physical reason of the degeneracy is the crystal symmetry. Two localized states transform to each other under a crystal symmetry transformation. Mass decoupling, observed by Kim and Chan [1], is caused by a kind of internal Josephson effect: the mass supercurrent inside phase coherent tunneling systems. Quantitative results are in reasonable agreement with experiments. 1. E. Kim and M. H. W. Chan, Nature 427, 225 (2004); Science 305, 1941 (2004).

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Vortices in two-dimensional superfluid atomic gases

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Atomic gases can be squeezed by optical lattices into thin, pancake shaped clouds that allow to probe the physics of two dimensional systems. In a homogeneous two dimensional system, Bose-Einstein condensation does not take place according to the Mermin-Wagner theorem, but nevertheless superfluidity can survive in the so-called “quasicondensate” state. For trapped atomic gases this picture changes since the system is no longer homogeneous, and the finite size of the system blurs the distinction between quasicondensate and condensate. Moreover, the inhomogeneity changes the binding energy of vortex-antivortex pairs, an essential ingredient of the Kosterlitz-Thouless theory of superfluidity in two dimensions. Here, we investigate these finite size effects on the phase diagram for condensed gases, and discuss the results in the light of recent experimental breakthroughs detecting the Kosterlitz-Thouless transition in trapped cold Bose gases.

Also atomic Fermi gases can become superfluid when pairing takes place between the atoms, driven by magnetically tunable interatomic interactions. S-wave pairing only takes place between atoms of different (hyperfine) spin state. Whereas in superconductors, the amount of spin-up and spin-down electrons to form Cooper pairs is equal, this does not have to be the case in atomic gases. Indeed, not only the interactions are tunable, but also the numbers of atoms in each hyperfine state can be selected experimentally.

We review shortly the recent experimental studies of population imbalanced superfluidity. Next, we investigate the phase diagram of two-dimensional fermionic superfluids, as a function of interaction strength, temperature, and population imbalance between the pairing partners. For this purpose, we set up a path-integral description that improves on the regular Nozieres & Schmitt-Rink theory. This allows us to predict the influence of population imbalance, and tunable interaction strengths, on the Kosterlitz-Thouless transition in Fermi superfluids [1], and reveals a rich variety of vortex types and superfluid dynamics in these systems [2].


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Doping and irradiation induced vortex pinning in iron-pnictide superconductors

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We report on a systematic study of the vortex pinning behavior in iron pnictide single crystals with defects induced by heavy ion and proton irradiation. Specific heat and magnetization measurements were carried out on (Ba\textsubscript{1-x}K\textsubscript{x})As\textsubscript{2}Fe\textsubscript{2}, Ba(Fe\textsubscript{1-x}Co\textsubscript{x})\textsubscript{2}As\textsubscript{2}, SmFeAs\textsubscript{O\textsubscript{0.85}F\textsubscript{0.15}}, and BaFe\textsubscript{2}(As\textsubscript{1-x}P\textsubscript{x})\textsubscript{2} with phosphor contents ranging from optimal doping (x\textasciitilde0.3, T\textsubscript{C} = 29.5 K) to highly overdoped (x\textasciitilde0.6, T\textsubscript{C} = 11K). For (Ba\textsubscript{1-x}K\textsubscript{x})As\textsubscript{2}Fe\textsubscript{2} we find a dramatic increase in the upper critical field slope for both H \textasciitilde c and H \textasciitilde ab, a reduction in the superconducting anisotropy and a pronounced increase in the critical current with defects induced by high-energy heavy ion irradiation. For Ba(Fe\textsubscript{1-x}Co\textsubscript{x})\textsubscript{2}As\textsubscript{2}, we find a systematic increase of the irreversibility line with dose matching field. For SmFeAs\textsubscript{O\textsubscript{0.85}F\textsubscript{0.15}}, the enhanced critical current from irradiation could be as high as 1 \times 10\textsuperscript{7} A/cm\textsuperscript{2}. Finally, for BaFe\textsubscript{2}(As\textsubscript{1-x}P\textsubscript{x})\textsubscript{2} we find a systematic decrease in the critical current with phosphor doping, displaying an intriguing evolution of the field dependence of the magnetization, ranging from fishtail magnetization behavior at optimal doping to a single distinct peak effect with overdoping and a nearly reversible magnetization with further phosphor doping. We show that this behavior can also be induced with proton irradiation induced defects, making BaFe\textsubscript{2}(As\textsubscript{1-x}P\textsubscript{x})\textsubscript{2} an ideal system to explore vortex pinning in the pnictide family. This work was supported by the Center for Emergent Superconductivity, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-AC0298CH1088 (WKK, LF, CC, YJ, GS, AEK, GWC) and by the Department of Energy, Office of Basic Energy Sciences and Nuclear Physics, under Contract No. DE-AC02-06CH11357 (UW, SZ).

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Doping and substitutions in LnFeAsO single crystals grown at high pressure: influence on superconducting properties and structure


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Investigations of intrinsic properties of LnFeAsO (Ln=La, Pr, Nd, Sm, Gd) oxide high T_c superconductors require single crystal studies. LnFeAsO single crystals were grown from flux at high-pressure of 30 kbar. An overview of the basic superconducting properties measured on single crystals of LnFeAsO will be presented. LnFeAsO compounds show the highest T_c and the highest upper critical fields. Superconductivity in LnFeAsO has been induced by partial substitution of O by F, Sm by Th, Fe by Co, As by P or by oxygen deficiency. Single crystal structure investigations show structure modification due to substitutions, which is linked to superconducting properties. By comparing our experimental data for Sm_{1-x}Th_xFeAsO, SmFeAsO_{1-x}F_y and SmFeAs_{1-x}P_xO compounds with other Fe-based pnictides it was found that the pnictogene height is a key factor that determines critical temperature. In SmFe(As,P)O samples superconductivity appears only after high pressure treatment which generates oxygen deficiency and induces electron doping. P substituted SmFeAsO samples without O deficiencies are non-superconducting however spin density wave is suppressed. Our detailed study of the transport properties of SmFeAs(O,F) single crystals reveals a promising combination of high (> 2 x 10^6 A/cm²) and nearly isotropic critical current densities up to 30 T at low temperatures. Point-Contact Andreev-Reflection spectroscopy studies show the existence of two gaps in the SmFeAsO_{1-x}F_x and SmFeAs_{1-x}P_xO crystals, which energy varies with doping level.

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New routes for epitaxial thin films of Fe-based superconductors


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With the recent discovery of the Fe-based superconductors, a major question raised is their suitability for applications. Many of the most interesting devices require the controlled production of thin films with clean interfaces. During the laboratory production of Fe-based superconductor thin films, a detailed analysis by TEM of the substrate/film interface revealed evidence for secondary phase formation. On the basis of the observation of the formation of an Fe layer at the substrate/film interface for Co-doped Ba-122, we designed a bonding scheme between Fe and the iron pnictide phase, resulting in a new thin film architecture we have termed the “Fe/Ba-122 bilayer” system. The first results from this system reveal greatly enhanced growth properties and critical current densities with regard to deposition on pure oxide substrates and may provide a key to understanding a more general growth mechanism in this system. The ramifications of Fe/Ba-122 bilayer growth will be discussed.

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Recent developments in crystal growth of LnFeAsO (Ln=rare earth) oxypnictide superconductors by high-pressure flux method

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Further progress in understanding the nature of superconductivity in the Fe-based compounds depends crucially on the availability sufficiently large single crystals of high-quality. Till now, crystal growth of LnFeAsO oxypnictides (Ln-1111 with Ln=rare earth) has proven to be a difficult task. We adopted the high pressure method and carried out a systematic investigation of the parameters controlling the growth of crystals, including the thermodynamic variables (T, P), reagent composition and kinetic factors, such as reaction time and cooling rate. By varying each parameter while keeping the others constant, we found the thermodynamic conditions under which an optimum equilibrium is reached. NaCl/KCl, NaAs, and Kas fluxes were used to grow Ln-1111 crystals at a pressure of 30 kbar. From NaCl/KCl flux, crystals with linear sizes up to 300 μm were reproducibly obtained. The reaction time was one of the key parameter that influences the crystal size. Millimeter-sized superconducting Nd-1111 and Sm-1111 single crystals were successfully grown from NaAs and Kas fluxes. This crystal growth starts with a 2-5 h dwell at ~1450 ºC, followed by a slow cooling (~4-5 ºC/h) to ~1150 ºC, and a final to room temperature within 2 h. The size of Ln-1111 crystals suggests that liquid NaAs or KaAs are sufficiently effective solvents, and allow oxygen to diffuse at high temperatures. In addition to substituting F for O, superconductivity has also been induced by substituting Th for Sm, Co for Fe, and P for As. Studies of the crystal structure confirmed high structural quality, and show modifications due to substitutions, which are linked to superconducting properties. The magnetic and transport properties of Ln-1111 crystals are compared with other Fe-based pnictides.
Vortex imaging in unconventional superconductors

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The real space imaging of vortices in unconventional superconductors not only provides important information about the effectiveness of flux pinning that can inform high current applications, but also yields crucial insights into the form of the superconducting order parameter. For example, the structure of the vortex lattice reflects effective mass and order parameter anisotropies within the material, and profiles of isolated vortices provide a local measure of the magnetic penetration depth that can be used to infer the superfluid density. We describe here the analysis of recent work whereby state-of-the-art scanning Hall probe microscopy (SHPM) has been used to perform vortex-resolved magnetic imaging on two distinct families of unconventional superconductors. SHPM has several advantages over alternative local imaging techniques; it is almost completely non-invasive, can be used over a very wide range of temperatures (300mK-300K) and magnetic fields (0-7T) and yields quantitative maps of the z-component of magnetic induction with very high signal:noise ratios. Two sets of results will be analysed in detail; (i) vortex lattice structural transitions in the p-wave superconductor Sr₂RuO₄ that reflect underlying anisotropies in the system and (ii) a quantitative analysis of vortex profiles in Co-doped 122 pnictide superconductors (SrFe₂₋ₓCoₓAs₂ & BaFe₂₋ₓCoₓAs₂) that allows one to infer the temperature dependent superfluid density. The latter has then been compared with predictions for different order parameter models for a multiband superconductor.
Multiple history effects near commensurate states in Y123 and Y124 single crystals

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Commensurability phenomena lie behind many of the key issues in Condensed Matter Physics. These phenomena are often highly complex but are extremely fruitful fields of research. They form an important basis for understanding in a host of different fields including superconductivity, liquid crystals, charge and spin density waves, plasmas, quasi-crystals, domain wall lattices, optical lattices, etc. Superconducting vortex matter is a powerful instrument for investigating fundamental issues related to commensurability, due to the great flexibility in varying most of the relevant parameters, such as vortex density, anisotropy, pinning strength and type, combined with a relatively easy control of these parameters. In HTSC the layered perovskite crystalline structure constitutes precise periodic potential for studying commensurability phenomena. Using novel experimental methods to study the transverse tilt of the locked commensurate vortex states in YBCO superconductors, we find pronounced history effects correlated with the commensurability points for the vortex lattice and the CuO-layers of HTSC. This behaviour has been revealed for both Y123 and Y124 superconductors.
Nanoengineered pinning centres in thick superconducting films: effects on critical current and critical current anisotropy

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Large scale applications of superconducting films and coated conductors (CC) require high critical current $I_c$, which is the actual critical parameter for applications (and not critical current density $J_c$), since the thickness of the superconducting film is a very small fraction of the conductor (largest part being the substrate, with or without buffer layers). By using nano-dots of various materials it was possible to grow thicker YBCO films without a dramatic decrease in $J_c$ \cite{1,2}. Strong artificial pinning centres in addition to natural ones are required for controlling the magnetic flux (vortex) dynamics, a subject of world-wide development research in these days. Here we report the growth and characterization of thick quasi-multilayers composed of BZO-doped YBCO layers interspaced with quasi-layers of Ag nano-dots, and of (BZO-doped YBCO)/CeO$_2$ bi-layers. We show that such nanostructured YBCO films have an increased critical current, especially in high magnetic fields, display very interesting dependencies of $J_c$ on the applied field intensity and orientation which can not be treated in the Blatter’s rescaling approach, and, quite important for practical applications in coils and solenoids, have a quite small value of the critical current anisotropy in a broad range of magnetic fields.


\cite{2} A. Crisan et al., Physica C 470, 840 (2010).

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High-pressure effect on pinning in MgB$_2$-based superconductors

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Effect of high 2 GPa, (HP) and 16-96 MPa (SPS) pressures on the formation of pinning centers in MgB$_2$-based nanostructural materials prepared directly from Mg and B powder mixture or from MgB$_2$ powder were investigated. Both methods allowed to produce near theoretically dense composites exhibiting high superconducting (SC) performance due to MgB$_X$ (X=4-20) and Mg-B-O inclusions acting as pinning centers in MgB$_2$-based matrix with nano-sized grains. A particular oxygen distribution could promote the critical current density $j_c$, increase and despite rather high amount of admixture oxygen, the synthesized materials demonstrated very high $j_c$. Higher synthesis pressures allowed to strongly suppress Mg release, which resulted in material’s lower porosity, formation of MgB$_X$ inclusions with higher boron contents (X=12-20) and, consequently, attaining higher $j_c$. The $j_c$ of the materials prepared directly from Mg and B powder mixture (both methods) was somewhat higher than that of the systems synthesized from MgB$_2$. The quality and impurity content (B, C, O, H, etc.) of the source B or MgB$_2$ strongly affected the structure and SC properties of the final products. Depending on the source materials addition of Ti, Ta, Zr, C or SiC could result either in increase or decrease of the materials’ $j_c$. The materials synthesized at high pressure from MgB$_2$ powder revealed deviation from the conventional behavior of doped MgB$_2$-based systems: $j_c$ around $10^6$ A/cm$^2$ at 1 T, 20 K; upper critical field ($B_{c2}$) and irreversibility field ($B_{irr}$) up to 15 T at 22 K for $B_{c2}$ and at 18.4 K for $B_{irr}$, respectively and $B_{c2}$ (0 K)=42.1 T. Materials are very promising for electric power applications: motors, magnetic bearings and fault current limitation, for creation high magnetic fields.

Of great interest is found superconducting performance of HP-synthesized MgB$_{12}$-based material (88.5 wt% of MgB$_{12}$ or Mg$_2$B$_{25}$, the rest was 8.87 wt% MgO and 2.63 wt% MgB$_2$): transition temperature $T_c$ of 37.4 K, $j_c$=10E3 A/cm$^2$ and $B_{irr}$=6T at 10 K. Its Vickers microhardness $H_V$=25.3±1.1 GPa was much higher than that of HP-manufactured MgB$_2$-based one ($H_V$=12.65±1.39 GPa). The MgB$_{12}$-based material contains predominantly 80-700 nm large MgB$_{12.0}O_{1.2-0.6}$ grains separated by 20-50 nm interlayers close to MgB$_{8.7}O_{8.9}$ in composition as Auger analysis shown. Despite of much smaller amount of residual MgB$_2$ phase as compare to the shielding fraction (around 11.5%) in the MgB$_{12}$-based material we cannot definitely attribute SC behavior to MgB$_{12}$ phase or to other higher magnesium boride.

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Superconducting critical fields in $K_{0.8}Fe_{2-y}Se_2$ compound

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We report the results of an experimental study of dc and low frequencies magnetic properties of $K_{0.8}Fe_{2-y}Se_2$ single crystal when the dc magnetic field is applied parallel to the ab plane. From the data obtained, we deduce the full H-T phase diagram which consists of all three $H_{C1}(T)$, $H_{C2}(T)$ and $H_{C3}(T)$ critical magnetic field plots. The two $H_{C1}(T)$ and $H_{C2}(T)$ curves were obtained from dc magnetic measurements, whereas the surface critical field $H_{C3}(T)$ line was extracted by ac susceptibility studies. It appears that near $T_C$, the $H_{C3}(T) / H_{C2}(T)$ ratio is approximately 4.4 which is much larger than expected 1.7 value.

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Knots of quantized vortices in self-trapped optical beams

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We demonstrate the spontaneous formation of knots and links of optical vortices in the field of perturbed spatial soliton. The mechanism of wave knotting is analysed in the basis of internal vibrational modes of two-dimensional soliton described by the nonlinear Schroedinger equation with saturable nonlinearity. We find that simultaneous excitation of the monople and quadrupole modes is sufficient for wave knotting.

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Localized surface plasmons are collective electron oscillations in metallic nanostructures at optical frequencies. These nanostructures can therefore be considered as optical nanoantennas or classical harmonic oscillators at the nanoscale. Applications of surface plasmon resonances are widespread, nurtured by nanotechnology, and approaching a level of maturity that gives them a prominent position to contribute to some of today’s most important challenges: energy harvesting, cancer treatment, disease diagnostics, DNA sequencing, and optical computing. A detailed control over the basic resonance characteristics – the resonance frequency, line width and line shape – forms the foundation for a successful development of such plasmonics-based technologies. We present fundamental ways to control, through nanostructuring, the line width and line shape of localized surface plasmon resonances (LSPR) in individual coherent plasmonic nanocavities. Our approach towards plasmonic line shaping focuses on the control of radiative losses by coupling different plasmonic resonators sustaining dipole and multipole resonances. This gives rise to subradiant and superradiant modes [1]. Moreover, the coherent coupling of these subradiant and superradiant plasmon resonances can result in Fano interference with asymmetric line shapes [2]. Our results for relatively simple nanostructures form a fundamental basis for the design and understanding of new, more advanced plasmonic nanosystems [3]. As an example, the immediate relevance of subradiant and Fano resonances for refractive index sensing applications (e.g. biosensing) is demonstrated [4]. [1] Y. Sonnefraud, N. Verellen, H. Sobhani, G.A.E. Vandenbosch, V. V. Moshchalkov, P. Van Dorpe, P. Nordlander, and S. A. Maier, ACS Nano 4(3), 1664–1670, 2010. [2] N. Verellen, Y. Sonnefraud, H. Sobhani, F. Hao, V. V. Moshchalkov, P. Van Dorpe, P. Nordlander, and S. A. Maier, Nano Letters, 9(4), 1663–1667, 2009. [3] N. Verellen, P. Van Dorpe, D. Verc.
Thu. 03

**Active nanodevices: the next challenge for plasmonics.**

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Plasmonic nanomaterials show unique potential in the design of active nanodevices, such as light sources, transistors, or energy cells. These novel materials are expected to overcome the speed of photonic devices with the nanoscale dimension of semiconductor electronics, opening a new technological era not constrained by the limitations in size and speed photonics and electronics devices show.

In this presentation we will discuss the potential of complementary plasmonic structures made of assemblies of strongly interacting nanorods [1] as well as plasmonic crystals [2] in providing effective solutions in the development of active nanodevices.


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Thu. 04

**Propagation of magnetic avalanches and fast emission of heat in Mn$_{12}$-Ac under high field sweep rates**

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Time-resolved measurements of the magnetization reversal in single crystals of Mn12Ac in pulsed magnetic fields, at magnetic field sweep rates from 1.5 kT/s up to 7 kT/s, suggest a new process that cannot be scaled onto a deflagration-like propagation driven by heat diffusion. The sweep rate dependence of the propagation velocity, increasing from a few 100 m/s up to the speed of sound in Mn12Ac, indicates the existence of two new regimes at the highest sweep rates, with a transition around 4 kT/s that can be understood as a magnetic deflagration-to-detonation transition [1].

Under the same, high filed sweeping rates, fast heat pulses have been detected which might be originating from emitted electromagnetic radiation (EMR). In order to detect these heat pulses from the molecular magnets, we performed an experiment based on two matched compensating thermometers, of which one is carrying the Mn12-Ac crystal. Two field pulses in the same field polarity were given, and as such the second pulse could be used as a background subtraction. In the second shot of the same field polarity, immediately after 1st shot, there is no heat peak corresponding to the sample. This confirms that the signal that is observed is due to the sample reversing its magnetization. Concerning 1st peak, as it is observed at 3rd resonance, this could be due to fast emission of EMR, i.e. superradiance. As for the second and broad peak, this could be from the sample heating after the deflagration. The latter could be avoided by insulating the crystal from the temperature sensor via a Teflon layer. More experiments are being planned to confirm these preliminary results.

References:

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Vortex-switched transparency window with meta-molecules utilizing superconducting dark resonators

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We have developed a high quality factor microwave-frequency meta-molecule to demonstrate a classical optical phenomenon analogous to electromagnetically induced transparency (EIT). The two-dimensional design employs two planar Nb split rings acting as dark resonators symmetrically placed around a thick Au strip acting as a bright resonator. When Nb is in the superconducting state, the significant loss contrast between Nb and Au opens a transparency window along with a strongly enhanced group delay. The data show a systematic evolution with increasing temperature in the superconducting state of Nb, and the features disappear in the resistive state when the loss contrast between the two types of resonators closes. We have also observed switching of the transparency window at high incident microwave power due to development of an RF critical state. The experimental results are in good agreement with numerical simulations of the same structure. Laser scanning microscopy images of the microwave current distributions in the dark resonators are also in good agreement with simulations.

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Ultrastrong light-matter interaction in superconducting quantum circuits

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Superconducting quantum circuits implemented by nanostructured superconductors allow for the investigation of fundamental quantum phenomena on a macroscopic scale and the implementation of solid state quantum information systems. A big advantage of superconducting quantum two-level systems (qubits) over natural atoms is their design flexibility and wide tunability by means of external control parameters such as magnetic fields. We address the coupling of superconducting flux qubits [1,2] to on-chip microwave resonators, giving rise to the prospering field of superconducting circuit quantum electrodynamics (c-QED), which allows us to study the fundamental interaction between artificial solid state atoms and single microwave photons as the basis for communicating quantum information. Recently, we succeeded to realize for the first time c-QED systems operating in the ultra-strong coupling regime, where the atom-cavity coupling rate reaches a considerable fraction of the atom transition frequency [3]. In this regime new objects are formed consisting of matter and light. We present spectroscopy data on these new objects providing insight into novel phenomena that could not be studied in atom cavity-QED so far. We also address the interplay of multi-photon processes and symmetries in a qubit-resonator system by spectroscopically analyzing a superconducting qubit-resonator system under one- and two-photon driving [4]. Finally, we address the tomography of propagating quantum microwaves using a dual path detection scheme [5,6].


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Coherent terahertz radiation phenomena from high temperature superconductor mesa structures

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Recently, the electromagnetic waves with THz frequencies have a great deal of attention, because there are immense hope and promise for future electronics industries concerning noninvasive sensing, imaging and spectroscopy across physical, medical, biological, pharmaceutical sciences and technologies as well as for novel applications in security, surveillance and high-frequency high-density communications, etc. However, the development has been hindered by the lack of compact and powerful solid state devices with continuous and coherent radiation, commonly known as the “THz gap”. Here, we propose an entirely new method to fill the THz gap using superconducting Josephson junctions, which are naturally furnished inside high-\(T_c\) superconductor Bi\(_2\)Sr\(_2\)CaCu\(_2\)O\(_{8+\delta}\) single crystal. Since these Josephson junctions are stacked in series along the crystallographic c-axis with a periodic thickness of atomic scale of about 1.53 nm and work synchronously together according to the ac-Josephson effect by the dc-voltage applied to the system (in fact this works in principle as a DA-converter). The ac-Josephson current can be produced in the mesa, where the electromagnetic waves are generated [1].

Since the discovery of strong emission of THz electromagnetic waves from a mesa of Bi\(_2\)Sr\(_2\)CaCu\(_2\)O\(_{8+\delta}\), a number of work have been performed to understand, firstly the mechanism of the interesting phenomenon, secondly, to make use of it technologically for applications. Recently, we have succeeded in generating tunable emission in a range of approximately 200 to 800 GHz by adjusting the I-V conditions [2].

In this particular contribution, we show, firstly, the present status of understanding of the mechanism of THz radiation from intrinsic Josephson junctions, secondly, the engineering approach to make radiation controllable, which is essential for the applications, i.e., a comparison of experimental radiation patterns and theoretical simulation calculations [3], thirdly, effort to increase the radiation power to at least 1 mW. So far the total power is only 30-50 \(\mu\)W from a stand-alone mesa. Furthermore, we present imaging set-up under development as an example of useful applications [4].

[3]. H. Asai, et al., to be published.

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Tunable terahertz emission from Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ mesa devices

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We have measured coherent terahertz emission spectra from Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ mesa devices as function of temperature and mesa bias voltage. The emission frequency is found to be tunable by up to 12 % by varying the temperature and bias voltage. We attribute the tunability to the fact that actual devices have lower symmetry than rectangular – as was implicitly assumed in previous work. Under these conditions the totally uniform synchronized state cannot exist, and the lowest-order modes that are consistent with the actual mesa geometry would have 1, 3, ... nodes along the c-axis in the oscillating electric field. As a consequence, the in-plane penetration depth enters in the resonance condition resulting in the observed temperature dependence. This interpretation is consistent with numerical simulations of the dynamics of intrinsic Josephson junctions in the mesa. Easily tunable emission frequency may have important implications for the design of terahertz devices based on stacked intrinsic Josephson junctions.

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Threshold critical current to trigger vortex avalanches in superconducting thin films

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The Bean critical state model is the simplest - and yet powerful - model for describing the smooth distribution of penetrated magnetic flux in type-II superconductors. This model allows one to estimate, from magnetization and susceptibility measurements, the maximum current a superconductor can bear before dissipating, i.e., its critical current (J_C). Nonetheless, under certain conditions of temperature and magnetic field, sudden flux bursts (avalanches) develop as a consequence of thermomagnetic instabilities, which occur when heat dispersion is slower than magnetic diffusion. Based on a systematic study of the ac magnetic response of Nb films we have found the existence of a threshold critical current density above which vortex avalanches are triggered. Two Nb films of 50 nm thickness were studied, one being a plain sample and the second a specimen decorated with a square array of square antidots (ADs), with sides of 0.4 μm and lattice parameter of 1.5 μm. The ac-susceptibility (χ_{AC} = χ' + iχ'') was measured as a function of the ac-excitation field (h) at several temperatures. Cole-Cole plots indicate a Bean-like behavior, ensuring that the temperature dependent critical current (J_C(T)) can be obtained from the peak in isothermal χ''(h) curves. We have thus built a J_c versus T/T_c diagram for several values of the DC applied field (H). These curves deviate from the expected power-law behavior for values of the critical current below a certain threshold J_C, which we take as the limiting point for the occurrence of avalanches. The results have shown that the threshold critical current value is nearly constant within the whole range of temperatures and magnetic fields investigated. This means that an avalanche is triggered once the critical current of the system reaches the threshold value. From this point of view, such avalanches are in close correspondence with those experienced by sandpiles, in which material slides down whenever the slope exceeds a threshold value, a feature that is typical of self-organized systems. Our experimental results - including magneto-optical imaging and magnetic measurements - support the notion that avalanches in the studied systems are manifestations of a self-accommodation mechanism.

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Vortex dynamics in YBCO films with engineered antidots and ferromagnetic nanostructures

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Understanding vortex pinning mechanisms and the interaction between vortices and defects is still one of the major goals to enhance efficiencies of superconductors. We have used the Focused Ion Beam (FIB) technique to create artificial pinning sites in YBCO thin films grown by chemical methods. Model systems with antidots have been generated by using the FIB as a high resolution milling technique. Moreover, with this aim to study interactions in hybrid superconductor-ferromagnetic systems we have filled the antidots with cobalt rods by focused electron beam induced deposition.

In-field transport critical current measurements have been performed in a wide temperature (T) and magnetic field (µ0H) ranges in order to study vortex dynamics in these novel systems. As far as YBCO thin films with ferromagnetic rods, we demonstrate a clear interaction between the magnetic field generated by the cobalt nano-rods and the superconducting matrix. Theoretical calculations have been performed in order to analyze the local magnetic field in the YBCO matrix, modified by the trapped magnetic field in the superconductor and the magnetization of the ferromagnetic nano-rods.

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Dynamics of kinematic vortices in a superconducting stripe

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In this work we solve the time dependent Ginzburg-Landau equation for a superconducting stripe under an applied current. Different attached leads are taken into account. We present the I-V curve, resistance, kinematic vortex velocity, and order parameter for two distinct leads: (1) one as a normal metal and (2) another one as a superconductor at a higher temperature. We find that the oscillations of the potential for case (2) have a significant larger frequency and smaller amplitude. We also show that for a large window of values of the applied current density, the stripe presents lower resistance as for case (1). In addition, with superconducting leads we have found a significantly larger upper critical current density $J_{c3}$. Work supported by the Brazilian agencies CNPq and FAPESP. Keywords: vortex, anti-vortex, applied current, I-V curve.

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Dynamic phases of vortex-antivortex molecules in a Corbino disk with magnetic dipole on top

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Vortices in superconductors have been intensively studied since Abrikosov's prediction of the vortex lattice. However, in mesoscopic samples the vortex configurations depend on the subtle balance between intervortex forces and the confinement forces due to the superconductor boundaries. The situation becomes more complex in inhomogeneous magnetic field, because of the possibility of coexistence of both vortices and antivortices in the sample. This is the case in mesoscopic superconductors with a ferromagnetic dot on top. In this work we study the vortex dynamics in the latter system, but with an additional radially applied electric current which decays as the inverse of the distance to the center of the disk, the so-called Corbino disk geometry. In this case, vortices and antivortices experience a spatially inhomogeneous force, which make them move in opposite directions to each other - but perpendicularly to the current. Using the Bardeen-Stephen equation of motion, we describe different dynamic regimes for vortices and antivortices. We observe that for a sufficiently weak current (which depends on the vortex configuration) the entire configuration rotates as a rigid body. This shows that, for sufficiently low currents, the vortex-antivortex attraction prevails, making both vortices and antivortices move in the same direction. The vortex dynamics become more complex for higher applied currents, because the forces due to the shielding currents produced by the ferromagnet overcome the vortex-antivortex attraction, tearing the rigid body rotation into different vortex and antivortex shells dynamics. Just above this threshold, an eight-loop dynamics of antivortices due to competing interactions is revealed. This highly correlated motion of vortices and antivortices (although with different angular velocities) becomes less pronounced as the applied current is increased. Finally an opposite circulation of vortices and antivortices is found for high applied currents.

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Performance of deterministic Josephson vortex ratchet with a load

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Josephson vortex ratchets offer a flexible way of implementing ratchet systems in the underdamped regime. In a long annular Josephson junction a vortex-particle moves in a periodic saw-tooth-like potential created by a suitable current injection profile with zero spatial average. By applying a deterministic (sinusoidal) driving current one can compel the vortex to move in a certain direction, producing average dc voltage across the junction. Being in such a rectification regime we also apply an additional dc bias current which tilts the potential so that the fluxon climbs uphill along the potential "staircase" due to the ratchet effect. The value of the bias current at which the fluxon stops climbing up defines the strength of the ratchet effect and is determined experimentally in quasi-static as well as in adiabatic regimes. This allows to estimate the loading capability of the ratchet, the output power and efficiency.

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Vortex matter not only represents a central issue for all applications of superconductivity. Its application in so called fluxonic devices ranging from intrinsic Josephson fluxonics to extrinsic Abrikosov fluxonics represents highly interesting physics and numerous intriguing opportunities for applications. The understanding of the behavior of magnetic flux in mesoscopically patterned superconducting systems and its manipulation provides an ideal model for the understanding of basic aspects of vortex matter and for potential applications of superconductivity in electronic devices. Starting with basic aspects of vortex generation, annihilation, flux trapping and guidance, we report on combination of dc and microwave (ranging from MHz to 20GHz) electronic measurements on micro- and submicro-patterned HTS films. Changes of the transmission coefficient \( S_{21} \) in experiments with mixed dc-rf currents indicate that microwave flux transport in form of Abrikosov vortices is limited by the Larkin-Ovchinnikov critical velocity. Above a geometrically defined frequency flux transport is most likely provided by a phase-slip type of mechanism. For example for 1.5\( \mu \)m structures this limiting frequency is about 2.5-3GHz. Nevertheless, guidance of flux (for instance via artificial arrays of holes/antidots) persists in these patterns up to much higher frequencies. The data obtained at microwave frequencies agree with values obtained for the critical vortex velocity with dc pulse measurements. The implications for the modification of the transport mechanism for fluxonic devices operating up to high GHz regimes are discussed.

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Flux avalanches triggered by microwave depinning of superconducting vortices

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Electromagnetic response of bulk type II superconductors in the presence of magnetic field is determined mostly by dynamics of Abrikosov vortices. Under the applied current vortices move and dissipate the energy, unless they are pinned by either structural inhomogeneities or by artificially manufactured defects.

Microwave excitation applied to superconductors in the critical state creates supercurrents which may depin edge vortices. A very important parameter describing vortex dynamics is characteristic depinning frequency $f_0$ which reflects a transition from weakly dissipative ($f < f_0$) to strongly dissipative ($f > f_0$) vortex motion with increasing frequency, when viscous forces (and enhanced losses) dominate the dynamic response to the external microwave drive [1]. Up to now, the vortex depinning frequency has always been determined by fitting (with depinning frequency as single fitting parameter) the surface resistance as a function of the drive frequency [1, 2]. This method, however, is efficient when there is only one dominant type of pinning centers. Here we show that the depinning frequencies for different defects can be found from the broadband permeability.

We report the observation of abrupt changes in the broadband microwave permeability of thin Pb superconducting films as functions of the wave frequency and intensity, as well as of external magnetic field. These changes are attributed to microwave-induced depinning of vortex lattice at the sample edges leading to flux avalanches. We map the experimental results on the widely used theoretical model by Gittleman & Rosenblum [1] and show that our measurements provide an efficient method of extracting so-called depinning frequencies for different pinning centers. The observed dependences of the extracted depinning frequencies on the microwave power, magnetic field and temperature are compatible with the concept of thermomagnetic instability creating the flux avalanches. Precise knowledge of the edge depinning frequencies of superconducting vortices could be of importance for understanding vortex pinning and for effective control over the vortex avalanches in microwave superconducting electronics.


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Josephson relation and Lorentz force

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For type II superconductors, Josephson has shown that moving vortices create an effective electric field. By definition the effective electric field is gradient of the electrochemical potential, what is the quantity corresponding to voltage observed with the use of Ohmic contacts. It relates to the true electric field via the local chemical potential. If vortices are moving, superconductor is out of equilibrium and gradient of superfluid fraction resulting in so called sn-interaction is present. Electric driving force felt by normal fluid and superfluid differs. We show, that effective electric field derived by Josephson is the electric driving force felt by the normal fluid.
Macroscopic quantum phenomena decay in LTS and HTS Josephson junctions

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Macroscopic quantum phenomena leave their quantum signature in the switching process from the zero voltage to the finite voltage branch in the current-voltage (I-V) characteristics. Mesoscopic effects encode their fingerprints as well in the I-V curves.

We investigate escape dynamics in junctions of reduced dimensions, characterized by different levels of dissipation. In moderately damped junctions phase diffusion processes coexist with thermal activation and macroscopic quantum tunneling. Measurements are carried out both on high (HTS) and low (LTS) critical temperature superconductor Josephson systems, characterized by different types of barriers, i.e. grain boundary and standard insulating layers. Experimental data are compared with numerical outcomes giving evidence of quantum coherent transport and size effects. Flavors of ‘novel’ features appearing in escape dynamics are discussed.

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Transport properties of Andreev polarons in a superconductor-semiconductor-superconductor junction with superlattice structure


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Transport properties of a superconductor-semiconductor-superconductor junction with superlattice structure are studied. Differential resistance as a function of voltage shows oscillatory behavior under the irradiation of RF waves of 1.77 GHz regardless of the junction geometry. Experimental data are explained in terms of the coupling of superconducting quasiparticles with long-wavelength acoustic phonons excited by the RF waves. We propose that the strong coupling causes the formation of novel composite particles, Andreev polarons. R. Inoue et al., Phys. Rev. Lett. 106 (2011) 157002.

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Ultrathin superconducting alloy films formed from bulk-immiscible elements by quantum stabilized growth

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In bulk form, Pb and Ga are immiscible. In this study, we synthesized atomically-smooth Pb\textsubscript{1-x}Ga\textsubscript{x} (x \approx 0.06) alloy films on a Si(111)-7 \times 7 substrate, where the films were stabilized by quantum confinement. Typical thicknesses of the ultrathin films are 8 ~ 10 atomic monolayers (ML). As with similarly prepared films of pure Pb,\textsuperscript{+} the alloy materials exhibit bilayer-by-bilayer growth; in the present case, however, the morphology of the resulting quantum growth differs substantially, consisting of 6 or 8 ML deep holes that penetrate to within 2 ML of the substrate. The superconducting transition temperatures T\textsubscript{c} indicate hole doping, consistent with the formation of a Ga-substituted alloy. The critical current densities J\textsubscript{C} are high (a substantial fraction of the estimated depairing current density), due to the deep, vortex-trapping holes. Furthermore, J\textsubscript{C}(T) exhibits a curious non-monotonic temperature dependence, as observed by both dc and ac magnetization. This anomaly is directly associated with the exceptional film morphology and is attributed to an onset of superconductivity in the 2 ML thick layer at the bottom of the vortex pinning centers.\textsuperscript{*} Özür M M, Wang C Z, Zhang Z Y and Weitering H H (2009) J. Low Temp. Phys. 157 221. \textsuperscript{+} Özür M M, Thompson J R and Weitering H H (2006) Nature Phys. 2 173. This research was supported by the U.S. Department of Energy, Basic Energy Sciences, Materials Sciences and Engineering Division (MMO, GD, JRT, and HHW), and by the National Science Foundation under contract No. DMR 0906025 (EJM).

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Observations of extreme magnetic anisotropy and multiple superconducting transition signatures in Nb/Ni heterostructures

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Superconducting (SC) [Nb(23nm)/Ni(5nm)]$_5$ multilayers (ML) exhibit extreme magnetic anisotropy and strong diamagnetism of confined supercurrents in DC magnetic fields $H$ applied nearly parallel to the film plane [1]. Longitudinal (AC and DC fields parallel to SQUID detection coils) SQUID magnetometry for a [Nb(23nm)/Ni(5nm)]$_5$ ML revealed oscillations of the SC onset temperature $T_C(H)$ and strong magnetic anisotropy that includes disappearance of the sample moment for $H$ parallel to the ML. Transverse (AC perpendicular to DC field) vibrating reed magnetometry yields large, abrupt shifts $\Delta T_C(H)/T_C \approx 0.1$ of $T_C(H) \approx 5$ K for $H$ applied nearly parallel to the ML, which may mark multiple SC phase transitions or vortex lattice rearrangements within the ML. Vibrating reed measurements ML in parallel field alignment revealed SC onsets $T_C(H< 8$ kOe) that are field-independent within experimental error, suggesting an absence of orbital pairbreaking. The strong sensitivity of $T_C(H)$ to DC field alignment and AC field amplitude suggest the abrupt shifts of $T_C(H)$ are due to dynamic instabilities between confined superconducting Nb layers whose SC phases are weakly coupled via proximity and pairbreaking effects within the Ni layers. These possibilities are explored in additional measurements of ferromagnetic resonance (FMR) and angle-dependent upper critical fields of Nb(x)/Ni(y)/Nb(x) and Ni(y)/Nb(x)/Ni(y) trilayers and Nb(x)/Ni(y) multilayers of various layer thicknesses x and y. [1] L. E. De Long et. al, Physica C 468, 523-530 (2008). *Research at the U. Kentucky is supported by U.S. Dept. Energy Grant No. DE-FG02-97ER45653

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Nanoscale structures and giant Nernst effect below the pseudogap in high-Tc superconductors

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Observations of a large Nernst signal in an extended region above the critical temperature Tc in hole-doped cuprates provides an accurate tool to study fluctuations in the pseudogap region. We show that the nanoscale structures in these layered superconductors may be caused by localized negative charges, which can collect a cluster of charge carriers around them. Our results support the scenario that superfluidity vanishes because long-range phase coherence is destroyed by a charge density wave instability induced by localized charges and the over-screening of the long-ranged part of the Coulomb interaction, which is enhanced due to decreasing carrier density. [1] When the carrier density is low enough localized charges begin to trap particles and form bound states of clusters of charge carriers, which we call Coulomb bubbles. These bubbles are embedded inside the superconductor and form nuclei of the new insulating state. The growth of a bubble is terminated by the Coulomb force and each of them has a quantized charge and a fluctuating phase. When clusters first appear they are covered by superfluid liquid due to the proximity effect and invisible. However when the carrier density decreases the size of bubbles increases and the superconducting proximity inside them vanishes. The insulating state arises via a percolation of these insulating islands, which form a giant percolating cluster that prevents the flow of the electrical supercurrent through the system. We present an effective Hamiltonian, which takes into account the Jahn–Teller distortion of the apical oxygen and provides two bands, the band of charge carriers and the localized impurity band causing the clustering. Our results are consistent with the two-component picture for cuprates deducted earlier by Gorkov and Teitelbaum [2] from the analysis of the Hall effect data and ARPES spectra. The Coulomb clusters are also observed in Scanning Tunneling Microscope (STM) experiments [3] and are responsible for the pseudogap [4].

Spin triplet superconductivity generation with CrO$_2$ and Co based SFS junctions

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It is now clear that odd-frequency spin triplets with equal spin components can be induced in ferromagnets and are sustained over long lengths since they are not susceptible to pair breaking by the exchange field. In particular, in 100% spin polarized ferromagnetic CrO$_2$, where superconducting contacts were deposited on top of the ferromagnetic films, we observed the supercurrent to flow over 700 nm [1]. We also have devices, however, where the supercurrent is absent, which indicates that the mechanism of triplet generation is not yet well controlled. Suggested by work on Co based junctions in vertical geometry [2], More control is possible by using an additional ferromagnetic layer, in our case 2 nm thick Ni on top of CrO$_2$, which led to the observation of a supercurrent over 800 nm. In addition to the CrO$_2$ based junctions, supercurrent generation in Co-based lateral junctions with a junction length over 100 nm will also be discussed.


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Coulomb-enhanced resonance transmission of quantum SINIS junctions

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According to the classical picture of the Coulomb blockade in gated structures the Coulomb interaction usually suppresses electronic transport through small conductors by introducing an additional energy barrier associated with the charging energy. Here we show that in ballistic SINIS junctions (here S stands for a superconductor, N is a normal-metal island, and I is an insulator), the Coulomb interaction can rather stimulate the supercurrent than suppress it. The supercurrent through a junction containing a ballistic normal island is mediated by Andreev states with energies controlled by the effective transparency of the double-barrier structure, which is determined by the wavelength of electrons. The extra charge on the dot affects not only the energy but also the wavelength of electrons. This makes the transmission extremely sensitive both to the gate voltage and to the charge on the Andreev states localized in the normal island. We show that charging of Andreev states can actually preserve the condition of resonance tunneling: the charge adjusts itself so as to compensate the deviation of the chemical potential caused by the change in the gate voltage thus increasing the transparency of the device for the supercurrent. We consider the normal island in the form of a short single-mode ballistic conductor (wire) connected to bulk superconducting leads via low-transparency contacts. This corresponds to the experimental situation which is realized in several recent experiments on nanowires. The conclusions are based on solution of the Bogoliubov-de Gennes equations for the system under consideration. First results are reported in [1].


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Room temperature detection of strong sub-terahertz emission from niobium Josephson junctions

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Essential applications of terahertz technology in fields such as astronomy, medicine, security and communications are urgently in need of compact, tunable solid-state continuous wave radiation sources. Through intensive investigation in the last decade, quantum cascade lasers offer satisfactory solutions at frequencies above 1.5 THz. However, no satisfactory solution is yet available for the frequency range of up to approximately 1.0 THz. Fortunately, Josephson junctions have inherent advantages for fulfilling this challenge. Here we present coherent tunable non-Josephson radiation of large series arrays of niobium Josephson junctions between 0.1 and 0.35 THz at liquid helium temperature, with off-chip radiation power of up to 7 μW detected at room temperature. The well-known obstacle to impedance matching is overcome by utilizing the resonances on the junction substrates serving as dielectric resonator antennae. The discovered mechanism of synchronization could be also useful for synchronizing various integrated oscillators including semiconductor devices on one chip to cover the sub-THz frequency range. The further increasing of the frequency, power and tunability of the investigated radiation will be discussed on the Conference. The work is supported in part by Russian Agency of Education under the Federal Program "Scientific and educational personnel of innovative Russia in 2009-2013" and by the Project 863 of China under Grant No. 2009AA03Z208.

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Design issues for active electrically small superconductive antenna

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The electrically small antenna (ESA), i.e. antenna with a size which is much less than wavelength, is very attractive for many up-to-date applications due to the small antenna size and the wide bandwidth. The use of superconductors instead of metal conductors substantially improves the antenna characteristics. Next critical advancing in the technology is development and implementation of an active ESA. This promises substantial improvement of all characteristics of the antenna. Possible approaches to synthesis of the active electrically small superconductive antenna were suggested and analyzed. The proposed antenna designs are based on implementation of series networks consisting of the cells each providing linear voltage responses. Either bi-SQUID or differential circuit of two parallel SQIFs can be used as the basic cells of the networks. The antenna prototypes were designed, fabricated and evaluated experimentally. In case of the antenna prototype based on series array of 12 bi-SQUIDs, the measured transfer factor is as high as 50 mV/mT. Increase in number of the cells used in the antenna network results in proportional rise of the transfer factor.

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Simulations of a dissipative (2+1)-dimensional XY model for quantum criticality of circulating currents in cuprates

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We present large-scale quantum Monte Carlo simulations of an effective model describing the quantum critical point (QCP) arising from a putative ordering of orbital magnetic moments within the unit cell of CuO$_2$ sheets in high-Tc cuprates. The quantum critical fluctuations originating with the QCP of this effective model has been proposed to provide the microscopic basis for the Marginal Fermi Liquid hypothesis, as well as the pairing glue in the cuprates. The origin of the effective model, which is a (2+1)-dimensional dissipative quantum XY model is briefly explained. We show that the critical dynamical exponent is given by $z=1$, i.e. the QCP features Lorentz-invariance and isotropic spatio-temporal critical correlations. A slight deformation of the model, such that it describes resistively shunted Josephson-junction arrays, yields a very different result, namely $z=\infty$. This means that the spatio-temporal critical correlations are highly anisotropic, with local spatial correlations and power-law temporal correlations, closely akin to what is required for providing a basis for the marginal Fermi Liquid hypothesis.

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Fluxon dynamics in stacked Josephson junctions at THz frequencies.

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Electromagnetic radiation from BSCCO type layered Josephson junctions at THz frequencies could have many important applications, for example as a local oscillator in an integrated receiver, a spectrometer, an imaging device etc. There are several methods to deal theoretically with this very nonlinear system. The stack of inductively coupled long Josephson junctions may be modeled as a system of coupled sine-Gordon equations. The key point for oscillator performance is to have in-phase coherent motion of fluxons in the different Josephson junctions in the stack. This may be obtained by having all the junctions in the stack interacting with each other as well as with a cavity. The corresponding fluxon dynamics is very non-linear, and numerical simulations are usually needed. In a few cases analytical results have provided a new insight in this complicated non-linear system. In several cases a negative differential resistance has been observed for parameters leading to emission. The role of a negative differential resistance for parameters leading to emission will be discussed.

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The anisotropy of high-Tc cuprate superconductors evokes various novel vortex effects. For instance, when the magnetic field is tilted away from the orientation perpendicular to the copper-oxide layers, the flux lines distort and kink into chain vortices consisting of alternating vortex "pancakes" located in the cuprate planes that are connected by Josephson vortex "strings" lying in the charge reservoir layers. The latter are weakly pinned, so that flux pinning is strongly reduced when the flux line is dominated by Josephson strings. In c-axis oriented thin films, however, some of these features are not experimentally accessible. On the other hand, a reduced symmetry can be obtained by growing thin films of YBCO on vicinal substrates that show a roof-tile like structure of the copper-oxide planes. It allows for a current path non-parallel to the ab planes and a magnetic field oriented at an arbitrary angle with respect to the planes. Such measurement geometry provides a finite Lorentz force on the Josephson vortices, inducing their sliding motion along the copper-oxide planes (vortex channelling). In previous works, vortex channelling was investigated primarily by measurements of the critical current, i.e., at very low vortex velocities and flux creep conditions. Here, we present measurements at intense currents on thin films of optimally doped YBCO, grown on vicinal substrates. A pulsed-current technique with a four-probe arrangement allowed to extend the current-voltage characteristics to supercritical currents. By suitable patterning of the samples the current was forced to flow at a finite angle with respect to the ab planes and the magnetic field was rotated in the plane defined by the c axis and the current direction. Distinct angle dependence of the resistance was found with a sharp peak at a magnetic field orientation parallel to the cuprate layers, an evidence for high-velocity sliding motion of vortices along the ab planes.
Polarons in High-Tc cuprates

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Usually shallow polarons do not exist in higher than one-dimensional systems with simple parabolic type band dispersion. However van-Hove singularity in the band structure of CuO$_2$ layers of high T$_C$ cuprates and charge transfer insulating gap make the self trapping favorable even in two-dimensional case. The localization energy exceeds the formation energy of potential well in this case. During the doping polarons are created as stationary particles located near to the saddle points of Brillouin zone at the same time with hole pockets in the vicinity of nodal points. Based on that kind of band structure several experimental data are discussed.

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The topic of quantum fluctuations in quasi-1D superconductors, also called \textit{quantum phase slips} (QPS), has attracted a significant attention [1]. It has been shown that the phenomenon is capable to suppress the zero resistivity of ultra-narrow superconducting nanowires at low temperatures $T \ll T_c$ [2, 3] and quench persistent currents in tiny nanorings [4]. It has been predicted that a superconducting nanowire in the regime of QPS is dual to a Josephson junction [5]. In particular case of an extremely narrow superconducting nanowire imbedded in a high-impedance environment the duality leads to an intuitively controversial result: the superconductor should enter an insulating state. Here we experimentally demonstrate that the I-V characteristic of such a wire indeed shows Coulomb blockade which disappears with application of a critical magnetic field and/or above the critical temperature proving that the effect is related to superconductivity. The quantum duality with Josephson systems goes even further: application of an external RF radiation can be synchronized with the internal Bloch oscillations of the current-biased ‘superconducting’ nanowire. The phenomenon is dual to the well-known Shapiro effect: the voltage steps for a Josephson junction are substituted by the current steps for a QPS wire. The position of the $n$-th step follows the relation $I_n = n \times (2e) \times f$, where $f$ is the frequency of external RF radiation and $2e$ is the charge of a Cooper pair. The effect is expected to lead to the important metrological application - the quantum standard of electric current.

AC-driven vortex ratchet reversal in superconducting films with asymmetric tilted washboard pinning potential

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The vortex ratchet is a system where the vortex can acquire a net motion in asymmetric periodic pinning potential in the presence of deterministic or/and stochastic forces with time averages of zero. One of the most intriguing ratchet effects, which have previously been studied only experimentally or by numerous simulations, is the ratchet reversal, i.e., a sign change of the dc response, as a function of ac driving amplitude and frequency. The vortex-vortex interactions are usually considered as a reason of the ratchet reversals to appear in nanostructured superconducting films. To examine this idea, we have theoretically considered the problem of the vortex motion in a superconductor with tilted cosine, i.e. initially symmetric, washboard pinning potential (WPP) in the presence of an ac driving [1]. The results have been obtained on the basis of the exact solution of the Langevin equation for non-interacting vortices, within the frame of a single-vortex stochastic model of anisotropic pinning which describes dc ratchet response of the vortex. There has been shown, that in a single-vortex approach [1], the sign of the dc response actually does not depend on the ac amplitude and frequency. In the present work, we consider the vortex motion in an asymmetric WPP, tilted by an external dc bias, in order to scrutinize the influence of an ac current of arbitrary amplitude and frequency on the dc-voltage-ac-drive single-vortex ratchet response. The results are obtained within the frame of exact solution of the appropriate Langevin equation in terms of a matrix continued fraction [2]. We argue that the vortex ratchet reversal is possible even in the single-vortex approach. Special attention is paid to the physical interpretation of the obtained results in quasi-adiabatic (Ω<<1, where Ω is the dimensionless driving frequency) ratchet responses taking competition between the asymmetry and the WPP’s tilt into account. The main physical reason provoking the ratchet reversal is the difference of the asymmetry and the tilting in their asymptotic large-current behavior in the adiabatic regime. In particular, in this limit the tilted adiabatic response is finite and equal to the tilt value [1], whereas for the asymmetric ratchet with a tilt this response is zero [3].

[1]. V.A. Shklovskij and O.V. Dobrovolskiy, to be published.

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Grain size dependent transport properties of superconducting nanocrystalline diamond:B

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A series of heavily boron-doped nanocrystalline diamond (B:NCD) thin films are synthesized by microwave plasma-enhanced chemical vapour deposition (MPECVD) method. By fixing the B/C-ratio at 5000 ppm and changing the CH₄/H₂-ratio from 1.5% to 5%, we obtain a set of B:NCD films with a systematic change in the grain size. Structural analysis via scanning electron microscopy (SEM) and X-ray diffraction (XRD) reveals that the increase in the CH₄/H₂-ratio results in a decrease in the mean grain size and hence, an increase in the grain boundary density. Thermoresistivity and magnetoresistivity measurements over a broad temperature range and at different magnetic fields, indicate the all-pervading influence of the grain size difference on the superconducting, insulating and normal state transport properties of the B:NCD films.

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POSTER PRESENTATIONS
Ground states of multi-band type-I and type-1.5 superconductors and interlaced type-I/type-II layered superconducting structures in external magnetic field

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We report a numerical study of magnetic field-induced structures in multiband/multi-component superconductors and type-I/type-II multilayers. The magnetic ground state in these different regimes shows very rich structure formation, because of non-pairwise vortex interactions. In particular we report vortex cluster formation in the cases of strong interband Josephson coupling. The results in particular can be applied to layered structures manufactured from interlaced layers of type-I and type-II superconductors yielding effectively the type-1.5 superconducting behavior with tunable intercomponent couplings.

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Multigap superconductivity – thermodynamic and magnetization studies

of NbS$_2$ and pnictides

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Multiple electronic bands crossing the Fermi level can lead at certain circumstances to an interesting existence of multiple superconducting energy gaps in one system. The most spectacular example of this phenomenon is MgB$_2$. Superconducting dichalcogenides have also multiple bands at the Fermi energy but completely different symmetry and coupling among them than in MgB$_2$. After STM measurements [1] had indicated appearance of two superconducting energy gaps in the quasiparticle spectrum we proved [2] on the NbS$_2$ single crystals that those two gaps are characteristic of a bulk material. We also recently brought evidence by point-contact spectroscopy that some pnictides are two-gap superconductors as well [3]. There the situation is even more interesting since exotic $s^\pm$ pairing mechanism is proposed to take place.

For detailed research of NbS$_2$ as well as some types of pnictides we performed thermodynamic and magnetization studies by means of ac-calorimetry and local magnetization measurements using array of miniature Hall probes. We inspected closely the phase diagram and resulting anisotropies of upper and lower critical field in NbS$_2$ and compared them with those of MgB$_2$. Similarities and differences will be demonstrated and interpreted. In our studies on pnictides [4] we have found that the irreversibility line, defined as the onset of diamagnetic response, is very rapidly shifted toward lower temperatures in NdFeAs(O,F) but remains close to the specific heat anomaly in (Ba,K)Fe$_2$As$_2$. These measurements strongly suggest that a vortex-liquid phase occupies a large portion of the mixed-state phase diagram of former system but not in later one.


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Two-gap superconductors in the Ginzburg-Landau domain

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Standard formulation of Ginzburg-Landau theory for the two-gap superconductors [1] has been shown to include incomplete terms of the higher order in expansion parameter \( \tau = 1 - T/T_C \) [2]. When these are omitted, the theory falls back to the single gap case and therefore does not allow for the experimentally observed two coherence lengths at low temperatures. As a result, the proper description of characteristic lengths for the gap variation in two-gap superconductors is currently the topic of a heated debate [3]. In order to correctly capture all important physics in the GL domain, which will allow us to continue to use the GL formalism for studies of vortex matter in two-gap superconductors, we performed the derivation of the extended two-gap GL theory, where we collected all the terms of the next-to-leading order [4]. Here we show that inclusion of these terms allows for differences in the characteristic length scales of the order-parameter variation, thus the system possesses again two different effective coherence lengths, albeit not entirely independent. We stress that these are different from the formally defined nominal coherence lengths of the two-gaps in the absence of coupling. Besides the quantification of different lengthscales in the extended GL theory, we also quantify the domain of the GL theory as a function of microscopic parameters, we compare the results to the standard GL theory and the microscopic theories, and that for different bulk materials (e.g. selected borides and pnictides), and nanoscale films and confined fermionic condensates where multiband superconductivity arises due to quantum confinement.


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The pattern formation due to the non-monotonic interaction

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Phase fluctuations in proximity coupled superconducting arrays

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We report transport measurements on triangular arrays of proximity-coupled superconducting islands placed on normal-metal substrates. The superconducting islands are well-understood coherent systems with long-range electron interactions, while the intervening normal metal channels introduce known dissipation into the system. We show how by changing the island spacing, we can tune characteristics such as the critical temperature and field. The arrays undergo a Kosterlitz-Thouless vortex-unbinding phase transition at zero-field, and we observe frustration-induced magnetoresistance oscillations at finite fields. We also observe unusual cusp-like behavior in resistance vs temperature at finite magnetic fields.

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Saw-tooth ratchet

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In general, ratchet effects in vortex systems are attributed to asymmetries within the unit cell of the pinning potential \cite{1}, \cite{2}. However, rectification effects should also occur as the conditions for vortex entry and exit in a system are significantly different \cite{3}. We report the observation of vortex rectification through sculpting of these boundary conditions. Introducing a saw-tooth-like array of micro-indentations on one side of an Al bridge we alter the current-density distribution along this edge of the film and create a path for easy entrance/exit of the vortices. The influence of the period of the array of indentations is investigated. Multiple reversals of the rectified voltage signal are seen in function of the magnetic field and temperature.

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\cite{3} V. V. Pryadun, J. Sierra, and F. G. Aliev, D. S. Golubovic and V. V. Moshchalkov, APL 88, 062517 (2006)

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Current-induced vortex pinning

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Most of today’s practical applications of superconductivity, such as Magnetic Resonance Imaging devices, have directly benefitted from the latest advances made in preventing the motion of quantum units of flux by trapping them in energy potential wells. In general, irrespective of the nature of the vortex traps, it is equally difficult to remove them in any direction. However, if the slope of the energy potential well is less steep along certain orientation, this will establish an easy path favoring the flux lines to escape. This latter case of asymmetric pinning centers is the essence of voltage rectification in superconducting systems, i.e. the ratchet effect. So far, no one has neither considered nor conceived the case of flux-line cages in which along one of the directions it offers no resistance at all to vortex displacement. We investigate experimentally and theoretically the vortex dynamics in a superconducting film with nano-engineered open vortex-traps which provide tunable pinning, ranging from no-pinning for zero bias current to finite pinning for certain current directions. The design is based on the confinement of the vortex motion within two repulsive walls, one with periodic micro-protrusions and the other one smooth. Clear commensurability effects are seen if the bias current drives the vortices inside the traps whereas these effects are much less pronounced when the current pushes the vortices against the smooth surface. For small periods of the protrusions or large vortex sizes, the properties displayed by the vortices, pushed against these two surfaces of dissimilar roughness can be thought of as due to the change of effective sliding friction.

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Vortex lattice studies in CeCoIn$_5$ with $H \perp c$


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We report on small-angle neutron scattering measurements on the vortex lattice (VL) in the mixed state of CeCoIn$_5$ with the magnetfield ($H$) along [100] and [110]. For both orientations a distorted hexagonal VL is observed, reflecting the penetration depth anisotropy of the screening current plane. With $H \parallel [100]$ the VL is oriented with Bragg reflections along the [001]-axis at all fields. For $H \parallel [110]$ the same VL orientation is observed at low fields, followed by a 90° first-order reorientation transition as $H$ is increased. For $H \parallel [100]$ we obtain the field dependence of the form factor ($|F|^2$) both within (50 mK) and outside (350 mK) the magnetic Q-phase. At both temperatures $|F|^2$ varies with $H$ in a manner similar to $H \parallel [001]$ (J.S. White et al., New J. Phys. 12, 023026 (2010)), due to a paramagnetic alignment of the unpaired electron spins in the vortex cores. Inside the Q-phase we observe an increased disordering of the field cool VL indicating a subtle coupling to the magnetic phase.

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Influence of pinning by periodic array of circular Py dots on broadband microwave response of superconducting Pb films

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Magnetic and superconducting vortices are topological anomalies which exist either when magnetization is confined in nanomagnets or magnetic flux quantization in the type II superconductors. A recent theory and static experiments indicate the possibility of interaction between magnetic and superconducting vortices in hybrid superconductor/ferromagnet structures [1-3]. Carneiro [1] investigated theoretically the interaction between a straight vortex line in a superconducting film and a soft magnetic nanodisk in the magnetic vortex state in the presence of in-plane magnetic field. He concluded that pinning of the vortex line by the nanodisk being predominantly from the interaction between the vortex line and the changes in the nanodisk magnetization induced the displacement of the magnetic vortex. Villegas et al. [2] reported on the influence of magnetic vortex state of the dense magnetic (Fe) nanodot array on the properties of thin Al films. Later Hoffmann et al. [3] observed similar effects in Nb films grown on lithographically defined array of Py circular dots concluding that pinning of superconducting vortices is strongly enhanced due to the magnetic vortices. However, Shapoval et al. [4] have found that the magnetic vortex core for Nb films over Py dots introduced only weak additional pinning. Here we report on broadband microwave response (300 kHz to 8.5GHz) in the 90 and 50 nm thick superconducting Pb films deposited on top of array of 1000 nm diameter and 35nm thick circular Py dots in the vortex ground state and arranges in square lattice with period of 2000 nm. At temperatures close to about 0.95Tc we find periodic variation of the microwave permeability as a function of external magnetic field. We clearly detect few interger (Hn) and rational (Hk/m) matching fields which are in accordance with recent measurements of microwave complex reflection on 50nm thick Pb film with periodic array of microholes inside rf coil [5]. In addition, we found that the variation of the relative amplitude of integer and rational pinning anomalies with frequency and microwave power indicates a transition from microwave induced vortex depinning at lowest rf powers (which increases the magnitude of the permeability anomalies) to rf induced heating which substantially decreases the matching anomalies in permeability. Finally, we investigate the influence of the vortex core alignment (cores up or down) on the asymmetry of the microwave response vs. magnetic field. [1] G. Carniero, Physica C460–462 1186 (2007). [2] J. Villegas, et al., Phys. Rev. Lett., 99, 227001 (2007). [3] A. Hoffmann, et al., Phys. Rev. B77, 060506R(2008). [4] T. Shapoval, et al., Phys. Rev. B81, 092505 (2010). [5] P.J. Cuadra-Solis, et al., Physica C468, 777 (2008).
Magnetoresistive response in thin Nb films with uniaxial ratchet pinning potential

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The guided vortex motion and vortex ratchets in nanostructured superconductors belong to the most fascinating fluxonic effects allowing one to manipulate fluxons through directional and orientational control of their motion, respectively [1]. Ratchet pinning potentials are in particular useful for the removal of unwanted magnetic flux in superconducting devices and provide a model approach to scrutinize the mechanisms ruling the vortex dynamics in widely used nanostructured superconductors. In the present work, we have used thin epitaxial films of Nb (110) furnished with linearly extended nanostructures in the form of asymmetric grooves, which provide such a ratchet washboard-like pinning potential (WPP). A direct mask-less nanofabrication tool, focused ion beam (FIB) etching, to fabricate such pinning nano-profiles has been employed. Its advantages include a tunable pinning intensity, high periodicity of the fabricated structures, and the availability of non-patterned (as-grown) films for reference purposes. The resistive response of the films has been investigated by dc magneto-transport measurements under magnetic field reversal in the vicinity of $T_C$ and small magnetic fields. Two transport current I orientations, namely (i) along the WPP grooves, i.e. the transverse (T-) geometry as the vortices move across the grooves, and (ii) across the grooves, i.e. the longitudinal (L-) geometry as the vortices move along the grooves, have been used. In the L-geometry, the current-voltage characteristics (CVCs) is an odd function with regard to the change $I \rightarrow -I$ or $B \rightarrow -B$, as is also the case for as-grown films. In the T-geometry, the CVC has been neither an even, nor an odd function in I or B, and demonstrating unequal critical current values for the weak- and strong-slope WPP directions. This leads naturally to the separation of its odd and even components which provide a step-like even magnetoresistivity component $R^+ = [R(+B)-R(-B)]/2$ and a peak-like odd component $R^- = [R(+B)-R(-B)]/2$, where the last acquires its maximum in the point of the steepest increase of $R^+$ and vanishes at higher current densities. The experimental results are analyzed in the frame of a single-vortex stochastic model of anisotropic pinning where the anisotropic pinning force is caused by an asymmetric saw-tooth WPP [2]. [1]. A. V. Silhanek, J. Van de Vondel, and V. V. Moshchalkov in Nanoscience and Engineering in Superconductivity, Chap. 1, pp. 1-24 (Berlin Heidelberg: Springer-Verlag, 2010). [2]. V. A. Shklovskij and V. V. Sosedkin, Phys. Rev. B 80, 214526 (2009).
Direct visualization of dynamical ordering effects in NbSe$_2$

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Systems that can be modelled as an elastic object in a disordered environment are omnipresent, and widely studied [1, 2].

In non-equilibrium, these physical systems can exhibit a rich structural phase diagram [3]. A playground to investigate this intriguing dynamical properties is a type-II superconductor in the mixed state. The competition between the vortex-vortex interaction and the potential generated by quenched disorder determines the electromagnetic response of a type-II superconductor in the mixed state. Under the influence of an ac-field excitation this competition introduces a critical threshold for dynamical reordering [4, 5]. By means of low temperature scanning hall probe microscopy, we have studied the dynamical reordering of the vortex lattice in a NbSe$_2$ crystal with single vortex resolution as function of temperature and ac-drive. Furthermore, we have used the recently developed local scanning susceptibility technique [6] to reveal the microscopic processes going on during the reordering process.

References:

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Flux avalanches triggered by ac magnetic fields in superconducting thin films

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Flux avalanches in type-II superconductors are characterized by sudden flux bursts which develop as a consequence of thermomagnetic instabilities which occur when thermal diffusion is slower than magnetic diffusion. Under certain conditions of temperature and magnetic field one can recognize their fingerprints as jumps in magnetization curves, or as a paramagnetic reentrance in ac susceptibility measurements. In a recent work, Colauto and co-workers [1] have shown that the variation of the magnitude of those flux jumps can be quantitatively linked to magneto-optical (MO) images taken under equivalent experimental conditions. In this work we carried out a systematic study of ac-susceptibility, residual magnetization (after application of an ac field, M_{res}), and MO imaging. Two Nb films were employed: Samples AD04 and AD08, which are Nb films with thickness of 50 nm, each decorated with a square array of ADs, with a lattice constant of 1.5 μm. The square ADs in AD04 have 0.4 μm sides, whereas in AD08 the sides are 0.8 μm. A third Nb pristine film was also studied as a reference sample. The ac-susceptibility and the residual magnetization after an applied ac field were measured as a function of an ac-excitation field (h) at several temperatures and DC applied fields. For the pristine and AD04 samples, the response of M_{res} for low temperatures consists of short plateaus followed by small jumps (small avalanches) whereas for higher temperatures, both jumps and plateaus are larger (big avalanches). At high amplitudes of the ac field, the curves are always noisy, i.e., flux avalanches occur at every increase on the ac-excitation. All curves for the AD08 film are noisy. These results were confirmed by MOI measurements. The set of results imply that the ac magnetic field triggers avalanches on Nb films, regardless of the presence of ADs. Nonetheless, the sample with larger ADs exhibits avalanches in the whole range of temperatures, whereas for other samples the size and separation (in terms of the excitation field) of the avalanches depend on the temperature; besides, avalanches appear only below a threshold temperature, whose value differs from sample to sample. Reference [1] F. Colauto et al. Supercond. Sci. Tech. 20, L48 (2007).

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The dynamics of vortex “shells” in circular channels in macroscopic Corbino disks

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The dynamics of vortex matter has been studied in mesoscopic superconducting Corbino disks, where vortices form shells as observed in micrometer-size Nb disks. Because of the interaction between vortices and the interface, the configuration of vortices experiences the transition from Abrikosov lattice to vortex shells with decreasing size of the system. The driving Lorentz force reaches the maximum at the center and reduces as 1/r along the radius in Corbino disks. The process of angular melting has been revealed in mesoscopic Corbino disks [1-4]. Depending on the specific vortex configuration, angular melting can start either from the center of the disk (where the shear stress is maximum) [1] or from its boundary (where the shear stress is minimum) [2-4]. Furthermore, unconventional angular melting [3,4], i.e., an outer shell, which is driven by a weaker Lorentz force, rotating faster than the inner adjacent shell, is found in simulations. However, in experiment, it is difficult to measure the angular velocity for each shell in such small disks. We propose to create artificial “shells” in macroscopic disks by circular channels (e.g., weak-pinning channel [5]). Therefore, we force vortices to form “shells” instead of Abrikosov lattice in macroscopic disks where the angular velocity for each channel can be measured in experiment. Vortex “shells” experience the same forces as in mesoscopic disks: inhomogeneous driving force and the interaction between “shells”. The commensurability effect and the order of the angular melting are investigated.


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MgB\textsubscript{2} thin films can be interesting candidates for magnetic sensor devices due to their relatively high transition temperature, large critical field, large coherence length and attractive critical current. Furthermore MgB\textsubscript{2} is easy to prepare and to process. However, vortex motion constrains the quality of such devices. In MgB\textsubscript{2} thin films there are two regimes of vortex motion. At temperatures below 10 K, magnetic avalanches lead to large vortex velocities and thus to a huge amount of noise. At higher temperatures, thermally activated flux creep remains as one limiting factor for the signal - to - noise - ratio. SQUID measurements show, that thermally activated flux creep in MgB\textsubscript{2} can depend on different parameters such as cover layers or even the magnetic history in the material. Magnetic avalanches in MgB\textsubscript{2} were investigated using a magneto-optical technique. The results show that the mechanisms for formation and propagation of magnetic avalanches have to be distinguished [1]. In particular, we find that inhomogeneities or granular structures strongly support the formation and propagation of avalanches. This means many applications require homogeneous superconducting structures. [1] S. Treiber and J. Albrecht, New J. Phys. 12, 093043 (2010).
Vortex motion in Nb/PdNi/Nb trilayers: new aspects in the flux flow state

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We study the dynamics of vortex lines in Superconductor/Ferromagnet/Superconductor (SFS) heterostructures. Microwave techniques are used to gain information in the small-oscillation regime, which does not perturb significantly the static vortex ordering. Wideband (1-20 GHz) Corbino disk and single-frequency (8 GHz) dielectric resonator techniques are combined to study the temperature (2.7 K-Tc) and field (up to Hc2) dependence of the vortex-state parameters (flux-flow resistivity \( \rho_{ff} \), depinning frequency) in Nb/PdNi/Nb trilayers with different thickness of the F (PdNi) layers. We stress that the high-frequency technique is able to disentangle pinning from dissipation, thus yielding the true flux flow resistivity. The heterostructures have been grown by UHV dc magnetron sputtering. They are composed by Nb layers of nominal thickness \( d_S=15 \) nm, and a ferromagnetic PdNi layer of thickness \( 1 \) nm <\( d_F < 9 \) nm. TEM and EXAFS analysis were employed to assess the morphology and the local structure. From the microwave complex response we obtained the true flux flow resistivity and the depinning frequency as a function of the field and temperature, and the resulting data were compared to data obtained in pure Nb.

We find that the depinning frequency is reduced with increasing thickness of the F layer. A striking result comes from the analysis of the flux-flow resistivity: for very thin F layers \( \rho_{ff} \) closely follows the expression obtained in the GL framework (different however from the simple Bardeen-Stephen model), in complete analogy to the results in pure Nb. However, at large \( d_F \) the flux-flow resistivity exceeds the theoretical expectations. In particular we find \( \rho_{ff} > \rho_n H/H_c2 \). However, it is still true (at large F thickness) that \( \rho_{ff} \) is a scaling function of the reduced field \( H/H_c2 \) (where \( H_c2 \) has been directly measured). Interestingly, at intermediate \( d_F \) the scaling is lost. Our results indicate that \( H_c2 \) is the only relevant field scale at small \( d_F \), where the magnetic effects are confined to a depression of \( T_c \) and the response is identical to a pure Nb sample, and at large \( d_F \), where we argue that the ferromagnet has a significant influence on the underlying superconducting state. At intermediate \( dF \) there are (at least) two different field scales that determine the flux-flow resistivity. Work partially supported by a MIUR-PRIN 2007 project.
Magnetic confinement effects in a multiply connected superconductor-ferromagnet hybrid

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The study of superconductor-ferromagnet hybrids has a remarkable interest based in the use of ferromagnetism to enhance some superconducting properties. Heterostructures of ferromagnetic and superconducting components also offer the possibility to investigate the coexistence between these two phenomena. In the framework of the Ginzburg-Landau (GL) theory we investigate the nucleation of the order parameter in a superconducting (SC) film pierced by an array of mesoscopic ferromagnetic (FM) disks. We solve numerically the GL equations to analyze the interplay between superconductivity and the magnetic texture due to both the FM disks and an external magnetic field. We observed a strong enhancement of the upper critical field $H^*$ when the FM discs are magnetized, with $H^*$ considerably larger than the bulk critical field $H_{c2}$. For $H_{c2} < H < H^*$, the superconducting condensate is confined in regions around the FM disks, in a way similar to the surface superconductivity observed in perforated SC films. However, in contrast with perforated superconductors, the confinement of superconductivity near a FM dot do not result from the boundary condition (the order parameter at the FM-SC boundary is assumed zero). Rather, it stems from a flux compensation effect due to the strongly inhomogeneous magnetic texture of the system. To bound the region of the phase diagram where this magnetic confinement takes place, we performed calculations as a function of applied magnetic field, magnetization of the FM disks, and temperature.

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Electroresistance and magnetoresistance effects in superconductor–insulator–ferromagnet hybrid structures

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We investigated superconducting YBa$_2$Cu$_3$O$_7$, insulator SrTiO$_3$, and ferromagnetic La$_{2/3}$Ca$_{1/3}$MnO$_3$ multilayered heterostructures grown by pulsed-laser deposition on <100> YSZ substrates. These hybrid structures have demonstrated strong superconducting properties with minimum influence by the ferromagnetic layer. We also report the unusual transport properties and negative differential resistance above $T_c$, as well as electro- and magnetoresistance effects in YBCO micro-bridge with top LCMO layer which may be the consequence of magnetic phase separation induced by electric current.

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Dynamics of AC driven vortex-antivortex matter in superconductor-ferromagnetic hybrid structures

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Experimental and theoretical studies that talk about hybrids structures using components of superconductors (S) and ferromagnets (F) appeared a few decades ago and has increased each day. In these artificial structures, two different and antagonistic orders of spins can be brought together in nanoscale to create new and unexpected physical phenomena. The S/F coupling can mainly induce two different types of interactions: the exchange interaction and the electromagnetic interaction. In particular, the first type of interaction can be limited by introduction an insulating buffer material between S and F components. Thin films comprised by hybrid S/F structures with pure electromagnetic coupling (without proximity effects) are interesting because all physical phenomena can be described using simple models (Ginzburg-Landau or London theories). In these films, the magnetic part of the structure is a source of an inhomogeneous magnetic field that interacting with vortices (v) and antivortices (av) in superconductors films can creating, pinning and guiding them. Despite the intense research on all this subject, little is known specifically about the actual microscopic dynamics of v-av and its effects on macroscopic quantities experimentally observed. In order to improve this topic we study in this work, using a hybrid algorithm that mix usual molecular-dynamic (Langevin equation) and creation and annihilation of vortex-anti vortex (v-av) pairs, the dynamic of vortices and antivortices in a bilayer made of superconductor thin film-magnetic dot array using AC transport currents. The study was made using different values of excitation period, magnetic moments, temperature and external current direction. The results show plateaus in curves of electric field and number of pairs versus applied current. Each of these mode-locking steps corresponds to a different number of birth-death events of v-av pairs.
Formation of multi-quanta vortices in mesoscopic superconductors: electronic, calorimetric and magnetic evidence

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The ground state with vorticity larger than one in mesoscopic superconductors in applied magnetic field may manifest as a ‘giant’-vortex, where all vortices coalesce into a single singularity of the order parameter [1]. Such a multi-quanta vortex may split into individual vortices (and vice versa) as a function of e.g. magnetic field or temperature. However, the existence of a giant-vortex has not yet been verified in experiment with absolute certainty [2]. Even in numerical calculations, it is very difficult to pinpoint the exact value of parameters for the giant-to-multi crossover, as the order parameter is severely suppressed between vortices in close proximity. In this work, we obtained a full self-consistent solution of the Ginzburg-Landau (GL) equations for both the superconducting order parameter and the magnetic field distribution in a superconducting disk applied perpendicular magnetic field. This enables us to calculate the Gibbs free energy at different temperatures, which in turn allows us to calculate the heat capacity of the sample. The calculated order parameter and vector potential were further plugged into the Green's function method, where the quasi-classical Eilenberger equations [3,4] are solved for our mesoscopic sample. Using such a combined method, we are able to include the effects of the magnetic field in the microscopic approach, while avoiding the time consuming self-consistent solution of Green's function or BdG equations which must be evaluated on the 1/kF scale. In such a way, LDOS is obtained as a function of the applied magnetic field, which is inaccessible by the GL theory. As a main result, we demonstrate that individual-to-giant vortex transitions can be identified by heat-capacity measurements, as the formation or splitting of giant-vortex results in a clear jump in measured heat capacity vs. external drive. We attribute this phenomenon to an abrupt change in the density of states of the quasiparticle excitations in the vortex core(s), and further link it to a sharp change of the magnetic susceptibility at the transition - proving that formation of a giant-vortex can also be detected by conventional magnetometry.

**YBCO thin film critical current behaviour described by vortex pinning on low-angle domain boundaries and vortex creep**

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A critical current model \( J_c(Ba) \) for high-quality YBCO thin films has been proposed combining vortex thermal creep probability with vortex pinning potential on columnar defects. Thermal creep of vortices has exponential character as it was proposed first in 60s by Anderson and Kim. Pinning for vortex creep has been taken as a strong pinning on chains of individual edge dislocations that form low-angle domain boundaries in high quality YBCO thin films. The model shows a plausible description \( J_c(Ba) \) in all field range. Electrical field criterion is incorporated providing the ability to compare measurements made with different criteria (including different measurement techniques). Applicability of this model has been verified by experimental data obtained by direct transport and magnetization measurements on high quality films grown by pulsed laser deposition. Pinning potential obtained from the fitting procedure is consistent with theoretical predictions. The model showed that the effective pinning landscape changes under influence of external conditions.

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Change of the vortex lattice symmetry in the vicinity of the macro-to-mesoscopic threshold

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The advances in nanofabrication techniques in the last two decades allowed the production and an intensive investigation of the properties of mesoscopic superconductors for which the dimensions involved are of the order of the coherence length, \( \xi(T) \), and/or the penetration depth, \( \lambda(T) \). In such materials, the vortex configuration is highly affected by sample geometry, differing from the Abrikosov lattice, which is the lowest energy state for ideal macroscopic samples. In a recent work [1] we have shown that, as the size of the sample is decreased, the influence of the surface of the material on the symmetry of the vortex lattice becomes more relevant. As the lateral size of the sample decreases, one eventually crosses a threshold line, \( L_c(T) \), which delimits the regions where the sample behaves as macro or mesoscopic. It is interesting to note that the limit established by such line is quite different from that which one naively could speculate, namely, \( \lambda(T) \). As a matter of fact, \( L_c(T) \) is larger than \( \lambda(T) \) by almost one order of magnitude. This change of behavior becomes also apparent from the symmetry of the vortex lattice, which is largely influenced by the surface in the mesoscopic regime. In the present work we study the influence of the surface on the vortex structure as a function of the sample size for different temperatures. It is shown that a crossover between an hexagonal lattice, which is characteristic of the macroscopic samples, and a square lattice occurs in the vicinity of \( L_c(T) \). Such study was carried out by computational simulations where we used the time dependent Ginzburg-Landau equations (TDGL) in the discretized form. The crossover from hexagonal to square symmetry is also present for samples with different values of the Ginzburg-Landau parameter, \( \kappa \), certifying the universal character of this feature. [1]R. Zadorosny, E. Sardella, A. L. Malvezzi, P. N. Lisboa-Filho, W. A. Ortiz, submitted to Phys. Rev. Lett. (2011).
Stationary states and dynamics of superconducting thin films

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The Ginzburg-Landau (GL) theory is a celebrated tool for theoretical modelling of superconductors [1]. We elaborate on different partial differential equations (PDEs) and boundary conditions for GL theory, formulated within the finite element method (FEM) [2]. Examples of PDEs for the calculation of stationary states with the GL equation and with the time-dependent GL equation are given. Moreover we study real time evolution with the so called Schrödinger-GL equation [3]. For simplicity we here present numerical data for a two-dimensional rectangular geometry, but we emphasize that our FEM formulation can handle complex geometries also in a three-dimensional superconducting structure. To include external currents in our modelling we discuss the role of the boundary conditions for the external magnetic field [4]. Finally we show results for the pinning of vortices with controlled impurities.

References:


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Vortices in a mesoscopic superconducting disk with surface defects

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In this work we study the vortex formation in a mesoscopic superconducting disk with metallic defects on its surface. As time evolves we show how the vortices are nucleated into the sample to form a multivortex, single vortex and giant vortex state. The metallic defects are take account using the de Gennes extrapolation length and making very small perturbations at the disk surface. We compute the Gibbs free energy, magnetization, vorticity as a function of the external magnetic field. We also show that first critical field is largely decreased while the second critical field remains practically unchanged compared with a surface without defects.

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Bogolubov-de Gennes solutions for the vortex phases in nanoscale superconductors

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In this research we investigated quantum size effects on superconducting behaviour and vortex configuration in both a thin disk and a flat superconducting square. Because the superconducting order parameter has strong spatial variation in this regime, we used the Bogolubov-de Gennes formalism (BdG) to construct the quasi-particle wave functions as linear combinations of the normal state solutions of the single electron Hamiltonian. This enabled us to calculate superconducting properties down to zero temperature. We investigated the change in free energy as a function of an externally applied magnetic field using a formula which expresses the free energy as a function of the quasi-particle wave functions. For the disk we found that there are sudden changes and even jumps in the free energy curves, corresponding to changes in the ground state as a function of applied field. These do not appear in the square system where we mainly focus on vortex configurations.

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Relaxation of non-equilibrium quasiparticles in a superconductor at ultra-low temperatures

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When an electron enters a superconductor it takes some time (distance) to find a matching particle to form a Cooper pair. Though the subject has been studied intensively since mid-70s [1], mainly the high temperature limit $T \to T_C$ has been investigated. There is a very poor understanding of the phenomena at low temperatures when the energy gap is much higher than the temperature. In our very recent experiments [2] spatially resolved relaxation of nonequilibrium quasiparticles in aluminium at ultralow temperatures was studied. It was found that the quasiparticle injection through a tunnel junction results in the modification of the shape of the I-V characteristic of a remote ‘detector’ junction. The effect depends on the temperature, injection current, and proximity to the injector. The phenomena can be understood in terms of the creation of quasiparticle charge and energy disequilibrium characterized by the two different length scales $\lambda_Q \sim 5 \text{ um}$ and $\lambda_T \sim 40 \text{ um}$. The findings are in good agreement with existing phenomenological models, while more elaborate microscopic theory is mandatory for a detailed quantitative comparison with the experiment. The results are of fundamental importance for understanding electron transport phenomena in various hybrid nanoelectronic circuits [1] See for an overview, Nonequilibrium Superconductivity, Phonons, and Kapitza Boundaries, ed. by K. E. Gray, Plenum Press NY, 1981. [2] K. Yu. Arutyunov, H.-P. Auraneva, and A. S. Vasenko, PRB 83, 104509 (2011), arXiv 1008.2259.

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Angular dependence of the high-frequency vortex response in YBCO thin films with self-assembled BaZrO3 nanorods.

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Nanosize particles are known to increase dramatically the vortex pinning in YBa₂Cu₃O₇₋ₓ (YBCO). Among the various inclusions that give rise to an increased pinning, BaZrO₃ (BZO) is one of the most studied. Interestingly, under certain circumstances BZO spontaneously self-assemble along columnar-like structures, with a diameter of a few nm and directed approximately along the c-axis of the YBCO film. This feature has relevant consequences for the practical use of YBCO superconductors. In this work we present a microwave study of the enhancement of pinning in YBCO thin films due to the addition of BZO particles, with particular emphasis on the angular dependence. The samples under study have been grown by pulsed laser ablation using a composite YBCO/BZO target containing BZO at 5 mol %. X-ray diffraction and TEM analysis were performed, and confirmed the excellent orientation of the YBCO film and the presence of columnar-like structures across the film. Microwave measurements were performed by means of a dielectric-loaded resonator operating at 48 GHz, in the temperature range between 60 K and T_c and in a static magnetic field up to 0.8 T, applied with a variable angle with the c-axis. Comparison with a pure YBCO sample revealed a very strong increase in the pinning strength, particularly relevant in the small-vortex-displacement regime here probed. The angular dependence of the complex microwave response directly showed that the balance between vortex dissipation and reactance, which is a measure of the pinning strength, changes from nearly unity (dissipation = reactance) when the field is directed along the c-axis (thus, along the BZO nanorods), to more dissipative when the field is directed in-plane. Thus, BZO nanorods are found to be more efficient in pinning the vortices in YBCO than the anisotropic (layered) structure itself. In order to describe more quantitatively the experimental results, we extract from our data the vortex parameters (vortex drag coefficient, vortex pinning frequency). We developed a model for the anisotropic motion of vortices in uniaxially anisotropic superconductor, at an arbitrary angle with the crystallographic axes, from which an expression of the effective anisotropic vortex drag coefficient is derived. The known limiting cases of vortices and motion along the crystallographic axes are recovered. We discuss our results in the light of the mentioned model. This work has been partially supported by the Italian FIRB project "SURE:ARTYST" and by EURATOM. N.P. acknowledges support from Regione Lazio.

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Penetration and de-pinning of vortices in sub-micrometer Ba(Fe,Co)$_2$As$_2$ thin film bridges


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The recently discovered family of superconductors, the iron arsenides, offers new challenges for the understanding of transport mechanisms in superconducting materials. One of the most promising candidates for nano-scaled device applications is the Ba-122 family. Epitaxial thin films of this material show a good long-term stability and are therefore interesting for applications. For development of superconducting radiation detectors, the thin films have to be patterned into sub-micrometer sized stripes while retaining high $T_C$ and $I_C$ values.

We present results on the study of the transport properties of micrometer and sub-micrometer wide bridges made from thin Co-doped BaFe$_2$As$_2$ films. The 50 nm thick films have been grown by pulsed-laser deposition on heated (La,Sr)(Al, Ta)O$_3$ substrates. The films were patterned into bridges by means of electron beam lithography and low-energy Ar ion milling. The patterning resulted in a shift of the superconducting transition towards lower temperatures for bridges with width $W \approx 600$ nm while micrometer wide bridges show only a minor reduction of $T_C$. The temperature dependence of the critical current density follows the predictions of the Ginzburg-Landau theory for the de-pairing current in the temperature range from $0.4 T_C$ up to $T_C$ [1]. This temperature range is much wider than $T > 0.95 T_C$, which is determined by the full vortex expulsion criterion $W < 4.4 \xi_{GL}$ ($\xi_{GL}(T)$ is the temperature dependent Ginzburg-Landau coherence length) [2]. Contrary, in the presence of external magnetic fields, we observed the deviation of the $j_C(T)$ dependence from the Ginzburg-Landau theory already at temperatures $T < 0.65 T_C$. The process of penetration and de-pinning of self-generated and externally excited magnetic vortices in sub-micrometer wide BaFe$_2$As$_2$ thin film bridges will discussed.

We report optical properties of a NbN superconductor in the far-infrared (FIR) region corresponding to terahertz (THz) frequency band. Detailed temperature dependence of transmission through a high quality thin NbN film grown on birefringent sapphire substrate is measured using FIR laser tuned to several frequencies both above and below its optical gap. Experimental results are consistent with theoretical calculations based on the BCS model of optical complex conductivity [1] applied for NbN film with numerical solution of the gap equation replacing the original simple approximation for the temperature dependence of the gap. The full quantitative agreement over the entire ranges of temperature and frequencies is found based solely on physical properties of this NbN film sample and on parameters of an identical sapphire substrate as measured by time-domain spectroscopy experiments, without use of any additional fitting parameters. The deduced temperature dependence of the transmission is notably affected by interference effects in the substrate that acts as a Fabry-Perot etalon possessing temperature dependent surface reflectivity.

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Hints of superconducting nanowires phenomena in nanoporferated Nb thin films

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In the recent years new experimental techniques enabling the fabrication of superconducting films with a dimension approaching the one dimensional (1D) limit were developed. These systems are very interesting because they provide unique experimental test-beds to investigate and discover novel superconducting phenomena in confined geometries. Here we report on the transport properties of superconducting Nb thin films grown on porous Si substrates. The films, deposited by UHV magnetron sputtering, are 10 nm thick and inherit from substrate the structure made of holes of 10 nm diameter and of 20 to 40 nm spacing. Due to their reduced dimensions, they are sensitive to thermal fluctuations typical of 1D superconductors and exhibit a nonzero resistance below the superconducting transition temperature ($T_C$). Clear hysteresis and finite jumps in the I-V curves are also observed as well as oscillations in the resistance as a function of the external magnetic field.

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Effects of non-homogeneous magnetization on the superconducting properties of Nb/Py/Nb trilayers

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Superconducting critical temperature, $T_c$, and upper critical magnetic fields (both perpendicular and parallel to the plane of the samples) have been measured in a series of Nb/Py/Nb (here Py = Fe$_{20}$Ni$_{80}$) trilayers having constant Nb thickness, $d_{Nb} = 25$ nm, and variable Py thickness, $d_{Py}$, in the range 10-350 nm. We have observed that, for $d_{Py}$ between 180 and 300 nm, resistive transitions shift towards higher temperature values when a stripe domain magnetic configuration is induced in the samples by applying a parallel magnetic field of 1 Tesla. Moreover, the coupling of the two Nb layers (estimated through the 2D-3D crossover temperature measured from the temperature dependence of $H_{C2}$) is present in the same range of Py thicknesses, i.e. for very thick ferromagnetic layers. We relate those observations to the non-homogeneous magnetization in the Py layer due to the presence of stripe domain structures.

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Thickness-induced crossover from weak to strong vortex pinning in YBa$_2$Cu$_3$O$_{7-\delta}$ ultra-thin films

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High-TC thin films are promising candidates for ultra-fast hot-electron bolometer detectors due to an electron energy-relaxation time of only a few picoseconds in YBa$_2$Cu$_3$O$_{7-\delta}$ (YBCO). The dynamics of vortices strongly influences the response of these superconducting detectors to pulsed [1] and CW [2] THz radiation. To analyze the dynamics of vortices in thin YBCO films we carried out a systematic study of the temperature dependence of the second critical magnetic field $B_{C2}(T)$ of films with thicknesses $d$ from 5 to 100 nm measured in magnetic fields up to 9 T. At $T < 0.95T_c$ (magnetic fields above 3 T) all films show the dependence $B_{C2} \sim (1-T/T_c)^n$ with $n = 1$ as predicted by the Ginzburg-Landau (GL) theory for conventional superconductors. At $T > 0.95T_c$ the $B_{C2}(T)$ dependences vary strongly with film thickness. We observed a downturn curvature of the $B_{C2}(T)$ dependence close to $T_c$ for ultra-thin films with thicknesses between 5 and 20 nm with the fit $B_{C2} \sim (1-T/T_c)^{n}$, where $n = 0.79$ for the 5 nm thick sample. The exponent $n = 0.5$ has been observed by Fang et. al [3] for twinned YBCO samples. The exponent $n$ increases with increasing film thickness converging to the linear GL dependence ($n = 1$) for $d \sim 30$ nm. The films thicker than 30 nm reveal an upturn curvature of $B_{C2}(T)$ shown by Yeshurun [4] and Tinkham [5] with an exponent of $n = 1.5$ for YBCO crystals. The thickest studied YBCO film with $d = 100$ nm shows a $B_{C2}(T)$ dependence with the exponent $n = 1.14$. The same crossover from a downturn to upturn curvature of $B_{C2}(T)$ with increasing film thickness we also observed in thin films of conventional low-temperature superconductors NbN and TaN. Since the activation energy $U$ for flux motion is inversely proportional to $B_{C2}$ we attribute the observed behavior to a change in the strength of vortex pinning in films with different thicknesses. Independent of material (low-$T_c$ vs. high-$T_c$, amorphous vs. epitaxial) there exists a characteristic film thickness below which the vortex pinning close to $T_c$ is very low. Therefore, vortices can propagate more easily in thinner films playing a major role in the detection mechanism of thin film superconducting detectors. [1] P. Probst, A. Scheuring, M. Hofherr, D. Rall, S. Wünsch, K. Il’in, M. Siegel, A. Semenov, A. Pohl, H.-W. Hübers, V. Judin, A.-S. Müller, A. Hoehl, R. Müller, and G. Ulm, YBa$_2$Cu$_3$O$_{7-\delta}$-quasioptical detectors for fast time-domain analysis of terahertz synchrotron radiation Applied Physics Letters 043504 (2011) [2] K.S. Il’in and M. Siegel, Microwave mixing in microbridges made from YBa$_2$Cu$_3$O$_{7-\delta}$ thin films Journal of Applied Physics 92, 1, 361 (2002). [3] M.M. Fang, V.G. Kogan, D.K. Finnemore, J.R. Clem, L.S. Chumbley, and D.E. Farrell, Possible twin boundary effect upon the properties of high-Tc superconductors Phys. Rev B 37, 4, 2334 (1988) [4] Y. Yeshurun and A.P. Malozemoff, Giant Flux Creep and Irreversibility in an Y-Ba-Cu-O Crystal: An Alternative to the Superconducting-Glass Model Phys Rev Letters 60, 21 (1988) [5] M. Tinkham, Resistive Transition of High-Temperature Superconductors Phys Rev Letters 61, 14 (1988)
Temperature dependence of quasiparticle energy relaxation time by flux-flow instability

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We use the flux-flow instability phenomenon as a tool to investigate the quasiparticle energy relaxation processes. From current-voltage (IV) measurements performed in a fixed magnetic field at different temperatures, we extract the vortex critical velocity behavior as a function of the temperature, $v^*(T)$. Thus the contributions coming from the electron-phonon scattering and the recombination processes are identified in the quasiparticle energy relaxation time. Comparing results on Nb and NbN samples, corresponding to different electron mean free paths, we find that in the NbN samples the two relaxation channels become comparable.

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Critical states generated by current and magnetic fields in thin TaN film structures

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Penetration and motion of magnetic vortices account for dissipation in micrometer and sub-micrometer wide superconducting structures and are permanently under intensive experimental and theoretical investigation. Besides the fundamental importance of understanding the vortex dynamics in type II superconductors this interest is greatly stimulated by utilizing of thin superconducting films in numerous applications as detectors and mixers of electro-magnetic radiation [1-3]. We present results of a systematic study of critical states in single-bridge structures (typical shape of the detector devices) made from thin TaN films. The thin TaN films (bulk samples of TaN are non-superconducting) are characterized by a critical temperature which is lower than in niobium nitride – the mostly used material for detector development – and therefore should demonstrate better sensitivity in infrared spectra range. The TaN bridges were made from films with a thickness about 10 nm deposited on heated sapphire substrates. The critical temperature and the critical current density measured at zero applied magnetic field were about 10.5 K and 9.5 MA/cm^2 at T = 4.2K, correspondingly. The critical states in TaN bridges with a width from 70 nm to 8 μm were generated either by the applied transport current or by the current and external magnetic fields B oriented normally to the sample surface. The temperature dependence of the critical current density measured at zero applied magnetic field of the sub-micrometer wide bridges follows the Ginzburg-Landau $j_C^{GL}(T)$ dependence for the de-pairing current in a wide temperature range till $T = 0.65T_C$ and differs from $j_C^{GL}(T)$ by less than 15% at 4.2K. An externally applied magnetic field leads to stronger deviations of the experimentally measured $j_C(T)$ from theoretical predictions, which appears at higher temperatures closer to $T_C$. The experimental results of $j_C(T, B)$ dependencies will be discussed in terms of penetration and de-pinning of magnetic vortices in thin TaN films. [1] K.S. Il’in and M. Siegel, Journal of Applied Physics 92, 361 (2002). [2] A.D. Semenov et al., Supercond. Sci. Technol. 19, 1051 (2006). [3] M. Hofherr et al., Journal of Applied Physics 108, 014507 (2010)
Non-monotonous temperature variation of the magnetization relaxation rate in YBCO films with BZO nanorods below the matching field

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Standard zero-field cooling magnetization relaxation experiments on optimally doped YBCO films with BZO nanorods along the c axis were performed. The films were prepared by PLD on (001) oriented STO substrates, and the matching field was around 20 kOe. A peculiar non-monotonous temperature $T$ dependence of the normalized magnetization relaxation rate $S$ at low external magnetic fields $H$ (oriented along the $c$ axis) was observed. For $H$ of the order of a few kOe $S(T)$ exhibits two maxima, located around 60 K and 30 K. It is shown that owing to the strong influence of the $T$ dependent macroscopic currents induced in the sample during measurements the columnar pins do not accommodate vortices in the low-$T$ domain, and the origin of the $S(T)$ maxima is discussed in terms of a current induced vortex-creep crossover at high $T$ and by considering the role of thermo-magnetic instabilities in the low-$T$ range.

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Near-field optical microscopy of plasmonic effects in anisotropic metamaterials

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Light-nanoobjects interaction for two types of structure was experimentally and numerically investigated. The first one was anisotropic metamaterials which were shown to manifest strong polarization in far field in the spectral vicinity of local and surface plasmon-polariton resonances using which an arbitrary polarization state could be achieved at the output of the metamaterial. Local-field analogues of the linear dichroism and circular dichroism effects are numerically and experimentally found in these metamaterials. High in-plane spatial variation of these effects indicates the key role of plasmons in establishing of the polarization-sensitive response of metamaterials. By means of far-field and near-field studies giant specific values of optical anisotropy are found in polarization-sensitive metamaterials. The polarization sensitivity arising from various high-quality plasmonic modes also manifests itself in the optical near-field in the form of plasmon-enhanced diattenuation. A nanowire array exhibits two-fold enhancement of the local-plasmon-induced linear dichroism as viewed by the polarization-sensitive modification of the scanning near-field optical microscope at distance about \( \lambda/20 \) near the surface. Rigorous calculation results reveal the near-field circular diattenuation of 35 dB from the geometrically achiral nanoellipse ensemble emerging from the interference of the propagating plasmon modes launched from individual nanoholes. The given data demonstrate that the polarization-sensitive metamaterials are capable of versatile polarization control independently of polarization basis both at macro- and nanoscales. We have also experimentally studied the formation of “optical vortexes” of in-plane near-field intensity distribution caused by excitation of resonant circular surface plasmons.
List of Participants

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<tr>
<th>Firstname</th>
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