MARIE CURIE ACTIONS

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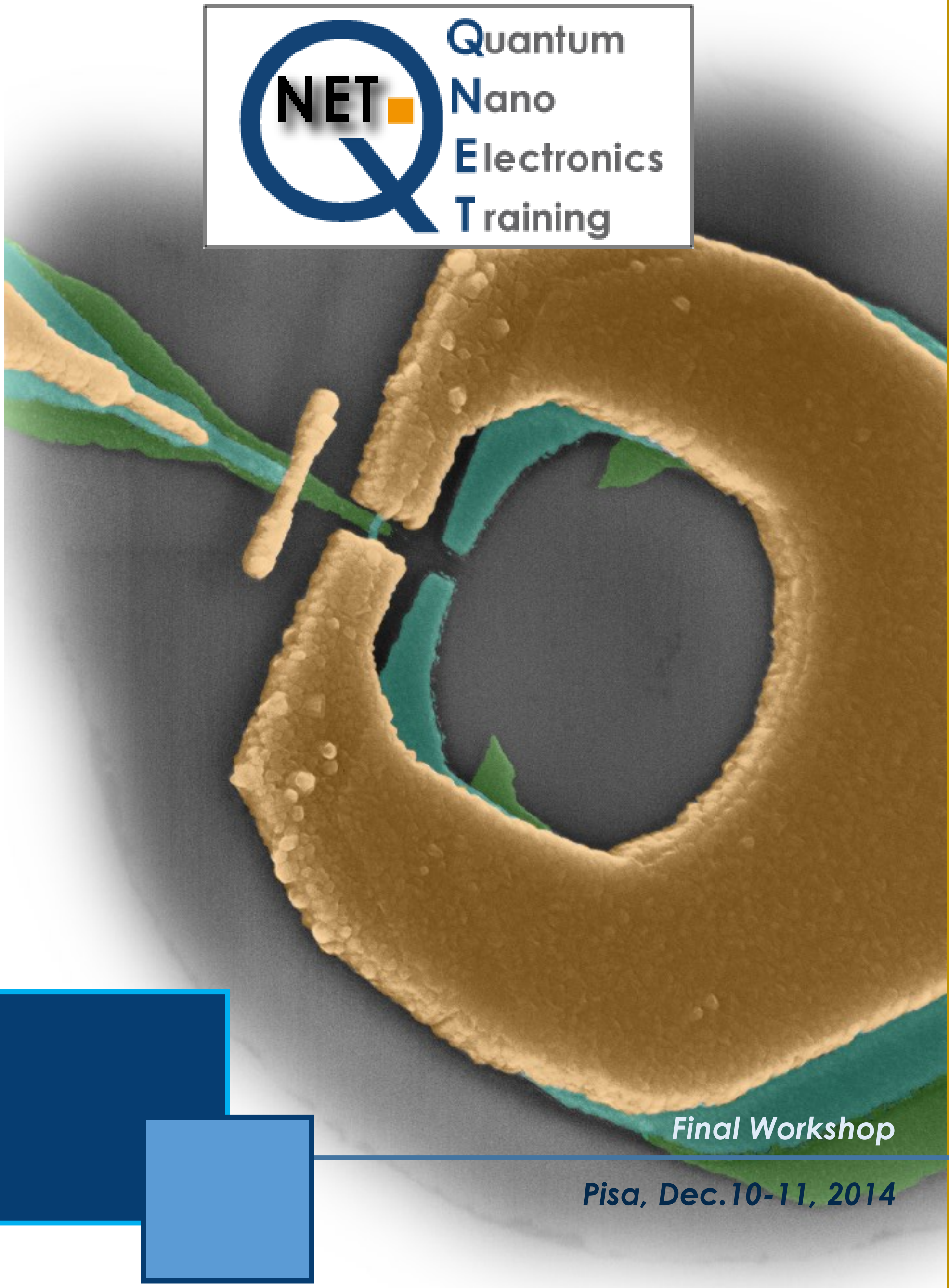
SCUOLA NORMALE SUPERIORE

Q-NET

Quantum Nano Electronics Training



Final Workshop

Pisa, Dec.10-11, 2014

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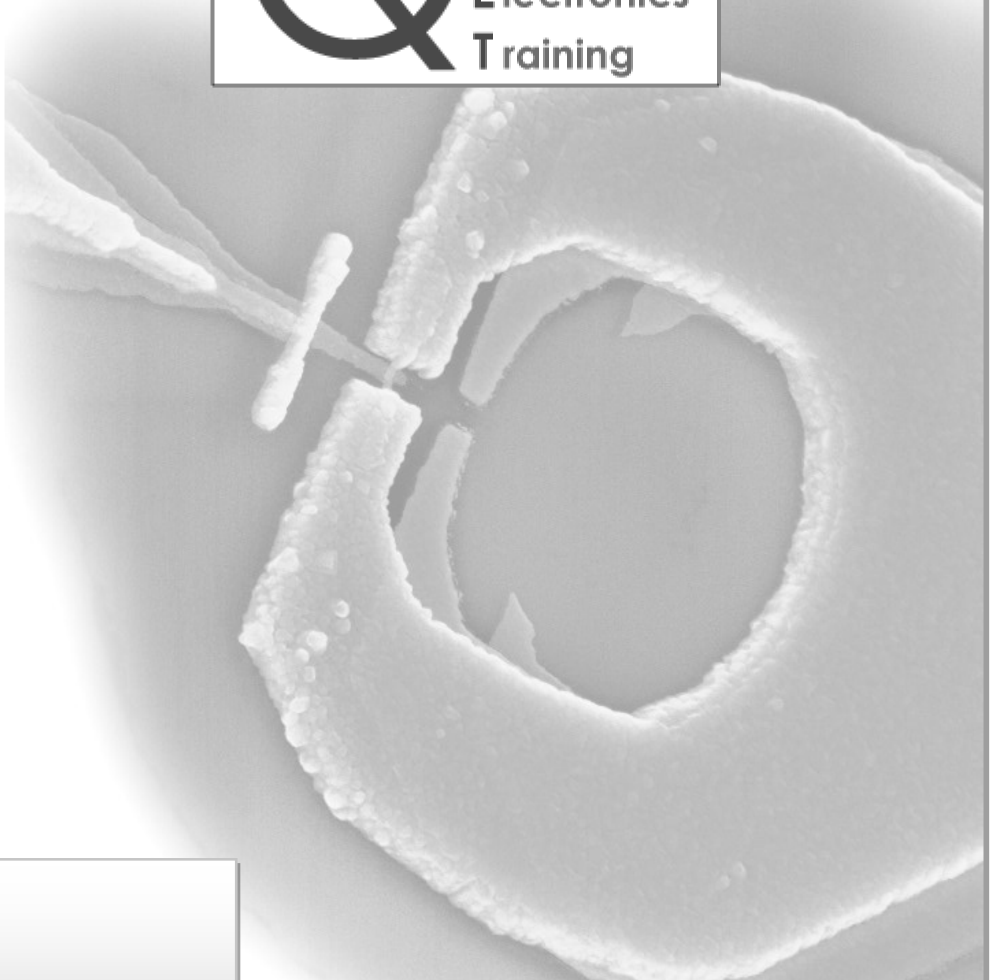

Final Workshop

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Cover image:

Pseudo-color scanning electron micrograph of a superconducting quantum interference proximity transistor (SQUIPT) based on Al-Cu technology.

Courtesy of A. Ronzani and C. Altimiras

Contents

Q-NET Project

The **Quantum - NanoElectronics Training** with acronym Q-NET, was launched in order to create a European network of experts providing state-of-the-art training for young researchers in the general field of experimental, applied and theoretical Quantum Nano-Electronics.

The aim to improve our understanding of quantum electron transport at the nanoscale needed for enabling the emergence of "Beyond C-MOS" nano-electronics devices has been accomplished by a combined effort in the topics of spintronics, molecular electronics, single-electronics, quantum dots, nanowires, and nano-cooling. Numerous publications have resulted in the framework of the Q-NET project enabled by the state-of-the-art technologies of nanofabrication, electron and near-field microscopies, transport measurement under extreme conditions (low temperatures, magnetic field, radio-frequency irradiation) and theoretical calculations.

Q-NET's general objective has been to increase the training level of the European researchers in the field of Quantum Nano-Electronics. In order to reach that objective, Q-NET has:

- Recruited 14 PhD students and 2 post-docs and trained them at the highest level with a wide set of carefully identified scientific and technological expertise in the field of Quantum Nano-Electronics.
- Equipped the Q-NET trainees with entrepreneurial mindsets, thus enhancing their employability in both the industry and academics.
- Made new S&T advances in the Quantum Nano-Electronics field by contributing to the development and application of both existing devices concepts, as well as new kinds of nano-structures with exciting new features.
- Provided world-class S&T training sessions in the field of nanoscience by organizing four sessions of the European School On Nanosciences and Nanotechnologies (ESONN) devoted to Quantum Nano-Electronics, combining both theoretical and practical training, and opening them to young researchers outside the consortium.

The objectives were met through intense collaboration between the consortium's partners, and with carefully defined research objectives. Systematic secondments of recruited researchers from one partner to several others were organized, including for every researcher a secondment of at least two months to a private sector partner, in order to train the seconded researchers and to achieve the S&T objectives.

Q-NET final meeting

The final meeting of the Q-NET project is hosted by NEST, National Enterprise for nano-Science and nanoTechnology, Istituto Nanoscienze-CNR, and takes place on December 10th–11th 2014 at Scuola Normale Superiore in Pisa.
Q-NET young researchers will present their work in 20-30 minute talks and participate some additional training. As a highlight and a tribute to a successful project, in addition to the normal meeting, the final meeting is a two-day workshop with the following distinguished invited speakers:

Sebastian Bergeret, San Sebastian, Spain

Stefan Heuen, Pisa, Italy

Ilari Maasilta, Jyväskylä, Finland

Frédéric Pierre, Marcoussis, France

Elke Scheer, Konstanz, Germany

Fabio Taddei, Pisa, Italy

Wilfred van der Wiel, Twente, The Netherlands

The hosts warmly welcome all the participants to nourish their scientific appetite at the workshop, as well as to join us in the celebration of our fruitful cooperation at the workshop dinners.

We wish you enjoy your stay in Pisa!

Partners

The Q-NET consortium includes 9 partners from 8 countries in total.

Participant	Private sector	Country	Legal entity name	Department / Division / Laboratory	Scientist-in-charge
Full network partners (beneficiaries)					
UJF		France	Université Joseph Fourier, Grenoble	Institut Néel and LPMMC http://neel.cnrs.fr http://lpm2c.grenoble.cnrs.fr	H. Courtois
AALTO		Finland	Aalto University , Espoo	Low Temperature Laboratory http://ltl.tkk.fi	J. P. Pekola
NEST		Italy	NEST CNR-INFM, Pisa	http://www.sns.it/en/laboratori/laboratoriscienze/nest	F. Giazotto
ATTO	X	Germany	Attocube systems, München	http://www.attocube.com	K. Karrai
LEEDS		United Kingdom	University of Leeds	School of Physics & Astro-nomy http://www.stoner.leeds.ac.uk/	C. H. Marrows
ETH		Switzerland	ETH Zürich	Laboratory for Solid State Physics http://www.nanophys.ethz.ch	K. Ensslin
CTH		Sweden	Chalmers University, Göteborg	Microtechnology and Nanoscience http://www.chalmers.se/mc2/EN	T. Bauch
NGU		Spain	NanoGUNE	http://www.nanogune.eu/en	L. E. Hueso
Associated partners					
AIVON	X	Finland	Aivon	http://www.aivon.fi	J. Penttilä


Q-NET Partners
Aalto University
School of Science and Technology
aivon
CHALMERS
UNIVERSITY OF LEEDS
attocube systems
ETH
NÉEL
CIC nanoGUNE
CNRNANO

Q-NET Young Researchers

Marco Arzeo

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Sweden

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GDP Laboratory, Chalmers University of Technology, Goteborg,
Sweden

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E.C. Stoner Laboratory, University of Leeds, Leeds,
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O.V. Lounasmaa (prev. Low Temperature Laboratory) Aalto University, ESPOO,
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Leeds,
United Kingdom

Agenda

Dec. 10th

09:00 - 09:05	Welcome address
09:05 - 09:50	**Elke Scheer**
09:50 - 10:10	**Robert Buda**
10:10 - 10:30	**Priyasmita Sinha**
10:30 - 10:50	*break*
10:50 - 11:35	**Ilari Maasilta**
11:35 - 12:05	**Anna Feshchenko**
12:05 - 12:35	**Timothé Faivre**
14:00 - 14:45	**Wilfried van der Wiel**
14:45 - 15:15	**David van Zanten**
15:15 - 15:35	**Jonna Paajaste**
15:35 - 16:05	*break*
16:05 - 16:50	**Frédéric Pierre**
17:00 - 17:20	**Pauline Simonet**
17:20 - 17:40	**Luca Pietrobon**
17:40 - 19:00	*lab visit*
from 20:00	*dinner*

Dec. 11th

09:00 - 09:45	**Sebastian Bergeret**
09:45 - 10:15	**Angelo di Marco**
10:15 - 10:35	**Marco Arzeo**
10:35 - 10:55	*break*
10:55 - 11:40	**Stefan Heun**
11:40 - 12:10	**Jorge Puebla**
12:10 - 12:30	**Nikola Pascher**
14:00 - 14:20	**Sayanti Samaddar**
14:20 - 14:40	**Emmanouil Masourakis**
14:40 - 15:00	**Astghik Adamyan**
15:00 - 15:45	**Fabio Taddei**
15:45 - 16:15	**Antonio Fornieri**
16:15 - 16:20	final word, *coffee break*

Abstracts

1. **Probing Odd-Triplet Contributions to the Proximity Effect by Scanning Tunneling Spectroscopy**.
   E. Scheer

2. **Surface characterization and electronic properties of CVD graphene on SiC.**
   R. Buda

3. **Dichroism and magnetism in epitaxially grown highly spin polarised B20 ε-Fe1-xCoxSi thin films.**
   P. Sinha

4. **Coherent control of thermal conduction in phononic crystals.**
   I. Maasilta

5. **Electronic thermometry and cooling.**
   A. Feschchenko

6. **Temperature fluctuations as the thermodynamic limit of bolometers and single photon detectors.**
   T. Faivre

7. **Ultrahigh Magnetoresistance at Room Temperature in Molecular Wires.**
   W. G. van der Wiel

8. **Quantized charge pumping through superconductor - quantum dot - superconductor hybrids.**
   D.M.T. van Zanten

9. **Pb/InAs nanowire Josephson junction with high critical current and magnetic flux focusing.**
   J. Paajaste

10. **Quantum circuits with arbitrary channels: from charge quantization to dynamical Coulomb blockade.**
    F. Pierre

11. **Electronic transport in graphene nanoribbons: relevance of etching process and substrate.**
P. Simonet

12. **Spin transport in CVD graphene.**
L. Pietrobon

13. **Spin and "Cooper-pairs" diffusion in hybrid structures with spin-orbit coupling.**
S. Bergeret

14. **Quantum Phase-Slip Junction Under Microwave Irradiation.**
A. Di Marco

15. **Decoherence in High critical Temperature Superconducting microwave quantum circuits.**
M. Arzeo

16. **Nanomaterials characterization by low-temperature scanning gate microscopy.**
S. Heun

17. **Scanning probe microscopy in an ultra-low vibration closed-cycle cryostat.**
J. Puebla

18. **Imaging the conductance of integer and fractional quantum Hall effect edge states.**
N. Pascher

19. **Transport vs local properties of mesoscopic graphene devices.**
S. Samaddar

20. **Lateral Tunnel Junctions for Molecular electronics and Spintronics.**
E. Masourakis

21. **Travelling-wave Parametric Amplifier.**
A. Adamyan

22. **Heat-charge separation for improved thermoelectric conversion.**
F. Taddei

23. **Heat current rectification and electronic refrigeration in superconducting hybrid devices.**
A. Fornieri

1

Probing Odd-Triplet Contributions to the Proximity Effect

by Scanning Tunneling Spectroscopy

S. Diesch[1], M. Wolz[1], P. Machon[1], C. Sürgers[2], W. Belzig[1], A. Di Bernardo[3], Y. Gu[3], J. Linder[4], M. G. Blamire[3], J. W. A. Robinson[3], E. Scheer[1]

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[4]Physics Institute, Norwegian Technical University, 7491 Trondheim, Norway

In this talk we will address the superconducting proximity effect between a superconductor (S) and a normal metal (N) linked by a spin-active interface. With the help of a low-temperature scanning tunneling microscope [1,2] we study the local density of states of tri-layer systems. The first example consists of aluminum (S), the ferromagnetic insulator (FI) EuS, and the noble metal silver (N) for varying thickness of the FI. In several recent studies it has been shown that EuS acts as ferromagnetic insulator with well-defined magnetic properties down to very low thicknesses [3]. For very thin FI with d-FI = 2 nm we find a strong enhancement of the induced minigap at the normal side. For intermediate thickness we observe pronounced subgap structures that vary from contact to contact. For dFI = 10 nm the spectra are in agreement with the diffusive theory for S/N structures (without FI) as confirmed in earlier studies [2]. We discuss our findings in the light of recent theories of odd-triplet contributions created by the spin-active interface [4,5,6].
The second example uses the ferromagnetic metal (FM) Ho between niobium (S) and gold (N) [7]. These measurements reveal pronounced changes to the Nb sub-gap superconducting density of states on driving the Ho through a metamagnetic transition from a helical antiferromagnetic to a homogeneous ferromagnetic state for which a conventional BCS gap is recovered. The results directly verify odd frequency spin-triplet superconductivity at superconductor / inhomogeneous magnet interfaces [8].
We gratefully acknowledge financial support from the Kompetenznetzwerk Funktionelle Nanostrukturen of the Baden-Württemberg Stiftung and the Leverhulme trust (IN-2013-033).

References
[1] C. Debuschewitz, F. Münstermann, V. Kunej, E. Scheer , A compact and versatile scanning tunnelling microscope with high energy resolution for use in a 3He Cryostat, J. Low Temp. Phys. 147, 525 (2007) - [2] M. Wolz, C. Debuschewitz, W. Belzig, E. Scheer, Evidence for attractive pair interaction in diffusive gold films deduced from studies of the superconducting proximity effect with aluminium, submitted - [3] J. Linder, A. Sudbø, T. Yokoyama, R. Grein, M. Eschrig, Phys. Rev. B 81, 214505 (2010) - [4] B. Li, N. Roschewsky, B. A. Assaf, M. Eich, M. Epstein-Martin, D. Heiman, M. Münzenberg, and J. S. Moodera, Phys. Rev. Lett. 110, 09700 (2013) - [5] A. Cottet, W. Belzig, Phys. Rev. B 72, 180503R (2005)- [6] P. Machon, W. Belzig, in preparation - [7] W. A. Robinson, J. D. S. Witt, M. G. Blamire, Science 329, 59 (2010) - [8] A. Di Bernardo, S. Diesch, Y. Gu, J. Linder, M.G. Blamire, E. Scheer, J. W. A. Robinson, submitted

2
Surface characterization and electronic properties of CVD graphene on SiC

Robert J. Buda[1], Jerzy T. Sadowski[2], Wlodzimierz Strupinski[3], Christopher H. Marrows[1]

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[2]*Center for Functional Nanomaterials, Brookhaven National Laboratory, 11973 Upton, USA,*
[3]*Institute of Electronic Materials Technology, 01-919 Warsaw, Poland*

Among methods of growing graphene, chemical vapour deposition (CVD) on silicon carbide seems to be one of the most promising. With this method it is possible to obtain high quality, large area graphene [1]. Graphene was grown on silicon-terminated face of 4H semi-insulating SiC, etched with hydrogen prior to the growth process. Two kinds of samples were prepared, namely graphene monolayer with so-called buffer layer and bilayer graphene (obtained by hydrogen intercalation of graphene/buffer layer samples). To confirm high quality of material grown by CVD on SiC, a number of characterization techniques was used.

Firstly, to confirm uniformity of grown graphene and to determine the thickness of the material, Low Energy Electron Microscopy was used. It was possible to extract a number of graphene layers from obtained data, as shown in Figure 1. Simultaneously, to confirm the existence of buffer layer and effectiveness of hydrogen intercalation, samples were measured with Low Energy Electron Diffraction.

Secondly, Angle-Resolved Photoemission Spectroscopy was used to confirm excellent electronic properties of the material. Single Dirac cones were observed for monolayer graphene and double cones for bilayer graphene. For both types of samples Fermi velocity of V_F ~$8*10^5$ m/s was observed, as well as doping changing from n-type in monolayer graphene to p-type in bilayer graphene due to hydrogen intercalation.

Thirdly, (magneto)transport measurements were conducted in order to better understand electronic properties of CVD graphene on SiC. Measurements were performed at temperature T = 1.4 K and magnetic field varying from -8 T to 8 T. These measurements confirm high quality of the material as well as type of hoping and carrier concentration.

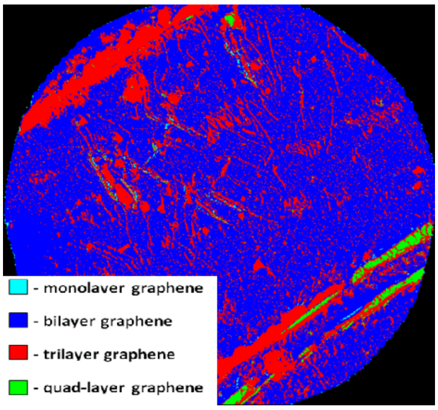

Fig. 1. False colour thickness map of bilayer graphene grown on SiC, 10 µm FOV.

References

[1] W Strupinski et al, Nano Letters, 11 (4), pp 1786-1791, (2011)

3

Dichroism and magnetism in epitaxially grown highly spin polarised B20 ε-Fe1-xCoxSi thin films

P. Sinha, N.A. Porter, C.S. Spencer, D.A. Arena, C.H. Marrows

School of Physics and Astronomy, University of Leeds, Leeds, LS2 9JT, U.K. National Synchrotron Light Source, Brookhaven National Lab, Upton, NY.

FeSi is a non-magnetic narrow band gap semiconductor which upon doping with Co substitutes onto an Fe site and a magnetic n-type semiconductor is obtained [1].

We studied epitaxial Fe1-xCoxSi thin films grown by MBE as a function of Co doping [2]. The ordinary Hall effect confirms the addition of one conduction electron per Co dopant. The temperature dependent resistivity changes upon Co doping, being semiconducting-like for low x and metallic for $x > 0.4$. SQUID loops show magnetic hysteresis, unlike bulk material (Fig.1(a)). Biaxial strain changes the volume of the unit cell and increases the ordering temperatures up to 77 K for $x = 0.4$ (Fig.1(b)). The saturation magnetic moment of the films varies as a function of Co doping, with a contribution of ~1 μB/Co atom for $x \leq 0.25$ (Fig.1 (c)). In combination with the carrier density, this signifies a very highly spin-polarised electron gas in the low x, semiconducting regime [3].

To understand the electronic structure and evolution of magnetism in B20 system we used soft X- ray absorption (XAS) and X-ray magnetic circular dichroism (XMCD) spectroscopy in total electron yield mode (TEY) to probe the L2,3 edges of Fe and Co in Fe1-xCoxSi thin films. Branching ratios (L3/(L2 + L3)) obtained [4] from XAS spectra of Co increases from 0.51 (x=0.1) to 0.56 (x=0.5) and that of Fe deviates little from 0.56. As a function of x, it suggests that the number of holes associated with Co increases from x=0.1 to x=0.5 where as that associated with Fe changes little. Variation in the occupation states of Fe and Co atoms coupled with shift in L2,3 edges (~500meV) and the evolution of the L3 edge line shape indicates a modified band structure. Evolution of the XMCD on both Fe and Co edges with doping is shown in Fig 2. The dichroism on Fe L3 edge (TEY) varies from 0.6x10-3 for x=0.1 to 1.4x10-3 for x=0.5 and that of Co evolves from being negligible for x=0.1 to 1.7x10-3 for x=0.5.Whilst the magnetism in Fe1-xCoxSi system arises from the Co doping, these asymmetry spectra clearly show that the magnetic moment is delocalised on both Co and Fe sites.

The work was supported by the EPSRC, FP7 ITN Q-NET, and the U.S. Dept. of Energy, Office of Science, Office of Basic Energy Sciences.

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[1] N.Manyala et al., Nature 404, 581 (2000).
[2] N. A. Porter et al., Phy.Rev.B, 86, 064423 (2012).
[3] P. Sinha et al., Phy.Rev.B, 89, 134426 (2014).
[4] B.T. Thole, et al., Phys. Rev. B. 5, 38 (1988).

4
Coherent control of thermal conduction in phononic crystals

Ilari Maasilta

Jyvaskyla University, Finland

Controlling thermal transport has become more relevant in recent years, in light of the strong push to develop novel energy harvesting techniques based on thermoelectricity, the need to improve the heat dissipation out of semiconductor devices, and the push to increase the sensitivity of bolometric radiation detectors. Traditionally, reduction of thermal conductivity is achieved by including impurities, nanoparticles, voids, etc., which increase the scattering of the relevant energy carrying quanta, electrons and phonons.

On the other hand, much less attention has been given to controlling phonon thermal conductance by engineering the phonon dispersion relations, in other words the phonon 'band structure'. Here, we discuss this line of approach for controlling thermal conduction and present our recent experimental and computational studies of thermal conductance in phononic crystals (PnCs) at sub-Kelvin temperatures. An order of magnitude reduction of conductance was achieved, fully consistent with the calculated coherent interference of phonons in the PnC structure in the ballistic limit.

5
Electronic thermometry and cooling

Anna Feschchenko

Aalto University, Finland

In my talk, I will present data from three different experiments that I have conducted during my PhD. Two of the experiments are about electronic thermometers and the last is about electronic refrigerator. One of the thermometers is a primary Coulomb blockade thermometer (CBT), where the temperature can be obtained by measuring the full width at half minimum of the conductance dip, $V_{1/2}$ or its height. The second thermometer is based on the single normal-insulator-superconductor tunnel junction (NIS), where an *I-V* characteristic of the junction is temperature dependent (this work has been done in collaboration with Basel University, with group of Diminik Zumbühl). I will present the data and show the lowest temperatures we were able to measure with these types of thermometers. The last experiment is based on the thermal transport through single – electron transistor (SET) that can be employed as an electronic refrigerator at temperatures below 100 mK. I will show how this device has been done, how it works, what cooling we have achieved so far and what can be improved in the present configuration.

6

Temperature fluctuations as the thermodynamic limit of bolometers and single photon detectors

Timothé Faivre

Aalto University, Finland

One of the discoveries of 2014 was made by the radio-telescope BICEP 2 (1). The large media coverage (2) trying to explain to the neophytes how the first stage of the universe can be observed did not focus on the technology which has made this discovery possible: the bolometer. Such a detector has two parts: an absorber and a thermometer. When incoming radiation hits the detector, the temperature rises in the absorber, leading to a signal to be detected by the thermometer. Ultimately all bolometers are limited by noise (3), that from the readout electronic, from the thermometer and, more surprisingly, from the absorber itself because its temperature is fluctuating. This last noise mechanism raised a debate (4a & 4b) in the 80's about the definition of the temperature itself. We are proposing to build and characterize a device which would we able to measure these temperature fluctuations. We use a titanium absorber, which is already in use in a popular kind of a bolometer called Transition Edge Sensor (TES). The titanium island, acting as an absorber, is isolated from the surroundings by means of a tunnel junction made of aluminum oxide. The thermometer is based on temperature dependent Josephson current trough a junction between aluminum leads and a titanium island (5). Our first results demonstrate the feasibility of such a device (6), and we are now optimizing both the readout and the device itself to achieve the resolution to observe temperature fluctuations.

7
Ultrahigh Magnetoresistance at Room Temperature in Molecular Wires

Wilfred G. van der Wiel

NanoElectronics Group, MESA+ Institute for Nanotechnology, University of Twente, The Netherlands

Systems featuring large magnetoresistance (MR) at room temperature and in small magnetic fields are strongly sought-after due to their potential for magnetic field sensing and data storage. Usually, the magnetic properties of materials are exploited to achieve large MR. Recently, we have discovered an **exceptionally large, room-temperature, small-field MR effect** in 1D, non-magnetic systems of molecular wires self-assembled in a zeolite host crystal [1]. This ultrahigh MR effect is ascribed to the dramatic consequence of spin blockade in 1D electron transport.

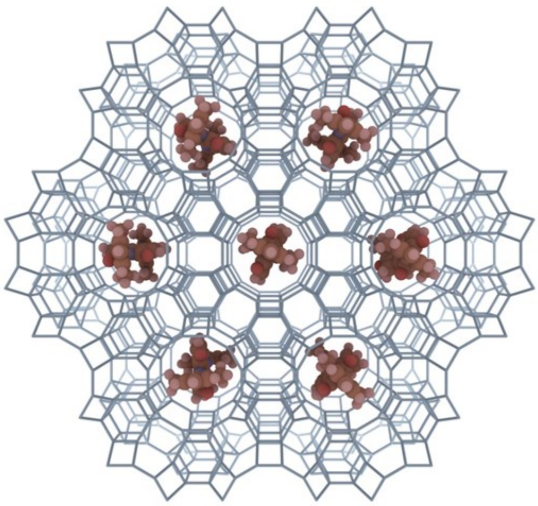

Fig. Zeolite L is an electrically insulating aluminosilicate crystalline system, which consists of many channels running through the whole crystal and oriented parallel to the cylinder axis. The geometrical constraints of the zeolite host structure allow for the formation of one-dimensional chains of highly uniaxially oriented molecules.

Reference:

[1] R.N. Mahato, H. Lülf, M.H. Siekman, S.P. Kersten, P.A. Bobbert, M.P. de Jong, L. De Cola and W.G. van der Wiel, Science 341, 257 (2013)

8

Quantized charge pumping through superconductor - quantum dot - superconductor hybrids

D.M.T. van Zanten, D.M. Basko, H. Courtois, C.B. Winkelmann

Institut Néel, CNRS and Université Joseph Fourier, Grenoble, France

Single electron pumps are foreseen to set the new quantum standard for current, thereby closing the quantum metrology triangle. During the past decade, significant experimental and theoretical effort has been spent on a variety of mesoscopic systems. Here we demonstrate quantized charge pumping in superconductor - quantum dot - superconductor hybrid turn- stiles. The quantum dot devices are formed by single gold nano-particles inserted in electromigrated aluminium constrictions. Charging energies and single level spacings are much larger than the superconducting gap, which allows charge pumping through a single electron level. The turnstiles are op- erated at pumping frequencies up to 200 MHz and reach an accuracy of ~1 %. We discuss the accuracy limitation set by the lead-quantum hybridiza- tion and pair currents through the dot. Conversely we show that the large level spacing protects the pumping accuracy from thermally induced errors over a large temperature range.

9

Pb/InAs nanowire Josephson junction with high critical current and magnetic flux focusing

J. Paajaste[1], M. Amado[1], S. Roddaro[1], F. S. Bergeret[2, 3], D. Ercolani[1], L. Sorba[1], and F. Giazotto[1]

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[3] Donostia International Physics Center (DIPC), San Sebastian, Spain

We report Josephson junctions formed by a highly n-doped InAs nanowire and Ti/Pb source and drain leads (Fig 1(c)). The system's current voltage properties are characterized with varying temperature (Fig. 1) and perpendicular magnetic field (Fig. 2). The critical current is measured to be as high as 615 nA and it persists up to 4 K, while superconductivity is observed up to 7 K. The maximum critical current as a function of the magnetic field reveals a high critical magnetic field value up to 0.3 T due to thin polycrystalline Pb-leads. At low temperatures the critical current has a hysteretic behavior with respect to the magnetic field sweep direction (Fig. 2(b)). This behavior is attributed to possible trapping of magnetic flux vortices in the superconducting leads as predicted in the case of impurities. On the contrary to the expected monotonous decay of the critical current versus the magnetic field in a narrow junction, the data reveals a diffraction pattern that can be explained by a strong magnetic flux focusing due to the geometry of the junction.

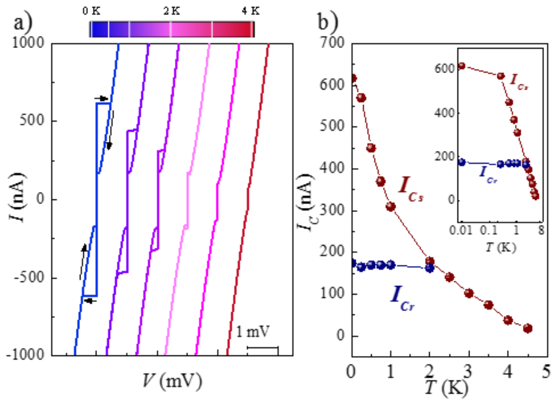
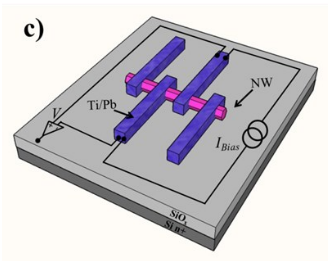


Figure 1. a) The back and forth IVCs for Pb/InAs NW/Pb junction at different electronics temperatures indicated in the color bar. b) Switching and retrapping currents I_{Cs} and I_{Cr} extracted from the IVCs as a function of the electronic temperature. c) A sketch of the final setup for the typical 4-wires configuration, where the Josephson junction is current biased and the drop of voltage is measured with a room temperature voltage preamplifier



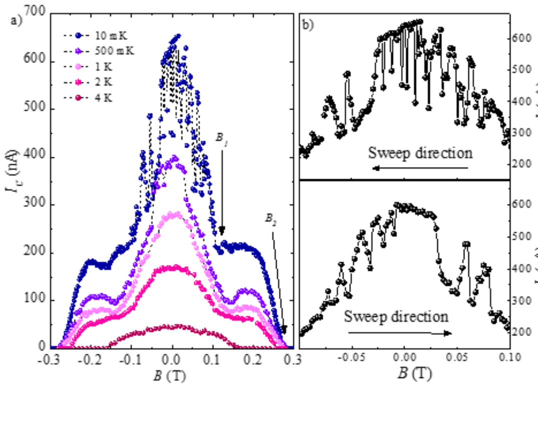


Figure 2. a) The critical current I_C as a function of perpendicular magnetic field B for different temperatures from 10 mK to 4 K. Each point represents one current voltage measurement where the magnetic field and temperature are constant. b) Hysteretic behavior is observed with respect to the magnetic field sweep direction.

10

Quantum circuits with arbitrary channels: from charge quantization to dynamical Coulomb blockade

Frédéric Pierre

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What are the laws governing electrical transport in circuits composed of distinct (not mixed by electron non-locality) quantum components? Such basic quantum engineering knowledge remains, for the most part, to be disclosed.

In this quantum electrodynamics problem, the granularity of charge transfers across a quantum conductor induces a coupling between the different circuit components. As a result, the circuit transport properties differ, sometimes strikingly, from those of its constitutive elements taken separately. One remarkable consequence is the arising of charge quantization in weakly coupled circuit nodes. Such quantization is at the root of the dedicated research field single-electronics, whose flagship is the single electron transistor. Another consequence is the apparition of a low voltage depression on the conductance of a quantum conductor embedded into a dissipative circuit, a phenomenon called dynamical Coulomb blockade.

These phenomena are well understood and thoroughly investigated experimentally in a particular limit of quantum conductors, the tunnel junction. I will present here an experimental investigation of the charge quantization and dynamical Coulomb blockade beyond the tunnel limit, in the presence of electronic quantum channels of arbitrary transmission probabilities τ.

The quantum crossover between quantized and continuous charge in a metallic node is studied versus the transmission probabilities of the connected channels, the charge quantization being determined from the visibility of conductance oscillations in a single electron transistor geometry. We first unambiguously demonstrate that the metallic node charge is not quantized as soon as one of the connected channels is fully transmitted $\tau=1$, thereby closing a long standing experimental controversy. Characterizing the quantum crossover near full transmission, we find that the visibility signaling charge quantization vanishes as $(1-\tau)^{0.5}$, in agreement with the two-decade old prediction of Matveev and Furusaki.

Although there is no charge quantization in the node in presence of a fully transmitted channel, the discreetness of charge transfers across the other partially transmitted channels still shows up in the low-energy reduction of their conductance. Remarkably, this dynamical Coulomb blockade effect can be linked theoretically to the Tomonaga-Luttinger liquids (TLL) model describing interacting electrons in one-dimensional conductors. We demonstrate experimentally this link by confronting the landmark TLL universal scaling curve with the conductance data. Moreover, we derive from a striking feature of the data a powerful phenomenological scaling law that allows calculating the reduced conductance in presence of a known linear environment. The predictive power and universal character of the derived scaling law is further established by the quantitative comparison with data obtained on a different physical system by another team (G. Finkelstein et al., Duke university).

11

Electronic transport in graphene nanoribbons: relevance of etching process and substrate

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Our work focuses on the electronic transport of graphene nanoribbons, either on a SiO_2 substrate with a doped Si back-gate or on a GaAs/AlGaAs heterostructure with a 90nm deep two-dimensional electron gas (2DEG).

We compare graphene ribbons on SiO_2 etched with two different methods: Ar/O_2 reactive ion etching and O_2 plasma ashing. We measure electronic transport through these different ribbons as a function of side-gate and back-gate voltages. Resonances with different couplings to the respective gates are distinguished, indicating the presence of one set of localized charges in the middle of the ribbon and another set at the edges of the ribbon or extending into the graphene leads. Capacitances from these localized states to the different gates indicate that plasma ashed ribbons feature larger and/or more edge localized states than reactive ion etched ribbons, as well as more charge traps. Raman spectroscopy maps of these devices show that graphene is not entirely removed by plasma ashing but some insulating, highly disordered carbon remains in the etched patterns. This could explain an increased presence of localized states at the edges and charge traps.

In a second set of experiments, we investigate a graphene nanoribbon capacitively coupled to a GaAs 2DEG. Graphene had to be etched using plasma ashing to avoid implanting defects in the 2DEG. Therefore, similar disorder is visible in the graphene conductance. The graphene side-gates are used to tune the ribbon density and simultaneously form a quantum point contact (QPC) in the GaAs. Additionally, the graphene ribbon can be used as a top-gate to tune the electron density in the GaAs QPC.

12
Spin transport in CVD graphene

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Due to the low intrinsic spin-orbit, graphene is a promising material for spintronics. Long spin diffusion lengths have been experimentally reported for exfoliated [1,2,3] and epitaxial graphene [4,5]. However, the most promising technique for industrial production of graphene devices remains the Chemical Vapor Deposition (CVD) one, for which the graphene spintronics literature is present [6] but not as abundant.
We report on the fabrication of lateral spin valve devices on CVD graphene transferred on SiO2 and show the importance of an interfacial AlOx layer for spin-injection. We also explore the influence of the substrate on the spin transport, fabricating spintronic devices on magnetic insulators.

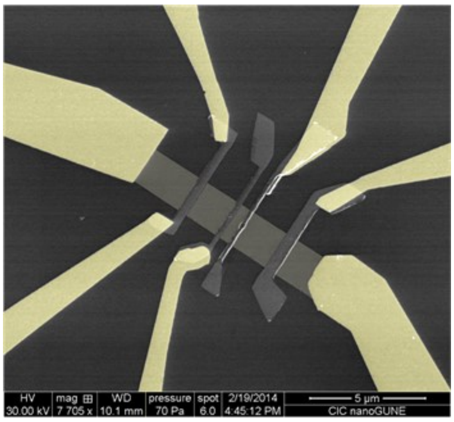

Figure 1: false color SEM image of a lateral CVD graphene spin valve on SiO2, where the graphene (grey), the Co (dark grey) and the Ti/Au electrodes (yellow) can be seen.

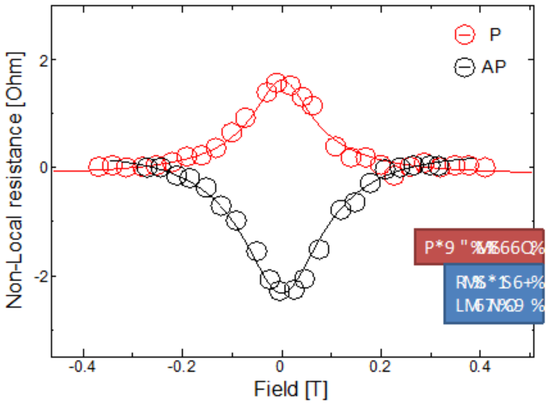

Figure 2: Hanle measurement over a lateral graphene spin valve. The accumulated spins precess around the direction of an out-of-plane magnetic field: fitting this data yields intrinsic quantities as the spin diffusion length and the spin flip time.

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13

Spin and "Cooper-pairs" diffusion in hybrid structures with spin-orbit coupling

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I will first present an interesting analogy between the spin diffusion process in normal metals and the generation of the triplet components of the condensate in a diffusive superconducting structure in the presence of spin-orbit coupling (SOC). From this analogy it turns out naturally that the SOC is an additional source of the long-range triplet component (LRTC) besides the magnetic inhomogeneities studied in the past. This analogy opens a range of possibilities for the generation and manipulation of the triplet condensate in hybrid structures. In particular, I will demonstrate that a normal metal with a SO coupling can be used as source of LRTC if attached to a superconductor-ferromagnet (S-F) bilayer.

In the second part of the talk, I will focus on charge and heat currents in superconducting structures with ferromagnetic insulators (FI). The spin-splitting of the BCS density of the states induced in the superconductor leads to very interesting phenomena which I will illustrate by discussing two examples: (i) a huge thermoelectric effect in a N-FI-S structure and (ii) a heat valve based on a ferromagnetic Josephson junction.

14

Quantum Phase-Slip Junction Under Microwave Irradiation

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We consider the dynamics of a quantum phase-slip junction (QPSJ) – a dual Josephson junction – connected to a microwave source with frequency ω_{mw}. With respect to an ordinary Josephson junction, a QPSJ can sustain dual Shapiro steps, consisting of well-defined current plateaus at multiple integers of $e\omega_{mw}/\pi$ in the current-voltage (I-V) characteristic. The experi- mental observation of these plateaus has been elusive up to now. We argue that thermal as well as quantum fluctuations can smear the I-V characteristic considerably. In order to understand these effects, we study a current-biased QPSJ under microwave irradiation and connected to an inductive and resistive environment. We find that these fluctuations are efficiently reduced when the inductance L of the environment is increased: the larger the inductance, the better defined are the current steps. Our results are of interest in view of future experiments aimed at the observation of dual Shapiro steps in QPSJ devices for the definition of a new quantum current standard.

15

Decoherence in High critical Temperature Superconducting microwave quantum circuits

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The experimental and theoretical investigation of superconducting artificial two-level systems (also known as quantum bits) made of High critical Temperature Superconductors (HTS) has potential applications in quantum computation [1] and can be used to study fundamental physics in previously inaccessible regimes [2]. The use of quantum bits could allow, in fact, the measurement of the HTS quasiparticles spectrum with an unprecedented energy resolution. This measurement will provide a better understanding of the nature of superconductivity in these materials.

For future applicative improvements and for a clear comprehension, the recognition of the different possible decoherence sources is crucial [3, 4]. In particular, decoherence induced by dielectric materials, involved in the fabrication process, can be one of the dominant mechanisms limiting the ultimate performance of superconducting quantum devices operated at millikelvin temperatures and low power (few photons) [4].

Here we report on both temperature (millikelvin range) and power dependence of microwave dielectric losses for materials commonly used as substrates for the growth of the high critical temperature superconductor YBa2Cu3O7-x (YBCO). The intrinsic dielectric losses at low power and millikelvin temperatures have been extracted from the measurement of the unloaded quality factor of Niobium CPW resonators. Our results indicate LSAT as an excellent choice as substrate material for YBCO based microwave quantum devices [5].

Moreover, we also demonstrate the feasibility of YBCO microwave quantum circuits operated in the same regime and implementing biepitaxial grain boundary Josephson junctions, patterned on LSAT covered by a seed layer of CeO2 [6].

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16

Nanomaterials characterization by low-temperature s

canning gate microscopy

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In my talk I will present our recent work on quantum point contacts studied by scanning gate microscopy (SGM). The study of low-dimensional ballistic systems has yielded a number of exciting observations and allowed to investigate several striking physical phenomena during the last 30 years. Despite the conceptual simplicity of the archetypical device, i.e. a quasi-1D constriction (or quantum point contact, QPC), these systems are still attracting much interest both from the point of view of fundamental electron-transport physics and for possible applications, for instance in spintronics. The origin of the anomalous transport feature appearing in QPCs at conductance $G \sim 0.7 \times (2e^2/h)$ – the so-called 0.7 anomaly – represents a long standing puzzle. Several mechanisms were proposed to explain it, but a general consensus has not been achieved. A key open issue is whether point defects that can occur in these low-dimensional devices are the physical cause behind this conductance anomaly. Here we use the SGM technique to map individual impurity positions in several quasi-1D constrictions and correlate these with conductance characteristics. Our data demonstrate that the 0.7 anomaly can be observed irrespective of the presence of localized defects, and we conclude that the 0.7 anomaly is a fundamental property of low-dimensional systems [1].
In the second part of my talk I will focus on the existence of fractional order within integer quantum Hall systems. In fact, integer edge states sometimes behave as monolithic objects with no inner structure, while other experiments clearly highlight the role of fractional substructures. Here we use SGM and demonstrate that fractional features are unambiguously observed in every integer quantum Hall constriction studied. We present also an experimental estimate of the width of the fractional incompressible stripes corresponding to filling factors 1/3, 2/5, 3/5, and 2/3 [2]. Our results compare well with predictions of the edge-reconstruction theory.

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17

Scanning probe microscopy in an ultra-low vibration closed-cycle cryostat

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We report on state-of-the-art scanning probe microscopy measurements performed in a pulse tube based top-loading closed-cycle cryostat with a base temperature of 4K and a 9T magnet. We introduced measures to reduce the level of mechanical and acoustic noise coupling into the system to enable scanning probe experiments. The extremely low vibration amplitudes in our system enabled successful imaging of 0.39nm lattice steps on single crystalline SrTiO3 as well as magnetic vortices in Bi2Sr2CaCu2O8+x superconductor. Fine control over sample temperature and applied magnetic field further enabled us to probe the helimagnetic and the elusive skyrmion-lattice phases in Fe0:5Co0:5Si with unprecedented signal -to-noise ratio of 20:1. Finally, we demonstrate for the first time quartz-crystal tuning fork shear-force microscopy in a closed-cycle cryostat.

References:

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18

Imaging the conductance of integer and fractional quantum Hall effect edge states

Nikola N. Pascher, C. Rössler, T. Ihn, K. Ensslin, C. Reichl, W. Wegscheider

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We have explored the internal structure of integer and fractional quantum Hall edge channels by modifying the edge potential locally with the voltage-biased tip of a scanning force microscope. We find unprecedented rich structure on local scales. In these scanning gate microscopy experiments we measure the conductance of a quantum point contact while the scanning tip induces an electron-depleted region in the two-dimensional electron gas underneath. At finite magnetic field and suitable integer quantum Hall states in the bulk of the sample we find a sequence of stripes in the maps of conductance as a function of tip position, which resemble theoretically predicted compressible and incompressible stripes of quantum Hall edge states. The stripes are rugged on scales of several 100 nm, i.e. on a scale much smaller than the zero-field elastic mean free path of the electrons.
Our experiments demonstrate that microscopic inhomogeneities are relevant even in high-quality samples and lead to locally strongly fluctuating widths of incompressible regions even down to their complete suppression for certain tip positions. Nevertheless the macroscopic quantization of the Hall resistance, which is experimentally measured in a non-local contact configuration, survives, and the relevant local energy scales turn out to be independent of tip position for integer quantum Hall edge states.

Reference:

N. Pascher, C. Rössler, T. Ihn, K. Ensslin, C. Reichl, and W. Wegscheider, Physical Review X 4, 011014 (2014).

19

Transport vs local properties of mesoscopic graphene devices

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We study the properties of mesoscopic graphene devices by combining in situ transport, AFM and STM measurements at milliKelvin temperatures. This allows cross-correlating the macroscopic properties seen in transport (charge neutrality point, mobility…) with local properties that can only be resolved by scanning probe microscopy (e-h puddles distribution, doping at graphene-lead interface, screening at the graphene edges, …). Using AFM, we study how the back gate potential applied to the device is screened by the graphene, as a function of device thickness, gate potential and distance to the graphene edges. Using STM we map the local density of states on the same samples, revealing variations of the local charge neutrality point, in particular near the contacts. Besides zero bias anomalies in the tunnel spectra - indicative of charging effects in the graphene - we further report striking fringes in the LDOS of few layer devices that can be understood in terms of incommensurate stacking-induced strain.

20
Lateral Tunnel Junctions for Molecular electronics and Spintronics

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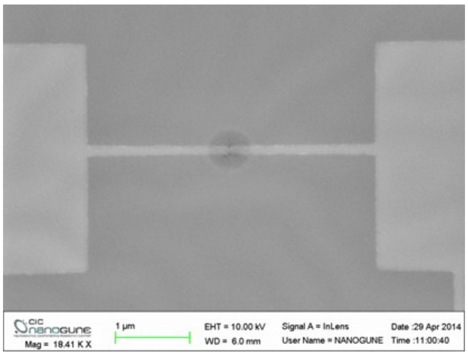
Molecular Electronics [1-2] and Spintronics [3] offer alternative solutions both for miniaturization and increased functionality of electronic devices. In the meantime, these fields offer unique opportunities to study nanoscale physical phenomena [4]. By incorporating tunnel junctions in organic and spintronic devices we are able to study the properties of charge and spin currents at the nanoscale.
Lateral tunnel junctions are created using three different fabrication techniques. C60 and Pentacene transport characteristics are observed in short-channel thin film transistors (TFTs). Using Py/Cu/Py lateral spin valves, we study the effect of spatial confinement on the Local and Non-Local magnetoresistance (MR). An asymmetric Py wire is used to study the transition from anisotropic magnetoresistance (AMR) to giant magnetoresistance (GMR) and tunneling magnetoresistance (TMR).



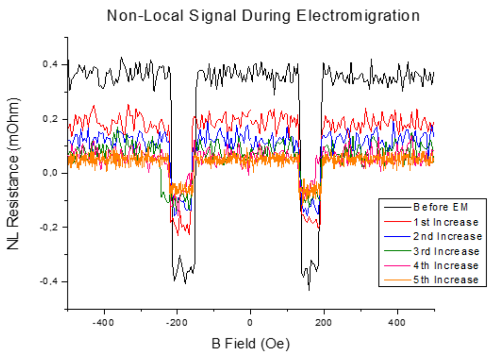


Figure 1. Right) A lateral tunnel junction in an thin film transistor with C60 as the channel. Left) Pure spin current signal during the electromigration of a lateral spin Valve

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21
Travelling-wave Parametric Amplifier

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To be able to non-invasively study quantum two-level systems with Near-field Scanning Microwave Microscope[1], as well as to realize single spin ESR measurements[2], the probing power must be kept close to a single photon level. While detecting such a small signal the best transistor amplifiers will add a noise on top of a signal with a level much larger than a single photon level, thus calling for the strong need of a wideband, ultralow-noise and high-gain amplifier. Recently a prototype travelling-wave parametric amplifier (TWPA) based on a nonlinear kinetic inductance of a superconducting transmission line was demonstrated with near quantum-limited noise and non-constant gain3. However to build fully operational, practical amplifier, there still remain issues to be solved, such as impedance matching, frequency- independent gain and defect-free transmission line from the fabrication point-of-view.

To address these issues, we follow and reproduce the TWPA approach demonstrated in B.H.Eom et.al[3]. Besides we propose our version of quasi-fractal design, where the best achievement reached so far is constant 3.5dB gain. The issues and technical problems mentioned above will be discussed along with preliminary results.

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22

Heat-charge separation for improved thermoelectric conversion

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Thermoelectricity has received enormous attention recently due to the constant demand for new and powerful ways of energy conversions. Progresses in understanding thermoelectricity at the nanoscale will have important applications for ultra-sensitive all-electric heat and energy transport detectors, energy transduction, heat rectifiers and refrigerators, just to mention a few examples. In particular, superconductors play an important role in the realization of electronic nano-coolers. Indeed, hybrid normal-metal/ superconducting nanostructures have proved to be efficient electronic refrigerators in the sub-Kelvin range of temperatures. Hybrid systems are also interesting since transport is determined by Andreev reflection, which makes them excellent conductors of charge, but very poor conductor of energy.

In normal two-terminal systems electrical and thermal currents are strictly interrelated, since charge and heat are transported by the same carriers, the quasiparticles. A consequence of this fact is observed in metals for low temperatures (where the Sommerfeld expansion is valid) where the ratio between electrical and thermal conductances is fixed to an universal constant (Wiedemann-Franz law). This means that controlling separately the two currents is impossible.

In this work we propose to overcome this restriction by spatially separating the two currents through the introduction of a third superconducting lead and forbidding electrical current to flow in one of the normal lead. In doing so electrical and thermal currents turn out to be at the same time non-negligible and separately controllable. We investigate the implications on the thermoelectric performance, finding that (under the Sommerfeld approximation) the thermal conductance, electrical conductance and thermopower can be separately controlled, thus leading to a controlled violation of the Wiedemann-Franz law and to thermodynamical performance that is very much improved with respect to that of a two-terminal system.

23

Heat current rectification and electronic refrigeration in superconducting hybrid devices

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In this contribution, we report recent theoretical and experimental advances in the manipulation of electronic thermal currents within devices based on tunnel junctions between superconducting (S) and normal metal (N) thin films at low temperatures (below 1 K). This kind of devices could be of great interest in many fields of nanoscience, such as solid state cooling, energy harvesting, thermal isolation, cryogenic radiation detection and quantum information.

In the first part, we focus on the experimental realization of a $N_1INISIN_2$ heat diode (where I stands for a tunnel barrier) [1]. Thermal transport through the diode depends on the sign of the temperature bias imposed to the thermal reservoirs N1 and N2. Our device is able to provide a ratio between heat currents flowing in opposite thermal bias configurations as large as 140 at a bath temperature of 50 mK. Furthermore, it demonstrates two different rectification regimes that were predicted theoretically: the first is based on the asymmetric coupling between the diode and the phonon bath [2], while the second relies on the thermal asymmetry given by the temperature dependence of the energy gap in the superconducting density of states [3,4].

Finally, in the second part of the seminar, we discuss theoretically the design and the operation of an electronic cooler based on a $S_2IS_1INIS_1IS_2$ junction (where S_1 and S_2 represent two different superconductors) [5]. This cascade geometry provides an efficient extraction of hot quasi-particles from the N island, which can be cooled down to about 100 mK starting from a bath temperature of 500 mK, thus improving the performance of more conventional SINIS refrigerators.

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