Workshop on the Physics
of
Micro and Nano Scale Systems

June 20-24, 2010

Ystad, Sweden

Sponsored by the ESF EPSD programme, the ESF QSPICE programme and the EU MICROKELVIN programme

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Scientific Topics

The International Workshop on the Physics of Micro and Nano Scale Systems will be held June 20-24, 2010 in Ystad, Sweden. The aim of this Workshop is to bring together leading researchers and young scientists working on micro and nanoscale physical systems to discuss and exchange ideas and knowledge about physics and application aspects of micro and nanostructures and devices. The following list summarizes the topics to be addressed at the workshop:

- Electronic refrigeration; new cooling methods and materials
- Nanoelectromechanics and quantum-electromechanics
- Thermometry and thermal detectors
- Non-linear effects in nanostructures
- Many-body phenomena in nanostructure; Kondo effects
- Spin physics in nanostructures; spintronic devices
- Thermodynamic issues and phenomena on the nanoscale
- Manipulation and control of spin qubits in quantum dots
- Correlations and entanglement of itinerant electrons
- Time dependent generation of single charge and spin excitations
- Transport in superconducting/ferromagnetic/semiconductor hybrid systems
- Full counting statistics of spins and charges in mesoscopic systems

Venue

The workshop will take place at Hotel Continental Ystad. Ystad is a beautiful medieval seaside town in southern Sweden, about 70 km southeast of Lund, and can be reached easily by local train from the Copenhagen Airport via City of Malmö in Sweden. There is plenty of scenic nature and historic attractions in Ystad and its surroundings. Ystad is also a perfect place for a leisure stay and has one of the best beaches in Sweden.

Organization

Hongqi Xu, Lund University, Sweden (hongqi.xu@ftf.lth.se)
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Sponsors

European Science Foundation Research Networking Programme Exploring the Physics of Small Devices (EPSD)

European Science Foundation Research Networking Programme Quantum Spin Coherence and Electronics (QSPICE)

European Microkelvin Collaboration (MICROKELVIN)

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Invited Speakers

Dmitri Averin, SUNY, USA
Wolfgang Belzig, University of Konstanz, Germany
Tobias Brandes, TU Berlin, Germany
Guido Burkard, University of Konstanz, Germany
Markus Büttiker, University of Geneva, Switzerland
Herve Courtois, CNRS, Grenoble, France
Per Delsing, Chalmers University of Technology, Sweden
Eduard Driessen, Delft University of Technology, The Netherlands
Klaus Ensslin, ETH, Switzerland
Massimiliano Esposito, Université Libre de Bruxelles, Belgium
Vladimir Falko, Lancaster University, UK
Silvano de Franceschi, CEA, Grenoble, France
Francesco Giazotto, SNS, Pisa, Italy
Francisco Guinea, ICMM/CSIC, Madrid, Spain
Alex Hamilton, University of New South Wales, Australia
Tero Heikkilä, Aalto University, Finland
Frank Hekking, Univ. Joseph Fourier, Grenoble, France
Manuel Houzet, CEA Grenoble, France
Koji Ishibashi, RIKEN, Japan
Heiner Linke, Lund University, Sweden
Rosa López, UIB, Palma Mallorca, Spain
Daniel Loss, University of Basel, Switzerland
Ilari Maasilta, Univ. Jyväskylä, Finland
Jesper Nygard, University of Copenhagen, Denmark
Jukka Pekola, Aalto University, Finland
Vittorio Pellegrini, SNS, Pisa, Italy
Lianmao Peng, Peking University, China
Frederic Pierre, CNRS LPN, Paris, France
Patrik Recher, University of Wurzburg, Germany
Bertrand Reulet, CNRS LPS, Paris, France
Patrice Roche, CEA Saclay and ENS, Paris, France
Stefano Roddaro, SNS, Pisa, Italy
Henning Schomerus, Lancaster University, UK
Pascal Simon, CNRS LPS, Paris, France
Gary Steele, Delft University of Technology, The Netherlands
Hideaki Takayanagi, Tokyo University of Science, Japan
Andreas Wacker, Lund University, Sweden
Gergely Zarand, Budapest University of Technology, Hungary

Workshop Program

Sunday 20/6.

18.00 - 22.00 Reception at the hotel.

Monday 21/6

8.50 Welcome and general information.

Thermal properties, heat transport and cooling I
Chair: M. Büttiker
9.05 F. Hekking, *Circuit approach to photonic heat transport*
9.40 T. Heikkilä, *Temperature fluctuations and their statistics in electron systems out of equilibrium*

10.15 Coffee

Spin properties and spintronics
Chair: D. V. Averin
10.45 D. Loss, *Nuclear Magnetism and Peierls-like transition in nanotubes and quantum Wires with Spin-Orbit Interactions*
11.20 A. R. Hamilton, *Spin properties of holes in GaAs quantum wires*
11.55 G. Burkard, *The spin-valley blockade in carbon-based double quantum dots*

12.30 Lunch

Fluctuation and dissipation effects
Chair: D. Loss
14.00 P. Delsing, *Excess dissipation in a Single-Electron Box: the Sisyphus resistance*
14.35 R. López, *Coulomb drag and fluctuation relations*.
15.10 D. V. Averin, *Violation of the fluctuation-dissipation theorem in time-dependent mesoscopic heat transport.*

15.45 Coffee

Graphene and carbon nanotubes I
Chair: P. Delsing
16.15 V. Falko, *Electrons in bilayer graphene: Lifshitz transition and spontaneous symmetry breaking*
16.50 F. Guinea, *Novel features of graphene devices*

17.30 Poster parade

18.30 Dinner

20.30 Poster Session

Tuesday 22/6

Superconducting nanostructures and Andreev Reflection I

Chair: K. Ishibashi

8.30 M. Houzet, *Multiple Andreev reflections in hybrid multiterminal junctions.*

9.05 P. Simon, *Self-consistent description of Andreev bound states in Josephson quantum dot devices.*

9.40 E. Driessen, *Phase slips in highly resistive superconductors*

10.15 Coffee

Noise and Full Counting statistics of quantum transport I

Chair: F. Giazotto

10.45 B. Reulet, *High frequency third cumulant of current noise : existence of quantum correlations in the zero-point fluctuations of electrons*.

11.20 W. Belzig, *Quasiprobability and quantum paradoxes in full counting statistics.*

11.55 H. Schomerus, *Counting statistics for mesoscopic conductors with internal degrees of freedom.*

12.30 Lunch

Superconducting nanostructures and Andreev Reflection II

Chair: F. Guinea

14.00 H. Takayanagi, *Superconducting transport in an LED with Nb electrodes.*

14.35 S. de Franceschi, *Spin spectroscopy and supercurrents in hybrid superconductor-semiconductor nanostructures.*

15.10 F. Giazotto, *Thermal effects in superconducting nanostructures and two-dimensional electron gas systems*

15.45 Coffee

Thermal properties, heat transport and cooling II

Chair: V. Pellegrini

16.15 M. Esposito, *Stochastic thermodynamics and finite time efficiency of small devices.*

16.50 I. J. Maasilta, *Phonon thermal conduction and cooling in nanostructures.*

18.30 Dinner

20.30 Poster Session

Wednesday 23/6

<u>Coherence, entanglement and interactions in the Quantum Hall regime</u>

Chair: F. Hekking

8.30 M. Büttiker, *Orbital entanglement and the two particle Aharonov-Bohm effect.*

9.05 F. Pierre, *Energy relaxation in the integer quantum Hall regime.*

9.40 P. Roche, *Probing decoherence in the Integer Quantum Hall regime.*

10.15 Coffee

<u>Nanoscale transport and devices</u>

Chair: A. R. Hamilton

10.45 V. Pellegrini, Spectroscopy *of Collective Modes in Few-electrons Quantum Dots.*

11.20 A. Wacker, *Consistent treatment of cotunneling and coherence in nanostructure transport.*

11.55 P. Recher, *Bulk transport in topological insulators.*

12.30 Lunch

<u>Superconducting nanostructures and Andreev Reflection III</u>

Chair: H. Courtois

14.00 K. Ishibashi, *Carbon nanotubes and semiconductor nanowires for building blocks of quantum nanodevices.*

14.35 J. Nygard, *Transport in semiconductor nanowire quantum dots with superconducting contacts.*

15.10 S. Roddaro, *Controlling InAs nanowire Josephson transistors by hot-electron injection.*

15.45 Coffee

<u>Noise and Full Counting statistics of quantum transport II</u>

Chair: I. J. Maasilta

16.15 T. Brandes, *Feedback Control of Quantum Transport.*

16.50 G. Zarand, *Non-equilibrium noise spectrum through a quantum dot: a functional renormalzitaion group study.*

18.00 Historical tour, Ystad

19.30 Workshop dinner

Thursday 24/6

Graphene and carbon nanotubes II

Chair: H. Takayanagi

8.30 K. Ensslin, *Electronic properties of graphene nanostructures.*

9.05 G. Steele, *Strong coupling of single-electron tunneling to nanomechanical motion in a clean carbon nanotube.*

9.40 L. -M. Peng, *Fabrication and performance of carbon based nanoelectronic and optoelectronic devices.*

10.15 Coffee

Thermal properties, heat transport and cooling III

Chair: K. Ensslin

10.45 J. P. Pekola, *Charge and heat transport in the hybrid single-electron turnstile.*

11.20 H. Courtois, *Electronic cooling in superconductor-based tunnel junctions : basics and practical limitations.*

11.55 H. Linke, *Thermoelectric effects in nanowire-embedded quantum dots.*

12.30 Concluding remarks

12.45 Lunch

14.00 Excursion, Lund Nano Lab, Lund University

Poster Presentations

Excitation of surface plasmons in planar periodic structures
N. Anttu and H. Xu

Proposal for non-local electron-hole turnstile in the Quantum Hall regime
F. Battista, and P. Samuelsson

Electronic cooling performance of SINIS and SIS'IS based tunnel junction with manganese doped aluminum
S. Chaudhuri and I. J. Maasilta

Kondo effect, multiple Andreev reflection and induced superconductivity in InSb nanowire hybrid devices
M. T. Deng, H. A. Nilsson, P. Caroff, P. Samuelsson, L. Samuelson and H. Q. Xu

Quantum dots in a high-mobility two-dimensional electron gas coupled to superconducting electrodes
F. Deon, V. Pellegrini, F. Carillo, F. Giazotto, G. Biasiol, L. Sorba, and F. Beltram

Studies of thermoelectric effects in nanowire-based quantum dots
S. Fahlvik Svensson, E.A. Hoffmann, H. Nilsson, L. Samuelson, and H. Linke

Realization of hole quantum dots in GaSb nanowires
B. Ganjipour, M. Borg, L.-E. Wernersson, L. Samuelson, C. Thelander, and H. Q. Xu

From adiabatic to nonadiabatic charge pumping in a phase-biased Cooper-pair sluice
Simone Gasparinetti

Reducing 1/f noise in Al-AlOx-Al tunnel junctions by thermal annealing
J.K. Julin, P.J. Koppinen and I.J. Maasilta

Conductance suppression in a spinless 2-level quantum dot
O. Karlström, J. N. Pedersen, H. A. Nilsson, H. Q. Xu, P. Samuelsson, A. Wacker

Nuclear-spin-induced singlet triplet mixing in a few-electron lateral InGaAs double quantum dot
M. Larsson, J. Sun, and H. Q. Xu

Kondo effect in spin-orbit mesoscopic interferometers
J. S. Lim, M. Crisan, D. Sánchez, R. López , and I. Grosu

Experiments on a Cooper pair insulator
H. Nguyen

Giant, level-dependent g-factors and spin correlations in InSb nanowire quantum dots
H. A. Nilsson, P. Caroff, C. Thelander, M. Larsson, J. B. Wagner, L.-E. Wernersson, L. Samuelson and H. Q. Xu

Wrap-gate-induced field-effect diodes in InP nanowires
G. Nylund, K. Storm, M. Borgström, J. Wallentin, C. Fasth, C. Thelander and L. Samuelson

Thermal effects in superconducting hybrid junctions
Laetitia Pascal

Cooling and Thermometry with KIDs
Nathan Vercruyssen

Abstracts of invited presentations

Circuit approach to photonic heat transport

F. Hekking
Université Joseph Fourier, Laboratoire de Physique et Modélisation, des Milieux Condensés, C.N.R.S., BP 166, 38042 Grenoble, France

We discuss the heat transfer by photons between two metals coupled by a linear element with a reactive impedance. Using a simple circuit approach, we calculate the spectral power transmitted from one resistor to the other and find that it is determined by the photon transmission coefficient, which depends on the impedances of the metals and the coupling element. We study the total photonic power flow for different coupling impedances, both in the linear regime, where the temperature difference between the metals is small, and in the non-linear regime of large temperature differences.

Temperature fluctuations and their statistics in electron systems out of equilibrium

T. Heikkilä

Low Temperature Laboratory, Aalto University, P.O. Box 15100, FIN-00076 AALTO, Finland

We study the fluctuations of the electron temperature in a metallic island coupled to reservoirs via resistive contacts and driven out of equilibrium by either a temperature or voltage difference between the reservoirs in the regime in which the electrons are completely decoupled from the lattice phonons. We quantify these fluctuations in the regime beyond the Gaussian approximation and elucidate their dependence on the nature of the electronic contacts [1]. Besides normal noninteracting contacts, we also study the temperature fluctuations and their effects on other transport properties in single-electron transistors in the regime of strong overheating [2]. We find three distinct regimes corresponding to cotunneling, sequential tunneling, and their coexistence. We find that the Fano factor of current fluctuations is enhanced around the crossover from coexistence to sequential tunneling by several orders of magnitude. This is because the SET is very sensitive to temperature fluctuations around this crossover. We also study the statistics of temperature fluctuations in these regimes and find the distribution to be strongly non-Gaussian.

[1] Tero T. Heikkilä and Yuli V. Nazarov, Phys. Rev. Lett. **102**, 130605 (2009).
[2] M. Laakso, Tero T. Heikkilä, and Yuli V. Nazarov, Phys. Rev. Lett. (in press) [arXiv:0912.2832]

Nuclear Magnetism and Peierls-like transition in Nanotubes and Quantum Wires with Spin-Orbit Interactions

D. Loss
Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

The interaction between localized magnetic moments and the electrons of a one-dimensional conductor can lead to an ordered phase in which the magnetic moments and the electrons are tightly bound to each other [1,2]. We show here that this occurs when a lattice of nuclear spins is embedded in a Luttinger liquid. Experimentally available examples of such a system are single wall carbon nanotubes grown entirely from 13C and GaAs-based quantum wires. In these systems the hyperfine interaction between the nuclear spin and the conduction electron spin is very weak, still it triggers a strong feedback reaction that results in an ordered phase consisting of a nuclear helimagnet that is inseparably bound to an electronic density wave combining charge and spin degrees of freedom. This effect can be interpreted as a Peierls-like strong renormalization of the nuclear Overhauser field and is a unique signature of Luttinger liquid physics. Through the feedback the order persists up into the millikelvin range. A particular signature is the reduction of the electric conductance of the wire by a universal factor 2. A similar effect appears without nuclear spins but in the presence of Rashba spin-orbit interaction [3]. In this case, the transition is driven by an external magnetic field in quantum wires or by intrinsic spin-orbit interaction in nanotubes. In the gapped phase, a perfect spin filter emerges that is stabilized by interaction effects and thus remains operational up to relatively high temperatures of tens of Kelvins.

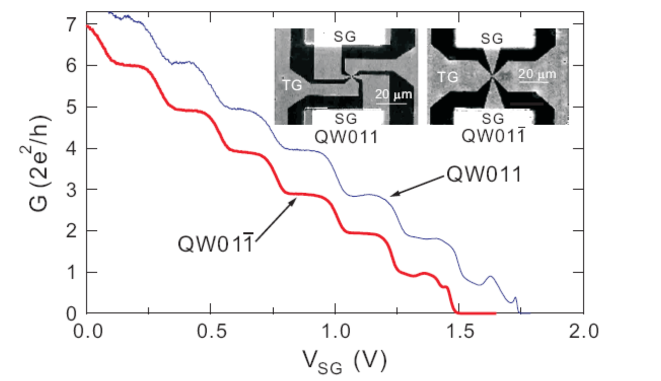
[1] B. Braunecker, P. Simon, and D. Loss, Phys. Rev. Lett. **102**, 116403 (2009).
[2] B. Braunecker, P. Simon, and D. Loss, Phys. Rev. B **80**, 165119 (2009).
[3] B. Braunecker, G. I. Japaridze, J. Klinovaja, and D. Loss, arXiv:1004.0467.

Spin properties of holes in GaAs quantum wires

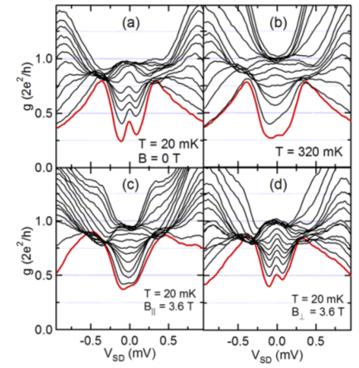
A.R. Hamilton[1], O. Klochan[1], J.C.H. Chen[1], A.P. Micolich[1], L.H. Ho[1], U. Zulicke[2], D.A. Ritchie[3], M. Pepper[3,4], M.Y. Simmons[1], K. Muraki[5], Y. Hirayama[6], D. Reuter[7], A.D. Wieck[7]
[1] *School of Physics, University of New South Wales, Sydney, Australia.*
[2] *Institute of Fundamental Sciences and MacDiarmid Institute, Massey University, New Zealand.*
[3] *Cavendish Laboratory, University of Cambridge, England*
[4] *Department of Electronic & Electrical Engineering, University College London, England*
[5] *NTT Basic Research Laboratory, NTT Corporation, 3-1 Morinosato Wakamiya, Atsugi , Japan.*
[6] *Department of Physics, Tohoku University, 6-3 Aramaki aza Aoba, Aobaku Sendai, Japan.*
[7] *Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany.*

This talk summarises our recent work on ballistic transport and spin-orbit coupling in one-dimensional (1D) GaAs hole systems. We have fabricated extremely high quality 1D hole quantum wires that show extremely clean and stable quantized conductance plateaus at B=0 [1], as well as the anomalous “0.7 feature” and a zero bias anomaly at low conductance [2].
In contrast to 1D electron quantum systems, we observe an extreme anisotropy of the Zeeman spin splitting of the 1D energy levels depending on the relative orientation of the in-plane magnetic field, the quantum wire, and the host crystal [3,4,5]. We find that both the “0.7 feature” and the zero bias anomaly share the same magnetic anisotropy as the single particle 1D hole states, suggesting that both are related to 1D physics.

We are able to eliminate 2D crystalline anisotropy effects by making hole quantum wires on higher symmetry (100)-oriented substrates. For these wires the anisotropic spin-splitting depends only on the orientation of the magnetic field with respect to the quantum wire [5]. However the orientation and *k*-dependence of the spin-splitting cannot be reconciled with existing theories, suggesting that more theoretical work is needed before we understand the physics of spin-3/2 holes, even on `simple' (100) surfaces.



Conductance quantisation in two hole quantum wires aligned along different crystal axes on a (100) substrate [5]



Magnetic anisotropy of the zero-bias anomaly in a quantum wire formed in a (311)A heterostructure. [3]

[1] O. Klochan *et al.*, Appl. Phys. Lett. **89**, 092105 (2006); R. Danneau *et al.*, Appl. Phys. Lett. **88**, 012107 (2006).
[2] R. Danneau *et al.*, Phys. Rev. Lett. **97**, 026403 (2006).
[3] R. Danneau *et al.*, Phys. Rev. Lett. **100**, 016403 (2008).
[4] O. Klochan *et al, New Journal of Physics* **11**, 043018 (2009).
[5] J. C. H. Chen, *et al*, New Journal of Physics **12**, 033043 (2010).

The spin-valley blockade in carbon-based double quantum dots

G. Burkard

Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

The spin blockade effect in the electric conduction through two semiconductor quantum dots connected in series has allowed the monitoring of spin-breaking effects, notably single-spin rotations induced via external fields in electron spin resonance (ESR) and spin decoherence due to the hyperfine coupling to the nuclear spin environment. Electrons in double quantum dots in graphene and carbon nanotubes comprise a valley degree of freedom in addition to their spin. We show that this can lead to a spin-valley blockade which is sensitive to both spin and valley breaking effects. The hyperfine interaction due to residual 13C nuclear spins turns out to be both spin- and valley-breaking, while non-magnetic atomic impurities can lead to pure valley-breaking. We study the magnetic-field dependent leakage current in the spin-valley blockade. Finally, we also take into account the effect of the spin-orbit interaction in carbon-nanotubes and its influence on the leakage current.

Excess Dissipation in a Single-Electron Box: The Sisyphus Resistance

F. Persson, C. M. Wilson, M. Sandberg, G. Johansson, and P. Delsing
Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology, SE-412 96 Göteborg, Sweden

We present measurements of the ac response of a single-electron box (SEB). We apply a radio frequency signal with a frequency larger than the tunneling rate and drive the system out of equilibrium. We observe much more dissipation in the SEB then one would expect from a simple circuit model. We can explain this in terms of a mechanism that we call the Sisyphus resistance. The Sisyphus resistance has a strong gate dependence which can be used for electrometery applications.

Coulomb Drag and Fluctuation Relations

R. Sánchez[1], R. López[2,3], D. Sánchez[2,3] and M. Büttiker[1]

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[2]*Department of Physics, Universitat de les Illes Balears, Spain.*

[3]*Institut de Física Interdisciplinar i de Sistemes Complexos IFISC (CSIC-UIB), E-07122 Palma de Mallorca, Spain.*

Transport in mesoscopic systems interacting whith each other through long range Coulomb forces becomes correlated. As a consequence non-equilibrium charge fluctuations in one conductor can induce a current in the other unbiased conductor. However, even in this situation far away from equilibrium where detailed balance is explicitly broken, theory predicts that fluctuation relations are satisfied. This surprising effect has, to date, not been confirmed experimentally. Here we propose a system consisting of a capacitively coupled double quantum dot where the nonlinear fluctuation relations are verified in the absence of detailed balance.

In more detail, the model consists of two capacitively coupled quantum dots in the Coulomb blockade regime where each dot belongs to a separate conductor and contains only a single level. Such a simple system can be described by rate equations, in the spirit of the theory of Coulomb blockade. We investigate the appearance of the drag current in one conductor due to the non-equilibrium noise in the other conductor. Drag currents appear for a four state model and require energy dependent tunneling probabilities. The correlation of currents can be directly measured. Alternatively a conductor can serve as a detector of the charge state of the other conductor and provide the full counting statistics.

Violation of the fluctuation-dissipation theorem in time-dependent mesoscopic heat transport.

D.V. Averin[1] and J.P. Pekola[2]

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[2]*Low Temperature Laboratory, Aalto University School of Science and Technology, P.O. Box 13500, FI-00076 AALTO, Finland*

We have analyzed the spectral density of fluctuations of the energy flux through a mesoscopic constriction between two equilibrium reservoirs. It is shown that at finite frequencies, the fluctuating energy flux is not related to the thermal conductance of the constriction by the standard fluctuation-dissipation theorem, but contains additional noise. The main physical consequence of this extra noise is that the fluctuations do not vanish at zero temperature together with the vanishing thermal conductance.

Electrons in bilayer graphene: Lifshitz transition and spontaneous symmetry breaking

Y. Lemonik[1], I Aleiner[1], C. Toke[2], and V. Falko[2]
[1]*Physics Department, Columbia University, New York, NY 10027, USA*
[2]*Physics Department, Lancaster University, Lancaster, LA1 4YB, UK*

Bilayer graphene is a gapless semiconductor with parabolic spectrum in the conduction and valence bands at intermediate energies and quasiparticles characterised by the Berry phase 2Pi. Since the Berry phase 2Pi is not topologically stable, two scenarios are possible for the low-energy properties of electrons:
(i) At some energy topology of isoenergetic lines undergoes Lifshitz transition, from single-connected at higher energy to four pieces at lower energy, surrounding four Dirac points (one in the middle with Berry phase -Pi and three off-side, each carrying Berry phase Pi).
(ii) The hexagonal symmetry of bilayer is unstable, and electronic system undergo phase transition into state with a deformed spectrum.

We derived the renormalization group equations describing all the short-range interactions in bilayer graphene allowed by symmetry, the long range Coulomb interaction, and the band parameters.
We find that the system is likely to undergo the first order phase transition into the uniaxially deformed gapless state. This transition is accompanied by the change of the topology of the electron spectrum, such that the asymmetric spectrum at low energies features two Dirac points, each carrying Berry phase Pi. The difference between two phases can manifest itself through the persistence of different filling factors in low-field Shoubnikov - de Haas oscillations.

Novel features of graphene devices

F. Guinea
Instituto de Ciencia de Materiales de Madrid. CSIC, Cantoblanco, E-28049 Madrid, Spain

Graphene is a two dimensional metal with unique flexibility and tunable electronic properties. We describe different devices, ranging from strained dots to interferometers and to plasmonic waveguides, which can be designed by making use of the special features of graphene.

Multiple Andreev reflections in hybrid multiterminal junctions

M. Houzet[1] and P. Samuelsson[2]
[1]INAC, SPSMS bât. C5 p. 511, CEA Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France,
[2]Division of Mathematical Physics, Box 118, SE - 221 00 Lund, Lund University, Sweden.

We investigate theoretically charge transport in hybrid multiterminal junctions with superconducting leads kept at different voltages. It is found that multiple Andreev reflections involving several superconducting leads give rise to rich subharmonic gap structures in the current-voltage characteristics. The structures are evidenced numerically in junctions in the incoherent regime.

Self-consistent description of Andreev bound states in Josephson quantum dot devices.

P. Simon

Laboratoire de Physique des Solides, CNRS UMR-8502, Universite Paris Sud, 91405 Orsay Cedex, France

I will present a general and simple perturbative framework to describe Andreev bound states (ABS) in interacting quantum dots connected to superconducting leads. A local effective Hamiltonian for dressed ABS, including both the atomic (or molecular) levels and the induced proximity effect on the dot is argued to be a natural starting point. A self-consistent expansion in single-particle tunneling events is shown to provide accurate results even in regimes where the superconducting gap is smaller than the atomic energies, as demonstrated by a comparison to recent Numerical Renormalization Group calculations. This simple formulation may have bearings for interpreting Andreev spectroscopic experiments in superconducting devices, such as STM measurements on carbon nanotubes, or radiative emission in optical quantum dots.

Phase slips in highly resistive superconductors

E. Driessen
Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046, 2600 GA Delft, The Netherlands

Highly resistive superconductors are becoming important for kinetic inductance detectors, quantum phase slips and single photon detection. In these materials the competition between localization and superconductivity leads potentially to electronic inhomogeneities, which are independent of the atomic microstructure. We study the resistive transitions and phase slip regime of NbTiN nanowires for a series of widths in order to identify the effect of these inhomogeneities on the superconducting properties.

High frequency third cumulant of current noise : existence of quantum correlations in the zero-point fluctuations of electrons

B. Reulet and J. Gabelli

Laboratoire de Physique des Solides, CNRS, UMR8502, Université de Paris-Sud 11, F-91405 Orsay, France

We have measured the high frequency third cumulant of voltage quantum fluctuations $\langle V(f)V(f'-f)V(-f')\rangle$ across a tunnel junction in the regime $hf' \sim 100MHz \ll kT \ll eV \ll hf \sim 6GHz$. This quantity is measured by the correlation between the fluctuations (at frequency f ’) of the high frequency noise $V(f)V(-f)$ and the low frequency fluctuating voltage $V(f')$. In this regime, the high frequency voltage/current fluctuations are due to zero point motion of electrons, of spectral density $\langle V(f)V(-f)\rangle = Rhf$ with R the resistance of the junction. After subtraction of the environmental contributions, which correspond to the dynamical response of noise to an ac excitation (and are very well controlled), we obtain that the third cumulant of current fluctuations is simply given by e^2I, independent of f. Despite its classical look, this result expresses that the fluctuations of the square of the high frequency current due to vacuum fluctuations are correlated with the low frequency fluctuating current. We discuss how this result raises the problem of calculating high frequency cumulants of noise for a given experimental setup. As a matter of fact, different expressions which give identical result at zero frequency may lead to very different predictions at finite frequency.

Quasiprobability and quantum paradoxes in full counting statistics

W. Belzig
University of Konstanz, Fachbereich Physik, M703, D-78457 Konstanz, Germany

The impossibility of measuring non-commuting quantum mechanical observables is one of the most fascinating consequences of the quantum mechanical postulates. Hence, to date the investigation of quantum measurement and projection is a fundamentally interesting topic. We propose to test the concept of weak measurement of non-commuting observables in mesoscopic transport experiments, using a quasiprobablistic description. We derive an inequality for current correlators, which is satisfied by every classical probability but violated by high-frequency fourth-order cumulants in the quantum regime for experimentally feasible parameters.

Counting statistics for mesoscopic conductors with internal degrees of freedom

H. Schomerus
Department of Physics, Lancaster University, Lancaster LA1 4YB, United Kingdom

This talk addresses the transport of electrons passing through a mesoscopic device possessing internal dynamical quantum degrees of freedom. The mutual interaction between the system and the conduction electrons contributes to the current fluctuations, which we describe in terms of full counting statistics. I identify conditions under which the device acts to dynamically bunch transmitted or reflected electrons, thereby generating super-Poissonian noise, and discuss how this can be realized in an Aharonov-Bohm ring which is electrostatically coupled to a double quantum dot.

Superconducting Transport in an LED with Nb Electrodes

H. Takayanagi[1,2,3], R. Inou[2,6], T. Akazaki[3,6], K. Tanaka[4,6], and I. Suemune[5,6]
[1]*International Center for Materials NanoArchitechtonics, NIMS, Tsukuba 305-0003, Japan*
[2]*Department. of Applied Physics, Tokyo University of Science, Shinjuku, Tokyo 162-8601, Japan*
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Superconducting transport is measured between two superconducting electrodes at the n-type semiconductor side of a superconductor-based LED where a Josephson junction is formed. The characteristics of the Josephson junction are found to be modulated by applying voltage to the normal electrode at the p-type semiconductor side. The Josephson junction characteristics show an extraordinary sensitivity to the radiative recombination process, which we estimate as the recombination efficiency.

Spin spectroscopy and supercurrents in hybrid superconductor-semiconductor nanostructures

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Nanostructured materials such as self-assembled semiconductor quantum dots and nanowires are currently investigated as potential building blocks for a wide range of applications, from (opto)electronics to biochemical sensing. At the same time, such nanomaterials offer unique opportunities to create relatively simple and tunable electronic systems in which complex quantum phenomena can be explored. In this talk, I will focus on quantum-dot devices obtained by contacting individual semiconductor nanostructures such as indium arsenide nanowires or silicon-germanium self-assembled islands.

I will present tunneling spectroscopy measurements in a magnetic field. These measurements provide accurate information on the quantum-dot electronic properties and, in particular, on the field-induced Zeeman splitting of the confined electronic states. In the case of silicon-germanium islands, our measurements reveal strong g-factor anisotropy as well as a pronounced gate-voltage dependence of the g-factor which may be ascribed to compositional and strain-field gradients in the silicon-germanium island. Such a gate tunability of the g-factor opens an opportunity for performing all-electrical spin coherent manipulations.

I will then discuss the experimental realization of Josephson junctions made from individual semiconductor quantum dots contacted by two aluminum-based superconducting electrodes. We have observed supercurrent transport resulting from the tunneling of Cooper pairs through single resonant levels. This supercurrent is modulated by the Coulomb blockade effect and it can be switched on and off by small gate voltage variations.

Thermal effects in superconducting nanostructures and two-dimensional electron gas systems

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In recent times, the interest in thermoelectric phenomena in mesoscopic systems has become more and more apparent [1]. In this context, solid-state refrigeration is particularly under the spotlight. Promising solid-state refrigeration schemes operating at sub-Kelvin temperatures rely on superconducting nanostructures [1-3], and have shown to yield remarkable electron and phonon temperature reduction. In these systems, a normal metal region is coupled to a superconductor through an insulating tunnel barrier. Quasiparticle cooling occurs thanks to the existence of the superconducting gap, which allows only the more "hotter" electrons to escape from the normal metal region. In the first part of this presentation we will show the implementation of all-superconducting electron nanorefrigerators based on the V/AlOx/Al materials combination. The structure were realized with standard electron-beam lithography and shadow-mask evaporation of metals. Notably, electron temperature reduction down to around 400 mK starting from a bath temperature of 1 K were routinely achieved in such devices. This makes V-based superconducting refrigerators promising for the implementation of the high-temperature stage in cascade solid-state cooling.

In the second part of this presentation we shall show that a lateral quantum dot (QD) defined in a GaAs/AlGaAs heterostructure can be used for the detection of local temperature gradients within the two-dimensional electron gas (2DEG) itself. Our method relies on the observation that a temperature bias across the QD changes the functional form of the Coulomb blockade resonant peaks. In our experimental system, the QD is coupled to a micrometer-sized electron reservoir which can be heated by DC current injection through two quantum point contacts coupled to the reservoir. This device is an ideal platform for the investigation of the energy relaxation mechanisms in 2DEGs, for instance, the electron-phonon interaction. To this end, we will show that the power transferred from the electrons to the phonon bath is proportional to the fifth power of the temperature, as expected for the screened piezoelectric interaction, and we provide a measure of the relative coupling constant.

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Stochastic thermodynamics and finite time efficiency of small devices

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Due to environment fluctuations, it is often natural to describe small systems by stochastic dynamics. I will show that with very few physical assumptions and the correct identification of entropy production, the stochastic dynamics provides a consistent nonequilibrium thermodynamics description of small systems. Such description enables the study of nonequilibrium current fluctuations and thermodynamic efficiencies of small devices. Applications to simple models of quantum dots, photoelectric cells and chemical reactions will be presented.

Phonon thermal conduction and cooling in nanostructures

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In this talk I will discuss our recent activities in the area of low-temperature phonon thermal conduction and tunnel junction cooling in low-dimensional geometries. More specifically, I will at least address how thermal conduction can be engineered in either 1D or 2D suspended structures. One recent observed result is that phonon thermal conduction is enhanced in thin SiN membranes, when the transition from 3D to 2D phonons takes place, a result that we predicted theoretically before. Preliminary theoretical results on modeling will be discussed, as well.

Orbital entanglement and the two particle Aharonov-Bohm effect

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We review recent theoretical investigations on the two-particle Aharonov-Bohm effect and its relation to entanglement production and detection. The difficulties of the entanglement detection due to dephasing and finite temperature are discussed regarding a recent experimental realization of a two-particle Aharonov-Bohm interferometer. We also discuss a theoretical proposal for a two-particle Aharonov-Bohm interferometer, which in contrast to the finite bias setup, is driven with dynamical single-electron sources allowing for the tunable production of time-bin entanglement.

Energy relaxation in the integer quantum Hall regime

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In the quantum Hall regime, the current is carried without dissipation along the sample's edges in channels usually considered as ideal 1D conductors. Interactions are ignored in the most widespread description of the integer quantum Hall regime. However, recent electron quantum optics experiments, using edge channels as light beams, have demonstrated interactions play an important role, which was up to now hidden due to the robustness of Hall currents (see e.g. the pioneer work [1] and P. Roche seminar). In order to reveal the interaction mechanisms, and their consequences on the quantum lifetime and nature of electronic states, we have developed an experimental approach based on the measurement of energy transfers along edge channels. The key ingredient of the experiment is the out-of-equilibrium spectroscopy of the energy distribution of electronic states located within an edge channel, using a discrete electronic level in a quantum dot as an energy filter [2]. The experiment was performed at filling factor two, where two adjacent channels propagate along the edge [3]. Whereas there are no discernable energy transfers towards thermalized states, we find an efficient energy redistribution between the two channels without particle exchanges. A quantitative comparison with recent theories [4,5] indicates that nearly one third of the injected energy leaks out towards additional states. The observed short energy relaxation length, typically a few microns for a mean excitation energy of about 10 μeV, challenges the usual description of quantum Hall excitations as quasiparticles localized in one edge channel.

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Probing decoherence in the Integer Quantum Hall regime

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The easy manipulation of the edge states of the Integer Quantum hall regime opens the way for quantum optic like experiments with electrons. This has renewed the interest of the community for studying decoherence mechanisms in the IQHE regime. In this talk, we will present an overview of experimental results on the interference visibility in Mach-Zenhder interferometers, carefully comparing the experimental data with the flourishing existing theories. More particularly, we will describe the process responsible for the observed 1/T temperature dependence of the coherence length, and we will discuss energy exchange effects possibly revealed with the Mach-Zehnder interferometer.

Spectroscopy of Collective Modes in Few-electrons Quantum Dots

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Quantum correlations among electrons confined in semiconductor quantum dots are expected to lead to exotic states of matter. Correlated states of few electrons in quantum dots are also ideal candidates for quantum information processing. In this talk I'll present our recent studies of spin states and electron correlation in nanofabricated AlGaAs/GaAs quantum dots in which the number of electrons is finely tuned by optical methods [1,2]. The experiments are based on resonant inelastic light scattering at the extreme conditions of ultra-low temperature. We probe the evolution of the neutral collective charge and spin excitations as the number of confined electrons is changed with single-electron accuracy. In the dilute limit, the impact of Coulomb correlation leads to the formation of molecular-like electron states with characteristic roto-vibrational modes. [2,3] Our findings open a new venue towards the all-optical manipulation and studies of few electrons in quantum dots.

* Work in collaboration with A. Singha, S. Kalliakos A. Pinczuk, M. Rontani, G. Goldoni, E. Molinari, L. N. Pfeiffer and K. W. West.

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Consistent treatment of cotunneling and coherence in nanostructure transport

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Coherent superpositions of states are of crucial relevance for a variety of different confined systems such as double dots, spin devices, or further systems exhibiting degeneracy. In the noninteracting case these can be conveniently taken into account by the transmission approach. However in the presence of electron-electron interaction, the inclusion of coherence results in many complications, such as the failure of the Hubbard-I approximation [1]. It is shown that our second order von Neumann approach [2] allows for a consistent treatment for the interplay between coherence and interaction in a nonequilibrium situation. In particular we are able to reproduce the recently observed canyon of conductance suppression for the alignment of different levels with identical spin [3].

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Bulk transport in topological insulators

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Topological insulators (TIs) are systems that have a bulk gap and surface states which are protected by time-reversal symmetry. I give an introduction into this fascinating new subject highlighting the transport aspect of it. In the two-dimensional TI, the surface is one dimensional and hosts the so called quantum spin Hall effect [1]. Prime examples of such two-dimensional TIs are HgTe quantum wells (QWs). Depending on the thickness of the QW, they can be topologically trivial (no edge states) or topologically non-trivial (helical edge states). However, I show using an effective 4-band model for the QW states, that the topology is also revealed in bulk transport experiments. I will discuss the conductance and shot noise of ballistic bulk transport in HgTe QWs [2].

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Carbon nanotubes and semiconductor nanowires for building blocks of quantum nanodevices

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Single-wall carbon nanotubes (SWCNTs) and semiconductor nanowires are grown in a self-assembled manner, and have diameters that are difficult to realize with conventional top-down technology. The one-dimensional characteristics of those materials include the formation of the simple shell structures and a possible fabrication of the superstructures or hetero-structures in the length direction. As examples, the talk covers the following topics below.

1) Introduction -Artificial atom behaviors of the SWCNT quantum dot [1-3]

It is shown that the electrons confined in the SWCNT behave those confined in the one-dimensional hard-wall potential. This makes the degeneracy of the quantum states, independent on the number of electrons or the quantum numbers. In the SWCNT quantum dots, the four or two electron shell structures are observed even with many electrons in the dot. The similar two-electron shell behaviors (the even-odd effect) appeared to be observed in our preliminary measurements on the Ge nanowire quantum dots. (The work on the Ge nanoires has been done in collaboration of Dr. Fukata of NIMS in Japan.)

2) Chemical modification of SWCNTs and their molecular scale nanostructures

Two examples of SWCNT-based molecular scale nanostructures are shown. The ring structures were fabricated with both SWCNT ends connected chemically. The scanning tunneling spectroscopy (STS) revealed a standing-wave pattern along the ring at a liquid nitrogen temperature, indicating the ballistic nature of the ring. Another example is SWCNT/molecule heterostructures. The STS study has made it possible to study the density of states and the confinement potential of a SWCNT terminated by molecules at both ends.

3) InAs nanowires with superconducting contacts

One-dimensional structures with superconducting contacts are unique SNS (Super/Nomal/Super) structures that could be applied to the Andreev qubit [4]. In this talk, I will present our recent results on the transport measurement of the InAs nanowires with Al contacts. We have observed the supercurrent that was modulated by the back gate and the effects of multi-Andreev scattering process in the current-voltage characteristics.

(This work has been done in collaboration with Dr. Tateno of NTT and Prof. Xu of Lund university)

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Transport in semiconductor nanowire quantum dots with superconducting contacts

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Semiconductor nanowires and carbon nanotubes are attractive materials for studying transport in tunable quantum dots with ferromagnetic or superconducting leads. I will focus on nanowires coupled to superconductors and give a few recent examples; strong conductance fluctuations [1], nonlinear transport in the Kondo regime [2] with enhanced subgap resonances [3], and Cooper pair splitting into double dots (crossed Andreev reflections) [4]. The latter two phenomena have also been observed in single-wall carbon nanotube devices by Eichler et al. [5] and Hermann et al. [6], respectively. All experiments reported here were based on III-V (InAs) nanowires grown by Molecular Beam Epitaxy [7].

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Controlling InAs nanowire Josephson transistors by hot-electron injection

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The ability to induce and control proximity effect in self-assembled nanoscale materials can open exciting opportunities in terms of novel devices and fundamental research. Recent experimental works demonstrated the potential of semiconductor nanowires for the implementation of nanometer-scale hybrid superconductor-normal devices [1-2]. Here we demonstrate InAs nanowire-based Josephson transistors whose supercurrent is controlled by the injection of hot quasiparticles through normal-metal electrodes coupled to the same nanowire. Josephson superconductor-normal-superconductor (SNS) junctions were realized by evaporating Ti/Al contacts on doped InAs nanowires (see Fig.1). Large supercurrent intensity up to 350 nA at 370mK will be shown and its dependence as a function of the temperature analyzed. We shall show that dissipationless transport in the nanowires can be effectively controlled by injection of hot electrons from (normal) Ti/Au contacts. This mechanism of supercurrent tuning is based on the modification of the electron distribution in the junction region and offers key advantages with respect to the more standard field-effect approach [3-5]. Power-budget analysis in the studied nanodevices will be presented and the resulting thermoelectric parameters discussed together with the magnitude of the electron-phonon interaction. The relevance of our experimental findings will be discussed in light of the development of novel hybrid devices [5].

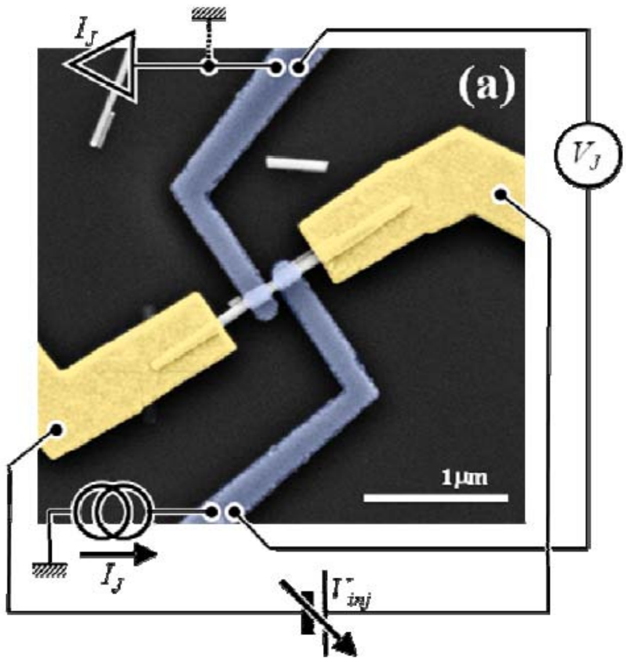

Figure 1- SEM image of one of our InAs nanowire Josephson transistors. A sketch of the measurement setupis also shown in the overlay schematics: hot carrier injection on Ti/Au normal contacts (yellow) is used to control Josephson current flowing through the two Ti/Al superconducting electrodes (blue) deposited on the nanowire.

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Feedback Control of Quantum Transport

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The current through nanostructures like quantum dots can be stabilized by a feedback loop that continuously adjusts system parameters as a function of the number of tunneled particles *n*. At large times, the feedback loop freezes the fluctuations of *n* which leads to highly accurate, continuous single particle transfers. For the simplest case of feedback acting simultaneously on all system parameters, we show how to reconstruct the original full counting statistics from the frozen distribution.

Non-equilibrium noise spectrum through a quantum dot: a functional renormalization group study

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We use functional renormalization group to study the frequency-dependent noise spectrum of a quantum dot in the local moment regime. We show that, to satisfy current conservation, one must renormalize the current vertex, which becomes non-local in time. We derive the corresponding scaling equations, and compute the frequency-dependent noise and the ac conductance through the dot in the perturbative regime, $V \gg T_K$ with T_K the Kondo temperature. The symmetrical noise shows strong features at frequencies, $\omega = \pm eV$, where a Kondo dip appears. Correspondingly, the ac conductance exhibits Kondo peaks at frequencies, $\omega = \pm eV$, which can be understood as photon-assisted tunneling through the finite voltage Kondo resonances. The observed singularities are found to be present already in simple real time perturbation theory, which is, however, unable to capture precisely the logarithmic features at $\omega \approx \pm eV$

Electronic properties of graphene nanostructures

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Graphene quantum dots and constrictions have been fabricated by mechanical exfoliation of graphene followed by electron beam lithography and dry etching. The single layer quality of graphene has been checked by Raman spectroscopy. A variety of nanostructures such as graphene constrictions, graphene quantum dots and graphene rings have been realized. In this talk we focus on the electron hole crossover in graphene quantum dots as well as the electronic transport through graphene double dots. The goal is to establish the peculiar consequences of the graphene bandstructure with its linear dispersion for the electronic properties of nanostructures. Furthermore we present time-dependent measurements of electron transport through graphene quantum dots as measured with a non-invasive detector.

Strong coupling of single-electron tunnelling to nanomechanical motion in a clean carbon nanotube

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In conventional nanotube quantum dot devices, nanotubes are first deposited on the surface of a substrate and subsequently patterned to make nanoscale devices. While this process is very flexible, it has the disadvantage that the nanotube can become contaminated and damaged by chemical and electron beam processing. Here, we present results from a new type of clean nanotube device that avoids all possible damage to the nanotube by growing it in the last step of fabrication.
By eliminating disorder, we now routinely confine single electrons and single holes in a confinement potential that can be tuned continuously from that of a single to a double quantum dot [1].

Clean carbon nanotubes also possess remarkable mechanical properties as high frequency nanomechanical resonators with quality factors exceeding 10^5 [2]. Here, we study the coupling of a quantum dot embedded in a suspended carbon nanotube to this mechanical motion [3]. Taking advantage of the high quality factor, we observe a shift in the frequency of the mechanical resonator due to the electrostatic force exerted on it by a single electron that is 100 times larger than the resonance linewidth. In addition to this static force, the quantum do also exerts a dynamic, fluctuating force on the mechanical resonator when current flows through the quantum dot. As a function of gate voltage, we observe single-electron tuning oscillations in the resonance frequency that are a mechanical analogue of single-electron tunneling oscillations in the quantum dot current.

Additional evidence for the strong coupling of mechanical motion and electron tunneling is provided by an energy transfer to the electrons causing mechanical damping, and a tunable nonlinear behavior that is controlled by the charge state of the quantum dot. We also observe a strong feedback due to this coupling in which the d.c. current through the quantum dot spontaneously drives the mechanical resonator, exerting an oscillating force that is coherent with the high-frequency resonant mechanical motion.

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Fabrication and performance of carbon based nanoelectronic and optoelectronic devices

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Ballistic n-type carbon nanotube (CNT) based field-effect transistors (FETs) [1] have been fabricated by contacting semiconducting single wall CNTs using Sc. Together with the demonstrated ballistic p-type CNT FETs using Pd contacts, this closes the gap for doping free fabrication of CNT based ballistic CMOS and high performance optoelectronic devices [2,3]. The feasibility of this doping free CMOS technology has been demonstrated by fabricating a simple CMOS inverter on a SiO_2/Si substrate [4,5], but in principle much more complicated CMOS circuits may be integrated on a CNT on any suitable insulator substrate. This CNT based CMOS technology only requires the patterning of arrays of parallel semiconducting CNTs with moderately narrow diameter range, e.g. 1.6-2.4nm, instead of the more stringent chirality control on the CNT. This may lead to the integration of CNT based CMOS devices or entire carbon based circuit [6] with increasing complexity and possibly find its way into many possible applications, including logic and optoelectronic circuits.

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Charge and heat transport in the hybrid single-electron turnstile

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We discuss the operation principle of the single-electron turnstile in form of a SINIS (S for superconductor, I for insulator, N for normal metal) single-electron transistor. We discuss experiments on it and show that it can potentially be used for the redefinition of unit ampere. We demonstrate that its performance can be improved by self-cooling. Different regimes of cooling via single-electron transport will be discussed.

Electronic cooling in superconductor-based tunnel junctions : basics and practical Limitations

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A significant electron cooling is routinely obtained in a micro-cooler made of a pair of Superconductor- Insulator-Normal metal (S-I-N) junctions biased at a voltage just below the superconducting gap. Nevertheless, the operation of such coolers appears usually to be less efficient than theoretical expectations. After introducing the basic principles at the heart of superconducting micro-coolers, I will review the practicals limitations to electronic cooling due to electron-phonon coupling, Andreev current, electron back-tunneling, thermal noise...

Thermoelectric effects in nanowire-embedded quantum dots

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Thermoelectric devices directly convert heat into electricity. Low-dimensional semiconductor systems, can be used to select the energy of electrons that can traverse these structures. Energy-filtering is required for any thermoelectric effect, but the additional tunability afforded by artificial low-D systems offers the opportunity to optimize the electronic conversion efficiency.

I will discuss theory [1,2], experiments [3,4] and modelling [5] on the fundamental limits of conversion efficiency in low-D structures. An ideal quantum dot can be used to transform heat into electricity near Carnot efficiency, but with negligible power output. Another limit of more practical interest is the maximum power regime, and I will compare modeling results on fundamental 0D, 1D and 2D systems with respect to their maximum power output and their efficiency near maximum power. I will also discuss proof-of-principle experiments to demonstrate near-Carnot efficiency in thermoelectric energy conversion using a quantum-dot based energy filter embedded into III-V, heterostructure nanowires at low temperatures, which we believe demonstrate electronic (ignoring phonons) thermal-to-electric conversion efficiency on the order of 90% of the Carnot limit.

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Abstracts of poster presentations in alphabetical order

Excitation of surface plasmons in planar periodic structures

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The interaction of light with sub-wavelength nanostructures can show various novel behaviors. If the nanostructures are made from metals, incident light with certain wavelengths can lead to the excitation of surface plasmons [1]. In this case the electromagnetic fields in the vicinity of the nanostructures can show complicated characteristics with the possibility of strong field enhancement. The optical transmission and reflection at these wavelengths also show characteristic features. These properties of metal nanostructures have potential applications in single molecule detection, in development of nano-biosensors, and in novel plasmonic crystals.

In this work, we report on a theoretical study of the optical near-field distribution, the optical transmission, and the optical reflection, of a metal film patterned periodically with sub-wavelength nano-holes. The studied system consisted of a gold plate of thickness 15-230 nm, patterned periodically with nano-holes of 60-170 nm in diameter, on a thick silicon dioxide. The nano-holes as well as the top side of the metal plate were filled with water. Light was sent in toward the plate from the silicon dioxide side. The optical response of the system was calculated for different wavelengths by solving the Maxwell equations using a scattering matrix method [2]. It was found that the optical extinction showed a number of peaks. The number of peaks and the positions of the peaks depended strongly on the periodicity of the hole array and the thickness of the gold plate. The analytical dispersion of surface plasmons in a smooth gold film was used to show that the peaks originate from surface plasmon resonances. The calculated electromagnetic field distribution showed that strong field intensities occur inside the patterned gold plate at these surface plasmon resonances. The results shed light on the physics of surface plasmon resonances in periodic structures, and could be employed for the development of novel plasmonic crystals that control effectively the flow of light at the nanoscale.

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Proposal for non-local electron-hole turnstile in the Quantum Hall regime.

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We present a theory for a mesoscopic turnstile that produces spatially separated streams of electrons and holes along edge states in the quantum Hall regime. For a broad range of frequencies in the non-adiabatic regime the turnstile operation is found to be ideal, producing one electron and one hole per cycle. The accuracy of the turnstile operation is characterized by the fluctuations of the transferred charge per cycle. The fluctuations are found to be negligibly small in the ideal regime.

Electronic cooling performance of SINIS and SIS'IS based tunnel junction with manganese doped aluminum.

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Voltage induced quasi-particle tunneling in a superconductor-insulator-normal metal-insulator-superconductor (SINIS) based tunnel junctions is a novel concept with many potential technological applications such as solid state cooling and thermometry [1]. The principle of quasiparticle cooling in such devices is based on the existence of forbidden energy states within the gap of the superconductor [2]. Upon application of a suitable bias voltage across the junctions, only those electrons in the metal which are above the Fermi level (E_F) can tunnel via the insulating barrier into the superconductor via one junction while quasiparticles with $E < E_F$ are retuned into the normal metal through the other thereby leading to a decrease in the average electron energy of the normal metal [3]. Furthermore, electrical characteristics of these NIS junctions are extremely sensitive to the temperature of the normal metal which makes these junctions ideal for accurate thermometry. Although the cooling power depends upon the superconducting energy gap, the inadvertent Joule heating of the normal metal electrode is an important factor that can affect the performance of these junctions. Manganese doped aluminum (Al:Mn) is an alloy whose resistivity can be tuned by varying the concentration of Mn. We are investigating the effect of the metal electrode resistivity on cooling characteristics of Al-AlO*x*-Al:Mn based NIS junctions. The cooling characteristics will be investigated as a function of the Mn concentration. Moreover, superconducting transition temperature of Mn doped aluminum is expected to be a function of the Mn concentration. For low enough Mn concentration we expect a suppression of Tc in Mn:Al. This means below the the critical temperature of Mn:Al the NIS junction behaves essentially as an SIS junction. The cooling characteristics in the SIS regime will also be investigated.

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Kondo effect, multiple Andreev reflection and induced superconductivity in InSb nanowire hybrid devices

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The authors present superconductor-semiconductor-superconductor hybrid-devices fabricated from InSb nanowires with Ti/Al metal leads. At low temperature, superconductivity induced by proximity-effect and Multiple Andreev Reflection are observed. Devices with different spacing between the Ti/Al leads are investigated, where a larger spacing allows the formation of a quantum dot between the metal electrodes. Here, also the Kondo effect is observed. Interesting interplays among these effects are investigated with magnetic field and temperature dependence measurements.

InAs/InSb heterostructure nanowires are grown by metal-organic vapor phase epitaxy from 40 nm Au aerosol seed particles deposited on a <111>B InAs substrate. In the first stage of growth, the InAs segments are grown from the gold particles. The grown InAs segments are then used as seed nanowires to favor nucleation of InSb in the second stage of growth. The InSb nanowire segments are zincblende crystals and free from twin boundaries, stacking faults, and tapering [1,2].

The grown InAs/InSb nanowires are transferred to degenerately doped, SiO_2 capped, Si substrates. After locating the wires, a set of two 200 nm wide electrodes with varying spacing are fabricated to each InSb segment using electron beam lithography. To obtain a clean metal/semiconductor interface, the exposed semiconductor contact areas are briefly etched in a $(NH_4)_2S_x$ solution followed by a rinse in H_2O. Finally, 5 nm Ti and 85 nm Al was deposited using physical vapor deposition. Electrical measurements are performed using a dilution refrigerator with temperatures in the range of T = 25 mK to T = 1 K.

In devices with short electrode spacing, approximately 30 nm, the device characteristics are governed by superconductivity proximity-effect and multiple Andreev reflections. Depending on the silicon back-gate voltage, we observe a critical current of the induced superconductivity in the device in the range of I_C = 0.1 nA to 7 nA with a strong correlation to the nanowire conductivity in the normal state. We investigate the magnetic field and temperature dependences of the induced superconductivity. At a magnetic field of B = 30 mT, the induced superconductivity is suppressed, resulting from a suppression of the superconductivity in the Ti/Al electrodes.

In voltage-bias measurements, the current through the superconducting device quickly increases until it reaches I_C of the induced superconductivity and the InSb nanowire turns resistive. However, as the critical current of the Al leads is large, metal electrodes are likely to remain superconducting. In these measurements we observe several gate-voltage independent lines of high differential conductance, at a source-drain biases of $|V_{sd}| < 0.35$ mV = $2\Delta_C$. We attribute these to Andreev reflection in a superconductor-normal metal-superconductor junction consisting of the Ti/Al electrodes and the InSb nanowire. Also, here, we investigate the magnetic field and temperature dependences. In this case the behavior agrees well with the standard theory of superconductors.

As the electrode spacing is increased to approximately 80 nm, a quantum dot is formed between the metal/semiconductor interfaces. Here, the induced superconductivity and multiple Andreev reflections persist. However, the effects of Coulomb charging and energy quantization also appear. In even charge configurations, the quantum dot shows clear multiple Andreev reflections. But as the quantum dot is tuned to an odd charge configuration a vertical stripe of high conductance appear at zero applied bias voltage. We attribute this Kondo-enhanced induced superconductivity. In this charge configuration, the first order Andreev reflection is strongly suppressed, and the second order is enhanced. Here, we also observe the third order Andreev reflection, which is not visible in the even charge state. Both temperature and magnetic field dependence of the Kondo-enhanced induced superconductivity is investigated. Due to the large *g* factor of InSb it is possible to split the Kondo-peak before the superconductivity is suppressed.

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Quantum dots in a high-mobility two-dimensional electron gas coupled to superconducting electrodes

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The interplay between nondissipative currents and single electron phenomena in nanoscale hybrid systems represents a frontier topic in modern solid state physics. Devices made of semiconductor quantum dots connected to superconducting leads have been indeed the subject of extensive theoretical and experimental research in the past few years.

Here we report on the realization of this hybrid device in a high mobility two-dimensional electron gas (2DEG) confined in an $In_{0.75}Ga_{0.25}As/In_{0.75}Al_{0.25}$ As epitaxial heterostructure. The quantum dot, defined in the junction between two Niobium leads is obtained with a top-down approach which allows for a large degree of tunability of the dot geometry and coupling to the leads. By means of zero bias spin-spectroscopy at finite magnetic fields we measure the effective gyromagnetic factors and demonstrate tunability of the few-electron spin states. At zero magnetic field, we show that quasiparticle transport through the dot is affected by the presence of a proximity-induced energy gap in the 2DEG density of states. These findings open promising venues for the exploitation of these nano-fabricated devices as tunable Josephson switches.

Studies of thermoelectric effects in nanowire-based quantum dots

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A quantum dot could be an efficient system for thermoelectric energy conversion, since the system makes it theoretically possible to have transport at an energy which fulfills the requirements for Carnot efficiency. The system together with thermovoltage measurements also has an importance for transport physics research in general since it offers new ways to investigate nanoscale thermoelectric effects, and can yield information that is complementary to traditional conductance measurements. Here we present experimental measurements of thermoelectric phenomena created by a single quantum dot at low-temperature and discuss possible future measurements, including the study of observed electron-hole asymmetries in thermovoltage, and spin effects.

Realization of hole quantum dots in GaSb nanowires

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Hole quantum dots were realized using GaSb segments of GaAs/GaSb heterostructure nanowires. The nanowires were grown from 30 or 40 nm gold aerosol particles which were deposited on a GaAs(111)B substrate. The sample consists of undoped GaAs/GaSb nanowires grown with MOVPE, where the precursors used were TMGa, TMSb and AsH_3. The nanowires were transferred from the growth substrates to highly doped Si substrates with a 100 nm thick SiO_2 capping layer. After the wires were located, Ti/Au contacts with a varying spacing were defined to each GaSb nanowire segment. To obtain clean metal-nanowire interfaces, the exposed semiconductor contact areas were briefly etched in an HCl solution prior to metal evaporation. The fabricated devices were characterized by low temperature transport measurements where periodic conductance oscillations due to Coulomb blockade were observed in the measurements with a charging energy of 5 meV. The conductance shows the typical back-gate voltage behavior expected for hole transport, as verified by biasing the device outside the Coulomb blockade regime, and from measurements at non-cryogenic temperatures.

From adiabatic to nonadiabatic charge pumping in a phase-biased Cooper-pair sluice

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The Cooper-pair sluice is a superconducting charge pump consisting of a tunable SSET with two DC SQUIDs acting as tunable Josephson junctions. It is effectively a two-level system that can be controlled adiabatically: during a pumping cycle, a closed path is described in the space of parameters while the non-degenerate ground state undergoes adiabatic evolution. The pumped charge can be directly related to the accumulated Berry phase, a fact that recently allowed for the measurement of the latter (3). Our current research aims at understanding the influence of environmental noise on the otherwise adiabatic evolution of such systems, which is of crucial importance with respect to the development of holonomic quantum computation in superconducting circuits.

Reducing 1/f noise in Al-AlOx-Al tunnel junctions by thermal annealing

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Al–AlOx–Al tunnel junctions can be stabilized by annealing them in a vacuum chamber at temperature of 400_C [1]. Here we report for the first time that the annealing procedure also reduces the characteristic 1/f noise in the samples. Both ultra high vacuum and high vacuum fabricated samples demonstrated a significant reduction in the 1/f noise level, but no effect was found between substrates of nitridized and oxidized silicon wafers. Temperature dependence of noise levels was studied at temperatures between 4.2 and 340 Kelvin where neither linear nor quadratic dependence was detected. The low frequency noise was measured using an AC bridge amplitude modulation technique, which effectively eliminates the otherwise dominating preamplifier 1/f noise [2].

Tunnel junction is a versatile nanoelectrical component, which has many applications such as radiation detectors, Coulomb blockade thermometers, single electron transistors, SINIS coolers and thermometers and an usage in quantum computation as a solid-state realization of a qubit. The instability of the junctions is a common problem for applications. The oxide barrier has imperfect crystal structure after fabrication, thus the barrier atoms may try to spontaneously reorganize to equilibrium positions. This is seen as an increase of tunneling resistance with time. At room temperature, this spontaneous relaxation takes a long time. One other possible explanation might be that the barrier absorbs other unwanted molecules inside to fill vacancies, since vacuum conditions prevent aging significantly.

1/f noise is still without commonly accepted theory, but experimental results indicate it originates from defects like a two-level system which spontaneously oscillates, like an impurity atom in a lattice [3]. One motivation to study 1/f noise in Al–AlOx–Al tunnel junctions is the possible use of tunnel junctions in quantum computation. Our results may have some relevance in reducing the critical current fluctuations in superconducting quantum bits based on tunnel junctions, where the 1/f noise causes decoherence [4].

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Conductance suppression in a spinless 2-level quantum dot

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The large level-dependent g-factors of InSb nanowires faciliate the study of level crossings in quantum dots. Recent experimental and theoretical studies [1] show that a strong conductance suppression results from the degeneracy of two levels with the same spin. This conductance suppression is strongly related to a large coherence between the levels. Our simulations show how the suppression is affected by couplings, charging energy, the position of the energy levels, applied bias and temperature. At low bias and temperature a strong conductance suppression is present around the electron hole symmetry point independent of the couplings, in agreement with previous results [2]. Away from electron hole symmetry the parity of couplings is essential for the conductance suppression. It is shown how broadening, interference and a finite interaction energy lead to a minimum in conductance away from degeneracy. A slight detuning of the energy levels results in peaks in the conductance. Introduction of a finite anti-crossing prohibiting inelastic co-tunneling leads to a decrease in the peak height. Simulations are carried out using the second order von Neumann method [3].

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Nuclear-spin-induced singlet triplet mixing in a few-electron lateral InGaAs double quantum dot

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Knowledge of the interaction between spins and the environment is critical in the implementation of spin qubits in semiconductor quantum dots. The hyperfine interaction between the electron spins on the quantum dot and the spins of the nuclei in the dots is a big source spin-decoherence in these systems and is therefore important to characterize. InGaAs is an interesting choice of material for spintronic devices owing to its large g-factor and spin-orbit interaction compared to more standard GaAs-based systems. We present low-temperature transport measurements and study the hyperfine interaction of a few-electron double quantum dot with an integrated charge sensor in the Pauli spin-blockade regime formed in an $In_{0.75}Ga_{0.25}As/InP$ heterostructure.

The sample was fabricated on a high-mobility $In_{0.75}Ga_{0.25}As/InP$ quantum well heterostructure by defining a quantum wire and quantum point contact by etching trenches and deposition of closely spaced finger gate electrodes.

Low-temperature transport measurements were performed in a dilution refrigerator. A double quantum dot system was formed in the quantum wire by applying negative voltages to the finger gates while the conductance of the quantum point contact was tuned such that it acted as a sensor for the charge states *(m,n)* of the double quantum dot. At the (2,5) charge state the double dot showed typical Pauli spin-blockade behavior at finite bias with suppression of the resonant and inelastic transport currents. For weak interdot coupling, a larger leakage current in the Pauli spin-blockade region was clearly visible in the case of resonant transport, indicating strong mixing of the singlet and triplet states of the left dot. We attribute this mixing to the hyperfine coupling to the non-zero nuclear spin of InGaAs, which gives rise to an effective nuclear magnetic field. By studying the leakage current in the inelastic transport region as a function of detuning of the energy levels of the two dots and as a function of an externally applied magnetic field, the effective nuclear magnetic field was determined to 2.7 mT.

Kondo effect in spin-orbit mesoscopic interferometers

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Spin-orbit interactions have attracted many interests since the advent of spintronics. A typical spin-orbit interaction is the Rashba interaction, which arises in inversion asymmetric semiconductor heterostructures [1]. Here [2], we consider a flux-threaded Aharonov-Bohm ring with an embedded quantum dot coupled to two normal leads. The local Rashba spin-orbit interaction acting on the dot electrons leads to a spin-dependent phase factor in addition to the Aharonov-Bohm phase caused by the external flux [3,4]. Using the numerical renormalization group method, we find a splitting of the Kondo resonance at the Fermi level which can be compensated by an external magnetic field [5]. To fully understand the nature of this compensation effect, we perform a scaling analysis and derive an expression for the effective magnetic field. The analysis is based on a tight-binding model which leads to an effective Anderson model with a spin-dependent density of states for the transformed lead states [6]. We find that the effective field originates from the combined effect of Rashba interaction and magnetic flux and that it contains important corrections due to electron-electron interactions. We show that the compensating field is an oscillatory function of both the spin-orbit and the Aharonov-Bohm phases. Moreover, the effective field never vanishes due to the particle-hole symmetry breaking independently of the gate voltage.

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Experiments on a Cooper pair insulator

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Ultrathin amorphous Bismuth films, patterned with a nano-honeycomb array of holes, can exhibit an insulating phase with transport dominated by the incoherent motion of Cooper pairs of electrons between localized states. We will show how this new localized state of Cooper pairs behaves when the underlying geometry of the substrate is modified. We will also show that the magnetoresistance of this Cooper pair insulator well below the pair formation temperature is positive and grows exponetially with decreasing temperature. It peaks at a field estimated to be sufficient to break the pairs and then decreases monotonically into a regime in which the film resistance assumes the temperature dependence appropriate for weakly localized single electron transport.

Giant, level-dependent g-factors and spin correlations in InSb nanowire quantum dots

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In bulk, InSb is a narrow band gap (E_g = 170 meV) semiconductor with high electron mobility (μ_n = 77 000 cm^2/Vs) and is therefore of relevance for low power and high speed transistor applications. It also has a low electron effective mass ($m_e^* = 0.015m_e$) and a very high electron g-factor $|g| = 51$ which is of interest for studies of quantum and spin physics.

InAs/InSb heterostructure nanowires are grown by metal-organic vapor phase epitaxy from 40 nm Au aerosol seed particles deposited on a <111>B InAs substrate. In the first stage of growth, the InAs segments are grown from the gold particles. The grown InAs segments are then used as seed nanowires to favor nucleation of InSb in the second stage of growth. The InSb nanowire segments are zincblende crystals and free from twin boundaries, stacking faults, and tapering [1].

The grown InAs/InSb nanowires are transferred to degenerately doped, SiO_2 capped, Si substrates. After locating the wires, a set of two 150 nm wide Ti/Au electrodes with varying spacing are fabricated to each InSb segment using electron beam lithography. At low temperatures the metal/semiconductor contacts act as barriers for the electrons, thereby creating a quantum dot in the InSb nanowire. By varying the spacing of the metal contacts quantum dots with different electron occupation number ranging from the many-electron down to the few-electron regime could be achieved.

In order to investigate the effective electron g-factors, magnetotransport measurements were performed on the fabricated InSb nanowire quantum dots. From these we can conclude that the g-factors are strongly level-dependant [2] and have values in the range of 19 to 68. Given the high, strongly level-dependant g-factors, we observe many level-crossings in the energy spectrum of the quantum dots.

In many cases we observe stripes of high differential conductance at zero source-drain bias inside the Coulomb-blockade region. These stripes are split by an applied magnetic field. We attribute these to S = 1/2 Kondo effect in the InSb quantum dots. In several cases we also observe an increased conductance over-bridging the Coulomb-blockaded gap at level crossings at finite magnetic field. This can be attributed to an integer spin Kondo-like effect.

In some cases it is also possible to indentify a crossing of quantum levels with *equal* spin. Here we find a stripe of suppressed cotunneling, over-bridging the Coulomb-blockaded gap and cutting through the direct tunneling lines. We attribute the suppression to destructive interference of electrons which pass the quantum dots through two indistinguishable spin-correlated many body states.

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Wrap-gate-induced field-effect diodes in InP nanowires

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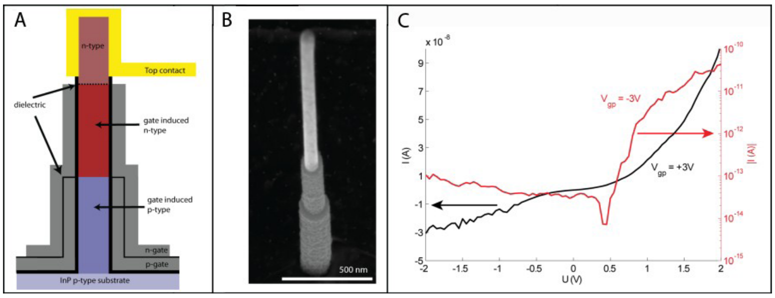
When designing and optimizing conventional semiconductor devices, the doping level is probably the single parameter that is most often tampered with. The drawback of using impurity-based doping to control the electrical properties of a semiconductor is that its effects are inherently static and permanent. The electrical properties can however, albeit to a lesser extent, also be manipulated in a more dynamic fashion using external electric fields, a technique known as field-effect gating. Many solid state electronic components, for instance the planar field-effect transistor, rely on both gating as well as doping in order to function. With the advent of more novel device geometries in recent years, it is slowly becoming feasible to create semiconductor components where the active properties are essentially determined by the use of field-effect gating alone, as opposed to being primarily defined by doping levels set during device fabrication.

In nanowire-based devices, for instance, it is relatively straightforward to create metallic gate electrodes that wrap all the way around the nanowire. The optimal geometry of such a symmetrical wrap gate provides unrivalled electrostatic control of the charges in the semiconductor channel, enabling highly efficient tuning of the Fermi level, capable of inducing both n-type and p-type behavior in an undoped nanowire segment. This dynamic gate-induced 'doping' could effectively replace conventional impurity-based *in situ* doping in some nanowire devices. Combined with other unique properties of nanowires – such as their natural affinity for studies of one-dimensional transport phenomena – this opens the door to a whole new family of novel devices waiting to be characterized.



We are presently working on a vertical InP nanowire device that utilizes two individually biased wrap gates in order to induce a field-effect diode, or 'articifical p-n junction', Fig. A. The nanowires are grown on a p-doped substrate and are capped with a short n-doped contact segment. The entire length of the active, gated region in the middle of the nanowire is grown nominally intrinsic, i.e. undoped. Fig. B shows a SEM micrograph of an unfinished dual-gated device, in which the upper wrap gate has just been deposited on top of the lower one. Initial measurements on a single nanowire device in a lateral geometry show promising behavior. When a positive voltage is applied to the lower wrap gate, electrons accumulate along the length of the nanowire, resulting in ohmic transport (black curve, left axis). By instead applying a negative voltage, the nanowire is locally inverted beneath the lower wrap gate, causing holes to accumulate. The result is the formation of a gate induced p-n junction in the active region, leading to rectifying, diode-like behavior (red curve, right axis).

Since we are able to set the gate voltages independently of each other – which in effect allows us to tune the Fermi level of the n-type and p-type regions separately – it should be possible to dynamically tweak the characteristics of the device in real time, notably by moving the position of the depletion region inside the active region, a feature that could have very interesting applications. If the device were to be operated as a light emitting diode, for instance, incorporation of a graded band gap in the active region would enable control of the emission wavelength by changing the location of the electron-hole recombination processes using the gate voltages. Another prospect worth pursuing would be to operate the dualgated nanowire device as a doping-free Esaki tunnel diode.

Thermal effects in superconducting hybrid junctions

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In order to deeply understand the cooling effect in superconducting hybrid nanostructures, we investigate the different thermal phenomena taking place in this kind of device. We experiment by using Normal-Insulator-Superconductor junctions as heating or cooling sources and probing temperature of electron and phonon populations. This enables us to quantify the various thermal couplings at work.

Cooling and Thermometry with KIDs

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In this work we succesfully integrate kinetic inductance detectors (KIDs) with microcoolers based on normal metal/insulator/superconducting (NIS) tunnel junctions. We unambiguously demonstrate cooling of the resonators at base temperatures of 300 mK. KIDs prove to be very sensitive thermometers, while at the same time they are in direct thermal contact with a large area. This technology is a promising alternative to adiabatic demagnetization refrigeration or a dilution fridge for space borne observations and spectrometry.