

CeNS PhD Students' Workshop 2005

Waldemar-Petersen-Haus, Hirschegg,
Kleinwalsertal



16.-18. September, 2005

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Program Committee:

Martin Benoit
Alexander Hoilleitner
Florian Marquardt
Friedrich Simmel

Organisation:

Eva Natzer
Evelyn Morgenroth

Program

Time	Friday, Sep 16, 2005	Saturday, Sep 17, 2005	Sunday, Sep 18, 2005
8.00	8.00 Bus Departure University	<i>Breakfast</i>	<i>Breakfast</i>
	8.30 Bus Dep. Munich East		
9.00-9.20		M. Benoit Characterizing properties of individual molecules with proper techniques	L. Kampschulte Hydrogen-bond Networks - Creating structures with cavities between 1.1 and 2.8 nm
9.20-9.40			
9.40-10.00		H. Dietz Protein Structure by Mechanical Triangulation	A. Piera Drug delivery with multifunctional polymer capsules
10.00-10.20		<i>Coffee break</i>	<i>Coffee break</i>
10.20-10.40		M. Schlierf Temperature Softening of a Protein in Single-Molecule Experiments	<i>Informal discussions</i>
10.40-11.00		M. Mickler Investigation of the HSP 90 by TIRF	
11.00-11.20-	<i>11.30 Arrival at Hirscheegg</i>	S. Strasser AFM and Forensics	
11.20-11.40	<i>11.30-13.00h Lunch break (lunch not provided)</i>	R. Sperling Surface modification and functionalization of polymer coated colloidal nanocrystals	
12.00-13.00		<i>Lunch</i> <i>12.00h-14.00h</i>	<i>Lunch</i> <i>12.00h-14.00h</i>
13.00-13.20	F. Marquardt		
13.20-13.40	The quest for quantum coherence in nanophysics		
13.40-14.00	B. Abel How fat is Schrödinger's Cat?		
14.00-14.20	C. Metzger Laser cooling of micromechanical systems	R. Neher Equilibrium and nonequilibrium physics of periodic DNA	<i>Informal discussions</i>
14.20-14.40	A. Holleitner Transport Spectroscopy of Nanostructures	P. Pierobon Dimeric 1d lattice gas: a model for collective molecular transport (or do molecular motors form jams?)	
14.40-15.00		C. Heussinger Stiff Polymers, Foams and Fiber Networks	
15.00-15.20	C. Roessler Freely suspended Quantum Dots	F. Simmel Why Nano and Bio come together: Examples for interactions between diverse fields	
15.20-15.40	D. Kupidura Probing a Kondo correlated quantum dot with spin spectroscopy		
15.40-16.00	<i>Coffee break</i>	<i>Coffee break</i>	
16.00-16.20	R. Toonen Transport in Few-Electron Quantum Dots with Three-Terminals	A. Reuter Nanobioscience with DNA	16.00h Bus Departure Hirscheegg
16.20-16.40	M. Kroner Absorption Spectroscopy on a Single Charge-Tunable Quantum Dot – Resent Results	<i>Informal discussions</i>	
16.40-17.00	D. Koenig NEMS actuation an probing		
18.00	<i>Dinner</i>	<i>Dinner</i>	
19.30	Poster Session		

Lectures Abstracts

How fat is Schroedinger's cat?

Benni Abel, Jan von Delft, Florian Marquardt

Department of Physics, Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-University, Theresienstr. 33, 80333 Munich, Germany

The laws of classical mechanics are no longer applicable when we study physics at the atomic scale. Particles start to behave like waves and their propagation is ruled by the Schrödinger equation. Consequently, a particle can be in two or more states at the same time. The corresponding wavefunction is a superposition.

But what happens if we apply the rules of quantum mechanics to macroscopic objects? Are superpositions of macroscopically large objects possible? Schroedinger raised this question in his famous thought experiment, in which a cat is in a superposition of two macroscopically distinct states, e.g. "dead" and "alive", [1].

In their quest to shed light on this question, recent experiments have tried to produce "macroscopic" superpositions. Examples include the superposition of coherent states of the microwave field in a cavity (Haroche), interference experiments with large molecules, [2], or coherent superpositions in small superconducting quantum interference devices (SQUIDs), [3], [4]. A SQUID in this context basically represents a superconducting ring in which a large number of paired electrons (Cooper pairs) either move clockwise or counterclockwise without any resistance. By controlling the externally applied magnetic flux it is possible to tune the average current to zero. In that case the ground state of the ring is a superposition of two states in which the Cooper pairs are flowing clockwise or counterclockwise.

The question which naturally arises is how "macroscopic" this superposition is. For the specific case of the SQUID this means: What is the number of Cooper pairs that have to change their state in order to turn the clockwise into the counterclockwise current state? A large number would suggest that we are indeed dealing with a large "Schrödinger cat".

In the present work we propose a quantitative measure for the size of a Schroedinger cat. This measure is in principle applicable to any superposition of two many-body states (with fixed particle number). It is consistent with previous approaches by other authors, [5], that had been restricted to a much smaller class of states. As an example we present results for the case of a three-junction SQUID as it had been studied in the experiments of the Mooij group. On the basis of these results, we will discuss in which region of parameter space experimentalists have to look in order to find a "fat" Schroedinger cat.

1. E. Schroedinger, "Die gegenwärtige Situation in der Quantenmechanik", *Naturwissenschaften*, 48, 807, 49, 823, 50,844 (1935).
2. A. Zeilinger, et al., *Phys. Rev. Lett.* 88, 1004041, (2002).
3. J. E. Mooij, et al., *Science* 285, 1036 (1999).
4. J. R. Friedman, et al., *Nature* 406, 43 (2000).
5. W. Duerr, C. Simon, and J. I. Cirac, *Phys. Rev. Lett.* 89, 210402 (2002).

Characterizing properties of individual molecules with proper techniques

Martin Benoit

Lehrstuhl für angewandte Physik LMU - Sektion Physik Amalienstr. 54

To resolve individual molecules the description of molecules as ensembles in thermodynamic equilibrium is not useful. It would be like averaging all the pixels on a computer screen to a single color, but the arrangement of individual pixels is lost. New methods had to come into play to measure single molecules individually. Especially the bio-molecules were in the focus of research for long time. Individual macro molecules like chromosomes were visualized quite early on by **Light Microscopy**. Structural analysis of crystallized bio-molecules with x-ray techniques gave rise to first reliable reconstructed pictures of single molecules on the atomic level. High-resolution **Electron Microscopy** generated pictures of individual molecules and their arrangements in cells. By **Fluorescence Microscopy** the location of single molecules becomes visible and one could trace their movements even in living cells. With **Confocal Microscopy** a 3-d image of the distribution of fluorescent molecules is obtained. A wide field of techniques (total internal reflection **TIRF**, fluorescence resonance energy transfer **FRET**, fluorescence correlation spectroscopy **FCS**...) is opened now since fluorescent labeled molecules can act as sensors too (temperature, concentration of specific ions, pH...). Fluorescent molecules can be used to measure distances on the atomic level by quenching or Förster transfer.

With **Optical** and **Magnetic Tweezers** single molecules can be manipulated and forces as well as mechanic properties can be measured. Same holds for **Atomic Force Microscopy** (AFM). AFM additionally generates pictures of single molecules with the resolution of Electron Microscopes, but in the natural liquid environment of bio-molecules. Therefore Fluorescence Microscopy, Optical Tweezers and AFM are the most prominent techniques to investigate bio-molecules. A completely different approach is **Patchclamp**. It allows tracing the activity of single pores or ion pumps in membranes or cells. A strong tool to understand and to evaluate data from single molecules is **Molecular Dynamic** simulation on large and fast computers. Additionally tools like genetic engineering and advanced bio-chemistry allow to design bio-molecules with almost all kind of variations and combinations. In the interplay of all these single molecule techniques the understanding of the complex nano world in biology (especially in cells) grows further and further.

Protein Structure by Mechanical Triangulation

Hendrik Dietz and Matthias Rief

We report a simple AFM based triangulation method to measure the spatial position of selected amino acids within a folded protein structure with Angstrom precision. The potential of this method is demonstrated by determining the position of three amino acids within Green Fluorescent Protein. Mechanical triangulation can find many applications where bulk structural methods or current single-molecule techniques fail.

Stiff Polymers, Foams and Fiber Networks

Claus Heussinger

In this talk we will be concerned with the elasticity of semiflexible polymer networks. By numerical simulations supplemented by scaling arguments we show that the elastic properties strongly depend on the specific architecture chosen. While cellular foam-like structures can very well be described by the response of a single cell, in fibrous networks mean-field behaviour is generically unstable. Instead, a subtle interplay between the architecture of the Network and the elastic properties of its building blocks leads to intriguing mechanical properties with intermediate asymptotic scaling regimes.

Transport Spectroscopy of Nanostructures

A. W. Holleitner

Various methods have been suggested and realized to contact nanostructures electronically. In this talk I will review conductance measurements on quantum dots, colloidal nanostructures, and single molecules. First, I will explain single electron phenomena, such as conductance quantization and Coulomb blockade. Then, I will discuss techniques how to wire up nanostructures in a reliable way. The most promising methods utilize nanometer sized gaps, in which the nanostructures are then deposited. It is assumed that electrical conductivity is obtained when a single nanostructure bridges the gap and conducts current. Although impressive success in measuring the conductance of organic and inorganic devices has been reported, serious problems are evident. The most notable are the uncertainty about the number of conducting channels and the lack of information about the shape and structure of the metal contacts near the nanostructure. Finally, I will present a promising method which relies on the combination of self-assembly and standard lithographical techniques.

Hydrogen-bond Networks – Creating structures with cavities between 1.1 and 2.8 nm

L. Kampschulte^{*,**}, M. Lackinger^{*}, T. Adlerstein^{**}, S. Griessl^{*}, H. Walch^{*}, G.W. Flynn^{**}, W.M. Heckl^{*,***}

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Self-assembled monolayers (SAMs) are an important grounding for future applications of long range ordered molecular structures in nanotechnology. Hence it is of general interest to understand the parameters determining the growth and stability of these systems. Bimolecular monolayers were grown by spontaneous self-assembly from solution at the liquid-solid interface and subsequently investigated by Scanning Tunneling Microscopy (STM). The co-adsorption of two different molecules, BTB (1,3,5-benzenetribenzoic acid) and TMA (trimesic acid) in open (loosely packed) networks was studied in two different solvents (heptanoic and nonanoic acid). Altering the absolute and relative concentrations of the two compounds in binary solutions resulted in phases with six different structures. Their cavity size ranges from 1.1 nm for a structure solely composed of the smaller TMA molecules up to 2.8 nm for a pure BTB network. All structures are stabilized by twofold intermolecular hydrogen bonding between the carboxylic acid head groups. Moreover, in-situ dilution of liquid mixtures induced phase transitions of the monolayer structures, accompanied by an alteration of the size and shape of cavity voids in the 2-dimensional molecular assembly.

NEMS actuation and probing

Daniel König

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Nano-electromechanical-systems (NEMS) are free standing three dimensional mechanical devices. They are fabricated by lithography and etch techniques like those used in the semiconductor industry. This makes them compatible with integrated circuits. NEMS are widely used in sensor applications. Sensitivities in the range of zeptograms and zeptonewtons have now been reached. Besides applications in the range of classical physics NEMS become increasingly relevant in fundamental research. With further miniaturization they are constantly being pushed closer towards the realm of quantum physics. The possibility to study and observe quantum mechanics in bulk material comes into reach.

Driving and probing mechanisms play an essential role in the investigation and application of these systems. For the operation of NEMS it is important to choose a driving mechanism which is compatible with the application in mind. In this talk a combination of a laser actuation mechanism combined with an electromagnetic detection mechanism is presented. This combination makes it possible to study laser actuation on NEMS with dimensions smaller than those systems which could previously be investigated by laser based driving mechanisms.

Absorption Spectroscopy on a Single Charge-Tunable Quantum Dot – Recent Results

M. Kroner¹, A. Högele¹, S. Seidl^{1,2}, R. J. Warburton², B. D. Gerardot^{3,2}, P. M. Petroff³ and K. Karrai¹

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²School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh, UK

³Materials Department, University of California, Santa Barbara, California, USA

We have recently reported resonant interband absorption in the excitonic ground state of a single self-assembled InAs/InGaAs quantum dot [1]. The excitonic state in the dot can be tuned from neutral to charged simply by applying a gate voltage, since the dots are embedded in a field-effect structure [2].

Transmission spectra of the neutral and the singly charged exciton are Lorentzian-shaped lines with a linewidth of $\sim 2\mu\text{eV}$. The neutral exciton transition reveals two linearly polarized resonances separated by the fine structure splitting. However, when the quantum dot is filled with one additional electron, the resonant absorption of the singly charged exciton shows only one line.

We show that by applying small electric and magnetic fields the basis of the excitonic states can be switched from linear to circular and vice versa. This sharp selection rules also allow us to optically read out the spin of the resident electron in case of a singly charged exciton [3].

[1] A. Högele *et al*, Physica E 21, 175 (2004); A. Högele *et al*, PRL 93, 217401 (2004).

[2] R.J. Warburton *et al*, Nature 405, 926 (2000).

[3] A. Högele *et al*, APL 86, 221905 (2005)

Probing a Kondo correlated quantum dot with spin spectroscopy

D. Kupidura^{1,*}, M. C. Rogge¹, W. Wegscheider², and R. J. Haug¹

¹ Institut für Festkörperphysik, Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany ² Angewandte und Experimentelle Physik, Universität Regensburg, D-93040 Regensburg, Germany

We report a competition between Kondo effect and spin blockade observed on a many-electron ($N \sim 160$) quantum dot. We make use of the spin spectroscopy to obtain the spin resolved charge configuration of our dot. The maintained charge structure contradicts the simple model of no interacting electrons within the quantum dot. After [1] we propose an alternative model of charge composition what enables us to explain our results qualitatively. We observe the Kondo effect to be terminated with raising spin blockade as the magnetic field increases.

[1] M. Ciorga, A. Wensauer, M. Pioro-Ladriere, M. Korkusinski, J. Kyriakidis, A. S. Sachrajda, and P. Hawrylak, **Phys. Rev. Lett.** **88**, 256804 (2002).

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The quest for quantum coherence in nanophysics

Florian Marquardt

Even though quantum mechanics is certainly needed to describe quantitatively any experiment on the nanoscale, controlling and exploiting quantum coherent effects in a reliable way is a rather difficult (yet important) goal that is actively being pursued today. In this talk I will sketch the developments that have taken place over the past two decades in mesoscopic physics and nanophysics, leading to ever more precisely tunable coherent quantum systems. Whenever possible, I will emphasize the connections to other disciplines like quantum optics and atomic physics.

Initial experiments focused on electron wave interference effects in disordered metals and semiconductors (comparable to scattering of laser light from rough surfaces), followed by experiments in custom-designed interference devices (“Aharonov-Bohm” rings etc., comparable to photon interferometers). Transport via tunneling (although itself a quantum effect) can be described by “classical” rate equations, unless coherence is maintained either by going to few-electron “quantum dots” inside a semiconductor or to superconducting metal islands containing billions of electrons. Both groups of devices have been proposed as implementations of “quantum bits”, i.e. building blocks for a “quantum computer”. Here the concepts of “entanglement” (nonclassical correlations between two quantum systems) and “decoherence” (destruction of quantum mechanical interference effects) become important, and I will explain their connection. The overview will conclude with some remarks on recent attempts and proposals to explore quantum coherent phenomena in nanomechanical systems.

Laser cooling of micromechanical systems

Constanze Metzger, AG Karrai

The prospect of realizing entangled quantum states between macroscopic objects and photons has recently stimulated interest in new laser-cooling schemes. For example, laser-cooling of the vibrational modes of a mirror can be achieved by subjecting it to a radiation or photothermal pressure, actively controlled through a servo loop adjusted to oppose its brownian thermal motion within a preset frequency window. In contrast, atoms can be laser-cooled passively without such active feedback, because their random motion is intrinsically damped through their interaction with radiation. Here we report direct experimental evidence for passive (or intrinsic) optical cooling of a micromechanical resonator. We exploit cavity-induced photothermal pressure to quench the brownian vibrational fluctuations of a gold-coated silicon microlever from room temperature down to an effective temperature of 18 K. Extending this method to optical-cavity-induced radiation pressure might enable the quantum limit to be attained, opening the way for experimental investigations of macroscopic quantum superposition states involving numbers of atoms of the order of 10^{14} .

Investigation of the HSP 90 by TIRF

Moritz Mickler, Martin Hessling, Thorsten Hugel
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The molecular chaperone Hsp90 is involved in folding, activation and stabilisation of substrate proteins.¹ It consists of two monomers that undergo major conformational changes during ATP Hydrolysis. Some of the amino acids of the monomers can be mutated into cysteines which can be specifically labelled with fluorophores. In addition, the biotinylation of its Lysine-groups opens the path to immobilize the chaperone onto a solid substrate and investigate it with various single molecule fluorescence methods.

We will excite the fluorophore in total internal reflection (TIR) geometry, to minimize the background radiation. This is done by excitation with a LASER that has a larger angle of incidence than the angle of total reflectance on the glass slide on which the HSP 90 will be immobilized. The penetration depth of the evanescent field is about 50 nm and therefore only excites fluorophores very close to the surface.

The ATP binding will be investigated with fluorescent labelled ATP.

Conformational changes will show up in a variation of the fluorescent signal.

The most sensitive method is fluorescence resonance energy transfer (FRET). Here, the two monomers are labelled with different fluorophores. One monomer is labelled with a fluorophor that is excited by the LASER and the other fluorophor can be excited by the emission energy of the first fluorophor. If the distance between the two fluorophores is smaller than the Förster Radius (about 5nm) the energy of the excited first fluorophor is transferred radiationless to the second fluorophor. This allows one to see a change in the distance changes during the ATP-cycle of the molecule in real time if they are close to the Förster Radius.

(1) H. Wegele, L. Müller, J. Buchner; *Rev Physiol Biochem Pharmacol* (2004)

Determination of FRET-efficiencies using PIE-FCCS

Barbara K. Müller, Christoph Bräuchle, Don C. Lamb

Physical Chemistry, Department of Chemistry and Biochemistry, Ludwig-Maximilians-Universität München, Butenandtstr. 11, 81377 Munich

Fluorescence correlation spectroscopy (FCS) and fluorescence dual-color cross-correlation spectroscopy (FCCS) are powerful methods for the analysis of molecular dynamics and interactions. From thermodynamic equilibrium fluctuations, particle concentrations, mobility and the fraction of interacting molecules can be determined. FCCS works well under conditions where there is minimal spectral cross-talk between the fluorescent labels. In addition, if the double-labeled complex undergoes fluorescence resonance energy transfer (FRET), the amplitude of the cross-correlation function is affected and quantitative results over molecule interactions are no longer possible.

Recently, we showed that pulsed interleaved excitation (PIE) can be used to extend the capabilities of multi-color experiments like fluorescence imaging and single-pair FRET measurements. For FCCS measurements, PIE can be used to eliminate spectral crosstalk, enhancing the sensitivity of the method, and allows quantitative results in the presence of FRET.

Here, we present the use of PIE in combination with FCCS to determine FRET efficiencies directly from the FCCS measurements. The FRET efficiency is calculated from the amplitude of various correlation functions that can be determined from PIE-FCCS. Corrections for the labeling efficiency of the donor and acceptor are unnecessary as they are automatically accounted for within the analysis.

Equilibrium and non-equilibrium physics of periodic DNA

Richard Neher

Basepairing of two complementary DNA strands is a paradigmatic example of molecular recognition in biology and its specificity is a prerequisite for the construction of DNA based nanoscale devices. A thorough understanding of the equilibrium and non-equilibrium properties of basepairing is important to understand transcription and replication of DNA inside cells and to use DNA as a nanomechanical, self-assembling building block. The thermodynamics and kinetics of DNA can be studied in melting experiments and by manipulating individual molecules with modern single molecule techniques. We study the basepairing dynamics of DNA theoretically and focus on periodic and nearly periodic DNA. Whereas natural DNA with unordered sequences has essentially one stable binding configuration, periodic DNA has many possible binding patterns with both strands locally shifted relative to each other. We show, that periodic DNA displays many unexpected phenomena absent in random sequences. Upon application of a shear force to opposite ends of a periodic double stranded DNA molecule, both strands may slide along each other until they are completely separated. Depending on the magnitude of the applied force, we find regimes of thermally activated sliding as well as diffusive and drift dominated motion. In these different regimes, the mean time required to separate both strands displays different scaling behavior with the size of the system.

When DNA is heated, more and more parts of the helical structure are broken up into single strands, until both strands separate completely at the melting temperature. A double stranded DNA molecule with periodic sequences and two strands of different length undergoes an additional transition before melting. At low temperatures, the excess bases of the longer strand form an overhanging end. In the intermediate phase, these excess bases are completely absorbed in the helical region. The melting transition itself is no longer a first order transition but a continuous one.

Drug delivery with multifunctional polymer capsules.

A. Piera¹, A. Muñoz Javier¹, C. Kirchner¹, R. A. Sperling¹, M. Zanella¹, A. S. Susha¹, A. L. Rogach¹, O. Kreft², A. Skirtach², G. B. Sukhorukov², W. J. Parak^{1,*}

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²Max Planck Institute of Colloids and Interfaces, 14424 Potsdam/Golm, Germany

Targeted drug delivery is one of the advantages that nanotechnology offers to medicine. Hollow polyelectrolyte microcapsules were chosen as drug delivery system. These microcapsules are loaded with fluorescent, magnetic and metallic nanocrystals. They give us the potential to know in every moment where the capsules are, localize them around the cancerous tissue and to release the drug only at the desired place. Due to their components, we have to check the cytotoxic effects of the nanocrystals in order to know if our drug delivery system is biocompatible.

Dimeric 1d lattice gas: a model for collective molecular transport (or Do molecular motors form jams?)

Paolo Pierobon
(Arnold Sommerfeld Center, LS Frey)

Intracellular transport of large molecules and vesicles cannot rely on simple diffusion and uses specific motor protein (molecular motors, usually kinesin and dynein), which have the property of moving on one-dimensional path (microtubules) always in the same direction consuming (hydrolyzing) ATP. As in the highway, the movement of many of these objects may present jams. A non-equilibrium statistical mechanics model that captures the essential features of this system is the one-dimensional driven lattice gas of dimers, where the particles not only can "walk" but also attach and detach in the bulk. We will present the main properties of this model together with the last studies on the phase diagram, based on Monte Carlo simulations combined with analytical (mean field) theory. We will have a look also at the quantities that should be possible to extract experimentally.

Nanobioscience with DNA

Andreas Reuter, Stefan Beyer, Tim Liedl, Michael Olapinski, Eike Friedrichs and Friedrich C. Simmel, Physics Department and CeNS, LMU München

Deoxyribonucleic acid (DNA) contains the genetic information within the cell. DNA is encoded with four interchangeable "building blocks", the bases adenine (A), thymine (T), cytosine (C), and guanine (G). Each base "pairs up" with only one other base: A-T, T-A, C-G and G-C. Two complementary DNA single-strands will hybridize and form a double helix. With a diameter of 2nm the DNA is an interesting material for nanotechnological applications. The double helix is mechanically much more stable than single stranded DNA. This feature allows us to construct artificial DNA structures, e.g. lattices, actuators and simple machines. These devices consist of flexible, single stranded, and stiff, double stranded parts. DNA "tweezers" have been constructed with two arms that can be closed and reopened upon addition of further DNA "fuel" strands. In a similar manner we created a DNA "hand" that can grab and release the protein thrombin. This is possible because certain short DNA or RNA single strands exist that are able to bind to ions, molecules or even proteins. They are called aptamers. To monitor conformational changes within our DNA devices, we use fluorescence spectroscopy. Fluorescence resonance energy transfer between two adjacent dyes serves as spectroscopic ruler: we can deduce the distance of the dyes from the efficiency of the transfer.

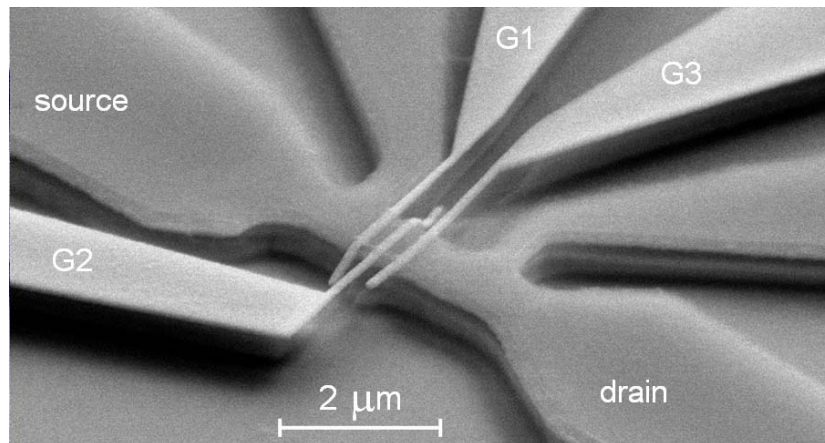
Freely Suspended Quantum Dots

Clemens Rössler, group: Stefan Ludwig, Lehrstuhl: Jörg P. Kotthaus

Electrons in quantum dots are confined in all three spatial directions. The confinement leads to a quantisation of the eigenenergy of the electron states. In my PhD project, I build such quantum dots by nanostructuring semiconductor heterostructures.

Semiconductor quantum dots are promising candidates for the realisation of quantum bits (qubits). Similar to a classical bit a qubit is based on two states, e.g. the spin orientation or the charge of a single electron in the quantum dot.

In order to benefit from the potential of quantum computing, it is necessary to perform a quantum calculation within the phase coherence time of the qubit. Charge fluctuations in the environment of a quantum dot as well as decoherence due to phonons are major sources of decoherence.



SEM picture of a freestanding structure taken under a tilt angle of 60° . Three golden gates G1, G2, G3 lie on top of an underetched GaAs/AlGaAs heterostructure. Electrons flow from source to drain.

Our phonon cavities are nanoscale bridges excavated from an AlGaAs/GaAs heterostructure. The latter contains a two-dimensional electron system which is depleted locally by applying a negative voltage to nearby gates (see picture). By this method it is possible to define freely suspended quantum dots.

We investigate the influence of the resulting restriction of the phonon spectrum onto the coherence time of electronic states in quantum dots. In addition, we exploit how the discrete mechanical cavity modes couple to the electronic states of the quantum dot [1].

Our research aims towards a deeper understanding of nano-electromechanical systems with regard to applications for quantum information processing.

[1] E. M. Höhberger, R. H. Blick, T. Brandes, J. Kirschbaum, W. Wegscheider, M. Bichler, and J. P. Kotthaus,

Single electron-phonon interaction in a suspended quantum dot phonon cavity, Physical Review Letters **92**, 046804 (2004).

Temperature Softening of a Protein in Single-Molecule Experiments

Michael Schlierf and Matthias Rief

Physik-Department E22, Technische Universität München, James-Franck-Strasse, 85748 Garching, Germany

Mechanical flexibility is crucial for the function of proteins. However, such material properties are not easily accessible experimentally. We used single-molecule force spectroscopy to study the stiffness of a single domain of *dictyostelium discoideum* filamin (ddFLN4) in a temperature range from 5°C to 37°C. Analyzing the distributions of unfolding forces allowed us to extract transition barrier heights and positions of the underlying energy landscape. We found a marked narrowing of unfolding force distributions with increasing temperature. This narrowing reflects an increase in transition state position from 2.7Å to 7.8Å and thus a reduction of the molecular spring constant of the protein by a factor of 7. We suggest this temperature softening reflects a shift in the nature of the interactions responsible for mechanical stability from hydrogen bonds to hydrophobic interactions. This result has important consequences for all interpretations of protein mechanical studies if experimental results obtained at room temperature are to be transferred to physiological temperatures.

Why Nano and Bio come together: Examples for interactions between diverse fields

Friedrich Simmel

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The on-going trend to miniaturize technological components leads to new scientific questions – e.g., quantization effects in small structures, fabrication of structures by self-assembly, domination of Brownian motion, etc. –, but also to interactions between seemingly unrelated scientific fields like condensed matter physics and biology. This is exemplified by the diverse areas of expertise of the member groups of the Center for Nanoscience.

In spite of this diversity, one can identify several common themes.

Miniaturization: The techniques developed for the fabrication of large scale integrated circuits can also be applied to other areas, e.g. biomedicine. Self-assembly: Complex structures in nature are built in a completely different way than current, artificially created technological structures. What can be learned, or taken over, from biological structure formation? Hybrid devices: If one can build “inorganic” structures of the same size as biomolecules – what happens at the interface?

Size effects: When solid state systems are spatially strongly confined (such as quantum dots), quantization effects become dominant. Can they be useful? New methods of

characterization: Techniques such scanning probe microscopy, single molecule spectroscopy, etc. can be used to obtain structural and dynamical information at a molecular or atomic level. Some techniques can even be used to manipulate matter on that scale.

These techniques can be applied to both learn about inorganic as well as biological structures. This knowledge in turn is essential in our attempts to imitate natural systems. In this talk, several examples for these interlinking themes with an emphasis on research within CeNS will be given.

Surface modification and functionalization of polymer coated colloidal nanocrystals

Ralph A. Sperling¹, Teresa Pellegrino¹, Marco Zanella¹, Jimmy K. Li^{1,2},
Walter H. Chang², and Wolfgang J. Parak¹

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²Center for Nano Biomedicine Technology, Department of Biomedical Engineering,
Chung-Yuan Christian University, Taiwan

Colloidal nanocrystals of different materials which show different properties such as fluorescence or magnetism are of particular interest for the fabrication of nanosized hybrid materials. For the specific binding of the nanoparticles to a target, their surface needs to be functionalized with chemical reactive groups or biological functional molecules such as biotin, DNA or antibodies.

First hydrophobic nanocrystals are rendered hydrophilic by a polymer shell, yielding stable particles of in principle any core material with the same surface chemistry of the polymer.

In the next step, poly(ethylene glycol) (PEG) is covalently bound to the particles, increasing their stability in buffers with high salt concentrations, while PEG molecules with two functional groups can be used to introduce new free functional groups on the surface of the particles.

Experiments were carried out to demonstrate the reactivity of these functional groups to which biological molecules like DNA or antibodies could be linked in subsequent steps.

AFM and forensics

Stefan Strasser

The exact determination of the date of crime is prevalent an unsolved problem in forensic science. However, this represents one of the most important forensic applications during crime scene investigation.

We are working on a new tool for the estimation of the date of crime. The atomic force microscopy (AFM) is used for high resolution imaging and elasticity measurements of blood stains and in future for collagen fibrils in bone sections. Elasticity measurements of blood stains could help to date back the crime a few days or weeks. The force spectroscopy of collagen fibrils in bone sections will be developed to clarify crimes which are several years ago and only skeletons or bones are left.

To construe elasticity datas received from bone sections an exact knowledge of the mechanical properties of single collagen fibrils is necessary. Structural and elasticity investigations of single collagen fibrils were done on in vitro assembled fibrils. Native and fibrous long spacing (FLS) collagen fibrils were formed by self assembly, using a special dialysis setup. Depending on the assembly conditions, collagen form a variety of different structures (native fibrils, FLS fibrils, cocoon-like fibrils). The received collagen fibrils of type I had a bending pattern of 67nm for the native fibrils, and 200nm to 300nm for the FLS fibrils. Collagen is a system that shows a large degree of polymorphism.

To determine the elastic properties of collagen fibrils the tip of the AFM was used as a nano-indentor by recording force displacement curves. The Youngs modulus can be calculated by the Hertzian theory. To confirm the collagen fibril assembly, the AFM was used as a nanodissection tool. Native fibrils were microdissected and the structure of the cut area was determined.

For the analytic procedure of the age determination of blood samples, a fresh spot was applied on a glas slide and the AFM-detection was started after drying the blood spot. After morphological investigations with high resolution AFM imaging, force distance curves were done on the blood sample. These measurements were repeated in determined intervals. The obtained elasticity pattern showed a decreasing elasticity over time, which is most probably influenced by the alteration of the blood spot during the drying and coagulation process. The preliminary data demonstrates the capacity of this method to use it for development of calibration curves, which can be used for estimation of blood stain ages during forensic investigations.

Transport in Few-Electron Quantum Dots with Three-Terminals

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In quantum dot circuits, screening electron clouds in strongly-coupled leads will hybridize with the states of the artificial atom. By using a third weakly-coupled lead [1], we directly probe the atomic structure of a quantum dot with Kondo coupling. Our measurements reveal that this hybrid system behaves as a non-linear molecular entity with orbital degeneracy. We present a simple three-level model, with a ground state s-level and two degenerate p-levels, to characterize our entire system. Using a voltage gate with capacitive-coupling to the quantum dot, we adjust the Fermi level of the system to create an artificial four-electron molecular entity—having a triplet state with lower energy than the singlet state, as expected. Geometric distortion reduces the symmetry, lowers the energy, and lifts the degeneracy—the Jahn-Teller effect [2]. We restore symmetry to our system by applying an external magnetic field perpendicular to the plane of the QD. We find that, to first order, our experimental data is in strong agreement with our theoretical model in the neighborhood of the point of restored symmetry. We use the agreement between the prediction and the measurement to de-embed relevant physical parameters of our system including the energy level spacing, the ferromagnetic exchange energy, the effective orbital g-factors, the Fermi level of the quantum dot and the asymmetric offset arising from physical non-idealities. Our discovery suggests a means of controlling the correlation of spatially separated pairs of entangled electrons (Einstein-Podolsky-Rosen pairs [3])—a condition which must be met for the physical realization of a quantum computer (DiVincenzo’s seventh requirement [4]). To detect the generation of these *flying qubits*, we have engineered an analog continuum cross-correlator to analyze the shot noise spectra of correlated output signals in the *X*- and *Ku*-bands (8 to 18 GHz).

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Poster Abstracts

Utilizing a Quantum Point Contact as a Spin Detector

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Narrow constrictions called quantum point contacts (QPCs) in a two-dimensional electron gas (2DEG) can act as spin detectors in magnetic fields of several Tesla, due either to Zeeman splitting when the field is in the plane of the 2DEG or to spin-resolved Landau quantization when the field is perpendicular to the 2DEG. The polarization of such a spin detector is controllable by the electrostatic influence of an adjacent gate, since a change of gate voltage alters the energy of the spin-polarized subbands of the QPC relative to the Fermi energy of the 2DEG-reservoirs. The ability to detect electron spins in mesoscopic systems is important for the field of spintronics and is also a powerful tool for investigating basic physical properties of spin coherent electronic devices.

We particularly exploit the possibility to detect and to manipulate optically excited spins by means of the QPC. For that purpose we focus a circularly polarized laser beam onto the surface of a semiconductor heterostructure in close vicinity of the QPC. As a consequence of the spin-orbit coupling in the valence band, the circularly polarized light induces spin excitations in the 2DEG, which will be consequently measured as an extra voltage drop across the QPC.

The QPCs are fabricated by a combination of both optical and electron beam lithography. We develop lithographical methods in order to ensure large subband energies of the QPC of about 10 meV, while the dimensions of the QPC are in the order of ~ 100 nm, and the quantum coherence of the mesoscopic device is still ensured. All optoelectronic experiments will be performed in a magneto-optical cryostat at 1.5 Kelvin with a magnetic field of up to 8 Tesla.

Scaling behavior of particle current and diffusion in symmetric tubes

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We study the transport of Brownian particles in two dimensional periodic tubes with varying cross-section and infinite length. Bottlenecks which produce entropic barriers hinder the motion of the particles. The key parameters are a stochastic force, $\xi(t)$, which is due to thermal fluctuations and whose strength is given by $2\eta k_B T$, and a constant force, F , acting along the orientation of the symmetric tube. Here ' η ' is the friction coefficient. We investigate the particle current (J) and diffusion coefficient (D) within an analytic approach and numerical simulations. The analytic treatment is done in terms of the so-called *Fick-Jacobs equation*. Fick and Jacobs have deduced an effective one-dimensional Fokker-Planck equation for the motion along the symmetry axis of a tube, which approximately describes the two dimensional problem. Here we observe a universal scaling behavior for particle current and effective diffusion, which holds for all values of noise strengths and applied forces.

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Calibration of self-assembled organic monolayers

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Scanning Tunneling Microscopy (STM) was used to study the structure of self-assembled organic monolayers at the liquid-solid interface. In saturated solutions the investigated molecules spontaneously form well-ordered networks (inter)connected via hydrogen bonds - an attempt to build custom tailored architectures on the nanometer scale from a bottom up approach. The aim of the shown investigations is to precisely determine the crystallographic relation between the molecular films and the underlying substrate.

Three molecules consisting of one or two benzene rings and two carboxylic groups, namely 1,4 benzene-dicarboxylic acid (TPA), 4,4'-stilbenedicarboxylic acid (SDA) and 2,6-naphthalenedicarboxylic acid are compared in terms of their quasi-epitaxy on a graphite substrate.

The split-image method is applied for the analysis. In the first part the adsorbate layer is imaged, in the second part the substrate lattice is imaged by decreasing the tunneling voltage and increasing the tunneling current set point. To determine periodic features contained in the STM images and to measure their dimensions precisely two-dimensional Fourier transformation is used. The adsorbate layers are calibrated in respect to the well-known graphite lattice, subsequently the relation between the two grids can be determined and classified as commensurate, coincident or incommensurate. TPA exhibits incommensurism, for NDA coincidence was found, SDA forms a commensurate overstructure.

Hybrid Systems of Single Wall Carbon Nanotubes and Nanocrystals: Synthesis and Optoelectronic Transport Properties

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This project covers the self-assembly of hybrid systems consisting of single wall carbon nanotubes (SWNTs) and either colloidal gold or II-VI semiconductor nanocrystals (NCs) like CdSe or CdTe. We characterize the physical properties of such a mesoscopic circuit by means of optoelectronic transport measurements.

To form a system of SWNTs and NCs one of the strongest noncovalent and irreversible bindings in biology, the biotin-streptavidin van-der-Waals interaction, is used. In a first step the ends of SWNTs are functionalized by binding to a biotin molecule. After functionalization each SWNT has a length of some hundreds of nanometers up to a micrometer and a cross section of some nanometers whereas a NC consists of a cluster of up to 1000 atoms having a size of 10 nm to 30 nm. The functionalized ends of the SWNTs interact with streptavidin-coated colloidal nanoparticles forming a linear system of SWNT-NC-SWNT which is shown in Fig.1.

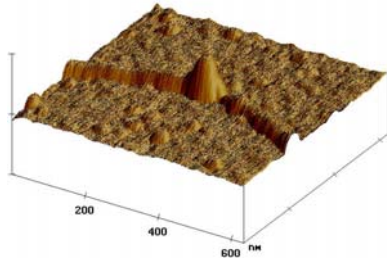


Figure 1. AFM-image of a SWNT-NC-SWNT junction formed by a streptavidin-biotin interaction. The NC here is a colloidal Au nanoparticle [1].

A watery suspension of the above system is then brought onto a conventional silicon substrate and characterized by atomic force microscopy giving the exact positions of SWNT-NC-SWNT-compounds on the substrate. The two SWNTs are contacted by methods of electron beam lithography in a way that the SWNTs act as contacts to the NC shown in Fig. 2.

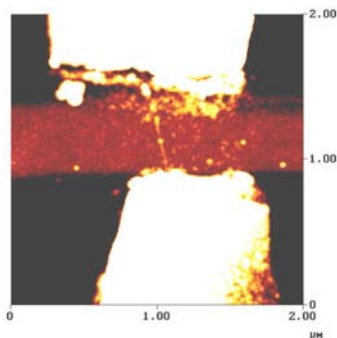


Figure 2. A SWNT-NC-SWNT system mapped as a thin, vertical line with a center dot in the middle of the picture contacted by two gold leads appearing as bright, white areas in the lower and upper third of the AFM image [1].

The optoelectronic, low temperature measurements of quantum transport through such a mesoscopic device involve the application of a source-drain-voltage with an additional gate potential to observe single electron effects like the Coulomb-blockade. The application of a magnetic field and the absorption of circularly polarized laser radiation defining a spin excitation in the system will provide insight into the optical properties and the spin transport through a SWNT-NC-SWNT hybrid system.

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