

V E N I C E
I N T E R N A T I O N A L
U N I V E R S I T Y

Nanoscience: Tools and Devices

**CeNS workshop
at Venice International University
24 – 28 September 2001**



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Organisation:

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Program

Monday, September 24th

- 9.30 – 10.00 Opening
- 10.00 – 11.00 **Daniel J. Müller** (Dresden)
Exploring function and interaction of cellular machines: Nanotechnology meets
Molecular Biology
- 11.00 – 11.30 Coffee / Tea
- 11.30 – 12.30 **Flemming Besenbacher** (Aarhus)
Formation and stability of nanostructures on metal surfaces
- 12.30 – 14.30 Lunch
- 14.30 – 15.00 **Rupert Krautbauer** (LMU)
Force spectroscopy of single DNA molecules
- 15.00 – 15.30 **Gregor Jung** (LMU)
Fluorescence Correlation Spectroscopy & Single Molecule Spectroscopy of the
Green Fluorescent Protein
- 15.30 – 16.00 **Rainer Hillenbrand** (München)
Phase contrast in optical near-field nanoscopy
- 16.00 – 16.30 Coffee / Tea
- 16.30 – 17.30 **Gerd Binnig** (Rüsclikon)
Nanomechanical Storage in Polymers
- 17.30 – 18.00 **Artur Erbe** (LMU)
Nanomechanical charge transfer and detection
- 18.30 Reception Dinner

Tuesday, September 25th

- 9.30 – 10.00 **Thomas Klar** (Göttingen)
Diffraction resolution barrier in fluorescence microscopy broken by Stimulated
Emission Depletion
- 10.00 – 11.00 **John Pethica** (Oxford, UK)
Nanomechanics and atom manipulation

- 11.00 – 11.30 Coffee / Tea
- 11.30 – 12.00 **Michael Reichling** (LMU)
Atomic scale analysis and manipulation with the force microscope
- 12.00 – 12.30 **Friedrich Simmel** (Bell Labs)
DNA-based nanomechanical devices
- 12.30 – 14.30 Lunch
- 14.30 – 15.30 **Robert Grober** (Yale)
Quantum Dots: Single molecules as optical nanoprobos
- 15.30 – 16.00 **Daan Wouters** (Eindhoven)
Metallo-Supramolecular Systems Based on Terpyridines
- 16.00 – 16.30 Coffee / Tea
- 16.30 – 17.00 **Jan Krauß** (LMU)
Manipulating photogenerated charge carriers with static and dynamic lateral superlattices
- 17.00 – 18.00 **Dan Rugar** (Almaden)
Magnetic resonance force microscopy: pushing the limits of force detection
- 18.00 – 19.00 Dinner
- 19.00 **Posters**

Wednesday, September 26th

- 9.30 – 10.00 **Jake Reder** (LMU)
Mesoporous Films with Molecular Functionality
- 10.00 – 11.00 **Jan von Delft** (LMU)
Transport through Ferromagnetic Nanograins with Discrete Electronic States
- 11.00 – 11.30 Coffee / Tea
- 11.30 – 12.00 **Dirk Haft**
Optical investigations of single quantum rings
- 12.30 – 14.30 Lunch
- 14.30 **Informal Discussions**

Thursday, September 27th

- 9.30 – 10.00 **Frank Wilhelm** (LMU)
Quantum computing, quantum measurements, and Schrödinger's cat in small superconducting circuits
- 10.00 – 11.00 **James Heath** (UCLA)
A Systems Approach to Molecular Electronics
- 11.00 – 11.30 Coffee / Tea
- 11.30 – 12.00 **Michael George** (LMU)
Cell-Semiconductor Hybrids: Strategies and Materials
- 12.00 – 12.30 **Posters**
- 12.30 – 14.30 Lunch
- 14.30 – 15.30 **Joachim Rädler** (LMU)
Nanoparticles in Gene Therapy
- 15.30 – 16.00 **Nikolay Petkov** (LMU)
Preparation of Oriented Channel Structures as Hosts for the Growth of Nanomaterials
- 16.00 – 16.30 Coffee / Tea
- 16.30 – 17.00 **Thorsten Hugel** (LMU)
Coupling Optical Excitation into Force Measurements
- 17.00 – 18.00 **Albert Libchaber** (Rockefeller University)
DNA dynamics and DNA protein interaction
- 18.00 – 19.00 Dinner
- 19.00 **Posters**

Friday, September 28th

- 9.30 – 10.00 **Christoph Bräuchle** (LMU)
Single Virus Tracing
- 10.00 – 10.30 **Martin Benoit** (LMU)
Measuring Adhesion Forces on Living Cells
- 10.30 – 11.00 **Carsten Sönnichsen** (LMU)
Colorful metallic nano-rods and -dots
- 11.00 – 11.30 Coffee / Tea
- 11.30 – 12.30 **Bertram Batlogg** (Bell Labs)
Title yet to be announced
- 12.30 Lunch

Lectures

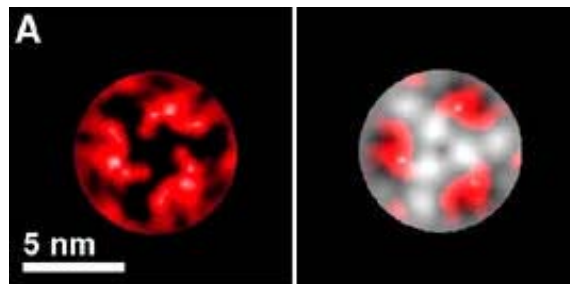
Abstracts

Exploring function and interaction of cellular machines: Nanotechnology meets Molecular Biology

Daniel J. Müller

Max-Planck-Institute of Molecular Cell Biology and Genetics, Dresden. www.mpi-cbg.de

Understanding and knowledge of complex biological systems on the scale of single molecules is of fundamental importance to control biological reactions and to develop new biological materials. Particularly, direct measurements of biological interactions on the molecular scale will provide new insights into biological processes. We use different biophysical techniques to observe single proteins, their function and their assembly under physiological relevant conditions at a resolution < 1 nm. Multifunctional atomic force microscopy (AFM) probes allow several signals to be detected simultaneously. Recorded with submolecular resolution these signals can be directly assigned to structural details of individual proteins. Examples discussed are the detection of structural variability and flexibility, of surface charges, and of electrostatic potentials of transmembrane ion channels (Figure). The recently invented combination of single-molecule imaging and force-spectroscopy enables the controlled manipulation of single proteins and to detect their inter- and intramolecular interactions. Improved experimental procedures and data analysis allows observing unfolding secondary structural elements of biological macromolecules such as α -helices, β -sheets and polypeptide loops. In future these and forthcoming methods will provide novel molecular biological insights into factors determining structure, stability and function of cellular machines.



Electrostatic potential detected on the transmembrane OmpF porin channels. The left image represents the negative potential from 0 (black) to 12.5×10^7 V/m (bright), the right image represents an overlay of electric potential and topography recorded simultaneously by AFM.

Many thanks to: Norbert Dencher, Andreas Engel, Hermann Gaub, Galen Hand, Wonpil Im, Max Kessler, Tiina Lehto, Clemens Möller, Ansgar Philippsen, Benoit Roux, Tilman Schirmer, Holger Seelert, Gina Sosinsky, Henning Stahlberg, Kitaru Suda.

Formation and stability of nanostructures on metal surfaces

F. Besenbacher (fbe@ifa.au.dk), J. V. Lauritsen, T. R. Linderoth, A. Kühnle

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In this talk I will discuss recent examples on how to nucleate and grow nanostructures on metal surfaces. In doing so we have exploited the unique resolving power of our STM to reveal the dynamics of surface processes by recording STM movies, i.e. many sequential atom-resolved, time-lapsed STM images with a fast-scanning STM [1].

I will start out by discussing surface diffusion of adatoms and clusters on surfaces. I will show how STM movies (see e.g. www.ifa.au/camp/movies) recorded at variable temperature can provide quantitative information on the surface diffusivity [2]. We have found that gas impurities enhance the diffusivity of the metal adatoms [3].

I will furthermore briefly address the area of nanocatalysis where the chemical activity is controlled by small nanoclusters. I will briefly show how fundamental insight into the surface structure and reactivity can be applied to design new catalysts [4]. Also I will show how STM has led to unprecedented new insight into the morphology and the details of the active sites for CoMoS nanoclusters relevant for the hydrodesulfurization (HDS) catalysis [5,6].

Finally, I will address recent results concerning a simple, biologically relevant molecule - the chiral, sulphur-containing amino acid cysteine - on the Au (110) surface [7]. By depositing the two enantiomeric forms as well as the racemic mixture we have discovered and investigated a number of exciting new phenomena relating to (i) the self-assembly of mono-disperse molecular nanoclusters and (ii) the formation of homochiral molecular dimers by chiral recognition. Implications of these findings for the importance of molecular recognition will be discussed.

References

1. F. Besenbacher, Reports on Progress in Physics **59** (1996) 1737
2. T.R. Linderoth, S. Horch, E. Lægsgaard, I. Stensgaard and F. Besenbacher, Phys. Rev. Lett. **78**, 4978 (1997), T.R. Linderoth, S. Horch, L. Petersen, S. Helveg, E. Lægsgaard, I. Stensgaard and F. Besenbacher, Phys. Rev. Lett. **82**, 1494 (1999),
3. S. Horch, H.T. Lorensen, S. Helveg, E. Lægsgaard, I. Stensgaard, K.W. Jacobsen, J.K. Nørskov and F. Besenbacher, Nature **398** (1999) 134
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Force spectroscopy of single DNA molecules

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On a molecular scale not only the energies, but also the forces involved in biological and chemical processes are important structural and functional parameters. The relevant forces range from sub-piconewton (pN) entropic forces that act over long distances up to the breakage of covalent bonds at a few nanonewtons (nN). The forces involved in molecular processes are always closely related to structure and function. By measuring and applying forces on the piconewton scale (*single molecule force spectroscopy*) it is therefore possible to directly obtain structural information by mechanical means.

Stretching profiles of individual doublestranded DNA show a highly cooperative overstretching transition at 65 pN and a rate dependent second transition at forces around 150 pN. During the overstretching process the double strand is mechanically separated into two single strands, leaving only a single strand attached between AFM-tip and substrate. These well known features were used to characterize the changes in DNA mechanics upon binding of different small molecules, allowing the direct observation of chemical reactions on single molecules.

Specifically, the effects of the cross-linking anti-cancer drug, cisplatin, the anti-trypanosomal minor-groove binder, berenil and the intercalating dye, ethidium bromide were studied. It could be shown that the force spectra are closely correlated to the mode of interaction of the DNA binding agents.

Fluorescence Correlation Spectroscopy & Single Molecule Spectroscopy of the Green Fluorescent Protein

G. Jung, C. Bräuchle, A. Zumbusch

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The green fluorescent protein (GFP) is the most widely used fluorescent marker in molecular biology due to its genetically encodable fluorescence. Its use allows the labelling of organelles, proteins and gene products in almost any cell. Commercially available mutants offer a wide color palette of fluorescence from blue to red. This facilitates studies of the interaction of proteins in-vivo. The recent demonstration of live cell single molecule detection opens many applications in this area. Successful applications of GFP with these techniques, however, require a complete understanding of its photophysical behavior on the single molecule level. A number of single molecule studies on GFP, its spectral variants and other related fluorescent proteins show their limited photostability and their relatively dim fluorescence under typical experimental conditions [1]. These observations can be explained by the presence of several metastable states, which are photophysically populated. These states cannot be excited and act therefore as dark states. The chemical nature of these states has so far been unknown. We used a newly developed double-resonance experiment on the single molecule level in order to identify the GFP's dark states [2]. One light source excites the fluorophore, whereas the other light source is absorbed by a dark state leading to its depopulation. The spectral properties of this dark state are used for its identification. Its population dynamics are investigated with fluorescence correlation spectroscopy. By this approach, we can derive a potential scheme that explains the dim fluorescence [3]. Additionally, this knowledge enables us to manipulate the population of bright and dark states by light. It is shown how this approach enhances the brightness of single GFP molecules in confocal microscopy [4].

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[3] G. Jung, C. Bräuchle, A. Zumbusch, *J. Chem. Phys.* 114 (2001), 3149.

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Phase contrast in optical near-field nanoscopy

Rainer Hillenbrand

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Near-field optical imaging (SNOM) can map optical properties down to the nanometer scale, providing the apertureless design is used, where the light scattered from a simple sharp tip carries the near-field information of the sample (scattering-type SNOM, sSNOM) [1,2]. Optical phase contrast has however not yet been exploited in this microscopy, although interesting phase effects can be expected for all resonant interactions such as absorption, lasing or resonant scattering.

We introduce how to extract a maximum of optical information which is usually encoded in a pair of observables, in our case amplitude and phase [3]. Our experiment consequently combines a s-SNOM at 633 nm with heterodyne interferometric detection of the backscattered light to generate simultaneous amplitude and phase images. The microscope is based on a tapping-mode AFM where commercial cantilevered tips are used as scattering probes. Higher-harmonic demodulation of the optical signal modulated by the tip's tapping motion suppresses background and topography-induced artifacts.

Experiments on nanostructured Au-films on Si show a near-field contrast, both in amplitude and phase, which is definitely material dependent. Backed by quasiolelectrostatic theory we demonstrate the significance and accessibility of complex optical constants on the nanoscale: phase contrast can be assigned to absorptive and amplitude contrast to refractive material properties [3].

Phase contrast is also seen to be decisive to map single particle plasmon resonance. Images with sub-particle resolution demonstrate that only amplitude *and* phase contrast clearly identifies the optical oscillation patterns. Examples of dominantly dipolar and quadrupolar plasmon modes will be presented. The <10 nm resolution of the microscope also allows to image gap modes confined between closely-spaced particles [4].

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[2] B. Knoll, F. Keilmann, "Near-field probing of vibrational absorption for chemical microscopy", *Nature*, **399**, 134-137 (1998).

- [3] R. Hillenbrand, F. Keilmann, "Complex optical constants on a subwavelength scale", *Physical Review Letters*, **85**, 3029-3032 (2000)
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Nanomechanical Storage in Polymers

Gerd K. Binnig, IBM Zürich

The Millipede concept with its first implementation in form of a thermo-mechanical data storage device is presented. A large amount of AFM-like cantilevers operate in parallel by modifying locally the structure of a thin polymer film. The modification can be viewed as a local compression of the material, which can be reversed simply by heating the region. This means bits can be written and erased very reliably on the single bit level. The modification is achieved through a combination of abruptly increasing the loading force of the tip electrostatically, and by heating the tip at the same time. For erasing only heating is required. This way a single bit switch can be constructed, that can be operated over many millions of switching cycles.

Nanomechanical charge transfer and detection

Artur Erbe, Sektion Physik, LMU, Geschwister-Scholl-Platz 1, 80539 München

Nanoelectromechanical resonators open the possibilities to build very sensitive detectors on a small length scale. We show how to operate simple nanomechanical wires as charge detectors. Dissipation leads to small quality factors and thus decreases the resolution of charge detection. First approaches to studies of Q-tuning in nanomechanical systems are shown.

Combining nanomechanical motion with current transport via tunneling barriers may lead to very sensitive displacement detection. Additionally, this combination can be a good candidate for a current standard, if Coulomb-Blockade effects are included. We show measurements on such a nanomechanical resonator shuttling single electrons at radio frequencies. In future experiments this tunneling mechanism can also be observed using nanomechanical wires in order to obtain well controlled mechanical coulomb blockade.

Diffraction resolution barrier in fluorescence microscopy broken by Stimulated Emission Depletion

Thomas A. Klar¹⁾, Marcus Dyba, Stefan Jakobs, and Stefan W. Hell

High Resolution Optical Microscopy Group,
Max-Planck-Institute for Biophysical Chemistry, Göttingen

The classical diffraction barrier responsible for limited resolution in far-field fluorescence microscopy is markedly overcome by hindering molecules at the outer region of the focal spot from emitting a fluorescence photon. To achieve that, each excitation pulse is followed immediately by a red-shifted pulse inducing stimulated emission in the excited dye. The depletion focus may either be displaced laterally with respect to the fluorescence spot or be shaped in a doughnut like mode around it. This deliberate change of the fluorescence spot is referred to as point-spread-function engineering. By driving the quenching process into saturation, we fundamentally reduce the spatial region from which fluorescence may occur and hence substantially break the diffraction barrier. Nearly spherical fluorescence spots with a diameter of 100 nm are obtained, increasing the axial and lateral resolution five-fold and two-fold, respectively, compared to confocal microscopes. Images of live cells reveal greater details (Opt. Lett. 19, p.780, 1994, Opt. Lett. 24, p.954, 1999, PNAS 97, p.8206, 2000). Further more, the concept of Stimulated Emission Depletion can be used to disclose the ultrafast dynamics of vibrational, solvent, orientational, and electronic relaxation in organic fluorescent samples at high confocal spatial resolution (APL, 77, p. 597, 2000).

1) Future address: LS Feldmann, CENS, Sektion Physik, LMU

"Nanomechanics and atom manipulation."

John B. Pethica, Dept. of Materials, University of Oxford

Recent years have seen considerable advances in atom resolved AFM and understanding of the forces which can arise at the tip in SPM. This talk will give an overview of some subject areas for which knowledge of these forces and corresponding energies is significant, ranging from atom manipulation and dissipation mechanisms, through AFM and STM imaging, to mechanical properties of nanostructures.

We have developed a non-resonant, low amplitude ($<0.5\text{\AA}$ pp) AFM method which gives direct and quantitative force spectroscopy. Long and short range interactions are distinguished, and the short range terms compare well with single atom interaction potentials. Atom resolved force gradient images will be described. The significant magnitude of the forces observed during regular STM imaging may affect interpretation of many STM images. At small, but still non-contact tip separations, significant energy dissipation is observed, the onset being smooth with separation. We suggest that relatively high energy atom displacement processes are involved, and a simple model of time constants is described. Stronger interaction still induces long term atom motion. Room temperature atom manipulation will be shown, and the range of mechanisms for manipulation discussed.

Non-resonant low amplitude AFM is particularly appropriate for liquid environments, and some of the application reasons for the importance of liquid studies will be indicated. We have recently observed lateral as well as normal stiffness oscillations as the tip-surface gap moves through commensurate and incommensurate molecular packing separations. The oscillation magnitude suggests new ways of understanding sliding of molecularly thin liquids and the role of short range ordering.

Atomic scale analysis and manipulation with the force microscope

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The investigation and manipulation of metal or semiconductor nanostructures on the atomic scale with tunnelling microscopy has reached a high standard and is now routine in many laboratories, however, electrically insulating materials have until recently been excluded from atomic scale analysis and manipulation. I will demonstrate that latest developments in dynamic force microscopy now allow us to also investigate insulating surfaces and nanostructures with atomic resolution and discuss how this technique could develop into a method for atomic scale structuring of insulators.

Atomic resolution on insulators has first been obtained on halide crystals where the emphasis in this talk will be on fluorides. Following a brief introduction into dynamic force microscopy, it will be shown that we are now able to image individual ions, vacancies and defects on flat terraces as well as nanostructures. As a recent important step forward towards quantitative scanning force imaging, it is demonstrated that in conjunction with extended theoretical modelling, we are now able to unambiguously identify ions from different sublattices of the insulator crystal structure. Strong interactions observed between the sensing atom of the force microscope tip and low coordinated surface ions indicate possibilities for a development of the method to chemical sensitivity.

Another most important class of insulating materials are oxides. Among them, alumina is the prototype material with innumerable applications in science, technology and industry. For the first time on an insulating oxide, we could directly reveal the atomic structure of the high temperature phase of α -Al₂O₃(0001). We provide evidence for the $\sqrt{31} \times \sqrt{31}$ reconstruction and confirm that this surface is composed of domains with hexagonal atomic order in the centre and less order in the periphery. Atomic order and disorder play an important role in the formation of hydroxide clusters forming a regular pattern of rings what is explained by self-organization involving cluster-surface and cluster-cluster interactions. Elaboration on the discovered processes is expected to allow us to deliberately manipulate hydroxide clusters and use them as a template for more complex nanostructures with chemical or biological functionality anchored on an oxide surface.

An important feature of force microscopy is the atomic scale dynamics inherent to the scanning process. During scanning, atoms swap from tip to surface and vice versa but we can also detect minor atomic re-arrangement of atoms on the tip by measuring subtle changes in the energy dissipated in tip-surface interaction. I will propose a method to utilize these dynamic phenomena for a manipulation of insulator nanostructures on the atomic scale.

DNA-based nanomechanical devices

Friedrich C. Simmel and Bernard Yurke

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The base-pairing interaction between single DNA strands with complementary base composition can be utilised to build complex supramolecular structures, but also to induce motion on the molecular scale. Here we demonstrate the operation of three simple and related nanomechanical devices based on DNA duplex formation and the process of branch migration. The operation of one of the devices has been checked for a large range of temperatures, pH values and salt concentrations. The design and operation principles of these devices might form the basis for a more complex molecular machinery based on DNA.

References:

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Quantum Dots: Single Molecules as Optical Nanoprobes

Robert D. Grober, Yale University

Optical spectroscopy of single fluorescent molecules and individual quantum dots is now a decade old. It has been demonstrated that one can use traditional far-field imaging to determine the location of these individual particles with spatial resolution of order 10's of nanometers, far in excess of the diffraction limit. This talk will highlight several examples where these particles are used as nanoprobes for determining the local properties of the host material in which they are embedded.

Metallo-Supramolecular Systems Based on Terpyridines

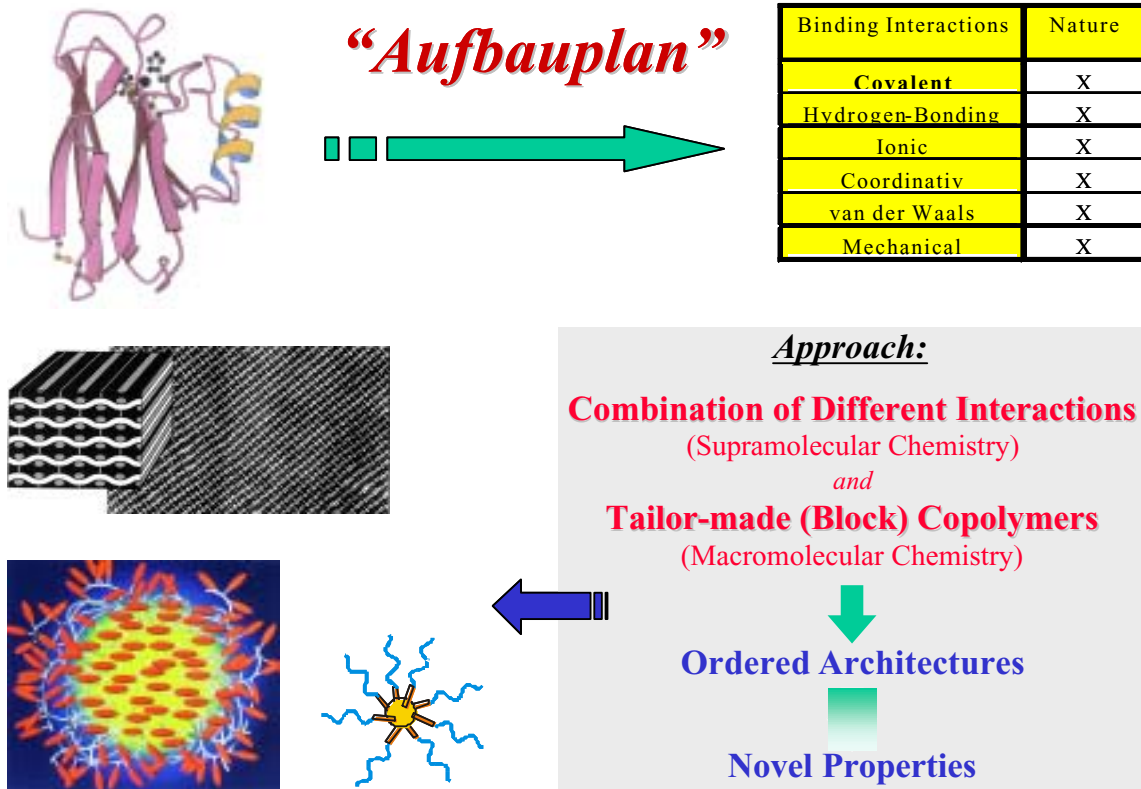
Daan Wouters^{1,3}, Bas G.G. Lohmeijer¹, Harald Hofmeier^{1,2}, Stefan Schmatloch^{1,2}, Christian Eschbaumer and Ulrich S. Schubert^{1,2,3}

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The use of metal-ligand interactions as non-covalent forces to assemble metallo-supramolecular systems is one modern approach towards well-defined ordered architectures. Such systems are expected to show new mechanical, thermal, electrochemical, photochemical or magnetic properties. Besides the synthesis of ligands and assemblies, the incorporation of these units into polymers and their self-organization behavior on surfaces is of special interest.



The lecture will focus on terpyridine as ligands in the design of supramolecular systems. A survey will be given of its use in the preparation of well-defined block-copolymers, (functional) nano-particles and self assembled monolayers. SPM techniques are used as a tool in the characterization of these systems.

Manipulating photogenerated charge carriers with static and dynamic lateral superlattices

J. Krauß, H.-J. Kutschera, C. Bödefeld, A. Wixforth, J.P. Kotthaus

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The deliberate manipulation of the optical properties of semiconductor heterostructures has recently attracted considerable interest also from a technological point of view. We show that static and dynamic lateral superlattices are an ideal tool to influence optically generated charge carriers.

The first part of the presentation is about the effect of a surface acoustic wave (SAW) on the dynamics of photogenerated carriers. For large SAW amplitudes, the piezoelectric fields accompanying the SAW at the speed of sound can be strong enough that a direct modulation of the conduction and valence band edges of a surface near semiconductor quantum well is possible. The corresponding electric fields lead to the ionization of optically generated excitons in the quantum well and a subsequent accumulation and storage of their 'fragments' (electrons and holes) in the resulting potential landscape. This can be directly observed in a quenching of the photoluminescence of the quantum well, as the probability for radiative recombination in the spatially separated electron-hole system is drastically reduced as compared to the homogeneous case. This spatial separation for low charge densities is approximately given by half an acoustic wavelength, about three micron in our case. The resulting wave function overlap in this spatially separated system is so small that the charge can be stored in the lateral potential wells for very long times: a 'photon conveyor belt' has been demonstrated in this context. Spatially and time resolved measurements show the dynamics of the quenching of the photoluminescence, the 'photon conveyer belt' in action, and the behavior of the photoexcited carriers in a standing wave.

In the second part, we demonstrate a similar system, where ionization of excitons is achieved not by the travelling field of a SAW, but the static in plane electric field of a pair of interdigitated electrodes with appropriate bias voltages. This system combines the storage of charge with the possibility to trigger fast radiative recombination after almost any desired delay simply by removing the bias. This enables us to visualize 2D carrier distributions and monitor their dynamics in the strongly nonlinear regime by taking "snapshots" at various delays. The resulting behavior agrees very well with the theoretical description, indicating we deal with an almost ideal model system to study 2D charge- relaxation.

Magnetic resonance force microscopy: pushing the limits of force detection

Dan Rugar, IBM Research Division, Almaden Research Center, San Jose, CA 95120 USA

Motivated by our interest in magnetic resonance force microscopy (MRFM), we have been exploring the limits of cantilever-based force detection. In this talk, we discuss the principles of MRFM and describe the various challenges for achieving single spin detection. We also discuss the various techniques we have developed using ultrathin silicon cantilevers that have allowed us to demonstrate force noise as small as 820 zeptonewtons in a 1 Hz bandwidth at 100 mK. In addition to MRFM, a number of other applications will be considered, including ultrasensitive cantilever magnetometry, measurements of magnetic fluctuations in individual submicron ferromagnets and sensitive measurements of non-contact friction.

MESOPOROUS FILMS WITH MOLECULAR FUNCTIONALITY

Jake Reder and Thomas Bein

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Porphyrin-based catalysts and catalyst precursor complexes have been covalently attached to high surface area, accessible mesoporous films of various types. Different attachment strategies are discussed. The methods for synthesizing and characterizing these films, as well as methods for catalyst synthesis, attachment, and composite evaluation are investigated. In an attempt to improve accessibility and site isolation, a method for re-orienting the pores of an MCM-41 film *perpendicular* to the substrate is detailed.

Mesoporous films grown at a substrate/liquid interface were studied with XRD, FTIR, atomic force, optical and electron microscopies. Removal of the template was best attained with either an oxygen plasma or UV irradiation, as calcination in air or N_2 is 10-15 times slower and often degraded the film structure. This process leads to crack-free films approximately 1 μm thick. Post-synthesis attachment of different linker molecules including (3-glycidioxypropyl) trimethoxysilane, bis(2-hydroxyethyl)-3-aminopropyltriethoxysilane (HETEOS), and bis(3-cyanopropyl)dimethoxysilane was achieved by reaction with the films in dry toluene. Subsequent reaction of the first two linkers with 5,10,15,20-tetrakis-(2-aminophenyl) porphyrin and the introduction of a catalytic centre (via the metal acetate) led to the desired thin film composite. The catalytic oxidation properties of these films are currently being investigated; the epoxidation of cyclohexene with H_2O_2 has been demonstrated.

MCM-41 films were formed by spin coating dilute, clear precursor solutions onto glass objectives. Without further treatment, the films show the characteristic XRD pattern, and TEM reveals the typical orientation i.e. parallel to the surface. However, the application of a 3 kV electric field to the freshly prepared films makes the film X-ray amorphous (as expected for “perpendicular” MCM-41), and an average pore spacing of ~ 3.7 nm can be seen in the TEM. Perfect hexagonal order is not preserved over long ranges, though domains of hcp pores are observed. Careful manipulation of experimental parameters is expected to improve the long range ordering.

Transport through Ferromagnetic Nanograins with Discrete Electronic States

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We propose a phenomenological model for an ultrasmall ferromagnetic grain, formulated in terms of the grain's discrete energy levels. We compare the model's predictions with recent measurements of the discrete tunneling spectrum through such a grain. The model can qualitatively account for the observed features if we assume (i) that the anisotropy energy varies among different eigenstates of one grain, and (ii) that nonequilibrium spin accumulation occurs.

Quantum computing, quantum measurements, and Schrödinger's cat in small superconducting circuits

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The physical realization of a universal quantum computer requires full control over a macroscopic array of coupled quantum-mechanical two-level systems. “Natural” controlled quantum systems such as ion traps or NMR-systems cannot be easily scaled to macroscopic size. On the other hand, this would be possible in “artificial” quantum systems based on solid-state electronics, however up to now the coherence properties of such macroscopic devices are not sufficient. Superconducting systems are promising candidates for reaching sufficient macroscopic coherence, because their low-energy quasiparticle-excitations are suppressed by the superconducting gap. I am going to review the theoretical and experimental status of two proposals for superconducting quantum bits based on Josephson junctions, where the qubit basis states are charge [1,2] and flux [3,4] states respectively. I am going to show experimental results on the macroscopic superpositions of quantum states consisting of the collective motion of about 10^6 Cooper pairs [4] and on the coherent dynamics of Cooper pairs in nanocircuits [2]. I am going to discuss theoretically how the quantum measurement postulate emerges on the macroscopic scale from a quantum-statistical theory of both the quantum system and the detector.

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A Systems Approach to Molecular Electronics

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Molecular-electronics-based devices present the possibility of an extremely energy efficient and scalable technology for both memory and logic applications. We have been developing molecular electronics within the framework of building a robust computing machine that can operate at an energy efficiency that is far superior to modern, silicon-based machines. To this end, we have taken a systems-level approach to the problem, which means addressing the problem at the multiple levels of complexity represented by architectures, molecular materials, devices, and circuits. My colleagues at Hewlett Packard and I have developed an architectural framework for molecular electronics that is based on cross-point-based structures that can either be used as random access memories or that can be electronically configured into wired-logic circuits. Critical to the experimental realization of such circuits are molecular-electronics switching devices capable of robust, ambient operation, and we have pursued the development of these devices jointly with Professor Fraser Stoddart and his group. Various reconfigurable molecular electronic switches will be discussed within the context of molecular structure/device property relationships, as demanded by circuit applications. Results from small crosspoint memory circuits (16- to 64-bit) will be presented; 0-lithography approaches toward the fabrication of crosspoint memories at true molecular dimensions also will be presented. Finally, the challenges associated with chemically characterizing these unique, nanoscale devices and circuits will be discussed.

Relevant Publications

1. Alexander Star, et al., "Preparation and Properties of Polymer-Wrapped Single-Walled Carbon Nanotubes," *Angew. Chem. Int. Ed.* **40**, 1721 (2001).
2. C.Patrick Collier, et al., "A [2]-Catenane Based Solid-State Electronically Reconfigurable Switch," *Science*, **289**, 1172-75 (2000).
3. C.Patrick Collier, et al. "Electronically Configurable Molecular-Based Logic Gates," *Science*, **285**, 391 (1999).
4. James R. Heath, P.J. Kuekes, Greg Snider, and R. Stanley Williams, "A Defect Tolerant Computer Architecture: Opportunities for Nanotechnology," *Science*, **280**, 1716 (1998).

Cell-Semiconductor Hybrids Strategies and Materials

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The realisation of a long-term stable, non-invasive connection between single cells and semiconductors is the key for a large variety of biosensor-devices. One of the most challenging ideas is the recording of extracellular potentials of individual cells adherent to surface potential sensors. Here, great demands on the sensor performance under harsh conditions as well as on the biocompatibility of the device have to be met. For example the investigation of interconnected neural-networks requires a stable cultivation of cells on chip for several weeks. Even after that period of storage in electrolytic solution the potential sensitivity of the device still has to be better than $100 \mu\text{V}$ at a temporal resolution of 1 ms. While most sensor concepts (like field-effect transistors, the light addressable potentiometric sensor (LAPS) or microelectrodes) employ silicon technology, the field-effect addressable potentiometric sensor (FAPS), which was proposed in the early years of CeNS, is based on epitaxially lift-off GaAs-heterostructures. In contrast to silicon that can be stably passivated by SiO_2 or Si_3N_4 , the chemical instability of the gallium arsenide surface apposes a serious limitation to its use under ambient conditions. Therefore coatings for GaAs that are stable under physiological conditions and the presence of electric fields have to be found. This is even more important since arsenic ions that go into solution have toxic effects on adherent cells. In turn, the thickness of the coating has to be kept below several ten nanometers in order to maintain the sensitivity of the device. In this work besides inorganic coatings (Si_3N_4 , SiO_2), the concept of thiol-based layers of polymerized organic mercaptosilanes has been studied. The electrical performance of GaAs and GaAs/InGaAs heterostructures in water was monitored via cyclic voltammetry and IU-characteristics of field-effect channels, and was found to be significantly stabilized by the insulating polymeric surface coatings, even under moderate electrochemical loads. In addition arsenic release was suppressed sufficiently to allow the cultivation of NRK-fibroblasts. These findings promise the implementation of GaAs technology in future cell-semiconductor hybrids.

Optical investigations of single quantum rings

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Self-assembled quantum structures have been the focus of considerable interest in the last years. These semiconductor quantum structures are also referred to as artificial atoms.

We investigated InAs self-assembled quantum dots and rings grown by molecular beam epitaxy in the Stransky-Krastanov mode. Quantum rings are obtained from dots by introducing an interruption in the growth after capping the dots with 1nm of GaAs. The quantum structures are embedded in a field-effect device which gives us the ability to bias-control single electron charging of single quantum dots. Additionally, excitons are optically pumped to act as probes for the investigated dots or rings.

The dots densities range between 1 billion and 10 billion per cm^2 . Experimental methods with high spatial resolution are required to isolate these structures for the spectroscopic analysis. Farfield methods like confocal microscopy allow us to obtain spatial resolutions in the range of $1\mu\text{m}$, whereas nearfield methods with nanoapertures or scanning probes extend this range down to 50nm. With different of these techniques we measured the emission spectra of excitons originating from many individual dots. The analysis of these spectra brings to us the magneto-optical properties for the different states of charging of these dots.

We present fundamental results: Neutral, singly, doubly and higher charged excitons are identified in the spectra, which means, the emission lines of these excitons change their color whenever a electron is added. By use of magneto-photoluminescence spectroscopy few-particle states were studied; they show a diamagnetic shift as well as Zeeman splitting. We show a new behaviour of some measured rings, namely a clear departure from the low field diamagnetic dispersion for fields larger than 6T.

Nanoparticles in Gene Therapy

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Supramolecular assemblies of nucleic acid, cationic lipids and polypeptides are used as gene delivery systems for human gene therapy. We investigate the structure, phase behavior and molecular order of cationic lipid-DNA composite complexes using synchrotron X-ray scattering. A series of novel structures with high liquid-crystalline order of alternating lipid-DNA layers are discovered, where molecular spacings and intrinsic correlation lengths vary in predictable fashion with composition and temperature. It can be shown that structure is related to the over-all gene transfer efficiency. In this respect liposomal and polymer-based systems are compared and the concept of molecular engineering soft nanoparticles with tailored properties for targeted gene transfer is introduced. One of the most important requirements is the control over the size distribution of the self-assembled systems. In order to assess the aggregation behavior of particles we use fluorescence microscopy and fluorescence correlation spectroscopy. The stabilization and encapsulation of anionic lipids and surfactants on dendrimer and polymer particles is shown.

PREPARATION OF ORIENTED CHANNEL STRUCTURES AS HOSTS FOR THE GROWTH OF NANOMATERIALS

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The ability to utilize structural and functional characteristics of mesoporous films provides an excellent avenue for numerous potential applications ranging from catalysis to the development of electronic and optical devices. Spin – coating induced evaporation self-assembly is used to form oriented mesoporous films on silicon substrates from preformed silica/iron/surfactant solutions with different compositions. These highly ordered host structures are used for the preparation of carbon nanotubes by catalytic decomposition of hydrocarbons.

Mesoporous films prepared on silicon wafers were studied with XRD, FTIR, atomic force and electron microscopy. The loading of the catalytic iron nanoparticles inside the host system was investigated with thermal analysis (TA), temperature programmed reduction (TPR) and UV – Vis spectroscopy. The catalytic growth of carbon nanotubes was followed by electron microscopy and Raman spectroscopy.

Different orientations of the host channels as well as various film thickness and surface morphology are obtained by varying the conditions of the spin – coating process and the initial sol composition. The role of the catalytic iron nanoparticles introduced directly with the synthesis sols for the growth of the carbon nanotubes is elucidated. The properties of the synthesized carbon nanomaterials are currently being investigated.

Coupling Optical Excitation into Force Measurements

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Abstract.

With AFM based single molecule force spectroscopy it is possible to measure inter- and intramolecular forces on single molecules, e. g. the unfolding of proteins or conformational transitions along polymer chains. In the presence of an applied stretching force the molecule is forced from a short (low energy) to an extended (high energy) conformation, which can be observed in the force-extension traces. Such molecular transitions between a short and an extended form are particularly interesting if they can be reversibly switched by means of external stimuli, which should allow the conversion of external excitation energy into mechanical work performed by a single polymer chain. Hereby, the coupling of optical excitation into the mechanical AFM experiment seems to be the most attractive approach for the general study of energy transductions at the single molecule level.

We have recently extended the scope of the AFM experiment towards the direct detection of light induced conformational changes. It is now possible to couple light from a flashlamp into an object slide, which acts as a lightguide. This allows for an optimal coupling of the evanescent excitation field to the polymer molecule between the surface of the object slide and the cantilever, and at the same time minimizes the unwanted influence of the light onto the AFM cantilever.

For the demonstration of opto-mechanical coupling at the level of single polymer chains we used synthetic poly-azopeptides containing the photoswitchable azobenzene moiety repeatedly along the polypeptide chain. It is known from bulk experiments that excitation with light filtered with a 365 nm bandpass filter results in a trans->cis isomerization of the poly-azopeptide (effective shortening), while the filtering with a 420 nm highpass filter results in the reverse cis-trans isomerization (lengthening) of the poly-azopeptide. With the current AFM setup we could detect the corresponding shortening and lengthening of single polyazopeptide chains. The influence of a stretching force on the photochemical transition is under current investigation.

DNA dynamics and DNA protein interaction

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The flow of molecular information in biology. We will pose the problem of biological information using some examples from our laboratory: recognition, recombination and evolution of DNA.

Colorful metallic nano-rods and -dots

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The collective oscillation of conduction electrons in metal nanoparticles is known as surface plasmon or particle plasmon. Strong light absorption and scattering, and considerable local-field enhancements, occur at the resonance frequency of the particle plasmon as a consequence of the large optical polarization associated with the collective electron oscillation. These properties are of great interest for a range of optical applications, including surface-enhanced Raman scattering (SERS) spectroscopy. Applications of particle plasmons often benefit from a weak plasmon damping, i.e., a slow dephasing of the optical polarization associated with the electron oscillation. The processes leading to this damping have been the subject of extensive research and debate.

Because of its central importance for the fundamental understanding of particle plasmons as well as for optical applications, a number of experiments have been performed to measure the dephasing time T_2 or homogeneous linewidth $\Gamma = 2\hbar/T_2$ of the particle plasmon. However, the T_2 times reported so far vary widely for particles of the same metal. These variations may be partially due to differences in particle size and shape and possibly to inhomogeneous broadening effects present in experiments on particle ensembles, and have made a systematic comparison with theory difficult.

We systematically study the dephasing of particle plasmons in gold nanoparticles as a function of particle size and shape. We determine the homogeneous linewidth of the plasmon resonance by spectrally investigating the light scattered by single particles, and we derive the dephasing time T_2 . This approach avoids the problem of inhomogeneous broadening of the plasmon resonance frequencies. We find a drastic reduction of the plasmon dephasing rate in nanorods as compared to nanospheres due to the suppression of the decay into interband excitations. This finding implies large local-field enhancement factors and a relatively high quantum efficiency for resonant light scattering in the nanorods. Comparison with theory shows that pure dephasing and interface damping give negligible contributions to the total plasmon dephasing rate in our particles.

Posters

Abstracts

Poster Sessions

Tuesday, September 25

Andres	Philip	Towards Metallo-Supramolecular Architectures and Polymers based on Terpyridine Ruthenium Complexes
Benoit	Martin	Measuring Adhesion Forces of Individual Adhesion Molecules
Bräuchle	Christoph	Single Virus Tracing: Infectious Entry Pathway of a Single Dye-Labeled Virus into a Living Cell
Drobek	Tanja	Genetically Based Supramolecular Architectures from Self Assembled DNA-Bases Coding for Amino Acids
Heckl	Wolfgang	Two Dimensional Self-Assembled Molecular Host Guest Architectures
Hillenbrand	Rainer	Phase Contrast in Optical Near-Field Nanoscopy
Höhberger	Eva	Magnetotransport in Freely Suspended Two-Dimensional Electron Systems
Huettel	Andreas	Semiconductor Quantum Dots as Qubits
Jöstl	Willi	Desorption of Single Polyelectrolyte Chains from Solid Substrates studied by AFM
Keßler	Max	Unfolding Bacteriorhodopsin Helix by Helix
Kirchner	Christian	Long Term Protection and Functionalization of GaAs-Surfaces in Aequous Environment
Kleff	Silvia	A model for Ferromagnetic Nanograins with Discrete Electronic States
Kohler	Sigmund	Molecular Wires in Laser Fields: The Ratchet Effect
Matzke	Rainer	Mechanics of Cellular Dynamics – AFM Studies

Thursday, September 27

Fertig	Niels	Glass Chip Device for High Throughput Electrophysiology
Franzl	Thomas	Plasmon Modes in Metal Nanoparticle Pairs
Meyer	Christine	Nanotweezers
Riechel	Stefan	Organic Semiconductor Random Laser Based on a Highly Disordered Self-assembled Colloidal Monolayer
Schmid	Gerhard	Stochastic Resonance as a Collective Property of Ion Channel Assemblies
Seebacher	Christian	Single Molecule Microscopy and Spectroscopy in Nanostructured Molecular Sieves
Strobl	Christoph	Acoustically Driven Planar Microfluidics
Thalhammer	Stefan	The Combination of Atomic Force Microscopy (AFM) and Laser-Based Microdissection as a Tool for Molecular Biology
van den Anker	Carlos	Towards Metallo-Supramolecular Fullerene Assemblies and Polymers
Vogel	Markus	Low Temperature Scanning Probe Microscopy of Surface and Sub-surface
Wehle	Angelika	Interactions between Single Stem Cells
Werner	Patrick	Quantum Effects in Nanomechanics
Wilhelm	Frank	An Asymptotical von-Neumann Measurement Strategy for Solid-state Quantum Bits
Wouters	Daan	Atomic Force Microscopy on Metallo-Supramolecular Polymers
Wu	Xiachun	Metal and Semiconductor Nanoparticles in Dendrimers: Synthesis, Properties and Submicrometer Patterning of Surfaces

Towards Metallo-Supramolecular Architectures and Polymers based on Terpyridine Ruthenium Complexes

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Terpyridines are well-known for forming complexes with a broad variety of metal ions in different oxidation states. The resulting metal-ligand interactions have the potential of creating new functional materials, some of them implying metallo-supramolecular architectures. The covalent attachment of terpyridines to different systems such as polymers, dendrimers, surfaces or biomaterial is one key point in creating new materials. The complexation of such terpyridines with ruthenium-ions opens an easy access to complexes with two different terpyridine-ligands. This may lead to possibilities for the creation of new non-covalent block copolymers. Also surface functionalization utilizing self-assembled monolayers (SAMs), incorporating terpyridine ruthenium complexes could be feasible.

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Measuring Adhesion forces of Individual Adhesion Molecules

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Cell adhesion is a precondition for the existence of single cells and organisms. Communication, recognition and stimulation of cells are decisively mediated by huge families of adhesion molecules. Many techniques have been developed to study adhesion of cells ranging from light microscopy to electron microscopy as well as centrifugation and shear flow essays or micro-pipette and AFM techniques. An important role for further understanding of processes on the molecular level plays the ability to isolate and genetically manipulate and handle individual molecules. Here an AFM-related technique - the cell adhesion force spectroscopy - is utilized to directly measure adhesion forces between living cells. Individual adhesion molecules were identified by switching the cells between different states or by testing genetically altered cells.

Single Virus Tracing: Infectious Entry Pathway of a Single Dye-Labeled Virus into a Living Cell

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Single molecule detection is a novel technique for the investigation of biological processes on the molecular level. The study of individual molecules allows one to look beyond ensemble-averaged properties, thus revealing details of the molecular behavior which are otherwise hidden by spatial, spectral and temporal averaging in ensemble measurements. Here we show for the first time that this method can be used for the kinetic characterization of the infection pathway of a single dye-labeled virus.

Single molecule experiments were conducted to follow the migration of individual Adeno-associated viruses on their infectious entry pathway into a living HeLa cell. Only one fluorescent dye molecule (Cy5) was attached to a virus in order not to influence its physiological behavior. The fluorescent dye-label allows one to observe the movement of a virus. For the first time we could obtain diffusion trajectories of single viruses in three different stages of the infection:

- 1.) Diffusion of the virus in front of the cell, adsorption at the receptor and penetration through the cell membrane
- 2.) Diffusion and transport of the endosome and the released virus in the cell plasma
- 3.) Penetration and diffusion of the virus in the cell nucleus

From the trajectories of individual viruses different modes of motion could be established and diffusion coefficients were obtained for all three stages. A detailed picture of the processes involved in the uptake of a virus in a living cell could be modeled.

Genetically Based Supramolecular Architectures from Self Assembled DNA-Bases Coding for Amino Acids

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The formation of highly ordered monolayers of the purine and pyrimidine DNA bases through physisorption mediated molecular self-assembly at the solid-liquid interface is an example for the spontaneous creation of order. We have proposed a functional role of this process for the emergence of terrestrial life which may also lead towards the construction of genetically based supramolecular architectures for modern technical applications.

We present the structure determination of DNA base molecules self assembled on mineral template surfaces after thermal evaporation of their aqueous solutions (“sizzling” technique) as well as by OMBE under UHV- environment. We show how the two dimensional molecular packing structure of these MBE grown films can be determined by the combination of real space data from STM and the reciprocal space data from LEED. Together with molecular force field calculations and the determination of the preparation parameters and thermodynamic variables, such as adsorption energy by TDS, clear models can be derived as a result.

In nature, the main example for coded self-organization is the DNA-double helix. Therefore it is obvious to investigate the hydrogen bonded nucleic acid base layers in a 2d-self- assembly system. Here, the steric arrangement of functional groups determine the blueprint of the whole system. For example, the RNA-base uracil dimerizes into a 2d-structure with defined motif and lattice constants. Furthermore The construction of supramolecular complexity through the control of the intermolecular bond, preferentially the H-bond is a goal which has been investigated in the case of an amino acid layer H-bonded on top of a templating nucleic acid base layer on a mineral template crystal. There the possibility of such a layered system as a primitive coding mechanism in the context of the origin of life on mineral templates has been proposed.

Primitive information coding two-dimensional systems may be used to construct peptide libraries, thus reducing the complexity of the ribosomal RNA- mediated process of polypeptide synthesis in nature in

every biological cell. We present the concept for a peptide library in the framework of the need for a primitive molecular assembler.

Glass Chip Device for High Throughput Electrophysiology

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Patch clamping is an outstanding method in electrophysiology, allowing to monitor conformation changes of single proteins, namely ion channels. The patch clamp technique is also widely used in drug screening to evaluate the potential action of compounds on ion channels. As currents through ion channels are directly measured by the patch clamp technique, it provides high fidelity and high information content data on ion channels. We have transferred the patch clamp technique from the commonly used glass pipettes to planar glass chips, enabling new kinds of experiments due to the planar geometry of the device. The chips also offer the potential for up-scaling, e.g. using an array of patch clamp units on a single chip, thereby allowing simultaneous measurements to be performed.

Plasmon Modes in Metal Nanoparticle Pairs

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The optical properties of metal nanoparticles are determined by surface plasmons. Spin-casting a solution of metal nanoparticles on glass substrates occasionally leads to the formation of particle pairs. If the distance between the particles is in the order of the particle diameter, the individual particle plasmons couple and split into a mode perpendicular (short-axis mode) and parallel (long-axis mode) to the connecting axis. The latter mode is significantly shifted to lower energies compared to the resonance of an isolated particle.

In ensemble measurements it is *impossible* to selectively excite one of the coupled plasmon modes if there is spectral overlap. By measuring the polarisation dependent scattering spectra of *individual* particle pairs, however, it is possible to address the modes separately. For a quantitative comparison with theoretical calculations the interparticle spacing is determined using an atomic force microscope.

Our results on spherical silver nanoparticles with diameters of 60 nm show mode splittings of up to 94 nm (470 meV).

The coupling of surface plasmons in particle pairs may be utilized to increase the sensitivity of plasmon resonances to changes in the environment and to shift the resonance energy to lower values.

Two Dimensional Self-Assembled Molecular Host Guest Architectures

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The adsorption of trimesic acid (TMA) molecules by OMBE on graphite and on AG(111) has been studied in air and UHV. The result is a two-dimensional host-guest system, with molecular caves, built via the directed hydrogen bridge bonding. STM, TDS (thermal desorption spectroscopy) and LEED show spontaneously self-assembly molecular layers as predicted from the bulk model and from theoretical considerations. Two different adsorbate structures can be distinguished and give rise to two possible guest configurations.

Phase contrast in optical near-field nanoscopy

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Near-field optical imaging (SNOM) can map optical properties down to the nanometer scale, providing the apertureless design is used, where the light scattered from a simple sharp tip carries the near-field information of the sample (scattering-type SNOM, s-SNOM) [1,2]. Optical phase contrast has however not yet been exploited in this microscopy, although interesting phase effects can be expected for all resonant interactions such as absorption, lasing or resonant scattering.

We introduce how to extract a maximum of optical information which is usually encoded in a pair of observables, in our case amplitude and phase [3]. Our experiment consequently combines a s-SNOM at 633 nm with heterodyne interferometric detection of the backscattered light to generate simultaneous amplitude and phase images. The microscope is based on a tapping-mode AFM where commercial cantilevered tips are used as scattering probes. Higher-harmonic demodulation of the optical signal modulated by the tip's tapping motion suppresses background and topography-induced artifacts.

Experiments on nanostructured Au-films on Si show a near-field contrast, both in amplitude and phase, which is definitely material dependent. Backed by quasielectrostatic theory we demonstrate the significance and accessibility of complex optical constants on the nanoscale: phase contrast can be assigned to absorptive and amplitude contrast to refractive material properties [3].

Phase contrast is also seen to be decisive to map single particle plasmon resonance. Images with sub-particle resolution demonstrate that only amplitude *and* phase contrast clearly identifies the optical oscillation patterns. Examples of dominantly dipolar and quadrupolar plasmon modes will be presented. The <10 nm resolution of the microscope also allows to image gap modes confined between closely-spaced particles [4].

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Magnetotransport in freely suspended two-dimensional electron systems

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We present magnetotransport measurements on freely suspended two-dimensional electron gases. Samples are prepared from GaAs/AlGaAs-heterostructures containing an additional sacrificial layer which is removed in a combination of anisotropic and isotropic etching steps. Here we report on the fabrication of suspended two-dimensional electron gases and of their characterization by means of magnetotransport measurements. Shubnikov-de Haas oscillations as depicted in Fig. 1 are used to determine both carrier density and mobility. An estimate for the side depletion width is derived. These suspended nanocrystals are ideal candidates for studies of electron-phonon coupling [1] and for integrated nanoelectromechanical systems (NEMS). NEMS promise to be extremely fast and sensitive tools for sensor and communication technology [2].

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Figure 1: Shubnikov-de Haas oscillations measured at $T = 4.2$ K. The inset shows a suspended hallbar and quantum dot structure.

Semiconductor quantum dots as qubits

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In terms of scalability, semiconductor quantum dots pose a viable alternative to other proposed qubit systems. Two different models are possible, utilizing molecular charge and spin states in double quantum dots. Measurements on capacitive coupling of charge states and observations of transport blockade via stable high spin states are reported.

DESORPTION OF SINGLE POLYELECTROLYTE CHAINS FROM SOLID SUBSTRATES STUDIED BY AFM

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Polyelectrolytes are of central importance both, in nature (conformation and adhesion of proteins) as well as in industrial processes (stabilization of inhomogeneous solutions, flocculation, etc). In biomaterials research, polyelectrolytes can be utilized to provide biocompatible surfaces. In all areas, the adsorption of polyelectrolytes onto solid (charged) surfaces is of central importance [1]. Experimental methods which allow the addressing of single molecules can provide useful data in order to improve our understanding of the adsorption process.

AFM single molecule spectroscopy [2] allows the addressing of single polymer chains which are being attached to the tip of an AFM cantilever and desorbed from a substrate surface. Hereby, force-extension profiles of single molecules can be detected, from which their interaction with different surfaces is deduced.

In this work the desorption of the polycations from negatively charged surfaces (silicon oxide) will be discussed [3]. For a series of polyvinylamines, the dependence of the desorption force upon the polymer's line charge density as well as typical parameters such as pH or salt concentration was studied by the AFM technique. As expected, the electrostatic contribution depends on all these parameters. However, next to a linear dependence upon the line charge density and the Debye screening length a constant (non-electrostatic) force was observed [4].

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Unfolding Bacteriorhodopsin Helix By Helix

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We used atomic force microscopy to extract individual molecules of Bacteriorhodopsin (BR) out of purple membrane (PM) patches in native environment. In high resolution images that were taken before and after the extraction of BR, we clearly can see that individual proteins were extracted. The force versus distance curves recorded during the extraction of the proteins provide detailed insight into the possible unfolding pathways of Bacteriorhodopsin. At the unfolding of Helix D and E and the adjacent loops, we can distinguish between four different pathways. The same phenomena occurs with the unfolding of Helix B and C respectively. The probability of these different pathways is not dependent on pH in the range from pH 4.2 to pH 10.0. Here we present a theory to explain our experimental results, that seems to fit quite well to current structural models of BR.

Long term Protection and Funktionalization of GaAs-Surfaces in aqueous Environment as a step towards the application of GaAs in biosensorics

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GaAs is a semiconductor with several advantages compared to silicon [1]. For example, GaAs based hetero structures provide sophisticated electronic properties [1], which allow for the design of ultrasensitive potentiometric devices. In biosensors like the field-effect potentiometric sensor/stimulator (FAPS) [2] GaAs is used this way to detect the electrical activity of single biological cells like neurons or cardiomyocytes. One big technological challenge is the solubility of GaAs in water [3].

This work investigates possible coatings for GaAs in aqueous solutions, which protect the semiconductor against corrosion and vice versa protect the electrolyte against contamination by the toxic arsenic acid, which is known to be released by hydrolysis from the native GaAs oxide overlay. Moreover, the protective layer should promote the adhesion of cells grown on top of the surface.

We propose a method of coating the GaAs surface with polymerizable organic thiols, which not only offers a perfect long-term stability in water but also introduces chemical groups for easy further functionalization of GaAs. Characterization of the polysiloxane layer and its protective role is done by atomic adsorption spectroscopy, AFM, ellipsometry and X-Ray reflectivity measurements. The electrical performance of GaAs and GaAs/InGaAs heterostructures in water was monitored via impedance measurements, cyclic voltammetry and IU-characteristics of field-effect channels, and was found to be significantly stabilized by the insulating polymeric surface coatings, even under moderate electrochemical loads. Biocompatibility of the surface is probed by measuring the population density of cell cultures on those surfaces and found to be excellent for cells from type NRK-fibroblasts and chickenembryo-cardiomyocytes. These findings promise the implementation of GaAs technology in future cell-semiconductor hybrids.

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A model for Ferromagnetic Nanograins with Discrete Electronic States

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We propose a simple phenomenological model for an ultrasmall ferromagnetic grain, formulated in terms of the grain's discrete energy levels. We compare the model's predictions with recent measurements of the discrete tunneling spectrum through such a grain. The model can qualitatively account for the observed features if we assume (i) that the anisotropy energy varies among different eigenstates of one grain, and (ii) that nonequilibrium spin accumulation occurs.

Molecular Wires in Laser Fields: The Ratchet Effect

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Recent experimental progress enabled the measurement of weak tunneling currents through molecules which are coupled by sulfur ligands to gold contacts. We present a study of the transport properties of such molecular wires under the influence of a laser field. Our approach is based on the single-particle Floquet states of the driven wire and allows even in the case of large molecules for an efficient numerical treatment.

In particular, we have investigated the possibility to use molecules for the demonstration of the so-called ratchet effect, i.e. directed transport in periodic structures induced by ac-fields. As a model we consider a molecule which consists of asymmetric units driven by a laser field. In such a system we observe a nonvanishing dc-current in the absence of an applied voltage. For long molecules, we find that the dc-current is basically independent of the molecule length; in short wires it has a strong length dependence. Most remarkably, we find current reversal with increasing wire length.

Mechanics of Cellular Dynamics – AFM Studies

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The Atomic Force Microscope (AFM) was used to study the mechanics of living cells. The elastic properties of cells are determined mainly by the cytoskeleton, which is a dynamic reorganized cross-linked polymeric network. The regulation and control of the elastic properties of cells is very important for many cellular processes. One examples is cell division. Here, a temporally and spatially controlled, local variation of the elastic properties is necessary for successful cell division. However, the actual mechanisms are not understood well and it is unclear, where the forces required for division are being generated. To approach this question, a technique that can monitor spatially resolved changes in cortical stiffness with good time resolution is required. The AFM offers the unique possibility to apply and detect small forces (around 10 pN), with high spatial resolution (10's of Nanometers on living cells) and the AFM can be operated under physiological conditions. Thus, local changes in the mechanical properties of living cells can be studied with the AFM.

Nanotweezers

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Small devices attract more and more interest in semiconductor physics as well as in biotechnology.

Currently there are only few methods to manipulate the arrangement of small particles. Here our nanotweezers can play an important role. By combining electron beam deposited (ebd) carbon-material with freely suspended semiconductor nanostructures we can build up a tweezers structure. Two finger-like tips are to be moved against each other electrostatically in order to grip particles with sizes in the nanometer range.

Another interesting approach regarding ebd-structures is to make them conductive. They are extremely sharp and could be used for STM imaging or as field emitters.

Organic semiconductor random laser based on a highly disordered self-assembled colloidal monolayer

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Stimulated emission and lasing in high gain organic semiconducting media has recently attracted a great deal of interest. Owing to the ease of processing, optically pumped lasing has been reported for various organic semiconductors in a variety of resonator structures including microcavities, DFB, DBR as well as two-dimensional (2D) or 3D-phonic crystals^{1,2}. We report on the realization of an optically pumped 2D random laser. The structure consists of a thin film of the organic semiconductor laser material Alq₃:DCM as active medium which is deposited on a highly disordered self-assembled colloidal monolayer.

Using a self-assembly technique monolayers of a two-dimensional colloidal crystals are grown on glass substrates from an aqueous solution of monodisperse polystyrene beads (mean diameter ≈ 315 nm). The maximum size of mono-crystalline domains is limited by the size-fluctuation of the beads. For a dispersion above $\sigma \approx 4\%$ we obtain completely disordered colloidal monolayers as seen in Fig 1. On top of the monolayer a ≈ 400 nm thick layer of Alq₃:DCM is deposited by thermal evaporation in high vacuum thus forming a very rough and strongly scattering slab waveguide. Under pulsed optical excitation a number of discrete narrow laser modes appears in the emission spectrum above a threshold excitation density. Fig. 2 shows emission spectra as recorded when a 50 μm wide stripe of variable length is excited with a constant excitation density. With increasing stripe length the number of laser modes increases, whereas the corresponding laser threshold decreases (see inset of Fig. 2).

Our results are explained by random lasing. Random closed loop cavities are formed by multiple scattering within the waveguide. Random lasing requires strong scattering with sufficiently low values of the mean free photon path. As a consequence of the high density of scattering centers in our sample, the mean free path between two consecutive scattering events is estimated to be less than $5.6 \mu\text{m} \approx 9 \lambda$. This is similar to the critical value reported by Cao et al. for random lasing in strongly scattering 3D structures³.

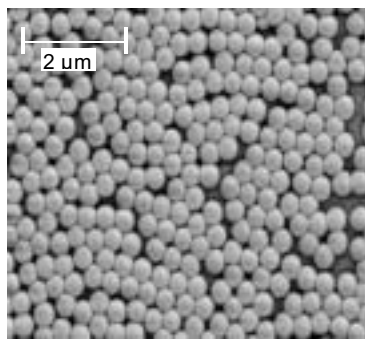


Fig. 1: SEM image of a disordered colloidal monolayer. Typical microcrystals are smaller than $\approx 2 \mu\text{m}$

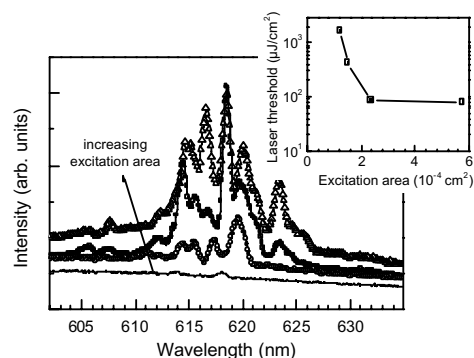


Fig. 2: Emission spectrum for varying excitation area. Inset: Dependence of threshold on the excitation area.

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Stochastic resonance as a collective property of ion channel assemblies

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By use of a stochastic generalization of the Hodgkin-Huxley model we investigate both the phenomena of stochastic resonance (SR) and coherence resonance (CR) in variable size patches of an excitable cell membrane. Our focus is on the challenge how internal noise stemming from individual ion channels does affect collective properties of the whole ensemble. We investigate both an unperturbed situation with no applied stimuli and one in which the membrane is stimulated externally by a periodic signal and additional external noise. For the nondriven case, we demonstrate the existence of an optimal size of the membrane patch for which the internal noise causes a most regular spike activity. This phenomenon shall be termed intrinsic CR. In presence of an applied periodic stimulus we demonstrate that the signal-to-noise ratio (SNR) exhibits SR vs. decreasing patch size, or vs. increasing internal noise strength, respectively. Moreover, we demonstrate that conventional SR vs. the external noise intensity occurs only for sufficiently large membrane patches, when the intensity of internal noise is below its optimal level. Thus, biological SR seemingly is rooted in the collective properties of large ion channel ensembles rather than in the individual stochastic dynamics of single ion channels.

Single Molecule Microscopy and Spectroscopy in Nanostructured Molecular Sieves

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Nanometre-scale sized structures in the bulk volume of molecular sieves cannot be characterized with high resolution methods such as X-ray diffractometry, electron microscopy or scanning probe techniques. We recently demonstrated the detection of single molecules in the volume of molecular sieves using confocal fluorescence microscopy. This allows us to use single fluorescent dye molecules as probes for the characterization of nanostructured porous materials. Investigations of static and dynamic systems exemplify the high potential of single molecule microscopy in material science.

First the incorporation of three differently sized dye molecules (Oxazine 1, 170 and 750) in an AlPO₄-5 (AFI) crystal was used to investigate the formation of nanostructures built within molecular sieves. In all three cases the molecular dimensions are bigger than the diameter of the pores. The smallest of these molecules aligns to the pore orientation and causes only minor defects, whereas the bulkier dyes generate distorted structures but do not affect the macroscopic habitus of the crystal.

In a second experiment we studied the diffusion of single terylene diimide (TDI) molecules incorporated into the channels of a cm-sized M41S-body. This molecular sieve was synthesized using a micellar liquid crystalline template. Our results reveal a high tortuosity of the channels. X-Ray diffraction measurements will only point out the existence of a hexagonal order of the pores in an otherwise amorphous solid body. Macroscopically the cm-sized monoliths appear completely transparent and anisotropic. Single molecule measurements in the pure hexagonal liquid crystalline phase of the used surfactant showed a longer ranging order of the micelles. From that we can deduce that the tortuosity of the channel-system is increased during the silication process.

Acoustically driven planar microfluidics

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We present a novel approach to actuate smallest amounts of liquid on a microchip. Unlike to ‘conventional’ methods, we do not use trenches or tubes to confine and steer the liquid on the chip but use ‘virtual beakers’ directly on the chip surface. Here, we rely on the fact that for small amounts of liquid the surface tension is the dominant force. A modulation of the substrate surface wettability hence enables us to create two-dimensional potential wells for single droplets. We demonstrate that planar microfluidics can be used to effectively actuate single droplets along lithographically defined fluidic tracks and give some examples for a new generation of microfluidic devices.

The combination of Atomic Force Microscopy (AFM) and laser-based microdissection as a tool for molecular biology

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The combination of high resolution microscopy, such as atomic force microscopy (AFM), and laser-based microdissection provides a direct approach for the investigation and isolation of biological specimen.

We present a non-contact isolation method, *laser pressure catapulting* (LPC), in combination with AFM for the isolation of cell clusters and single cells from tissue sections, cell compartments, metaphase chromosomes and chromosomal parts. The laser precisely cuts around the selected area leaving a micron sized gap. To investigate the isolation procedure, atomic force microscopy in contact mode was performed on the biological specimen. The isolated probes are subsequently ejected from the slide by single laser shots onto a collection device. The isolated material can be used for further biochemical analysis. We show the results on different biological applications: a) isolation of single chloroplasts for evolutionary studies in botany; b) detection of virus particles in infected tissue sections. The isolation of single cells and cell clusters were performed with tissue sections infected with the TTV virus. TTV is a newly described circular single stranded DNA virus; c) „donut-isolation“ for the isolation of a single nucleus with subsequent isolation of the remaining cytoplasm; d) isolation of single metaphase chromosomes and chromosomal parts for studies in molecular cytogenetics

Towards Metallo-supramolecular Fullerene Assemblies and Polymers

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The very interesting photochemical and electrochemical properties of Buckminsterfullerene (C₆₀) offer possibilities for the application of these units in functional materials. One promising approach uses the combination of self-assembling metallo-supramolecular building blocks and fullerenes.

However, up to now there are only very few examples known using a non-covalent link between different fullerenes. The major drawback in this direction is the synthesis of soluble fullerene-heterocyclic building blocks. Terpyridine ligands are especially suited for a combination with fullerenes due to the special electronic and redox properties of their corresponding metal complexes, which have been extensively studied in the last century e.g. in the direction of applications in photocatalysis or energy conversion (hundreds of complexes with transition metal ions like cobalt, copper, manganese, iron, chromium, nickel or ruthenium have been already investigated Co(Br)). Here we describe a synthetic procedure for fullerene derivatives connected to terpyridines (4'-position), some first non-covalent assemblies as well as monolayer preparation with layer by layer self-assembly technique.

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Low temperature scanning probe microscopy of surface and sub-surface charges

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Electronic properties of nanostructures are usually investigated by means of optical or transport spectroscopical experiments. In principle, such measurements can be complemented by the use of electrostatic scanning force spectroscopy. So far, however, the limited electrostatic force sensitivity commonly achieved makes it still impossible to measure single electron properties.

We have developed a method of measuring electrostatic forces down to few electronic elementary charges. In this poster we demonstrate the operation of a new cryogenic scanning force microscope with a sensitivity of about $50\text{fN}/\sqrt{\text{Hz}}$ at 5kHz modulation [1].

By applying a voltage between the metallic tip and a back gate inside the sample we can use this microscope as a scanning electrometer to map local electrostatic forces. Evaluation of this force distribution leads, e.g., to an image of surface charges on an insulating substrate. We demonstrate this by writing structures onto an initially homogeneously charged PMMA surface and imaging this structure afterwards. The goal is to reach the sensitivity for detecting a single electronic charge. This would open the door to a wide field of interesting experiments, such as single electron spectroscopy on nano structures (e.g. quantum dots).

Since the electrostatic force acting on the AFM tip depends on the tip to sample capacitance, the microscope can also be used for mapping changes in local capacitance originating from variations of the dielectric constant. This is demonstrated by measurements on a test structure where we get sub aF resolution in capacitance. Due to the long range of electrostatic force we are even capable of imaging structures buried as far as 300 nm.

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Interactions between single stem cells

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Force spectroscopy with Atomic Force Microscope (AFM) has revealed various molecular properties like elasticity and unfolding forces of single molecules. Especially the feasibility to study living systems under physiological conditions is essential for the work with living cells. In this work we studied the forces in molecular bonds between single cells.

With a single cell attached to the very end of a tip-less cantilever one can probe other cells and measure the force between adhesive molecules in the membrane of cells. By varying the duration of the cell contacts, it is possible to investigate time dependent adhesion phenomena. Also the pulling velocity plays an important role for the magnitude of the adhesion forces. By adding certain proteins the changes in the adhesion between two cells can be investigated and the physiological role of these proteins can be analyzed.

In this single cell investigation hematopoietic stem cells, which exist in parallel in two different states, were employed. In one state the cell is quiescent and there exists an other state in which the cell rounds up and loses its adhesion to the surface. This is the beginning of the differentiation of the stem cell towards a blood cell. In this process Interleukin 6 and the Stem Cell Factor (SCF) regulate the equilibrium between the two different cell states among other things. The signal transduction molecule CD34 plays an important role in this development. The quiescent cells are CD34-negative and can be discriminated from the CD34-positive cells, which are on the way to become blood cells.

The changes in the maximum force, the molecular force and the tether length were probed. The maximum force that is built up between the cells is, for short contact times shorter for the round - round cell contact than for the round - flat cell contact, but the tether length increases. For times shorter than one minute the molecular adhesion force does not increase, but at longer contact times an increase can be observed.

Quantum Effects in Nanomechanics

Patrick Werner

In the last years experimental physicists were able to push electromechanical systems from the mikroscale (MEMS) to the nanoscale (NEMS). Focussing on the mechanical aspects, a carbon nanotube represents for instance an elastic beam of lowest dimensions. We are interested to investigate whether quantum effects modify the conventional description of such systems in terms of continuum mechanics. Quantum phenomena like mechanical macroscopic quantum tunneling or quantum fluctuations seem not (yet) in reach of experimental preparation techniques and observation.

An Asymptotical von-Neumann Measurement Strategy for Solid-State Quantum Bits

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A strategy for performing quantum measurements on quantum bits is proposed, which uses the entanglement of the qubit with asymptotically orthogonal states of a weakly damped harmonic oscillator.

Due to this entanglement, this measurement comes arbitrarily close to von-Neumann's measurement postulate. Applying results from a systematic approximation scheme, it is shown, that this measurement very rapidly decoheres the state into a mixture of meter-eigenstates, but only very slowly relaxes this mixture. The implementation of this strategy in Josephson quantum bits is described and discussed in the context of existing proposals.

Atomic Force Microscopy on Metallo-Supramolecular Polymers

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Terpyridines are well-known for forming complexes with a broad variety of metal ions in different oxidation states. These non-covalent forces are used to assemble novel supramolecular structures with special properties and applications. Among these structures are very well defined block copolymers, functionalized nanoparticles and self-assembled monolayers on metal surfaces. The poster will show various metallo-supramolecular assemblies and the application of Scanning Probe Microscopy as a tool in their characterization.

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Metal and Semiconductor Nanoparticles in Dendrimers: Synthesis, Properties and Submicrometer Patterning of Surfaces

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Dendrimer molecules are highly branched, cage-shaped molecules with nanometer dimensions and a narrow size distribution. Therefore they are good templates for the synthesis of nanoparticles. Pd and Au nanoparticles were synthesized in generation 4 dendrimers that are terminated with OH groups. Due to the strong binding of Pd²⁺ to the tertiary amine groups in the dendrimer, Pd nanoparticles can be synthesized via a direct chemical reduction inside the cage. Au³⁺ cannot bind as strongly, hence Au nanoparticles are synthesized via a displacement reaction between Cu nanoparticles (inside the dendrimer) and AuCl₄⁻ ions. TEM images show that the Pd particles have an average size of 2nm with a narrow size distribution while the Au particles have 4nm average size in a relatively large size distribution.

Dendrimer molecules can self-assemble on Si wafers. A patterned linear structure was obtained by direct MicroContact Printing of dendrimers on Si wafers. Pd nanoparticles were synthesized in the dendrimers and used as catalyst for the electroless deposition of a cobalt layer, resulting in 400 nm wide cobalt lines.

CdS nanoparticles are a good photoluminescent material. CdS/dendrimer nanocomposites were synthesized. They show strong photoluminescence. The effects of preparation conditions such as Cd²⁺/S²⁻ ratio, dendrimers with different terminal groups (-OH, -COOH and -NH₂), dendrimer diameter and temperature are discussed. This composite material was also printed on Si wafers. Its photoluminescence is under investigation.