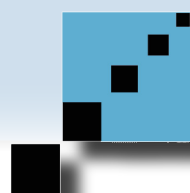
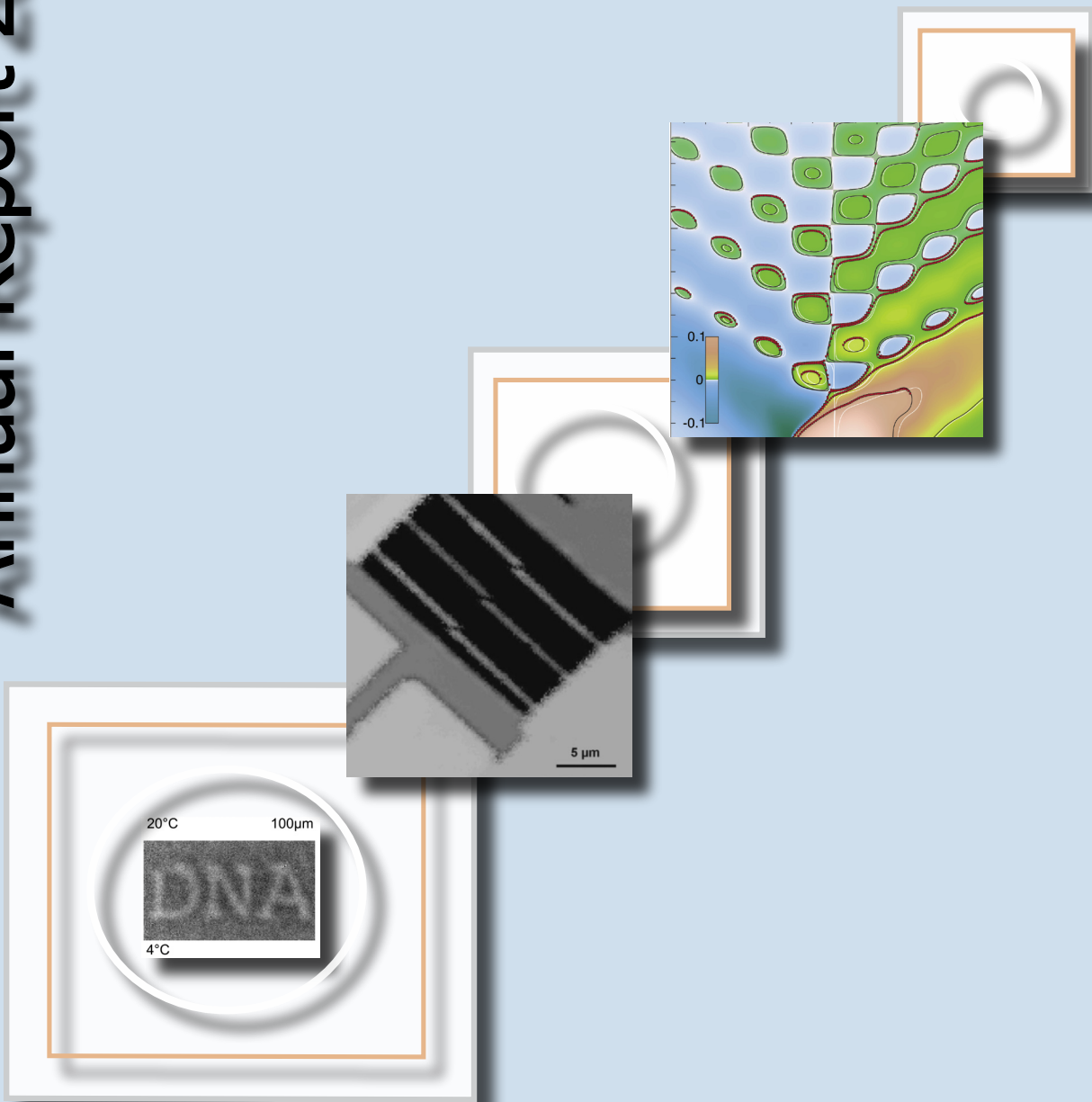


Annual Report 2005



CENS

Center for NanoScience
Ludwig-Maximilians-Universität



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For further information about CeNS and the web-based version of this report please visit our website: www.cens.de

Introduction

In 2005 CeNS continued to flourish. Our membership grew with Prof. Ernst Wagner, holding a chair for Pharmaceutical Biology at LMU, Prof. Joost Wintterlin, a recent LMU appointment in Physical Chemistry and Prof. Stefan Kehrein, a new member of the Theoretical Physics group, joining as full members. As extraordinary members we welcome Dr. Kay Eberhard Gottschalk, Liebig Fellow in the group of Hermann Gaub, Dr. Thorsten Hugel, designated Junior Professor at TU München, and Dr. Bernd Irmer, CEO of our spin-off company Nanotools.

Again, junior researchers at CeNS received attractive faculty positions elsewhere with Berenike Maier leaving for an associate professorship at the University of Münster, Frank Wilhelm as associate professor to the University of Waterloo, Canada and Andreas Zumbusch for a senior position at University College London. We wish them all lots of success in their new environment.

CeNS associates continued to receive special recognition for their outstanding work. Starting with the youngest, Hendrik Dietz, a CeNS graduate student, received the “Scientific Award BMW group” for his outstanding diploma thesis, in which he developed a molecular force sensor for living cells. Our spin-off company Nanion collected two major prizes with CEO Dr. Niels Fertig receiving the Nanoscience Award 2005 of the competence centre HanseNanoTec and Nanion recognized by the Bavarian Innovation Award 2005 and being named “Bavarian Small/Medium Enterprise of the year 2005”. In an international survey of companies fabricating automatic patch clamp systems Nanion was also ranked best. Finally, our very successful spin-off company Advalytix was acquired and expanded by Olympus Life and Material Science Europe.

In 2005 CeNS expanded its involvement in interdisciplinary schools and workshops, namely the already traditional biannual CeNS Winterschool in Mauterndorf, Austria, this time with the theme “From Quantum Bits to Life Science”, the yearly meeting “CeNS meets industry” at LMU as well as a CeNS workshop exclusively for graduate students and junior researchers (No professors allowed!) at Hirschegg, successfully aimed at informal exchange about current research topics within CeNS. Together with the International Graduate School (IDK) “Nano-Bio-Technology” supported via the Elite Network Bavaria, CeNS organized a summer school on “Nanoscience and Systems Biology” at the LMU Gene Centre in Martinsried and, together with the ODEON center of LMU, an IDK workshop on “Nano-Bio-Technology and Management” in Tutzing. CeNS also supported the 87. Bunsen Discussion Meeting “Mechanical Induced Chemistry - Theory and Experiment”, in Tutzing and the IDK workshop “Brownian Motion: A Paradigm of Soft Matter and Biological Physics”, in Munich. All these meetings were very lively and highly appreciated, in particular by our young researchers. Further details can be found via the past events column (www.cens.de/Past_Events.40.0.html) of the CeNS calendar (www.cens.de/Calendar.15.0.html) which also lists the many prominent speakers in our weekly seminars.

Again, several groups, mostly from abroad, visited CeNS interested to learn more about how we function successfully and are able to stimulate interdisciplinary research and exchange. These included delegations from the University of Alberta, Canada, recently becoming the host for a National Institute of Nanotechnology (nint-innt.nrc-cnrc.gc.ca), the Hitachi company, Japan, government delegations from Thailand and Malaysia, a delegation from SEMI (Semiconductor Equipment and Materials Institute, www.semi.org), and last not least the advisory board (“Hochschulrat”) of LMU.

All the above activities were made possible only by the continuous voluntary involvement of many CeNS members. It is my great pleasure to thank them all for their fruitful and stimulating contributions to the culture of CeNS.

Munich, June 30, 2006

A handwritten signature in black ink, appearing to read 'J. P. Kotthaus', with a long horizontal flourish extending to the right.

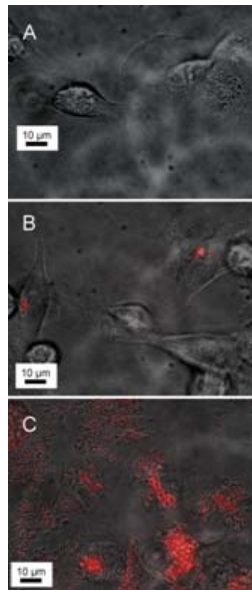
Jörg P. Kotthaus
Speaker of the board

Nanoengineered polymer capsules: tools for controlled delivery and site specific manipulation (Andrey Rogach, Wolfgang Parak, Dieter Braun, Martin Benoit, Joachim Rädler)

Multi-functional nanoengineered polymer capsules can find their application as a drug delivery system in medicine. In our project, we addressed three issues of capsule multi-functionality: (i) luminescent semiconductor nanocrystals embedded into capsule walls allow for imaging and identification of different capsules; (ii) magnetic nanoparticles embedded into capsule walls allow for external manipulation of capsules by magnetic fields, in particular the macroscopic delivery of capsules to desired parts of a cell culture/tissue; (iii) surface coatings allow for specific cellular uptake. In particular, magnetic Fe_3O_4 nanoparticles have been incorporated into the capsule shells, together with luminescent CdTe nanocrystals. By using a flow channel system for modeling the bloodstream in the circulatory system, and by locally creating a magnetic field gradient caused by a permanent magnet, specific trapping of polymer capsules simultaneously functionalized with two types of nanoparticles has been demonstrated. In the regions where the capsules were trapped by the magnetic field, drastically increased uptake of capsules by cells has been observed. This illustrates a way for magnetic delivery of polymer capsules loaded with pharmaceutical agents to pathogenic parts of a tissue. In another part of our joint activities, (co-financed by CeNS), adhesion-mediated internalization of polymer microcapsules by cells has been studied by atomic force microscopy and optical microscopy.

Dynamics of DNA release from artificial virus-like particles
(Christoph Bräuchle, Don Lamb, Joachim Rädler)

Positively charged polymers such as PEI (polyethylenimide) bind negatively charged DNA to form nanometer sized polyplexes. These polyplexes can be used as gene delivery systems for gene therapy. To be effective as gene delivery systems, the DNA has to be released from the polyplex in the target cell. It is currently unknown how the polyplexes release their DNA. One idea is that the high concentration of RNA about the cell nuclease replaces the DNA. C. Bräuchle and D. Lamb are investigating the dynamics of RNA binding and DNA release from polyplexes in vitro in collaboration with J. Rädler. The



Living breast cancer cells adherent at the bottom of the flow channel which are located at different distances (decreasing from A to C) from the edge of the permanent magnet. Capsules impregnated with magnetic Fe_3O_4 nanoparticles taken up by the cells are recognizable by their luminescence determined by CdTe nanocrystals. (A. Rogach, W. Parak)

PEI, DNA and RNA are labeled with different colors and are detected in separate channels. A stoichiometry factor is determined from the relative brightness of the three components, allowing a measurement of the relative population of each component in the polyplexes. Following the time course of the stoichiometry factor will reveal how DNA release occurs from the polyplexes.

Synthetic virus-like drug delivery systems
(Ernst Wagner, Joachim Rädler, Christoph Bräuchle)

Natural viruses are very effective in intracellular delivery. The Wagner group develops synthetic-virus-like drug delivery systems which contain elements mimicking the efficient, dynamic delivery process of viral infection. Targeting DNA/polycation complexes ('polyplexes') to tumors can be obtained by cell binding ligands which trigger cellular uptake. The surface charge of the polyplexes can be masked against unspecific interactions by incorporation of polyethylene glycol, as confirmed in biophysical analyses performed by J. Rädler. The hydrophilic polymer coat can be designed to be bioresponsive, protecting the polyplex in the first delivery phase during circulation in the blood; and being released in the second delivery phase by the intracellular acidic milieu of endosomes, to expose domains which

destabilize the endosomal membrane and release the drug within the cell. Melittin peptide analogs can enhance this endosomal release. Single particle microscopy at the lab of C. Bräuchle demonstrates cellular uptake of poly-ethylenimine polyplexes involving actin cytoskeleton followed by transport along microtubules. The concept was extended into therapeutic studies. EGF polyplexes containing synthetic RNA (poly IC) induced rapid cell killing in EGF receptor overexpressing tumors. Mice with brain tumors, when intratumorally treated, were cured by the 'synthetic RNA virus'.

Nanoparticles as local probe for measuring viscoelastic properties
(Wolfgang Parak, Joachim Rädler, Friedrich Simmel)

We have developed a new method for locally measuring viscoelastic properties. This is an important technique for many biological questions, for example cell migration. Cells migrate by locally assembling and disassembling their actin network. This goes hand in hand with a change of the cells' viscoelastic properties. By adding fluorescent nanoparticles we could optically detect the degree of polymerization of actin networks. The diffusion of the nanoparticles strongly depends on the degree of polymerization of the actin. In this way we hope to get new insights into cell migration soon.

Synthetic biology and DNA nanodevices
(Friedrich Simmel, Joachim Rädler)

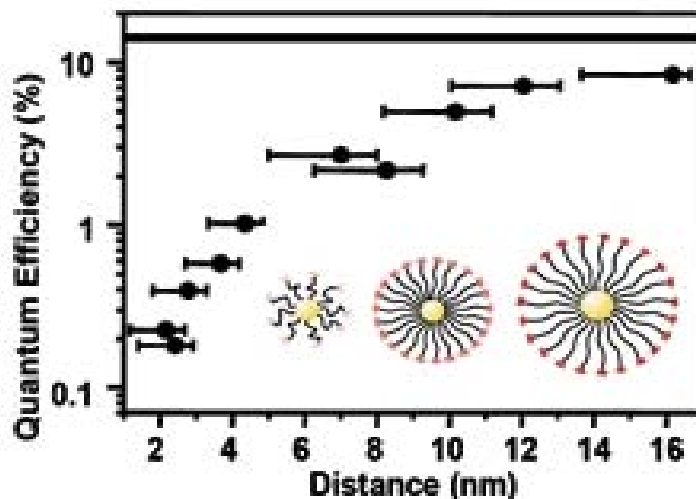
Synthetic biology is an emerging scientific discipline which complements the efforts of researchers in „systems biology“ to understand the dynamics of complex biochemical interaction networks. Among others, it deals with the reconstruction of gene regulatory motifs which possess certain information processing properties such as „switching“ or „memory“. Such artificial control mechanisms may find widespread applications in biotechnology. In this collaboration, it could be shown for the first time, how transcriptional regulation of artificial „genes“ could be used to control the behavior of simple DNA-based nanodevices.

Programmable viscoelastic behavior of single DNA molecules (Ulrich Gerland, Hermann Gaub)

DNA is a central molecule for molecular biology as well as many applications in nanotechnology. In both contexts it is often crucial that the physical properties of DNA are sequence-dependent, and thereby programmable through the choice of the nucleotide sequence. Experimentally, these processes are probed quantitatively using single-molecule techniques. On the theoretical side, these properties often involve rich stochastic dynamics through the coupling of different physical degrees of freedom, e.g. the internal base-pairing dynamics and the dynamics of the polymer contour. We have recently shown that this coupling can lead to viscoelastic behavior of a single DNA molecule: in response to an external force, the molecule can respond elastically (like a spring), when the force is rapidly increased, and display a viscous flow (somewhat like honey) of the two strands with respect to each other, when the force is slowly increased. This behavior occurs when the sequence of the DNA is periodic (e.g. CAGCAGCAG...) or nearly periodic. Such periodic sequences can be fabricated and also occur in the genome, where they are sometimes linked to certain genetic diseases. Interestingly, the mechanism whereby the two DNA strands slide against each other is based on the same fundamental mechanism (bulge loop creation) that is also relevant for the extension of repetitive sequences inside genomic DNA. In the lab of H. Gaub, this mechanism has been probed experimentally in parallel to our theoretical work.

Spectroscopic studies on gold-nanoparticle / organic molecule hybrid systems (Wolfgang Parak, Thomas Klar, Jochen Feldmann)

Gold nanoparticles are a promising tool to be used in bio-spectroscopy. Due to their collective oscillation of the conduction band electrons (the so called particle plasmons), they quench and alter the radiative rate of fluorophores in their neighbourhood and they scatter light in dependence of the protein concentration inside their nano environment. All these effects can be used for molecular sensing and medical diagnostics. In order to unravel the detailed physical mechanisms behind these spectroscopic effects we prepare well defined hybrid systems consisting of gold nanoparticles, proteins, oligonucleotides and fluorophores. Their spectral signatures are revealed using either single nanoparticle spectroscopy or picosecond time



Dye molecules (Cy5) are attached to gold nanoparticles using oligonucleotides of different lengths and different surface coverage. This allows to control the distance between the dye molecules and the gold nanoparticles. The fluorophores are quenched over a wide range of distances not because of energy transfer, but because of a manipulation of the radiative rate of the molecules by the gold nanoparticles. (J. Feldmann, T. Klar, W. Parak)

resolved ensemble measurements. For instance, it was possible to create a distance sensor on the 2 to 16 nm length scale using fluorescence quenching that relied not on energy transfer but on the manipulation of the radiative rate of fluorophores by gold nanoparticles.

DNA-Nanowires (Thomas Carell, Christoph Bräuchle, Jens Michaelis)

The DNA molecule is ideally suited to build up nano-structures. However, the DNA molecule itself has no exploitable function, so these nano-structures are functionless. The Carell group has now developed a chemical method to develop DNA molecules of almost arbitrary length, which have hundreds of additional functional groups. These groups can be coupled in a second step with a multiplicity of functional molecules, for example with magnetic or interesting optical characteristics. In a first step the DNA was modified with groups of aldehydes (- CHO) and afterwards covered with a thin silver film. This procedure resembles black-and-white photography (Metallization). Together with the Bräuchle and Michaelis groups, these nano-wires are structurally examined at present. Subsequently, measurements of the conductivity will be made.

The conformation of DNA-nanotweezers (Don Lamb, Friedrich Simmel)

Advances in research have made it possible to construct and observe nanomachines. DNA is often used as a template for building nanomachines because its structure is well understood, it self assembles, and interactions can be programmed into the DNA through its sequence. The nanomachines that are formed function as individual complexes and are best understood studying them at the single molecule level. In collaboration with Friedrich Simmel, we are investigating the function of nano-tweezers made out of DNA. Using a method that is very sensitive to distances between two markers in the 2 – 10 nm range (Fluorescence Resonance Energy Transfer), we are investigating the conformation of the nano-tweezers as a function of salt concentration and the addition of other DNA strands.

Atomic Force Microscopy (AFM) of biological macromolecules
(Reinhard Guckenberger)

The ability of the Atomic Force Microscope (AFM) to work very well in buffer solution makes the AFM an excellent tool for investigations of biological specimens on the single molecule level. Our main focus is on the function of such macromolecular complexes which are involved in the folding and degradation of proteins. Proteins can only fulfil their function correctly when they are in the correct folding state. Some proteins need the help of so called chaperonins to reach this state. Degradation of proteins is part of the functional cycle of cells (recycling of proteins) but is also important to remove incorrectly folded proteins (a kind of quality control).

In particular, we investigated the functional cycle of the chaperonin GroEL which is driven by ATP, for various protein substrates to be folded. In our experiments we focussed on the single ring mutant of GroEL. Our second biological project is about the 20S proteasome which is responsible for the degradation of incorrectly folded proteins in prokaryotes. Our interest lies in the mechanism of the transport of the protein substrate into the interior of the proteasome.

Drug delivery with polymer capsules

(Wolfgang Parak , Andrey Rogach, Martin Benoit, Hermann Gaub)

Polymer capsules have been modified in their shell with fluorescent, magnetic, and metallic nanoparticles and drugs can be loaded in their inside. In order to destroy cancer cells we target these polymer capsules to the target tissue by using magnetic field gradients, in which the capsules can be guided. The position of the capsules can be observed by the embedded fluorescent nanoparticles. Once ingested by the cell we heat the metallic nanoparticles in the shell of the capsules by irradiation with infrared light. The metallic nanoparticles start to vibrate, the shell of the capsules ruptures and the drug is released inside the cell. We have demonstrated all the essential steps in cell culture experiments. In the future we want to transfer this technology to tissue cultures.

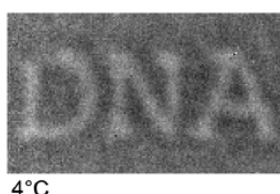
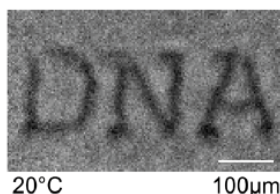
Transport of liquids and molecules in micro- and nanofluidics with microscopically small temperature gradients (Dieter Braun)

We have developed methods to optically transport liquids and molecules in micro- and nanofluidics with microscopically small temperature gradients.

(i) Water is pumped with an infrared laser scanning microscope by nonlinear thermal expansion. The pump pattern is freely defined with microscopic resolution. Pump speed increases for thinner chambers, enabling light-driven nanofluidics. The method allows all-optical micro- and nanofluidics.

(ii) Temperature differences move DNA from hot to cold, due to an effect called thermophoresis. Compared to electrophoresis, temperatures can be applied with micrometer resolution in microfluidics, yielding an alternative to electrophoresis for biomolecule analysis. For the first time, we can explain thermophoresis without free parameters by the energy gradient at the nanoscopic interface between particles and solvent. The steady state depletion in a temperature gradient directly relates to the entropy of solvation. This allows the all-optical measurement of effective charge for colloids at a previously impossible wide size range. We use the method to measure effective charge and particle diameter of nanocrystals of the group of Wolfgang Parak.

(iii) An optothermal molecule trap was devised to attract 1000bp DNA to a single spot by optically moving a temperature front radially. Like a snow shovel, the laser heated ring moves the DNA molecules in the liquid to the center.



Temperature differences move DNA from hot to cold, due to an effect called thermophoresis. Compared to electrophoresis, temperatures can be applied with micrometer resolution in microfluidics, yielding an alternative to electrophoresis for biomolecule analysis. (D. Braun)

(iv) We showed for the first time that thermophoresis becomes nonlinear for large temperature gradients. The measurements thus abolish a linear law that was assumed for many decades in thermophoresis. The finding clarifies several experimental puzzles. The coincidence of nonlinear transport and local disequilibrium was discussed with

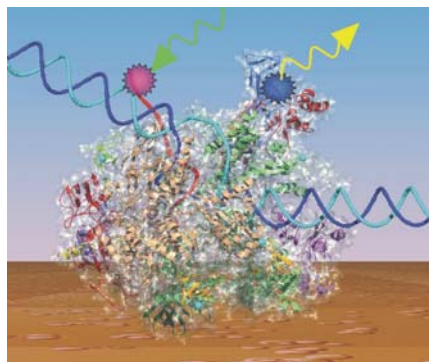
U. Gerland.

(v) We showed that exponential DNA amplification is driven by simply dipping a hot wire into the solution. The convection leads to a high speed PCR amplification which can compete with the fastest PCR cyclers on the market.

Mechanistic insight into eukaryotic transcription (Patrick Cramer, Jens Michaelis)

In a collaboration between the Cramer and Michaelis group we are studying the molecular mechanisms of eukaryotic transcription. Crystal structures in the Cramer lab have revealed details of the molecular machinery responsible for copying the genetic code from DNA into RNA, namely RNA Polymerase II from yeast. In addition, the complex interplay of the protein complex and nucleic acids has been studied by determining the structure of artificial elongation complexes. In this way a snapshot of the enzyme in the process of transcription is obtained. While the center of the complex can be mapped with high precision in the crystal structure, the nascent RNA can only be followed for a short stretch, before its mobility renders it invisible for crystallographic purposes. To overcome this limitation, we have used fluorescence energy transfer to map interactions between protein and RNA, by introducing dye molecules to the surface of the protein as well as to the RNA. The study of these interactions is extremely important since the interactions are likely to provide clues as to how the transcription is regulated in vivo.

In order to observe transcription directly and on the single-molecule level we have furthermore developed an assay for studying a single RNA polymerase II enzyme in an optical trap apparatus. The high time and spatial resolution of the instrument will allow us to observe transient changes in the elongation, which again are linked to regulation pathways.



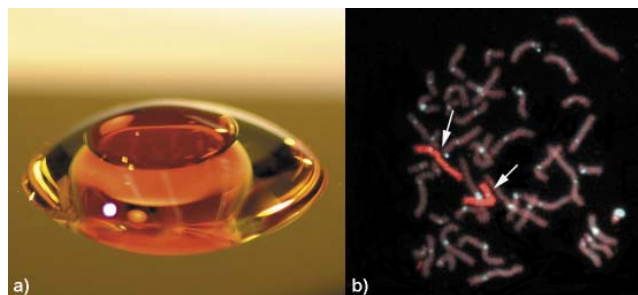
The figure shows a schematic of FRET experiments aimed to elucidate transient interactions in elongation complexes. Dye labels are introduced onto the polymerase as well as to the nascent RNA. (P. Cramer, J. Michaelis)

Multifunctional lab-on-a-chip (Stefan Thalhammer, Achim Wixforth)

Advances in molecular biology over the past decade have helped to enhance the understanding of the complex interplay between genetic, transcriptional and translational alterations in e.g. human cancers. These changes are the basis for an evolving field of high-throughput technique using microscopic amounts of patient-based tissue. On this account there is a high demand for the supply of DNA-microarrays as well as RNA- and protein-microarrays. Currently different approaches aim to meet this increased request: SNP-arrays based on short (25mer) oligonucleotides, longer 60mer oligonucleotide arrays and BAC arrays with different density which cover the genome with a resolution of 1 Mb to 100 Kb. Tendency is the development of customized arrays with high variability in the diagnostic field.

The groups of S. Thalhammer and A. Wixforth develop a multifunctional lab-on-a-chip combining different platform elements like microdissection-, nanofluidic- and detection-modules. This chip combines serial processing with parallel downstream applications by using a minimum amount of genetic material as source for further investigations. Two different microdissection methods (atomic force microscopy and laser-based micromanipulation) provide the possibility to isolate samples in the range from several cells down to a single chromosomal band without the risk of contamination.

Instead of employing conventional micro-machined fluidics, we are using surface acoustic waves propagating on the surface of the substrate. This enables us to actuate smallest amounts of fluid (1 l down to 100 pl) along so-called “virtual tracks” without any channels or tubes. Such “virtual tracks” are fabricated by a monolayer surface treatment to laterally modulate the wettability of the substrate. The incompressibility of the fluid leads then to the streaming and continuous flow of the probe.



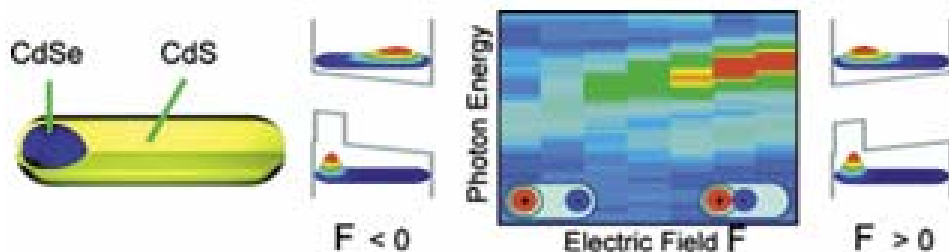
- a) Microfluidic PCR; 1 μ l PCR mix covered with 5 μ l mineral oil to avoid evaporation.
 - b) Chromosomal painting probe generated after single chromosome isolation and microfluidic PCR (pool of 10 PCR reactions).
- (S. Thalhammer, A. Wixforth)

Physical Properties of Nanostructures

Optoelectronic properties of nanocrystals

(John Lupton, Jochen Feldmann)

We have studied the optoelectronic properties of both organic semiconductors and inorganic semiconductor nanocrystals intensively using time resolved ensemble spectroscopy and single molecule spectroscopy. A highlight of the year was the monitoring of spin relaxation phenomena in organic semiconductors in real time. We were able to show that the application of external electric fields allows excitons to be stored in bulk films for durations orders of magnitude longer than the radiative lifetime. During this storage very little quantitative change in the spin configuration of the exciton is observed, which has dramatic implications for the operation of organic light-emitting diodes. The key message is that triplet excitons form the dominant species of excitations in devices based on these nanostructures and therefore constitute a formidable loss channel which must be overcome. More detailed work on single conjugated polymer molecules allowed us to identify individual chromophores on these molecules and for the first time illustrate how the molecular weight directly controls the spectroscopic complexity in the single molecule emission. This study of single conjugated nanostructures constitutes one of the most detailed correlations of chemical structure with photophysical property to date. Finally, we were also successful in designing novel single particle optoelectronic devices. We demonstrated the quantum confined Stark effect in the emission of a single elongated semiconductor nanocrystal. Both a change in emission energy and in radiative rate were observed. The experiments show how useful modulators can be constructed using single particles but also show how external manipulation of the excited state by electric fields provides insight into the nanoscale physical structure. In particular, we were able to correlate anomalies in the exceptional Stark effect observed with geometrical properties of these nanostructures.



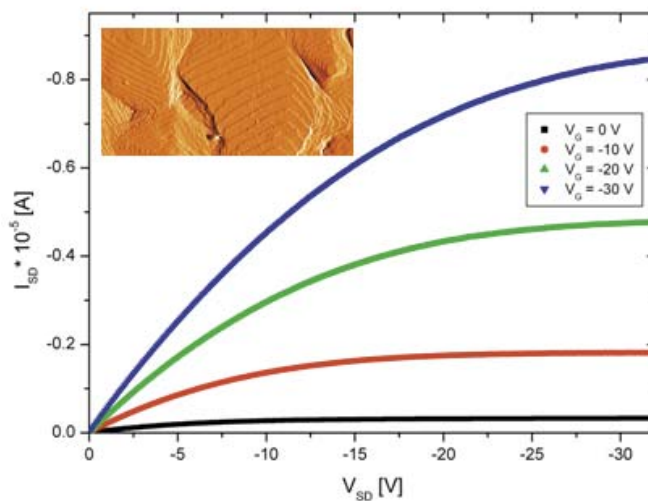
The quantum confined Stark effect in single elongated CdSe/CdS core/shell semiconductor nanocrystals. (J. Lupton, J. Feldmann)

Pentacene thin film transistors – structural and electronic properties
(Udo Beierlein, Bert Nickel)

Organic thin film transistors (TFTs) were fabricated in bottom contact geometry and electronic transport as well as photocurrent were measured in the group of Udo Beierlein. Evaporation of thin pentacene films onto silicon chips and characterization of the samples by x-ray scattering were carried out in the group of B. Nickel.

In order to study the structure-function relationship, we performed in situ x-ray diffraction measurements in ultra high vacuum during thin-film growth at the synchrotron source at W1 HASY Lab, Hamburg. We determined the crystalline structure of the thin-film phase of pentacene on different substrates, which was unknown so far, by using novel x-ray diffraction techniques and a sophisticated custom made data fitting model coded with Matlab. Additionally, we determined the defect densities of the organic thin-films by analyzing rocking-scans x-ray measurements and compared them to electronic measurements.

Our pentacene TFTs achieved charge carrier mobilities larger than $1.0 \text{ cm}^2/\text{Vs}$. By using C-V measurements, we investigated the dynamical electronic properties of our TFTs and thus got information about the influence of interface traps on charge carrier transport characteristics. We further developed an experimental setup to measure position resolved photocurrent in order to explore correlations of structure and electronic properties.



Source-drain current as a function of source-drain voltage for different gate voltages of a pentacene TFT. Inset: AFM image of a pentacene thin film on SiO_2 .
(U. Beierlein, B. Nickel)

Transport spectroscopy on quantum dots
(Stefan Ludwig, Jörg Kotthaus)

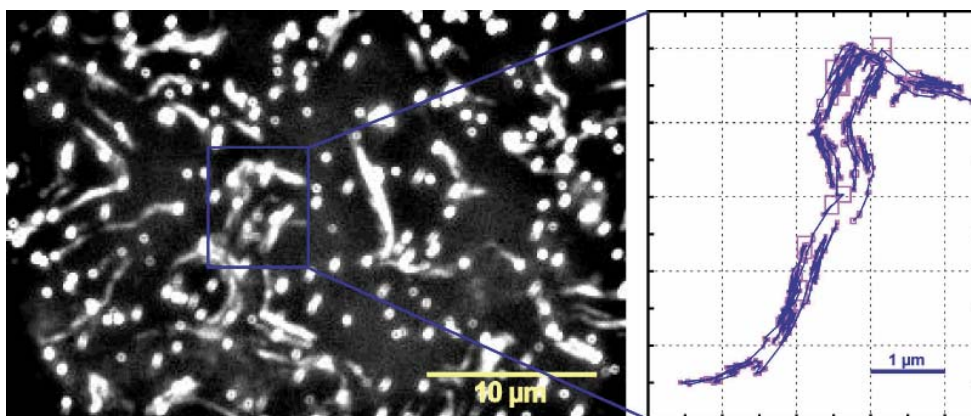
The ongoing progress in quantum information processing calls for the realization of scalable and controllable solid-state-based nanoscale systems. Lateral quantum dots defined in the two-dimensional electron gas of a GaAs/AlGaAs heterostructure are promising candidates for the implementation of solid-state-based quantum bits. A variety of such gate-controlled structures are fabricated lithographically in our clean room on heterostructures grown at the MPI Stuttgart, the Walter-Schottky Institute at TU Munich and the University of Regensburg and studied via single electron transport experiments at low temperatures. Previously, we already demonstrated full control of the quantum mechanical states of a widely tunable few electron double quantum dot. Present studies aim at a better fundamental understanding of electronic transport and interactions in few electron systems including spin-dependent phenomena such as the Kondo effect. We observed for the first time the Kondo effect in a double quantum dot charged by only one or two electrons. Quantum dots and quantum point contacts are potential building blocks of the desired solid-state-based quantum computer. In order to understand the interplay between such nanoscale systems we study the effect of a biased quantum point contact onto a nearby capacitively coupled system that consists of a quantum point contact, a quantum dot or a double quantum dot. In a nanoscale bridge etched out of a heterostructure we successfully defined a quantum dot controlled by a top gate. At low temperatures such suspended nanostructures are governed by a discrete phonon spectrum and make possible detailed studies of the electron-phonon interaction. Our experimental work profits tremendously from the stimulating interactions with members and guests of the theory group of J. von Delft.

Optical spectroscopy on single self-assembled quantum dots (Khaled Karrai)

In order to use self-assembled quantum dots as building blocks for quantum computing and information transfer, their physical properties have to be studied and understood in detail. Recently we developed the method of absorption spectroscopy on a single quantum dot which provides highest spectral resolution. Quantum dots embedded in a FET-heterostructure, grown at the University of California in Santa Barbara, can be charged with single electrons one by one. Individual quantum dots in such a device have been studied concomitantly with photoluminescence and absorption spectroscopy. Tunnel coupling to the environment add dephasing for certain gate voltages that normally cannot be resolved in photoluminescence but has been studied with absorption spectroscopy. Further, a difference in the charging behavior for the two spectroscopy methods was observed. In cooperation with Richard Warburton's group at Heriot-Watt University in Edinburgh a theoretical model was developed which explains these effects and extracts the Coulomb interactions between the charges in the quantum dot. In cooperation with Atac Imamoglu's group at ETH Zurich the populations of the two Zeeman branches with single electrons in magnetic fields up to 9 T were measured. A clear enhancement of the population in the upper branch caused by Pauli blocking could be demonstrated at temperatures of 1.5 K.

Diffusion of single molecules in nanoporous materials (Christoph Bräuchle, Thomas Bein)

The diffusional behaviour of individual fluorescent dye molecules incorporated into nanoporous systems is investigated using widefield imaging microscopy with single molecule sensitivity. In a close cooperation between the groups of C. Bräuchle and T. Bein a variety of nanoporous materials is synthesized and characterized. The dye molecules in very low concentration are added directly to the synthesis solutions and 200 nm thin films of nanoporous materials filled with dyes are obtained by spin-coating. The diffusion of the single molecules in the nanoporous network is observed in real-time movies. Tracking of the positions of the molecules in successive images results in the image of the diffusional trajectories. This method provides not only insight into the structure of the nanoporous systems but gives also details about the influence of the pores on the dynamical



Left: Overlay of 1000 widefield images in one movie. The blurred traces correspond to single molecules moving up and down in the nanometer-sized channels of the substrate. Donut shaped spots correspond to molecules aligned perpendicular to the sample plane. Right: Exemplary single molecule trajectory which reflects the high degree of structure in the porous system (movies available from C. Bräuchle).

behaviour of the dye molecules inside these systems. With these techniques, the dynamics of single molecules in confined geometries can be studied in great detail for the first time.

Femtochemistry in colloidal zeolites (Thomas Bein)

This project aims at the elucidation of ultrafast switching phenomena of organic dyes in the controlled environment of nanoscale periodic pore systems. These phenomena can have applications in optical data storage and in the detection of molecules (chemical sensing). For example, in collaboration with the group of E. Riedle (Physics LMU) and V. de Waele (CNRS, Paris) we investigate the ultrafast deprotonation of the dye 2-(2'-hydroxyphenyl)benzothiazole (HBT) in nanoscale suspended crystals of the microporous zeolite materials FAU and MFI. These nanoscale crystals measure only 40-100 nm in diameter and can form clear colloidal suspensions which enable us to perform ultrafast spectroscopy with these systems. We find that depending upon the inner surface properties of the zeolite crystals (acidic or more basic), we can stabilize either one or the other stable form of the switchable dye (keto- or enol). Upon excitation with UV-light, the HBT-keto form can be converted to the enol form in both zeolites. This photoconversion takes place via an ultrafast deprotonation within just 1,5 picoseconds.

Within this project, we also investigate the non-destructive characterization of the colloidal zeolite suspensions; we have found that even liquid-phase NMR can give valuable information on the type of crystal structure formed and on the included molecules because the crystals are extremely small and thus mobile enough in suspension to give well-resolved spectra.

Phonon photonics (Rainer Hillenbrand)

In the group of R. Hillenbrand mid-infrared surface phonon polaritons on polar crystals are investigated. Besides the fundamental mechanisms of resonant phonon-photon coupling in nanostructures also the application potential in the fields of data storage, sensing and subwavelength-scale infrared energy transport is explored.

The group showed that the propagation of locally excited surface phonon polaritons can be imaged by scattering-type near-field optical microscopy. From the images taken on SiC crystals both the wavevector and the propagation length of the electromagnetic surface waves could be directly measured.

Developing a shear force sensor based on protein unfolding (Matthias Rief, Hermann Gaub)

Bio-molecules are specialized nano-tools inside and outside an organism. With the help of cloning techniques artificial bio-molecules can be designed by combining useful properties into one molecule. Both groups have knowledge in measuring mechanical properties of single molecules by unfolding several proteins by force spectroscopy. In this collaboration a well-characterized force sensitive molecule as a sensor in liquid is designed. One aim is for example to directly measure shear forces in laminar flow profiles.

Detection of covalent immobilized hAGT by SOI technique
(Matthias Rief, Hermann Gaub, Andreas Bausch)

Another very important issue is the immobilization of bio-molecules on surfaces in a covalent way without affecting the functionality of a linked active site (enzyme or antibody...). E.g. hAGT(human alcygguanintransferase)-protein has proven to be an excellent candidate for a covalent protein surface coupler. Such immobilization strategies for biomolecules are quantified on Silicon-on-Insulator (SOI) surfaces in the group of A. Bausch.

Complete description of azobenzene mechanics by ab-initio calculation combined with freely rotating chain model
(Thorsten Hugel, Roland Netz, Hermann Gaub)

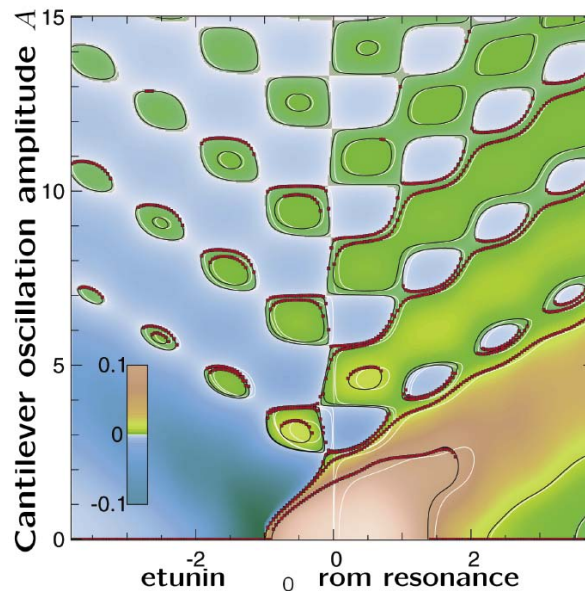
Since the mechanical properties of individual polymers have become accessible with single molecule force spectroscopy, detailed insight was gained into the molecular origin of their elasticity. We combine experimental data and calculations to describe the mechanical properties and optical actuation of poly(azobenzene-peptides) in the complete force regime accessible by AFM. Poly-azobenzene is an optically switchable polymer (between cis and trans configuration) that was introduced as photonic muscles and used in single molecule motors. The high force regime of both configurations is very well described by ab-initio quantum mechanical calculations, while for the low force regime we combine ab-initio calculations with a description of the entropic forces based on the freely rotating chain model. Finally, we obtained a one-parameter fit for the different configurations of the poly(azobenzene-peptide) and a quantitative description of the optically induced actuation. This is a major improvement compared to the previously employed extended freely-jointed-chain (FJC) and wormlike-chain (WLC) models, where three fitting parameters (persistence length, contour lengths, elastic modulus) are needed. In addition, these models give a considerably wrong description for the optical induced actuation. Especially if the two states have large differences in their elasticity's, like in poly-azobenzene. All the above-mentioned limitations are overcome with our new one-parameter fit.

Fabry-Perot cavity with an oscillating mirror (Florian Marquardt)

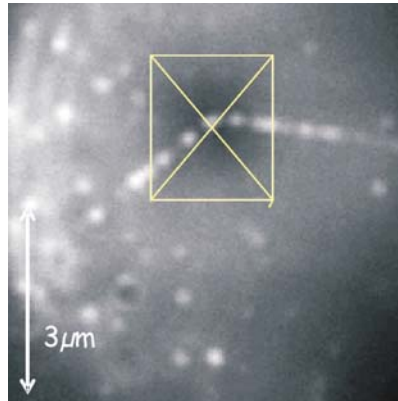
The field of mechanical devices in the nano-/micrometer range has seen remarkable progress in recent years, and introducing an interaction with light makes the physics of such devices even more interesting.

Recently, we have completed a detailed theoretical study of the dynamics of one of the simplest optomechanical systems: a Fabry-Perot cavity with an oscillating mirror. This work is highly relevant for experiments performed in the group of Khaled Karrai. A cavity light mode is coupled to the position of the cantilever carrying the mirror via radiation forces. The effective coupling may become very strong: for a high optical finesse the light intensity is very sensitive to small displacements down to the picometer scale, and vice versa the mechanical motion is influenced by slight variations in the light intensity when friction is weak. We have predicted an attractor diagram for the light-driven self-sustained nonlinear cantilever oscillations, which might also find applications in sensitive measurements.

Currently, we are extending the description towards low-finesse cavities where the dynamics of multiple light modes becomes relevant, as seen in the experiments.



Attractor diagram for the light-driven self-sustained nonlinear cantilever oscillations. (F. Marquardt)



A chain of light emitting polymers is being manipulated by an AFM cantilever. (position indicated in yellow, J. Michaelis)

Single-molecule studies of artificial polymers

(Jens Michaelis, John Lupton, Jochen Feldmann)

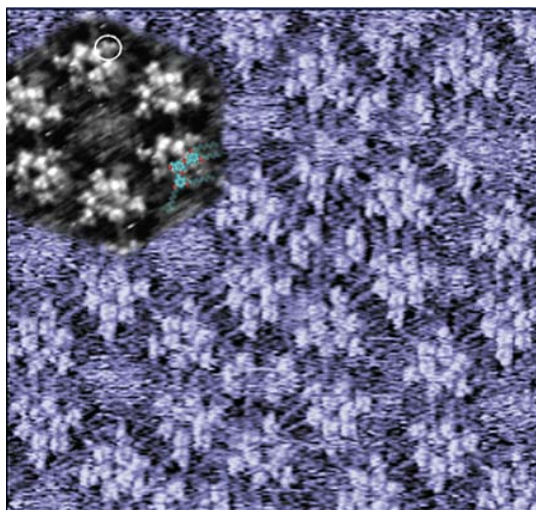
Single-molecule manipulation of polymers has been pioneered by members of CeNS. By studying the force-extension curves of polymers, properties of the molecule itself, as well as its interaction with surfaces are obtained. In the last year we have extended these studies to self-interacting polymers in bad solvent environments. Here, the AFM can be used for dissolving polymers, one molecule at a time and important parameters such as intermolecular interaction and solvation energies can be determined.

In a collaboration between the Lupton/Feldmann and the Michaelis group we are extending these ideas to light emitting polymers. Here, the intermolecular interactions influence the optical properties of the polymer. Using single molecule force spectroscopy we have mapped these interactions in detail for solvents of different qualities. These studies could provide novel clues for the design of more efficient polymer light emitting devices.

Chemical Assembly of Nanostructures

Dynamic behavior of octyl-decorated Fréchet-type dendrons on graphite surfaces (Bianca Hermann)

Nature's engineering is based on self-organization of molecular and supramolecular components using molecular level encoding. Employing self-organization for technical applications in molecular electronics, catalysis, sensor surfaces and surface coating is an attractive prospect because thickness, structure as well as defects in monolayers could be controlled. Research on self-organization focused in the past on studying small, flat and stiff molecules on highly-controlled surfaces. Larger and flexible molecules



Scanning tunneling microscopy image of an alcohol Fréchet dendron on a graphite surface: the pattern is based on molecular trimers assembled into a hexagonal host structure. A highly mobile molecule (observed as noise in the centre of the rosette) remains in the middle of the hexagonal host structure. The displayed image shows a row of molecules between two domains of hexagonal arrangement. The grayscale insert (obtained by averaging a 10 nm x 10nm frame over 10 positions) has a space-filling model of the molecule overlaid. (E. Constable, B. Hermann)

were thought to be too problematic due to the high degree of conformational freedom. However, our recent scanning tunneling microscopy (STM) studies on flexible aldehyde and alcohol terminated Fréchet-type dendrons deposited by solution casting on graphite surfaces show excellent self-organization properties. The combination of interactions between interdigitated octyl chains of adjacent molecules, interactions between octyl chains and the graphite surface, as well as π - π -stacking interactions of the phenyl rings with the graphite results in strong (but not covalent) binding. In this collaboration with C. Housecroft, Basel, images at sub-molecular resolution were obtained at room temperature in air. Initially, these molecules form a pattern on graphite based on trimeric units, assembled into hexagonal host structures with a pseudo-unit cell of seven molecules, one of which remains highly mobile. Within hours (or days in the case of the alcohol Fréchet-type dendron), the supramolecular ordering changes from a trimeric to a dimeric pattern. This conversion can be followed by STM measurements. Future work aims to a more detailed understanding of the observed conversion in collaboration with the Frey group.

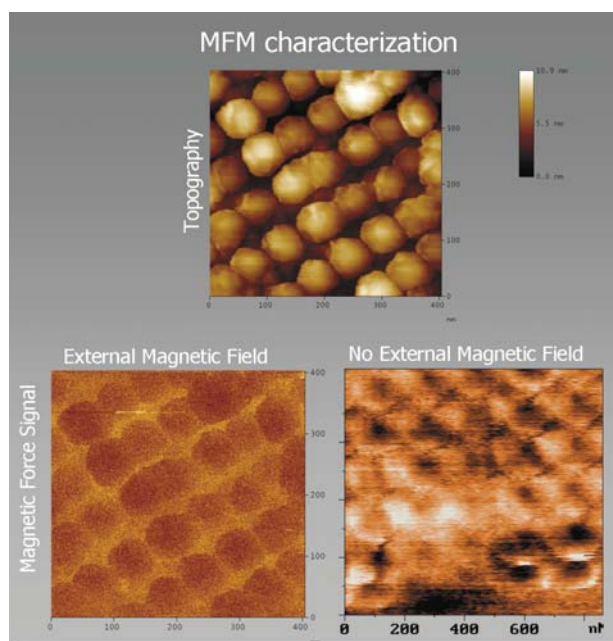
Nanowire growth in mesoporous channels (Thomas Bein)

The relentless reduction of the dimensions of transistors and other devices on computer chips will, at some point, reach the physical limits of lithographically defined silicon structures. It is therefore of interest to explore alternative strategies for the collection and processing of information on the nanoscale. In this project we study the growth and stabilization of metallic and semiconducting wires in the insulating channels of mesoporous silica. For example, we have demonstrated the electroless reduction of gold in the nanosized channels of mesoporous materials that were modified with chemical thiol-anchors for the attachment of ultras-small precursor clusters. This strategy allows us (a) to limit the growth of the wires mostly to the interior of the channels, and (b) to achieve the formation of 5 nm thin gold wires over hundreds of nanometers. This approach is presently being extended to the preparation of vertically oriented mesoporous channels and to the electrochemical growth of metallic and semiconducting nanowires.

Assembly of magnetic nanoparticles (Ulrich Schubert)

The technological importance of magnetic storage and sensing applications fuels also the research on the magnetic properties of nanomaterials. Not only their synthesis and the characterization of their properties are in focus of recent research projects but also important questions regarding their efficient assembly in defined patterns became a topic of growing interest.

We developed a possibility to arrange and stabilize magnetic nanoparticles in defined areas by using chemically active surface templates, prepared by electro-oxidative nanolithography approaches. Thereby an electrochemical oxidation process is initiated by means of conductive SFM tips, conductive stamps or by water. As a result an oxidation of the surface terminal $-\text{CH}_3$ groups of a n-octadecyltrichlorosilane monolayer self-assembled on silicon to chemically useful $-\text{COOH}$ functions is performed. We used these templates to site-selectively grow well defined iron nanoparticles on this positions. Individual nanoparticles with a typical height of 7 nm and an interparticle spacing of ~ 50 nm could be prepared. Their magnetic behavior in the presence and absence of external magnetic fields was studied by magnetic force microscopy. This versatile approach to use chemically active surface templates as assembly sites for nanomaterials is interesting also for other groups of CeNS. Collaborations with the group of J. Feldmann and A. Rogach are already established, where magnetic and fluorescent nanoparticles are used to study particle cooperative phenomena that are triggered by their spatial organization on surfaces. Besides these nanofabrication approaches fundamental questions of the patterning process have been studied, and further possibilities were investigated to assemble nanomaterials on chemically active surface templates. Further possibilities for the design of polymeric systems by using orthogonal supramolecular interactions have been exploited.



Magnetic Force Microscopic investigation of an array of individual iron nanoparticles. Top: Topography of the nanoparticle array. Bottom: Homogeneous orientation of the magnetic moments of the individual particles in the presence of an external magnetic field (left) and the random orientation of the magnetic moments without external magnetic field (U. Schubert).

Simulation of mechanically induced chemistry in single molecules
(Irmgard Frank, Christoph Bräuchle)

In collaboration with Wacker Chemie GmbH we investigate the chemical reactions that occur in siloxanes under extreme tensile stress. Siloxanes are less stable when exposed to tensile stress than are hydrocarbon polymers, although the Si-O bond is very strong from an energetical point of view. Our first-principles simulations show that Si-O bonds break by an ionic mechanism in contrast to C-C bonds which break into radicals. On the basis of our simulations we presently simulate mechanically induced reactions in condensed phase in order to explain the macroscopic phenomena which limit the technical applicability of siloxanes. Systems under investigation include single polymer strands in different solvents, siloxanes in contact with or covalently bound to a silica surface, and the bulk polymer.

Properties of chromophores under tensile stress
(Irmgard Frank, Jens Michaelis, John Lupton)

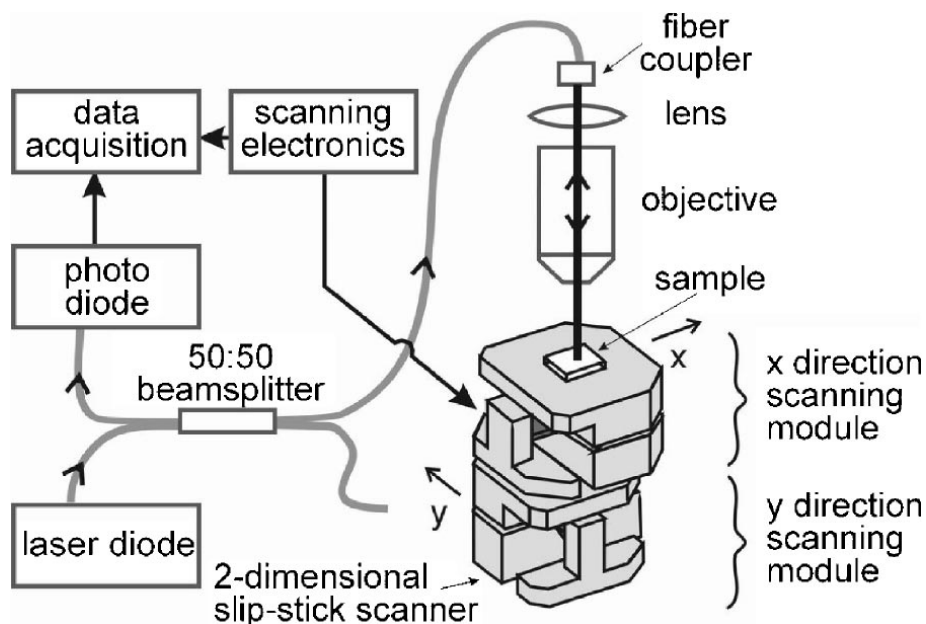
We investigate the changes of the optical properties of dyes if they are exposed to tensile stress. Understanding such mechanooptical phenomena would for example allow the development of new stress sensors. A first system under investigation is polyphenylene-vinylene (PPV) that is used as a material for organic light-emitting diodes. The nature of the light-absorbing units in these conjugated polymers is not clear yet. From the trend in the absorption and emission wavelengths of PPV oligomers, it has been estimated that the typical length of a chromophore is in the range of 11 to 17 PPV units. At first glance this seems to be in contradiction to static quantum-chemical calculations that yield a delocalized chromophore for an undistorted polymer structure. In addition, single molecule experiments by Lupton et al. yielded but a few peaks for systems with a polymer length above 1000 units, which according to the above estimation should contain like 100 chromophores. Molecular dynamics simulations shall help to provide a general explanation for these observations.

Analytical and Imaging Methods

Optical imaging of nanostructures

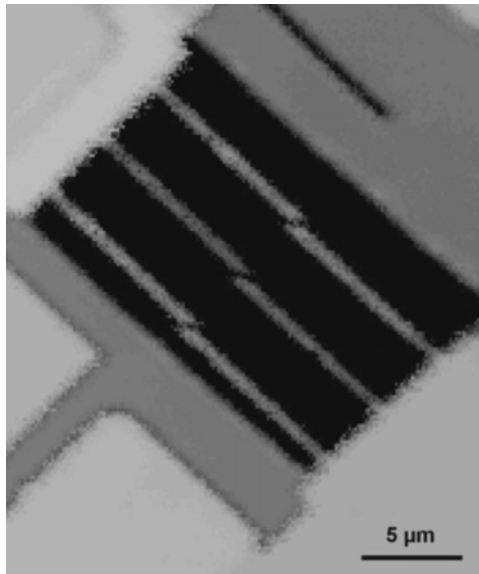
(Khaled Karrai, Heribert Lorenz, attocube systems AG)

Nanomechanical systems are both fascinating objects for fundamental studies in the quantum regime and promising for a large variety of applications like extremely sensitive sensors and actuators. Advances in the field include improvements in fabrication processes, new methods for actuating and detecting motion at the nanoscale. In cooperation with attocube systems AG the groups of H. Lorenz and K. Karrai have developed a slip-stick positioning system to work as a step-by-step scanning device. Step sizes are ranging between 40 and 400 nm at room temperature and steps smaller than 5 nm are obtained at 4.2 K. Scanning confocal optical images on samples with nanomechanical systems are taken in reflectivity using a 635 nm wavelength laser and an objective of numerical aperture=0.8. They show exceptional low distortion and high linearity. The use of the slip-stick step motion for image scanning simplifies the scanning confocal microscope since the long-range positioning unit and the scanning unit merge into only one unit that can do both.



Schema of a confocal slip-stick step-scanning optical microscope.

(K. Karrai, H. Lorenz, attocube systems AG)



Slip-stick step-scanned confocal optical image of three pairs of silicon nanocantilevers freely suspended above a rectangular hole aperture. Each cantilever (10 μm long, 120 nm thick, 200 nm wide) faces another one, forming a pair with their free ends separated by 200 nm (K. Karrai, H. Lorenz, attocube systems AG)

Nanoscopic temperature sensing (Dieter Braun)

Nanoscopic temperature sensing is achieved using a pH sensitive dye that detects the temperature shift of a buffer solution. To achieve precise results, we have to take also into account the thermophoresis of the dye itself. Both have comparable effects and lead to a sensitivity of the dye of around 3%/K, which allows measurement precision of 0.1°C. We measured the temperature around particles prepared for remote opening using infrared radiation in collaboration with A. Skirtach and the groups of Möhwald and Sukhorukov, and W. Parak at CeNS.

Basics of tapping mode AFM (Reinhard Guckenberger, Robert Stark)

Part of our AFM work aims at a better understanding of the tapping mode that is especially useful when imaging single macromolecules in buffer solution. This work is strongly supported by R. Stark concerning model calculations and interpretation of our experimental results.

Scanning near-field optical microscopy (SNOM) in fluorescence
(Reinhard Guckenberger, Fritz Keilmann, Rainer Hillenbrand, Christoph Bräuchle)

Fluorescence allows easy identification of labelled spots of biological specimens. Compared to the confocal laser scanning microscope, SNOM achieves a higher resolution and allows to acquire a topographical signal simultaneously with the optical signal which facilitates interpretation of the images. By combining principles of two types of SNOM, the aperture and the scattering SNOM, we had developed a new SNOM probe which allows to image single fluorophores at a resolution even below 20 nm. In 2005 we tried to achieve a better understanding of the basic physics of this probe for further improvements. Simultaneously we tested procedures for a simplified production of this probe.

Multi-spectral scattering-type near-field microscopy
(Rainer Hillenbrand, Fritz Keilmann, Reinhard Guckenberger)

The group of R. Hillenbrand develops scattering-type near-field optical microscopy (s-SNOM) that allows nanoscale resolved optical imaging, simultaneously at visible and infrared frequencies.

A s-SNOM operating at infrared frequencies was demonstrated to allow nondestructive imaging of chemical, structural and electronic properties of nanocomposite materials. By local probing of lattice vibrations in polar crystals we could demonstrate nanoscale resolved mapping of crystallinity, stress and doping.

The s-SNOM also offers the possibility of subsurface imaging, providing a nondestructive method of examining nanocomposite materials, thin oxide layers and coatings. This was demonstrated in collaboration with F. Keilmann by nanoscale resolved mid-infrared s-SNOM imaging of gold islands buried beneath a 50 nm polymer film.

Near-field spectroscopic mapping of nanoparticles and viruses (Fritz Keilmann, Rainer Hillenbrand)

We achieved extending the operation of scattering-type near-field microscopy into the spectroscopic dimension. Line-tunable lasers were used to obtain consecutive images at systematically varied illumination frequencies. From these the spectra are extracted and assigned to each pixel. We scanned the wavelength range from 5.5 to 6 μm to spectrally characterize polymer and protein nanostructures. Specific infrared vibrational signatures are obtainable with even very thin sample material, as for example, a single TMV virus diameter of 18 nm only. The role of phase contrast spectral signatures was clarified. Robust chemical recognition by vibrational “fingerprints” was established with nanoparticles of different sizes, crowded in nanoscale neighborhood.

Frequency-comb infrared spectrometer and microscope (Fritz Keilmann)

We have developed and realized a new scheme to do Fourier-transform infrared spectroscopy (FTIR) with two advantages, of using a coherent, laser-like beam on one hand, and of operating entirely in the time domain, that is, without movable parts, on the other. This allowed to collect broadband infrared spectra in snapshot exposures of only 1-10 μs duration, and at repeat rates up to 1000 Hz. The principle of comb-FTIR is the superposition of two beams derived by difference-frequency generation from mode-locked Ti:sapphire lasers with 10 fs pulse duration, and of detecting a multi-heterodyne beat or comb spectrum with a fast infrared detector.

We have furthermore combined coherent comb-FTIR with s-SNOM (scattering-type near-field microscopy), illuminating with and registering broad-band infrared spectra of each pixel scanned. The snap-shot feasibility of c-FTIR allows time-resolving the tip-tapping oscillation, enabling a new way to suppress background scattering.

Quantitative dynamic atomic force microscopy (Robert Stark, Reinhard Guckenberger)

Dynamic atomic force microscopy (AFM) is a key method for the characterization and manipulation of matter on the nanometer scale. The analysis of time dependent forces is basic for a deeper understanding of phenomena such as friction, plastic deformation or wetting phenomena. However, the dynamic characteristics of the force sensor used for such investigations are determined by various factors such as material and geometry of the cantilever, detection alignment, and the transfer characteristics of the detector. Thus, for a quantitative investigation of surface properties by dynamic AFM first an appropriate dynamic calibration of the force sensor is required. Such a characterization has to go beyond the usual parameters spring constant, quality factor, and detection sensitivity. The direct measurement of the transfer function provides such a characterization (system identification) that fully accounts for the dynamic properties of the force sensor such as higher eigenmodes or the transfer characteristics of the detection system. We have demonstrated the estimation of the transfer function in a large bandwidth of 1 MHz from vibrations induced by snap-to-contact and snap-off-contact events. Procedures for a parameter free estimation (empirical transfer function estimate, ETFE) and a parametric estimation of the transfer function were determined. These identification procedures provide an intrinsic calibration as they dispense largely with a priori knowledge about the dynamics of the force sensor.

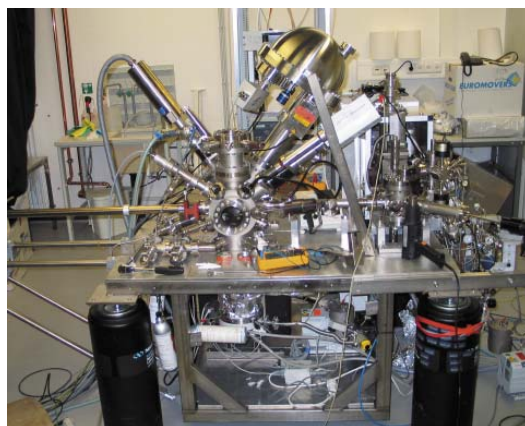
Conformational segregation and switching of 2,2'-bipyridine-functionalized Fréchet dendrons (Bianca Hermann)

In order to engineer molecules in a way that they will show excellent and programmed self-organization properties, a fundamental understanding of molecular recognition characteristics and self-organization algorithms has to be gained by basic research. In a collaboration with C. Housecroft, Uni. Basel, we have analyzed conformational segregation in domains and conformational switching of a flexible aromatic molecule on a graphite surface. Solution casting of second-generation and first-generation Fréchet dendrons with 2,2'-bipyridine-central core units resulted in good quality monolayers showing multiple domains. The high resolution images obtained with scanning tunneling microscopy on the second-generation 2,2'-bipyridine dendrons allowed identification of single molecules almost without further interpretation. Interestingly we observed two different conformations of this molecule on the surface, segregated in domains, each of the domains being homo-conformational. The first-generation 2,2'-bipyridine dendron formed lamellar rows. The unit cell of the

molecular layer can be deduced from a Fourier spectrum. Molecular models of all relevant conformations were analyzed using computer graphics and fitted to the STM data. Also in this case, two different conformations (only differing in a single rotation around one bond) of the first-generation 2,2'-bipyridine dendron could be determined. By applying HCl-gas the trans conformation of the first-generation bipyridine dendron could be successfully switched into a cisoid conformation.

STM under high gas pressures (Joost Wintterlin)

Scanning tunneling microscopy (STM), one of the main analytical techniques of nanoscience, has always shown an amazing power of creating “spin-off” methods, such as various local probe spectroscopies that display an extreme spatial resolution capability. The group of J. Wintterlin is currently exploring the ability of STM to work under high gas pressures. Most of the present STM work is performed under ultra-high vacuum, where one can resolve and do spectroscopy on single atoms and molecules, and even monitor their thermal motions and chemical reactions. However, the experimental conditions clearly represent a highly artificial environment, and it is an open question, in how far the effects observed can describe the processes in a “real” chemical process, such as in a catalytic reaction under ambient pressure. The Wintterlin group has developed an STM inside a reactor cell that can operate at pressures of up to 1 bar and at temperatures of up to 220 °C. First data with atomic resolution have been obtained. The STM shall finally image the surface of a working catalyst with atomic resolution.



High-pressure STM system. The small, 3 liter stainless-steel chamber at the right hand side is the high-pressure cell that contains the STM, the larger chamber at the left is a standard ultra-high vacuum system that can be connected to the STM cell. (J. Wintterlin)

For more information and complete publication lists please refer to www.cens.de or the individual websites of the research groups:

Bein
<http://www.phys.chemie.uni-muenchen.de/Bein/publications.htm>

Bräuchle
<http://www.cup.uni-muenchen.de/pc/braeuchle/>

Braun
<http://www.biophysik.physik.uni-muenchen.de/>

Carell
<http://www.cup.uni-muenchen.de/oc/carell/>

Cramer
<http://www.lmb.uni-muenchen.de/cramer/publications.html>

Feldmann
<http://www.phog.physik.uni-muenchen.de/>

Frank
<http://www.chemie.uni-muenchen.de/pc/frank/index.html>

Frey
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Gaub
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<http://www.biochem.mpg.de/baumeister/spm/>

Hermann
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Holleitner
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Karrai
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Keilmann
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Netz
<http://www1.physik.tu-muenchen.de/lehrstuehle/T37/index.html?main=publications.html>

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<http://softmatter.physik.lmu.de/tiki-index.php?page=PublicationsRaedler>

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<http://www2.nano.physik.uni-muenchen.de/nanobio/>

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S. Boeckle, E. Wagner and M. Ogris

“C- versus N-terminally linked melittin-polyethylenimine conjugates: the site of linkage strongly influences activity of DNA polyplexes”

J. Gene Med. 7, 1335 (2005)

M. Brehm, H. G. Frey, R. Guckenberger, R. Hillenbrand, D. Kazantsev, F. Keilmann, N. Ocelic and T. Taubner

“Consolidating apertureless SNOM”

J. Korean Phys. Society 47, S80-S85 (2005)

W. U. Dittmer, S. Kempter, J. O. Rädler and F. C. Simmel

„Using gene regulation to program DNA-based molecular devices”

Small 1, 709 (2005)

S. Duhr and D. Braun

“Two-dimensional colloidal crystals formed by thermophoresis and convection”

Appl. Phys. Lett. 86, 131921 (2005)

E. Dulkeith, M. Ringler, T. A. Klar, J. Feldmann, A. Munoz Javier and W. J. Parak

„Gold nanoparticles quench fluorescence by phase induced radiative rate suppression”

Nano Letters 5, 585 (2005)

S. Grimm, C. Bräuchle and I. Frank

„Light-driven unidirectional rotation in a molecule: ROKS simulation”

ChemPhysChem. 6, 1943 (2005)

C. Hellriegel, J. Kirstein and C. Bräuchle

„Tracking of single molecules as a powerful method to characterize diffusivity of organic species in mesoporous materials”

New Journal of Physics 7 (23), 1 (2005)

M. Hennig and D. Braun

“Convective polymerase chain reaction around micro immersion heater”

Appl. Phys. Lett. 87, 183901 (2005)

S. Hoepfener and U. S. Schubert

„Magnetic Nanostructures – Fabrication via the Electrochemical Oxidation of Self-Assembled Monolayers and Site-selective Derivatization of these Surface Templates”

Small 1, 628 (2005)

A. Högele, S. Seidl, M. Kroner, K. Karrai, M. Atatüre, J. Dreiser, A. Imamoglu, R. J. Warburton, B. D. Warburton, B. D. Gerardot, and P. M. Petroff

“Spin-selective optical absorption of singly charged excitons in a quantum dot”

Appl. Phys. Lett. 86, 221905 (2005)

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“Combination of Different Orthogonal Supramolecular Interactions in Polymeric Architectures”

Chem. Commun. 2423 (2005)

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 Appl. Phys. Lett. 87, 081103 (2005)
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Chemistry 11, 2307 (2005)
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Patents

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Theses finished in 2005

Habilitation Thesis

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Doctoral Theses

Sabine Boeckle
Improved nonviral gene vectors - Efficient and non-toxic polyplexes with enhanced endosomolytic activity

Thomas Endreß
Single Virus Tracing: Untersuchungen zum Infektionsverhalten von Adeno-Assoziierten Viren (AAV-2) sowie von Human Immunodeficiency Virus (HIV-1) an und in lebenden Zellen

Stephan Grimm
Theoretische Untersuchungen von p-Bindungssystemen im Restricted Open Shell Kohn-Sham-Modell

Christian Hellriegel
Translational, Orientational and Spectral Dynamics of Individual Molecules in Nano-Structured Materials Studied with Single-Molecule-Spectroscopy

Alexander Högele
Laserspektroskopie von einzelnen ladbaren Quantenpunkten

Andreas Klaus Hüttel
Gekoppelte Quantenpunkte im Bereich niedrigster Elektronenzahlen

Alexander Müller
Sensorische Anwendungen mit akustischen Oberflächenwellen

Josef Müller
Elektrische Manipulation der Lichtemission von einzelnen CdSe/CdS Nanostäbchen

Gregor Neuert
Einzelmolekül-Kraftspektroskopie an molekularen Maschinen und Rezeptor-Ligand-Systemen

Christel Nonnenberg
Moleküldynamische Untersuchungen von ultraschnellen Reaktionen

Gunnar Raschke
Molekulare Erkennung mit einzelnen Gold-Nanopartikeln

Martin Reufer
Exziton- und Spindynamik in organischen Halbleiterlasern

Jens Schiener
Atomic force microscopy on macromolecular protein complexes

Christoph Strobl
Mikro- und Nanofluidik auf piezoelektrischen Substraten

Silke van der Piepen
Nichtvirale Gentransfersysteme zur Tumorthherapie in verschiedenen Mausmodellen

Daan Wouters
Bottom-up and top-down assembly of functional nanostructures

Diploma Theses

Roland Dietmüller
Photosensibilisierung von Fulleren-Mikrokristallen durch Halbleiter-Nanokristalle

Matthias Fiebig
Elektronische Transport-, Kapazitäts- und Photostrommessungen an Pentacen-Dünnschichttransistoren

Eike Friedrichs
Herstellung und Charakterisierung von RNA-Aptameren

Ulrich Hoyer
Manipulation von Nanopartikeln auf chemisch modifizierten Oberflächen

Andreas Huber
Abbildung der strukturellen Eigenschaften von SiC mittels IR-Nahfeldspektroskopie

Johann Kecht
Preparation of transition metal containing nanoscale zeolites for the generation of metal clusters by gamma irradiation

Andreas Keilbach
Synthesis of Copper Nanowires within Mesoporous Host Materials

Robert Lugmaier
Aufbau eines AFM-Lichtmikroskop Hybrids und kraftspektroskopische Messungen

Julia Morfill
Hochauflösende Einzelmolekül-Kraftspektroskopie von doppelsträngiger DANN

Sebastian Rémi
Laserspektroskopie an selbstorganisierten Halbleiterquantenpunkten

Camilla Scherb
Templatynthese und Hochdurchsatzuntersuchungen zur Darstellung von UTD-1

Albert Schliesser
Multiheterodyn-Spektroskopie mit Frequenzkämmen im mittleren Infrarot

Julia Schmitz
Kraftspektroskopie an menschlichen T-Lymphozyten

Tobias Smorodin
Selbstorganisation von Kohlenstoff Nanoröhrchen durch chemische Funktionalisierung

Hoi Nok Tsao
Charge Transport in Pentacene Thin Film Transistors

Franz Weinert
Pumping Nanofluidics Optically along freely defined patterns

Andreas Zürner
Synthese TEM-transparenter, mesoporöser Filme

Bachelor

Florian Feil
Nanosized clusters of platinum and silver incorporated in zeolite films

Verena Stockhausen
Synthesis and Surface Modification of Luminescent II-VI Semiconductor Nanocrystals

Awards

Science Foundation Ireland, Walton Award for Andrey Rogach (visiting professorship at the Trinity College Dublin, October 2005-September 2006)

Feodor-Lynen-Fellowship for Thomas Klar from the Alexander von Humboldt Foundation to carry out research at the Purdue University, Indiana, USA, for three months each year from 2005 to 2007

Scientific Award BMW group for Hendrik Dietz

Nanoscience Award 2005 of HanseNanoTec for Niels Fertig

Bavarian Innovation Award "Bavarian small/Medium enterprise of the year 2005" for Nanion Technologies GmbH

External Funding

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and SP 1121, SP 1175 and the Emmy-Noether-Program www.dfg.de

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Joint Projects for Education and Training

CeNS Winter School, Mauterndorf

IDK Summer School, "Systems Biology"

CeNS PhD-Students-Workshop, Hirschegg

IDK Workshop, "Nano-Bio-Technology and Management", Tutzing

"CeNS meets Industry", Munich

International Graduate Program "Nano-Bio-Technology"

New Members in 2005

New ordinary CeNS members:

Prof. Stefan Kehrein, Department of Physics, LMU

Prof. Ernst Wagner, Department of Pharmacy, LMU

Prof. Joost Winterlin, Department of Chemistry, LMU

New extraordinary CeNS members:

Dr. Kay Eberhard Gottschalk, Department of Physics, LMU

Dr. Thorsten Hugel, Physics Department TU München

Dr. Bernd Irmer, CEO of Nanotools GmbH