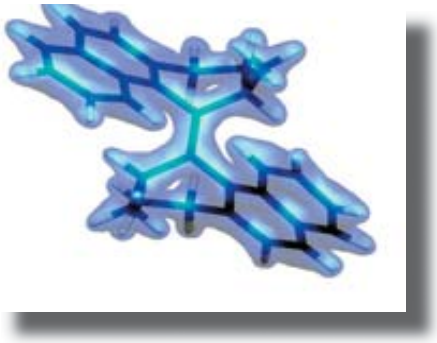
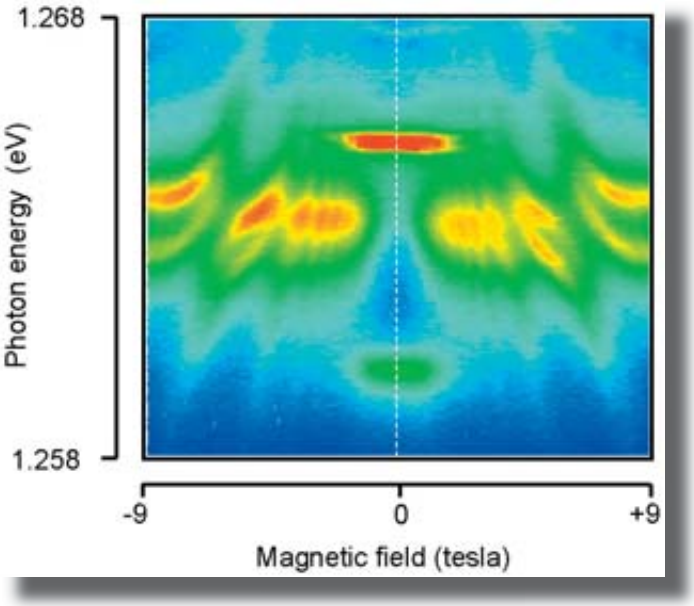
Annual Report 2004





CeNS
Center for NanoScience
Ludwig-Maximilians-Universität

Cover Pictures: I. Frank, U. Schubert, K. Karrai

Index

Research Fields of CeNS:

Other Activities in 2004

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

Introduction

2004 has been another scientifically fruitful and successful year for CeNS and its members. In part this is reflected by the decision of the LMU governing board to guarantee continued funding for CeNS for the next four years 2005 to 2008.

The attraction of CeNS is also mirrored by the continuous applications for membership and we are pleased to welcome as new full members Prof. Erwin Frey in the Department of Physics, who strengthens the theory in the areas of soft condensed matter and biophysics and Prof. Thomas Carell in the Department of Chemistry, whose expertise in repair and synthesis of DNA is an equally valuable asset to the interdisciplinary potential of CeNS. We are also happy about the new junior scientists joining CeNS in 2004, namely Dr. Berenike Maier and Dr. Dieter Braun, both new Emmy Noether awardees of the German Science Foundation, Dr. Alexander Holleitner and Dr. Florian Marquardt, both appointed on positions earmarked for a junior professorship, Dr. Pavlos G. Lagoudakis, a guest scientist supported by an LMU postdoctoral research fellowship and Dr. Marc Tornow, a member of the Walter Schottky Institute of the Technical University of Munich. We congratulate Prof. Wolfgang Heckl for his new position as general director of the „Deutsches Museum", the largest technical museum in Europe as well as for receiving the René Descartes prize of the European Commission for science communication to the public. Our congratulations also go to Prof. Thomas Carell for receiving a prestigious Leibniz award of the German Science Foundation.

Again CeNS members have accepted attractive faculty positions at other universities, namely Prof. Roland Netz and Prof. Wilhem Zwerger, both appointed as Full Professors in Theoretical Physics at the Technical University of Munich, and Dr. Gregor Jung, now Junior Professor for biophysical chemistry at the University of Saarbrücken. We wish all of them continued success in their professional careers.

CeNS contributed again to stimulate interdisciplinary research and education through the various workshops and seminars listed below and often co-organized with others, introducing the CeNS network to a larger audience in research institution and industries. In particular these have been:

"1st Workshop of the Munich Systems Biology Forum (MSBF)"
Munich, March 1, 2004

Joint "CNSI - CeNS Workshop" at the California NanoSystems Institute (CNSI) in Santa Barbara , March 15 - 17, 2004

"NanoEngineering" (Cooperation Forum of Bayern Innovativ with strong CeNS participation), Munich, May 10, 2004

"ENNaB-Workshop - BMBF Junior Groups in Nanotechnology"
Munich, July 22, 2004

"CeNS meets Industry", LMU Munich, July 23, 2004

A particular highlight was again the biannual CeNS workshop at the Venice Internatlonal University, this time entitled "Nanoscience: Linking disciplines", which attracted prominent guest speakers from all across the globe and now is already part of the CeNS tradition.

In addition CeNS hosted prominent speakers in the weekly "CeNS Oberseminar" presenting stimulating talks on a variety of nanoscience topics. CeNS also co-organized a large number of additional seminars presented by visiting scientist from all over the world as well as CeNS members and associates. The weekly CeNS calendar (www.cens.de - calendar) reflects these stimulating educational activities and also documents many of the scientific visitors.

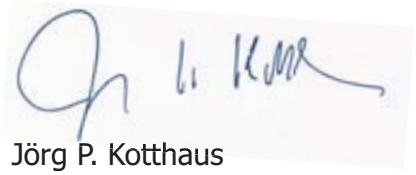
CeNS was also well presented at the Nanofair 2004 in St. Gallen, Switzerland, September 21-23, and the Munich Science Days, LMU Munich October, 22-26, 2004.

Finally CeNS was successful in being granted one of the few International Doctoral Colleges supported within the excellence program of the Bavarian Government and presented the chosen subject area "Nano-Bio-Technology" at the two start-up events in Munich on November 04 and 22, 2004.

As in the past CeNS hosted various visitors interested to learn about the structure and operation of CeNS, among them a prominent delegation from the University of Alberta, Canada which is in the process of establishing a nanosciene and technology center, and a delegation of the japanese Nitto Denko Corporation, one of Asia's leading companies in Material Production.
In addition CeNS members presented nanoscience and the scientific work of CeNS both to general public audiences as well as in numerous conferences to professional colleagues.

The successful interdisciplinary research activities at CeNS are again best demonstrated by the completion of many master (21) and doctoral (18) thesis, as well as two habilitation theses. Quite a few of them have been jointly supervised by CeNS members. The small selection of scientific papers published in 2004 and listed in this report reflects in particular the interdisciplinary interactions within CeNS. To gain access to all publications of CeNS members, please visit their respective homepage, which often also list the invited talks presented by CeNS members.

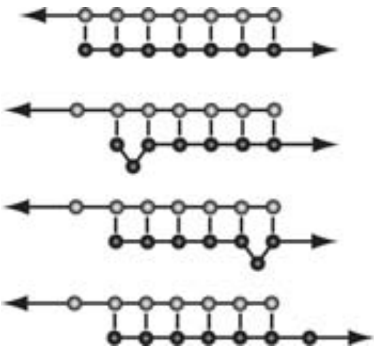
Finally we are also glad to report that the CeNS spin-off companies Advalytix, Attocube, Ibidi, Nanion, Nanoscape, and Nanotools are steadily expanding and marketing an increasing range of nanotechnology products while continuously hiring CeNS graduates. This combined with the strong contribution to the advancement of basic nanoscience as well as the wide spectrum of educational efforts demonstrates that CeNS continues to be a fruitful endeavor living from the voluntary contributions of all its participants. It is my pleasure to thank all members and associates for their enthusiasm and all direct or indirect funding institutions for their continuous support.



Jörg P. Kotthaus
Spokesman of the board

Dynamics of force induced DNA-slippage (R. Neher and U. Gerland)

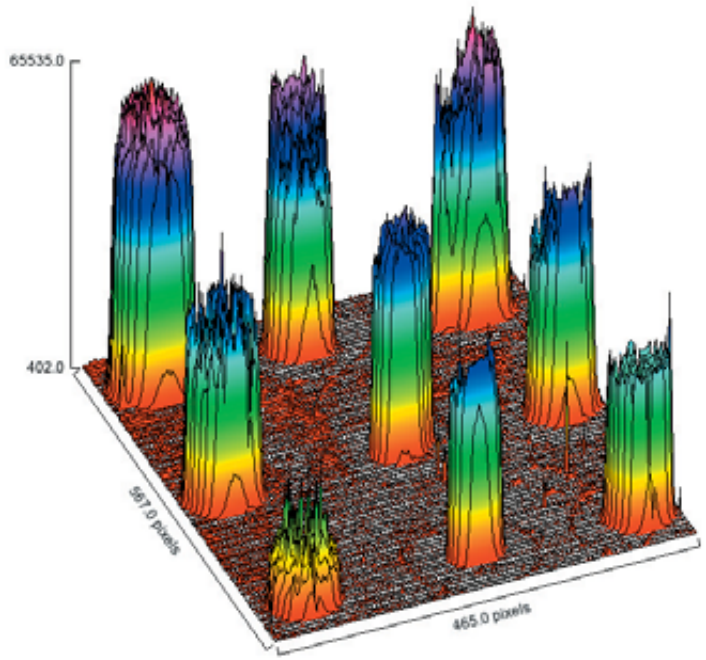
The dynamics of basepairing is the key to the unique capability of DNA to store information and keep it accessible at the same time. Two complementary periodic DNA strands can bind to each other in many different configurations. By studying transition between different configurations one can learn a lot about the dynamics of basepairing.
We address the question, how microscopic opening and closing of basepairs can lead to relative motion of two periodic DNA strands. Such DNA slippage is mediated by diffusion of bulge loops along the DNA, as illustrated in the figure. Within our model, we study the dependence of the drift and diffusion properties of DNA slippage on an external shear force, the size of the system and energy parameter of the basepairs.
When the applied force is small, the time it takes to separate both strands completely increases exponentially with the size of the system. The scaling changes to cubic at a critical force and is quadratic in the super critical regime. At very high force, we find a crossover to linear scaling. The critical forces marking the boundaries of these regimes can be calculated exactly within our model.
This work is done in a vivid collaboration with Julia Morfill and Ferdinand Kühner from the lab of Hermann Gaub, who are currently performing experiments regarding DNA sliding.



Microscopic opening and closing of basepairs can lead to relative motion of two periodic DNA strands. Such DNA slippage is mediated by diffusion of bulge loops along the DNA .
(R. Neher, U. Gerland)

Bacterial gene transfer studied at the single molecule level (B.Maier, J. Rädler)

Bacteria employ a variety of molecular motors near the cell envelope to move and communicate with their environment. Madeleine Leisner, Martin Clausen and Berenike Maier are interested in the molecular machine that transports DNA through the bacterial envelope during transformation. Transformation enables bacteria to acquire genetic diversity, including antibiotic resistance and virulence traits. The first step to transformation is transport of DNA through a nanometer-sized pore in the bacterial cell envelope.
In preliminary experiments we used laser tweezers with living Bacillus subtilis to show that the DNA transport machinery is a force-generating motor. The goal of our current project is to understand the physical mechanism and regulation of this transport process: How does the molecular motor drive the translocation of DNA through a nanopore in the cell membrane?
Transport of macromolecules through nanometer-sized pores is a ubiquitous theme in microbiology and cell biology and a challenging problem in physics. An in vivo assay is used to study the kinetics, force generation and regulation of DNA transport at the single molecules level. Optical methods (laser trapping and single molecule fluorescence) are combined with microbiological techniques.



Fluorescence intensity of a hagt-functionalized protein chip (S. Kufer, H. Gaub)

Single molecule Biophysics (H. Gaub)

Our research is focused on biophysics and material sciences and ranges from structure and dynamics of lipid films to molecular processes at cell surfaces. There is a two-fold interplay between physics and life science, which spurs our research activities.

i) Modern biology provides stunningly clean and well-controlled samples making precise Physics experiments possible and allowing the design of new materials with novel properties. Concepts that were developed in Physics allow a better understanding of the basic mechanisms of the organization of life systems. Key problems may now be address quantitatively and backed up with theory.

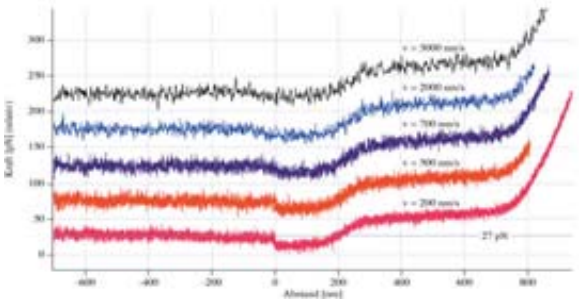
ii) The complexity of biological systems requires as many different techniques as possible. Many novel experimental approaches were developed in Physics. Biophysicists may integrate both sides and are adept best to further develop the techniques according to the specific needs of life.

Special emphasis is put on : Molecular recognition, cell to cell adhesion (together with Nanion), single molecule force spectroscopy, unfolding of individual proteins.

Atomic Force Microscopy (AFM) of biological macromolecules (R. 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 investigate 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

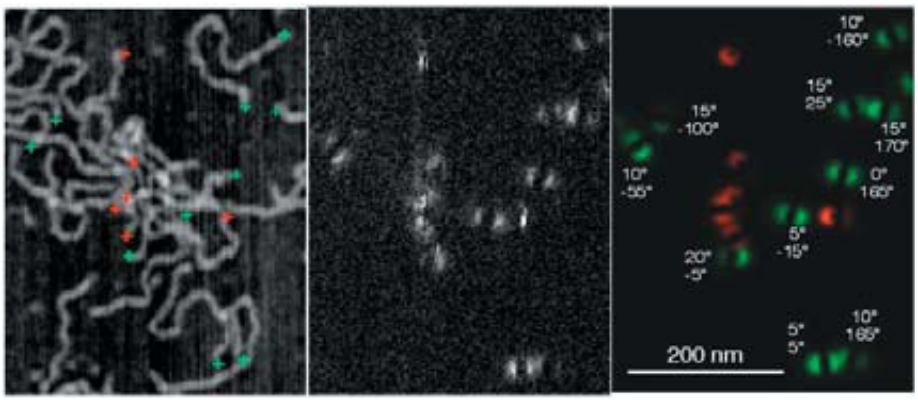


Force distance plots derived from stretching the Pilus of an E-coli bacterium with a Force-spectrometer at different velocities (R. Lugmaier, H. Gaub).

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.

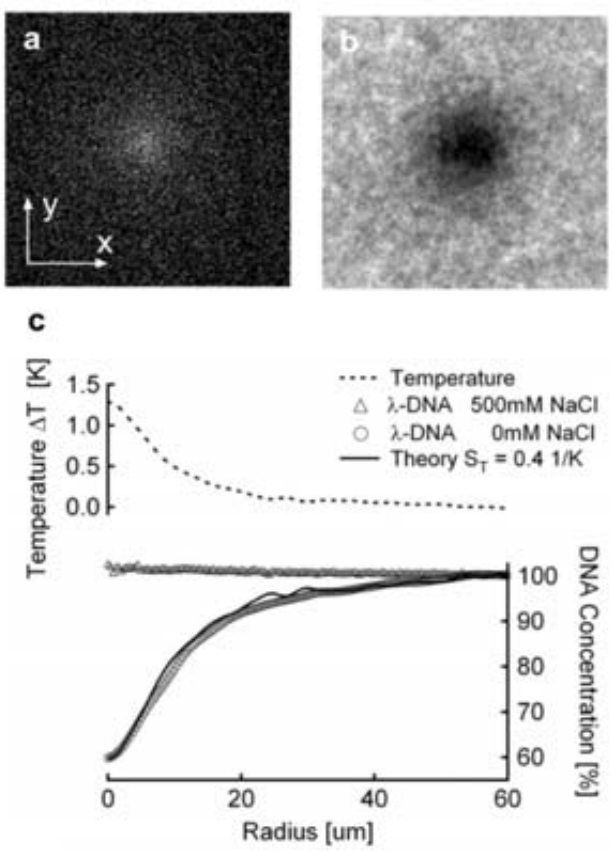
Temperature gradients for microfluidic analytics (D. Braun)

We explore temperature gradients for microfluidic analytics. We focus on five effects
(i) Temperature differences move DNA from hot to cold, due to an effect called thermophoresis. Its origin is yet to be explained, our studies indicate that the energy stored in the nanoenvironment of the charged DNA is minimized by the movement. Since temperature fields can applied flexibly using infrared laser scanning, a large variety of DNA traps and guidances can be written into microfluidics. For example microfluidic flow opposing a heat spot leads to 10-fold accumulation of DNA, an effect useful to enhance surface-based DNA detection. Understanding thermophoresis will allow all-optical measurement of particle diffusion constants and their zeta potential.
(ii) Temperature gradients drive exponential DNA amplification simply by convection. In mm-sized chambers, steady state convection is triggered either by infrared radiation or simply by 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.

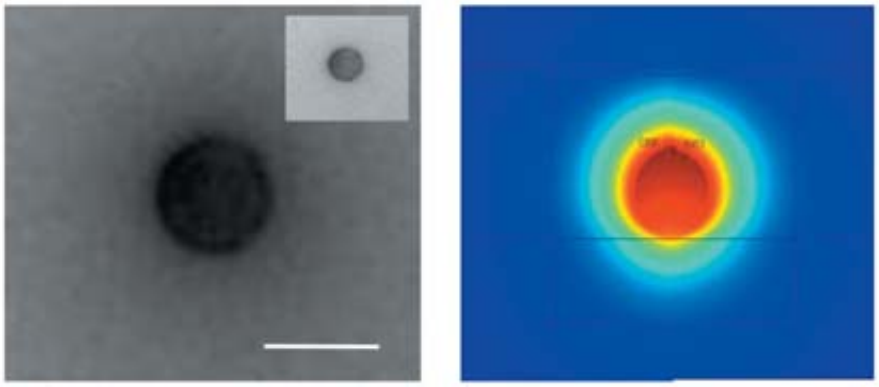


Simultaneously taken topography and fluorescence of DNA with Cy-3 labelled termini prepared on mica, together with corresponding data modelling. The images were acquired by SNOM using the new TOA probe.
Left: Topography, together with the calculated positions of the analyzed dye molecules marked by " +". Middle: Fluorescence. Right: Fitted fluorescence patterns, together with resulting tilt angles (upper numbers) and azimuth angles (lower numbers). Good fits are displayed in green; problematic fits due to, e.g., blinking or bleaching of the dyes are marked in red. Scale bar: 200 nm.(R. Guckenberger)

(iii) Convection highly enhances thermophoretic accumulation. Besides being capable of accumulating DNA more than thousandfold, polystyrene beads can be compressed by thermophoresis into a two-dimensional crystal. In combination with above convection-based replication, we speculate that similar systems are ideally suited for archaic molecular evolution in pores of rock neighboring hydrothermal vents.
(iv) 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 2%/°C, which allows measurement precisions of 0.1°C. In collaboration with Andre Skirtach and the groups of Parak, Möhwald and Sukhorukov, we measured the temperature around particles prepared for remote opening using infrared radiation.
(v) We can pump fluids in free-defined geometries by fast infrared laser scanning with speeds of several 10µm/s. We are working to understand the effect, the momentum is probably generated by deflecting the laser in a lagging thermal lens.



DNA moves from hot to cold to minimize energy in its ionic nanoenvironment. This effect, called thermophoresis, is analogous to electrophoresis, however better applicable in microfluidics. Thermophoresis was quantified using a microfluidic all-optical approach: water is heated by 1K with infrared radiation and temperature is measured with a temperature sensitive fluorescent dye. As a result of the heating, fluorescently labelled DNA depletes by 50% from the heated spot. (D. Braun)



Nanoscopic metal particles allow the construction of capsules that are remotely opened by infrared radiation to deliver drugs only where necessary. Critical to the design of the particles is the temperature needed to open the capsules. In collaboration with Andre Skirtach and the groups of Parak, Möhwald and Sukhorukov, we measured the temperature around the capsules using a temperature dependent fluorescent dye. The temperature sensitivity of the nanoscale dye is a combination of thermophoresis and pH dependence, summing to a darkening with about 2%/°C.(D. Braun)

Infrared nanoscopy (M. Brehm, T. Taubner, F. Keilmann)

The group has applied infrared near-field microscopy to image protein films and single virus particles, at <50 nm spatial resolution. The method uses scattering-type near-field microscopy illuminated by a CO laser which can be tuned in the 5.5-6.5 µm region. This covers a strong vibrational resonance, the amide vibration band which is well known to reveal information about the secondary structure of proteins. The infrared spectrum of a single virus was observed, simultaneously in both amplitude and phase contrast, and found good agreement with theoretical expectations. The spectrum could even be mapped as function of position on the virus.

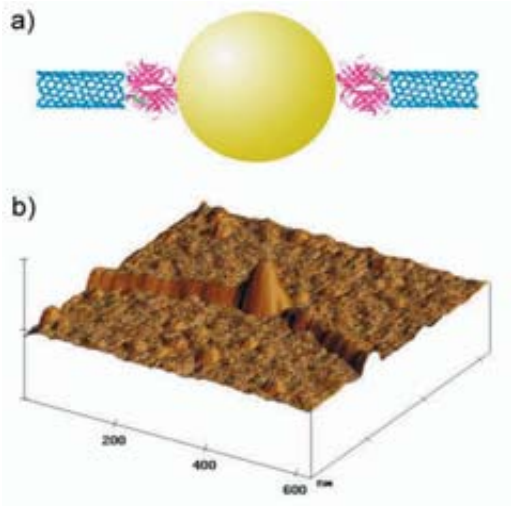
Nanoelectronics and biomolecular nanoscience (U. Beierlein, F. Simmel, J. Kotthaus)

In the group of Udo Beierlein, biomolecular self-assembly was used to contact gold nanoparticles with carbon nanotubes. To this end, single-wall carbon nanotubes (SWNTs) were functionalized with biotin at their ends and side-walls in a series of chemical reactions. Streptavidin-coated gold nanoparticles were attached to the biotin-modified SWNTs in solution in a self-assembly process and contacted for electronic transport measurements. At low temperatures, Coulomb blockade oscillations were observed as a function of gate voltage. In the group of Friedrich Simmel, DNA templates were used to direct the growth of chains of semiconductor nanoparticles and

also of polyaniline nanowires, which were subsequently characterized with electronic transport measurements.
In a different project focusing on the construction of DNA-based molecular machines, it could be demonstrated that DNA aptamers can be modified to produce molecular „hands“ which can repatedly bind and release proteins. It was also shown that the motion of DNA machines can be controlled by the transcription of artificial gene sequences. In a collaboration between Friedrich Simmel, Wolfgang Parak and Nanion Technologies, soft lithographic methods were used to control the adhesion properties of quantum dot labeled live cells. Using the techniques developed in this collaboration, differential cell motility and also cell viability experiments can be conducted. In another collaboration with Nanion Technologies, lipid bilayers and also live cells were investigated using high-frequency spectrocopic methods.

Colloidal nanoparticles (W. Parak, J. Rädler, A. Rogach)

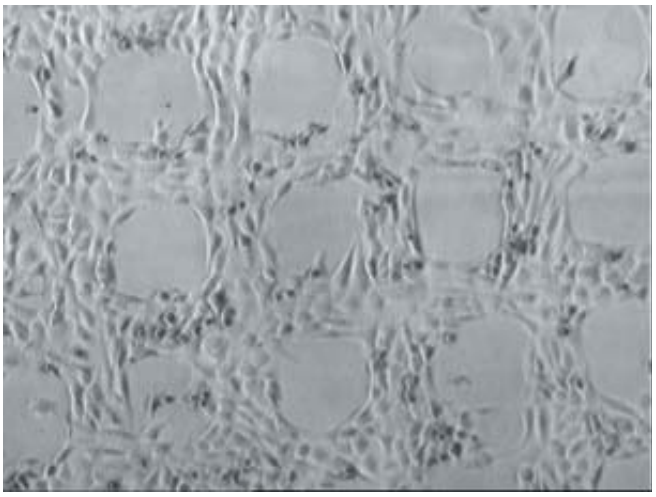
Colloidal Nanoparticles possess interesting functional properties, such-as fluorescence or magnetism. High quality nanoparticles can be grown in organic solvents. However, for biological applications these particles have to be transferred to aqueous solution. For this purpose we have developed a general protocol to transfer nanoparticles from organic to aqueous phase. Amphiphilic polymers are wrapped around the particles with their hydrophobic chains pointing towards the particle surface and their hydrophilic backbones pointing towards the aqueous solution. This protocol has been successfully applied to different classes of nanoparticles, such-as fluorescent semiconductor and magnetic metal oxide particles.



(a) Schematic representation of two SWNTs attached to a gold nanoparticle via streptavidin. (b) AFM image of such a SWNT-nanoparticle-SWNT junction. (U. Beierlein, J. Kotthaus)

Biocompatibility of nanocrystals (W. Parak, Nanion Technologies)

In a collaboration between the group of Wolfgang Parak and the team at Nanion Technologies an aspect of biocompatibility of fluorescent CdSe/ZnS nanocrystals has been investigated. The nanocrystals were prepared by the Parak group and specifically coated to increase biocompatibility. Using Nanions planar patch clamp technology, impairment of currents through ion channels upon incubation of cells with nanocrystals were analyzed. Two cell lines were investigated regarding changes in their morphology and their electrophysiological properties upon incubation with nanocrystals.
For nanocrystal concentrations in the nM range and incubation



MDA-MB 235s breast cancer cells spread on a glass slide with squares made hydrophobic with OTS by PDMS (F. Simmel)

times of up to 2 days in serum containing medium, no morphological changes of the cells were identified using high magnification light microscopy, although uptake of the nanocrystals by the cells was clearly verified by fluorescence microscopy. Patch-clamp recordings under identical experimental circumstances of untreated and incubated cells revealed no changes of ion channel function and characteristic electrophysiological properties of the cells. As ion channels play an important role in the cells vitality and function, their characteristics and functionality are a subtle indicator of the condition and viability of the cells.
In this study, the complementary set of technologies available within the CeNS groups could be very productively used for a joined research project.

AFM nanomanipulation and laser-based microdissection of biological specimen (S. Thalhammer)

Nanomedicine is the application of nanotechnology to the prevention and treatment of disease in human body. The discipline is in its infancy. It has the potential to change medical science dramatically in the 21st century. The most elementary nanomedical devices will be used for diagnosis. The combination of high resolution microscopy, such as atomic force microscopy (AFM), AFM nanomanipulation and laser-based microdissection provides a direct approach for the investigation, isolation of biological specimen and the generation of specific molecular probes for diagnostic applications. Chromosome-specific paint probes and band-specific probes provide a powerful tool with wide applications in cytogenetic and cancer research. In cooperation with CeNS members (Hermann Gaub, Jörg Kotthaus, Bert Lorenz, Achim Wixforth, ibidi) and external partners the methodical parts for the generation of specific painting probes using AFM and laser based microdissection was developed.
In pathology and forensics AFM offers significant information on e.g. the fibrillar assembly and ultrastructure of collagen fibrils, which may provide insight into both the physiological and eventually pathogenic pattern of collagen fibrils, but also into possible diagenetic destructive changes of those fibrils. For the extraction of ancient DNA paraffin embedded sections of bone samples from ancient Egypt (New Kingdom, appr. 1500 – 1000 BC) were used and bone sections of 50 µm in diameter were isolated for DNA analysis. This non-contact isolation procedure decreases the problem of contamination. To confirm specificity of the isolated material PCR for β–actin and amelogenin DNA was performed. These diagnostic and isolation methods were also performed on the 5300 year-old mummy of the Tyrolean Iceman, Ötzi.
Rate-dependent single molecule force spectroscopy by AFM-related techniques was used in cooperation with Hermann Gaub to characterize the binding of LexA with the DNA binding motif, recA and yebG. The technique can be applied to further correlated studies on physical affinity and biological relevance of the controlled gene and can be used a possible new mapping strategy.

Pulling on Polymers (T. Hugel, M. Rief, H. Gaub, R. Netz)

If one pulls on a polyelectrolyte adsorbed on a surface, for example using an atomic-force-microscope (AFM), the polymer will either slip or stick (or maybe both, depending on force load or other parameters). If the polymer sticks, one obtains a characteristic force-extension profile from which one can learn a lot about the elastic behavior of the stretched polymer that is bound between surface and AFM tip. We concentrated on the large-force regime above 500 pN, where conformational polymer fluctuations constitute only small corrections to the stretching response. We experimentally investigated three different polymer architectures, namely, single-stranded DNA (ss-DNA), polyvinylamine, and peptide molecules. at stretching forces up to 2 nN, made possible by very stable attachments between polymers and cantilever tips and substrate surfaces. The enthalpic stretching modulus of these different synthetic and biopolymers is obtained from ab-initio quantum-chemical calculations and compares well with experimental data at high forces above 400 pico-Newton At smaller forces, entropic contributions are well described within the discrete-chain model, whereas the commonly used worm-like-chain model is shown to be inadequate for describing experimental stretching data on synthetic chains.

Nanomechanics (J. Michaelis)

The research in the nanomechanics group is divided into two parts. On one hand we are interested in understanding the molecular mechanisms that underlie the biological activity of proteins. Enzymatic processes such as polymerization reactions, or DNA translocation, are studied in well defined in-vitro assays. Single-molecule force spectroscopy is employed to investigate, how force, applied to a molecule externally, influences its enzymatic activity. In order to apply such a force we use micro-fluidics as well as optical- and magnetic tweezers. Furthermore single-molecule fluorescence techniques, such as confocal microscopy, total internal reflection microscopy, fluorescence resonance energy transfer or single particle tracking, are applied to observe the dynamic behaviour of proteins or DNA molecules during the in-vitro processes. Using these single-molecule techniques our group can determine how conformational changes are coupled to enzymatic activity.
With these techniques in collaboration with Patrick Cramer and Thomas Carell we started a project that is aimed to understand the molecular mechanism of eukaryotic transcription and transcription coupled repair. The direct and real-time single-molecule measurements are an important addition to structural or biochemical research, since averaging over an ensemble of molecules is avoided.
The second principal area of research of the nanomechanics group

is the understanding of the mechanical properties of polymer molecules. Atomic force microscopy is used to exert well defined forces on single molecules, such as DNA or conjugated polymers. By applying polymer stretching models the physico-chemical properties of these molecules are investigated. In addition the intermolecular and surface interactions are probed by a controlled variation of experimental conditions, such as solvent exchange or different surface preparations.
In a collaborative effort with John Lupton, we are using this technique to study the effect of polymer conformation on the luminescent properties of light emitting polymers.

Molecular electronics (P. Hänggi, J. Kotthaus)

Molecular electronics is recognized as a key candidate to possibly succeed the Silicon based technology. In this context various possibilities to control current and heat through molecular wires that are either exposed to mechanical vibrations (vibration –assisted electronic transport) or to impinging light fields (irradiated junctions) are explored.

Pentacene thin film transistors – structural and electronic properties (N.Tsao, S. Schiefer, U. Beierlein, B. Nickel)

Organic thin film transistors (TFTs) were fabricated in top and bottom contact geometry and the electronic transport as well as the 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 was carried out in the group of Bert Nickel.The pentacene TFTs achieved electron charge mobilities of up to $\mu = 0.5\ cm^2/Vs$. In order to maximize the mobility, we varied the preparation parameters and functionalized the gold contacts with a self-assembled monolayer of short chain alkane thiols.

Metallo-supramolecular Molecular Wires (U. Schubert, U. Beierlein, J. Kotthaus)

Self-assembling supramolecular systems have been connected between electrodes and investigated on the nanoscale. The connection was made via thiol-end groups to gold electrodes. The subsequent addition of free bis-functionalized ligands and suitable metal ions (such as cobalt(II)) lead to the formation of „molecular“ wires. The properties of such systems have been studied in first experiments.

Electronic transport through quantum dots (R. H. Blick, J. P. Kotthaus und S. Ludwig)

The ongoing progress in quantum information processing calls for the realization of scalable and controllable solid state based systems. Lateral quantum dots defined in the two-dimensional electron gas of a GaAs/AlGaAs heterostructure are promising candidates for the implementation of such solid state quantum bits. Our investigations of single electron transport through quantum dots aim at realizing well-defined charge and spin states at low temperatures. In order to manipulate the coupling between adjacent quantum dots in a controlled way, few-electron quantum dots are desirable. The charge state of these artificial molecules can then be read out by means of integrated quantum point contacts. We successfully fabricated a serial double quantum dot and demonstrated full charge control in the few-electron limit. For the case of the double quantum dot charged with only one electron we undoubtedly determined the interdot tunnel splitting by means of transport spectroscopy at finite bias voltage. New measurements in the Kondo regime of a double quantum dot in the one- and two-electron limit have excited intensive discussion with the theory group of Jan von Delft.
Another aspect of our work deals with the coupling of quantum dots to the solid state environment. In order to gain control of phonon-mediated dephasing processes, a lateral quantum dot has been integrated in a free-standing nanobridge. Due to its strongly confined acoustic spectrum the nanobridge is a realization of a phonon cavity. Here, the electron-phonon coupling is modified, which becomes apparent in a phonon blockade of single electron tunneling. This can be understood in a model based on the Franck-Condon principle. In addition to our studies on single dot phonon cavities we seek to implement double quantum dots into free-standing beams.

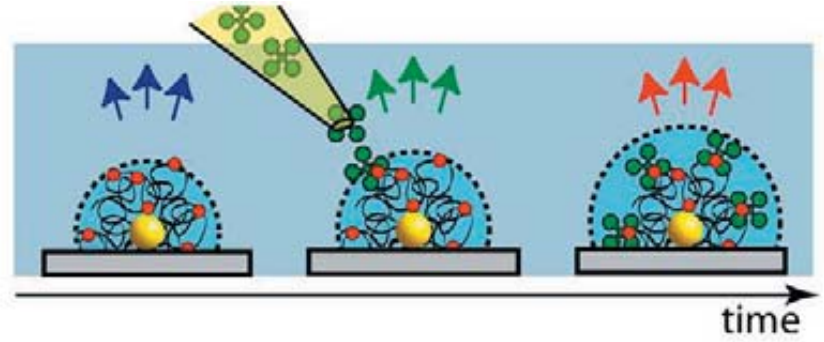
Nanoshells (J. Lupton, T. Klar, J. Feldmann)

A co-operation between Roche Diagnostic, Penzberg, and the Photonics and Optoelectronics Group investigates a novel sensor format comprising a single gold nanoparticle as a biomolecular sensor. Because the signal of a single gold nanoparticle is sufficient to give a detectable signal, we are able to register the binding events of only 100 molecules to a gold nanoparticle. If the gold nanoparticles are pre-functionalised with specific binding agents, a biomolecular sensor can be built which is not only sensitive but also selective. In 2004 we extended our collaboration to the Group of Thomas Bein. This allowed us to set up the synthesis and characterisation of gold nanoshells. Using gold nanoshells instead of solid gold nanospheres improves the sensor three fold: (i) it allows to access the so called

biological window, a spectral region where physiological liquids like blood are highly transmissive, (ii) it increases the sensor signal for a comparable amount of bound molecules and (iii) the single gold nanoshell scattering spectrum is much sharper compared to a scattering spectra of solid gold nanospheres.

Au-DNA-Cy5 Hybrids (J. Lupton, W. Parak, J. Feldmann)

In a close cooperation between the Group of W. Parak and the Photonics and Optoelectronics Group we investigated the fluorescence of red emitting dye molecules (Cy5) that are attached to gold nanoparticles using single stranded DNA linkers. Different lengths of ssDNA and a variation of the surface coverage allow us to tune the distance between the dye and the gold nanoparticles between 2 and 16 nm. Time resolved fluorescence measurements using a streak camera revealed, that the gold nanoparticles decrease the radiative rate of the dye molecule which leads to a pronounced fluorescence quenching. This is due to a phase shift between the induced dipole on the gold nanoparticle and the molecular dipole which leads to a weakening of the overall dipole moment of the dye-gold hybrid system. The energy transfer from the dye molecule to the absorbing gold nanoparticle plays only a minor role.



Sensing analyte molecules with a single gold nanoparticle: The scattering spectrum of a single functionalized gold nanoparticle is monitored for a few minutes (blue arrows). After addition of the solution to be analyzed, the analyte molecules specifically bind to the gold nanoparticle. This causes a red shift of the scattering spectrum. (J. Lupton, T. Klar, J. Feldmann)

Well defined Gold functionalisation of sharp cantilever tips (S.Schöffberger, J. Kotthaus, F. Kühner,J. Morfill, H. Gaub)

Purpose of the cooperation was to test different deposition methods of thin Gold films on AFM tips. Different sputtering- and evaporation-techniques for the gold functionalisation / coating were applied. In addition these gold films were chemically treated. Following, the cantilever tips were analyzed by Scanning Electron Microscopy and the quality of gold film deposition on the tip was evaluated. These experiments gave us additional information about the behaviour of the differently deposited gold films in liquid solutions.

Passivation of micro fluidic- and sensor-chips with quartz (S.Schöffberger, J. Kotthaus, A. Wixforth)

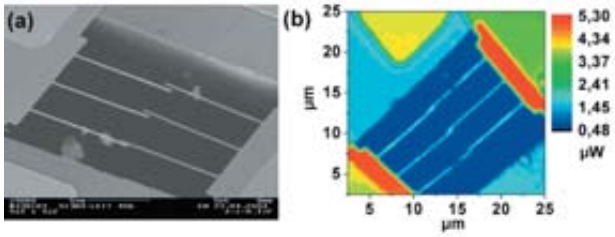
For micro fluidic- or sensor applications quartz (SiO_x) is deposited on the surface of a piezoelectric substrate. With this coating a chip gets a uniform surface layer and is passivated against aggressive chemicals and electrolytic corrosion. For this cooperation the coating is deposited by sputter process. Using this room temperature process it is possible to structure the layer by lift-off techniques. The quality and density of the coating is controllable for protecting metallic electrodes against electrolytic corrosion by avoiding a polarization of the electrodes.

Optical imaging of freely suspended nanostructures using a slip-stick step-scanner (C. Meyer, H.Lorenz, and K. Karrai, in collaboration with O. Sqalli and D. Haft, attocube systems AG)

We fabricate nanoelectromechanical structures (NEMS) that consist of two opposing silicon cantilevers with a length of some micrometer and a width and height of some 100 nm. If a voltage is applied between the two nanocantilevers, they are bent by capacitive attraction and thus the distance between the cantilevers is reduced by some nanometers.
Slip-stick positioning devices from attocube systems AG are used as step-by-step scanners to image these structures and their deflections in a scanning confocal optical microscope. A removal of the substrate beneath the nanostructure enhances the image contrast and additionally eliminates the parasitic electrostatical influence of the substrate. This combination allows us to optically image structures well below the diffraction limit. Despite the used wavelength of 635 nm, the structures of 200 nm width are clearly resolved and a separation of about 200 nm between two beams is identified. In contrast to scanning electron microscopy (SEM) imaging, the optical imaging is absolutely damage free and can be easily carried out under ambient conditions.

Nano-optomechanical and nano-electromechanical systems (K.Karrai, J. Kotthaus, R. Blick)

Nano-Electro-mechanical systems (NEMS) are fascinating objects for investigating the fundamental physical quantum behaviour of systems with a mechanical degree of freedom. At the same time they promise a large variety of applications, like extremely sensitive force sensors and mechanical filters for signal processing. A typical challenge for NEMS is how to easily and resonantly excite nanomechanical elements and control their motion, such as suppressing unwanted thermally excited motion.
In analogy to passive cooling of atoms, i.e. without active feedback, we were able to directly observe experimental evidence for passive optical cooling of a micromechanical resonator [Figure (a)].



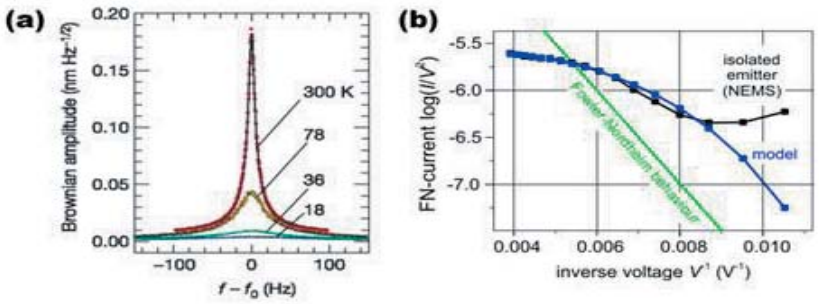
(a) Scanning electron micrograph of a set of six nanocantilevers that are 10 µm long and 200 nm wide. The hole-aperture beneath them reaches through the whole substrate (oblique view).
(b) Scanning confocal optical image of the structure shown in (a) using an imaging wavelength of 635 nm and a slip-stick positioner (attocube systems AG) in step-scan mode for imaging (top view).
(C. Meyer, H.Lorenz, and K. Karrai, in collaboration with O. Sqalli and D. Haft, attocube systems AG)

Extending this method to optical-cavity-induced radiation pressure might enable the quantum limit to be attained, opening the way for experimental investigations of macroscopic quantum superposition states involving numbers of atoms of the order of 10^{14}.
In collaboration with Robert H. Blick at the University of Wisconsin (UW) and Christoph Weiss at the University of Oldenburg, we have furthermore observed field emission from an electrically isolated gold island at the end of a nanoscale cantilever. Besides strongly enhancing the effective excitation force, field emission in such a system yields entirely new I-V-characteristics, which strongly deviate from the classic linear Fowler-Nordheim description [Figure (b)].

Optical properties of self-assembled quantum dots (K. Karrai)

In the group of Khaled Karrai optical properties of self-assembled quantum dots are investigated by means of photoluminescence and laser transmission spectroscopy. The complementary techniques provide insight into electronic and excitonic states bound to self-assembled quantum dots. Optical spectroscopy allows to study not only the discrete nature of localized states but also their interaction with the solid-state environment as well as with electromagnetic field, both features of high relevance with regard to application of quantum dots in quantum information processing.
The self-assembled InAs quantum dots are grown by molecular beam epitaxy in the group of Pierre Petroff at the University of California, Santa Barbara. In cooperation with the group of Richard Warburton (Heriot Watt University, Edinburgh), know-how of charging quantum dots with a well-defined number of excitons and electrons was combined with the expertise developed to perform luminescence and absorption experiments on single quantum dots at cryogenic temperatures. Photoluminescence of triply charged excitons in high magnetic fields and coherent absorption of the neutral and charged excitonic ground states are representative examples for spectroscopy of individual charge tuneable quantum dots.
The charge tuneable quantum dots are also very suitable in order

to investigate many body problems in a strongly confining potential. In an international collaboration, the experimental studies are complemented by theoretical work of Alexander Govorov aiming to understand the interaction between excitons in the dot and a nearby Fermi sea. For instance it is predicted that excitons confined in a quantum dot can couple to a nearby two-dimensional electron system to form a Kondo exciton, an aspect of quantum dot optics also investigated theoretically in the group of Jan von Delft using the numerical renormalization group. Another signature of the coupling between the localized quantum dot states and the electronic continuum has been observed recently in the optical spectrum and is expected to be closely related to the Fano effect.

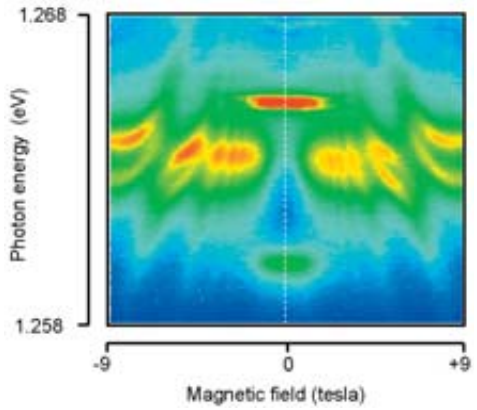


(a) Cavity-induced cooling of the lever vibrational resonance. Thermal motion amplitude spectra of the lever vibrational resonance measured for four different laser power levels. (b) Model calculation and experimental data of a nano-mechanical emitter pendulum, strongly deviating from linear Fowler-Nordheim behaviour. (K. Karrai, J. Kotthaus)

Theoretical Condensed Matter Physics (J. von Delft)

We used the numerical renormalization group to study various transport and optical properties of quantum dots exhibiting Kondo effects. The effect of the latter on the absorption and emission spectra of quantum dots of the type currently being studied in the group of Khaled Karrai was studied in the diploma thesis of Rolf Helmes, leading to a number of predictions for future experiments. We also developed a theory for the inelastic scattering rate off magnetic impurities, which governs the decoherence rate of disordered conductors with magnetic impurities. A second goal of our work was to generalize the density matrix renormalization group (DMRG), used for the treatment of strongly correlated one-dimensional systems, to time-dependent situations. This endeavour led to a paper, coauthored by one of our PhD students, Corinna Kollath, which formulated the adaptive time-dependent DMRG and constitutes a breakthrough in the field.

We also investigated various aspects related to solid state qubits. Regarding the decoherence of charge states in quantum dots, we have shown that the decoherence caused by cotunneling to the leads can be suppressed by application of a finite voltage – a current stabilizes excited charges. This turns out to be crucial for experiments as they are planned at CeNS in the group of J. Kotthaus. Furthermore, we have investigated how to detect quantum noise in nanostructures. Notably, we have proposed a detector for the current skewness, the third cumulant, using a tunnel junction. This quantity is expected to provide new insight into transport mechanisms at the quantum level. We have developed tunable couplers including a potentially negative mutual inductance between superconducting qubits. We have shown using control theory, that such a device enables the efficient implementation of quantum logic gates with off-the-shelf equipment.



Evolution of the photoluminescence spectra with magnetic field of a single InAs self-assembled quantum dot charged with three electrons. The series of spectacular oscillations which are a signature of the continuum of energies located well above the bounds state energies are made visible in high magnetic field. (K. Karrai)

Phonon Photonics (R. Hillenbrand)

In the group of Rainer Hillenbrand mid-infrared surface phonon polaritons on polar crystals are investigated. Besides fundamental mechanisms of resonant phonon-photon coupling in nanostructures the application potential in the fields of data storage, sensoring and subwavelength-scale infrared energy transport is explored.
The group showed that subwavelength-scale tailoring of surface phonon polariton properties on SiC is possible by modification of the local crystal structure, in this experiment by a focused ion beam (FIB). As features down to 200 nm could be clearly resolved by infrared near-field microscopy the method could be applied for longterm, archival data storage where data encoding is by local crystal structure. The nanoscale resolution of infrared near-field microscopy promises an read-out capability down to 1 Tbit/cm^{-1}.
Further it was demonstrated that the optical resonance of a near-field coupled system can be tuned by controlled adjustment of the distance between the interacting entities. Therefore infrared scattering from a tip in phonon-resonant near-field interaction with a SiC surface was

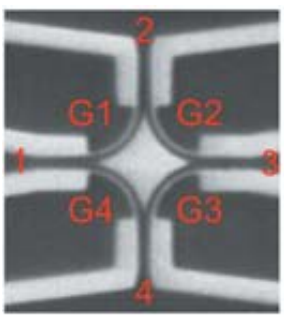
measured. Amplitude and phase recording revealed a strong phase shift while approaching the tip towards the surface. A spectral analysis allowed to explain the effect by a red-shifting of the resonance which could be exploited for nanomechanical manipulation of light fields.

Temporal and spatial dynamics of excitons in semiconductor double quantum well structures (J. Kotthaus, A. Gärtner, D. Schuh)

The temporal and spatial dynamics of excitons in semiconductor double quantum well structures at low temperatures were studied and manipulated using temporally, spatially and energetically resolving optical detection. Long-living excitons can be driven in-plane at will over macroscopic distances exceeding 150 µm by electrically tunable artificial potential landscapes. Similar as in a recently realized photonic camera SiO_2-patterns are used to create artificial traps for excitons, pointing the way towards the generation of high exciton densities and, ultimately, Bose-Einstein condensation. For further details see http://www.nano.physik.uni-muenchen.de/research/index.html

Ballistic Rectification (A. Lorke, J. Kotthaus)

Ballistic rectification is a novel concept to realize active semiconductor devices, such as rectifiers, mixers or second harmonic generators, by controlling the shape of the sample, rather than using combination of different materials, as in common devices. We have realized 4-terminal rectifiers, where the motion of the electrons are not only ballistic, i.e. scatter-free, like billiard balls on an oddly shaped table. The devices also show features that are characteristic for the quantum (wave-like) nature of the electrons.
The samples are etched out of a sheet of a high-mobility electron gas (see figure below). Four leads (1 –4) are connected by narrow channels (dark strips in the center of the image), which are arranged in a diamond-like geometry. These channels are made tunable in width by four gates (G1 – G4), which are separated from the channels by etched trenches (light strips).



4-terminal rectifier. The sample is etched out of a sheet of a high-mobility electron gas (A. Lorke).

When the gates are biased to induce an appropriate asymmetry, the current-voltage characteristic becomes strongly non-linear. This figure also shows that the non-linearity, which is at the heart of any active semiconductor device, is solely give by the gate-voltage-induced asymmetry. Input and output terminals are interchangeable and the output polarity can be chosen freely.

Characterization of gene-delivery nanoparticles (J. Rädler)

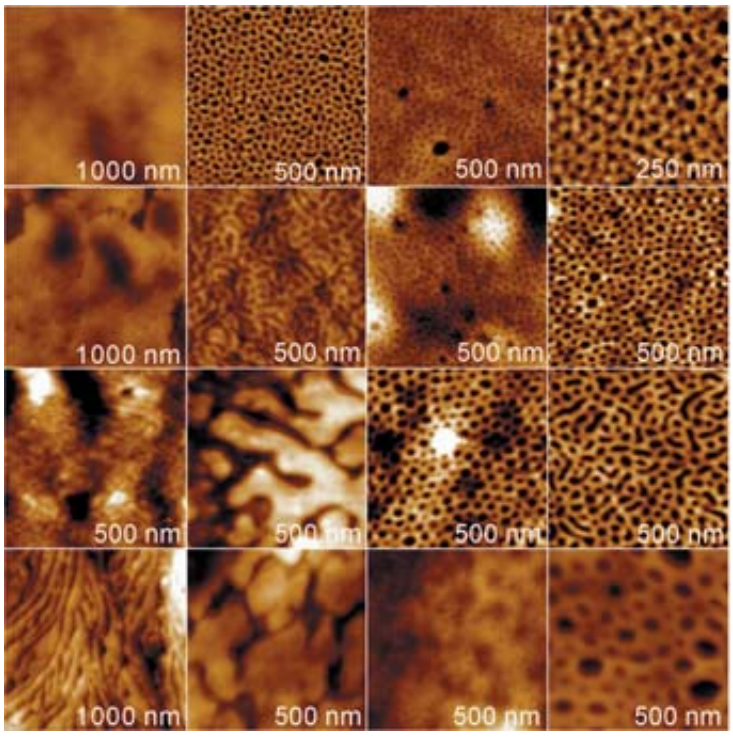
The structure of DNA-peptide complexes was investigated by synchrotron X-ray scattering experiments. Polylysin-PEG block-copolymers were synthesized in the group of Ernst Wagner and used for construction of stochiometric DNA complexes. Using fluorescence correlation spectroscopy it was shown that monomolecular aggregates are formed which have potential use as gene delivery system for antisense DNA or interfering RNA.

Structural Investigations of DNA-peptide complexes (J. Rädler, C. Bräuchle)

The structure of DNA-peptide composite complexes was in the focus of synchrotron X-ray scattering experiments of the Rädler group. In particular DNA-polylysine complexes were studied and the phase behaviour as a function of salt compared with theoretical calculations from Roland Netz. One of the intriguing medical application of DNA complexes is to design molecular carriers that are able to efficiently deliver plasmid DNA, antisense DNA or interfering RNA as therapeutic agents. A rational design of synthetic gene transfer systems aims at mimicking natural viruses using self-organized DNA/lipid/polypeptide aggregates. This approach is pursued in a trias collaboration between E. Wagner at the pharmaceutical department, the Bräuchle group and the Rädler group, that cover synthesis, particle tracing and complex characterization respectively.

Self-organization of Metallo-supramolecular Block-Coploymer Architectures (U. Schubert, J. Feldmann)

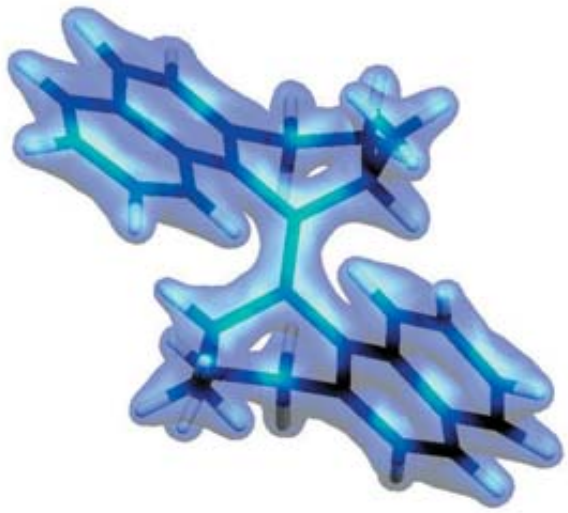
The specific affinity of bipyridine and terpyridine ligands for transition metal complexes was utilized as new “smart” connection point between molecules, polymers and nano-objects. Besides functionalized fullerene units, conducting moieties or protein recognition groups also the self-organization of nano-particles was studied. The method was used in order to assemble macromolecules: Suitable functionalized polymers (decorated with terpyridine units) were combined to A-A, A-B, AB-C (graft) block copolymers and other architectures. The synthesis and combination of four suitable “A”-blocks and four “B”-blocks resulted in a 4×4 library of AB-block copolymers with varying molecular weight and block ratios. Scanning probe microscopy studies on thin spin-casted films of polyethylene glycol-block-polystyrene were performed, giving insight into the phase separation behavior of these materials.



The thin film morphology of a 4×4 library consisting of polystyrene-b-poly(ethylene glycol) metallo-supramolecular diblock copolymers was studied by AFM. On the vertical axis the molecular weight of poly(ethylene glycol)s is varied (3000, 5000, 10000 and 17000 g/mol) on the horizontal axis the molecular weight of polystyrene (2000, 7500, 21000 and 25000 g/mol) The full width of the scans is indicated in the bottom right corner (U. Schubert)

Simulation of a light-driven unidirectional nanorotor (I. Frank)

A nanorotor represents the first step in the construction of more complex devices such as a nanomotor. Rotational motion is ubiquitous in molecular systems, however, it is nontrivial to achieve repeated unidirectional rotation. In nature, for example, the chromophore of rhodopsin rotates unidirectionally by 180 degrees from the 11-cis to the all-trans form upon absorption of light. The back reaction, however, involves a complex biological process. Feringa et al. were the first ones to synthesize a molecule that rotates unidirectionally by 360 degrees about a bond. This rotation is achieved in four steps, namely two photoreactions, that lead to energetically higher lying structures, and two thermal relaxations. With a recently developed first-principles molecular dynamics approach the excited state reaction on a picosecond timescale has been simulated. It was demonstrated how the complex excited state dynamics determines the direction of rotation. This knowledge about the mechanism now may be used to develop more efficient rotors.



A light-driven nanorotor. Upon irradiation with light, the system rotates unidirectionally about the central double bond. (I. Frank)

Simulation of mechanically induced chemistry in single molecules (I. Frank, H. Gaub, C. Bräuchle)

Using AFM techniques the group of Hermann Gaub succeeded to break a single covalent bond and to measure the force that is necessary to trigger this event. These new possibilities to mechanically influence single molecules lead to asking the question what kind of chemistry may occur under such extreme conditions. Using first principles molecular dynamics, it was shown how the ring of a glucose molecule may be opened by mechanical stress. Surrounding water molecules catalyze the process. A single open glucose ring like observed in the simulations may act as a highly reactive species for very local chemistry.
In collaboration with Wacker Chemie GmbH the reactions that occur in siloxanes in the moment of bond breaking are simulated. Siloxanes are less stable with respect to tensile stress than are hydrocarbon polymers, although the Si-O bond is quite strong from an energetical point of view. Our simulations show that Si-O bonds break with a ionic mechanism in contrast to C-C bonds, thus falsifying earlier theoretical work. The next step is to simulate consecutive reactions in condensed phase in order to explain macroscopic phenomena like crack propagation, that limit the technical applicability of siloxanes.

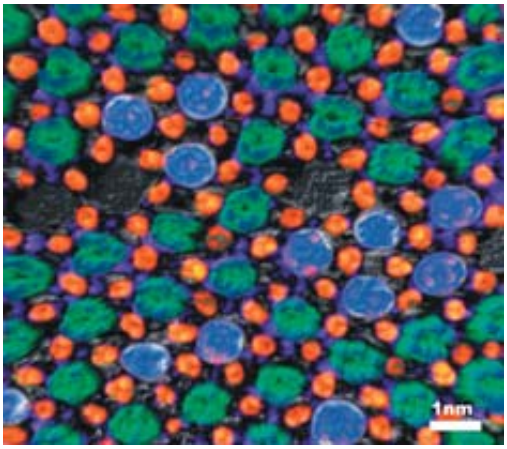
Organizing Supramolecular Squares (B. Hermann, J. Rädler, B. Nickel)

Scanning tunnelling microscopy (STM) developed to a powerful method to visualize supramolecular species on surfaces. In this collaboration between Bianca Hermann and Christoph Schalley´s group as well as Peter Broekmann´s group, both University of Bonn, large molecular squares were self-organized on various surfaces. The precise structure of this long-range ordering of the adsorbed molecular layers depends on the delicate balance between molecule-molecule and molecule-substrate interaction forces. On a graphite surface in a dry environment, the molecule-molecule interactions dominate over the molecule-substrate interactions. The supramolecular squares are hindered from lying flat on the surface: the molecule from a lamellar, interdigitated structure, which can be imaged with STM in a high lateral resolution. On a charged Cu-surface in an electrochemistry environment, a template of chloride ions on top of the Cu-surface forced these molecules to lie flat. This and further molecular systems are subject of a collaboration with Bert Nickel and Joachim Rädler for structural characterization with small angle x-ray scattering.

Analytical and Imaging Methods

Analytical and Imaging Methods in assembling nanostructures (S. Griessl, W. Heckl)

Organic molecular beam epitaxy in UHV and molecular self-assembly via sizzling technique under ambient conditions and on the liquid-solid-interface allows for the spontaneous creation of two dimensional organic crystals. The process of directed molecular self-assembly is investigated with the aim of building custom tailored (functional) architectures from a bottom up approach on the nanometer scale. Besides high resolution imaging the STM tip allows for the direct manipulation and investigation of the interaction of single molecules via nanoablation. A possible application of direct molecular writing of nanosized patterns with possible may be in the area of massive data storage. In a current project in the group of Wolfgang Heckl a host structure of i.e. Trimesic Acid molecules on crystal surfaces is realized. The structure is characterized by a non dense packing of the molecules allowing for the incorporation an manipulation of guest molecules. The variety of guest species make this system relevant for biological systems (incorporation of DNA bases, proteins) as well as for surface science (nanostructures, optical activity of surfaces).
Furthermore the self-assembly of the various isomers of benzene-di- and tri- carboxylic acids at the interface between solution and a graphite substrate are compared. In the case of planar benzene-dicarboxylic acids, it was possible to observe long-range ordered monolayers by STM. In order to enhance the cavity size of the porous structures tailored molecules have been synthesized and self assembled on the surfaces.



The colored and filtered STM image shows still standing (green) and rotating (blue) coronene molecules in a hexagonal template of trimesic acid molecules (red) on a graphite surface. The dark voids represent places where coronene molecules have been removed by means of STM. (S. Griessl)

Multi-spectral scattering-type near-field microscopy (R. Hillenbrand, F. Keilmann, R. Guckenberger)

In this project, scattering-type near-field optical microscopy (s-SNOM) that allows nanoscale resolved optical imaging, simultaneously at visible and infrared frequencies, was developed.
An infrared s-SNOM is used for nondestructive probing of chemical and structural properties of nanocomposite materials. By local probing of lattice vibrations in polar crystals crystallinity, stress and doping are investigated. Structural microscopy by nanoscale resolved mapping of crystal damage induced by focused ion beam implantation (FIB) was demonstrated.

Basics of tapping mode AFM (R. Guckenberger, R. Stark)

Part of our AFM work aims at a better understanding of the tapping mode. This work is strongly supported by a collaboration with R. Stark, concerning model calculations and interpretation of the results. A simple but efficient numerical model could be developed for the force sensor. Numerical as well as experimental investigations show that harmonics and subharmonics can be generated under standard conditions. Even a weak chaos is possible.
As practical outcome of this work the imaging stability could be improved when working in fluid by exploiting the second harmonic of the tapping signal. This allows now continuous imaging even during exchange of the buffer solution and thus enables to directly visualize the function of single macromolecular biological complexes.

Scanning near-field optical microscopy (SNOM) in fluorescence (R. Guckenberger, F. Keilmann, R. Hillenbrand, A. Kriele, B. Lorenz, C. 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. To minimize bleaching of fluorophores, the aperture SNOM is best choice, but the scattering SNOM achieves higher resolution. The advantages of the both types of SNOM were combined by creating a metal tip on the aperture of a conventional fiber tip. With this new kind of probe in fluorescence a resolution below 20 nm with single fluorophores was achieved, which is an excellent result. The production of the special probe involves growing an electron beam deposited (EBD) tip.

Infrared spectroscopy (A. Schliesser, M. Brehm, F. Keilmann)

A novel infrared spectrometer (FTIR) was presented which features a laser-like coherent beam and needs no moving parts, and therefore, is well suited to illuminate the tip of an infrared near-field microscope. Two independent mode-locked fs pulse lasers are employed to generate infrared by a nonlinear process. Because the spectra are regular harmonic-frequency combs beat spectra appear at radio frequencies that exactly replicate the infrared spectra, obtainable in rapid sequence of 100 to 1000 spectra/s as needed for scanning infrared-spectral images of nanostructures.

Interaction of phospholipid vesicles with charged peptides (J. Rädler)

Fluorescence correlation spectroscopy (FCS) was used to examine the binding constant of small peptides to phospholipid vesicles. The peptides are fluorescently labeled and the FCS time correlation allows discriminating bound and unbound molecules. FCS proves to be sensitive down to the nanomolar concentration regime and hence is superior to conventional methods to determine binding constants.

Combined imaging and unfolding of membrane proteins (H. Gaub)

Purple membrane patches were first imaged, then an individual protein was allowed to adhere either via a cystein to the Au tip or by nonspecific adsorption.
This protein was gradually extracted and unfolded and the void was imaged afterwards. The force profiles during extraction revealed drastic differences between the different helices of the protein and the individualism of their unfolding pathways. Since these experiments follow the folding pathway future experiments on mutants and other membrane proteins will shed light on the general folding mechanisms of membrane proteins.

Selected Publications of 2004

K. Blank, A. Lankenau, T. Mai, S. Schiffmann, I. Gilbert, S. Hirler, Ch. Albrecht, M. Benoit, E. Gaub and H. Clausen-Schaumann.
"Double-chip protein arrays: force-based multiplex sandwich immunoassays with increased specificity"
Anal Bioanal Chem. 379, 974–981 (2004)

D. Braun.
"PCR by Thermal Convection"
Modern Physics Letters B. 18, 775-784 (2004)

D. Braun and A. Libchaber.
"Thermal force approach to molecular evolution"
Physical Biology 1, P1-P8 (2004)

A. C. J. Brouwer, J. Köhler, A. M. van Oijen, E. J. J. Groenen and J. Schmidt.
"Single-molecule fluorescence autocorrelation experiments on pentacene. The dependence of intersystem crossing on isotopic composition"
J. Chem. Phys., 110, 9151 (1999)

S. Camalet, S. Kohler and P. Hänggi.
"Shot-noise control in ac-driven nanoscale conductors"
Phys. Rev. B 70, 155326 (2004)

A. J. Daley, C. Kollath, U. Schollwöck and G. Vidal
“Time-dependent density-matrix renormalization-group using adaptive effective Hilbert spaces”
J. Stat. Mech.: Theor. Exp. (2004) P04005

W. U. Dittmer, A. Reuter, and F. C. Simmel.
"A DNA-based machine that can cyclically bind and release thrombin"
Angewandte Chemie Int. Ed., 43, 3550 (2004)

W. U. Dittmer and F. C. Simmel.
"Transcriptional control of DNA-based nanomachines"
Nano Letters, 4, 689 (2004)

S. Duhr, S. Arduini and D. Braun.
"Thermophoresis of DNA determined by microfluidic fluorescence"
European Physical Journal E 15, 277-286 (2004)

C. Friedsam, A. Del Campo Bécares, U. Jonas, H. E. Gaub and M. Seitz.
"Polymer Functionalized AFM tips for Long-Term Measurements in single-Molecule Force Spectroscopy"
ChemPhysChem 5 (3), 388-393 (2004)

H. G. Frey, S. Witt, K. Felderer, and R. Guckenberger.
"High-resolution imaging of single fluorescent molecules with the optical near-field of a metal tip"
Physical Review Letters 93, 200801 (2004)

S. Griessl, M. Lackinger, F. Jamitzky, T. Markert, M. Hietschold and W. M. Heckl. "Incorporation and Manipulation of Coronene in an Organic Template Structure" Langmuir 20, 9403-9407 (2004)

S. Griessl, M. Lackinger, F. Jamitzky, T. Markert, M. Hietschold and W. M. Heckl.
"Room Temperature STM Manipulation of Single C60 Molecules at the Liquid Solid Interface - Playing Nano-Soccer"
J. Phys. Chem. B 108, 11556-11560 (2004)

Z. Guttenberg, A. Rathgeber, S. Keller, J. O. Rädler, A. Wixforth, M. Kostur, M. Schindler and P. Talkner
"Flow Profiling of a surface acoustic wave nanopump"
Physical Review E, 70, 056311, 2004

S. de Haan, A. Lorke, J. P. Kotthaus, W. Wegscheider, and M. Bichler, Rectification in Mesoscopic Systems with Broken Symmetry: Quasiclassical Ballistic Versus Classical Transport, Phys. Rev. Lett. 92, 056806 (2004)

D. Haefliger, J. Plitzko and R. Hillenbrand.
"Contrast and scattering efficiency of scattering-type near-field optical probes"
Appl. Phys. Lett. 85, 4466 (2004)

T. T. Heikkilä, Pauli Virtanen, Göran Johansson,and Frank K. Wilhelm
„Measuring Non-Gaussian Fluctuations through Incoherent Cooper-Pair Current“
Phys. Rev. Lett. 93, 247005 (2004)

A. Högele, S. Seidl, M. Kroner, K. Karrai, R. J. Warburton, B. D. Gerardot, and P. M. Petroff.
"Voltage-controlled optics of a quantum dot"
Phys. Rev. Lett., 93, 217401 (2004)

C. Höhberger Metzger and K. Karrai.
"Cavity cooling of a microlever"
Nature 432, 1002 - 1005 (2004)

H. Hofmeier, J. Pahnke, Ch. H. Weidl and U. S. Schubert.
"Combined biotin-terpyridine systems: A new versatile bridge between biology, polymer science and metallo-supramolecular chemistry"
Biomacromolecules, 5, 2055 (2004)

K. Karrai, R. J. Warburton, A. Högele, B. Urbaszek, C. Schulhauser, E. J. McGhee, A.O. Govorov, J. M. Garcia, B. D. Gerardot and P. M. Petroff.
"Hybridisation of electronic states in quantum dots through photon emission"
Nature, 427, 135 (2004)

F. Keilmann, C. Gohle, and R. Holzwarth.
"Time-domain mid-infrared frequency-comb spectrometer"
Optics Letters 29, 1542 (2004)

F. Keilmann and R. Hillenbrand.
"Near-field microscopy by elastic light scattering from a tip"
Phil. Trans. R. Soc. London A 362, 787 (2004)

J. Krauß, A. Wixforth, M. Hanson, D. C. Driscoll, D. Schuh, M. Bichler, A. C. Gossard and J. P. Kotthaus.
"Capture and release of photonic images in a quantum well"
Appl. Phys. Lett. 85, 5830 (2004)

F. Kühner, L. T. Costa, P. M. Bisch, S. Thalhammer, W. M. Heckl and H. E. Gaub.
"LexA-DNA Bond Strength by Single Molecule Force Spectroscopy"
Biophysical Journal, 87, 2683-2690 (2004)

M. Lackinger, S. Griessl, T. Markert, F. Jamitzky and W. M. Heckl.
"Self-assembly of benzene-dicarboxylic acid isomers at the liquid solid interface - steric aspects of hydrogen-bonding"
J. Phys. Chem. B 108, 13652-13655 (2004)

M. Lambacher, C. J.-F. Dupraz, U. Beierlein, J. P. Kotthaus, U. S. Schubert, and P. R. Andres.
"Device for conductance measurements of molecular systems"
IEEE nano, August, 515 (2004)

J. Lehmann, S. Kohler, V. May and P. Hänggi.
"Vibrational effects in laser-driven molecular wires"
J. Chem. Phys. 121, 2278 (2004).

C. Meyer, O. Sqalli, H. Lorenz and K. Karrai.
"Fully suspended nanostructure with no substrate beneath: fabrication and optical imaging"
Proceedings of the IEEE 4th Conference on Nanotechnology, 435 (2004)

R. A. Neher and U. Gerland
"Dynamics of Force-Induced DNA Slippage"
Phys. Rev. Lett. 93, 198102 (2004)

P. Nickels, W. U. Dittmer, S. Beyer, J. P. Kotthaus, and F. C. Simmel.
"Polyaniline nanowire synthesis templated by DNA"
Nanotechnology, 15, 1524 (2004)

C. Nonnenberg, I. Frank and T. Klapötke.
"Die Ultraschnelle Kaltreaktion im Treibstoffgemisch Monomethylhydrazin / Distickstofftetroxid: CPMD-Simulation"
Angew. Chem, 116, 4686 (2004); Angew. Chem.Int. Ed. Engl.,43, 4586 (2004)

N. Ocelic and R. Hillenbrand.
"Subwavelength-scale tailoring of surface phonon polaritons by focused ion beam implantation"
Nature Mater 3, 606 (2004)

T. Pellegrino, L. Manna, S. Kudera, T. Liedl, D. Koktysh, A. L. Rogach, S. Keller, J. Rädler, G. Natile and W. J. Parak.
"Hydrophobic nanocrystals coated with an amphiphilic polymer shell: a general route to water soluble nanocrystals"
Nanoletters, 4, 703-707 (2004)

H. Qin, A. W. Holleitner, A. K. Hüttel, R. H. Blick, W. Wegscheider, M. Bichler, K. Eberl, and J. P. Kotthaus.
"Probing coherent electronic states in double quantum dots"
phys. stat. sol. (c) 1, 2094 (2004)

G. Raschke, S. Brogl, A. S. Susha, A. L. Rogach, T. A. Klar, J. Feldmann, B. Fieres, N. Petkov, T. Bein, A. Nichtl and K. Kürzinger.
"Gold Nanoshells Improve Single Nanoparticle Molecular Sensing"
Nano Letters, 4, 1853-1857 (2004)

U. F. Röhrig, L. Guidoni, A. Laio, I. Frank and U. Röthlisberger.
"A Molecular Spring for Vision"
J. Am. Chem. Soc., 126, 15328 (2004)

U. F. Röhrig, S. Grimm, I. Frank, L. Guidoni, A. Laio and U. Röthlisberger.
"QM/MM Simulation of the First Step of Vision"
in High Performance Computing in Science and Engineering 2003 – Transactions of the Second Joint HLRB and KONWIHR Result and Reviewing Workshop, Springer (2004)

L. Rusu, A. Gambhir, S. McLaughlin and J. O. Rädler
"Fluorescence Correlation Spectroscopy Studies of Peptide and Protein Binding to Phospholipid Vesicles"
Biophys. J. 87 (2) (2004)

C. Safarowsky, L. Merz, A. Rang, P. Broekmann, B. A. Hermann, C. A. Schalley.
"Second-Order Templation: Ordered Deposition of Supramolecular Squares on Chloride-Covered Cu(100) Surface"
Angewandte Chemie 116, 1311-1314 (2004)

D. V. Scheible, C. Weiss, J. P. Kotthaus, and R. H. Blick.
"Periodic field emission from an isolated nano-scale electron island"
Phys. Rev. Lett. 93, 186801 (2004)

J. Schiener, S. Witt, M. Stark, and R. Guckenberger.
"Stabilized atomic force microscopy imaging in liquids using second harmonic of cantilever motion for setpoint control"
Rev. Sci. Instr. 75 , 2564-2568 (2004)

F. Schindler, J. M. Lupton, J. Feldmann and U. Scherf.
"A universal picture of chromophores in pi-conjugated polymers derived from single

molecule spectroscopy"
Proc. Natl. Acad. Sci. USA, 101, 14695 (2004)

R. W. Stark.
"Spectroscopy of higher harmonics in dynamic atomic force microscopy"
Nanotechnology 15 (3), pp. 347-351 (2004)

R. W. Stark, G. Schitter, M. Stark, R. Guckenberger, and A. Stemmer.
"State-space model of freely vibrating and surface-coupled cantilever dynamics in atomic force microscopy"
Physical Review B 69, 085412 (2004)

T. Taubner, R. Hillenbrand, and F. Keilmann.
"Nanoscale polymer recognition by spectral signature in scattering infrared near-field microscopy"
Appl. Phys. Lett. 85, 5064 (2004)
T. Taubner, F. Keilmann, R. Hillenbrand.
"Nano-mechanical resonance tuning and phase effects in optical near-field interaction"
Nano Lett. 4, 1669 (2004)

S. Thalhammer and W. M. Heckl.
"Atomic Force Microscopy as a tool in nanobiology - Part I: imaging and manipulation in cytogenetics"
Cancer Genomics & Proteomics, 1: 59-70 (2004)

S. Thalhammer, S. Langer, M. R. Speicher, W. M. Heckl and J. B. Geigl.
"Generation of chromosome painting probes from single chromosomes by laser microdissection and linker-adaptor PCR"
Chromosome Research, 12: 337-343 (2004)

E. M. Weig, R. H. Blick, T. Brandes, J. Kirschbaum, W. Wegscheider, M. Bichler, and J. P. Kotthaus.
"Single electron-phonon interaction in a suspended quantum dot phonon cavity"
Phys. Rev. Lett. 92, 046804 (2004)

D. Wouters and U. S. Schubert.
"Nanolithography and nanochemistry: Probe related patterning techniques and chemical modification for nanometer-sized devices"
Angew. Chem. Int. Ed., 43, 2480 (2004) (Frontispiece)

G. Zarand, L. Borda, J. von Delft, N. Andrei.
„Theory of inelastic scattering from magnetic impurities“
Phys. Rev. Lett. 93, 107204 (2004)

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

Beierlein
http://www2.nano.physik.uni-muenchen.de/
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
http://www.theorie.physik.uni-muenchen.de/lsfrey
Gaub
http://www.biophysik.physik.uni-muenchen.de/
Guckenberger
http://www.biochem.mpg.de/baumeister/spm/
Hänggi
http://www.physik.uni-augsburg.de/theo1/publikationen/html/ordered_list.shtml
Heckl
http://www.nano.geo.uni-muenchen.de/
Holleitner
http://www.cip.physik.uni-muenchen.de/~holl/
Karrai
http://www2.nano.physik.uni-muenchen.de/%7Ekarrai/index.html
Keilmann
http://www.biochem.mpg.de/baumeister/spm/
Kersting
http://www.phog.physik.uni-muenchen.de/
Kotthaus
http://www.nano.physik.uni-muenchen.de/
Lagoudakis
http://www.phog.physik.uni-muenchen.de/
Lorenz
http://www.nano.physik.uni-muenchen.de/
Maier
http://softmatter.physik.lmu.de
Marquardt
http://www.theorie.physik.uni-muenchen.de/~florian/publications.html
nanion
http://www.nanion.de/content/papers/papers.php
Netz
http://www1.physik.tu-muenchen.de/lehrstuehle/T37
Parak
http://www.biophysik.physik.uni-muenchen.de/
Rädler
http://softmatter.physik.lmu.de
Schubert
http://www.schubert-group.de/publications_frames.html
Simmel
http://www2.nano.physik.uni-muenchen.de/nanobio/
von Delft
http://www.theorie.physik.uni-muenchen.de/lsvondelft
Wixforth
http://www.physik.uni-augsburg.de/exp1/publikationen/publikationen_2004.html
Zumbusch
http://sms.cup.uni-muenchen.de/publications.php

Theses finished in 2004

Habilitation Thesis

Irmgard Frank
Die quantenchemische Simulation komplexer Reaktionen

Frank Wilhelm
Quantum Coherence and Control in Mesoscopic Systems

Doctoral Theses

Philip Andres
Supramolecular assemblies and materials based on 2,2':6',2'-terpyridine metal complexes

Florian Beil
Akustische Hochfrequenzanregung von Nanoresonatoren auf Halbleiterbasis

Eric Dulkeith
Optische Charakterisierung von Hybridsystemen aus Gold Nanopartikeln und Farbstoffmolekülen

Heinrich Gotthard Frey
High-resolution optical near-field probe for investigations of biological samples by fluorescence

Igor Goychuk
Quantum dynamics with fluctuating parameters

Andrew Hards
Kombinierte AFM Manipulation und Fluoreszenz-Imaging einzelner DNA Moleküle

Thomas Hellerer
CARS-Mikroskopie: Entwicklung und Anwendung

Harald Hofmeier
Metallo supramolecular architectures based on terpyridine metal complexes

Sigmund Kohler
Transport through driven nanoscale conductors"

Bas G. G. Lohmeijer
Playing LEGO with macromolecules

Christine Meyer
Nanoelektromechanische Siliziumaktuatoren und deren optische Charakterisierung

Dominik Scheible
Integration elektronischer Funktionalität in nanomechanische Systeme

Christian Schulhauser
Electronic Quantum Dot States Induced through Photon Emission

Michael Sindel
Numerical Renormalization Group studies of Quantum Impurity Models in the Strong Coupling Limit

Bernhard Stein
Entwicklung von Potentialsensoren für die Zell-Halbleiter-Kopplung

Michael Sztucki
The use of Synchrotron Radiation to study Overgrowth Phenomena in InAs/ GaAs Nanostructures

Thomas Taubner
Infrarotspektroskopie im Nahfeld einer Tastspitze

Eva M. Weig (neé Höhberger),
Elektron-Phonon Kavitäten: Transporteigenschaften freitragender Quantenpunkte

Diploma Theses

Sandra Brogl
Optische Spektroskopie an einzelnen Goldnanoschalen - Partikelplasmonen und ihre Anwendung in der biomolekularen Erkennung

Florian Buchner
STM und STS Untersuchungen an Wasserstoffverbrückten Netzwerken an Umgebungsbedingungen

Christian Gerl
Implementierung einer STM –Mechanik in einer UHV-Kammer und erste Experimente

Rolf Helmes
The Effect of Kondo Correlations on the Absorption Spectrum of Semiconductor Quantum Dots

Sebastian Hohenstein
STM Messungen an wasserstoffverbrückten organischen Adsorbaten unter Umgebungsbedingungen

Ulrike Holz
Optisch durchstimmbare Dynamik von nanomechanischen Systemen

Konstanze Jähne
Superconducting single-charge transistors in a tunable dissipative environment: The JQP cycle

Daniel König
Nano-elektromechanische Transistoren

Martin Kroner
Spektroskopie an einzelnen ladungsdurchstimmbaren selbstorganisierten Halbleiter-Quantenpunkten

Stefan Kufer
Etablierung einer gentechnischen Methode zur kovalenten Verankerung von Proteinen an Festkörperoberflächen

Michael Lambacher
Elektronischer Transport durch molekulare Leiter

Robert Lewis
Visualisierung einzelner HepA-Moleküle auf DNA-Entwicklung einer Methode zur Aufklärung des transskriptionsgekoppelten Reparaturmechanismus

Tim Liedl
Biologische Anwendungen von Nanokristallen

Stephanie Mugrauer
Fluoreszenzmikroskopische Untersuchung einzelner HIV-Partikel unter besonderer Berücksichtigung der Virus-Zellmembran-Wechselwirkung

Almudena Muñoz Javier
Synthesis and characterization of colloidal nano-crystals

Patrick Nickels
Elektronische Eigenschaften von DNA-basierten Nanodrähten

Clemens Rössler,
Kohärente Spin–Phänomene in elektrostatisch definierten Quantenpunkten

Felix Schöfer
Electron-Phonon-Wechselwirkung in niedrigdimensionalen Halbleiter-Heterostrukturen

Joachim Stehr
Optische Temperaturmessungen an metallischen Mikro- und Nanostrukturen

Stefan Strasser
Biomechanical investigation of collagen fibrils

Manfred Walter
Spinkorrelationen in polymerischen Halbleitern

Awards

Descartes Prize for Science Communication to Wolfgang Heckl (2004)

Leibniz Preis der DFG 2004 to Thomas Carell

DFG Junior Groups (Emmy Noether Program):
Berenike Maier
Dieter Braun

Dissertation prize of the LMU München for Alex Holleitner

CeNS in the Media

ZDF Heute-Journal: „Kleinstes Fußballspiel der Welt“ (24.7.2004)

„Schlauer Klebstoff“ Spiegel (Nr. 22/24.05.04)

„Der Plot der kleinen Dinge“ Süddeutsche Zeitung (02.06.04)

„Den Krankheiten vergangener Kulturen auf der Spur“
Münchner Merkur (06.Okt.2004)

„Fantastic Plastic” Nature, News and Views, 429, 709 (2004)

„Auf dem Weg zum Kunststofflaser” FAZ (Frankfurter Allgemeine Zeitung 16.8.2004
Natur und Wissenschaft)

„Licht aus Plastik“ Süddeutsche Zeitung (17.8.2004)

„Licht aus Polymeren“ FAZ (Frankfurter Allgemeine Zeitung) (3.11.2004)

Materials Today (December, p. 25)

External Funding

Advalytix AG, München http://www.advalytix.de/

Agfa http://www.agfa.de/

Alexander von Humboldt - Stiftung http://www.avh.de/

BASF http:/www.basf.de

Bayerische Forschungsstiftung http://www.forschungsstiftung.de

Bayerisches Staatsministerium für Wissenschaft, Forschung und Kunst
http://www.stmwfk.bayern.de

BMBF - Bundesministerium für Bildung und Forschung http://www.bmbf.de/

DAAD - Deutscher Akademischer Austausch Dienst http://www.daad.de/

DFG-Sonderforschungsbereiche SFB 413, SFB 455, SFB 486, SFB 563, SFB 631 and

Emmy-Noether-Program http://www.dfg.de

DFG Einzelprojekt DE 730/3-1 http://www.dfg.de

DFG- CNRS http://www.dfg.de

Dutch Polymer Institute (DPI) http://www.polymers.nl/PRO1/general/default.htm

EADS http://www.eads.com/

EMBO - Young Investigator Programme http://www.embo.org/projects/yip/

ENNaB Excellence Network NanoBioTechnology http://www.ennab.de

European Union + European Commission Spintronics Research Training Network
http://europa.eu.int/

Fonds der Deutschen Chemischen Industrie http://www.vci.de/

ForNano http://www.abayfor.de/fornano

ForPrion http://www.abayfor.de/forprion

Leibniz-Rechenzentrum http://www.lrz.de

Max-Planck-Institut für extraterrestrische Physik http://www.mpe-garching.mpg.de/

NWO - Netherlands Organisation for Scientific Research http://www.nwo.nl

Schweizer Nationalfonds http://www.snf.ch/

Studienstiftung des deutschen Volkes http://www.studienstiftung.de/

VolkswagenStiftung http://www.volkswagen-stiftung.de/

Wacker-Chemie GmbH http://www.wacker.com

Joint Projects for Education and Training

CNSI - CeNS Workshop, Santa Barbara

ENNaB-Workshop - BMBF Junior Groups in Nanotechnology, Munich

„CeNS meets Industry", Munich

CeNS-Workshop: „Nanoscience: Linking disciplines", Venice

New members in 2004

New Ordinary CeNS Members:

Prof. Thomas Carell
Prof. Erwin Frey

New extraordinary CeNS members:

Dr. Pavlos G. Lagoudakis
Dr. Berenike Maier
Dr. Dieter Braun
Dr. Alex Holleitner
Dr. Florian Marquardt
Dr. Marc Tornow