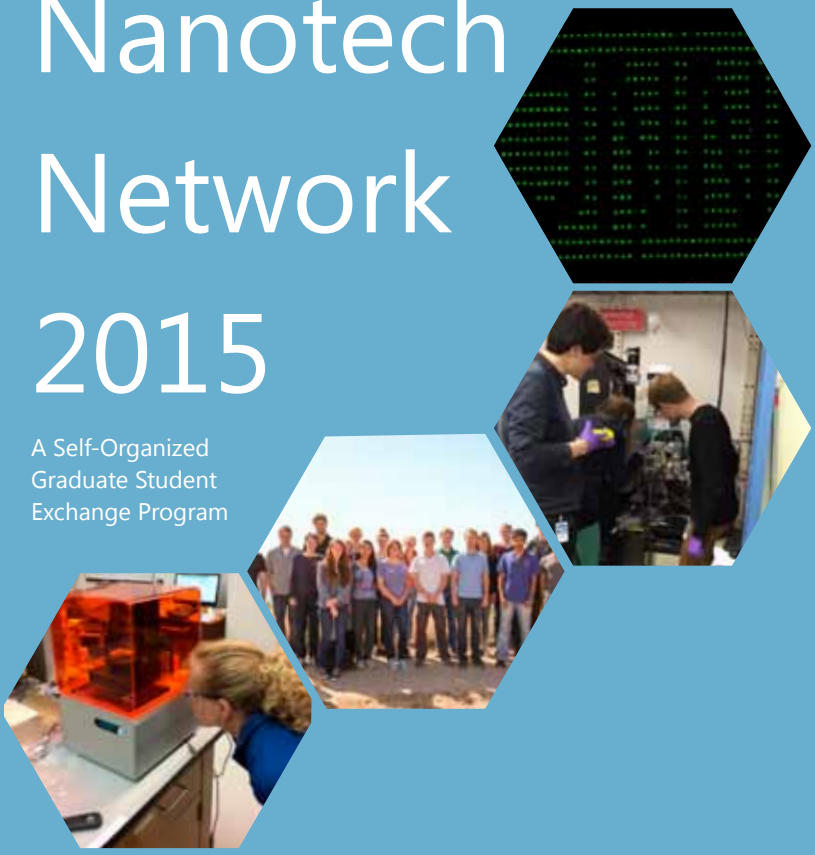
Junior Nanotech Network 2015

A Self-Organized Graduate Student Exchange Program



CeNS
Center for NanoScience | LMU

MRL
MATERIALS RESEARCH LABORATORY

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Preface

Scientific progress relies on practitioners with a variety of 'hard' and 'soft' skills. Hard skills are those that result from long-term training, as it occurs in the classroom and at the lab bench, focusing on fundamental understanding and application of basic principles of physics, chemistry, biology, etc. Hard scientific skills are relatively clearly defined, and their acquisition forms the basis of undergraduate and graduate curricula.

In contrast, soft skills are less well-defined; they include a wide range of interpersonal talents, personal contacts, cultural understanding, and communication-oriented abilities that enable the spread of scientific ideas. Soft skills can complement, and even supplant, hard skills - for example, developing a new lab technique in isolation can be difficult or impossible, yet can be made facile by knowing and contacting the right person. Yet, traditional scientific curricula tend to focus on the hard skills to the exclusion or detriment of the soft.

With this hard / soft disparity in mind, we are extremely pleased to report on the 6th Junior Nanotechnology Network (JNN) between the Center for Nanoscience (CeNS) at LMU, and the Materials Research Laboratory (MRL) at UC Santa Barbara. This exchange program included 22 graduate students, 11 from each institution, who effectively underwent an immersive combination of soft- and hard-skill training program by hosting a partner student in their own domicile, learning novel techniques over 2 weeks of focused lab rotations, and presenting their own research at two conferences on two continents both as oral talks and poster presentations. We are certain that the long-term careers of the participating students will benefit, both through specific contacts made at the partnering universities and breadth of knowledge gained during the personalized lab rotations and the lively conference meetings.

The success of such program hinges on the efforts of dozens of people who we would like to thank. First and foremost, we thank the students themselves for all of their efforts in preparing and executing the lab rotations, filling the programs of the conferences with content and arranging a wide variety of cultural visits and social events. We also acknowledge the group leaders from both institutes who allowed the students to take part, as well as permitting their laboratories to be involved in the exchanges. We thank the financial sponsors of the exchange: UCSB's Materials Research Laboratory, and the German BaCaTeC program. And finally we want to express our gratitude to the managing directors of this program, Susanne Hennig of CeNS and Sara Sorensen of MRL, who excelled in making this exchange a great success.

Tim Liedl, Omar Saleh, and Deborah Fygenson

About the Junior Nanotech Network

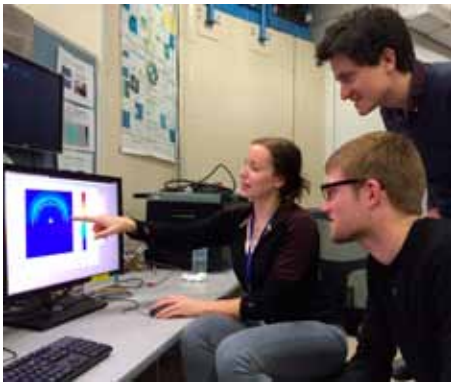
The Junior Nanotech Network 2015 was an exchange program between the Center for NanoScience (CeNS) at LMU Munich and the International Center for Materials Research (ICMR) at UC Santa Barbara. The scientific aim of the program was to transfer complementary sets of knowledge and skills between PhD students from the participating research groups and to spark new research directions. The scientific programs in both locations comprised two main elements: hands-on experimental training and workshops including talks and posters by the PhD students. In May, eleven graduate students from Santa Barbara were the scientific and housing hosts for eleven CeNS students; in September the German group hosted the UCSB students for a three-week European visit.

Lab Work and Learning from Peers

One prominent feature of the JNN was its self-organized character. In particular, the PhD students were asked to design, teach, and supervise their scientific experiments independently. Each hosting group offered a two- or three-day lab course, in which the hosts taught the visiting peers state-of-the-art experimental techniques used in their labs.

Each student followed about five different lab courses, thereby guaranteeing the active trading of skills. The PhD students could choose which set-up they wished to learn about, so their final schedule was tailor-made and teaching could be performed on a very individual basis with small groups of 2-4 participants Over the course of two weeks, the visiting PhD students thereby gained profound insights into the possibilities and limits of a wide variety of techniques, while the hosting students obtained teaching experience and had the opportunity to look at their own set-ups and methods through the eyes of practitioners from other fields.

In this way, participants from different areas of nanosciences were exposed to a variety of cutting-edge technologies.



Workshops

Two workshops in Santa Barbara and Venice brought together the JNN participants and experienced scientists from the fields of physics, chemistry and molecular biology. The workshops were a valuable complement to the lab courses and gave the PhD students the chance to extend their scientific network to include CeNS and UCSB researchers beyond the participants of the JNN.

Intercultural Exchange

As a unique feature of the program, all participating students were hosted by a partner from abroad, i.e., the Californian participants provided accommodation for the German visitors in their own homes and vice versa. This led to an intensive intercultural exchange with benefits beyond science as well as reduced financial and logistical overheads.

The scientific program was complemented and enriched by the social, cultural and outdoor activities which were organized by the host students. Combining joint lab work with common leisure activities enabled strong bonds to be created between the participants.

Workshops and Excursions

Conference in Santa Barbara

During the second week of the JNN exchange all students were invited to a four-day conference on the campus of the University of Santa Barbara (UCSB). Renowned professors and the JNN participants gave presentations about their field of research. The speakers came from different universities such as Stanford University, Caltech, UCLA, and UCSB. Their talks covered a variety of topics, resulting in a very diverse and interesting conference. A highlight of the conference was certainly the presentation of Paul Rothemund (Caltech), the inventor of DNA origami, who gave a fascinating overview of the latest developments in DNA nanotechnology.

In addition, the conference featured an introduction to the American educational outreach program, which aims to familiarize regional students, teachers, and parents with cutting-edge science and technology.

Two outreach representatives from Caltech gave an interactive talk about their program. All conference participants had the opportunity to try out 'SKIES', a web-based platform that gives students and teachers the opportunity to communicate and exchange knowledge. The outreach project was very new to most German PhD students and inspired them to adapt some of their ideas for similar projects.

In addition, all JNN participants had to present their own research covering topics from material science, biochemistry and physics. This gave the speakers the great opportunity to discuss their projects with the other participants and to get new ideas. Beside the enriching and inspiring discussions during the conference, the PhD students and professors also enjoyed informal conversations on the sunny rooftop of the university during coffee and lunch breaks.

CeNS Workshop in Venice

The title of the CeNS workshop 2015 "Channels and Bridges to the Nanoworld" spoke for itself: twenty-five talks over five days combined various aspects of nanoscience with the magical atmosphere of San Servolo and Venice. The program committee had invited renowned international scientists to give the graduate students and post-doctoral researchers of CeNS and the JNN participants an overview of current research topics on nanometer-scale science.

As usual at the annual CeNS workshops, a wide assortment of research areas was covered: These included single-molecule spectroscopy, cryo-EM techniques, biomolecular design, organic electronics, carbon nanostructures, and nanoparticles with different applications.

The JNN participants had the opportunity to join in many lively discussions with internationally renowned researchers as well as with their fellow CeNS students from the fields of physics, chemistry and biology taking place in the lecture hall, but also during the poster sessions and breaks in the green gardens of San Servolo. In the evening, the participants explored late summer Venice with its charming piazzas, restaurants, canals, and bridges.

Lab Projects

Microfluidic encapsulation of single cells using homemade chip

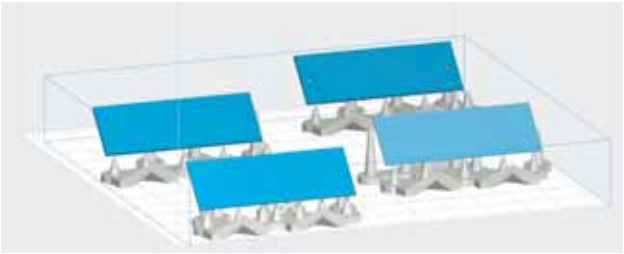


Figure 1: *Student designed chips in the 3D printing software, ready to be printed.*

In the field of neuroscience, Multi Electrode Arrays (MEAs) are used to record electrical signals from neural tissue. These signals are then studied to reveal the complex behavior of neural circuitry and to understand how diseased neurons differ from healthy neurons. Current MEAs are a planar 2D array of electrodes and neurons are plated on them in an unnatural 2D conformation. Our lab has developed a flexible 3D pillar electrode array with the goal of recording neurons in a more natural 3D conformation, as they grow in the brain in vivo. We have already made the arrays and now are studying new ways to grow and pattern neurons in 3D. One reason we might want to pattern neurons is to have reproducibility from one culture to the next, to know if differences in the recordings are really due to different neuron types (diseased vs healthy) and not due to the random way they connect when not patterned.

Our research aims to encapsulate single neurons into gel micro-droplets for further placement on the MEA for 3D patterning of neurons and electrical recording of those neurons. The student researcher is involved in designing and making the chamber, as well as testing it in the lab, teaching the student the basics of AutoCAD, 3D printing, microfluidics and cell culture.

First the student designed a microfluidic chamber that can be used to encapsulate a cell into gel micro-drops, suspended in oil. The design process was done in AutoCad and then exported to a .Stl file which could be handle by the 3D printing software. The chips are then placed on stilts and evaluated for stability for printing. The student then came into the wet lab to prepare the 3D printer and run it with our custom file. The chips were printed, cut away from the stilts and polished for use. Next, the student brought the chips into lab for testing. The student learned how to culture cells and handle them in a sterile manner so that they would be viable and uncontaminated. The students learned how to use the microfluidic setup including syringe pumps and the basics of microfluidics including flow rate, use of surfactants, aqueous gel and oil phases.

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Two-dimensional molecular self-assembly of trimesic acid at the liquid-solid interface

Self-assembly of organic molecules on surfaces is an appropriate approach for the synthesis of long ranged ordered two dimensional (2D) nanostructures. The tunability of the electronical and structural properties of these nano-networks makes them promising for application in molecule-based devices. Scanning tunneling microscopy (STM) has stablished itself as a powerful tool for investigation and characterization of the structures on surfaces with high-resolution down to the submolecular scale. Therefore we used STM to investigate the self-assembly of trimesic acid (TMA, Fig. 1) on highly oriented pyrolytic graphite (HOPG) surface.

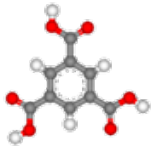

Figure 1: *Molecular structure of trimesic acid, a benzene ring functionalized with three carboxyl groups.*

In my lab course we discussed different possibilities for synthesizing 2D networks under ultra-high vacuum (UHV) or ambient conditions. Besides the possibility to elaborately prepare a self-assembled monolayer in an UHV chamber, it is also possible to investigate the self-assembly from solution, i.e. molecules dissolved in a solvent, at the liquid-solid interface by STM under ordinary atmospheric conditions.

First we got to know how to work with the STM and image graphite with atomic resolution. The advantage of graphite samples is the swift preparation due to its layered structure. As the interlayer bonds are relatively weak van der waals bonds, through Scotch tape technique is possible to cleave the upper layers and prepare a clean surface. After imaging graphite surface to verify its cleanliness on the atomic scale we deposit the molecules on the surface. Therefore we applied a droplet of a saturated solution of TMA in heptanoic acid to the surface. The adsorbed TMA molecules on graphite surface self-assemble into an ordered monolayer with the chickenwire structure (Figure 2). STM allows resolving single molecules and even submolecular features as illustrated in figure 2. It is also possible to determine the lattice parameter and intermolecular distances of the imaged structure. The red arrows on the STM image show the unit cell vectors. The driving force resulting in this structure is the hydrogen-bonds between carboxyl groups as depicted on the right side of Fig. 2.

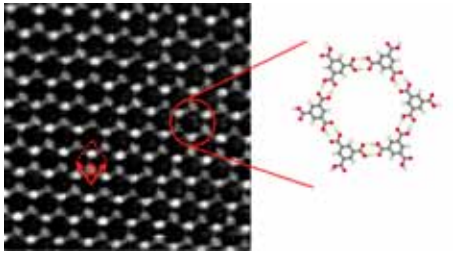

Figure 2: *STM image of molecules self-assembled in the chicken wire structure with the lattice parameter of 1.7 nm, α=60°. The image size is 15 × 15 nm².*

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Heterogeneity in bacterial populations – a single-cell study

During this 2-day research project, the topic of heterogeneity in bacterial populations was investigated using the colicin E2 system of *E. coli* by means of the three important methods in quantitative biophysics: Experimental study, data analysis, and numerical modelling of the system. The focus of the project was adjusted to the individual preferences of the exchange students.

Colicins are bacterial toxins produced by *E. coli* that act against related bacteria. It is thought that production of these colicins is stochastically regulated. In general, observable characteristics of organisms are called phenotypes and presence of different phenotypes in isogenic populations is referred to as phenotypic heterogeneity. In the colicin E2 system, the producing and the non-producing states are considered different phenotypes. In this research project, we studied and characterized phenotypic heterogeneity of colicin production mainly by means of fluorescence microscopy.

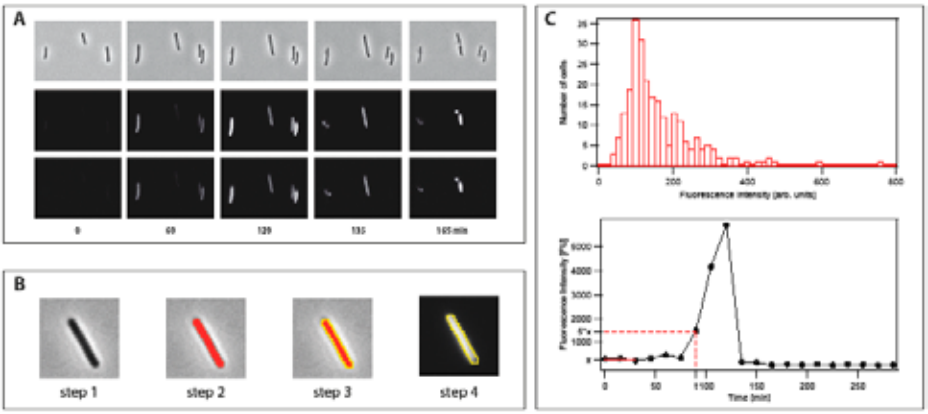

Figure 1: *(A) Sample microscope images show heterogeneity of fluorescence timing between cells, (B) image analysis procedure, (C) fluorescence intensity distribution in a population (top), fluorescence intensity trace of a single cell (bottom).*

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Synthesis of metal oxide nanostructured films using microplasma spray deposition

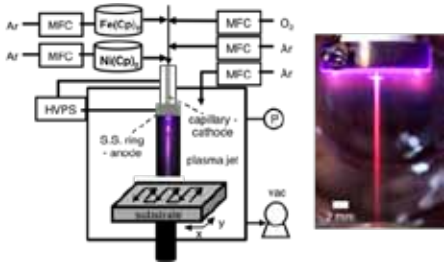

Figure 1: *Schematic of a microplasma deposition reactor (left) and Ar plasma jet in operation (right) at 20 Torr.*

A major focus of our group's research is the development of a novel microplasma-based deposition technique for the synthesis of nanostructured metal oxide films (fig. 1). We utilize a geometrically confined (< 1 mm), flow stabilized plasma jet to synthesize large area nanostructured films with high surface areas, which are interesting for a broad scope of technologies, including catalysis, gas sensors, energy harvesting and storage, and magnetic data storage. Sublimed organometallic precursors are fed with an Ar/O_2 gas mixture to the highly reactive environment of a hollow cathode plasma discharge where metal oxide nanoparticles are formed and subsequently spray deposited onto any substrate, resulting in nanostructured thin films. Microplasmas offer many features that are advantageous for nanomaterial synthesis; high-energy electrons (~10 eV), high gas-phase collision frequencies (~ 10^{10} – 10^{11} s^{-1}), and short space times (< 1µs) in the hollow cathode region of the MP allow for rapid gas-phase nucleation of crystalline nanoparticles (< 10 nm) with narrow particle size distributions. These gas-phase nanoparticle "building blocks," combined with highly directed deposition and raster scanning of the substrate, enable the production of uniform, large area films for single or multiphase oxide systems with small grain sizes, and high interfacial densities and surface areas. In this experimental module, students deposited nanostructured metal oxide thin films (i.e., NiO and Fe_2O_3) on single crystal Si substrates using microplasma jets. The morphology and structure of these films were characterized using scanning electron microscopy (SEM) and grazing-incidence x-ray diffraction (GI-XRD), respectively. Students gained the following knowledge after completion of this module: (1) general understanding of the operation of plasma jets and their role in nanomaterial synthesis, and (2) how electron microscopy and x-ray diffraction can yield valuable information about thin film structure and morphology.

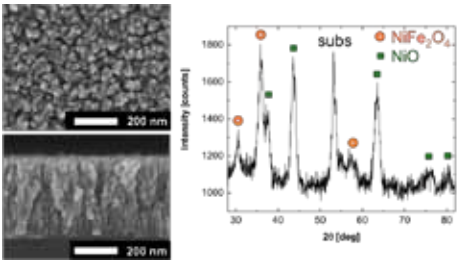

Figure 2: *Plan and cross section SEM micrograph of a biphasic $NiFe_2O_4$/NiO film grown with microplasmas (left), and the corresponding GI-XRD scan (right).*

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Nanoscale chemical imaging using tip-enhanced near-field optical microscopy

One research focus of the Gordon group is the design and construction of near-field optical microscopes with the capacity to perform spectroscopy over nano-length scales. The technique used is referred to as tip-enhanced near-field microscopy (TENOM), tip-enhanced Raman spectroscopy (TERS), or scanning near-field optical microscopy (SNOM). A laser is focused onto the apex of a sharpened Au probe (dia. 20-50 nm), where it efficiently excites plasmon resonances and generates a localized, intense optical field. The size of this field is not limited by diffraction of the incident beam, but instead by the dimensions of the Au probe. An atomic force microscope (AFM) is then used to scan the illuminated probe over a sample surface, allowing spatially correlated near-field optical spectra to be collected.

This JNN research module consisted of two tasks. The first was the production of an optically active, nanoscale patterned sample. A nanosphere lithography process was used to place a monolayer of 1 μm dia. functionalized silica beads onto the surface of a glass cover slip. A thermal evaporator was then used to deposit approximately 10 nm of metal-free phthalocyanine (H_2Pc) onto the surface, with the monolayer acting as a mask. Sonication in water selectively removed the silica particles, leaving only the H_2Pc pattern on the glass surface. This pattern primarily consists of triangular features produced at the interstitial sites of the close packed spheres.

Figure 1

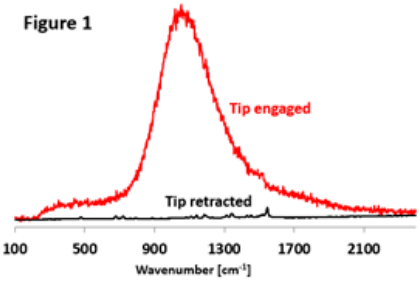
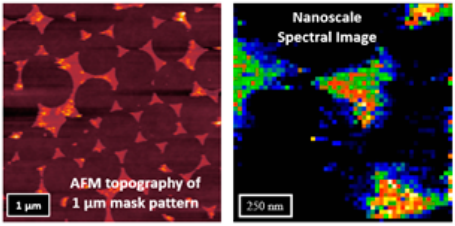


Figure 2



The second task in this module was the use of a custom-built TENOM instrument to collect near-field optical images of the H_2Pc pattern. When a plasmonically-active probe illuminated with 647 nm radiation was engaged on the sample surface, an intense photoluminescent signal appeared (Fig. 1). Note that this signal was not observed with the tip retracted from the surface, which is indicative of the presence of an intense optical near-field at the tip apex. Fig. 2 shows a 1x1 μm spectral image obtained by integrating the intensity of this signal at each pixel. The triangular H_2Pc features are clearly reproduced when compared to the adjacent AFM image of the same sample. The lateral spatial resolution achieved in this image is 40-50 nm, roughly one order of magnitude below the diffraction limit.

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Biomolecule dynamics in electro-diffusive non-equilibrium systems for the quantification of aptamer - protein binding

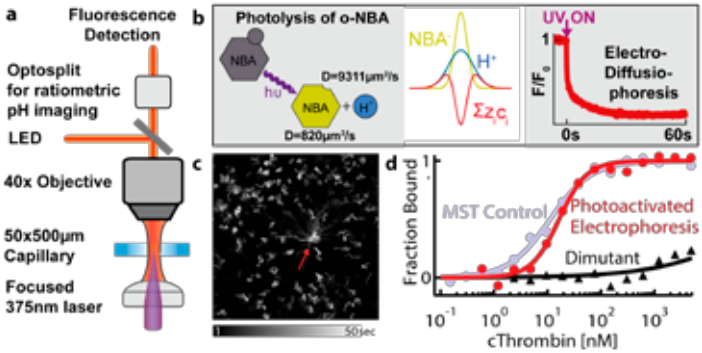

Figure 1: *(a) Fluorescence microscopy setup with focused near UV triggering (b) Photolysis of a caged compound (here o-NBA) leads to the emergence of concentration gradients. Differential diffusion leads to local perturbation of electroneutrality. Probe molecules, such as fluorescently labeled DNA or polystyrene beads move by means of electro- and diffusio-phoresis. A typical fluorescence time trace at the laser position for negatively charged macromolecules upon o-NBA photolysis is shown in the last panel. (c) Transport of fluorescently labeled 2µm COOH-beads induced by ferrocyanide photolysis. (d) Binding curve of the thrombin-aptamer interaction measured by o-NBA photolysis and MST.*

Coupling of physical transport phenomena can lead to intricate feedback situations. In the last years, thermal gradients proved to be versatile non-equilibrium systems. With microscale thermophoresis (MST), a novel biotechnological technique for binding affinity evaluation was established. In the context of origin of life research, temperature gradients were exploited for accumulation, polymerization, replication and selection of molecules. In my PhD project, I explore a novel optically induced non-equilibrium system. We use a focused near-UV laser to trigger a localized photochemical dissociation reaction. Upon irradiation a photoactive compound releases a small ion, inducing steep concentration gradients. Differential diffusion of the differently charged and sized photoproducts leads to the emergence of a net charge distribution and hence of electrical fields accompanied by ionic strength gradients. Macromolecules subjected to these fields move by means of electro- and diffusiophoresis. (Fig. 1b)

In the first part of the JNN experiment we observed the transport of large negatively charged fluorescent beads triggered by the photolysis of two different photoactive compounds, o-nitrobenzaldehyde (o-NBA) and hexacyanoferrate. We observed transport away from and towards the laser focus (Fig. 1c), respectively.

In the second part we exploited the dependence of transport on the probe molecule's charge, size and ionic shell to quantify the binding affinity of a DNA aptamer to its target protein thrombin. By localized o-NBA photolysis we found an affinity in the low nanomolar range, which is in good agreement with literature values. For comparison we also quantified the affinity by well established Nanotemper MST. (Fig. 1d)

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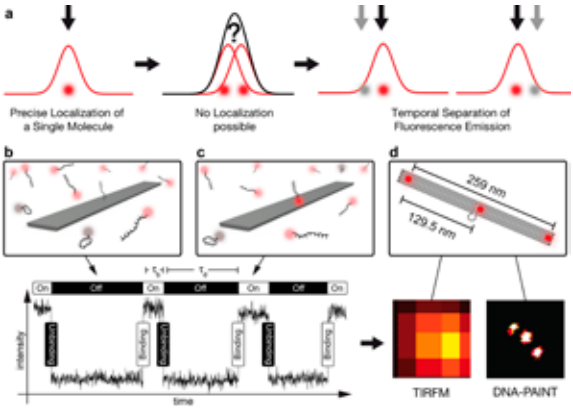
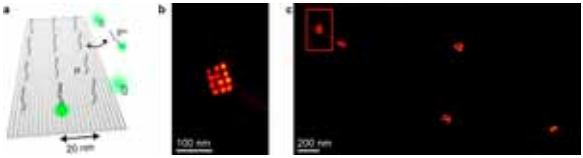
Super-resolution microscopy using DNA-PAINT



Super-resolution microscopy, that is optical microscopy below the classical diffraction limit, is starting to transform the way we look at biology today. One method to perform super-resolution imaging is DNA-PAINT (points accumulation for imaging in nanoscale topography), a technique which uses the transient binding of short fluorescently labeled oligonucleotides for simple and easy-to-implement multiplexed super-resolution imaging that achieves sub-10-nm spatial resolution *in vitro* on synthetic DNA structures. In this introductory module, the students were first acquainted with the basic working principle of DNA-PAINT (Fig. 1). Subsequently, they learned how to prepare a DNA nanostructure sample for DNA-PAINT imaging and performed image acquisition and post-processing. This lab class included the familiarization with the preparation of different microscopy slides, including surface and sample preparation and the use of TIRF (total internal reflection fluorescence) microscopy for DNA-PAINT. TIRF uses the fact, that when incident light is totally internally reflected at the glass-oil interface an evanescent wave is created. This allows the illumination and hence excitation of fluorophores in a restricted region close to that interface. As a result, the imager strands in the background do not contributed to the fluorescence emission signal. Additionally, imager strands are diffusing throughout the sample and only upon binding to the docking strand on the nanostructure, a so-called "blinking" event occurs, as the fluorophore on the imager strand is immobilized for a short time. Due to this immobilization, the fluorescence signal is "higher" compared to when "floating" in the background solution.



10,000 raw images of these blinking events were acquired. Subsequent spot detection and fitting in a post-processing step allowed us to reconstruct the super-resolution image. In the lab course, a so-called 20 nm grid DNA origami sample (Fig. 2a) was imaged. The resulting DNA-PAINT image is shown in Fig. 2b while an overview image is shown in Fig. 2c.

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Measuring spatio-temporally evolving concentration profiles with a Fabry-Perot Interferometer[1]

Many systems of biophysical, physical, and chemical interest involve solutions that evolve in space and time, yet it is extremely difficult to measure concentration profiles with good spatial and temporal resolution, particularly if fluorescent labels are not used. In this module, we demonstrated to the students a new technique that we have developed in our lab to measure chemical concentration profiles in microfluidic systems, with approximately 10 Hz temporal resolution and micron-scale spatial resolution. The technique uses multiple-beam interferometry within a mirrored microfluidic channel to track changes in index of refraction as one solvent (or solute) diffuses into another, from which the spatio- temporally evolving concentration profile can be extracted.

The students were first shown how to fabricate their own microfluidic chips for these kinds of experiments. Glass slides were pre-coated with a 50 nm layer of silver to make them semi-reflective (not part of the module). A laser cutter was used to cut channels into double sided tape, which was then sandwiched between two glass slides. PDMS inlets were ozone bonded to the top glass slide to hold inlet/outlet tubing.

After device fabrication, PEG-DA hydrogels were polymerized in situ using microscope projection lithography[2]. These gels allow for the generation of diffusive chemical gradients, by being permeable to diffusive transport but impermeable to convection. To measure binary diffusivities in water, the device was initially filled completely with water. The flow in the measurement region was stopped and flow to the side channel was switched from water to various solutes, to measure their diffusivities. After performing chemical switch, interferometry was used to track the evolution of the chemical gradient. FECO fringe displacements were tracked over time to determine the relative shift in refractive index as a function of position. The refractive index shifts were then converted to concentrations using concentration vs. refractive index data.

[1] Vogus et al. Lab on a Chip, 2015
[2] Paustian et al. Physical Review X, 2013

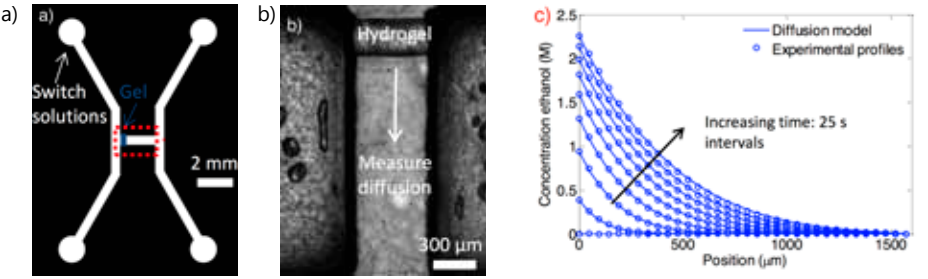

Figure 1: *(a) Microfluidic channel geometry for diffusivity measurements (b) Microscopic image of photo-polymerized PEG-DA gel and region for diffusivity measurements (c) Experimentally measured evolution of glycerol diffusive front compared to numerical diffusion model.*

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Therapeutic nanoparticle formation as application of acoustic waves in chemistry and biology

After a short introduction "Surface acoustic waves in a nutshell" the exchange students became acquainted with the ability of acoustic waves for biological and chemical applications. We learned the basics about the generation of surface acoustic waves (SAW) on piezoelectric substrates, characterized the radio frequency driven SAW chips and used them for tunable manipulation of nanoliter volumes via acoustic streaming. The principle of acoustic mixing was applied in experiments on the production of therapeutic nanoparticles (TNP). Ultralow volumes of polymer solution and plasmid DNA were mixed with SAW-devices to generate TNP in two different ways: an open droplet based system and a closed continuous-flow system using micro-channels.

For screening purposes by using disposable superstrates (hydrophobic cover slips) on a thin layer of coupling fluid on the chip we fused and mixed droplets with a volume of 500 nanoliter. In each fusion experiment one droplet contained plasmid DNA while the second droplet contained a polymer solution. In dynamic light scattering experiments we analyzed the size distribution of the particles and found that in these preliminary tests the self-assembled particles already had a promising size distribution around a particle diameter of 50 nm. For the continuous production of higher amounts of particles we used a setup as sketched in figure 1. Therefore on the first day of the lab module we produced micro-structured molds in the cleanroom using photo lithography processes and prepared the polymer Polydimethylsiloxane (PDMS) channels afterwards. On the second day we combined the produced PDMS-channels with SAW-chips to the desired hybrid system. The exchange-students got some first experiences in microfluidics and the handling of all necessary additional components like syringe-pumps, radio frequency generator and amplifier. Employing this setup we studied the mixing of solvents of different viscosity and surface tension as optimization step for ongoing studies on TNP production. Possibilities to optimize and extend these particle synthesis devices and their relevance were discussed. On the one hand using a pipetting robot and a SAW-chip design with multiple mixing spots would ensure precise positioning and improved statistics. On the other hand parallelization of the continuous flow system by use of multiple channels and an advanced chip design could help to further increase the overall flow rate and thus the particle production rate. Both will be part of prospective studies.

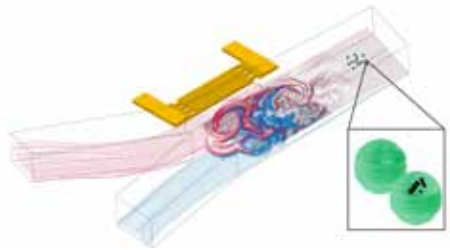

Figure 1: *Sketch of the used setup to produce self assembled nano particles using a SAW-hybrid chip. DNA in aqueous solution and a polymer solution are mixed in a micro-channel by using chaotic advection driven by a surface acoustic wave.*

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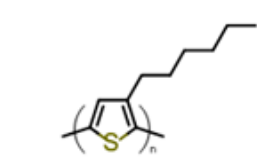
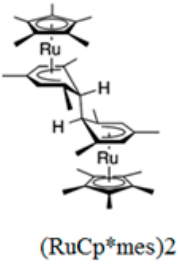
Temperature dependent EPR of organic semiconductors





Conjugated organic molecules are an important class of electronic materials for use in thin film organic electronic devices such as light emitting diodes (LEDs), thin film transistors (TFTs) and thermoelectrics. Organic semiconductors are attractive because they are flexible, light weight and low cost. However they suffer from low electrical conductivities which must be enhanced in order to realize practical devices. Doping enables improvements in electrical conductivity by boosting effective carrier mobilities by filling trap states and by increasing the density of free charge carriers. In this module, we fabricated and studied the electrical properties of P3HT thin films doped with $(RuCp^*mes)_2$. EPR is a spectroscopy technique used to study unpaired electrons in a material. We used this technique in order to determine the spin concentration in organic semiconductor materials, which when used in conjunction with other characterization techniques (such as conductivity measurements) can provide greater understanding about the nature of the doping mechanism and charge carriers (i.e. are they polarons or bipolarons). Temperature dependent EPR can provide more in depth information about the temperature dependent behavior (which is of interest in designing organic thermoelectric materials) such as activation energies for doping reactions and information about transport mechanisms.

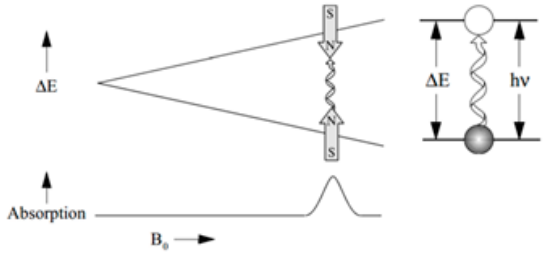


Figure 1: *Underlying concepts of EPR: Energies of spin states diverge linearly as magnetic field increases. Microwave photons are incident on the sample. When photon energy is equal to that of difference in energy of spin states, unpaired electrons are allowed to move between the two spin states.*

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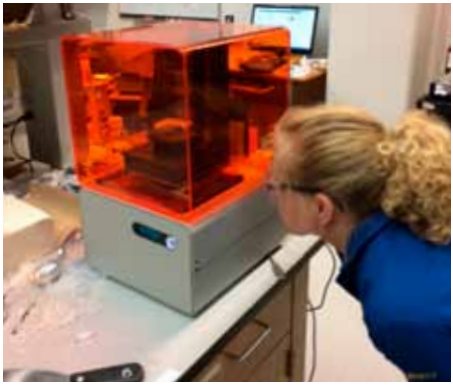

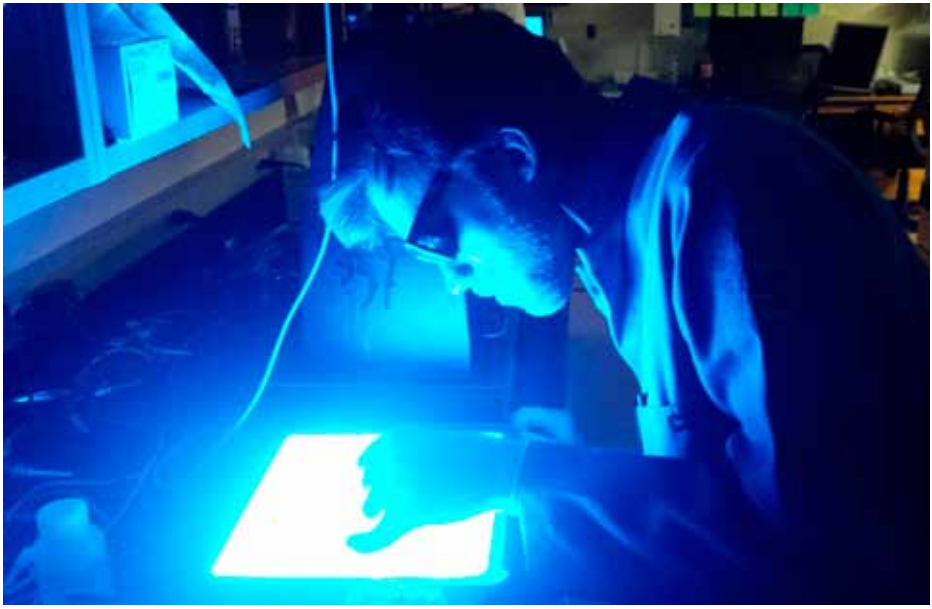

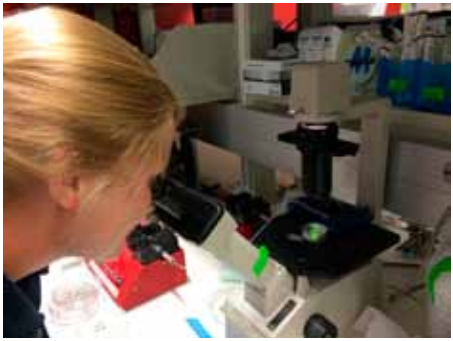

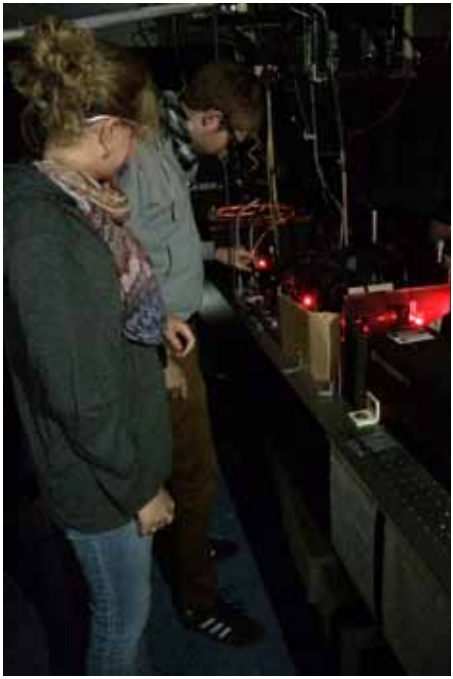

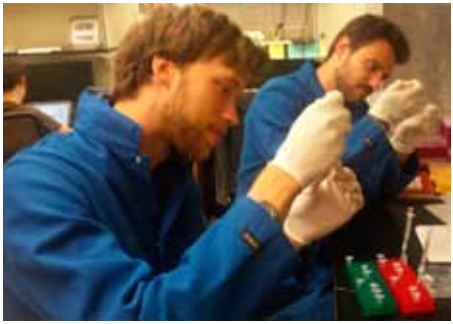


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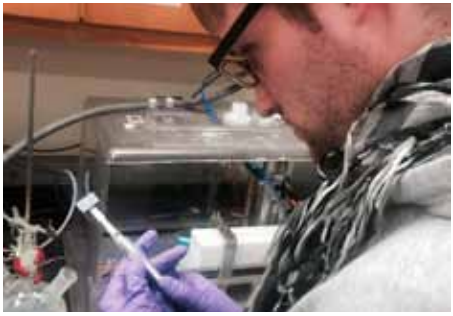
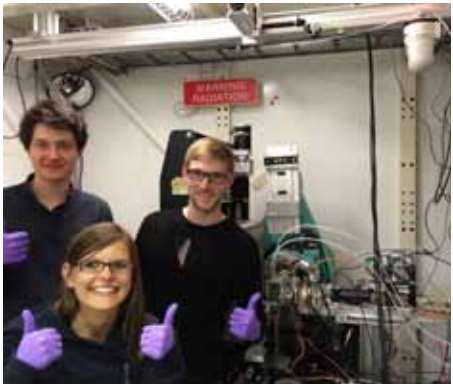


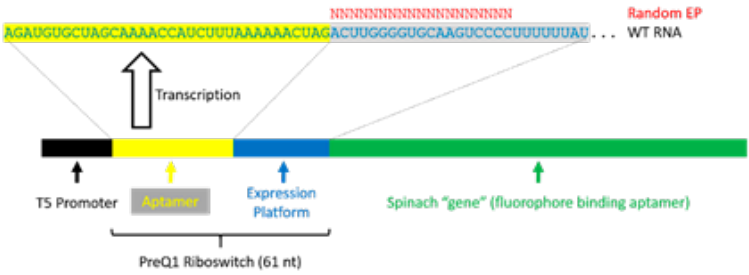


Using fitness landscapes to explore the sequence-structure-function relationships of an evolved riboswitch

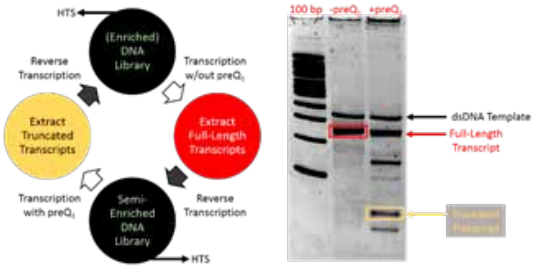
Riboswitches are regulatory elements found in the 5′ untranslated region of (usually) bacterial mRNA. They consist of an aptamer (serving as a sensor) and an expression platform (EP), which is a bi-stable structural element that adopts one of two structures depending on the binding state of the aptamer. One of the structures allows transcription or translation to occur normally, while the other either terminates transcription prematurely or prevents translation by sequestering the ribosome binding site, depending on the riboswitch.

The preQ1 riboswitch is transcriptionally-acting; it produces full-length transcripts in the absence of preQ1, and truncated transcripts in the presence of preQ1. This is the smallest known riboswitch, with a 34 nucleotide aptamer, and a 27 nucleotide EP. Ultimately, the goal is to randomize and select for novel expression platform regions, but for the two day JNN module, the behavior of the wild-type riboswitch in response to preQ1 was investigated. A double stranded DNA construct (see figure) was created that includes the constitutive T5 E. coli promoter, the preQ1 riboswitch, and the Spinach2 aptamer (to serve as the 'gene' being regulated). On the first day of the module, transcription was performed on this construct in both the presence and absence of preQ1. The transcription reactions were then run in a denaturing polyacrylamide gel, and the bands containing the full length and truncated products were excised from the gel. On the second day, the RNA was extracted from the excised gel slabs and roughly quantified by spectrophotometry. This was a simple introduction to the behavior of riboswitches, but confirmed that the preQ1 riboswitch responds as predicted to the presence or absence of preQ1.

As mentioned, the extension of this project will involve creating a selection pool with a randomized EP region. This pool will then be transcribed in the absence of preQ1; full length bands will be extracted and reverse transcribed (regenerating the promoter). This process will then be repeated, except that transcription will be carried out in the presence of preQ1; truncated bands will then be extracted and reverse transcribed (regenerating the promoter and truncated region of the construct), and then submitted for high-throughput sequencing. This cycle (see figure) constitutes one round of selection, and will be repeated until the selection pool shows a high (or unchanging) degree of convergence. The sequencing data for each round of selection will then be analyzed via fitness landscapes. This involves assigning each functional sequence a fitness value related to



its abundance or enrichment throughout the selection. These landscapes provide a way to quantitatively map sequence information to functional activity. Additionally, a second, independent fitness landscape will be created that maps predicted secondary structure to activity. By comparing these two different landscapes, we hope to see potential EP evolutionary trajectories, as well find patterns in both sequence and structure that contribute to optimized activity levels. The ultimate goal is to develop a set of computational tools that will aid in the analysis of any arbitrary nucleic acid based selections.



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Introduction to Fluorescence Correlation Spectroscopy (FCS): From lipid diffusion on membrane models to beer viscosity

Fluorescence correlation spectroscopy (FCS) primary parameter of interest, unlike other fluorescence techniques, is not the fluorescence intensity but rather its fluctuations which appear due to the system stochastic deviations from thermal equilibrium. Therefore, FCS is based on the time correlation of fluorescent signal fluctuations induced by the fluorophore movement in and out of the detection volume. The acquired signal is characteristic to particular particle species and conditions, thus reflecting the particle dynamics. Due to its high sensitivity and single particle resolution, FCS can be used to assess the local physical environment.

In this introductory module, first the students were introduced to the classical use of FCS for determining particle diffusion, in this case in model lipid membranes. Further, the sensitivity of the method was probed for the analysis of different types of beer.

Lipid membranes play a pivotal role in different biological processes, in confining reaction spaces and mediate all kinds of exchange between them. The modulation of the membranes' physical properties is one of the possible mechanisms to regulate biological processes.

In the last few decades, a number of in vitro methods have been developed that allow the investigation of different biological processes under defined and controlled conditions. A

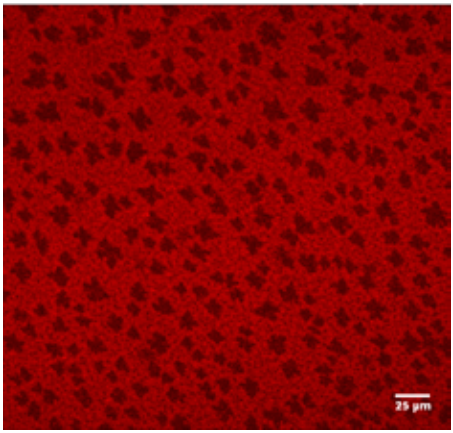

Figure 1: *Representative confocal microscopy image of a DMPC:DSPC (50:50) (labeled with ATTO655-DOPE) phase separated supported lipid bilayer.*

variety of minimal membrane systems, as giant unilamellar vesicles (GUVs), supported lipid bilayers (SLBs) and lipid monolayers, allow the study of different feature of lipid bilayers, as well as, lipid-protein interactions down to a single-molecule level. These systems, though highly simplified in their composition and topography, when properly employed, retain the core of the interaction under investigation and minimize the number of variables in the analysis. Thus, the comprehension of the advantages and limitations of each system is necessary for a correct approach for the chosen scientific problem. This mini-project included the familiarization with the preparation of different model membranes (GUVs, SLBs and monolayers) and the use of confocal microscopy and fluorescence correlation spectroscopy (FCS) techniques for theirs characterization, more specifically, in terms of theirs physical properties, such as lipid organization and diffusion. Classical well characterized lipid compositions were thus used (1) to observe lipid phase separation (fig. 1) and (2) compare the different membrane models. Accordingly, it was shown that DOPC lipids diffuse faster on lipid monolayers, than on bilayer models, due to the absence of interleaflet coupling and lower surface pressure. Moreover, the presence of a support renders a slower diffusion of lipid in SLBs in comparison to the free-standing GUVs.

Beer plays an important role in social and economic aspects of Bavarian society. The analysis of beer is thus important for the evaluation of its quality, nutritional aspects, organoleptic characteristics and safety. Various methods have been developed and established over the years to characterize and quantify different beer properties and characteristics.

In this second mini-project, it was proposed to use FCS as a method to indirectly characterize the viscosity of the beer, strongly influenced by the sugar content of the beer. Thus, the free diffusion of ATTO655 dye was probed in beer samples of different brands and types: Jever, Altenmünster, Augustiner Wiesn and König Ludwig Dunkel. After appropriate calibration with a sucrose solution of average beer viscosity (≈1.3463), it was possible to calculate the viscosity of the different beer samples showing that accordingly, Pils have a lower viscosity than Wiesn and Dunkel beer.

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Accumulation and selective gelation of DNA in a thermal gradient

In our lab, we study the physics of biomolecules in microscale non-equilibrium environments. Our aim is to gain insights into possible first steps of molecular evolution and the transition from dead molecules to living systems. In this lab project, we studied the accumulation and sequence selective gelation of DNA strands driven by a thermal non-equilibrium. A thermal gradient across a solvent-filled borosilicate chamber is created by the absorption of infrared laser light. The gradient drives the movement of solute DNA towards the cold side (thermophoresis). When superimposed with the thermally triggered fluid convection, both effects accumulate DNA strands depending on their length. Strands with the ability to elongate and interlink by hybridization form large gel-like superstructures (Fig. 1), where strands with different sequences are spatially separated. Unlike DNA origami, the DNA gels are not static but feature a steady turnover of DNA stands. Hence, such an elongation and linking scheme allows for the replication of given sequences of strands. Such a hybridization-based template replication mechanism is also relevant in a broader scope. When convection is too fast to allow gelation, elongation can still be catalyzed by prior binding of individual strands to an already elongated sequence of strands. Here, elongation is driven by the spatial proximity of the strands while being bound.

During the lab course, we discussed the physics of thermophoresis, thermoviscous pumping generating convection inside the camber, the interactions between the different DNA species, and the experimental setup including the fine-grained spatio-temporal temperature control. We observed the accumulation of DNA in the chamber and the resulting formation of competing DNA gels (Fig. 1).

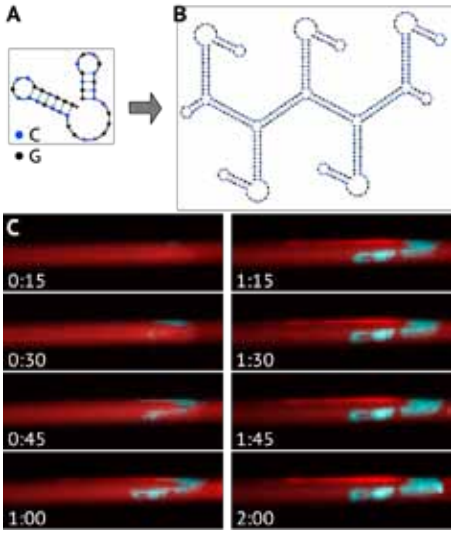

Figure 1: *Formation of DNA gels. A: Secondary structure of a single DNA strand with three self-complementary domains. The outer two facilitate the formation of long chains, the middle one crosslinking to other chains. B: Network formed by several DNA strands. At sufficiently high local concentrations, the network grows to sizes observable via ordinary fluorescence microscopy. C: Formation and evolution of two competing DNA gels within two hours. One DNA species is labeled with Cy5 (red), the other with FAM (blue). Due to the blue strands' twofold higher initial concentration, the blue gel grows to larger sizes more quickly than the red one. As the two species' sequences are orthogonal, the two gels do not mix.*

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Small angle X-ray scattering for structural analysis of biological macromolecules in solution

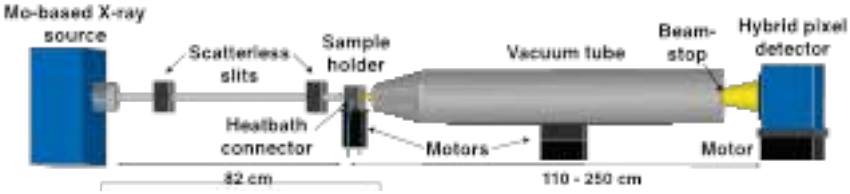

Figure 1: *Schematic view of the in-house SAXS setup.*

The three dimensional shape of macromolecules affects their physiological functionality in each organism. Our lab is interested in the characterization of the shape, conformational changes and interactions of macromolecules, such as proteins and nucleic acids. We apply small angle X-ray scattering (SAXS) to study molecules under different solution conditions, including (near-) physiological to highly denaturing. In this technique, X-rays are directed through a sample containing the molecules in solution and the scattered X-ray intensities are recorded. SAXS experiments are routinely performed at state-of-the art 3rd generation synchrotron X-ray sources. As a complimentary approach we apply an in-house setup for SAXS (Fig. 1) measurements, which was developed in collaboration with the lab of Bert Nickel. The aim of the lab course was to introduce the students to the basic theory of X-ray scattering and to prepare and conduct a SAXS measurement. We prepared lysozyme, which is a standard and already well characterized protein and corresponding buffer solutions. The setup was aligned and calibrated and the measurements ran overnight. The raw data from the detector were circularly averaged, data from the sample and the buffer were then averaged and buffer profiles were subtracted. We analyzed the resulting intensity graph (Fig. 2a) and defined the radius of gyration and the folding state of the protein based on a Kratky plot (Fig. 2b).

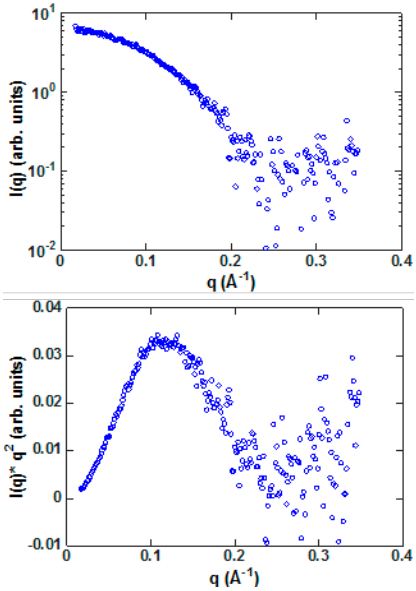

Figure 2: *Scattering data from lysozyme. (a) Scattering intensity I(q) versus scattering vector q. (b) Kratky representation where the intensity is multiplied with q^2.*

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The non-equilibrium structural behavior of self-assembling DNA hydrogels

The highly tunable, sequence-dependent hybridization of DNA has enabled construction of DNA hydrogels with applications ranging from drug delivery and gene therapy to tissue engineering and biosensing. To precisely control release of embedded effectors, these hydrogels have been engineered to structurally respond to a variety of environmental stimuli. However, fundamental to any responsive polyelectrolyte system is understanding how structural behavior relates to salt. Though many have examined the salt response of covalently cross-linked DNA hydrogels, the behavior of non-covalently cross-linked DNA networks remains poorly understood. In this module, students constructed a recently developed microfluidic device to observe the dynamic formation, ageing, and degradation of DNA hydrogels comprised of branched DNA nanostars with palindromic overhangs. The device, a flow cell containing permeable membranes, enabled salt exchange to the sample chamber without loss or dilution of the DNA nanostar sample, thereby allowing us to influence gel formation/degradation by modulating the degree of electrostatic screening and overhang hybridization propensity. Using fluorescent microscopy, we observed non-equilibrium structural behavior that appears to run counter to what is expected solely from electrostatics.

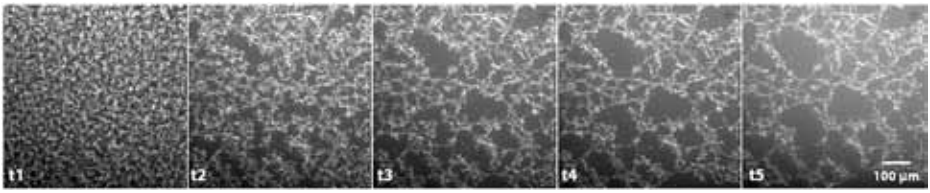

Figure 1: *The non-equilibrium evolution of DNA hydrogel networks*

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DNA origami scaffold preparation

It was shown that DNA is a suitable material to self-assemble arbitrary three dimensional objects at the nanoscale in a highly parallel fashion. The spatial addressability of the DNA nanostructures allows not only to build such structures but also to use them as templates for the arrangement of e.g. fluorescent dyes and metal nanoparticles. Using this technique, functional materials that are difficult to produce for example with lithographic techniques can be constructed and studied. In the last years, different strategies for the production of such template DNA structures such as scaffolded DNA origami, tile assembly, and DNA bricks were developed.

The scaffolding DNA origami technique employs a virus-based DNA single strand as a scaffold, which is folded into the desired shape by the help of hundreds of short DNA staple strands. The key and limiting parameter in that method is the long single-stranded scaffold molecule. Usually, the single-stranded genome of the bacteriophage M13 is used as a scaffold molecule.

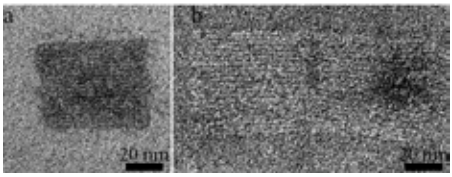

Fig. 2: *TEM images of the folded DNA origami structures. (a) TEM image of a rectangular two layer sheet (2LS) structure and (b) of two 2LS linked together. Scale bar 20 nm.*

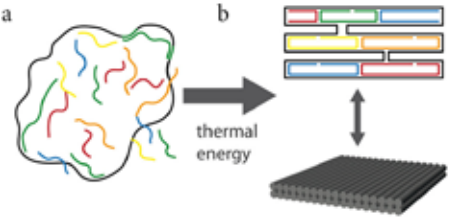

Fig. 1: *Schematic overview of DNA origami folding. (a) The long viral scaffold strand is mixed together with around 200 small, complementary synthetic staple strands and buffer. (b) While exposing the sample to a thermal annealing ramp starting at 65°C going down to 25°C structures with the designed shape are folding by DNA base pairing.*

During a two-day lab-project, this single-stranded scaffold molecule is prepared, a DNA origami structure is designed and then folded together with the freshly produced scaffold. The production of the scaffold is done by the help of E.coli bacteria. Therefor, a liquid bacterial culture will be grown and infected with virus particles. The bacteria reproduce the virus and constantly secret new virus particles to the surrounding growth medium. The virus particles will be purified from the E.coli cells and the surrounding medium and the genomic DNA will be isolated from the virus. After purification, this genomic DNA will serve as the scaffold. We have a variety of target DNA origami designs on stock and can assemble the desired structure from the prepared scaffold material and characterize it via gel electrophoresis and TEM (transmission electron microscope).

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Novel methods in nucleic acid aptamer discovery

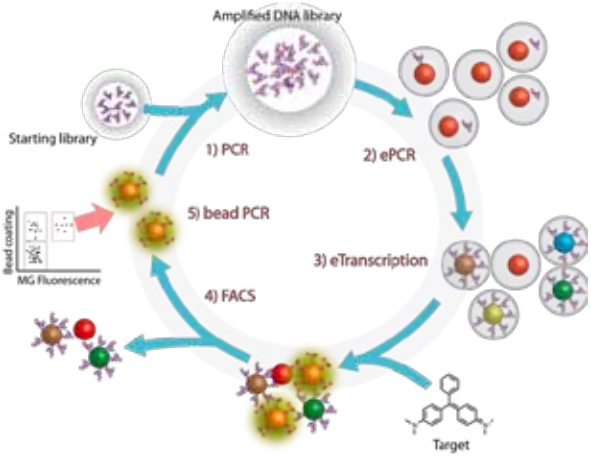

Figure 1: *Gene-linked RNA Aptamer Particle (GRAP) scheme. 1) A starting DNA library is 2) transformed into monoclonal DNA particles using emulsion PCR (ePCR). 3) These then undergo a process of emulsion Transcription (eTranscription) resulting in a population of particles monoclonally expressing RNA sequences. 4) The GRAPs are incubated with target resulting in fluorescence enhancement upon successful binding. Those particles exhibiting enhanced fluorescence are separated from the uncoated or nonbinding particles and 5) the DNA sequences are amplified from the sorted beads to restart the process.*

Nucleic acid aptamers are a promising alternative reagent to antibodies in molecular diagnostics and therapy. Because their discovery often relies on an iterative process of in vitro evolution, aptamers hold a distinct advantage over other affinity reagents in that they can be evolved to bind to highly toxic or non-immunogenic targets. Additionally, because they are synthesized artificially, they can be distributed as sequence information rather than distributed as a fragile biological sample. Using technologies only recently developed in our lab, we performed multiple rounds of directed evolution on a random RNA library to screen for aptamers that bound to the small molecule dye Malachite Green. Using the Gene-linked RNA Aptamer Particles (GRAP) scheme shown (Figure 1), we first transformed a large pool of random RNA molecules into a collection of micron-sized magnetic particles expressing numerous (>105) copies of a single RNA sequence. These particles were then challenged with Malachite Green and those that bound were separated from the rest of the pool using a fluorescence activated cell sorter (FACS), and the successful sequences amplified for use in further rounds of evolution. By clever use of flow cytometry, we were not only able to detect fluorescence-enhancing binders to malachite green, but also found a unique motif that exhibited a unique spectral profile for the fluorescence enhancement of this small molecule. This is the first example of directly selecting aptamers for fluorescence enhancement and the process can likely be expanded to select for aptamers exhibiting arbitrary functions against numerous different target.

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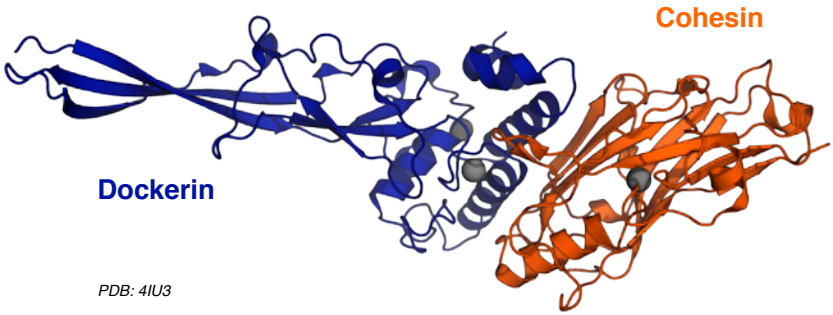
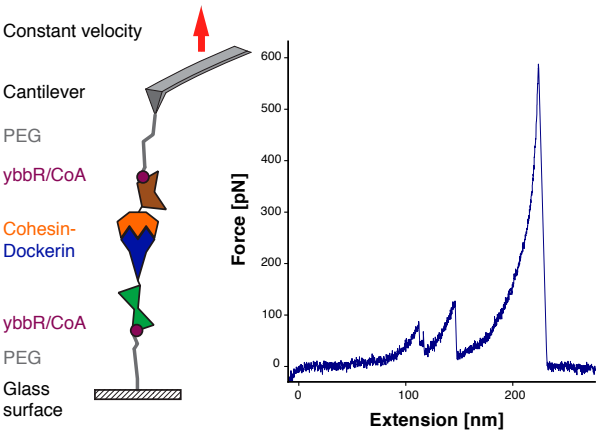
Covalent protein immobilization for single molecule techniques

When positioning and manipulating single molecules on surfaces, specific and reliable conjugation of individual nanoscale objects is key in acquiring low-background, low-noise, and high-yield data. Not only single molecule force spectroscopy as used in our lab, but any surface based method greatly benefits from covalent pulldowns as opposed to non-specific adsorption. Thus the objectives of this project were to share our lab's protocol to covalently immobilize proteins onto surfaces, to perform force spectroscopy on our custom-built Atomic Force Microscopes (AFM), and finally to determine the rupture force of a protein-protein complex.

Mechanical forces play a pivotal role in biological systems such as cell signaling and gene expression or cell differentiation. While the affinity of biological receptor-ligand systems is often known, the characteristic force necessary to sever the complex is not. Using single molecule force spectroscopy our group measures the forces between two individual molecules to establish an estimate of the energy landscape that governs a biomolecular complex or the unfolding and refolding pathways of a protein. As a model system we studied the stability of a cohesin-dockerin complex. This family of protein-protein interactions is prominently found in cellulosomes, branched multienzyme systems native to specialized meso- and thermophilic bacteria, that excel at breaking down lignocellulosic biomass into sugars, making them a promising candidate for efficient biofuel production. Cohesin-dockerin interactions exhibit high affinities with KDs in the lower nanomolar range, and have attracted our curiosity with their extraordinary mechanostability exceeding more than 500 pN for the complex depicted, roughly a third of the force necessary to break a covalent bond.

Our protocol to immobilize proteins onto surfaces includes many incubation steps and takes about 5 hours to complete. Initially an aminosilanized glass slide and silicon AFM cantilever is covered in a 5000 Dalton heterobifunctional polyethylenglycol (PEG) linker terminating in a succinimide and a maleimide group respectively. The succinimide group forms a covalent bond with the amines on the surfaces. Next the surface is covered in a coenzyme A (CoA) solution. The free thiol in the CoA reacts into a covalent bond with the maleimide group on the PEG, which now serves both as a passivation agent and a means to immobilize our proteins of interest in the next step. For the final step,





the proteins of interest are equilibrated in a buffer containing magnesium chloride, which is required by the coupling enzyme phosphopantetheinyl transferase (SFP). SFP catalyzes a covalent bond between the so called ybbR tag, an 11 amino acid sequence we engineer onto the proteins used in this study, and the CoA previously reacted to the PEG. This step completes the fully covalent link between the surface and our proteins of interest.

The data acquisition consists of repeated approaching and retracting of the AFM cantilever at varied constant speeds from the surface. If a receptor-ligand complex is formed upon approach the retraction trace will show a characteristic sawtooth pattern of rising and rapidly dropping force, corresponding to protein domain unfolding until the final complex rupture as shown in the figure. As the forces reached with the cohesin-dockerin complex are substantial, the covalent linkage as outlined above is essential to the success of the experiment. Without this stable pulldown the cantilever would quickly pick up molecules and clog. Additionally it imposes a fixed and controlled geometry during pulling cycles that nonspecific attachment lacks.

After sorting the force-distance traces acquired overnight, typically tens of thousands, and excluding traces without any or interactions with multiple tethers. Finally we could determine a good estimate of the most probable rupture force for a given velocity from our data.

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Inelastic light scattering on 2D semiconductor materials

Two-dimensional, layered transition metal dichalcogenides (TMDCs) are of increasing interest for fundamental research as well as device applications. Especially semiconducting TMDCs with an electronic band gap in the regime of visible light are promising for optoelectronic applications. Therefore, a comprehensive knowledge about the interaction with light as well as the electron-phonon coupling of the materials is essential. TMDCs form hexagonally arranged layers of molecular thickness (Figure 1) that are stapled to form a bulk crystal. Adjacent layers are hold together by weak van-der-Waals forces, opening the possibility to obtain thin films of few crystal layers or even a single layer by micro-mechanical exfoliation.

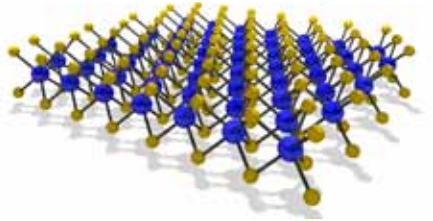

Figure 1: *Structure of a single MoS_2 layer: one plane of hexagonally arranged molybdenum atoms is sandwiched between two congruent planes of hexagonally arranged sulfur atoms.*

We utilize inelastic light scattering to study the structural and electronic properties of mono- and few-layer MoS_2 and WSe_2. Inelastic light scattering is a powerful, non-destructive tool providing access to phonons, electronic excitations and spin excitations. As shown in Fig. 2(b), the phonon energies depend on the number of layers and furthermore, they are sensitive to defects, strain and doping.

In the JNN lab course, the JNN students learned how to fabricate few-layer 2D crystals via micromechanical exfoliation and how to transfer and stack different 2D crystals via viscoelastic stamping. We characterized TMDC heterostructures of MoS_2 and WSe_2 with Raman spectroscopy. From the measurements we determined the different areas of the heterostructure, as well as the number of layers and discussed the electronic band structure of the different materials. Furthermore, we discussed the fabrication of samples on nanometer scale during a detailed tour through our cleanroom facilities.

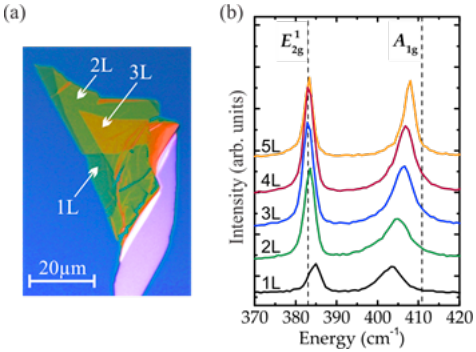

Figure 2: *(a) Optical microscopy image (false color) of a MoS_2 flake exhibiting mono- (1L), bi- (2L) and multilayer areas. (b) Raman spectra of monolayer and few-layer flakes of MoS_2. The dashed lines mark the phonon energies for bulk MoS_2.*

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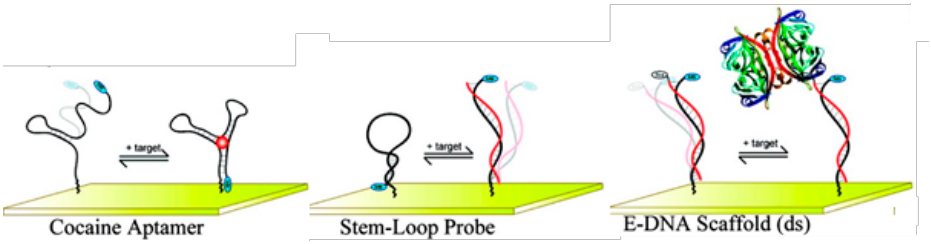
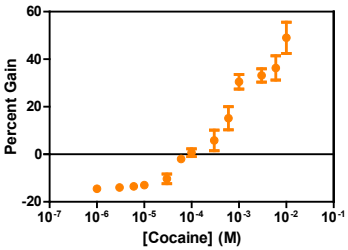
Detecting proteins, nucleic acids, and small molecules using different sensor architectures



The sensitive and specific detection of biological molecules of interest has applications in medicine, law enforcement, and research. A relatively new class of biosensors, electrochemical biosensors, generally rely on a redox-labeled oligonucleotide tethered to an electrode surface. As the electrochemically active redox tag approaches the electrode surface, the electron transfer rate between the redox tag and the electrode increases, and the transfer of electrons between the redox tag and the gold electrode is measured as current. Additionally, these systems can be "signal-on" or "signal-off", depending on the biosensor architecture used.

This module explored three different architectures: aptamer-based, stem-loop probe, and scaffold. The electrochemical biosensors built as a part of this module can be used to detect cocaine, single-stranded DNA of a specific sequence, and the anti-digoxigenin antibody (respectively). To prepare the electrodes, the gold surface was both manually abraded and electrochemically cleaned. Next, the electrode was incubated in an aqueous solution of alkanethiol-modified DNA, already reduced with 10mM TCEP during the electrode cleaning. To remove any non-specifically adsorbed DNA and to passivate the exposed gold surface, the electrodes were rinsed and incubated overnight in a 20mM mercaptohexanol solution, which forms a self-assembled monolayer. Finally, the electrodes were interrogated by square-wave voltammetry to produce titration curves against the appropriate targets (cocaine, complementary ssDNA, or anti-digoxigenin).



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A biofilm model for the human oral cavity

Bacterial biofilms are aggregates of bacteria in which cells adhere to each other or to a surface in order to build a spatiotemporally organized community. Formation is sequential and highly structured, necessitating intercellular communication across species and extracellular matrices. The high level of organization helps optimize growth conditions for bacteria in hostile environments, making penetration by foreign molecules extremely difficult. Conventional drugs that are effective against colonies in liquid culture seldom achieve any efficacy against pathogenic bacteria in biofilms.

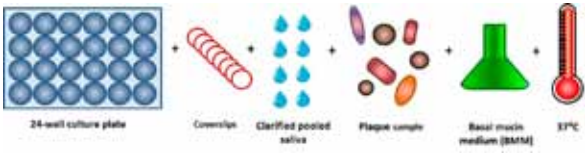

Figure 1: *Basic components of the biofilm model, in approximate order of addition. Coverslips are plastic. Shapes in "Plaque Sample" represent different types of bacteria.*

Bacteriophages are viral particles that can propagate their genetic information through bacteria. Because they can exponentially multiply and evolve with their host bacteria, phages have the potential to combat biofilm diseases, especially those phages that lyse their hosts, killing the cells in the process. Unfortunately, phage-bacteria interaction in a highly structured community is not well understood. Since clinical studies are time-, labor-, and cost-intensive, a model biofilm is needed to elucidate the basic mechanics of bacteria-phage interaction. In this study, we choose the dental surface as the model environment. Our near-term goal is to find conditions that help optimize the colonization process on tooth enamel in order to build an in vitro model. The purpose of this experiment was to verify the method of dental biofilm growth outlined by Lemos and coworkers in 2010. We used clarified saliva to form the pellicle on the natural tooth surface, basal mucin medium to supply nutrients, and dental plaque samples to seed the surface for colonization (Figure 1). After 12-16 hours of incubation at 37°C, we observed the biofilms under wide field light microscopy. Our results show varying levels of biofilm initiation, with no mature formation (Figure 2). We also observed the presence of some bacteria in the control (data not shown) and will need to refine conditions to minimize contamination.

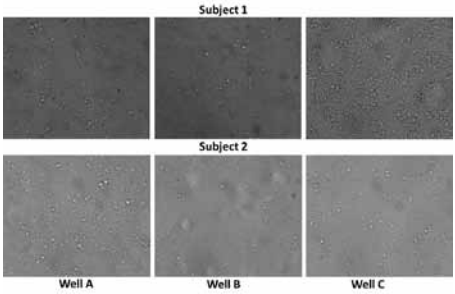

Figure 2: *Wide field microscopy images from the biofilms seeded by two different subjects. The three wells represent triplicates of the sample. Bacterial distribution is sparse and nonuniform.*

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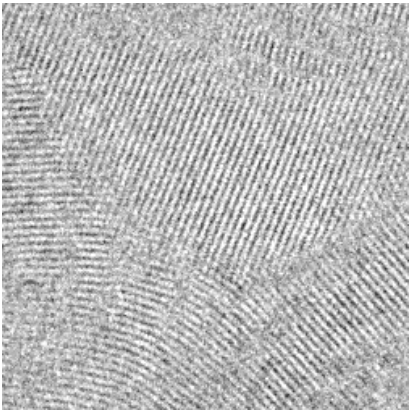
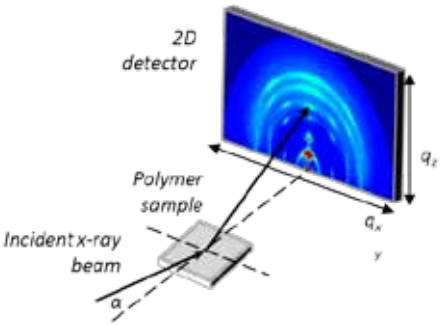
Understanding the nanoscale morphology of molecularly doped semiconducting polymer thin films

The sensitive and specific detection of biological molecules of interest has applications in medicine, law enforcement, and research. A relatively new class of biosensors, electrochemical biosensors, generally rely on a redox-labeled oligonucleotide tethered to an electrode surface. As the electrochemically active redox tag approaches the electrode surface, the electron transfer rate between the redox tag and the electrode increases, and the transfer of electrons between the redox tag and the gold electrode is measured as current. Additionally, these systems can be "signal-on" or "signal-off", depending on the biosensor architecture used. This module explored three different architectures: aptamer-based, stem-loop probe, and scaffold. The electrochemical biosensors built as a part of this module can be used to detect cocaine, single-stranded DNA of a specific sequence, and the anti-digoxigenin antibody (respectively). To prepare the electrodes, the gold surface was both manually abraded and electrochemically cleaned. Next, the electrode was incubated in an aqueous solution of alkanethiol-modified DNA, already reduced with 10mM TCEP during the electrode cleaning. To remove any non-specifically adsorbed DNA and to passivate the exposed gold surface, the electrodes were rinsed and incubated overnight in a 20mM mercaptohexanol solution, which forms a self-assembled monolayer. Finally, the electrodes were interrogated by square-wave voltammetry to produce titration curves against the appropriate targets (cocaine, complementary ssDNA, or anti-digoxigenin).





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Networking beyond Science

Besides sharing a common interest in science, all participants connected very well on a personal level from the first day on and spent most of their free time together taking part in various activities. The activities helped the students to get to know each other and created bonds not only between the foreign students but also between the students from one place, who might work in the same building but exchanged scientific ideas for the first time in a Californian restaurant.

California (Santa Barbara)

On weekdays after the scientific program, many students went out for dinner together, sometimes followed by bowling, karaoke, a movie night, or just a couple of beers – work hard, play hard!
In addition to the evening events organized by the studnets themselves, UCSB sponsored the great first-week welcome BBQ, a symposium dinner, and a farewell dinner. This brought together not only all of the students but also faculty members and symposium speakers, and enabled the participants to get to know each other in an informal setting.

During the weekends, UCSB provided vans that were used to travel around California. The wine tasting trip to Santa Ynez valley, hiking in the beautiful Channel Islands National Park, and an exciting weekend trip to San Diego with its nightlife, a baseball game, the zoo, the beaches, and an aircraft carrier museum were unforgettable expereinces.

Germany (Munich)

During the second part of the JNN, the Californian participants experienced Munich and all aspects of the Bavarian lifestyle - from a Bavarian welcome breakfast at the Oktoberfest, to hiking in the Bavarian mountains followed by a barbecue at Professor Hermann Gaub's house near lake Schliersee, and the farewell dinner in a typical Bavarian restaurant.
In additon, the participants enjoyed a guided tour of historical Augsburg and spent a weekend hiking and enjoying the fantastic views in the Dolomites.

Italy (Venice)

The five-day CeNS workshop took place on the beautiful island of San Servolo, only a ten-minute boat-ride away from Venice's Piazza San Marco. After days full of world-class science, the evenings were dedicated to sight-seeing in one of the most beautiful European cities.

Participants' Voices

"I just want to reiterate how lucky I feel for getting to participate in the program. I think it's easy to get stuck in your own world of research, and opportunities like this really allow students to explore other new and interesting types of research, not to mention the benefit of the social and cultural exposure. I wish everyone could participate in something like this."

"I think the JNN program is absolutely incredible and went beyond my expectations. The excellent science pursued at both universities makes the program an extremely worthwhile scientific experience, while the close-knit nature of the program allowed me to develop lasting friendships, both socially and professionally."

"An overall really great program! I think the networking aspect worked very well, between the Americans and Germans as well as between the German groups. This was one of the most important expectations for me and did work out."

"The Venice trip was incredible. Not only was I able to become aware of the pressing issues/topics in nanoscience, but the close setting/environment really fostered social/cultural/intellectual discussion. Simply put, it was great!"

"Very nice symposium in Santa Barbara with very high quality talks and well prepared speakers, I have definitely taken many new ideas from it."

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This program was supported by

BaCaTeC