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CeNS Workshop 2016

Nanoscale Matter – Novel Concepts and Functions

September 19 - 23, 2016
Venice International University (VIU), San Servolo, Italy

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Cover Picture: Dr. Christof Mast

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Upon arrival in Venice, participants will receive their vaporetto tickets from CeNS staff.

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No. 1 (Ferrovia "E", 46 min to S. Zaccaria): 18.24/18.36/18.48/19.00

No. 2 (Ferrovia "E", 34 min to S. Zaccaria): 18.22/18.34/18.46/18.58

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Monday, 19 September

9.00 **Welcome**

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Covalently doped carbon nanotubes: Photophysics and emerging potential for nanotube photonics

10.00 **Matthew Paszek**
Mechanobiology of the cellular glycocalyx

10.45 Coffee

11.15 **Thomas T. Perkins**
Optimizing 1 µs-resolution single-molecule force spectroscopy for studies of protein folding

11.35 **Patrick Maletinsky**
Quantum sensing and nanoscale imaging with single spins in diamond

12.20 Lunch Break

14.15 **Kurt V. Gothelf**
Templated assembly of polymers and other materials

15.00 **Alberto Morpurgo**
Electronic transport through transition metal dichalcogenides and their interfaces

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16.15 **David Cahen**
Electron transport across peptides and proteins

17.00 **Michael Nash**
Single-molecule mechanics of ultrastable protein receptor-ligand complexes

Tuesday, 20 September

9.00 **John E. Anthony**
Organic semiconductors for applications from electronics to imaging - molecular design considerations

9.45 **Jeffrey Schwartz**
Phosphonate monolayers are a stable platform for surface property modification

10.30 Coffee

11.00 **Jan Philipp Junker**
Spatially resolved transcriptomics and single cell lineage tracing

11.45 **Jan Budich**
Topological Insulators: A New Periodic Table for Physics

12.30 Lunch Break

14.15 **Ann McEvoy**
3D super-resolution microscopy using a double-helical point spread function

15.00 Poster Session I and Coffee

17.00 **Karsten Reuter**
Predictive-quality theory for surface nanostructures

Wednesday, 21 September

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9.45	**Josef A. Käs** Why do rigid tumours contain soft cancer cells?
10.30	Coffee
11.00	**Emanuel Lörtscher** Single-molecule electronics and optics
11.45	**Alberto Salleo** Charge transport in conjugated polymers: from molecular scale to mesoscopic effects
12.30	Lunch and informal discussions

Thursday, 22 September

9.00	**Dieter Braun** Can we create evolution from scratch?
9.45	**Tony F. Heinz** Seeing electrons in 2D – light/matter interactions in atomically thin semiconductors
10.30	Coffee
11.00	**Heiko Weber** Charge transport in large-area graphene
11.45	**Valentina Cauda** Tailoring properties and structures of zinc oxide nanomaterials for energy to biomedical applications
12.30	Lunch Break
14.15	**Michael Knap** Periodically driven quantum systems
15.00	**Florian Schüder** Whole cell imaging with DNA-PAINT on a spinning disk confocal microscope
15.20	**Suchitra Sebastian** Exploring materials universes: the case of an exotic insulator that behaves like a metal
16.05	Poster session II and Drinks

Friday, 23 September

9.00	**Wesley Legant** From cell mechanics to light sheet microscopy: imaging molecules, cells, and embryos at high spatiotemporal resolution
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10.50	**Closing remarks**
11.00	Departure

Vaporetto no. 20 from San Servolo to San Zaccaria:
11.20/12.10

Take vaporetto no. 1, 2, 4.2. or 5.2 from San Zaccaria to S. Lucia train station:

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Train to Munich 13.50
Arrival: 20.23

INVITED TALKS

Covalently Doped Carbon Nanotubes: Photophysics and Emerging Potential for Nanotube Photonics

Stephen K. Doorn

Center for Integrated Nanotechnologies, Los Alamos National Laboratory

New red-shifted emitting states in carbon nanotubes (CNTs), introduced by stable covalently-bound dopants,[1,2] are gaining attention for their potential to boost photoluminescence quantum yields,[1,2] add new functionality,[3,4] and serve as single photon emitters.[5] Critical to these possibilities is the demonstration of exciton localization or trapping at individual dopant sites.[6] This talk will present an overview of photoluminescence (PL) spectroscopy, imaging, and time-resolved studies revealing the origins of these new CNT optical behaviors. Results from oxygen-doped tubes leading to the demonstration of room-temperature single photon emission from the dopant states will be described. Direct imaging evidence for exciton localization at dopant sites will also be shown. As a consequence of trapping, exciton dynamics are significantly altered, with photoluminescence (PL) lifetimes being extended significantly.[4] A detailed study of the emission dynamics associated with dopant states introduced by aryl diazonium functionalization of semiconducting carbon nanotubes will be discussed. Dopant-state PL lifetimes are found to increase by around a factor of 10 in comparison to E11 exciton lifetimes. Dependence of lifetimes on nanotube chirality, specific dopant, and dielectric environment will be presented and shown to exhibit a strong dependence on emission energy. Relaxation mechanisms will be discussed in terms of multi-phonon decay processes and exciton detrapping. A spectroscopic link between the two will be demonstrated.

1. Ghosh, S. et al., Science, 330, 1656 (2010).
2. Piao, Y. et al., Nature Chem., 5, 840 (2013).
3. Kwon, H. et al., J. Phys. Chem. C, 119, 3733.
4. Akizuki, N. et al., Nature Comm., 6, 8920 (2015).
5. Ma, X. et al., Nature Nanotech., 10, 671 (2015).
6. Hartmann, N.F. et al., Nanoscale, 7, 20521 (2015).

Mechanobiology of the Cellular Glycocalyx

Matthew Paszek

Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, NY 14853, USA

The glycocalyx is a polymer meshwork on the cell surface comprised of proteins and complex sugar chains called glycans. From a physical perspective, the glycocalyx has long been considered a simple "slime" that protects cells from mechanical disruption or against pathogen interactions, but the dramatic complexity of the structure argues for the evolution of more advanced functionality. With this overarching hypothesis in mind, I will discuss our recent efforts to develop new tools to investigate what the physical functions of the glycocalyx in regulating complex cellular behaviors. Combining our innovative imaging technologies with approaches from computational biology and glycoscience, we have now begun to dissect how changing patterns of glycosylation and glycoprotein expression alter cell surface receptor function at nanometer length scales. Recently, we've found that the biophysical properties of the glycocalyx can play a major role in aggressive, lethal cancers. I will discuss these findings and suggest how factors, such as diet, metabolism, and sugar biosynthesis are critical determinants of glycocalyx structure and function.

Optimizing 1 μs-resolution single-molecule force spectroscopy for studies of protein folding

Thomas T. Perkins[1,2]

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2 Department of Molecular, Cellular, and Developmental Biology, Univ. of Colorado, Boulder, CO 80309 USA
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Protein folding is understood as a set of transitions between states. Yet, an oversimplified view of the folding process emerges if briefly populated states remain undetected due to ensemble averaging and/or limited instrumental precision. Atomic force microscopy (AFM)-based single-molecule force spectroscopy (SMFS) is widely used to mechanically measure the folding and unfolding of proteins. However, the temporal resolution of a standard cantilever is 50–1,000 μs, masking rapid transitions and short-lived intermediates. I will focus on a set of improvements to AFM cantilevers that leads to enhanced force stability, force precision and temporal resolution. To do so, we used a focused ion-beam to micromachine a short (L = 40 μm) commercial cantilever and then extended this concept further to modify an ultrashort cantilever (L = 9 μm), achieving 1-μs temporal resolution on a commercial AFM. To demonstrate the biophysical utility of these modified cantilevers, we unfolded a polyprotein, a popular assay. In the second assay, we unfolded bacteriorhodopsin (bR), a model membrane protein. The resulting force-extension curves for bR show unprecedented detail. Numerous, newly detected intermediate states—many separated by as few as 2–3 amino acids—exhibited complex dynamics, including frequent refolding transitions and state occupancies of <10 μs. These results dramatically sharpen the picture of membrane protein folding and, more broadly, enable experimental access to previously obscured protein dynamics.

Quantum sensing and nanoscale imaging with single spins in diamond

Patrick Maletinsky

Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

Individual electronic spins may can yield close-to-ideal magnetometers to investigate magnetic phenomena on the nanoscale. Spins are natural magnetometers by virtue of their Zeeman response to magnetic fields. Furthermore, quantum coherence and quantum control can be exploited to taylor their response towards excellent magnetic field sensitivities. Lastly, spins can be localised to atomic lengthscales, which enables nanoscale resolution in imaging. The electronic spin of the Nitrogen-Vacancy center in diamond has been identified as a particularly fruitful system to implement these concepts. It combines the above benefits with the ability of optical spin readout and initialisation, and operates from cryogenic temperatures to ambient conditions, all while maintaining exceptional quantum coherence. In the best case, this results in a non-invasive and quantitative magnetometer with single-spin sensitivity and nanoscale spatial resolution - a device with many highly promising applications in science and technology.

In my talk I will present recent activities of the Quantum Sensing Group at the University of Basel in nanoscale NV magnetometry of condensed-matter systems. Specifically, I will describe our experimental approach to realising such quantum magnetometers and discuss two systems we currently investigate using this technique. Specifically, I will discuss an experiment where we used scanning NV magnetometry to image individual vortices in the high-temperature superconductor $YBa_2Cu_3O_7$, and some more recent results, where we were able to image and study domains in the magnetoelectric antiferromagnet Cr_2O_3. In both cases, NV magnetometry allowed us to quantitatively determine essential system parameters of the materials under study - the London penetration depth for YBCO and the surface magnetic moment density for Cr_2O_3. Both are central quantities for the understanding of the respective materials, and both have been notoriously hard or impossible to determine using previously existing experimental approaches. Our results therefore illustrate the power of NV magnetometry in exploring local magnetic properties of electronic systems with nanoscale resolution and the promise our technology holds for future exploration of complex, condensed matter systems.

Templated Assembly of Polymers and other Materials

Kurt Vesterager Gothelf

Center for DNA Nanotechnology (CDNA), iNANO and Department of Chemistry, Aarhus University, 8000 Aarhus C, Denmark

DNA is used as a programmable tool for directing the self-assembly of molecules and materials. The unique specificity of DNA interactions and our ability to synthesize artificial functionalized DNA sequences makes it the ideal material for controlling self-assembly and chemical reactions of components attached to DNA sequences. We are using DNA origami, large self-assembled DNA structures as a template for positioning of materials such as organic molecules, dendrimers and biomolecules.[1-2] We have recently prepared conjugated phenylene vinylene polymers and attached DNA strands along the polymer, which provides control of the structure of single molecule polymers by their assembly on designed paths on DNA origami.[3] This system has been used for a range of optical and dynamic studies of the polymer (Fig 1).[4] Based on the concepts of DNAdirected chemistry we have developed a new method for site-selective conjugation of DNA to proteins, including antibodies.[5] Very recently this has been extended to the site-directed conjugation of small molecules to proteins.

[1] Voigt, N. V. et al. Nature Nanotech. 2010, 5, 200-205.
[2] Liu, H. et al. J. Am. Chem. Soc. 2010, 132, 18054-18056.
[3] Knudsen et al. Nature Nanotech. 2015, 10, 892
[4] Krissanaprasit, A. et al. ACS Nano, 2016, 10, 2243-50
[5] Rosen, C. B. et al. Nature Chem. 2014, 6, 804–809.

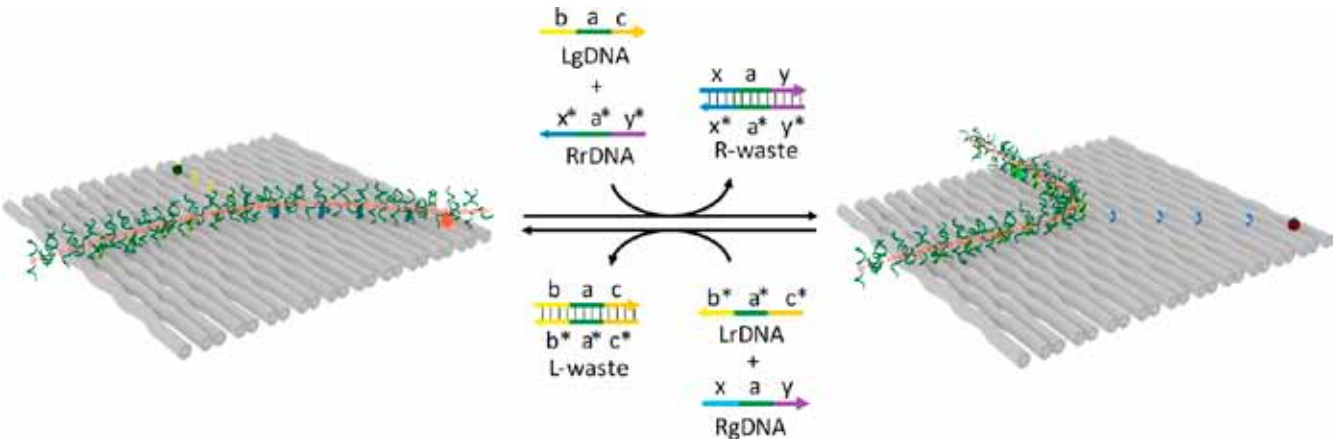

Figure 1. Illustration shifting the position of a poly(DNA-phenylene vinylene) on DNA origami.[4]

Electronic transport through transition metal dichalcogenides and their interfaces

Alberto Morpurgo

Department of Quantum Matter Physics, Ecole de Physique, 24, quai Ernest-Ansermet, CH-1205 Geneva, Switzerland

Following the discovery of graphene, it has become clear that there is a very broad category of materials enabling the realization of virtually perfect two-dimensional crystals of atomic thickness, exhibiting new interesting physical phenomena. Research on these "2D Materials" is developing at an impressive pace disclosing new results and posing interesting fundamental questions. The long-term goal is to understand and control the electronic properties of materials, and of their heterostructures, at the atomic scale, exploiting mechanisms that are at the same time unexpectedly powerful and simple.

In this talk I will discuss our work on transport and opto-electronics of two-dimensional semiconducting transition metal dichalcogenides, i.e., materials like WS_2 and MoS_2. Much of the results that we have obtained originate from the study of transport through field-effect transistors with ionic-liquid gates, which enable the accumulation of surface charge carrier densities significantly in excess of 1014 cm^{-2} for both charge polarities (i.e., for both electrons or holes). Results that I will discuss include the observation of gate-induced superconductivity in MoS_2, for multilayer of all thickness down to individual monolayers; the use of ionic liquid gate to extract the band-gap of a semiconductor from simple measurements of transport in a field-effect transistor; the realization of light emitting transistors based on mono and bilayers of WS_2. I will also discuss experiments on van der Waals hetesrostructures combining WS_2 and graphene, which allow us to induce a very strong spin-orbit interaction in graphene, while preserving the high-electronic quality of the material and the basic aspects of Dirac electron physics.

Electron Transport across Peptides and Proteins*

David Cahen

Weizmann Institute of Science, Israel

Electron transport (ETp), i.e., electronic conduction across peptides and proteins in a solid state–like configuration is surprisingly efficient, comparable to or, normalized to length, at times even more efficient than via completely conjugated molecules.[1] Working with modified proteins and with homopeptides we find both cofactors and secondary structure to matter for ETp efficiency. An open question is if contact to the external world is the dominant factor, or intraprotein transport. This is important, also for electron transfer, ET: nature regulates ET via redox chemistry, i.e., injection and extraction of electrons; this is where ET and ETp are related, because the analog in the latter is the coupling to the electrodes (T_C in the Landauer formalism).

In ET control over the process is achieved at the free energy price of a redox event, while for ETp a redox process is not necessary. This allows studying ETp via non-redox proteins, such as the rhodopsins (relevant also for olfaction) and albumin ("dopable" proteins), which points to peptides as efficient transport medium. Therefore, ETp via them, including coupling to them, can be a way to learn about protein ETp.

[1] N. Amdursky et al., Adv. Mater. 42,7142-7161(2014) Electronic Transport via Proteins, 10.1002/adma.201402304

* collaboration with Profs. Mordechai Sheves & Israel Pecht. Work involved and involves former group members, Drs. R. Lovrincic, L. Sepunaru, Xi Yu, N. Amdursky, and present group members Drs. C. Guo, J. Fereiro, S. Mukhopadhyay. Computational theory was done by Prof. L. Kronik, Drs. P. Agrawal D. Egger & S. Refaely-Abramson, and Prof. Y. Levy and Y. Gavrilov from the Weizmann Inst. of Science.

Single-molecule mechanics of ultrastable protein receptor-ligand complexes

Michael Nash

University of Basel, Department of Chemistry, Klingelbergstrasse 80, 4056 Basel, Switzerland

Cellulosomes are large multi-component protein complexes comprising networks of non-catalytic protein scaffolds, catalytic enzymes and other ancillary domains. These intricate structures reside on the extracellular surface of select anaerobic bacteria, and serve to convert cellulose into soluble sugars. Cohesin-dockerin (Coh-Dock) pairs are the ligand-receptor modules that hold the network components together. The extreme environments in which Coh-Dock pairs operate (e.g., elevated temperature, extreme pH) has led to natural selection for robust protein interactions, both in terms of biochemical affinity and as I will demonstrate in this talk, high mechanical strength. Here I present recent work on the Coh-Dock toolbox from the perspective of single-molecule biophysical chemistry and synthetic systems. First I describe an ultrastable Coh-Dock pair that exhibits complex rupture forces of 600–800 pN at loading rates of 10-100 nN/s. Steered molecular dynamics and mechanical anisotropy experiments shed light onto the origins of this impressive stability. Next, I will describe how Dock can be used as a universal 'handle' domain for on-chip gene expression and force spectroscopy, enabling extremely high relative precision when comparing multiple proteins in parallel. Finally, we demonstrate a unique dual mode of Coh-Dock recognition that is contrary to the standard lock and key model for receptor-ligand interactions. Finally I will give an overview of incorporation of Coh-Doc components into gel-forming chemical reaction systems. Given the diversity, modularity and mechanical robustness of Coh-Dock pairs, we propose these modules as invaluable proteins domains for a variety of applications in the nanobio sciences.

Organic semiconductors for applications from electronics to imaging - molecular design considerations

John E. Anthony

Department of Chemistry and Center for Applied Energy Research, University of Kentucky, Lexington, KY 40509-0055 USA

The electronic and photophysical properties of organic materials depend critically on the precise arrangement of chromophores in the solid state. In the most highly ordered cases - organic single crystals - intermolecular shifts in solid state order of only a few tenths of an Å can render a high-performance semiconductor useless, and minuscule changes in substitution pattern can dramatically enhance performance. Using a simple functionalization scheme, we have developed a reproducible method for altering and tuning the solid-state order of a wide array of linearly-fused aromatic and heteroaromatic semiconductors. The scheme can induce an array of π-stacked arrangements, and the impact of solid-state order on performance in several different device applications has been explored. Further, changes to the chromophore by addition of heteroatoms (and their associated functionalities) can tune both molecular parameters and fine-tune solid-state ordering. Further, constant vigilance must be maintained to detect thin film polymorphs, where the thin-film order can differ substantially from that seen in the bulk crystal. While simple steric bulk / crystal packing relationships can yield a general prediction of crystal packing, a finer degree of structural understanding is required to tune solid-state order for optimum performance in applications such as thin-film transistors, photovoltaics, and bioimaging materials. To this end, we have begun to investigate solid-state "synthons" - interactions between specific atom types that subtly modify solid-state order. For example, Ar-H - - - F type hydrogen-bonding, and repulsive S - - - S interactions in the solid state can be enhanced or excluded by careful tuning of the molecular structure, leading to subtle changes in solid-state configurations. In the extreme (for example, changing positions of sulfur substituents to force sulfur-sulfur interactions) completely new crystal packing motifs can be induced. In this lecture, I will present our latest efforts in modifying our crystal packing scheme, describe how the resulting changes in crystal packing impact film morphology and device performance, and describe the application of the resulting design rules to new chromophore types.

Phosphonate Monolayers are a Stable Platform for Surface Property Modification

Jeffrey Schwartz

Department of Chemistry, Princeton University, Princeton, NJ, USA

Organophosphonates as a class of surface modification reagents have superior interfacial properties with regard to air, hydrolytic and mechanical stability, and they can be prepared with great structural variation. The synthesis and characterization of organophosphonate monolayers on oxides will be discussed. Several uses for these monolayers to affect electrode characteristics for molecular electronics will be presented, including surface dipole engineering for OLEDs, gate dielectric treatments for organic thin transistors, and replacement of metallic complexes in dye-sensitized solar cells; in each case, focus will be on how structural aspects of the phosphonate relates to device performance. The synthesis of nanometer thick oxide "adhesion layers" will be described; these have device applications in their own right, and they enable translation of the phosphonate chemistry of bulk oxides to applications for organic polymer or non-oxide-terminated inorganic surface modification. In this latter regard, the evolution of phosphonate methods from monolayer applications to participation as nanoarchitectural components will be highlighted as a means to enable cell adhesion and cell alignment on polymers to create tissue regeneration devices.

Spatially resolved transcriptomics and single cell lineage tracing

Jan Philipp Junker

Berlin Institute of Medical Systems Biology (BIMSB) of the Max Delbrück Center (MDC), Germany

Embryonic development is a study in contrasts between variation and stability. On the one hand, generation of complex spatial patterns proceeds with striking precision: the different tissues and organs are generally formed at the correct position, at the right time, and with a defined size. On the other hand, regulation should also not be too rigid, since embryos need to flexibly adjust to environmental perturbations and correct errors caused by noisy gene expression. We study the interplay between variation and stability by using the zebrafish embryo as a model system. We aim to understand the stochastic mechanisms that underlie phenotypic diversity in isogenic populations, and to identify the error repair mechanisms that ensure robust pattern formation in the presence of perturbations. Systematic investigation of variability and robustness during vertebrate organ formation requires development of novel approaches for spatially-resolved gene expression profiling and lineage analysis, ideally on the single cell level. We have recently developed a method for spatially-resolved transcriptomics called 'tomo-seq', and we are currently establishing an approach for massively parallel single-cell lineage tracing. We use these approaches in combination with light microscopy and tools from zebrafish developmental biology. My presentation will focus on our current efforts in method development, and I will give an outlook on specific biological questions that we plan to address with these tools.

Topological Insulators: A New Periodic Table for Physics

Jan Budich

University of Innsbruck, Institut für Theoretische Physik, Technikerstr. 21A, 6020 Innsbruck, Austria

The recent discovery of topological insulators -- materials that are electrically insulating in the bulk but feature anomalous metallic surface states -- has given a new twist to our understanding of solids, culminating in the discovery of a new periodic table that lists topologically distinct systems. In this introductory lecture, I first review the basic notion of topological band structures in a broadly accessible way. Furthermore, I give an outlook on possible technological applications as well as on my own research activity aimed at understanding non-equilibrium properties of topological quantum matter.

3D super-resolution microscopy using a double-helical point spread function

Ann McEvoy

Double Helix LLC, Boulder, CO, USA

Recent advances in optical microscopy now allow for images of biological samples with unprecedented resolution. These technologies, known as super-resolution microscopy, take advantages of different light patterns and/or photoswitchable fluorophores to observe the nanometer scale resolution of labeled protein complexes. In this talk, I will give an overview of these technologies including their advantages, limitations and biological applications. Emphasis will be placed on use of a double-helical point spread function for 3D single-molecule localization microscopy. This technology is capable of the imaging a large depth range (~2.5 μm) while maintaining very precise localization (20-30 nm laterally, 35 nm axially). I will compare this technology to others in the field, discuss recent advances and introduce a commercial option for straight-forward adoption.

First-Principles Based Multiscale Modeling of Dynamical Processes in Hybrid Materials Systems

Karsten Reuter

Lehrstuhl für Theoretische Chemie, Technische Universität München, Lichtenbergstr. 4, D-85747 Garching, Germany

Detailed insight into electronic and molecular processes in hybrid material systems is a key driver for advances in application areas like nanotechnology, molecular electronics or drug delivery. While predictive-quality computational modeling assumes an increasing role in providing this insight, current methodology still battles with the strong variations in entropic contributions and electron localization that are often characteristic at solid-gas or solid-liquid interfaces. First-principles techniques are challenged in the description of molecular levels and concomitant electronically excited states in particular at metal surfaces. Many relevant molecular processes are rare events and correspondingly necessitate extended time-scale simulations that capture the complex and rough free energy barriers especially at solid-liquid interfaces. The need for methodological advances extends thereby over both accurate reference techniques and efficient approaches for a computational screening. I will review our recent activities in this context, focusing on functional organic molecules at surfaces, as well as on electron transfer in and dissolution from molecular crystals.

A mechanical topological insulator

Sebastian Huber

Institut f. Theoretische Physik, ETH Zürich, Wolfgang-Pauli-Str. 27, CH-8093 Zürich, Switzerland

A topological insulator, as originally proposed for electrons governed by quantum mechanics, is characterized by a dichotomy between the interior and the edge of a finite system: The bulk has an energy gap, and the edges sustain excitations traversing this gap. However, it has remained an open question whether the same physics can be observed for systems obeying Newton's equations of motion. We conducted experiments to characterize the collective behavior of mechanical oscillators exhibiting the phenomenology of the quantum spin Hall effect. The phononic edge modes are shown to be helical, and we demonstrate their topological protection via the stability of the edge states against imperfections. Our results may enable the design of topological acoustic metamaterials that can capitalize on the stability of the surface phonons as reliable wave guides.

Why do rigid tumours contain soft cancer cells?

Josef A. Käs

University of Leipzig, Faculty of Physics and Earth Science, Linnéstraße 5, 04103 Leipzig, Germany

As early as 400 BCE, the Roman medical encyclopaedist Celsus recognized that solid tumours are stiffer than surrounding tissue. However, cancer cell lines are softer, which facilitates invasion. This paradox raises several questions: Does softness emerge from adaptation to mechanical and chemical cues in the external microenvironment, or are soft cells already present inside a primary tumour? If the latter, how can cancer tissue be more rigid than normal tissue and yet contain more soft cells?

Here we show that in primary samples from patients with mammary and cervix carcinomas, cells do exhibit a broad distribution of rigidities, with a higher fraction of softer and more contractile cells compared to normal tissue. Mechanical modelling based on patient data reveals that tumours with asignificant fraction of very soft cells can still remain solid. Moreover, in tissues with the observed distributions of cell stiffness, softer cells spontaneously self-organize into multicellular streams, possibly facilitating cancer metastasis.

Single-molecule Electronics and Optics

Emanuel Lörtscher

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The vision of molecular electronics is to employ single molecules as functional building blocks in electronic circuits.[1] Various candidates are characterized using a mechanically controllable break-junction and a statistical measurement procedure.[4] Besides current rectification[2] conductance switching is one fundamental operation required for electronic applications. Organometallic compounds[3] with embodied redox-active metal centers are a promising novel class of functional molecules as they do not need to undergo conformational changes upon changing their redox state. Compounds bearing Fe, Ru or Mo metal centers with an extensive charge-delocalization over the entire unsaturated organometallic backbone[5] are equipped with various anchoring schemes[6] including direct σ-bonds.[7] A strong hybridization of metal states and molecular orbitals as in case of direct C-Au bonds leads to a high conductance but prohibits intrinsic redox degrees of freedom.[8] By reducing the coupling strength in S-(4-ethynylphenyl)-ethanethioate anchored bis(σ-arylacetylide) complexes, voltage-induced conductance switching can be preserved. In case of Mo, the pronounced and abrupt switching with on/off conductance ratios up to 400[9] will be discussed by DFT and a two-channel transport mechanism that can also be found in purely organic Azulene derivatives.[10]

In the second part, bottom-up and directed integration concept of ensembles of molecules on a planar Silicon platform will be shown. By selective etching of a stack of various oxides, vertical nanopores can be fabricated on atomically-flat bottom electrodes[11] to act as compartments for the self-assembly of molecules for applications in molecular electronics but also in molecular factories.[12] Transport properties of alkane-dithiols will be reported revealing 3 orders of magnitude reduced conductance fluctuations in these fixed-gap devices, accompanied with the expected exponential decay in conductance as a function of molecular length. In contrast to break-junction measurements that require UHV and cryogenic temperatures, this ensemble platform can be operated under ambient conditions which represents a significant step towards the integration of molecular building blocks on a technologically relevant platform.

In the third and last part, fabrication of ultra-narrow gaps[13] with sub-5nm in-plane separations achieved by electron-beam lithography under ultra-silent conditions[14] will be demonstrated. This concept does no more require mechanical actuation to establish small gaps between the electrodes and can furthermore be used to create plasmonic antennas for single-molecule spectroscopy based on Raman scattering. Novel sensing functionalities will be demonstrated based on an alternation of optical selections rules to harvest additionally infrared modes in Raman scattering experiments to provide more comprehensive information for spectroscopy based on field-gradient Raman mechanisms.

[1] M. A. Ratner and A. Aviram, Chem. Phys. Lett. 29, 277 (1974)
[2] E. Lörtscher, B. Gotsmann, Y. Lee, L. Yu, C. Rettner, H. Riel, ACS Nano, 6, 4931 (2011)
[3] B. Kim et al.. J. Phys. Chem. C, 111, 7521 (2007)
[4] E. Lörtscher, H. B. Weber, H. Riel. Phys. Rev. Lett. 98, 176807 (2007)
[5] F. Lissel, T. Fox, O. Blacque, W. Polit, R. F. Winter, K. Venkatesan, H. Berke. J. Am. Chem, 35, 4051 (2013)
[6] F. Lissel, F. Schwarz, O. Blaque, H. Riel, E. Lörtscher, V. Venkatesan, H. Berke. J. Am. Chem. Soc., 136, 14560 (2014)
[7] Z. L. Chen, R. Skouta, H. Vazquez, J. R. Widawsky, R. Schnebeli, W. Chen, M. S. Hybertsen, R. Breslov, L. Venkataraman. Nature Nanotech., 6, 353 (2011)
[8] F. Schwarz, G. Kastlunger, F. Lissel, H. Riel, K. Venkatesan, H. Berke, R. Stadler, E. Lörtscher. Nano Lett., 4, 14, 5932 (2014)
[9] F. Schwarz, G. Kastlunger, F. Lissel, C. Egler-Lukas, S. N. Semenov, K. Venkatesan, H. Berke, R. Stadler, E. Lörtscher. Nature Nanotechnology, 11, 170 (2016)
[10] F. Schwarz, G. Kastlunger, M. Koch, H. Berke, R. Stadler, K. Venkatesan, E. Lörtscher. Angewandte Chemie International Edition, accepted (10.1002/anie.201605559) (2016)
[11] G. Puebla-Hellmann, M. Mayor, E. Lörtscher. IEEE Nano, 15, 1197 (2016)
[12] G. Puebla-Hellmann, M. Mayor, E. Lörtscher. CHIMIA, 70, 432-438 (2016)
[13] C. M. Gruber, L. O. Herrmann, A. Olziersky, G. F. Puebla-Hellmann, U. Drechsler, T. von Arx, M. Bachmann, M. Koch, Z. J. Lapin, K. Venkatesan, L. Novotny and E. Lörtscher. IEEE Nano, 15, 20 (2016)
[14] E. Lörtscher, D. Widmer, B. Gotsmann. RCS Nanoscale, 5, 10542 (2013)

Charge transport in conjugated polymers: interplay of length-scales and disorder

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Design rules to impart high carrier mobility to polymeric semiconductors have often been built under the assumption that a high degree of order and crystallinity is needed. Recently however, record-breaking semiconducting polymers have challenged this paradigm by exhibiting a high mobility and a surprisingly low degree of order. Indeed, charge transport in semicrystalline polymers depends on the complex interplay of different phases and their connectivity and cannot be simply related to overall crystallinity. In this talk I will discuss the role of different length-scales on transport. I will start at the molecular scale, where small changes to the side-chains can have a large impact on transport. I will then analyze the interplay of the amorphous and crystalline regions of the polymer by discussing disorder in the crystallites and their connectivity through the amorphous regions. Finally, I will show a theoretical model that explicitly take into account the macromolecular nature of the semiconductor, which provides an explanation for the existence of a type of electronic trap that is unique to polymers. Ultimately, a multiscale approach is necessary to understand why polymers exhibit high mobility and evolve design rules to further enhance charge transport.

Can we create evolution from scratch?

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How could life start on the early earth? Central to the question is how molecular evolution - replication, selection, mutation - can be driven 'hands-free' from basic building blocks under geologically plausible conditions. We will not answer the historical Origin of Life question - but shed light into how living systems in principle can originate from the possibilities of early planets, comets and asteroids.

We focus on non-equilibrium settings to drive simple systems:
- We show long term feeding of a polymerase chain replication by a thermal gradient, harnessing a newly found length selectivity. The replication of long DNA is out-competing short DNA.
- pH gradients form by the selective accumulation of phosphate in a thermal trap. This will allow the build up of pH gradients on vesicles to drive the chemiosmotic reactions such as ATP-Synthase.
- Shallow thermal gradients of only 100K per 1 meter can already drive replication and accumulation in a pore - however at a slower time scale.
- The ribo-PCR of Gerald Joyce, a 200mer RNA molecule that replicates short RNA similar to PCR, was driven by in a thermal convection.
- DNA accumulates 1000-fold next to air bubbles in a thermal gradient. The mechanism is based on capillary flow, continuous evaporation and recondensation cycles and thermophoresis.
- Cooperative ligation implements nonlinear replication very similar to hypercycles. The reaction does not require many replicators, but is implemented in sequence space on a DNA molecule. The result is a mode of replication that decides between sequences spontaneously in a concentration dependent manner, setting the stage for Darwinian Evolution.

We argue based on the last experiments that in-situ condensation will allow long term replication cycles of homogeneous, chiral and sequence pure DNA molecules. The necessary starting materials for such a molecular evolution could be merely 3 molecules when driven by a thermal trap.

Seeing Electrons in 2D – Light/Matter Interactions in Atomically Thin Semiconductors

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Graphene, a single atomic layer of carbon atoms, has attracted great attention because of its novel physical properties and potential for technology. Recently, this interest has expanded to the wider class of two-dimensional materials that occur naturally as 2D layers of van-der-Waals crystals. While preserving graphene's flexibility and tunability by external perturbations, atomically thin layers of this broader set of materials provide access to more varied electronic and optical properties, including semiconducting and insulating behavior.

In this paper, we will discuss some of the distinctive properties of atomically thin 2D semiconductors. We will focus on the family of transition metal dichalcogenides (MX_2 where M = Mo, W and X = S, Se, Te) and how these materials interact with and can be probed by light. Although weak light emitters as bulk crystals, at monolayer thickness they emit light efficiently, a consequence of the change in band structure to direct-gap materials. We will present some of the surprising characteristics exhibited by these systems in the extreme 2D limit, including their strong and anomalous excitonic effects and their valley selective excitation and control. We will also describe progress in forming heterostructures of such 2D layers and the novel electronic and optical properties that these new artificial materials exhibit.

Charge transport in large-area graphene

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Early experiments on charge transport in graphene were carried out in micrometer sized exfoliated samples. I will report on experiments using large-area samples, in which quite different physics becomes apparent. In monolayer graphene, the charge transport is dominated by electron-electron interaction corrections, which can be seen both in the (magneto-) conductivity [1] as well as in tunnelling experiments. In bilayer graphene, stacking faults between the two layers dominate the transport properties, leading to a spectacular classical linear magnetoresistivity [2], an enigmatic phenomenon in solid state physics that was so far barely understood. I will further show that such stacking faults that can easily be imaged [3], and generate rich phenomenology. In particular, stacking faults in conjunction with evanescent states may resolve the puzzle of the bimodal insulating/conducting low-temperature charge transport the bilayer.

[1] J. Jobst, D. Waldmann, I.V. Gornyi, A.D. Mirlin, H.B. Weber, Electron-Electron Interaction in the Magnetoresistance of Graphene, Physical Review Letters, 108 (2012) 106601.
[2] F. Kisslinger, C. Ott, C. Heide, E. Kampert, B. Butz, E. Spiecker, S. Shallcross, H.B. Weber, Linear magnetoresistance in mosaic-like bilayer graphene, Nat Phys, 11 (2015) 650-653.
[3] B. Butz, C. Dolle, F. Niekiel, K. Weber, D. Waldmann, H.B. Weber, B. Meyer, E. Spiecker, Dislocations in bilayer graphene, Nature, 505 (2014) 533-+.

Tailoring properties and structures of zinc oxide nanomaterials from energy to biomedical applications

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Zinc Oxide (ZnO) micro- and nanostructured materials have been developed since almost two decades, however they are still attracting a lot of interest in various research fields and applications. Actually, ZnO shows the co-presence of several unique physical properties, being not only a semiconductor, but also a piezoelectric and pyroelectric material.[1] It can be easily synthesized in various morphologies and shapes, which allows therefore the proper tuning of crystallinity, surface area and chemistry, including chemical functionalization, as well as optical and electrical properties and control of the wetting behavior.[2] In addition, it was recently explored the possibility of doping ZnO nanomaterials with other elements to increase the plethora of possible applications.[3] ZnO has been therefore proposed for a wide range of devices, including laser and light-emitting diodes,[4] piezoelectric nanogenerators and transducers,[5,6] gas sensors,[7] anode for water splitting photodevices,[8] dye sensitized solar cells[9] and lithium-ion batteries,[10] and recently also a combined temperature-pH- ultraviolet multisensor[11] and a protein biosensors.[12] This lecture will cover a broad overview of the above mentioned properties and structures of ZnO nanomaterials and the related applications which can be obtained.

[1] V. Cauda, R. Gazia, S. Porro, S. Stassi, G. Canavese, I. Roppolo, A. Chiolerio in B. Bhushan, et al. (Eds.) "Handbook of Nanomaterial Properties", 2014, XXVII, 1464 pages, Springer Verlag, Berlin Heidelberg.
[2] C. Ottone, S. Stassi, P. Motto, M. Laurenti, D. Demarchi, V. Cauda in L. J. Wilson Ed. "Nanowires: Synthesis, Electrical Properties and Uses in Biological Systems" 2014, pp.1-57, Nova Publishers.
[3] M. Laurenti, G. Canavese, A. Sacco, M. Fontana, K. Bejtka, M. Castellino, F. C. Pirri, V. Cauda Adv. Mater. 2015, 27, 4218.
[4] M. Sessolo, H. Bolink, Adv. Mater. 2011, 23, 1829.
[5] V. Cauda, S. Stassi, A. Lamberti, M. Morello, C. F. Pirri, G. Canavese Nano Energy 2015, 18, 212.
[6] S. Stassi, V. Cauda, C. Ottone, A. Chiodoni, C. F. Pirri, G. Canavese, Nano Energy 2015, 13, 474.
[7] Calestani, D. M. Zha, R. Mosca, A. Zappettini, M.C. Carotta, V. Di Natale, L. Zanotti, Sensors Actuat. B Chem. 2010, 144, 472.
[8] S. Hernández, V. Cauda, A. Chiodoni, S. Dallorto, A. Sacco, D. Hidalgo, E. Celasco, C. F. Pirri ACS Appl. Mater. Interf. 2014, 6, 12153.
[9] D. Pugliese, F. Bella, V. Cauda, A. Lamberti, A. Sacco, E. Tresso, S. Bianco ACS Appl. Mater. Interf. 2013, 5, 11288.
[10] V. Cauda, D. Pugliese, N. Garino, A. Sacco, S. Bianco, F. Bella, A. Lamberti, C. Gerbaldi Energy 2014, 65, 639.
[11] B. Miccoli, V. Cauda, A. Bonanno, A. Sanginario, K. Bejtka, F. Bella, M. Fontana, D. Demarchi Sci. Rep. 2016, 6, 29763.
[12] A. Sanginario, V. Cauda, A. Bonanno, S. Sapienza, D. Demarchi RSC Adv. 2016, 6, 891.

Periodically driven quantum systems

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Periodically driving quantum many-body systems often leads to exotic phenomena that are absent in their undriven counterparts. Examples include, topolgically non-trivial band structures that are realized by driving topologically trivial systems and metals that are created by driving fully insulating systems. We will discuss how such exotic phases can be stabilized in generic interacting many-body systems via an intermediate prethermal regime. Furthermore will explore the response of an insulating, many-body localized system and how this robust phase can be melted by periodic driving. Understanding these questions, paves the way for realizing novel out-of-equilibrium quantum phases that do not possess an equilibrium analogue.

Whole cell imaging with DNA-PAINT on a spinning disk confocal microscope

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While DNA-based super-resolution imaging has many advantages over traditional methods, there is also one major drawback, which thus far has prevented DNA- and Exchange-PAINT to be truly useful for the single-molecule analysis of whole cells or even tissues: Dye-labeled imager strands are non-fluorogenic, which means that total internal reflection or oblique illumination is necessary to efficiently detect single-molecule binding events over the "background" of unbound, diffusing molecules. The necessity for these imaging conditions (TIR and oblique illumination) limits DNA-PAINT to targets close to the glass surface. In order to overcome this limitation, we adapted DNA-PAINT to Spinning Disk Confocal (SDC) microscopes. With only slight modifications to a commercial SDC unit (mainly increasing laser excitation power), it is possible to obtain 2D super-resolution optical "sections" (~500 nm thick) throughout a whole cell using 3-target Exchange-PAINT for microtubules, TOM20, and HSP60 with ~20 nm spatial resolution.

Additionally, by introducing optical astigmatism in the detection path, we were able to achieve true 3D super-resolution in single optical sections. This now enables ~20 nm spatial in the x-y dimension and ~80 nm in the z dimension on a standard commercial SDC unit, opening the door to whole-cell and even tissue-scale imaging systems biology with DNA-PAINT.

Exploring Materials Universes: the case of an exotic insulator that behaves like a metal

Suchitra Sebastian

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Materials comprise trillions of electrons that interact with each other to create a diversity of physical behaviours. We owe much of modern technology - from powerful computing to the marvels of communication - to discoveries of new types of collective electron behaviours in materials. Such discoveries, however, are often serendipitous, given that materials can be thought of as complex universes teeming with vast numbers of electrons, making their behaviours challenging to understand or predict. A question we are often confronted with is how to make progress in discovering novel collective electron behaviours akin to new universes. I will discuss possible approaches to increasing the odds of making discoveries, with examples from cases such as new superconductors and new types of dual metal-insulating materials. In particular, I will discuss the surprising case of the Kondo insulator SmB6 in which we have observed a Fermi surface characteristic of a metal. Potential models will be discussed in the context of our findings.

From cell mechanics to light sheet microscopy: imaging molecules, cells, and embryos at high spatiotemporal resolution

Wesley Legant

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By definition, living specimens are animate. Therefore, a full understanding of dynamic biological systems will only be obtained by observing them with enough 4D spatio-temporal resolution and for a sufficient duration, to capture the phenomena of interest. Unfortunately, conventional widefield or confocal microscopes are either too slow, lack the spatial resolution, or induce too much photodamage to meet these requirements. To address these limitations, we have developed Lattice Light Sheet Microscopy, a new sub-cellular light-sheet microscopy method capable of imaging fast 3D dynamic processes in vivo at signal to noise levels approaching those obtained by total internal reflection fluorescence (TIRF) illumination. By utilizing 2D optical lattices, we generate a thin (~800 nm full width half maximum) plane of light coincident with the focus of a high numerical aperture detection objective. Using this technique, we demonstrate substantial advantages in speed, sensitivity and reduced phototoxicity compared to conventional point scanning and spinning disc confocal microscopes as well as light-sheet microscopes utilizing single Gaussian or Bessel beams. We leverage these advantages to image samples ranging over three orders of magnitude in length scale from single molecules to whole embryos. Specific examples include: single molecule tracking of fluorescently tagged transcription factors in densely labeled embryonic stem cell spheroids, 3D imaging of microtubule growth phases and organelle dynamics throughout the course of cell division, 3D cell migration through collagen matrices, and protein localization throughout the course of dorsal closure in Drosophila embryos. Further, by combining lattice light sheet microscopy with point accumulation for imaging of nanoscale topography (PAINT) microscopy and novel fluorescent probes, we demonstrate 3D super-resolution localization microscopy over large fields of view and in thick 3D samples such as dividing cells and small embryos.

DNA Nanopores

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DNA-based nanopores are synthetic biomolecular membrane pores, whose geometry and chemical functionality can be tuned using the tools of DNA nanotechnology. These features make them promising molecular devices for single molecule sensing and applications in nanomedicine or synthetic biology. In this talk a new generation of DNA nanopores will be introduced and their potential applications will be outlined. The pores spontaneously insert into lipid bilayer membranes, display stable electrical properties and vary in diameters and stem lengths. Membrane incorporation is facilitated by large numbers of hydrophobic functionalizations or using streptavidin linkages between biotinylated channels and lipids. Spontaneous insertion was demonstrated using giant unilamellar vesicles in a fluorescent dye influx assay. Electrical single channel recordings demonstrate a correlation between channel geometry and electrical conductance and a large DNA channel with a ≈ 4 nm diameter pore was shown to permit passage of double-stranded DNA molecules.

S. Krishnan et al., Nature Communications, in press, September 2016

Electrospray Ion Beam Deposition of Proteins, Peptides, and Sugars: Macromolecular Structure Revealed by STM

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Measuring and understanding the complexity that arises when synthetic or natural, molecular nanostructures interact with their environment are a current challenge of nanoscale science and technology. High-resolution microscopy methods such as scanning probe microscopy or electron microscopy have the capacity to investigate nanoscale systems with ultimate precision, for which, however, atomic scale precise preparation methods of surface science are a necessity. Often however, ultrahigh vacuum surface science and biological molecules are incompatible. Preparative mass spectrometry (pMS) with soft ionization sources links the world of large, biological molecules and surface science, enabling atomic scale chemical control of molecular deposition in ultrahigh vacuum.

In this talk I explore the application of high-resolution scanning probe microscopy to the characterization of structure and properties of large molecules at surfaces. I briefly introduce the fundamental principles of the combined experiments electrospray ion beam deposition. Examples for the deposition and investigation of single particles, for layer and film growth, and for the investigation of structure, conformation, and electronic properties of individual nonvolatile molecules are presented.

They show that our methodology offers a highly controlled and pure path to high resolution microscopy with unique features of the deposition due to the use of charged polyatomic particles. This new field is an enormous sandbox for researching novel, sequence controlled molecular materials and large, individual molecules.

[1] S. Rauschenbach, M. Ternes, L. Harnau & K. Kern: Mass Spectrometry as a Preparative Tool for the Surface Science of Large Molecules. Annu. Rev. Anal. Chem. 9 (2016) pg 16.1–16.26

POSTER ABSTRACTS - SESSION I (A-KRI)

Fully Inorganic Lead Halide Perovskite Nanocrystals for Light-Emitting Electrochemical Cells

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Hybrid organic-inorganic and fully inorganic lead halide perovskite materials have the potential to revolutionize not only the photovoltaics industry but also lighting technologies. In particular, their nanostructures have energized the lighting communities' efforts to create devices from earth abundant and inexpensive constituents due to their narrow size distributions as well as their narrow emission line widths, and high photoluminescence quantum yields (PLQY) of over 90%. Recently, fully inorganic perovskite nanocrystals (NCs), such as $CsPbX_3$ (X = Cl, Br, I) NCs, have become particularly interesting for lighting applications due to their higher stability over hybrid organic-inorganic ones and efficient synthesis methods. Here, we have synthesized fully inorganic $CsPbBX_3$ (X = Cl, Br, I) NCs using a hot injection synthesis route. We have characterized their structural, morphological and photophysical properties in detail. We have found that the purification of NCs is very important for the film formation, where we have observed rods and inhomogeneous coverage if no further purification steps were employed after the synthesis. We have implemented these NCs with high PLQYs into light emitting electrochemical cells (LECs), achieving a brightness of 8 cd/m^2 for the NCs based on a mixture of bromide and iodide halides at low driving currents. Overall, we believe that fully inorganic perovskite NCs are promising components of lighting devices thanks to their outstanding performance.

Quantitative single-molecule three-color FRET for the study of coordinated intramolecular motion

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Single-pair FRET (spFRET) has become a standard tool to monitor conformational changes of biomolecules *in vitro*. In solution-based burst analysis, the burst of photons emanating from molecules diffusing through the confocal volume gives access to the underlying distribution of the FRET efficiency. Multiple intramolecular distances can be explored in individual experiments, however information about the coordination of motion is not available. A promising approach to address the coordination of motion within complex biological systems is multicolor FRET, allowing multiple distances to be monitored simultaneously. While several three- and four-color FRET studies have already been performed, quantitative analysis of multicolor single molecule data remains a challenge. This is due to the inherent problems encountered in three-color FRET, i.e. increased shot noise due to the distribution of the fluorescence signal on three channels, more complicated FRET efficiency calculations, and higher experimental imperfections because spectrally more similar fluorophores have to be used. Multicolor FRET is thus still limited to the extraction of average values due to the complexity of the analysis, losing additional information encoded in the distribution of FRET efficiencies.

Here, we present a statistical model for the three-color FRET process in diffusion-based single-molecule FRET experiments to effectively deconvolute the experimentally obtained photon count distribution, allowing to directly address the physically relevant underlying distance distribution quantitatively. Based on simulated and experimental data, we demonstrate that the underlying probability distributions of the three interdye distances can be extracted with high accuracy, and that information about the coordination of intramolecular motions can be obtained. The new method is applied to elucidate the role of allosteric effects in different members of the Hsp70 protein family.

Establishing a DNA origami platform for single-molecule fluorescence studies of DNA double-strand break repair

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Custom-designed DNA nanostructures (DNA origami) are a useful platform for precisely arranging molecules on the nanometer scale. Thus, it is possible to create a locally high concentration of biomolecules and to investigate biomolecular interactions with low affinity, while maintaining the overall concentration low enough to perform single-molecule experiments. We use DNA origami as a model system to explore mechanisms and dynamics of macromolecular complexes, e.g. during the repair of DNA double-strand-breaks (DSBs). DNA DSBs are considered the most cytotoxic form of DNA damage and efficient repair is crucial to maintain genomic integrity. Although the overall process of non-homologous end joining (NHEJ) – the major pathway to repair DNA DSBs in higher organism – is well documented, little is currently known about the dynamics during the assembly of the repair complex. To investigate the molecular mechanism during NHEJ, we designed a DNA origami structure with attachment sites for two DNA double-strands to specifically mimic a DNA DSB. Following assembly and purification, transmission electron microscopy (TEM) images demonstrated the correct folding of our DNA origami. In a proof of principle experiment, two fluorescently labeled DNA double-strands were bound to the DNA origami and their complementary overhangs of four nucleotides "repaired" with the T4 DNA ligase. The successful ligation reaction was monitored by single-molecule Förster Resonance Energy Transfer (FRET). Thus, the presented DNA origami structure provides a useful platform for further single-molecule fluorescence studies of DNA DSB repair.

Terminal domains of *Streptococcus pneumoniae* TIGR4 pilus-1 tip protein RrgA mediate human fibronectin-interaction displaying distinct molecular biomechanics

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Streptococcus pneumoniae represents a major human pathogen with high mortality rates worldwide. Among other virulence factors surface appendages (pili) are involved in host colonization and invasion. Pneumococcal TIGR4 pilus-1 is composed of a cell wall anchor (RrgC), multiple covalently linked RrgB backbone subunits and a terminal RrgA adhesion molecule. RrgA is a four domain (D1-D4), elongated molecule with multiple binding motifs capable to interact with specific host components like extracellular matrix molecules (ECMs).
This study describes molecular details of RrgA – ECM fibronectin (Fn) interplay, with particular emphasis on underlying biomechanics. Single molecule force spectroscopy defines RrgA-Fn interaction as rapid dissociation with fast rebinding with binding forces in the force range of typical receptor-ligand systems whereas RrgB shows no specific binding towards Fn. ELISA based analysis reveals Fn interaction to be mainly mediated by the two distinct, terminal domains D3 and D4 of RrgA which bind to Fn in a similar force range as full-length RrgA but apparently display a different kinetic behaviour.
Ongoing studies will translate these data into a functional context of pilus-1 related pneumococcal pathogenesis and evaluate potential general principles applicable to other systems of pilus-mediated host interaction.

AFM revealed pH-dependent interactions in dimeric subunits to regulate structure and mechanics of the blood clotting protein von Willebrand factor

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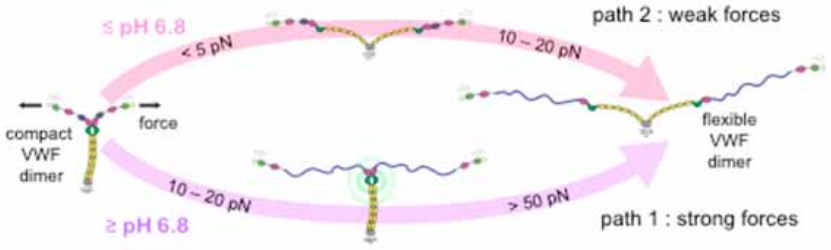
Von Willebrand factor (VWF) is a multimeric glycoprotein in the blood plasma that is activated to trigger blood clotting by increased hydrodynamic forces in the blood stream, e.g., at sites of vascular injury or vasoconstrictions. By atomic force microscopy (AFM) imaging and single-molecule AFM force measurements, we could show that the structure and mechanics of VWF are governed by multiple pH-dependent interactions with opposite trends within VWF's dimeric subunits. AFM force measurements revealed that a strong intermonomer interaction, which involves VWF's D4 domain induces a firmly closed, compact con-



Two pathways at pH-values above 6.8 (path 1) and below 6.8 (path 2) from a compact (left) to a flexible VWF dimer (right) under force. In pathway 1 first the A2-domains unfold (schematic lines) followed by the strong D4 domain mediated interaction (fading rings) opening at forces above 50 pN.

formation of dimers[1]. This conformation occurred with highest frequency at pH 7.4, but was essentially absent at pH values below 6.8. In contrast, single molecule AFM imaging showed that the ratio of compact dimers increased with decreasing pH below pH 6.8[2]. Therefore, we concluded that the compactness of dimers at pH values below 6.8 is promoted by weaker interactions that possess low mechanical resistance compared to the strong intermonomer interaction (see Figure). By investigating VWF constructs lacking the D4 domain, we found that compactness at low pH primarily was mediated by the D4 domain, i.e., remarkably by the same domain that also mediates the strong intermonomer interaction. The less compact the more sensitive VWF is to shear stress in the vasculature. Since our data suggest that VWF is compacted with highest mechanical resistance at physiological pH, local deviations from physiological pH, (e.g. at sites of vascular injury) may represent a means to enhance VWF's hemostatic activity. Overall, our findings provide new insights into the mechanisms behind VWF's force-dependend function, and thus help to understand VWF related diseases, such as bleeding disorders and thrombosis.

[1] Müller J.P., et al. "Force sensing by the vascular protein von Willebrand factor is tuned by a strong intermonomer interaction" 2016, PNAS 113 (5), 1208–13
[2] Müller J.P., et al. "pH-Dependent Interactions in Dimers Govern the Mechanics and Structure of von Willebrand Factor" 2016, Biophys J ; 111, 312–22

Multistate Emissive N-Doped Carbon Dots: The Trade-off between Photoluminescence Properties and Photocatalytic Hydrogen Generation

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Luminescent carbon dots have garnered the attention of modern research as a new generation of carbon material due to their potential applicability for several photonic, bio-photonic and light-energy conversion devices. However, the fundamental understanding of complicated photophysics, especially the origin of multistate luminescent behavior, is still at an early stage. Considering the current demands, we have synthesized citric acid- derived carbon dots, varying the concentration of a nitrogen-containing precursor, a branched polyetheleneimine (BPEI), in a simple microwave irradiation technique. Upon increasing the BPEI content gradually, the florescence quantum yield (QY) of the carbon dots gradually increases up to a certain extent and after that it starts decreasing. In contrast, solar light- driven photocatalytic hydrogen generation follows the reverse trend of QY. This process does not require any metal co-catalyst, when illuminated with a full spectrum Xenon lamp. Finally, we are able to achieve an optimized carbon dot having the highest photocatalytic performance (~450 µmole H_2/gram) and consequently lowest PL QY (~<1%). This indicates a controlled trade-off mechanism between the luminescent properties (based on radiative and/non-radiative recombination) and overall charge separation processes followed by photocatalytic hydrogen generation. In-depth morphological investigation (based on Raman spectroscopy, X-ray photoelectron spectroscopy, electron microscopy etc.) and time resolved optical spectroscopic data has been carried out to illustrate the overall inter-dependency of multi-state emissive properties and photocatalytic activity. In general, these results can be highly beneficial for carbon-based material research and further their applicability for several light-energy conversion devices.

Investigation of the interface layer between a living cell and its substrate

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Cell adhesion plays an essential role for all animals and plants and it is a huge challenge in many medical applications including implants and electrodes. When cells attach to a substrate, an ultrathin layer of the order of a few 10 nm between the plasma membrane of the cell and the substrate is formed. This extracellular matrix (ECM) layer is modulated by the cell by adhesion molecules and other interactions. The huge experimental challenge is how to characterize this buried layer. For example, one would like to understand to which extend water and ions in this interface layer exchange with the growth media.
Here, we focus on the structural properties of this submicron cleft between the cells and the substrate. For this purpose, we have developed a sample chamber which allows studying confluent layers of epithelial cells on SiO_2 by scattering techniques. Additionally the chamber is equipped with a holographic microscope allowing us to observe the cells during growth and even during a scattering experiment. Using this setup, we determine the thickness and the scattering length density across the cleft with neutron reflectometry. We also investigate the fluid exchange in the cleft by contrast variation by H_2O/D_2O buffer exchange.

Ultrafine ruthenium-iridium oxide nanoparticles with enhanced electrocatalytic activity for water oxidation

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Generation of hydrogen via electrochemical water splitting is one of promising technologies to overcome our dependency on fossil fuels, but the efficiency of this process is very low without catalysis of both half-reactions. Particularly, catalysis of oxygen evolution reaction (OER) is of great importance for improving the total efficiency of water electrolysis. Ruthenium oxide is a state of the art OER catalyst for acidic electrolysis, but its serious drawbacks are high price and a limited stability in acidic electrolytes. These issues can be efficiently addressed via optimization of composition via doping and via the nanoscaling [1, 2].

In the current project we have explored the ways to improve electrocatalytic activity and stability of ruthenium oxide via formation of mixed Ru/Ir oxides and doping with Co and Ni, as well as via increasing the accessible surface of the catalyst due to decreasing particle size. We report fabrication of dispersible ultrasmall crystalline nanoparticles with a size down to a sub-nanometer range. TEM and DLS measurements reveal the amorphous nature of the $RuIrO_x$ nanoparticles with sizes down to 0.6 nm. Electroactive layers prepared from these nanoparticles demonstrate extremely high electrocatalytic activity with a very low initial overpotential of OER (η_{OER}) of 223 mV, and a mass normalized oxidation current of 65 $mA/mg_{oxide\text{-}film}$ measured at η_{OER} = 280 mV. Chronopotentiometry measurement at current densities of 10 mA/cm^2 revealed a stable catalyst material within a 72 h measurement period with an increase in the required cell voltage by only 84 mV.

The electrocatalytic activity can be further improved via the synthesis of supported and templated films of ultra-small catalyst nanoparticles and successive low temperature calcination at 300 °C. A positive effect of Co doping and Co-coating on the catalytic activity and stability revealed the potential of this approach towards the synthesis of high performance, cost-efficient and stable OER catalyst material.

[1] M. Bernicke et al, Chemsuschem, 8, 1908-1915 (2015)
[2] R. González-Huerta et al, J. Power Sources, 268, 69-76 (2014)

Creation of neural networks by manipulation of neurons employing Surface Acoustic Waves

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We propose the implementation of a new lab-on-a-chip based system for the tunable and deliberate stimulation of cell growth ranging from directed wound healing to the controlled formation of neural networks. By combining sophisticated microfluidic techniques with surface acoustic waves (SAW), we can create and stimulate simple life-on-a-chip systems. We envision precisely controlling neural network formation and signal propagation in networks of increasing complexity. We designed a SAW-Chip consisting of the piezoelectric material 128° y-cut $LiNbO_3$ with four electrodes, so called interdigital transducers (IDT), each aligned 45° to the main propagation direction. By employing a high frequency signal to the IDT structures, crossed standing waves with according nodes and antinodes are formed between the IDTs. The expected grid of pressure nodes was confirmed and visualized using atomic force microscopy. When restricted in z-direction by adding a PDMS-channel system, this equidistant patterning grid allows us to control the position of objects in space and time. Polystyrene beads of 2-10 µm were used to validate the possibility and accuracy to pattern µm-sized objects on these chips. We control temperature and pH in the microchamber on the chip to ensure cell growth conditions. Finally, by using SaOs-2 cells, we demonstrate single cell alignment, adhesion and growth at the pressure nodes on the chip. In the future, we plan on transferring this technique to single neurons. Once dynamic control of a single neuron is established, we believe this can be scaled to the network level enabling us to control and to understand how neural networks connect, interact, and communicate.

Conformational Changes and Flexibility of DNA Devices Observed by Small-Angle X-Ray Scattering

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A fundamental aim of nanotechnology is to design synthetic objects that can adopt specific conformational states and carry out functions at the molecular scale, e.g. in molecular transport, signal transduction, or molecular circuitry. Self-assembled DNA origami nanostructures enable the creation of precisely defined versatile two- and three-dimensional shapes reaching over 100 nm in size and molecular weights of several MDa. Increasingly, DNA origami goes beyond static structures towards switchable DNA devices that potentially afford completely novel functionalities for diagnostic, therapeutic, or engineering applications. Such functional and dynamic origami structures require techniques that can probe and resolve their conformational changes and three-dimensional structures, ideally in solution, free of potential biases from surface attachment or labeling. Here, we demonstrate that small-angle X-ray scattering (SAXS) can quantitatively resolve the conformational changes of a DNA switch device based on shape-complementarity and base stacking interactions as a function of the ionic strength of the solution[1]. In addition, we show how SAXS data allow for refinement of the predicted idealized three-dimensional structure of the DNA object using a normal mode approach based on an elastic network model. The results reveal significant deformations of the idealized design geometries. Our results establish SAXS as a powerful tool to investigate conformational changes and solution structures of DNA origami and we anticipate our methodology to be broadly applicable to increasingly complex DNA and RNA devices.

[1] Bruetzel, et al. Nano Letters (2016), in press

DNA-guided self-assembly of nanoparticles

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Gold particles are widely used in recent application concerning nanosensing, bioimaging and biomedicine. These implementations, especially in the sensing of single molecules, strongly benefit from the plasmonic coupling between the particles. Here we report a novel method for a controlled self-assembly of gold clusters varying in size, which could later be used as nanosensors. In order to achieve this, two complementary DNA-coated gold nanoparticles are mixed in various stoichiometries. The resulting cluster growth, which emerges through diffusion limited aggregation, is restricted by the binary system. Additionally, the usage of various sized gold nanoparticles gives rise to further modulation of the cluster growth. This adjustable size modulation goes hand in hand with a distinct plasmonic coupling between the gold nanoparticles, which leads to a change of the optical properties of the particle solution. As a result, the extinction spectra can be stepwise modulated over a range of 100nm. This spectral shift can be additionally increased by using other noble metals like silver. By combining extinction measurements with single cluster spectroscopy, the resulting optical spectra can be fully understood. For a structural analysis of the clusters, darkfield measurements and cryo EM imaging are used.

In Vitro Tumor-Targeting of Functionalized Nanoparticles Fails *in Vivo*

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Nanoparticle-based therapies hold the promise of targeted drug delivery for treatment of cancers with high therapeutic efficiency and reduced systemic toxicity.1, 2 Tumor cell-specific targeting often involves functionalization of the surface of nanoparticles with ligands for receptors that are specific or overexpressed in cancer cells. Here, we show that different ligand-functionalized mesoporous silica nanoparticles specifically and efficiently target receptor-overexpressing cell lines in vitro but lose specificity when tested in vivo in genetically modified tumor mouse models.3 Functionalized nanoparticles failed to accumulate in receptor-overexpressing flank or lung tumors but accumulated in the liver or tissue-resident macrophages when applied systemically or locally to the lungs, respectively. Nanoparticle-bound targeting ligands are thus shielded by the distinct biological environment in the serum and the lining fluid of the lung and redirected to phagocytosing mononuclear cells. Novel strategies that overcome these natural defense mechanisms of the organism to foreign materials are thus required to establish efficient cell-specific nanoparticle-mediated delivery of drugs for tumor therapy.

[1] C. Argyo, V. Weiss, C. Bräuchle and T. Bein, Chemistry of Materials, 2014, 26, 435-451.
[2] K. Ulbrich, K. Holá, V. Šubr, A. Bakandritsos, J. Tuček and R. Zbořil, Chemical reviews, 2016, 116, 5338-5431.
[3] D. A. Bölükbas, S. Datz, C. Meyer-Schwickerath, M. Vreka, T. Agalioti, D. Gößl, L. Yang, C. Argyo, S. H. v. Rijt, M. Lindner, O. Eickelberg, T. Stöger, O. Schmid, G. T. Stathopoulos, T. Bein and S. Meiners, submitted.

Synergetic effects in composite networks of hydrogels and DNA coated colloids

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Tuning the mechanical properties of hydrogels is a major challenge for biomedical research due to their biocompatibility and similarity to natural tissues. Expanded functionality like drug delivery or bio-sensing can be achieved by integrating nanoparticles. We investigate the influence of colloidal structure formation on the rheological characteristics of such a composite network. The system consists of DNA coated polystyrene beads embedded in a photoactivatable polyacrylamid matrix. Using a binary system of complementary DNA coated Beads enables a specific binding and precise control over the diffusion limited structure formation by adjusting bead ratios or volume fractions. Consequently we can create composites of identical components but different pre-defined arrangements. Special focus was put on the comparison of colloidal gels and monodispersed beads, while varying the material properties of the matrix over a wide range. Within a lower polyacrylamide regime, colloids lead to an increased storage modulus in the order of one magnitude. Synergetic effects of colloidal gels like enhanced toughness and load-bearing capacity occur for higher matrix concentrations. The limit of reversible deformation could be increased up to eight times and was determined by applying stepwise shear strain. The viscoelastic measurements are performed with an oscillating rheometer and the structure formation of the colloids is monitored by confocal microscopy.

AG Physics of Nanosystems

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We will give an overview of the research performed in the newly established AG Physics of nanosystems. We aim to understand the basic electronic properties of two dimensional materials such as graphene and work in the field of organic semiconductors. Organic semiconductors are promising components of future flexible electronics. We aim to answer the following questions with our work: What are the fundamental limits to charge transport in semiconducting polymers and small molecules? How do lattice imperfections such as grain boundaries impact the transport properties? For example, we found that grain boundaries are responsible for the degradation of organic thin films under bias stress. Two dimensional materials such as graphene are highly interesting systems to study low-temperature fundamental charge transport. We study the effects of interacting charge carriers in graphene. For example, we found that in ultra-clean bilayer graphene, the exchange interaction leads to the opening of a gap in the density of states. The exact nature of the ordered state is unclear and topic of our current interest.

Spatial organization of cell-free RNA circuits

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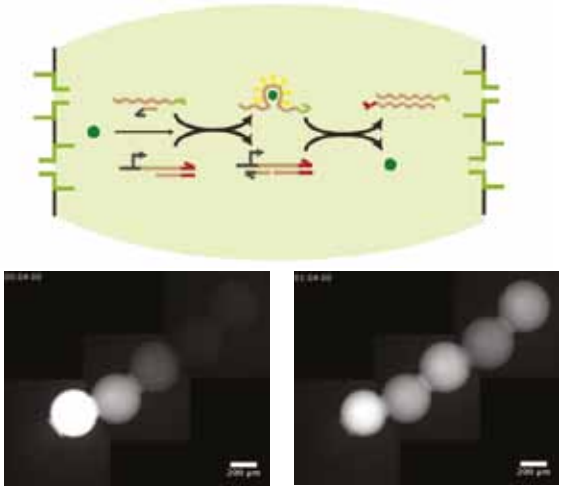
Cellular metabolism consists of vast networks of parallel reactions, whose cross-talk can be reduced and efficiency increased by localization and compartmentalization. The effect of compartmentalization on synthetic gene circuits has notably been studied in isolated water-in-emulsion droplets[1,2]. However, the communication was mediated only by non-specific diffusion. In contrast, our goal is to build large biomimetic networks exhibiting controlled communication and topology. Such a spatial organization should allow for more complex circuit dynamic behaviors. To this end, we employ the droplet-interface-bilayer technique[3] to construct spatially organized networks of defined composition. In these networks, protein pores exhibiting chemical selectivity incorporate in lipid bilayer interfaces to mediate the communication between droplets, similarly to natural cell membranes. We first proved the functionality of our networks' interfaces by placing the transcription of an RNA aptamer as an output for the translocation of a nucleotide. We then built an excitable medium using an internal negative feedback loop. We find that, upon diffusion of an inducer from a reservoir droplet, a spatial pattern emerges in the form of a propagating fluorescence pulse with tunable time delay. In the future, we envision the implementation of more complex circuits within such networks, including in vitro protein expression systems. Using spatial organization as a tool to extend the scope of biochemical circuits may lead to the creation of artificial cells and multicellular assemblies capable of more complex dynamics than isolated compartments.

[1] M. Weitz et al., Nature Chemistry (2014)
[2] M. Schwarz-Schilling et al., Integrative Biology (2016)
[3] T. Wauer et al., ACS Nano (2014)



Travelling wave circuit – a) Scheme of the RNA circuit. b) and c) Fluorescence image of the droplets array b) at assembly and c) after one hour.

Affinity of activated amino acids to RNA motifs to elucidate early patterns of the genetic code

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What defined specific assignment of amino acids to their cognate codons during the emergence of the genetic code? According to the stereochemical theory, the assignments were established based on affinity interactions between amino acids and their codons/anticodons. In the structure of the modern tRNA molecule, the acceptor stem with the amino acid and the anticodon loop with the anticodon triplet are separated by 6 nm in space, making direct interaction impossible. However, two alternative primal tRNA structures have been proposed that bring together in space the amino acid and the codon determinant [1, 2]. Both structures contain tetraloop-like geometries – simple structures that were recently shown to possess enzymatic activity such as ligation, cleavage, and terminal recombination[3].
In this project, we experimentally study the binding of stable AMP activated amino acid analogs to RNA motifs of AMP-binding aptamers as a testbed or to the above mentioned tetraloop-like structures containing corresponding coding triplets using microscale thermophoresis. We aim to elucidate patterns of anticodon-amino acid correlations for the emergence of the genetic code.

[1] J.J. Hopfield, Proc. Natl. Acad. Sci. U. S. A. 75, 4334–8 (1978)
[2] A.S. Rodin et al., Biology Direct 4, 4 (2009)
[3] P. Stadlbauer et al., Chemistry 21, 3596–604 (2015)

Biomolecular Sensor Based on a Gold-DNA-Structure with Switchable Chirality

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Detecting small sequences of RNA in biological samples such as microRNA or viral RNA demands highly sensitive and specific methods. Recent advances in nanoplasmonics have shown the potential of using reconfigurable DNA-templates to create plasmonic chiral active structures in the visible spectrum [1, 2]. DNA Origami has been used to construct switchable structures and to precisely arrange metal nanoparticles [3]. In our experiments, the chiral arrangement of gold nanorods on such DNA structures leads to the generation of strong circular dichroism by plasmon-plasmon interactions. Using a switchable cross-like DNA structure, the chirality of the plasmonic system can be flipped, producing a distinct change in the CD spectrum [3]. Switching of the DNA structure is achieved by the addition of nucleic acid sequences that act as a lock-and-key mechanism and arrest the cross-like DNA origami structure in one of the possible chiral states. By employing the specific and sensitive molecular recognition of nucleic acid sequences, specific target sequences can be detected via the structural changes of the DNA origami structures and their resulting plasmonic CD responses. Here we present the first steps towards the development of such nanoswitches as quick, optical-based detectors for pathogenic RNA or DNA sequences. Our target is a 22 bases long RNA sequence that is present in the 5' non-translating region of the hepatitis C virus genome [4]. The RNA binds to a complementary sequence which is part of the lock mechanism inside the DNA structure and thus leads to the formation of a defined and detectable chiral state of the plasmonic system. With this approach we were able to detect this specific RNA sequence at concentrations as low as 10 pM.

[1] A. Kuzyk et al., Nature 483, 311–314 (2012)
[2] A. Kuzyk et al., Nature Materials 13, 862-866 (2014)
[3] P. W. K. Rothemund, Nature 440, 297-302 (2006)
[4] P. Friebe et al., J Virol. 83(22), 11989-11995 (2009)

Migration of cancer cells in predefined 3D collagen matrices

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The metastasis of tumor cells is one of the biggest threats of cancer. The mobility of tumor cells is influenced by the structure of the surrounding tissue.[1] To study this influence, we designed several artificial tissue gels with different structures using collagen I as model system. The movement of invasive MDA-MB-231 breast cancer cells was tracked and analyzed in these gels, to determine which gel structure enhances or hinders cell migration and to further improve the understanding of the mechanisms behind the migration of these cells in connective tissue.[2] The collagen fiber length was controlled via temperature during the gelation process. Without further modification, gels consisted of randomly oriented collagen fibers. To achieve an alignment of the fibers two different methods with different rates of alignment were developed; alignment via Surface Acoustic Waves and via magnetic beads. The resulting gels were then used to measure the movement of MDA-MB-231 cells in different surroundings. The results of these measurements revealed a strong influence of the collagen fibers on the cells. The movement of the cells reaches from random migration in short collagen fibers without alignment to nearly linear movement in a collagen gel with long fibers and a high rate of alignment. These findings indicate that long, stiff, and aligned fibers promote invasion of tumor cells into connective tissue, as opposed to small, randomly oriented fibers.[3]

[1] P. Provenzano, D. Inman. K. Eliceiri, J. Knittel, L. Yan, C. Rueden, J. White, P. Keely (2008). Collagen density promotes mammary tumor initiation and progression. BMC Med. 6, 1–15.
[2] G. Doherty, H. McMahon (2008). Mediation, modulation, and consequences of membrane-cytoskeleton interactions. Annu. Rev. Biophys. 37, 65–95.
[3] K. Levental, H. Yu, L. Kass, J. Lakins, M. Egeblad, J. Erler, S. Fong, K. Csiszar, A. Giaccia, W. Weninger, M. Yamauchi, D. Gasser, V. Weaver (2008). Matrix Crosslinking Forces Tumor Progression by Enhancing Integrin Signaling. Cell 139, 891–906.

Femtosecond pulse shaping microscopy on single nanostructures

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Multi-pulse experiments are well-known in microscopy and spectroscopy. On the one hand the time resolution provided by these techniques allows the investigation of ultrafast dynamics and processes as demonstrated by pump-probe experiments for example. On the other hand multi-pulse experiments contain spectral information which is accessible by Fourier transformation of the pulse delays [1]. This enables for instance the determination of absorption spectra of individual nanostructures such as carbon nanotubes by broadband two pulse excitation correlation. Importantly, these measurements are not limited to two pulses, but can be extended to three and four pulse schemes, which form a well-established tool in vibrational spectroscopy named 2D IR spectroscopy. It enables the investigation of the molecular structure, its vibrational dynamics and also allows monitoring of reactions on very short time scales. Furthermore, 2D spectroscopy can be utilized for time-resolved investigation of coherent dynamics in materials. In recent years the technique was extended and applied to two-dimensional electronic spectroscopy revealing coherent dynamics of electronic states by detection of photocurrent [2,3]. We report on our results using this technique to study the nonlinear properties of one- and two-dimensional nanostructures in detail.

[1] Piatkowski et al., Nat. Commun. 7, 10411 (2016)
[2] Karki et al., Nat. Commun. 5, 5869 (2014)
[3] Cassette et al., Nat. Commun. 6, 6086 (2015)

Immune response to functionalized mesoporous silica nanoparticles for targeted drug delivery

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Multifunctional mesoporous silica nanoparticles (MSN) have attracted substantial attention with regard to their high potential for targeted drug delivery. Due to their different possible molecular functionalization in the core and the shell, the MSN can be equipped with internal functionality for controlled host-guest interactions, a system for cargo release responding to external stimuli, as well as targeting ligands towards the cells of interest. A broad variety of different triggered-release capping systems were presented in the past years, based on external stimuli, or triggered by intracellular events. We recently reported a multifunctional system based on a pH-responsive polymer (poly(2 vinylpyridine), MSN-PVP)[1] that allows for the facile delivery of membrane-permeable cargos into cancer cells. With the possibility to integrate almost any functionality of interest, this system holds promise for wide-ranging biological and medical applications. With spatio-temporally controlled release of their therapeutic cargo, such nanoparticles have the potential to increase drug efficacy while minimizing undesired off-target effects. However, due to their nanoscale size, chemical composition and surface reactivity, nanoparticles can be potentially detected by and interact with the host immune response. While in certain applications (e.g. vaccine delivery) an immunostimulatory function may be desirable, uncontrolled systemic immune activation will limit their therapeutic use. Thus, the profound understanding of a nanomaterial's interaction with the immune system and its possible stimulatory and suppressive actions are a critical prerequisite for any clinical application.

In this contribution, we assess the biocompatibility and functionality of multifunctional MSN in freshly isolated, primary murine immune cells. [2]We show that the functionalized silica nanoparticles are rapidly and efficiently taken up into the endosomal compartment by specialized antigen-presenting cells such as dendritic cells. The silica nanoparticles showed a favorable toxicity profile and did not affect the viability of primary immune cells from the spleen in relevant concentrations. Cargo-free MSN induced only very low immune responses in primary cells as determined by surface expression of activation markers and release of pro-inflammatory cytokines such as Interleukin-6, -12 and -1β. In contrast, when surface-functionalized MSN with a pH-responsive polymer capping were loaded with an immune-activating drug, the synthetic Toll-like receptor 7 agonist R848, a strong immune response was provoked.
We thus demonstrate that functionalized MSN represent an efficient drug delivery vehicle to primary immune cells that is both non-toxic and non-inflammagenic, which is a prerequisite for the use of these particles in biomedical applications.

[1] S. Niedermayer, V. Weiss, A. Herrmann, A. Schmidt, S. Datz, K. Müller, E. Wagner, T. Bein, C. Bräuchle, Nanoscale 2015, 7, 7953–7964.

[2] Simon Heidegger, Dorothée Gößl, Alexandra Schmidt, Stefan Niedermayer, Christian Argyo, Stefan Endres, Thomas Bein, Carole Bourquin, Nanoscale 2016, 8, 938–948.

Optimal compartmentalization strategies for metabolic microcompartments

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Intracellular compartmentalization of cooperating enzymes is a key strategy in cell metabolism for alleviating the challenges of toxic pathway intermediates, competing metabolic reactions, and slow turnover rates. Inspired by nature, synthetic biologists also seek to encapsulate engineered metabolic pathways within vesicles or proteinaceous shells to enhance the production yield of syn- thetic chemicals and biofuels. Although enzymatic compartments have been extensively studied experimentally, a quantitative understanding of the underlying design principles is still lacking. Here, we studied a model two-step pathway encapsulated within a permeable shell and ask what are the optimal strategies for distributing enzymes among compartments so as to maximize the total rate of product formation. We find that maximizing productivity requires compartments larger than a certain critical size. The enzyme density within each compartment should be tuned according to a power-law scaling in the compartment size. If compartments are constrained to be smaller than the critical size, then the optimal strategy is to pack enzymes as densely as possible within these com- partments. We explain these observations using an analytically-solvable well-mixed approximation, and examine how these strategies are altered in parameter regimes where this approximation breaks down. Our results suggest that the different sizes and enzyme packings of α- and β-carboxysomes each constitute an optimal compartmentalization strategy given the properties of their respective protein shells.

Direct observation of the first steps in gelsolin-mediated actin filament nucleation

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Actin filament elongation has been extensively studied in bulk assays. The direct observation of the nucleation process on the single molecule level, however, has not been possible due to the relatively large concentrations needed for actin filament formation. Zero-mode waveguides provide a very small observation volume, which allows the measurement of concentrations up to the micromolar range. By using zero-mode waveguides, we directly observe the binding of individual fluorescently labeled actin monomers during filament formation. Here, we present measurements of actin filament nucleation mediated by gelsolin, a barbed-end binding protein. We measured the binding kinetics of the association of the first five actin monomers. Blocking the conformational transition associated with filament formation slows down nucleation and stops elongation. Actin filament nucleation requires flattening of the actin monomer, which facilitates association and allows further elongation.

Hybrid Perovskite/Perovskite Heterojunction Solar Cells

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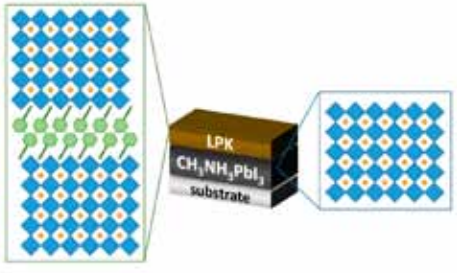
Recently developed organic-inorganic hybrid perovskite solar cells combine low-cost fabrication and high power conversion efficiency. Impressive advances in perovskite film optimization have led to an outstanding power conversion efficiency of more than 22% within only seven years of development. Looking forward, shifting the focus towards new device architectures and interface engineering holds the great potential to induce the next leap in device performance. Here, we report the first demonstration of a perovskite/perovskite heterojunction solar cell. We developed a facile solution-based cation infiltration process to deposit layered perovskite (LPK) structures onto methylammonium lead iodide (MAPI) films. Grazing-incidence wide angle X-ray scattering experiments were performed to gain insights into the crystallite orientation and the formation process of the perovskite bilayer. Our results show that the self-assembly of the LPK layer on top of an intact MAPI layer is accompanied by a reorganization of the perovskite interface. This leads to an enhancement of the open-circuit voltage and power conversion efficiency, as well as improved moisture stability in the resulting photovoltaic devices. Our work opens new doors to all-perovskite heterojunction architectures for highly efficient perovskite solar cells.



Schematic representation of a hybrid perovskite film composed of a MAPI/LPK bilayer.

Spectral function of a quantum dimer model for the pseudogap metal

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We solve the quantum dimer model[1,2], which describes the pseudogap phase of hole-doped cuprates at low hole density p, with exact diagonalization on a 6 x 6 lattice. The Hilbert space of the system is spanned by neutral, spinless, bosonic dimers and fermionic dimers with charge $+e$ and spin $S = 1/2$. The spectral function at zero and finite temperature confirms the experimental results of the so-called pseudogap at the antinode in momentum space.

[1] D. S. Rokhsar and S. A. Kivelson, PRL 61, 20 (1988)
[2] M. Punk, A. Allais and S. Sachdev, PNAS 112, 31 (2015)

Red Blood Cell Aggregates in Malaria - the Role of Flow

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Malaria causes about half a million deaths and more than 200 million new patients per year. Most casualties occur due to the adhesion-based sequestration of red blood cells in the microvasculature, which causes blood vessel obstruction and subsequent failure of vital organs. So far, *static* assays already revealed many biomolecular aspects of the involved adhesion phenomena being linked to the development of the illness. However, they cannot account for the *flow-induced* shear in the microcirculation. We investigate the influence of shear forces on rosetting and sequestration *in vitro*, employing microfluidic techniques at the interface of biology, medicine and physics. We developed microfluidic channels to mimic vessels of the microvasculature system to analyze the dynamics of rosettes under physiological flow conditions. Referring to a static reference, we found a large deviation in rosetting frequency under flow and a correlation of rosetting frequency and shear rate. On this basis, we plan to study rosette formation and stability *in situ*, the interplay of cytoadhesion and rosetting as well as more complex biological systems by implementing von Willebrand factor and platelets to gain new insights into fundamental mechanisms of the pathophysiology of malaria.

Enzyme Activity at Lipid Membranes – Correlation of Activity and Membrane State

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Enzymes are crucial to form and maintain life by catalyzing slow and unspontaneous chemical reactions. This study regards the activity of the water soluble enzyme ADAMTS13 bound to large unilamellar phosphatidylcholine vesicles mimicking physiological and cellular conditions in a first order approach. The kinetics at various constant temperatures show a dependence of the enzyme activity in strong correlation with the phase state of the lipid membrane. As a result, the dependence of the activity is not purely Arrhenius, but shows an additional peak at the phase transition temperature of the lipid membrane. This is in accordance with the theory of Konrad Kaufmann that predicts a correlation of increased system fluctuations at the phase transition and the activity of an enzyme.

Microthermal Approaches to the Origin of Life

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All known living systems are built around information stored in RNA and DNA. To protect this information against molecular degradation and diffusion, the second law of thermodynamics imposes the need for a non-equilibrium driving force. In cells, this task is performed by a highly advanced protein machinery. On early earth this process must have been possible in a naturally occurring environment. We have shown that heat gradients across sub-millimetre sized pores can drive an accumulation, replication, and selection of ever longer molecules, implementing all the necessary parts for Darwinian evolution [1,2].
We show in silico that shallow temperature gradients – down to 100 K over one metre – can still drive an efficient accumulation of protobiomolecules [3]. Following the trajectories of single molecules in the simulated pores, we also find that they are subjected

to frequent temperature oscillations, facilitating e.g. template-directed replication mechanisms. This finding opens the door for various environments to potentially host the origins of life – most notably volcanic, water-vapour, or hydrothermal settings – which significantly increase the number of potential sites where the first building blocks for life could have formed.
We also found that laminar thermal convection can efficiently drive an RNA-catalyzed form of polymerase chain reaction. The laminar convection hereby offers a variety of temperature cycle conditions for bulk material, yielding higher replication efficiencies compared to a conventional thermal cycler. The RNA polymerase ribozyme replicates short RNA strands up to 10 nucleic acids, thus enabling the propagation of information in the absence of proteins.

[1] C. B. Mast et al., PNAS 110, 8030-8035 (2013)
[2] M. Kreysing et al., Nat. Chem. 7, 203-208 (2015)
[3] L. Keil et al., PCCP 18, 20153-20159 (2016)

Optimized combinatorial nanoparticles for systemic, tumor-specific siRNA delivery and *in vivo* gene silencing

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Synthetic siRNA molecules represent an attractive tool for the specific downregulation of disease-related proteins, comprising a wide clinical potential to treat various diseases, especially cancer. Though, successful treatment of cancer using this novel strategy is dependent on efficient and tumor-specific delivery of the therapeutic siRNA, as nucleic acids by itself provide poor pharmacokinetics. Therefore, carrier systems need to accomplish multiple different tasks, including stable transport of siRNA throughout the extracellular environment, tumor-specific accumulation followed by internalization into the target-cells, as well as the efficient cytosolic release.
Strategically tailored nanoparticles provide a number of favourable properties to overcome the described hurdles. For the current approach of systemic siRNA-mediated gene silencing, precise, sequence-defined and multifunctional siRNA carrier systems were generated by solid phase-assisted synthesis. From a library of oligomers, we chose polycations with individual properties that were covalently coupled in co-formulations to combine their particular strengths, while simultaneously compensating their drawbacks. Biodistribution profiles and tumor targeting ability of these co-formulations were evaluated using near infrared imaging methods to detect the systemically applied Cy7-labeled siRNA in subcutaneous folate receptor overexpressing L1210 mouse-tumor models. Consequently, the most promising combinatorial polyplexes were selected for a systemic gene silencing approach, exploiting the mitosis blocking EG5 siRNA. Encouragingly, tested formulations resulted in a significant knockdown of EG5 gene confirmed by RT-qPCR analysis of the harvested tumors.

Mechanotransduction on the Single Cell Level: Investigating Mechanosensitive Genes using Single-Cell Force Spectroscopy

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Mechanical forces play a key role in proliferation and differentiation of human cells such as mesenchymal stem cells, chondrocytes and osteoblasts. Especially, cells of heavily loaded tissues like cartilage or bone require mechanical stimulation, in order to fulfill their biological function. One reaction of chondrocytes in response to mechanical forces is the increased production of extracellular matrix (ECM) to ensure the compressive strength and structural integrity of the cartilage.[1, 2]
Tissue Engineering aims at repairing pathological tissue and providing functional cell based tissue substitutes. Due to the lack of self-renewal capacities of articular cartilage, cartilage is an attractive target for tissue engineering. So far, tissue engineered cartilage often does not reach the mechanical properties of natural cartilage. In order to obtain functional tissue engineered cartilage substitutes, it is therefore crucial to identify the forces required to stimulate cells to produce an optimal ECM, and understand the role of mechanical stimulation in cell proliferation and differentiation.[3, 4, 5]
In order to investigate the response of human mesenchymal stem cells and chondrocytes to mechanical stimuli, we plan to stimulate cells using single cell force spectroscopy (SCFS). SCFS allows for the precise control of the applied forces. Therefor, single cells will be assembled in small cavities, to sustain a systematical stimulation. The resulting change of the expression of selected marker genes will be determined by fluorescent tagged gene products and quantitative PCR. In addition, immunohistochemically staining of ECM components, and the cultivation of stimulated cells to investigate the long term effects of the mechanical stimuli will be carried out.

[1] Bougault, C.; Paumier, A.; Aubert-Foucher, E.; Mallein-Gerin, F. BMC Biotechnology 2008, Vol. 8, p. 1-10
[2] Hatton, J.; Pooran, M.; Li, C.; Luzzio, C.; Hughes-Fulford, M. Journal of Bone and Mineral Research 2003, Vol. 18, p. 58-66
[3] Mauck, R.; Soltz, M.; Wang, C.; Wong, D.; Chao, PH.; Valhmu, W.; Hung, C.; Ateshian, G. Journal of Biomechanical Engineering 2000, Vol. 122, p. 252-260
[4] Duda, G.; Haisch, A.; Endres, M.; Gebert, C.; Schroeder, D.; Hoffmann, J.; Sittinger, M. Journal of Biomedical Materials Research 2000, Vol. 53, p. 673-677
[5] Cancedda, R.; Dozin, B.; Giannoni, P.; Quarto, R. Matrix Biology 2003, Vol. 22, p. 81-91

Staple threading in a DNA origami tube

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In contrast to the static picture of DNA origami, which is conveyed by, e.g., class-averaged electron microscopy images, origami structures are in fact highly fluctuating and dynamic in solution. It has been demonstrated, for e.g., that single-stranded extensions of DNA staple strands can thread through the highly dynamic DNA meshwork of an origami structure. As a consequence, the orientation of a single-stranded staple extension on a monolayered DNA sheet is not well-defined, and the staple may thread from one side of the sheet to the other. In order to study this threading phenomenon in more detail using single-molecule FRET (smFRET), we constructed a tubular hollow origami structure. Neighboring staples on one of the sidewalls of the origami tube were labeled with a donor-acceptor pair. The presence of donor Atto 565 and acceptor Atto 647N dyes on the same side of the tube wall resulted in high FRET values, while upon threading the FRET value was reduced. We analyzed the temporal change of the smFRET signals in detail in order to study threading kinetics and also the influence of various parameters on this process. Our experiments shown that a critical staple extension has a length of ≈16 nt, above which threading is strongly reduced.

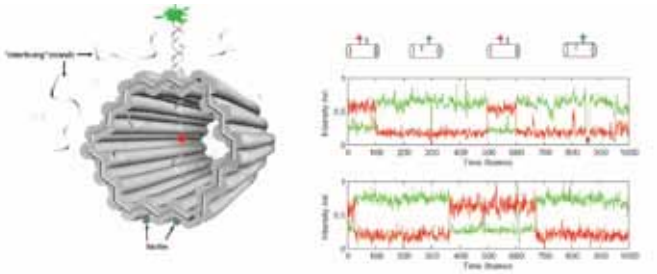

Figure. To obtain clear difference between high and low FRET signal short "interfering" strands were used. Traces for donor and acceptor interaction.

Probing mechanical properties of nucleic acids with magnetic tweezers: the torsional stiffness of DNA

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DNA is the carrier of the genetic code and central to all cellular life. The read-out and processing of the (sometimes) highly-packed DNA is regulated by its mechanical properties and interactions with proteins. Small deformations from the nucleic's equilibrium, can be described by the *isotropic elastic rod model*, including *bending, stretching* and *twisting.*

Magnetic tweezers (MT) can probe the response of single molecules to external *forces and torques*. In MT, the molecule of interest, here DNA, is tethered between a glass cover slip and a magnetic bead. By controlling the position and rotation of permanent magnets, above the flow cell, forces and torques can be applied to stretch and twist the DNA tether. Forces in a range of 0.1 pN up to 100 pN can be reached. In particular also small forces (< 1 pN), characteristic of non- covalent macromolecular interactions, can readily be applied and measured. Furthermore, our MT setup is able to *track multiple beads* (currently up to ~60) at the same time, enabling the collection of statistics in a single measurement run.

Currently, we are investigating the precise response of DNA to applied forces and torques at varying salt concentrations, using *magnetic torque tweezers* (MTT). Preliminary analysis of the torsional stiffness of DNA indicates a weak dependence on salt for forces < 1 pN, where bending deformations play a crucial role, suggesting a coupling between bending and twisting. In contrast, no dependence on salt is observed for higher forces, which suggests that the intrinsic torsional stiffness of DNA does not depend on ionic strength. At the same time, the bending persistence length is known to decrease with increasing ionic strength, which is in line with the current data on the torsional stiffness of DNA.

POSTER ABSTRACTS - SESSION II (KRÖ-Z)

Single-molecule and biochemical studies of human myosin IXa

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Human myosin class IXa and b, have been shown to control epithelial morphogenesis and immune cell migration, respectively. They are thought to act as motorized signaling molecules, as they contain a RhoGAP domain in the tail which can alter the dynamics of the actin cytoskeleton. Class IX myosins contain a unique insertion in the head region which has been proposed to allow these single-headed motors to be processive. To date only myosin IXb has been studied *in vitro* and very little is known about the mechanical and biochemical properties of myosin IXa. Using TIRF microscopy we resolved actin bundles assembled by myosin-IXa. Electron microscopic data revealed that the bundles consisted of highly ordered 2D lattices with parallel actin polarity. The myosin-IXa motor domains aligned across the network, forming crosslinks at a repeat distance of precisely 36 nm, matching the helical repeat of actin. Single particle image processing resolved three distinct conformations of myosin-IXa in the absence of nucleotide. Using cross-correlation of a model acto-myosin crystal structure we identified sites of additional mass which can only be accounted for by the large insert in loop 2 exclusively found in the motor domain of myosins class IX. We show that the large insert in loop 2 binds calmodulin and creates two coordinated actin binding sites that constrain the acto-myosin interactions generating the actin lattices. The actin lattices introduce orientated tracks at specific sites in the cell and may also install a force sensing mechanism into the cytoskeleton in cell polarization and collective cell migration. We are now investigating the single molecule mechanics of myosin-IXa using an optical-tweezer transducer.

Delivery of CRISPR/Cas9 ribonucleoprotein complexes via multifunctional nanoparticles

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Genome engineering developed rapidly since the discovery of the CRISPR/Cas system, short for clustered regularly interspaced short palindromic repeats and the associated nuclease Cas9. Its highly precise and site-specific endonuclease activity, simple design and easy usage revolutionised the field of genome editing.

The binding of single guide RNA (sgRNA) by the associated Cas9 protein results in the formation of negatively charged ribonucleoprotein (RNP) complexes. Successful transport of this functional complex into cells is imperative for efficient usage of the CRISPR/Cas9 system. Previous studies have shown that the direct delivery of the Cas9/sgRNA RNPs has several advantages over the delivery of corresponding nucleic acid precursors such as plasmid DNA or mRNA: fast intracellular degradation reduces off-target effects; preformed RNP complexes provide a rapid genome editing activity without need for translation; additionally, there is no risk for spontaneous integration into genomic DNA.

The negatively charged RNPs can be complexed with positively charged polymers resulting in the formation of nanosized polyplexes. Our lab designed and synthesised a series of polymers containing multifunctional structural elements that enable nanoparticle formation, cell-specific targeting, cellular uptake and endosomal release. This polymer library is utilized for the screening and development of ideal delivery vehicles for the intracellular Cas9/sgRNA transduction and represent potential future treatments of diseases that originate in genetic aberrations.

Chemically Driven Ligation Chain Reaction – Toward Protein-free Hypercycles in Sequence Space

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Which mechanism could have fostered the stable emergence of functional sequences in an RNA world? Eigen's hypercycles suggests that cooperating replication leads to hyperexponential selection.
Hypercycle dynamics can be implemented via competitive oligonucleotide ligation in long-term experiments. Even under serial dilution, this process enhances the replication of majority sequences and allows their spontaneous emergence from a random sequence pool. The hyperexponential replication arises from the competitive binding kinetics of ligation: oligonucleotides with long-range sequence correlations ligate faster through cooperative hybridization. It can even counteract the information loss by thermodynamically favored sequences. Besides oligonucleotides and ligation chemistry, the mechanism only requires thermal cycling – a non-equilibrium boundary condition that could be provided by heat flow across pores of rock[1].
While proteins were used in above LCR experiment, our preliminary investigastions show that EDC can be used in an in-situ activated ligation reaction at low temperatures [2][3]. Numerical models involving the full set of rate equations hint towards a chemically driven ligation chain reaction with exponential replication dynamics[4]. Thus, we aim towards implementing a protein-free hypercycle in sequence space using EDC as condensing agent.

[1] S. Toyabe, D. Braun. In Review 2016.
[2] M. Jauker et al. Angew. Chem. Int. Ed. 2015, 54, 14559-14563.
[3] Taran et al. J. Sys. Chem. 2010, 1:9, 1-16.
[4] H. Krammer et al. PRL 2012, 108, 238104.

Imaging electronic bottlenecks in organic field-effect transistors with photocurrent microscopy

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Improving the performance of organic electronic devices in terms of higher charge carrier mobility requires a detailed investigation of the electronic bottlenecks. These bottlenecks, e.g. contact resistance or charge carrier traps, obstruct the charge transport, leading to unwanted voltage loss in the active device regions. Here, we use scanning photocurrent microscopy (SPCM) to highlight the dominant voltage loss mechanism in pentacene transistors under ambient conditions.[1] We make use of a highly asymmetric transistor (voltage loss of >94% in the defective direction) in order to separate contact resistance from channel resistance within the same device. In the defective direction, SPCM maps highlight contact resistance at the source electrode due to charge separation. In the ohmic direction SPCM shows areas of high trap density deep within the transistor channel, caused by trap release.
In future, we are going to apply SPCM on transistors with the hydrogen-bonded semiconductor epindolidione. This promising material shows high mobility together with an exceptional stability of the device characteristics.

[1] C. Liewald, D. Reiser, C. Westermeier, and B. Nickel, "Photocurrent microscopy of contact resistance and charge carrier traps in organic field-effect transistors", Applied Physics Letters 109, 053301 (2016).

Two-Dimensional Raman Mapping of MoS_2 Crystals at Cryogenic Temperatures

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Molybdenum disulfide (MoS_2) exhibits fascinating optical properties when thinned down to a two-dimensional monolayer [1]. Complementary to photoluminescence, Raman spectroscopy provides versatile and powerful means for the inspection of material quality being sensitive to the number of layers [2] or the degrees of charge doping [3] and strain [4] in crystalline layered MoS_2. In our studies we implement cryogenic two-dimensional Raman mapping of individual MoS_2 monolayer crystals grown by chemical vapor deposition and transferred onto silicon oxide substrates. By raster-scanning the sample with respect to the focal spot of ~ 0.6 µm in diameter we acquired spatial maps of single- and poly-crystalline flakes at the cryogenic temperature of 3.1 K and different magnetic fields. We observe significant inhomogeneities in the characteristics of vibrational Raman modes over the MoS_2 flake and interpret our findings on the basis of spatial variations in the crystal quality, charge doping level, and local environment.

[1] X. Xu et al., Nat. Phys. 10, 343 (2014).
[2] C. Lee et al., ACS Nano 4, 2695 (2010).
[3] B. Chakraborty et al., Phys. Rev. B 85, 161403(R) (2012).
[4] C. Rice et al., Phys. Rev. B 87, 081307(R) (2013).

Dissecting intra-molecular interactions in the vascular protein von Willebrand factor with magnetic tweezers

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Excessive blood loss at a site of vascular injury is prevented by the recruitment of platelets to the subendothelium and the formation of a platelet plug. The large, multimeric plasma protein von Willebrand factor (VWF) plays a central role in this process. VWF senses hydrodynamic forces in the bloodstream and responds to elevated forces, as for instance occurring at sites of vessel damage, with an abrupt elongation that correlates with an increase in VWF's adhesiveness to platelets and subendothelial collagen. To dissect the molecular mechanisms underlying VWF's remarkable force-sensing ability, we recently performed atomic force microscopy-based single-molecule force and imaging experiments on dimers, the smallest repeating subunits of VWF multimers. We could show that the mechanics and structure of VWF dimers are governed by two distinct intermonomer interactions that are both mediated by VWF's D4 domain, but possess opposite pH dependencies and markedly different mechanical stabilities. However, the weaker interaction could not be characterized comprehensively, as it involves forces below the resolution limit of the AFM. Furthermore, so far the relaxation of stretched dimers and the reformation of the intermonomer interactions have not been investigated, although they have far-reaching implications for the activation and down-regulation of VWF. To address these issues, we will employ magnetic tweezers (MT), which allow for single-molecule force measurements over a wide range of forces and with a very high force resolution. Concretely, we will use VWF dimers equipped with specific peptide tags that enable site-specific and covalent linkage to the surface of the flowcell and to the magnetic bead (Fig. 1). By performing MT measurements in force-clamp mode, we aim at elucidating both the association and dissociation kinetics of the interactions of interest. Thereby, we hope to deepen our understanding of the mechano-regulation of VWF's hemostatic activity.

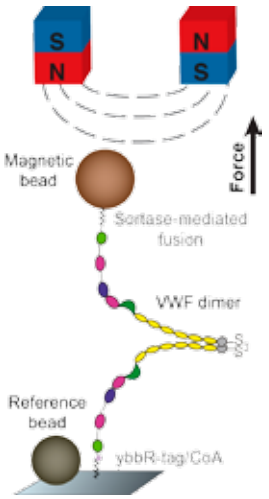

Figure 1. MT schematic. Magnets (top) exert forces on a magnetic bead that is tethered to a molecule of interest, which in turn is attached to the surface of a flowcell (bottom). In our case, VWF dimers possessing two different peptide tags at their termini will be used, allowing for specific attachment to bead and surface via Sortase chemistry and ybbR-tag/CoenzymeA (CoA) chemistry, respectively. Changes in the extension of the dimer due to the dissociation or reassociation of an intermonomer interaction can be monitored by the change in the position of the magnetic bead relative to a reference bead.

Heat-Flow-Driven Oligonucleotide Gelation Separates Single-Base Differences

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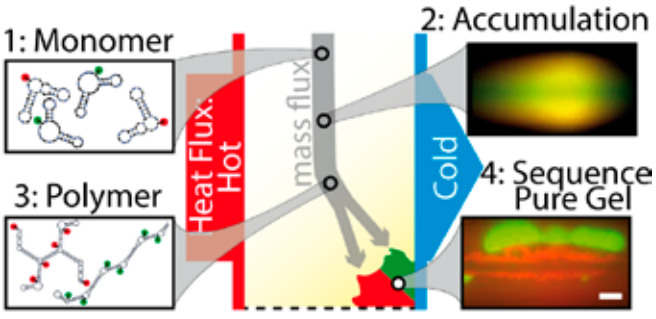
We show that a moderate temperature gradient across a water-filled chamber implements a non-equilibrium sorting-machine that separates and gelates self-elongating DNA strands according to their sequence with single-base resolution: DNA strands with two slightly different gel-forming sequences separate into sequence-pure hydrogels under constant physiological solvent conditions. Only sequences with the ability to arbitrarily elongate upon accumulation (e.g. by hybridization) are effectively concentrated and gelated by the process. Already a single base mismatch in the hybridizing regions of an otherwise self-sticky 36mer DNA inhibits gelation. On the contrary, equilibrium aggregates that were formed by dry concentration did not show any sequence separation. RNA is expected to behave similar owing to its equal thermophoretic properties. The highly sequence-specific phase transition points towards interesting, non-equilibrium possibilities during the origins of life.



DNA strands that can fold into multiple hairpins are selected against their imperfect siblings with single base mutations by their gelation in a thermal trap. Slight sequence differences within the gel-forming strands lead to their separation into spatially distinct, sequence pure oligomer gels.

[1] Christof B. Mast, Severin Schink, Ulrich Gerland and Dieter Braun, PNAS 110, 8030-8035 (2013)

[2] Matthias Morasch, Dieter Braun, Christof B. Mast, Angewandte Chemie International Edition 23, 6788-6791 (2016)

Electrochemical studies of single- and few-layer MoS_2

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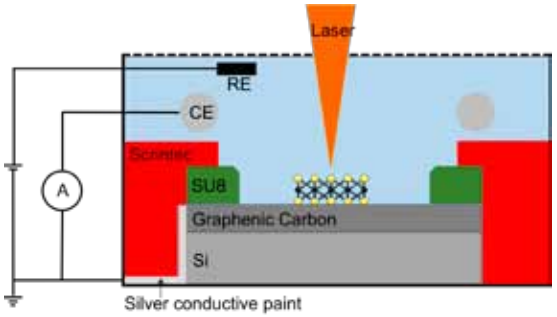
MoS_2 is a promising two-dimensional 'van der Waals' material with outstanding electronic, optical and catalytic properties. The formation of a direct band gap in the single-layer limit, together with a high catalytic activity makes single-layer MoS_2 a very promising material for solar energy conversion by photocatalytic hydrogen evolution.
The photocatalytic stability and performance of exfoliated single- and few-layer MoS_2 immersed in an acid electrolyte is investigated. The corrosion process is in-situ monitored by Raman spectroscopy. We find that while the basal plane of MoS_2 can be treated as photocatalytically stable, the edge sites and most presumably also defect sites are highly affected by a photo-induced corrosion process. In contrast, edge sites of single-layers exhibit a significantly reduced degradation under light irradiation compared to MoS_2 multi-layers [1]. Also for high illumination intensities using a white-light source and immersed in a one molar sulfuric acid as electrolyte, MoS_2 shows high stability during the hydrogen evolution reaction.
In addition, a platform for the electrochemical examination of the catalytic performance of single MoS_2 flakes was developed (see figure). A carbon substrate, covered with an electrically insulating photoresist (SU8) is used as working electrode. A 100 µm window in the photoresist enables the contact to the electrolyte and the positioning of single MoS_2 flakes with known geometry. The cell is covered with a transparent glass window, allowing the illumination of the electrode with sub-µm lateral resolution. The catalytic properties regarding the HER is measured by cyclic voltammetry. An increased catalytic activity of MoS_2 with decreasing number of layers is observed. Edge sites and defects show higher activities than the basal plane. The influence of additional illumination on the catalytic activities will be investigated.

[1] Parzinger, E.; et al., Photocatalytic stability of single- and few-layer MoS_2, ACS Nano, 9(11), 11302(2015).



Electrochemical cell consisting of a graphenic carbon substrate covered with an electrically insulating photoresist (SU8). A 100 µm diameter window enables the contact between electrode and electrolyte and the positioning of single MoS_2 flakes with known geometry.

Monomer accumulation in a 3D printed thermal trap

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Thermogravitational traps were shown to be an elegant solution for the concentration problem of the origin of life [1, 2]. It was, however, difficult to create experimentally reliable traps. We therefore developed a new microfluidic approach to accumulate molecules with an optical readout and a wide range of chamber geometries. Our goal is to use this technique to accumulate DNA or RNA monomers to high local concentrations in water, facilitating a polymerization reaction.
In the past, we could show that polymerizing oligonucleotides inside such a trap can undergo a self-enhancing cycle, where ever larger molecules were accumulated exponentially better [1]. We could also show that cyclic guanosine monophosphate (cGMP) polymerizes at elevated temperatures in the dry state [3] and it was suggested that this is possible in an aqueous environment [4]. We therefore aim to accumulate polymerizing/ligating monomers or short oligomers inside the trap to facilitate an elongation reaction.

[1] C. B. Mast et al., PNAS 110, 8030-8035 (2013)
[2] M. Kreysing et al., Nat. Chem. 7, 203-208 (2015)
[3] M. Morasch et al., ChemBioChem 15, 879-883 (2014)
[4] G. Costanzo et al., ChembioChem 13, 999-1008 (2013)

Kinetics and order of apoptosis events assessed in high through-put on single cell lattices microscopy

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Cell fate decisions like apoptosis are outcomes of intricate signaling cascades being highly heterogeneous both in strength and dynamics when observed at the single-cell level. Programmed cell death is induced by various pathways each showing organelle-specific signals as the central integrator of apoptosis. Lysosomes are discussed as triggers for death but also mitochondria or caspases are believed to be central executioners of apoptosis . The symptomatic order and timing of events in the signaling cascades during programmed cell

death, however, are not systematically captured. Here, we monitor the time lines of apoptotic signals in automated time-lapse microscopy in combination with single cell micro-arrays. By pair wise labeling we establish sequences of events with high temporal resolution using time correlation analysis. For cell death induced by amino-functionalized polystyrene nanoparticles, staurosporine and the FAS-ligand we find distinct timing in the signal pathway and distinct variance in event correlations indicative of cross-talk in the apoptotic pathways. Hence multi-dimensional time-correlation provides a dynamic fingerprint of signaling pathways that is likely to be useful in nanotoxicology to identify the effect of nanoparticles as well as in cancer research to distinguish chemotherapeutic drugs and their synergistic effect in combination.

Inorganic Perovskite Nanocrystals with Tunable Halide Composition and Thickness for Tunable Light Emission

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Perovskites have received significant research attention over the last five years due to their unique optoelectronic properties [1]. Among these, high fluorescence quantum yields (QYs), large absorption cross-section, long diffusion lengths, long recombination times, and solution processability make them potential candidates for photovoltaic and light emitting applications. We will present the synthesis of inorganic perovskite nanocrystals (NCs) with controlled dimensionality, composition and thickness for tunable optical and electronic properties. High angle annular dark field scanning transmission electron microscopy (HAADF-STEM) revealed the atomically resolved cubic crystal structure and surface termination of the NCs. In addition, we show the quantum size effects in inorganic perovskite nanoplatelets by tuning their thickness down to only 3-6 monolayers. [2, 3].

[1] H. He, L. Polavarapu, J. Sichert, A.S. Urban, A. L. Rogach, Nat. Asia. Mater, 2016, (In press).

[2] Y. Tong, E. Bladt, M. Ayguler, A. Manzi, K. Z. Milowska, V. A. Hintermayr, P. Docampo, S. Bals, A. S. Urban, L. Polavarapu, J. Feldmann, Angew. Chem. Int. Ed., 2016 (revision submitted)*

Atomic force microscopy imaging and indentation measurements to assess murine cartilage properties during development

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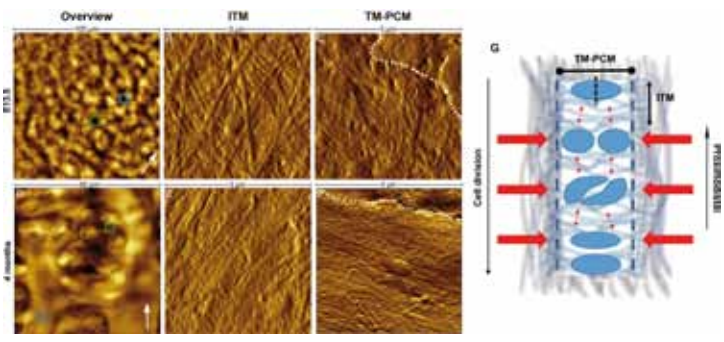
The growth plate (GP) is a special from of hyaline cartilage localized between the epiphysis and diaphysis of long bones during skeletal development. Within GP proliferative zone chondrocytes undergo rapid division accompanied by the establishment of a unique columnar arrangement, driving longitudinal bone elongation [1]. It is increasingly recognized that the fate of cells is tightly controlled by the biomechanical properties of their micro-environment. GP proliferative zone comprises several matrix compartments distinct by their composition. The pericellular matrix (PCM) immediately surrounds chondrocytes. The adjacent territorial matrix (TM) encloses the PCM and clustered chondrocytes, defining the columnar chondron. The interterritorial matrix (ITM) is located between the columns (Fig.1). We assume that the columnar arrangement of the proliferative zone might be driven by structural and biomechanical properties of GP matrix. We performed atomic force microscopy (AFM) imaging and indentation measurements, in order to correlate matrix structural and mechanical properties among different developmental stages of murine tibial GP. AFM images showed a progressive



AFM overview and ECM detail images at embryonic stage and mouse adulthood. The AFM overview images (A, D; blue square=ITM, green square=TM-PCM) show an increasing cell flattening perpendicular to cartilage proximodistal axis (indicated by white arrows) with progressive age. AFM detail images within GP ITM (B, E) and TM-PCM (C, F) reveal a progressive collagen density and fibril orientation during cartilage maturation (dotted line indicate the position of chondrocytes). G: Model for chondrocyte columnar arrangement due to different mechanical properties of the surrounding ECM. Chondrocytes within the soft TM-PCM divide parallel to the proximodistal axis. The stiff matrix of the ITM resists further cell elongation. Consequently, chondrocytes rotate around each other and move into the softer matrix in order to flatten again.

cell flattening and arrangement into columns from embryonic day (E) 13.5 until postnatal week 2, correlated with an increasing collagen density and matrix stiffness. At all stages a marked difference in collagen density and fibril orientation was observed between ITM and TM-PCM accompanied by a higher stiffness of the TM PCM. We conclude, that local stiffness forces chondrocytes to arrange into columns and thus, drive bone elongation during skeletal development. Furthermore, our results indicate, that AFM is a powerful tool to compare structure-biomechanical properties, and to resolve mechanical properties of distinct matrix compartments. Therefore, our results are of interest for the comparison with genetically modified mice to investigate the role of matrix components during cartilage and bone development.

[1] Dodds, G.S., Row formation and other types of arrangement of cartilage cells in endochondral ossification. The Anatomical Record, 1930. 46(4): p. 385-399.

Investigation of G-protein Coupled Receptor Oligomerization with Image Cross-Correlation Spectroscopy

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Homo- and heterodimerization of G-protein coupled receptors (GPCRs) have been reported to regulate ligand binding, signaling and receptor trafficking. However, quantitation of membrane protein interactions in living cells presents many challenges and commonly used methods for probing protein-protein interactions suffer from various drawbacks. Coimmunoprecipitation requires disruption of the cell membrane, which may also disrupt weak or transient interactions. Fluorescence resonance energy transfer (FRET) and bimolecular fluorescence complementation (BiFC) depend on the relative positioning of probes to detect an interaction and are thus prone to false-negatives when probes are positioned too far apart. Additionally, BiFC can produce false-positives due to self-assembly of probe fragments. Here, we apply image cross-correlation spectroscopy (ICCS) and raster ICCS (RICCS) to study the oligomerization of human chemokine receptor CXCR4 as well as its potential heteromerization with the viral GPCR US28. By correcting for slow fluctuations and spatial inhomogeneities inherent in living cell membranes, we are able to correlate only the diffusive receptor species. Our results demonstrate the effectiveness of image correlation as a non-invasive and probe-proximity-independent method for quantifying receptor interactions in living cells.

Covalent organic frameworks as active materials for optoelectronics

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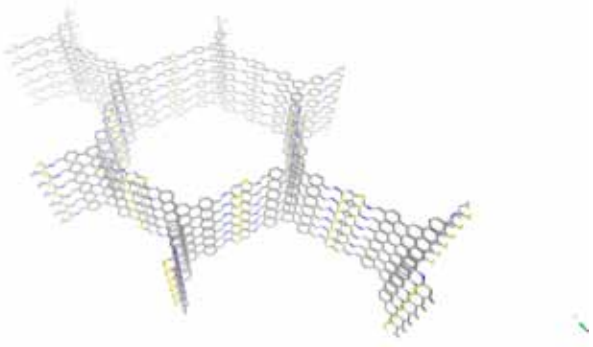
In recent years the interest in organic semiconductors with regard to the design of optoelectronic devices has continued to increase. In this context, a novel class of highly ordered photoactive materials named covalent organic frameworks (COFs) is being investigated. Due to their defined pore size, crystalline structure, high specific surface area and broad structural diversity COFs have recently been proposed as photoactive materials and integrated into photovoltaic devices [1]. Therefore the development of new two-dimensional COFs featuring desired optoelectronic properties represents an important field of research (see figure 1) [2]. Desired functionality can be achieved by a rational design of photoactive building units and their incorporation into the COF backbone. Such components can display various preferred properties such as high charge carrier mobilities and a broad absorption spectrum in the visible region. Thereby the physical and chemical characteristics of an anticipated COF structure, such as thermal stability, absorbance or conductivity can be tailored. In addition, by integrating these building blocks into a COF either through the formation of boronate esters or fully conjugated imine bonds, different electronic properties can be realized [3].

[1] M. Dogru et al., Angew. Chem. Int. Ed. 52(10), 2920-4 (2013)
[2] A.P. Côté et al., Science. 310(5751), 1166-1170 (2005)
[3] M. Calik et al., J. Am. Chem. Soc. 136(51), 17802-17807 (2014)



2D 3PB-TT COF formed by the condensation reaction of thienothiophene dialdehyde and triaminophenyl.

Tuning the Optical Properties of Perovskite Nanoplatelets through Composition and Thickness by Ligand-assisted Exfoliation

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Organic/inorganic halide perovskites have received great attention in the past few years due to their remarkably high light-harvesting efficiency. This novel semiconductor also displays a huge potential for light emitting applications. In order to further improve the efficiency and functionality of applications based on this material a better control of its optical properties is desirable.

Here, we focus on a facile colloidal synthesis method for the preparation of hybrid organic/inorganic halide perovskite nanocrystals of different size and composition. Prepared by ligand-assisted exfoliation we obtained highly stable perovskite nanoplatelets that show strong quantum confinement and nanocrystals that exhibit bulk like optical properties. Moreover we show the tunability of the optical properties of the nanocrystals by varying the halide ion used (I, Br, and Cl). Through this method and by controlling their size the photoluminescence can be tuned over the entire visible spectral region (360-765 nm) and their optical properties can be investigated. We observe a decrease in the photoluminescence lifetime with decreasing thickness, likely due to increasing radiative rates.

Nanocrystals produced in this manner can lead to applications for light emission and also permit further studies on optical and electronic properties of perovskites, leading to important insights into this fascinating material.

Collective behavior of myosin-driven actin filaments

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Collective motion is quite common in nature, for example schools of fish, flocks of birds, swarm of insects. Within these ensembles, each individual follows a reduced set of basic rules and interacts only with its closest neighbours. However, from these local interactions, a collective behaviour emerges, which can be orders of magnitude greater, and in which a single perturbation can propagate much faster than the single individual.

These collective phenomena are not restricted to "thinking beings", as purely synthetic systems can exhibit collective behaviour. Our study focuses on the collective behaviour of actin filaments propelled by HMM-II (muscle myosin fragment). At the concentrations of actin usually used for in vitro motility assay (~ 100 – 500 nM), each actin filament follows a random walk, without any correlation between the motion of the filaments. However, when the actin concentration is increased to near physiological values (> 2 μM), the interactions between actin filaments generate collective behaviour, with all actin filaments moving in the same direction.

Preliminary results show that the characteristics of this collective behaviour such as the time between the change of direction of the flow/or the distance travelled by a single filament before changing direction is highly dependent on the actin concentration and the temperature.

In order to better understand the interactions involved in this collective behaviour, a model based on the cellular automation proposed by Schaller *et al.* 2010 is being developed.

Generation of stable radical cations in a wurster-type covalent organic framework

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Two-dimensional covalent organic frameworks (2D COFs) are porous, crystalline materials formed from rigid organic building blocks that interconnect through covalent bonds, forming extended 2D sheets. The self-organization of these sheets by dispersive forces creates a layered material featuring defined pore sizes and shapes, and high surface areas. The extended, conjugated π-systems and the long-range order make COFs promising candidates for applications in organic electronics. [1,2]

Wurster-type compounds are aromatic amines in which the lone pair of the amine can be selectively oxidized, rendering it a radical cation. The generated free charge can be resonance stabilized within the aromatic system. [3] Here, we demonstrate two novel dual-pore, fully conjugated imine-based 2D COFs including a Wurster-type motif. The COFs feature long-range order, accessible pores as well as good thermal stability. Furthermore, the electron-rich frameworks exhibit two low-lying quasi-reversible redox processes, which render them interesting redox-active porous platforms.

Using chemical doping, we show the effect of bleaching of conjugated COFs. We investigate the changes in optical properties related to the employed dopant and study the formation and stability of free charge-carriers in the system. The stability of these charge-carriers is of great interest for extending the absorption spectrum into the NIR region and to enhance charge transport in the framework.

[1] A. P. Côté et al., Science. 310, 1166-1170 (2005).
[2] T.-Y. Zhou et al., J. Am. Chem. Soc. 136, 15885-15888 (2014).
[3] L. Michaelis et al., J. Am. Chem. Soc 61, 1981-1992 (1939).

Slow conformational dynamics detected by ^{1}H relaxation rotation interference

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In the past years, Zero-Mode Waveguides (ZMWs) have emerged to a powerful application in modern life science. They provide sub-diffraction detection volumes in single-molecule fluorescence measurements and hence experimental performance at physiological concentrations of fluorescently labeled biomolecules.
Here, Atomic Force Microscopy (AFM) and ZMWs are combined in order to investigate force-activation pathways of enzymes. For this purpose, high concentrations are dictated by experimental conditions and requirements, this being high Michaelis-Menten constants of enzymes and the limited time span of keeping the protein's binding pocket open/accessible.
Although force-triggered ATP binding events were already investigated for Titin Kinase with simultaneous force fluorescence spectroscopy, the yields of these events remained low. This can be attributed to the absence of site-specific immobilization chemistry. By introducing covalent site-specific chemistry to ZMWs together with an optical non-invasive cantilever localization routine, experimental yields are expected to increase. In the future, this improved methodology will be applied to investigate also further enzymes upon possible force-activation mechanisms e.g. Myosin Light Chain Kinase or Focal Adhesion Kinase.
Along with ongoing development in protein Single Molecule Cut & Paste (SMC&P), this leads the way for future investigations on enzymatic networks inside ZMWs.

Towards Simultaneous Force and Fluorescence Spectroscopy

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Along with ongoing development in protein Single Molecule Cut & Paste (SMC&P), this leads the way for future investigations on enzymatic networks inside ZMWs.

Quantum-size Effects in Organometal Halide Perovskite Nanoplatelets

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In the last 7 years organic/inorganic metal halide perovskites have not only proven to be a promising material for solar cells with the highest efficiencies exceeding 20 % but they have also shown a huge potential for light-emitting applications. Exploiting the optical properties of specifically tailored perovskite nanocrystals could greatly enhance the efficiency and functionality of applications based on this material. We have investigated the quantum size effect in 2-dimensional lead bromide perovskite nanoplatelets. Their thickness and their photoluminescence (PL) can be controlled by varying the ratio of organic cations, methylammonium and octylammonium. We find that an increasing amount of the capping ligand octylammonium leads to the formation of thinner structures and a PL blue-shift of more than 90 nm. Kronig-Penney model calculations match well with the experimental values. Stacking of nanoplatelets leads to a further shift in the bandgap energies. Moreover, a comparison of the calculated values with experimental data suggest a large exciton binding energy up to several hundreds of meV in the strongly confined nanoplatelets.

Characterization of trapped, dipolar excitons

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In coupled quantum wells (CQW) photogenerated electron-hole pairs can form a bound indirect exciton (IX) state, with electron and hole localized in adjacent QW. This spatial separation increases the lifetime of IX and therefore enables cooling of IX down to lattice temperature. Moreover, it allows tuning of the IX energy via the Quantum Confined Stark Effect (QCSE). Such IX ensembles represent an ideal system to study many-body effects of weakly interacting bosons and are expected to exhibit various phases, e.g. exciton liquid [1] and Bose-Einstein condensation [2].

We report on photoluminescence measurements and preliminary characterization via inelastic light scattering in a GaAs - $Al_{0.34}Ga_{0.66}Al$ CQW field effect device with semi-transparent electrostatic gates. We define circular shaped trap geometries and tune the in-plane potential landscape via the QCSE [3]. Employing a ^{4}He refrigerator with a base temperature of 1.55K we create and probe a dense ensemble of cold excitons in our trap. Since the thermal de Broglie wavelength exceeds the excitonic separation in this temperature regime, many-body correlations between trapped excitons are expected [4,5].

Our preliminary measurements show a well-defined Stark shift with narrow lines originating from radiative recombination of IX. We reproduce the trap-antitrap transition reported by Kowalik-Seidl *et al.* [6] and verify the control of the in-plane IX potential.

[1] M. Stern, et al., Science 343, no. 6166, pp. 55-57 (2014).
[2] L. V. Keldysh, A. N. Kozlov, Zh. Eksp. Teor. Fiz. 54, 978 (1968).
[3] G. Schinner, et al., Phys. Rev. B 83, 165308 (2011).
[4] B. Laikhtman, et al., Phys. Rev. B 80, 195313 (2009).
[5] G. Schinner, et al., Phys. Rev. B 87, 205302 (2013).
[6] K. Kowalik-Seidl, et al., Nano Lett. 12, 326-330 (2012).

Exploring the limits of cell adhesion under shear stress mimicking inflammatory conditions on a chip

Melanie E. M. Stamp[1,2], Anna M. Jötten[1], Dominik Breyer[1], Florian G. Strobl[1,2], Achim Wixforth[1,2], and Christoph Westerhausen[1,2]

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Cell adhesion processes are of ubiquitous importance for biomedical applications such as optimization of implant materials or tissue engineering. Here, not only physiological conditions such as temperature or pH but also topographical structures play crucial roles. In this study, we systematically investigate cell adhesion under static, dynamic and physiologically relevant conditions employing a lab-on-a-chip system. We screen adhesion of SaOs-2 cells on a titanium implant material for pH and temperature values in the physiological range and beyond, to explore the limits of cell adhesion, e.g. for inflammatory conditions. A detailed study of different surface roughness gives insight into the correlation between the cells' abilities to adhere and withstand shear flow and the topography of the substrates, finding a local optimum of $R_q = 22$ nm. We determine the shear stress induced by acoustic streaming inside a closed, small volume chamber and the corresponding time-dependent detachment rates of cells. We find an optimum of cell adhesion for T = 37 °C and pH = 7.4 with decreasing cell adhesion outside the physiological range, especially for high T and low pH. We find constant detachment rates in the physiological regime, but this behavior to collapse at the limits of 41 °C and pH 4.

Single cells on micro-lattices: optical distortions and 3D shape reconstruction

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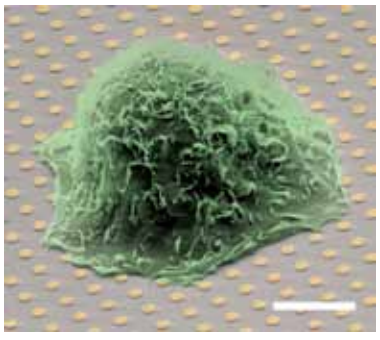
In methods like single particle tracking or traction force microscopy, markers are localized with a high precision. However, when the imaging is done through biological tissue, specimen induced aberrations arise. These aberrations degrade resolution and contrast of the image and introduce image distortions. Until now, aberrations have mainly been examined to restore the resolution and contrast when imaging through thick specimen. For thin specimen like single cells, the loss of resolution and contrast is small, but the extent of specimen induced distortions has not been assessed systematically so far, as there is no established tool to quantify the distortions directly. Here we utilize a micro-structured gold lattice and measure single cell induced distortions of up to 400 nm with a spatial sampling of below two µm and an accuracy of a few nm. We furthermore investigate the origin of the distortions in an optical model and utilize the distortions in a novel approach to reconstruct the cell shape in 3D. Our results demonstrate that the distortions of single cells can considerably impede the localization accuracy of subjacent objects, for example in fluorescence microscopy or traction force microscopy. The 3D cell shape reconstruction from a single 2D image provides a tool for fast cell volume measurements, without the need for cell labeling.



Scanning electron micrograph of an A549 cell on a patterned substrate in false color. The scale bar denotes 5 µm.

2D antimony phosphate nanosheet based photonic nose for touchless finger motion tracking

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One-dimensional Photonic Crystals (1D PC), also referred to as Bragg stacks (BS), are bioinspired periodic multilayered nanostructures exhibiting a photonic band gap - a forbidden spectral range for photons propagating through the nanostructure. The photonic stop band can be dynamically changed by chemical, physical or biological stimuli, thus environmental changes can be directly translated into color changes, which renders these platforms promising candidates for smart optical detectors.

Herein we present 1D PCs fabricated by bottom-up assembly of colloidal metal oxide nanoparticles and colloidally stable suspensions of antimony phosphate 2D nanosheets. The PCs show an ultrasensitive response to local humidity changes caused by the moisture-induced swelling of the nanosheets, resulting in a full-spectrum color change. While these 1D PCs are highly selective to water vapor, we demonstrate that a range of other volatile organic compounds (VOCs), including chemically similar alcohols, can be distinguished by means of their response times and the extent of the stop band shift. The combination of high sensitivity and selectivity to water vapor, cycling stability and response times on the subsecond time scale allowed us to detect local humidity changes in a spatially and temporally resolved fashion. As the human finger is surrounded by a humid atmosphere, finger positions and motions can be tracked by structural color changes of the BS in realtime under touchless conditions. These experiments bode well for a new touch*less* device architecture as viable alternative to the touchscreen technology, where common disadvantages of the contact based technology such as lack of hygiene and mechanical wastage could be avoided.

K. Szendrei, P. Ganter, O. Sanchez-Sobrado, A. Kuhn, B. V. Lotsch, European Patent Application, 2015.

K. Szendrei, P. Ganter, B.V. Lotsch, Proc. SPIE 9885, 2016, Photonic Crystal Materials and Devices XII, 98850Z. DOI: 10.1117/12.2227431.

K. Szendrei, P. Ganter, O. Sanchez-Sobrado, R. Eger, A. Kuhn, B. V. Lotsch, Adv. Mater. 2015, 27, 6341–6348.

P. Ganter, K. Szendrei, B. V. Lotsch, Adv. Mater. 2016, DOI: 10.1002/adma.201601992.

Tailorable metal ion release from antibacterial novel implant materials

Jochen Taiber[1], Sascha Buchegger[1], Rudolf Herrmann[1], Caroline Vogel[1], Bernd Stritzker,[1] Achim Wixforth[1,2,3], Christoph Westerhausen[1,2,3]

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The quantity of medical implants is still rising which sets priorities to find novel wear-resistant implant materials which avoid subsequent infections in the first days after surgery. Therefore we use polymer samples, transform their surface into a highly wear-resistant DLC (diamond-like carbon) layer and implant different nanoparticles.

The aim is to tailor adapted time-dependant antibacterial properties: a large initial antibacterial activity during the first few hours to eliminate bacteria followed by a decreasing ion release to conserve the eukaryotic cells. This customisation is realized by using different nanoparticles (Cu, Ag, ZnO). Therefore we are studying the ion release depending on depth, distribution and sort of particles which can be described by two exponential functions with different time constants. Especially the first decay time is strongly dependent of the implantation depth of the ions and subordinate of the concentration in the DLC layer.

To realize a DLC transformation of complex structures (e.g., joint heads) it is necessary to manipulate the trajectory of the metal ions. Therefore we provide a simulation of the ion implanting process using a Python script in order to find the optimally formed cathode in relation to the given medical implant.

Targeted, sequence-defined polymeric carrier systems for tumor-selective drug delivery

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The tubulin-binding agent pretubulysin has been shown to be a highly potent drug exhibiting antitumoral, antiangiogenic and antimetastatic properties. However, the medium-sized molecule suffers from rapid clearance, biodegradation and undesired toxicity at non-cancerous sites. Since adverse effects of anticancer drugs are responsible for a narrow therapeutic window and therapy limitations, the incorporation into polymeric carrier systems or nanoparticles to affect biodistribution and unspecific toxicity is a promising approach to overcome these limitations.

Recently, our lab developed a technology for the design of precise, sequence-defined polymers for intracellular delivery, based on solid-phase supported synthesis. We aim to target cancer cells by conjugating pretubulysin to several oligoaminoamide carriers containing different structural moieties, PEG and a targeting ligand. The conjugates display triple responsiveness: firstly, a pH- labile hydrazide bond to target tumor acidity, secondly, a reactive disulfide bond that is cleaved in the intracellular reductive milieu and thirdly, a targeting ligand for tumor selectivity. Experiments with pretubulysin-polymer constructs have shown promising results in the drug delivery to folate receptor overexpressing KB- and L1210-cancer cell lines.

Ultra-sensitive detection of bacterial growth and motility on surfaces

David Volbers[1], Valentin Stierle[1], Konstantin Ditzel[1], Joachim O. Rädler[1], Madeleine Opitz[1], Philipp Paulitschke[1]

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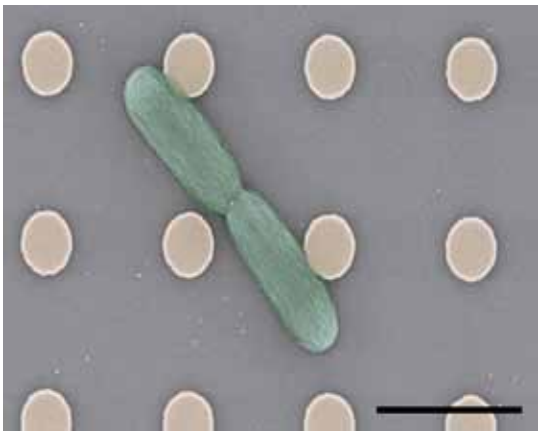
The formation of bacterial biofilms on surfaces causes severe problems in industrial processes, where biofilms induce biofouling and corrosion, as well as in medical healthcare, when biofilms form on heart valves or catheters. Additionally, mature biofilms can resist antibiotic concentrations of up to 1000 times higher than their planktonic counterparts. The quantitative assessment of bacterial growth and motility, two essential parameters of bacterial fitness, is therefore crucial in biotechnical research and medical diagnosis. We report on a highly sensitive interferometric method to detect bacterial growth starting from a single bacterium. This is done by utilizing a 2D diffraction grating consisting of nano-scaled gold islands. Cell growth on top of the grating induces a perturbation of diffracted light that can be quantified by analyzing the diffraction peak intensity. The spatially structured surface furthermore gives rise to intensity fluctuations induced by moving bacteria und thus allows for simultaneous, quantitative motility assays. This method, which can be employed on almost any surface, is suitable as an online monitoring device with ultra-high sensitivity and time resolution.



Introducing selectivity into MOF based photonic crystal sensors by post-synthetic modification

Alberto von Mankowski, Laura Nichols, Charlotte Koschnick and Bettina V. Lotsch

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Metal-organic frameworks (MOFs) are porous coordination networks formed by the linkage between metal atoms/clusters and organic linkers with (potential) applications in catalysis, luminescence, drug delivery and imaging as well as gas storage and separation.[1] Our group has demonstrated the potential of MOFs as sensors by the successful incorporation of MOF nanoparticles as the vapor sorption component in one dimensional photonic bandgap sensor materials (PBSMs).[2] Post-synthetic modification (PSM) enables further tuning of MOF properties and the introduction of new functional groups into the framework.[3] PSM of MOF nanoparticles in PBSMs could therefore help to increase selectivity of the optical response to different analytes. We demonstrate a versatile approach for incorporating selectivity into MOF based PBSMs by a simple and mild on-platform PSM. For this purpose one dimensional PBSMs of TiO_2 and the MOF CAU-NH_2 were fabricated, the latter one defining the functional layer. The structures were directly modified under mild conditions with acetic and hexanoic acid anhydride altering the chemical affinity of the CAU-1 layer while retaining the photonic structure. The optical and sorption properties of the multilayers were analysed with ellipsometric porosimetry, confirming increased selectivity of the modified PBSMs in response to different solvent vapors.

[1] R. J. Kuppler, D. J. Timmons, Q.-R. Fang, J.-R. Li, T. A. Makal, M. D. Young, D. Yuan, D. Zhao, W. Zhuang, H.-C. Zhou, Coord. Chem. Rev. 2009, 253, 3042-3066; H. Furukawa, K. E. Cordova, M. O'Keeffe, O. M. Yaghi, Science 2013, 341.

[2] F. M. Hinterholzinger, A. Ranft, J. M. Feckl, B. Ruhle, T. Bein, B. V. Lotsch, J. Mater. Chem. 2012, 22, 10356-10362; A. Ranft, I. Pavlichenko, K. Szendrei, P. M. Zehetmaier, Y. Hu, A. von Mankowski, B. V. Lotsch, Microporous Mesoporous Mat. 2015, 216, 216-224.

[3] K. K. Tanabe, S. M. Cohen, Chem. Soc. Rev. 2011, 40, 498-519.

Periodic Migration of Single Cells on Short Microlanes

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Regulation, initiation and maintenance of polarization in migrating cells are of importance for many biological mechanisms like chemotaxis, embryogenesis and cancer metastasis. Recent studies imply that cell polarization and therefore the arrangement of the cytoskeleton is critically influenced by mechanical cues and cell geometry. Here we use micropatterns to study cell migration and repolarization of MDA-MB-231 breast cancer cells that are confined to defined geometries. On short stripes cells perform regular oscillatory movements where they repeatedly turn around at the tip of the stripes. The migration behavior in dependence on the stripe length can be quantified by Fourier analysis. Additionally we vary the tip geometry to detect the actin dynamics of the cell front. This allows us to study the influence of diverse cell shapes on cytoskeleton arrangements and cell repolarization.

THz-circuits driven by photo-thermoelectric graphene-junctions

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For future on-chip communication schemes, it is essential to integrate nanoscale materials with an ultrafast optoelectronic functionality into high-frequency circuits. The atomically thin graphene has been widely demonstrated to be suitable for photovoltaic and optoelectronic devices because of its broadband optical absorption and its high electron mobility. Moreover, the ultrafast relaxation of photogenerated charge carriers has been verified in graphene. Here, we show that dual-gated graphene junctions can be functional parts of THz-circuits. As the underlying optoelectronic process, we exploit ultrafast photo-thermoelectric currents. We describe an immediate photo-thermoelectric current of the unbiased device following a femtosecond laser excitation. For a picosecond time-scale after the optical excitation, an additional photo-thermoelectric contribution shows up, which exhibits the fingerprint of a spatially inverted temperature profile. The latter can be understood by the different time-constants and thermal coupling mechanisms of the electron and phonon baths within graphene to the substrate and the metal contacts. The interplay of the processes gives rise to ultrafast electromagnetic transients in high-frequency circuits, and it is equally important for a fundamental understanding of graphene-based ultrafast photodetectors and switches.

Nanostructured architectures of transparent conducting oxides for bioinspired optoelectronics

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Photoelectrochemical energy conversion based on the natural systems such as enzymes or photosystems is an attractive and intensively explored concept, which could benefit from the evolution-optimized conversion efficiency of the biological units. The development of bioelectronic devices requires connecting the biological systems in an optimized way to the electrodes and understanding the fundamental issues in the context of their interfacing. We have developed transparent electrodes with custom designed porous 3D-electrode architectures enabling incorporation of large amounts of biomolecules and featuring optical transparency allowing interaction with light. Our approach is based on the assembly of nanoparticles of transparent conducting oxides such as antimony-doped tin oxide (ATO) and indium tin oxide (ITO) directed by different templates for porosity such as novel amphiphilic polymers (PEO-b-PHA) or PMMA beads [1-3]. The high crystallinity of the nanoparticles serving as building blocks enables the formation of fully crystalline porous transparent scaffolds with high electrical conductivity and accessible porosity, which can incorporate various redox moieties ranging from small redox proteins to large protein complexes and show greatly enhanced electrochemical response proportional to the electrode surface area [3-4].

[1] Peters, K.; Zeller, P.; Stefanic, G.; Skoromets, V., Němec, H.; Kužel, P.; Fattakhova-Rohlfing, D. Chem. Mater. 2015, 27, 1090–1099.

[2] Liu, Y.; Peters, K.; Mandlmeier, B.; Müller, A.; Fominykh, K.; Rathousky, J.; Scheu, C.; Fattakhova-Rohlfing, D. Electrochim. Acta 2014, 140, 108.

[3] Peters, K., Lokupitiya, H. N., Sarauli, D., Labs, M., Pribil, M., Rathouský, J., Kuhn, A., Leister, D., Stefik, M., Fattakhova-Rohlfing, D., Advanced Functional Materials 2016, DOI: 10.1002/adfm.201602148.

[4] Sarauli, D.; Wettstein, C.; Peters, K.; Schulz, B.; Fattakhova-Rohlfing, D.; Lisdat, F. ACS Catal. 2015, 5, 2081–2087.

Laser induced forward transfer of living cells using femtosecond laser pulses

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Laser induced forward transfer (LIFT) has been used in recent years for the rapid 3D-biopriting of cells. Because of the high transfer rates and superior cell survival rates, this technique has great potential for tissue engineering applications. However, the fact that material from an inorganic sacrificial layer, which is required for energy absorption, is usually transferred to the printed target structure, constitutes a major drawback of LIFT based cell printing. Here we present a method for the rapid, laser induced transfer of hydrogels and mammalian cells, which does not require any sacrificial inorganic material for energy absorption. Instead, we focus an ultrashort (fs) laser pulse (λ = 1030 nm, 450 fs, few µJ) directly underneath the gel surface, to induce a rapidly expanding cavitation bubble, which generates a jet of material transferring cell-laden hydrogel from a gel/cell reservoir to an acceptor stage. With this new method we were able to reproducibly transfer hydrogel spots with 70 – 100 µm diameter to the acceptor stage. The survival rate of human mesenchymal stem cells (SCP1 cell line), transferred with this method was nearly 100%.

NOTES

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Böhm	Daniel	LMU München	
Bohn	Bernhard	LMU München	
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Schendel	Leonard	LMU München	
Schollwöck	Ulrich	LMU München	
Schüder	Florian	LMU München	
Schwartz	Jeffrey	Princeton University	
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Zhou	Fang	LMU München	
Ziegler	Daniela	TU München	
Zimmermann	Philipp	TU München	
Zoller	Florian	LMU München	

ACCOMMODATION

Accommodation for all participants is provided on San Servolo. The buildings are situated in the island's beautiful green parkland. All bedrooms have air conditioning, television, telephone and internet access. A twenty-four hour reception service is guaranteed.

WELCOME RECEPTION

The Welcome Reception for all participants will take place on Sunday, Sept. 18, at about 8:00 pm on San Servolo in Sala Basaglia (main building).

BREAKFAST AND LUNCH

The cafeteria is located on the ground floor of building 15. The cafeteria is open every day with the following timetable:

Breakfast	7.30 am - 9.30 am
Lunch	12.00 pm - 2.30 pm
Dinner	7.00 pm - 9.15 pm

For participants with accommodation on San Servolo, breakfast is included (*please sign for your breakfast at the list at the counter in the cafeteria*). Prices for lunch or dinner are € 11.00 and include a pasta course, a main course, a side order of vegetables or salad, yoghurt, bread and water. There are also reduced menus available (pasta course, side order of vegetables or salad, water and bread, or: main course, side order of vegetables or salad, water and bread).

A coffee bar offering snacks and warm and cold beverages is also available on campus and is located on the ground floor of Area 6 in the main building. The coffee bar is open from 7.50 am to 5.50 pm.

For self-catering, supermarkets are located close to the boat stops Piazzale de Roma and Zattere.

INTERNET

All hotels room on San Servolo have WLAN access. In addition, there will be a conference WLAN in the lecture hall.

WLAN Conference Network San Servolo: UNIVIU
username: censworkshop2016
password: censworkshop2016

Internet activity will be monitored and recorded as required by Italian law.

TIMETABLES

TRAIN TO VENICE AND BACK TO MUNICH

To Venice (18.09.)		Back to Munich (23.09.)	
Munich Main station	**Venezia Santa Lucia**	**Venezia Santa Lucia**	**Munich Main station**
11:37	18:10	13:50	20:23

BOAT LINE 20 TO WORKSHOP LOCATION (SAN SERVOLO)

The boat from Venice to San Servolo leaves from the Riva degli Schiavoni at San Marco/San Zaccaria; the stop (San Zaccaria M.V.E. "B") is in front of the Londra Palace Hotel. Boat number 20 goes to San Servolo. Remember to arrive a few minutes before departure time.

To San Servolo		Back to Venice	
S. Zaccaria	**S. Servolo**	**S. Servolo**	**S. Zaccaria**
6:55	*7:05*	*7:05*	*7:15*
7:15	*7:25*	*7:35*	*7.45*
8:10	*8:20*	*8:30*	*8:40*
8:40	*8:50*	*8:50*	*9:00*
9:00	*9:10*	*9:10*	*9:20*
9:20	*9:30*	*9:40*	*9:50*
9:50	*10:00*	*10:00*	*10:10*
10:30	*10:40*	*10:50*	*11:00*
11:10	*11:20*	*11:20*	*11:30*
11:50	*12:00*	*12:10*	*12:20*
12:30	*12:40*	*12:40*	*12:50*
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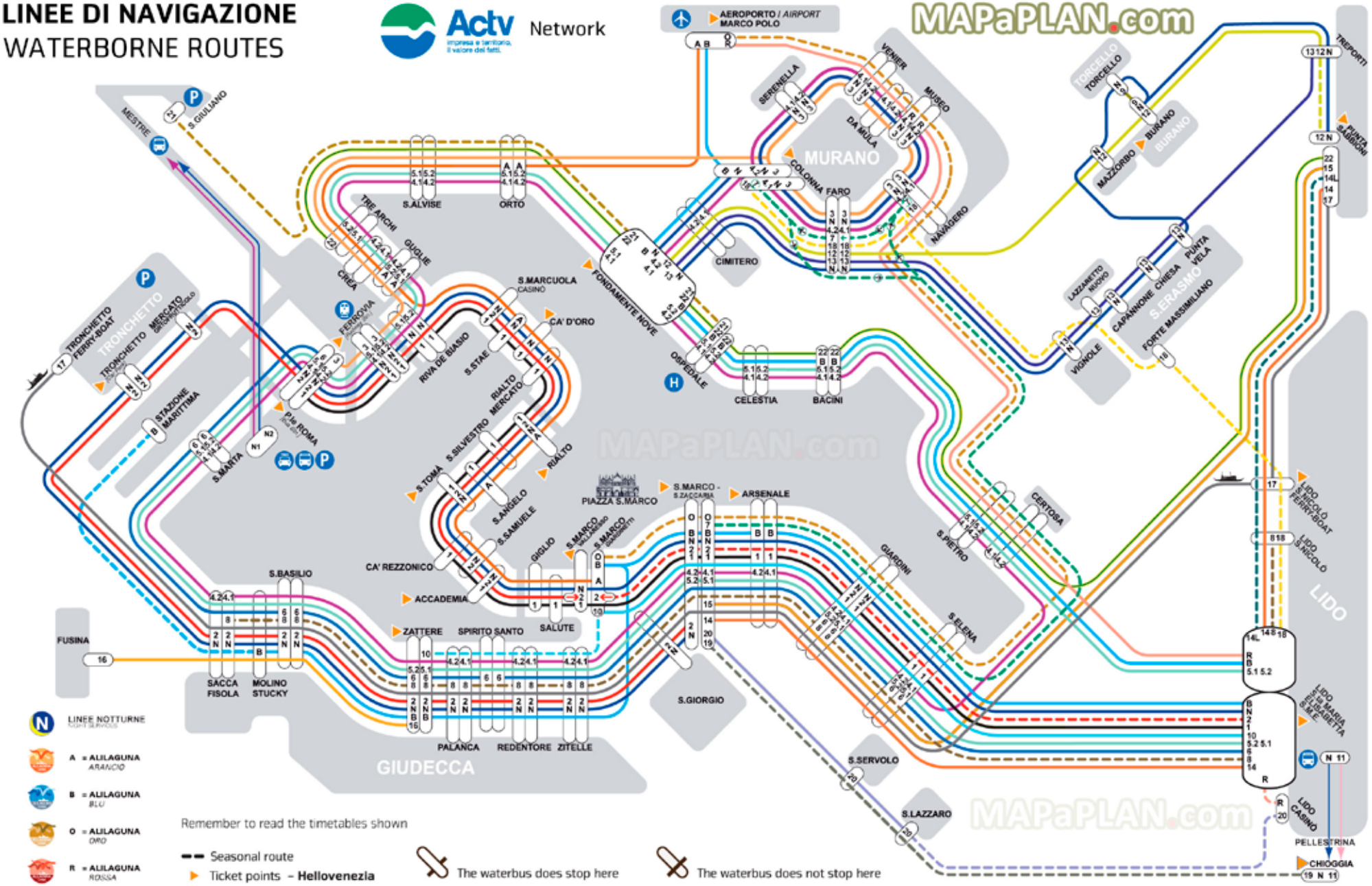
21:30	*21:40*	*21:40*	*21:50*
22:30	*22:40*	*22:40*	*22:50*
23:30	*23:40*	*23:40*	*23:50*
0:25	*0:35*	*0:35*	*0:45*
1:20	*1:30*	*1:30*	*1:40*

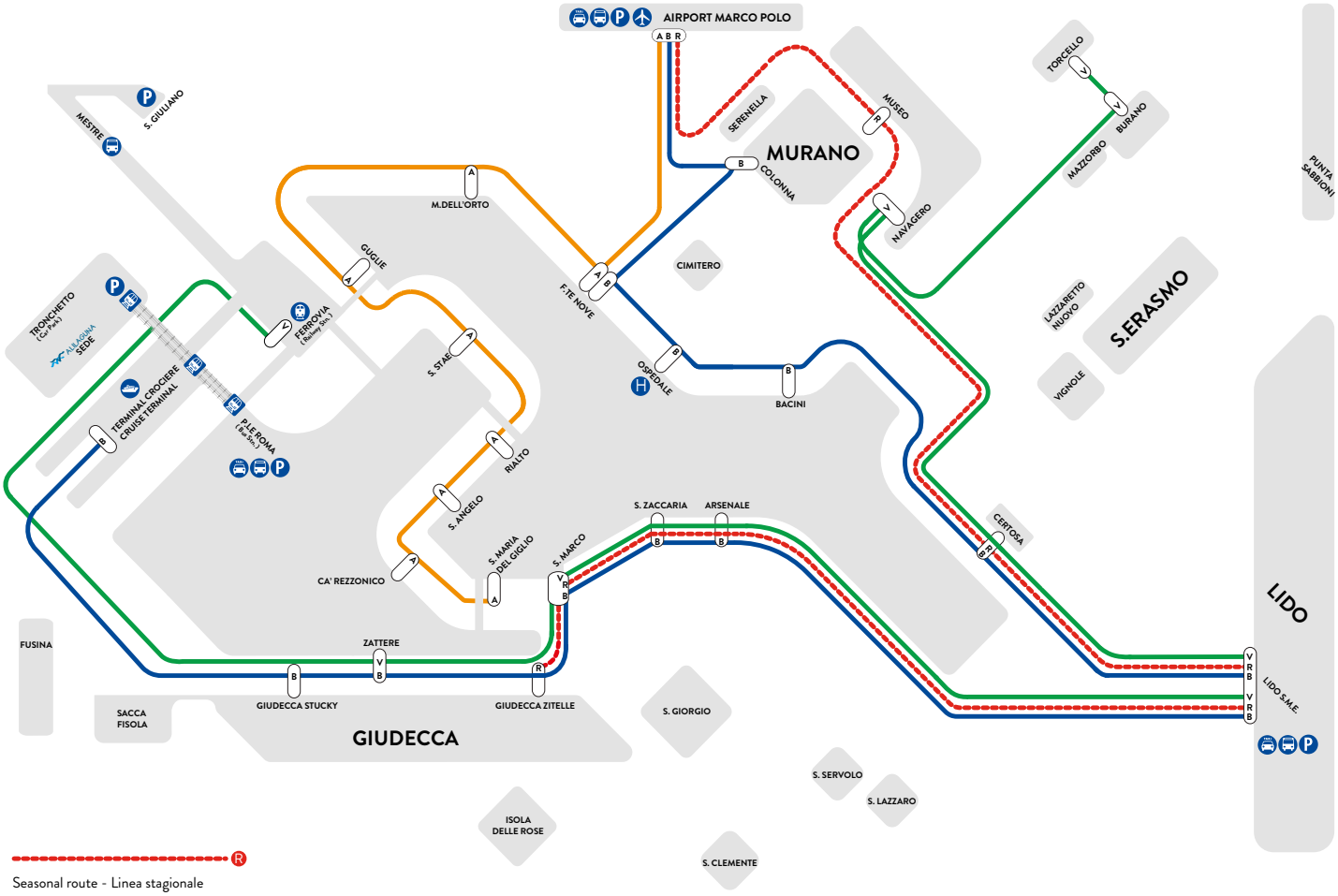
LINEE DI NAVIGAZIONE
WATERBORNE ROUTES

Actv Network



ALILAGUNA TRANSPORTATION (AIRPORT)

Please note that the ACTV tickets are not valid on Alilaguna lines (and vice versa).



Seasonal route - Linea seasonale

LINEA ROSSA AIRPORT - MURANO - CERTOSA - LIDO (S.M.E.) - S. MARCO - ZITELLE

APT > ZITELLE

AIRPORT	09:40	10:40	11:40	12:40	13:40	14:40	15:40	16:40	17:40	18:40	-
MURANO MUSEO	10:10	11:10	12:10	13:10	14:10	15:10	16:10	17:10	18:10	19:10	-
CERTOSA	10:25	11:25	12:25	13:25	14:25	15:25	16:25	17:25	18:25	19:25	-
LIDO S.M.E.	10:37	11:37	12:37	13:37	14:37	15:37	16:37	17:37	18:37	19:37	-
S.MARCO	10:52	11:52	12:52	13:52	14:52	15:52	16:52	17:52	18:52	19:52	-
GIUDECCA ZITELLE	10:59	11:59	12:59	13:59	14:59	15:59	16:59	17:59	18:59	19:59	-

ZITELLE > APT

ZITELLE	08:10	09:10	10:10	11:10	12:10	13:10	14:10	15:10	16:10	17:10	18:10
SAN MARCO	08:15	09:15	10:15	11:15	12:15	13:15	14:15	15:15	16:15	17:15	18:15
LIDO S.M.E.	08:30	09:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	18:30
CERTOSA	08:40	09:40	10:40	11:40	12:40	13:40	14:40	15:40	16:40	17:40	18:40
MURANO MUSEO	08:53	09:53	10:53	11:53	12:53	13:53	14:53	15:53	16:53	17:53	18:53
AIRPORT	09:23	10:23	11:23	12:23	13:23	14:23	15:23	16:23	17:23	18:23	19:23

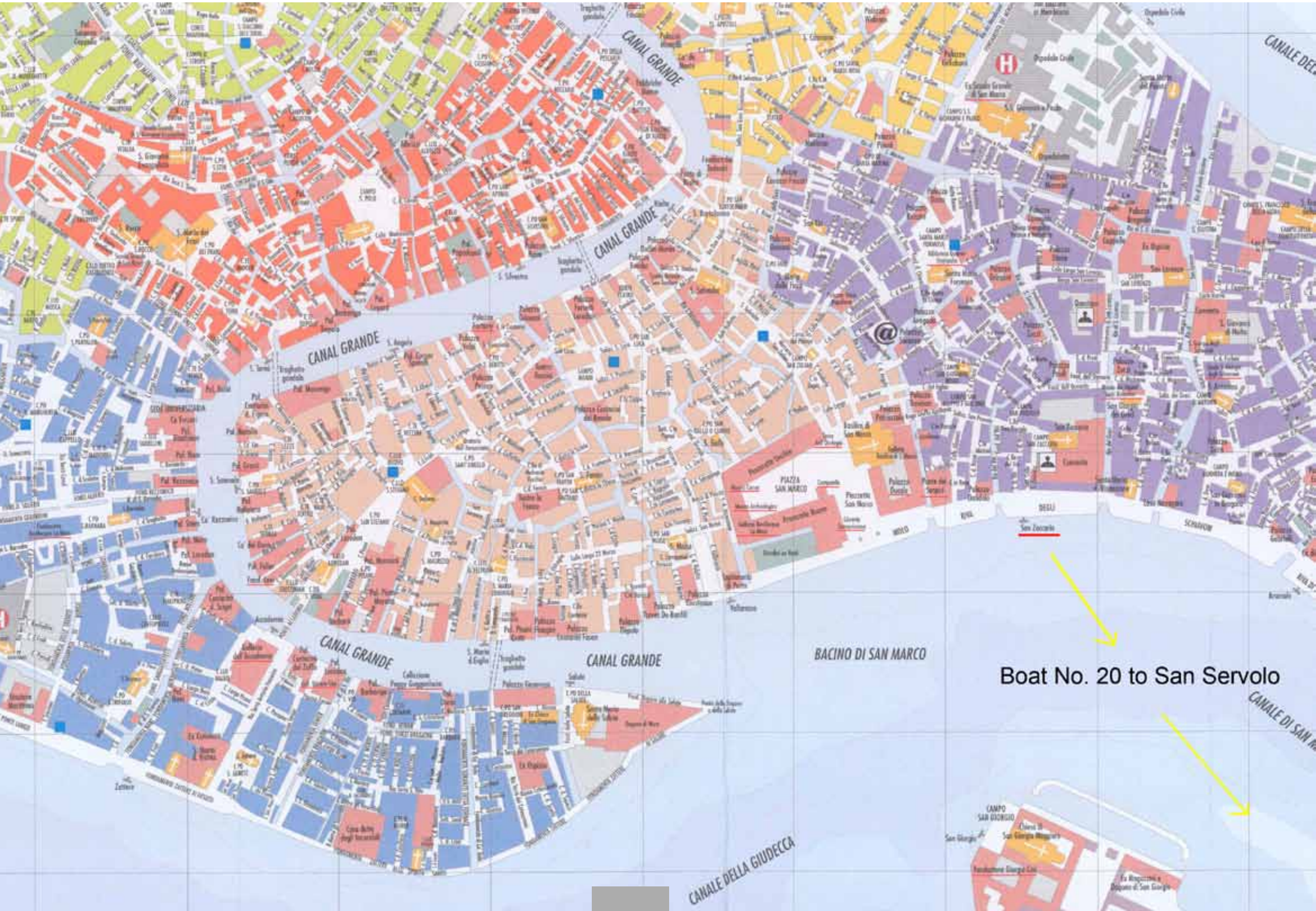
LINEA BLU AIRPORT - MURANO COLONNA - F.TE NOVE - OSPEDALE - BACINI - CERTOSA - LIDO S.M.E. - ARSENALE - S. ZACCARIA - S. MARCO - ZATTERE - GIUDECCA STUCKY - CRUISE TERMINAL

AIRPORT > CRUISE TERMINAL

AIRPORT	06:15	07:15	08:15	09:00	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:40	23:20	00:00	00:40
MURANO Colonna	06:45	07:45	08:45	09:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:10	23:50	00:30	01:10
F.TE NOVE	06:55	07:55	08:55	09:41	10:11	10:41	11:11	11:41	12:11	12:41	13:11	13:41	14:11	14:41	15:11	15:41	16:11	16:41	17:11	17:41	18:11	18:41	19:11	19:41	20:11	20:41	21:11	21:41	22:11	22:41	23:21	00:00	00:40	01:20
OSPEDALE	06:59	07:59	08:59	09:45	10:15	10:45	11:15	11:45	12:15	12:45	13:15	13:45	14:15	14:45	15:15	15:45	16:15	16:45	17:15	17:45	18:15	18:45	19:15	19:45	20:15	20:45	21:15	21:45	22:15	22:45	23:25	00:04	00:44	01:24
BACINI	07:03	08:03	09:03	09:49	10:19	10:49	11:19	11:49	12:19	12:49	13:19	13:49	14:19	14:49	15:19	15:49	16:19	16:49	17:19	17:49	18:19	18:49	19:19	19:49	20:19	20:49	21:19	21:49	22:19	22:49	23:29	00:08	00:48	01:28
CERTOSA	07:11	08:11	09:11	09:57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20:27	20:57	21:27	21:57	22:27	22:57	23:37	00:16	00:56	01:36
LIDO S.M.E.	07:20	08:20	09:20	10:06	10:36	11:06	11:36	12:06	12:36	13:06	13:36	14:06	14:36	15:06	15:36	16:06	16:36	17:06	17:36	18:06	18:36	19:06	19:36	20:06	20:36	21:06	21:36	22:06	22:36	23:06	23:46	00:25	01:05	01:45
ARSENALE	-	-	-	10:18	10:48	11:18	11:48	12:18	12:48	13:18	13:48	14:18	14:48	15:18	15:48	16:18	16:48	17:18	17:48	18:18	18:48	19:18	19:48	20:18	20:48	21:18	21:48	22:18	22:48	23:18	23:58	00:37	01:17	01:57
S.ZACCARIA	-	-	-	10:24	10:54	11:24	11:54	12:24	12:54	13:24	13:54	14:24	14:54	15:24	15:54	16:24	16:54	17:24	17:54	18:24	18:54	19:24	19:54	20:24	20:54	21:23	21:53	22:23	22:53	23:23	00:03	00:42	01:22	02:02
S.MARCO	07:32	08:32	09:32	10:28	10:58	11:28	11:58	12:28	12:58	13:28	13:58	14:28	14:58	15:28	15:58	16:28	16:58	17:28	17:58	18:28	18:58	19:28	19:58	20:28	20:58	21:28	21:58	22:28	22:58	23:28	00:08	00:47	01:27	02:07
ZATTERE	-	08:42	09:42	10:38	11:08	11:38	12:08	12:38	13:08	13:38	14:08	14:38	15:08	15:38	16:08	16:38	17:08	17:38	18:08	18:38	19:08	19:38	20:08	20:38	21:08	21:38	22:08	22:38	23:08	23:38	00:18	00:57	01:37	02:17
GIUDECCA Stucky	-	-	-	10:43	11:13	11:43	12:13	12:43	13:13	13:43	14:13	14:43	15:13	15:43	16:13	16:43	17:13	17:43	18:13	18:43	19:13	19:43	20:13	20:43	21:13	21:43	22:13	22:43	23:13	23:43	00:23	01:02	01:42	02:22
CRUISE TERM.	-	08:49	09:49	10:49	11:19	11:49	12:19	12:49	13:19	13:49	14:19	14:49	15:19	15:49	16:19	16:49	17:19	17:49	18:19	18:49	19:19	-	-	-	-	-	-	-	-	-	-	-	-	-

CRUISE TERMINAL > AIRPORT

CRUISE TERM.	-	-	-	-	-	-	07:56	08:26	08:56	09:26	09:56	10:26	10:56	11:26	11:56	12:26	12:56	13:26	13:56	14:26	14:56	15:26	15:56	16:26	16:56	17:26	17:56	18:26	-	-	-	-	-	-
GIUDECCA Stucky	-	04:35	05:35	06:35	07:05	07:35	08:05	08:35	09:05	09:35	10:05	10:35	11:05	11:35	12:05	12:35	13:05	13:35	14:05	14:35	15:05	15:35	16:05	16:35	17:05	17:35	18:05	18:35	19:35	20:05	20:35	21:20	22:20	22:35
ZATTERE	-	04:40	05:40	06:40	07:10	07:40	08:10	08:40	09:10	09:40	10:10	10:40	11:10	11:40	12:10	12:40	13:10	13:40	14:10	14:40	15:10	15:40	16:10	16:40	17:10	17:40	18:10	18:40	19:40	20:10	20:40	21:25	22:25	22:40
S.MARCO	03:50	04:50	05:50	06:50	07:20	07:50	08:20	08:50	09:20	09:50	10:20	10:50	11:20	11:50	12:20	12:50	13:20	13:50	14:20	14:50	15:20	15:50	16:20	16:50	17:20	17:50	18:20	18:50	19:50	20:20	20:50	21:35	22:35	22:50
S.ZACCARIA	03:55	04:55	05:55	06:55	07:25	07:55	08:25	08:55	09:25	09:55	10:25	10:55	11:25	11:55	12:25	12:55	13:25	13:55	14:25	14:55	15:25	15:55	16:25	16:55	17:25	17:55	18:25	18:55	19:55	20:25	20:55	21:40	22:40	22:55
ARSENALE	03:59	04:59	05:59	06:59	07:29	07:59	08:29	08:59	09:29	09:59	10:29	10:59	11:29	11:59	12:29	12:59	13:29	13:59	14:29	14:59	15:29	15:59	16:29	16:59	17:29	17:59	18:29	18:59	19:59	20:29	20:59	21:44	22:44	22:59
LIDO S.M.E.	04:10	05:10	06:10	07:10	07:40	08:10	08:40	09:10	09:40	10:10	10:40	11:10	11:40	12:10	12:40	13:10	13:40	14:10	14:40	15:10	15:40	16:10	16:40	17:10	17:40	18:10	18:40	19:10	20:10	20:40	21:10	21:55	22:55	23:10
CERTOSA	04:18	05:18	06:18	07:17	07:48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19:18	20:18	20:48	21:18	22:03	23:03	23:18
BACINI	04:24	05:24	06:24	07:24	07:54	08:24	08:54	09:24	09:54	10:24	10:54	11:24	11:54	12:24	12:54	13:24	13:54	14:24	14:54	15:24	15:54	16:24	16:54	17:24	17:54	18:24	18:54	19:24	20:24	20:54	21:24	22:09	23:09	23:24
OSPEDALE	04:27	05:27	06:27	07:27	07:57	08:27	08:57	09:27	09:57	10:27	10:57	11:27	11:57	12:27	12:57	13:27	13:57	14:27	14:57	15:27	15:57	16:27	16:57	17:27	17:57	18:27	18:57	19:27	20:27	20:57	21:27	22:12	23:12	23:27
F.TE NOVE	04:32	05:32	06:32	07:32	08:02	08:32	09:02	09:32	10:02	10:32	11:02	11:32	12:02	12:32	13:02	13:32	14:02	14:32	15:02	15:32	16:02	16:32	17:02	17:32	18:02	18:32	19:02	19:32	20:32	21:02	21:32	22:17	23:17	23:32
MURANO Colonna	04:39	05:39	06:39	07:39	08:10	08:40	09:10	09:40	10:10	10:40	11:10	11:40	12:10	12:40	13:10	13:40	14:10	14:40	15:10	15:40	16:10	16:40	17:10	17:40	18:10	18:40	19:10	19:40	20:40	21:10	21:40	22:25	23:25	23:40
AIRPORT	05:09	06:09	07:09	08:09	08:40	09:10	09:40	10:10	10:40	11:10	11:40	12:10	12:40	13:10	13:40	14:10	14:40	15:10	15:40	16:10	16:40	17:10	17:40	18:10	18:40	19:10	19:40	20:10	21:10	21:40	22:10	22:55	23:55	00:10


CANAL GRANDE
CANAL GRANDE
CANAL GRANDE
CANAL GRANDE
CANALE DELLA GIUDECCA
BACINO DI SAN MARCO
PIAZZA SAN MARCO
San Zaccaria
Boat No. 20 to San Servolo
CANALE DI SAN

CeNS Workshop Venice 2016: Nanoscale Matter – Novel Concepts and Functions

Sunday, Sept 18	Time	Monday, September 19	Time	Tuesday, September 20	Time	Wednesday, September 21	Time	Thursday, September 22	Time	Friday, September 23
	09:00	Welcome	09:00	John Anthony	09:00	Sebastian Huber	09:00	Dieter Braun	09:00	Wesley Legant
	09:15	Stephen Doorn							09:45	Daniela Ziegler
	10:00	Matthew Paszek	09:45	Jeffrey Schwartz	09:45	Josef Käs	09:45	Tony Heinz	10:05	Stephan Rauschenbach
	10:45	Coffee break	10:30	Coffee break	10:30	Coffee break	10:30	Coffee break	10:50	Closing remarks
	11:15	Thomas Perkins	11:00	Jan Philipp Junker	11:00	Emanuel Lörtscher	11:00	Heiko Weber		
	11:45	Patrick Maletinsky	11:45	Jan Budich	11:45	Alberto Salleo	11:45	Valentina Cauda		
Arrival		Lunch (12:30-14:15)		Lunch (12:30-14:15)		Lunch (from 12:30) Boat at 12:40		Lunch (12:30-14:15)		Boat leaves at 11:20 / 12:10 Train to Munich leaves at 13:50 h from train station
	14:15	Kurt Gothelf	14:15	Ann McEvoy		Informal discussions	14:15	Michael Knap		
	15:00	Alberto Morpurgo		Posters session I & coffee (15:00-17:00)			15:00	Florian Schüder		
	15:45	Coffee break					15:20	Suchitra Sebastian		
	16:15	David Cahen						Posters session II & coffee/drinks (16:05-18:30)		
	17:00	Michael Nash	17:00	Karsten Reuter						
20:00	Welcome reception									