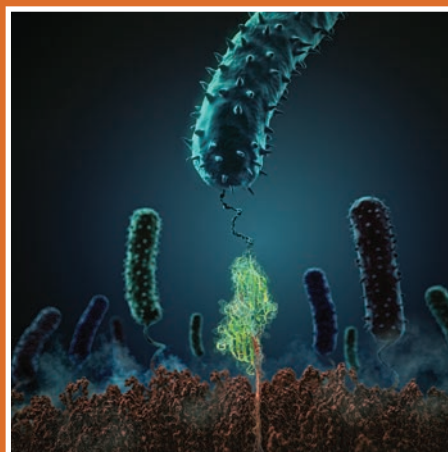
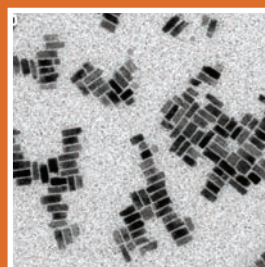
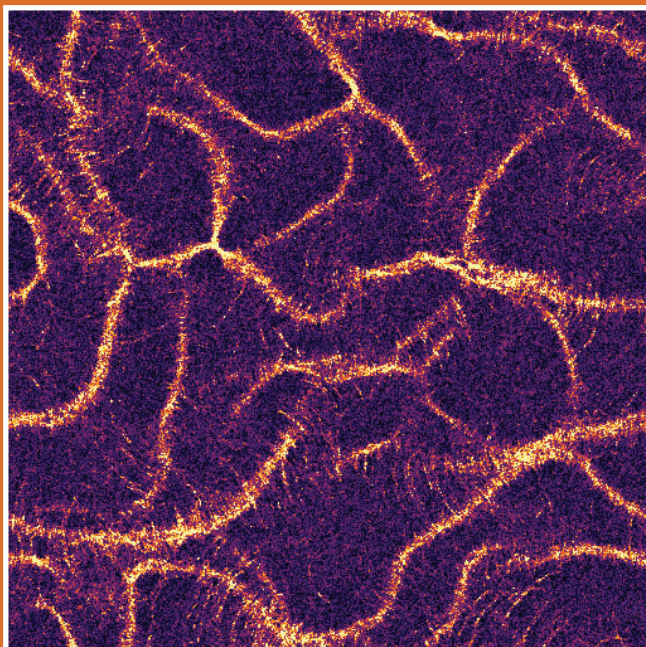


# CENTER FOR NANOSCIENCE ANNUAL REPORT 2018



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**CENTER FOR NANOSCIENCE**  
**ANNUAL REPORT 2018**

## WELCOME



20 years and still going strong, possibly stronger than ever. This year has seen many developments and exciting achievements for CeNS and the nano-community in Munich – with CeNS' 20th anniversary and the accompanying events as highlights.

The CeNS anniversary was celebrated at the Venice Workshop with the witty title “Celebrating NanoScience!” The workshop was a beautiful combination of revisiting the history of CeNS and recognizing outstanding current developments presented by our speakers. The festive anniversary colloquium then took place in Munich in January, exactly 20 years after the opening symposium.

It can be clearly stated that nanotechnology is still the central cross-sectional theme spanning all the disciplines from physics to chemistry and biology, and will increasingly expand into the medical sciences. The nanoscale is where atomic and molecular building blocks come together and where functions emerge, both in physics and in biology. CeNS is a place where many disciplines converge, and new ideas nucleate into innovative projects and initiatives.

Many activities have taken place in the CeNS 2018 calendar. The winter retreat was reinitiated by the CeNS student representatives and brought together PhD students and postdocs in the Marburger Haus in Kleinwalsertal. A group of PhD students learned and worked with peers at the

Center for the Physics of Living Cells in Urbana-Champaign within the Junior Nanotech Network 2017/2018. CeNS also supported several workshops, including the 3rd Functional DNA Nanotechnology Workshop co-organized by Tim Liedl, the “Key Challenges in Biophysics” symposium of SFB1032, as well as the 6th European Workshop on Advanced Fluorescence Methods organized by Don Lamb. With the Munich 2D Materials (M2M) initiative, a new research community was established, and M2M meetings are organized regularly by dedicated participants including Alex Högele, Achim Hartschuh, Thomas Weitz, and Alex Holleitner.

The last year has also seen some significant changes in the funding structure of the CeNS community. The CeNS related excellence clusters NIM and CIPSM are expiring, and new topics and focus areas are emerging. Notably, CeNS members now participate in the newly-founded excellence clusters e-conversion, Munich Center for Quantum Science and Technology, and Origins, which are funded for an initial period of 7 years. With the TRR 235 “Emergence of Life”, Dieter Braun succeeded in establishing another important coordinated research center for the CeNS and Munich community.

CeNS' liveliness is strongly connected to the success and commitment of its members. Dieter Braun and Tim Liedl received the next ERC Advanced and Consolidator grants, respectively. ERC Proof of Concept grants went to Alex Högele and Ralf Jungmann. Thomas Bein received the 2018 Lifetime Achievement Award, Hanna Engelke was awarded the Arnold-Sommerfeld-Preis of the Bayerische Akademie der Wissenschaften, and

Peter Hänggi received the Blaise Pascal Medal of the European Academy of Science. Jan Lipfert from the Faculty of Physics won the “Preis für gute Lehre” of the Faculty of Chemistry and Pharmacy, demonstrating the good relationships between the disciplines!

CeNS has again been very successful in translating new ideas into the real world. CeNS member Heinrich Leonhardt was part of the team that received the Leibniz Gründerpreis 2018 for the start-up Tubulis Technologies. Similarly, Peter Marinkovic as well as the team of Johannes Wöhrstein and Heinrich Grabmayr received GO-Bio Biotechnology awards for new start-up projects. Companies that started as CeNS spin-offs have made great achievements this year; Nanotemper, neaspec and GNA Biosolutions earned several awards, and GATTAquant now offers its commercial DNA origami application in Munich after a recent relocation.

For me personally, coming back to Munich after many years and setting up the labs at the campus in Großhadern has been a special delight. Discovering that the same spirit of scientific excitement, interdisciplinary exchange, and actualized cooperation catalyzed by CeNS had remained strong was one of the most important aspects. It was such a warm welcome for the group, and the new members easily adapted to the spirit of CeNS.

We hope you will enjoy reading the CeNS annual report with all the recent activities, new developments, and – most importantly – the science that drives us.

Last but not least, on behalf of all CeNS members, we express our gratitude to the crew that keeps things running smoothly and helps turn all ideas into fully realized initiatives: Susanne Hennig, managing director, Marilena Pinto, program manager, and Claudia Leonhardt, team assistant.

*Prof. Philip Tinnefeld*

Member of the Scientific Board of CeNS

## NEW MEMBERS

### DR. TAYEBEH AMERI

LMU Munich



Dr. Tayebah Ameri is currently a team leader and lecturer in the department of Physical Chemistry / chair of Prof. Bein at the Ludwig-Maximilians-Universität München (LMU). Her main research interests include investigation and development of

organic and hybrid optoelectronic devices with a focus on energy applications. She obtained her master degree in Solid State Physics at Ferdowsi University of Mashhad in Iran. After her master study, she joined Konarka GmbH Austria and received her PhD in Engineering Sciences from Johannes Kepler University Linz in 2010. Afterwards, she worked as postdoctoral researcher and group leader in the department of Material Science and Engineering at Friedrich Alexander University Erlangen-Nürnberg (FAU) and undertook her Habilitation at FAU from 2013 till 2017.

### DR. HEINRICH GRABMAYR

LMU Munich



Dr. Heinrich Grabmayr studied physics at the University of Konstanz and the Technical University of Munich (TUM). He completed his PhD in the field of STED microscopy at Prof. Andreas Bausch's chair for cellular biophysics at the TUM. From 2014 until 2017, he joined the lab of Thomas Gregor at

Princeton University as a research associate, focusing on lattice light sheet microscopy. In 2017, he was one of the co-founders of DEOXY at LMU where he has since been responsible for technology development.

### DR. PETAR MARINKOVIC

LMU Munich



Dr. Petar Marinkovic successfully led the project NanoCapture from proof-of-principle studies to the fully funded BMBF GO-Bio project. Currently located at the Department of Pharmacy at LMU, the NanoCapture team works on developing novel approaches to

significantly improve the selectivity of drug delivery during tumor chemotherapies. Dr. Petar Marinkovic studied molecular biology at the University of Belgrade, Serbia. He completed his PhD in the group of Prof. Thomas Misgeld at the TUM where he studied axonal transport of mitochondria. After a postdoc with Prof. Jochen Herms at the German Center for Neurodegenerative Diseases and LMU, he teamed-up with Dr. Oliver Thorn-Seshold at LMU to translate the fundamental research into clinical applications.

**DR. LAKSHMINARAYANA  
POLAVARAPU**

LMU Munich



Dr. Lakshminarayana Polavarapu studied chemistry at the University of Hyderabad in India, where he obtained his M.Sc. degree in 2005. He joined the ultrafast laser spectroscopy lab at the National University of Singapore (NUS) and pursued his PhD thesis about the

linear and nonlinear optical properties of plasmonic nanocrystals. After receiving his doctoral degree in 2011 from NUS, he worked with Prof. Luis M. Liz-Marzán as a postdoctoral fellow at CIC biomAGUNE and University of Vigo in Spain from 2012 to 2014, where he worked on the shape-controlled synthesis of plasmonic nanocrystals for SERS applications. In 2015, he joined the chair for photonics and optoelectronics at the LMU as an Alexander von Humboldt research fellow. Since September 2017, he has been a junior research group leader at the Chair lead by Prof. Jochen Feldmann. His current research focuses on the shape-controlled synthesis of halide perovskite nanocrystals for applications such as LEDs, lasers and photovoltaics.

**DR. PETRA ROVÓ**

LMU Munich



Dr. Petra Rovó is a junior group leader at the Department of Chemistry at LMU. She studied chemistry at the Eötvös Loránd University in Budapest in Hungary, where she obtained her PhD under the supervision of András Perczel studying the folding and dynam-

ics of artificial mini-proteins by solution-state NMR spectroscopy. As a Fulbright fellow, she spent a year in the United States and learned about Redfield relaxation theory with Jeffrey W. Peng at the University of Notre Dame. After graduation, she joined the lab of Rasmus Linser at the Max Planck Institute for Biophysical Chemistry in Göttingen, where she dived into solid-state biomolecular NMR with a special emphasis on microsecond time scale protein motion under fast magic angle spinning. In 2018, she started her own lab at LMU where she uses both solution and solid-state NMR techniques to gain insight into the driving forces behind protein aggregation and self-organization. In her lab, she applies genetic engineering, bacterial protein expression, and spin dynamics simulations to aid the analysis of the NMR spectra.

## NEW MEMBERS

### PROF. OLIVER TRAPP

LMU Munich



Prof. Oliver Trapp is full professor at the Department of Chemistry at LMU since 2016. He is a graduate of Tübingen University. After a postdoc at Stanford University with Richard N. Zare, he became an independent Emmy Noether Research Group Leader at the

Max Planck Institute for Coal Research in Mülheim / Ruhr in 2004. From 2008 until 2016 he was a professor at Heidelberg University. He was awarded the Analytical Chemistry Division Award of the Gesellschaft Deutscher Chemiker (GDCh) in 2003, the Heinz Maier-Leibnitz Award of the Deutsche Forschungsgemeinschaft (DFG) in 2008, the Northrhine-Westphalian Innovation Award in 2008, and an ERC Starting Grant in 2010. Very recently, he was appointed as a Max Planck Fellow by the Max Planck Society. He has published over 140 publications. He is interested in understanding self-amplifying and autocatalytic reaction networks leading to symmetry breaking, evolution on the molecular level, and pathways leading to early life in the context of the Origin of Life.

### DR. JOHANNES B. WÖHRSTEIN

LMU Munich



Dr. Johannes Wöhrstein studied physics with a specialization in biophysics at the TUM. He completed his master thesis in the group of Prof. Fritz Simmel at the TUM and at the Wyss Institute at Harvard University. From 2015 until 2017, he undertook his PhD in

the group of Prof. Ralf Jungmann at the MPI of Biochemistry. He has been a project leader at DEOXY since January 2017.



## CALLS & APPOINTMENTS



**Prof. Rasmus Linser** (LMU) accepted a position as W3 (Chair for biomolecular NMR spectroscopy) at the Technical University Dortmund.



**Prof. Alexander Urban** (LMU) was appointed as W2 professor (tenure track) at the Faculty of Physics.

## CENS BOARD



**Prof. Dieter Braun** (LMU) was elected as new spokesman of the CeNS board.



**Prof. Philip Tinnefeld** (LMU) was elected as a new member of the CeNS board.



**Prof. Tim Liedl, Prof. Claudia Veigel and Prof. Ulrich Schollwöck** (LMU) were confirmed as members of the CeNS board.

## AWARDS & FUNDING

### ERC GRANTS



**Prof. Dieter Braun** (LMU) received an ERC Advanced Grant for his project "Mechanisms of emergence and replication of primary sequence information of life in the geothermic microfluidics of the early earth".



**Prof. Alexander Högele** (LMU) received an ERC Proof of Concept Grant for his project "Cavity-enhanced optical microscope".



**Prof. Tim Liedl** (LMU) received an ERC Consolidator Grant for his project "DNA-based functional lattices".



**Prof. Ralf Jungmann** (LMU) won an ERC Proof of Concept Grant for his research project "From Tissues to Single Molecules: High Content in Situ Super-Resolution Imaging with DNA-PAINT".

In addition, he received a Young Investigators' Grant from the Human Frontier Science Program.

### AWARDS



**Prof. Thomas Bein** (LMU) received the 2018 Lifetime Achievement Award (IMMA) and was selected as 2018 Highly Cited Researcher by Clarivate Analytics.



**Dr. Hanna Engelke** (LMU) was awarded the Arnold Sommerfeld Prize of the Bavarian Academy of Sciences and Humanities.



**Prof. Peter Hänggi** (Augsburg University) received the Blaise Pascal Medal in Physics of the European Academy of Science.



**Prof. Jan Lipfert** (LMU) won the "Preis für gute Lehre" of the LMU Faculty of Chemistry and Pharmacy.

## START-UP AWARDS



**Prof. Heinrich Leonhardt** (LMU) received the Leibniz Gründerpreis 2018 together with Dr. Jonas Helma-Smets, Dr. Dominik Schumacher and Prof. Christian Hackenberger of the FMP Berlin for their start-up Tubulis Technologies.



**Dr. Petar Marinkovic** (LMU) received a GO-Bio Biotechnology award of the BMBF for the start-up project NanoCapture.



**Dr. Johannes B. Wöhrstein and Dr. Heinrich Grabmayr** (LMU) received a GO-Bio Biotechnology award of the BMBF for the start-up project DEOXY.

## COLLABORATIVE RESEARCH PROJECTS

Three new **Clusters of Excellence** with CeNS participation receive funding in the framework of the German Excellence Initiative: The **e-conversion Cluster of Excellence** is exploring ways to deliver a stable, efficient and sustainable supply of energy by combining nanoscience with energy sciences. e-conversion merges the powerful concepts of nanoscience and mechanistic energy research to create well-defined and tunable reference systems, and to establish fundamental understanding through their comprehensive characterization. The chemists and physicists involved in the

research network, thereof 12 CeNS members, plan to analyze these processes in detail and to optimize the molecular structures of these interfaces for maximum efficiency.

■ [www.e-conversion.de](http://www.e-conversion.de)

The purpose of the **Munich Center for Quantum Science and Technology (MCQST)** is to further explore the principles of quantum information with a view to the practical application of quantum effects. Six CeNS members are part of MCQST.

■ [www.mcqst.de](http://www.mcqst.de)

The **Cluster of Excellence Origins** will study the evolution of the cosmos – "From the Origin of the Universe to the First Building Blocks of Life". Its goal is to show that life is the product of a natural process, a logical outcome of the evolution of the Universe – which can be understood based on the laws of physics and chemistry and the initial conditions created by the Big Bang. Five CeNS members will contribute to the cluster with their biophysical expertise on the evolution of early life.

■ [www.origins-cluster.de](http://www.origins-cluster.de)

The evolution of life on earth: This question will be examined by **TRR 235 "Emergence of life: Exploring mechanisms with cross-disciplinary experiments"** in a comprehensive approach, connecting the disciplines of astronomy, earth sciences, physics, chemistry and biology. The long-term goal is to reproduce primitive living systems in the laboratory under conditions that could have existed on the young earth.

The new Transregio joins groups from LMU, TUM, MPI of Biochemistry, MPI of Extraterrestrial Physics, Helmholtz Center Munich, Deutsches Museum, University of Stuttgart and University of Heidelberg, thereof 40% CeNS members. Spokesman is Prof. Dieter Braun (CeNS/LMU).

■ [www.emergence-of-life.de](http://www.emergence-of-life.de)

## NANO INNOVATION AWARD 2018

The Nano Innovation Award focuses specifically on innovative work by junior researchers with promising application potential in technology or medicine. In 2018, two young researchers from Munich received the award for promising results as part of their master's or doctoral thesis in application-oriented nanosciences. The Bavarian-wide prize is endowed with 9,000 euros and is awarded annually by a jury of experts from science and business.

### Cell monitoring for cancer research

An innovative and easy-to-use microscopy technique is the basis for the work of Konstantin Ditzel, who received the award for the best master's thesis with prize money of €3,000. The physicist from the team of Dr. Philipp Paulitschke at the LMU Chair of Soft Matter and Biophysics used lens-less microscopy technology to test the efficacy of anticancer drugs. Konstantin Ditzel has developed the experimental set-up and the evaluation of data in such a way that the influence of a drug on several cell vitality parameters can be determined simultaneously in a high-throughput, label-free manner. This allows continuous monitoring of the behavior of

cells treated with drugs, as well as quick and reliable determination of the efficacy - for example in cancer or stem cell research.

### DNA construction kit in the maxi format

The award for the best doctoral thesis endowed with €6,000 went to Dr. Klaus Wagenbauer from the group of Prof. Hendrik Dietz, Experimental Biophysics at the Faculty of Physics of the TUM. Klaus Wagenbauer has developed a new approach of tailor-made, controlled and self-directed assembly of large, three-dimensional objects from the genetic material DNA. He used building principles from nature to realize artificial nanostructures, inserting nanometer-sized DNA objects into each other like Lego bricks. The shape of the building blocks themselves is stored in the sequences of a small number of DNA molecules, and the shape of the individual building blocks in turn encodes the shape and size of the final object. Using this technique, Klaus Wagenbauer succeeded in forming defined objects the size of viruses or small cell



Nano Innovation Award winners Konstantin Ditzel (second from left) and Klaus Wagenbauer (fourth from left) with Dr. Susanne Hennig (Managing director CeNS), Michael George (Nanion), Prof. Achim Hartschuh (CeNS board) and Prof. Khaled Karrai (attocube).

organelles out of such tiny building blocks – an unprecedented nanotechnological achievement. This method might create the basis for promising new types of therapy and diagnosis of diseases.

### An institution with a thrust for the career

"The CeNS Nano Innovation Award has become an institution. Young researchers now regard it as visible proof of the quality of their work and an important award for their careers," said jury member Prof. Achim Wixforth from the University of Augsburg. "The number and quality of applications impressed me especially this year – which made the selection of the winners a difficult task." A total of 26 doctoral theses and 12 master theses were submitted from research institutions throughout Bavaria. From these, the jurors nominated five candidates for the final selection.

CeNS awarded the Nano Innovation Award together with four companies that are spin-offs from CeNS: attocube systems, ibidi, Nanion Technologies and NanoTemper Technologies. "CeNS with its outstanding scientists fosters nanoscience at the highest level – honoring them is our motivation to support the award," said Dr. Niels Fertig, CEO and founder of Nanion Technologies and member of the jury.

■ [www.cens.de/research/nano-innovation-award](http://www.cens.de/research/nano-innovation-award)



Prof. Feldmann, Bernhard Bohn, Robin Wein and Dr. Jacek Stolarczyk received the CeNS Publication Award for their paper in Nature Energy.

## CENS PUBLICATION AWARDS

On November 30, the winners of the 2018 CeNS Publication Awards were announced to the CeNS members after the CeNS Annual Assembly. The awards recognized remarkably successful cooperation projects within CeNS as well as outstanding research by individual research groups from CeNS.

### Best interdisciplinary publications:

- Kopperger, List, Madhira, Rothfischer, **Lamb, Simmel** (*Science* 2018).
- Mücksch, Blumhardt, Strauss, Petrov, **Jungmann, Schuille** (*Nano Letters* 2018, see p. 50).
- Hellenkamp, Schmid, ..., **Cordes, ..., Lamb, ..., Tinnefeld, ..., Michaelis, ..., Hugel** (*Nature Methods* 2018).
- Huber, Suzuki, Krüger, **Frey, Bausch** (*Science* 2018, see p. 27)

### Scientific breakthroughs:

- Lindlau, Selig, Neumann, Colombier, Förste, Funk, Förg, Kim, Berghäuser, Taniguchi, Watanabe, Wang, Malic, **Högele** (*Nature Comm.* 2018, see p. 31).
- Milles, Schulten, **Gaub**, Bernardi (*Science* 2018, see p. 29).
- Wolff, Frischmann, Schulze, Bohn, Wein, Livadas, Carlson, Jäckel, **Feldmann**, Würthner, **Stolarczyk** (*Nature Energy* 2018, see page 51).

### Best junior scientist publications:

- Eberle, Markert, **Trixler** (*JACS* 2018, see page 40).
- Tong, Fu, Bladt, Huang, Richter, Wang, **Müller-Buschbaum**, Bals, Tamarat, Lounis, **Feldmann, Polavarapu** (*Ang. Ch. Int. Ed.* 2018, see p. 49).
- Virmani, Rotter, Mähringer, von Zons, Godt, **Bein, Wuttke**, Medina (*JACS* 2018, see p. 52).

■ [www.cens.de/research/cens-publication-award](http://www.cens.de/research/cens-publication-award)

## SPIN-OFF NEWS

### ATTOCUBE

With the ultra-modern NanoFactory in Haar, Munich nanotech specialist attocube systems and its neaspec subsidiary are setting out on a path into the future hand-in-hand with Wittenstein SE, the parent company. Less than two years after the ground breaking dig, the new headquarters in Eglfinger Weg 2 were officially opened on October 11, 2018 at a formal evening event in the presence of international guests, customers and other close associates. The motto for the evening "grow up. stay young. shape the future." reflected the spirit of the new building as well as the rapid evolution of the two nanotechnology firms, both twenty first century startups. Around 150 people have meanwhile moved into the NanoFactory premises – including the sales team of Wittenstein alpha GmbH, who until now had been based in Ottobrunn – with more to come. *[Source: attocube press release]*

■ [www.attocube.com](http://www.attocube.com)

### GNA BIOSOLUTIONS

GNA Biosolutions was named the winner of the American Association of Clinical Chemistry's (AACC) Disruptive Technology Award competition 2018. The AACC Disruptive Technology Award recognizes innovative testing solutions that improve patient care through diagnostic performance or access to high-quality testing. GNA Biosolutions also won the audience choice award.

■ [www.gna-bio.de](http://www.gna-bio.de)



Impressions of attocube's new nanofactory in Haar.

## NANOTEMPER

In the 25th anniversary round of the TOP 100 Innovator competition, NanoTemper Technologies once again achieved a leading position: the company came in first place in its size category (companies with 51 to 200 employees) for the second time in a row. NanoTemper was also awarded the German Brand Award 2018.

In addition, the DPG Technology Transfer Award went to NanoTemper Technologies, together with CeNS and its Systems Biophysics group of Prof. Dieter Braun as well as the LMU Spin-off Service. The award was given for NanoTemper's outstanding development of micro-scale thermophoresis that enables analysis of extremely low levels of drug ingredients in natural environments, for the successful transfer of this technology to a spin-off, and for the successful commercial exploitation of this technology in drug development. The DPG Technology prize is jointly awarded to the institute where the technology was developed, to the technology transfer manager, and to the technology-implementing company.

■ [www.nanotemper.de](http://www.nanotemper.de)



**Left:** Prof. Dieter Braun, Dr. Philip Baaske (NanoTemper) and Christoph Zinser (LMU Spin-off Service) received the DPG Technology Transfer Award. **Right:** TOP100 Award for NanoTemper, presented by Ranga Yogeshwar.

## NEASPEC

neaspec received the Deloitte Technology Fast 50 Award 2018. The rankings are based on the percentage sales growth of the last four fiscal years from 2014 to 2017. neaspec achieved a growth of more than 190 percent during this period. The proprietary nano-FTIR technology developed by neaspec GmbH contributed significantly to this sales growth.

■ [www.neaspec.com](http://www.neaspec.com)



CENS ANNIVERSARY - VENICE WORKSHOP AND FESTIVE COLLOQUIUM



The title of the 2018 CeNS workshop spoke for itself – “Celebrating NanoScience!”. On the occasion of the 20th anniversary of CeNS, members, students and guests met once again at Venice International University on the beautiful island of San Servolo. The program was not only devoted to the past achievements of the scientific field, but also focused on current developments and the future of nanoscience. The list of speakers included long-standing friends and supporters of CeNS, such as advisory board members David Awschalom and Cees Dekker, and founding members Khaled Karrai from attocube and Wilhelm Zwerger from the TUM.

The CeNS board once more had remained true to the workshop’s concept of mapping nanoscience in all its breadth and invited an impressive line of international speakers: Jeremy Baumberg, Jeff Brinker, Paola Caselli, Zhen-Chao Dong, Mohamed Eddaoudi, Peter Fratzl, Atac Imamoglu, Tobias Kippenberg, Justin Molloy, Laura Na Liu, Michel Orrit, Vahid Sandoghdar, Cecile Sykes, Robert Westervelt, and Shimon Weiss. This was complemented by talks of researchers from the Munich area – Jonathan Finley, Bettina Lotsch, Petra Schwillle, Fritz Simmel, Philip Tinnefeld, and Jacek Stolarczyk. The recently introduced “Key Challeng-



**Left:** Prof. Atac Imamoglu, Prof. Khaled Karrai, Prof. Alexander Högele, Prof. Wilhelm Zwerger, and CeNS PhD students enjoying the CeNS anniversary dinner. **Right:** Venice International University gave CeNS a beautiful birthday cake as a present for longstanding co-operation.



es" format was continued with two lectures by Tobias Kippenberg and Friedrich Simmel to stimulate discussions on future developments within a special field.

On the last evening of the workshop, there were multiple reasons to celebrate: on the one hand, the CeNS anniversary, and on the other, the success of three new excellence clusters at LMU and TUM with the participation of CeNS groups. Prof. Hermann Gaub moderated the memorable evening on San Servolo. Prof. Achim Wixforth gave a wonderful jubilee speech in which he gave an entertaining review of the beginnings and developments of CeNS. Last but not least, a spontaneous CeNS choir performed two special songs together with Kevin Martens, Hanna Engelke and Martin Benoit from UnCeNSiart: "Mit CeNS ist es schön", formerly known as "Bei mir bist Du scheen", and the famous Beatles song "Help!", now known as "CeNS!". A sweet highlight was the enormous CeNS birthday cake, a gift from Venice International University. The ceremonial cutting of the cake was performed as a joint effort of current and



**Top:** CeNS Anniversary Colloquium.

**Bottom:** CeNS founding members reunited: Prof. Wilhelm Zwerger, Prof. Johann Peisl, Prof. Jörg Kotthaus, Prof. Khaled Karrai, Prof. Hermann Gaub, and Prof. Jochen Feldmann.



**Top:** Prof. Hermann Gaub was the Master of ceremonies at the CeNS birthday party. **Bottom:** Students, members and staff joined the CeNS birthday choir.

former CeNS board members. The evening continued with music and dance in a late summer atmosphere.

Exactly 20 years after the opening symposium of CeNS on January 18th 1999, a festive anniversary colloquium took place in Munich. The anniversary was celebrated with opening addresses by LMU President Prof. Huber and the Dean of the Faculty of Physics, Prof. Bender, followed by a speech of CeNS spokesman Prof. Braun.

The scientific component was comprised of invited talks by Florian Marquardt (MPI Erlangen) and Joachim Spatz (MPI Heidelberg) and two talks by CeNS members Dr. Tayebah Ameri and Prof. Alexander Urban. Among the many guests, there were also all six CeNS founding members – Prof. Jochen Feldmann, Prof. Hermann Gaub, Prof. Khaled Karrai, Prof. Jörg Kotthaus, Prof. Johann Peisl, and Prof. Wilhelm Zwerger.

■ [www.cens.de/calendar/workshops-events](http://www.cens.de/calendar/workshops-events)

## FOCUS WORKSHOPS



The **Munich2D Materials** initiative brings together 15 theoretical and experimental groups from the greater

Munich area working on novel 2D materials. Regular meetings with short talks with a focus on discussion are at the heart of this initiative. Eight CeNS groups (Hartschuh, Holleitner, Högele, Keilmann, Krenner, Punk, Nickel, and Weitz) are participating in this forum. CeNS funded the first meetings at LMU.

■ [www.munich2dmaterials.de](http://www.munich2dmaterials.de)

The **3rd Functional DNA Nanotechnology Workshop** was held in Rome from June 2 to 8, 2018. The workshop was organized by CeNS member Tim Liedl and Francesco Ricci and financially supported by CeNS. It provided a premier forum where scientists with diverse backgrounds came together to share knowledge and ideas about functional DNA nanotechnology, bioengineering, synthetic biology, DNA-based sensing, aptamers, and DNA-peptide chimera.

■ [www.fdn2018.com](http://www.fdn2018.com)

Supported by CeNS and SFB 863, the SFB1032 organized a workshop on **“Key Challenges in Biophysics”** in Kloster Seeon (July 31- August 2, 2018). Twenty-seven renowned international speakers presented their latest research to the SFB1032/ CeNS audience.

■ [www.sfb1032.physik.uni-muenchen.de/news/key-challenges](http://www.sfb1032.physik.uni-muenchen.de/news/key-challenges)

The **6th European Workshop on Advanced Fluorescence Methods** took place from December 10-14, 2018 at LMU. Organized by Don Lamb and supported by CeNS, the workshop consisted of advanced theoretical lectures by experts in the field and computer-based training on data analysis and simulations, underscoring what was taught during the lectures. The theoretical part was complemented by hands-on laboratory training using the fluorescence microscopy instrumentation of the LMU.

■ [www.cup.uni-muenchen.de/pc/lamb/workshop](http://www.cup.uni-muenchen.de/pc/lamb/workshop)

## CENS MEETS INDUSTRY

On July 13, students, members, and alumni now working in the industrial sector joined to share experiences and ideas at the event “CeNS meets Industry”. The speakers covered a wide range of business branches – from the TUM spin-off Dynamic Biosensors to large companies such as Infineon and Clariant, a specialty chemicals company. In addition, representatives from the consulting company d-fine and a company for lab automation, Hamilton Robotics, gave insights into their work.

Together with SFB1032, CeNS organized a lunch for female junior scientists with the two invited female speakers of the event, Dr. Klara Malinowska (Hamilton) and Dr. Friederike Möller (Dynamic Biosensors) to exchange career advice in an informal atmosphere. The event was followed by the presentation of the Nano Innovation Award winners 2018 and the summer party in the Sallinhof in perfect weather, with music by “Un-CeNSiert”, food and drinks.

■ [www.cens.de/calendar/workshops-events/cens-meets-industry-2018](http://www.cens.de/calendar/workshops-events/cens-meets-industry-2018)



## CAREER EVENTS AND KEY QUALIFICATION WORKSHOPS

CeNS supported its junior researchers on their way to becoming independent scientists with several special events. In the CeNS/SFB1032 workshop **“Postdoc careers: stairway to heaven or highway to hell?”**, Prof. Chase Broederz (LMU), Dr. Nicolai Hartmann (Neaspec), Dr. Hannes Mutschler (MPI of Biochemistry), Prof. Thomas Weitz (LMU), and Dr. Ursula Wurstbauer (TUM) shared their personal postdoc experiences with the CeNS students, while Dr. Anna Pahl and Brice Rousseau from LMU Research Services provided information about funding schemes and scholarships for postdocs. The workshop **“Leading and supervising in science”** addressed advanced PhD students and postdocs and dealt with supervising Bachelor and Master students in the lab effectively. Another workshop **“Kreativitätstechniken für die Promotionsphase”** was aimed at more junior PhD students, giving them tools to systematically analyze problems, dissolve thinking blocks, be inventive and evaluate ideas. In addition, CeNS organized two **company visits** for PhD students at the CeNS spin-off ibidi in Martinsried and at Bain & Co.

■ [www.cens.de/calendar/past-workshops-events](http://www.cens.de/calendar/past-workshops-events)

## CENS RETREAT

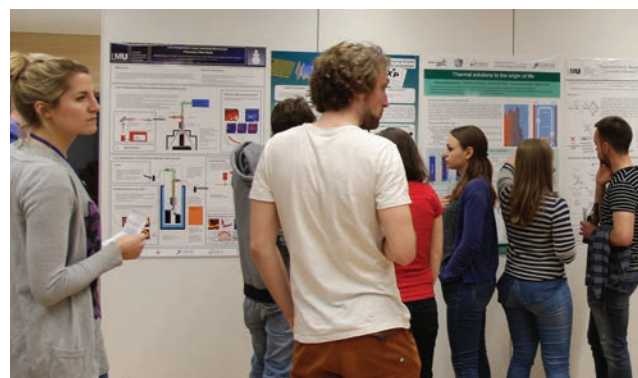
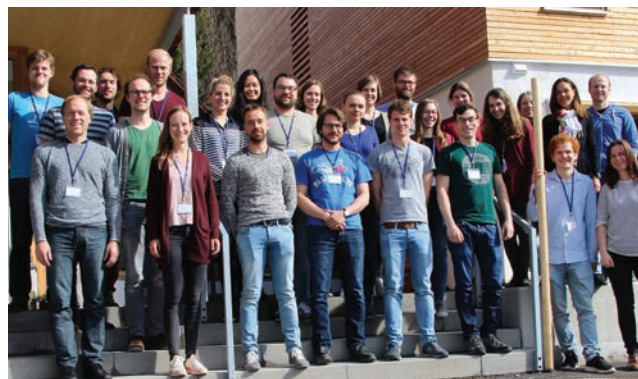
The CeNS retreat 2018 in the Marburger Haus/ Kleinwalsertal was initiated and planned by the CeNS student representatives. It brought together about 25 graduate students and postdocs from CeNS in an informal atmosphere. In talks and poster sessions, the participants could get an overview of current research within CeNS and discuss their results. Two workshops on job applications in English and on conflict management complemented the program. Talks from academia (Prof. Tim Liedl) and industry (Dr. Norma Minar and Dr. Johann Feckl) gave excellent insights to different career paths after the PhD. In addition to the scientific program, the students enjoyed joint social activities such as a pub quiz, hiking, and skiing.

■ [www.cens.de/calendar/workshops-events/cens-retreat-2018](http://www.cens.de/calendar/workshops-events/cens-retreat-2018)

## PEER-TO-PEER TRAINING: LABVIEW

Initiated by CeNS alumnus Dr. Fabian Wehnekamp, CeNS started a new and very successful peer-to-peer training on the LabVIEW software in 2018. Two PhD students from CeNS, Julian Stein (AG Braun) and Frank Mieskes (AG Lamb) taught a three-day introduction course on LabVIEW to 10 students from different CeNS groups. The workshop was jointly organized with SFB1032. Due to the high request, it was repeated in autumn 2018 and in 2019.

■ [www.cens.de/calendar/workshops-events/labview-workshop](http://www.cens.de/calendar/workshops-events/labview-workshop)



## JUNIOR NANOTECH NETWORK 2017/2018

Networking and exchanging scientific expertise is a key challenge in research. Participating in the Junior Nanotech Network (JNN) not only gave us insights into a wide field of different scientific areas but also improved our soft skills.

2017 four graduate students – Alice, David, Gloria and Lauren from Urbana-Champaign – came to enjoy Munich’s and Augsburg’s research facilities and attended the CeNS workshop in Venice. During the first two weeks, JNN participants Andrej, Daniela, Kristof, Linh, Ricarda and Stefanie prepared several 2-day experiments to give the visiting graduate students insights into our current research topics. The Illinois students partook in experiments to investigate a number of research interests: bacterial cell division driven by FtsZ characterized in deformable compartments, DNA origami functionalization with nanoparticles and subsequent characterization, antibody binding to cells with flow cytometry, or lastly cell membrane permeabilization and its applications in drug delivery.

Apart from research, we also had a couple of social activities planned; we organized a tour through Munich and Augsburg, where we showed them our favorite places and points of interest. We gave

them insights into the Bavarian culture by visiting the Oktoberfest and cooked home-made Pizza together.

However, “the icing on the cake” highlight was participating in the one-week CeNS Workshop in Venice. Here, everyone presented a poster with their latest research achievements. Furthermore, we could enhance our knowledge in different scientific areas by attending the talks of the keynote speakers or other participants. Last but not least, we had the opportunity to network at the workshop dinners and at the sight-seeing activities.

Our visit one year later to Illinois was just as nice. We were welcomed by a 3-day excursion to Chicago with a boat tour on the Chicago River, Deep-dish Pizza and a swim in Lake Michigan. Afterwards, we traveled to Urbana-Champaign where we were introduced to the “real” USA college experience. We took part in the everyday life centered at the huge University campus, which included sharing tiny rooms at the dorms and enjoying team sport activities such as volleyball or Frisbee. Another highlight of our stay was the LabEscape Exit-the-Room game, where we had to solve the mystery of the missing of the quantum-physicist Professor S.



The research schedule started with a hands-on programming course on cell scale simulations at the Luthey-Schulten Research group. The following week we participated in the CPLC (Physics of Living Cells) summer school, where each one of us could choose an experiment theme in advance. We chose between the themes Physics of DNA, RNA Regulation in Eukaryotes, Quantitative Imaging and Cell Simulations of Small Regulatory RNA, Evolution of Chemotaxis, and Neurobiology. Each day started with a talk from the group leaders about one of those themes. Afterwards, we visited the labs and carried out the experiments planned for the workshop. Concerning the Physics of DNA theme, we analyzed the looping efficiency of short DNA samples produced by NucSeq with smTIRF and FRET at the Ha Lab. Additionally, we simulated the flexibility of short DNA samples at the Aksimentiev Group. On the final day, every group presented their results in front of the whole CPLC audience. The summer school ended with a nice dinner party and a visit to the clubs in Urbana-Champaign.

*Ricarda Berger, AG Rädler (JNN participant)*

■ [www.cens.de/international/exchange-programs/jnn/](http://www.cens.de/international/exchange-programs/jnn/)



JNN participants with Prof. Zan Luthey-Schulten at UIUC.





**SELECTED  
RESEARCH PROJECTS**

## SELECTED RESEARCH PROJECTS

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## OPTOCHEMICAL DISEQUILIBRIUM TO MEASURE BIOMOLECULE CHARGE

Friederike M. Möller, Michael Kieß, Christof Mast, and Dieter Braun

(LMU Munich, Faculty of Physics)

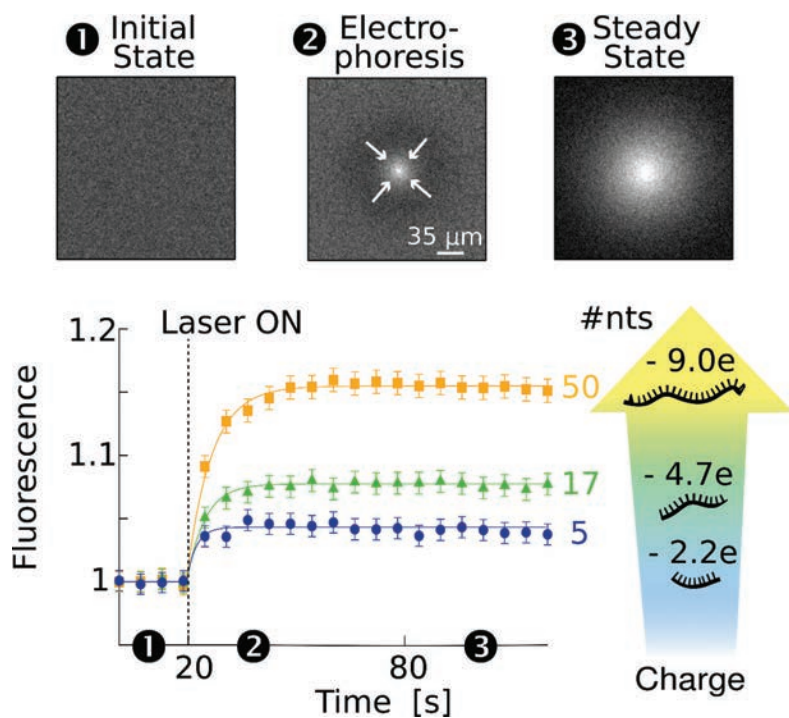
■ [www.biosystems.physik.uni-muenchen.de](http://www.biosystems.physik.uni-muenchen.de)

Non-equilibrium settings on the nanoscale offer unique opportunities to measure particle properties. For example, measuring the charge of a molecule inside a conducting fluid such as water is difficult. One of the commonly used techniques is electrophoresis. But this approach is macroscopic and does not work without gels for most biologically relevant molecules since the electrophoretic drift is constant. But the measurement in gels is cumbersome experimentally and does not reflect the native biological environment for

the molecules.

Here we implemented a miniaturized, electrophoresis-based method on the microscale using an optically driven photodissociation reaction. Inside a focused laser beam, oppositely charged species of different size are created which diffuse out of the beam with different velocities. This creates a local electrical field which moves charged biomolecules via electrophoresis in the diffusion-dominated regime of low Peclet numbers ( $Pe < 1$ ). The steady state fluorescence in the center is used to

determine the effective biomolecule charge even for large molecules with charge-independent electrophoretic mobilities. We tested the mechanism for DNA and proteins and used two different photochemical reactions to generate inward or outward pointing electrical fields. A master curve described the proton transfer from the photodissociation reaction to the buffer. The full mechanistic understanding offers many possibilities for the all-optical manipulation of molecules. On a more fundamental level, we could show that electrophoresis can be studied in the diffusive regime and trigger all-optically. With these results, we see the possibility to do with electrophoresis what we have done with thermophoresis, a development that led to the foundation of NanoTemper.



■ Friederike M. Möller, Michael Kieß, Christof Mast and Dieter Braun: *Optochemical disequilibrium to measure biomolecule charge*; Physical Review E 98, 062601 (2018) doi.org/10.1103/PhysRevE.98.062601.

**Fig. 1.** Non-equilibrium settings on the nanoscale offer unique opportunities to measure particle properties. Here we showed how electrophoresis can be triggered all-optically on the micrometer scale by a photodissociation reaction. The fluorescence signal can be used to infer the charge of the labelled biomolecule under physiological conditions.

## STOCHASTIC NONLINEAR DYNAMICS OF CONFINED CELL MIGRATION

David Brückner, Alexandra Fink, Christoph Schreiber, Peter Röttgermann, Joachim Rädler, and Chase Broedersz (LMU Munich, Faculty of Physics)

■ [www.theorie.physik.uni-muenchen.de/lsfrey/group\\_broedersz](http://www.theorie.physik.uni-muenchen.de/lsfrey/group_broedersz)

■ [www.softmatter.physik.uni-muenchen.de](http://www.softmatter.physik.uni-muenchen.de)

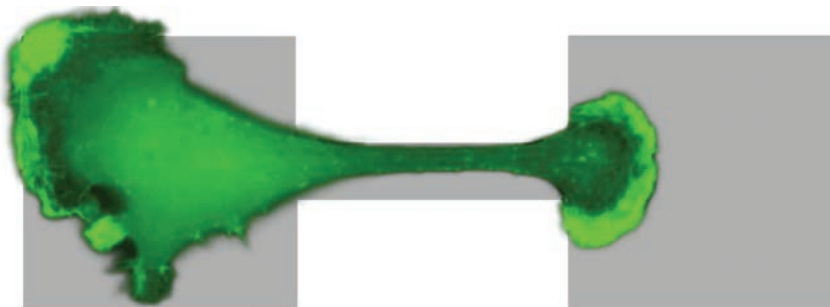
In many biological processes, migrating cells are faced with the challenge of overcoming physical barriers and thin constrictions. Recently, a collaboration of theoretical and experimental biophysicists led by Prof. Chase Broedersz and Prof. Joachim Rädler proposed a new way of studying the migration of confined cells using a data-driven approach.

The team designed a minimal experimental system comprised of two adhesive squares connected by a thin bridge. On these patterns, single cells repeatedly 'hop' back and forth between the square 'islands', and hundreds of cells of the same type moving in identical microenvironments could be monitored. The large amount of data produced by this approach enabled the physicists

to successfully apply tools from statistical physics to analyse cell motion at a quantitative level. To unravel the stochastic dynamics of confined cell migration on micropatterns, they adopted a data-driven modelling approach. The goal of this approach is to use experimentally determined statistical data to infer a stochastic equation of motion of a confined cell. This approach disentangles the dynamics into conceptually distinct components of cell motion: a deterministic component, which tells us what the cells do on average; and a stochastic one, which quantifies the inherent fluctuations in the cell dynamics. With this framework, the group established a new connection between the fields of cell migration and dynamical systems theory: the deterministic dynamics of a cell moving on the

confining micropatterns can be analysed in terms of a geometrical representation of the trajectories in a two-dimensional plane of the cell's position and velocity. This also enabled a classification of the behaviour of different cell types. Specifically, a breast cancer cell line (MDA-MB-231) was found to exhibit qualitatively different dynamics to a non-cancerous breast cell line (MCF10A): The cancerous cells perform deterministic oscillations described in terms of limit-cycles. By contrast, the non-cancerous cells are excitably bistable; they deterministically relax to either of two stable fixed points associated to each of the adhesive island. This work could also have applications to the quantitative assessment of cell behaviour in more complex biological environments and may help to quantify how different types of cancerous cells have distinct degrees of invasiveness.

■ **D. B. Brückner, A. Fink, C. Schreiber, P. J. F. Röttgermann, J. O. Rädler, and C. P. Broedersz:** *Stochastic Nonlinear Dynamics of Confined Cell Migration in Two-State Systems*; *Nature Physics* 19, 1592 (2019).



**Fig. 1.** Microscopy image of a breast cancer cell (MDA-MB-231) squeezing across a thin constriction: the motion of the cell is confined to an area consisting of two adhesive squares connected by a narrow bridge (grey area; actin labelled in green). Over time, the cell performs repeated transitions between the two squares.

## EMERGENCE OF COEXISTING ORDERED STATES IN ACTIVE MATTER SYSTEMS

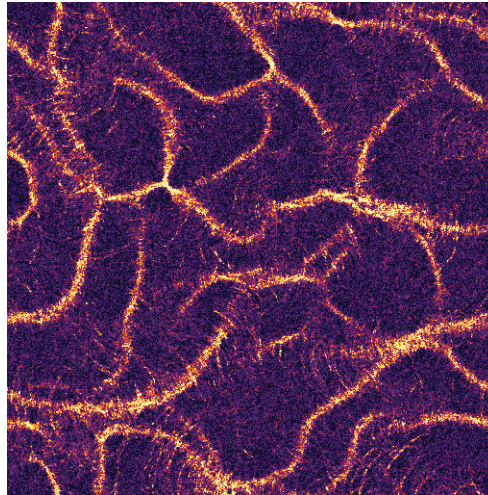
Lorenz Huber, Ryo Suzuki, Timo Krüger, Erwin Frey (LMU Munich, Faculty of Physics), and Andreas Bausch (TU Munich, Physics Department)

- [www.theorie.physik.uni-muenchen.de/lsfrey/group\\_frey](http://www.theorie.physik.uni-muenchen.de/lsfrey/group_frey)
- [www.bauschlab.org](http://www.bauschlab.org)

Life relies on the emergence of order. Understanding this unique ability of living organisms to self-organize their constituents into functional ensembles is the declared central objective of active-matter physics. Recently, several breakthroughs have demonstrated that principles of active matter are indeed capable of describing the emergence of robust types of macroscopic order, such as topological or defect-dominated states in cells or tissues.

In this project, researchers from two different CeNS groups joined forces to combine theory and experiment to show that active matter systems are able to produce phase transitions and steady states that have no equilibrium analogue: the dynamic coexistence of patterns with polar and nematic symmetry.

This is achieved by carefully manipulating the particle interaction of an actomyosin motility assay and analyzing a multiscale computer model. From a physical point of view, this shows that the famous Gibbs phase rule and the



**Fig. 1.** Snapshot of a motility assay simulation, comprised of more than 2 million individual moving filaments. The system exhibits a dynamic coexistence of polar waves, nematic lanes and disorder.

universality principle do not hold for nonequilibrium systems. From a biological point of view, this finding implies that the emergence of order in living systems is not necessarily constrained by underlying constituent symmetry, but is flexible to produce different types of order from identical building blocks and conditions. This work marks a breakthrough in the field of active matter: previously, order, symmetry, and phase transitions in active matter were thought to be robust and share similarities to equilibrium systems. In addition to the high-throughput experiments in the lab, the introduced computational method is unprecedented

in performance and agrees with the experiments on all relevant scales – from resolving actin filament dynamics on the local scale to millions of collectively moving filaments. Overall, the findings connect intracellular biology with fundamental theorems of statistical physics and pattern formation of nonlinear dynamics.

- **L. Huber, R. Suzuki, T. Krüger, E. Frey, A.B. Bausch:** *Emergence of Coexisting Ordered States in Active Matter Systems*; *Science* 361, 6399 (255–258), <https://doi.org/10.1126/science.aao5434> (2018).

## OPTIMIZED SINGLE MOLECULE FORCE SPECTROSCOPY SHARPENS THE VIEW ON THE MECHANICS OF INDIVIDUAL MOLECULES

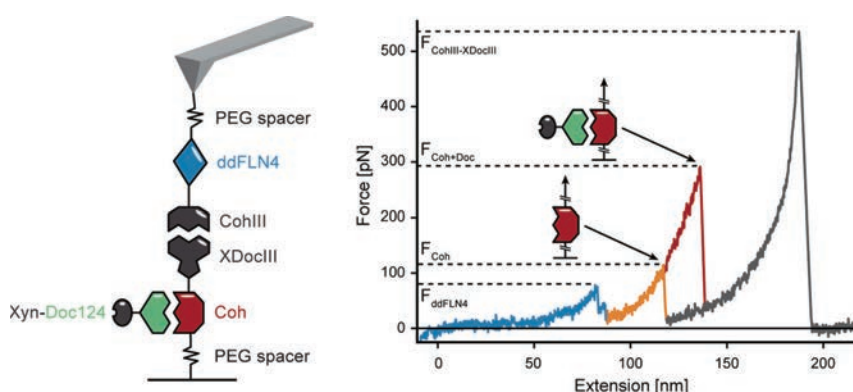
Katherine R. Erlich, Steffen M. Sedlak, Markus A. Jobst, Lukas F. Milles, Leonard C. Schendel, Diana A. Pippig, Eduard M. Unterauer, T. Nicolaus, Wolfgang Ott, Ellis Durner, Tobias Verdorfer, **Hauke Clausen-Schaumann** (Hochschule München), **Tim Liedl**, and **Hermann E. Gaub** (LMU Munich, Faculty of Physics)

- [www.biophysik.physik.uni-muenchen.de](http://www.biophysik.physik.uni-muenchen.de)
- [www.softmatter.physik.uni-muenchen.de/liedl\\_group](http://www.softmatter.physik.uni-muenchen.de/liedl_group)
- [www.fb06.fh-muenchen.de/fb/index.php/de/labhome.html?labid=74](http://www.fb06.fh-muenchen.de/fb/index.php/de/labhome.html?labid=74)

Reliable (functional and native) immobilization of proteins for binding assays and in particular for atomic force microscopy (AFM) based single molecule force spectroscopy (SMFS) is a critical prerequisite for high quality experiments with individual molecules. Different enzymatic coupling strategies

(e.g. 4'-phosphopantetheinyl transferase, sortase A, and asparaginyl endopeptidase) were assessed to optimize the covalent immobilization of the molecule of interest to a substrate (1). Pioneering protocols for SMFS were developed to establish versatile single molecule force experiments (2). Such

optimized SMFS experiments discovered a change in mechanical stability of a library of cohesin receptor domains upon binding of their dockerin ligands (fig. 1). The cohesin-dockerin receptor-ligand family (cellulosomes) is the key element in the formation of multi-enzyme lignocellulose-digesting extracellular complexes (3). Also the force response of DNA origami was assessed together with Tim Liedl in comprehensive detail by combining the SMFS experiments with simulations using oxDNA, a coarse-grained model of DNA at the nucleotide level (4). And the well studied, fundamental receptor ligand interaction between Streptavidin and Biotin was revised with these new site-specific attachment strategies combined with improvements of computational resources resulting in stunning insights into the mechanics of monovalent biotin/streptavidin complexes (5). From these results also the AFM based single-molecule cut-and-paste (originally involving individual hierarchical interactions of single DNA oligomers) a complementary protein only based strategy evolved to promote DNA free



**Fig. 1.** In a typical single molecule experiment a fusion protein consisting of a fingerprint domain (e.g. ddFLN4) and a handle (e.g. CohIII) is immobilized to the cantilever. A Fusion protein with consisting of a protein of interest (Coh) as well as a cognate to the handle (XDocIII), are expressed and immobilized on a glass slide. The CohIII-XDocIII receptor-ligand pair serves as a highly specific pulling handle. At a later stage in the experiment, Xyn-Doc124 is added to the experimental buffer solution and can then bind to each Coh.

In the overlay to the right two exemplary force-distance curves appear when retracting the cantilever with constant speed. First, the poly-protein stretches and the ddFLN4 fingerprint domain unfolds in two steps at a relatively low force (blue). The poly-protein is stretched further and the cohesin domain unfolds at higher force (orange). In the presence of Xyn-Doc124, the cohesin unfolds at an even higher unfolding force (red) and finally, the CohIII-XDocIII pulling handle unbinds at the highest force (grey) whereafter the force ultimately drops back to zero.

arrangements of individual enzymes and specific enzyme networks (6).

■ [1] **W. Ott, E. Durner, and H. E. Gaub:** *Enzyme-Mediated, Site-Specific Protein Coupling Strategies for Surface-Based Binding Assays*; *Angew. Ch. Int. Ed.*, DOI: 10.1002/anie.201805034 (2018).

[2] **T. D. Becke, S. Ness, S. Sudhop, H. E. Gaub, M. Hiller- ingmann, A. F. Schilling, H. Clausen-Schaumann:** *Covalent Immobilization of Proteins for the Single Molecule Force*

*Spectroscopy*; *Journal of Visualized Experiments*, DOI: 10.3791/58167 (2018)

[3] **T. Verdorfer and H. E. Gaub:** *Ligand Binding Stabilizes Cellulosomal Cohesins as Revealed by AFM-based Single-Molecule Force Spectroscopy*; *Scientific Reports*, DOI: 10.1038/s41598-018-27085-x (2018).

[4] **M. C. Engel, D. M. Smith, M. A. Jobst, M. Sajfutdinow, T. Liedl, F. Romano, L. Rovigatti, A. A. Louis, and J. P. K. Doye:** *Force-Induced Unravelling of*

*DNA Origami*; *ACS Nano*, DOI: 10.1021/acsnano.8b01844 (2018).

[5] **S. M. Sedlak, L. C. Schendel, M. C. R. Melo, D. A. Pippig, Z. Luthey-Schulten, H. E. Gaub, and R. C. Bernardi:** *Direction Matters: Monovalent Streptavidin/Biotin Complex under Load*; *Nano Lett.*, doi:10.1021/acsnanolett.8b04045 (2018).

[6] **K. R. Erlich, S. M. Sedlak, M. A. Jobst, L. F. Milles and H. E. Gaub:** *DNA-free directed assembly in single-molecule cut-and-paste*; *Nanoscale*, doi:10.1039/C8NR08636B (2018).

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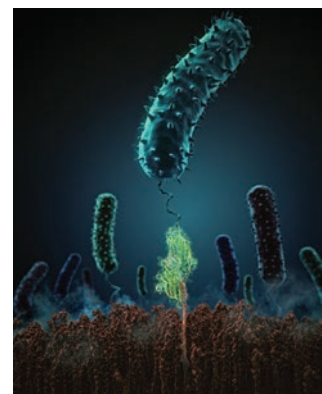
## MOLECULAR MECHANISM OF EXTREME MECHANOSTABILITY IN A PATHOGEN ADHESIN

Lukas F. Milles, Eduard M. Unterauer, T. Nicolaus, Klaus Schulten, Rafael C. Bernardi, and Hermann E. Gaub (LMU Munich, Faculty of Physics)

■ [www.biophysik.physik.uni-muenchen.de](http://www.biophysik.physik.uni-muenchen.de)

High resilience to mechanical stress is crucial, when pathogens adhere to their target to initiate infections. Staphylococcal pathogens adhere to their human targets with exceptional resilience to mechanical stress. The prototypical staphylococcal adhesin SdrG, which targets a short peptide from human fibrinogen  $\beta$  was in focus of this project (fig. 1). Steered molecular dynamics simulations revealed, and single-molecule force spectroscopy experiments confirmed, the mechanism by which this complex withstands

forces of over 2 nanonewtons, a regime previously associated with the strength of a covalent bond (1). The target peptide, confined in a screwlike manner in the binding pocket of SdrG, distributes forces mainly toward the peptide backbone through an intricate hydrogen bond network. Thus, these adhesins can attach to their target with exceptionally resilient mechanostability, virtually independent of peptide side chains. The force propagates to the bacterium through the complex via small, Ig-like folds called B domains. The



**Fig. 1.** Illustration of the pathogenic bacterium (from above) strongly connecting via adhesin (green protein) to the rod-like human fibrinogen target (red protein string).

mechanical stability of these folds also were investigated by atomic force microscopy-based single-molecule force spectroscopy SMFS. The force required to unfold a single B domain turned out larger than 2 nN – the highest mechanostability of a protein to date by a large margin. B domains coordinate three calcium ions, which were identified as crucial for their extreme mechanical strength (2).

Understanding the underlying biophysical mechanisms for this extraordinary strong molecular adhesion is fundamental to develop strategies to clinically fight such pathogens effectively.

■ [1] L. F. Milles, K. Schulten, H. E. Gaub, R. C. Bernardi: *Molecular mechanism of ex-*

*treme mechanostability in a pathogen adhesin*; Science, DOI: 10.1126/science.aar2094

[2] L. F. Milles, E. M. Unterauer, T. Nicolaus, H. E. Gaub: *Calcium stabilizes the strongest protein fold*; Nature Comm., DOI: 10.1038/s41467-018-07145-6 (2018).

6

## VISUALIZATION OF CHARGE CARRIER DIFFUSION IN HYBRID HALIDE PEROVSKITE THIN FILMS

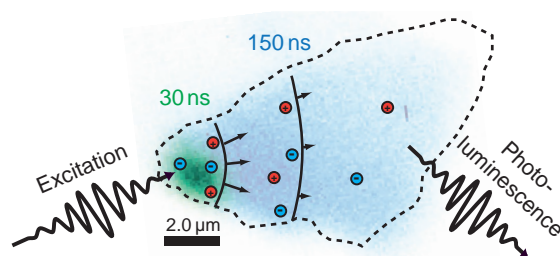
**Achim Hartschuh, Thomas Bein** (LMU Munich, Faculty of Chemistry and Pharmacy)

- <http://physchem.cup.uni-muenchen.de/hartschuh/>
- <http://bein.cup.uni-muenchen.de/>

Micro- and nanocrystalline methylammonium lead iodide (MAPI)-based thin-film solar cells today reach power conversion efficiencies of over 23%. We investigated the impact of grain boundaries on charge carrier transport in large crystal MAPI thin films using time-resolved photoluminescence (PL) micros-

copy and numerical model calculations. Crystal sizes in the range of several tens of micrometers allow for the spatially and time resolved study of boundary effects. While we detected efficient diffusive charge carrier transport reaching more than ten microns within single crystals, we found no indication for

diffusive transport across grain boundaries. We also discovered that the observed PL transients crucially depend on the microscopic geometry of the crystal and the point of observation. In particular, spatially restricted diffusion of charge carriers leads to slower PL decay near crystal edges as compared to the crystal center. In contrast to many reports in the literature, our experimental results show no quenching or additional loss channels due to grain boundaries for the studied material, which thus do not negatively affect the performance of the derived thin-film devices.



**Fig. 1.** Time-resolved detection of efficient charge carrier diffusion in a hybrid halide perovskite thin film. Upon pulsed laser excitation in the left corner of a perovskite crystal, delayed photoluminescence emission is detected for increasing distances reflecting carrier transport on the timescale of tens of nanoseconds.

- **R. Ciesielski, F. Schäfer, N. F. Hartmann, N. Giesbrecht, T. Bein, P. Docampo, A. Hart-schuh:** *Grain Boundaries Act as Solid Walls for Charge Carrier Diffusion in Large Crystal MAPI Thin Films*; ACS Appl. Mater. Interfaces 10, 7974 (2018).

7

## THE ROLE OF MOMENTUM-DARK EXCITONS IN THE ELEMENTARY OPTICAL RESPONSE OF BILAYER WSe<sub>2</sub>

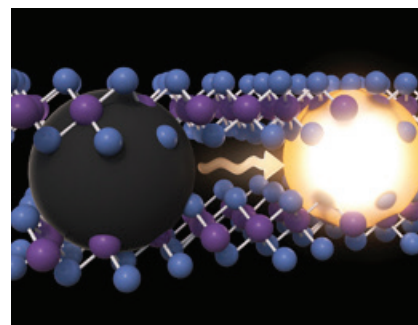
Jessica Lindlau, Malte Selig, Andre Neumann, Léo Colombier, Jonathan Förste, Victor Funk, Michael Förg, Jongwhan Kim, Gunnar Berghäuser, Takashi Taniguchi, Kenji Watanabe, Feng Wang, Ermin Malic, Alexander Högele (LMU Munich, Faculty of Physics)

■ [www.nano.physik.uni-muenchen.de](http://www.nano.physik.uni-muenchen.de)

Monolayer transition metal dichalcogenides undergo substantial changes in the single-particle band structure and excitonic optical response upon the addition of just one layer. As opposed to the single-layer limit, the bandgap of bilayer transition metal dichalcogenide semiconductors is indirect which results in reduced photoluminescence with richly structured spectra that have eluded a detailed understanding to date. The work provides a closed interpretation of cryogenic emission from bilayer WSe<sub>2</sub> as a representative material for the wider class of layered semiconductors. By combining theoretical calculations with comprehensive spectroscopy experiments, it identifies the crucial role of

momentum-indirect excitons for the understanding of bilayer photoluminescence. The results shed light on the origin of quantum dot formation in bilayer crystals and will facilitate further advances directed at opto-electronic applications of layered semiconductors in van der Waals heterostructures and devices.

■ **J. Lindlau, M. Selig, A. Neumann, L. Colombier, J. Förste, V. Funk, M. Förg, J. Kim, G. Berghäuser, T. Taniguchi, K. Watanabe, F. Wang, E. Malic, A. Högele:** *The role of momentum-dark excitons in the elementary optical response of bilayer WSe<sub>2</sub>*; Nat. Commun. 9, 2586 (2018).



**Fig. 1.** Artistic view of the radiative decay of momentum-dark excitons in bilayer tungsten dichalcogenide upon phonon emission. Image: C. Hohmann, Nanosystems Initiative Munich (NIM).

## LASER CAN "SELF-DETECT" INFRARED NEAR-FIELD IMAGES

Fritz Keilmann (LMU Munich, Faculty of Physics)

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The infrared nanoscope (short for scattering near-field microscope, s-SNOM) pioneered at MPI Biochemie, Martinsried, and marketed by CeNS spinoffs Neaspec GmbH and Attocube AG has world-widely become a powerful analytic tool, because "fingerprint" infrared and THz contrasts routinely enable chemical recognition at 20-nm spatial resolution.

The present development step obviates detecting the scattered light by a detector—that has limits anyway because (i) different detector elements are needed for different spectral regions, and (ii) require cryo-cooling—but rather employs the laser itself for detection: the laser instantaneously responds to

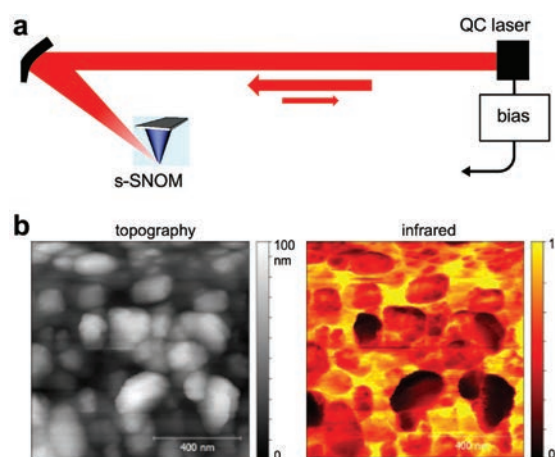
back-scattered light as can be read by a voltage in the laser's bias circuit.

Quantum-cascade lasers were employed for first demonstrations of the technique in both the mid-infrared and THz spectral regions. The setup is elegantly simple (Fig. 1a): the collimated laser beam, after a path length of about 50-100 cm, is sharply focused on the probing tip. Back-scattering is then automatically aligned to reach the laser. An attenuator has been found useful to keep the feedback to the laser in a regime of linear response. Interferometric detection required for s-SNOM no longer involves a beam splitter/combiner, but indeed functions because the long beam path

works as a resonator coupled to the laser cavity. Both amplitude and phase contrasts are therefore imagable as in standard s-SNOM.

A first realization of laser-self-detected s-SNOM in the mid-infrared resulted in high-sensitivity, fast performance (Fig. 1b) with one commercial QCL (but surprisingly low-sensitivity in another one [C. Liewald, Y. Durmaz, unpubl.]). Extending the technique to the THz region proved of especially high value as it turned out extremely sensitive while obviating liquid-He cooling that would be required for common THz detectors.<sup>[1]</sup>

■ M.C. Giordano, S. Mastel, C. Liewald, L.L. Colombo, M. Brambilla, L. Viti, A. Politano, K. Zhang, L. Li, A.G. Davies, E.H. Linfield, R. Hillenbrand, F. Keilmann, G. Scamarcio, and M.S. Vitiello: *Phase-resolved terahertz self-detection near-field microscopy*; *Optics Express* 26, 18423 (2018).



**Fig. 1.** Laser-self-detection mode of near-field nanoscopy. **a**, optical layout where near-field back-scattering is simply sensed by the bias circuit of the illuminating laser; **b**, near-field image ( $1 \times 1 \mu\text{m}^2$ ) of strongly corroded Cu surface exhibiting up to 100 nm high particles; the infrared frequency of  $1650 \text{ cm}^{-1}$ , chosen outside pertaining vibrational resonances, highlights (in yellow) nanoscale regions of highest local conductivity that are assigned to uncorroded Cu (sample courtesy of C.M. Johnson).

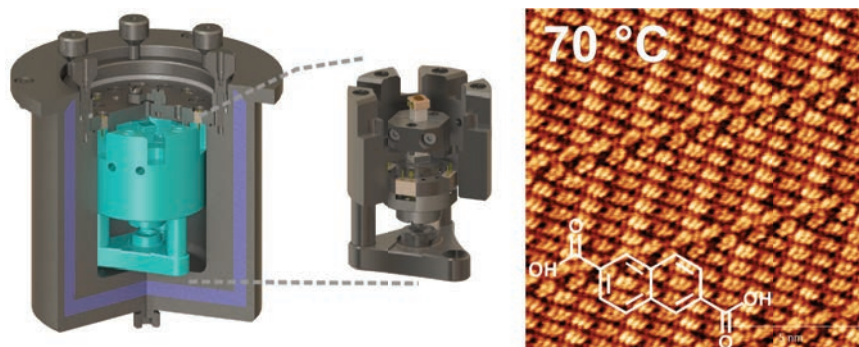


## IMMERSION-SCANNING-TUNNELING-MICROSCOPE FOR LONG-TERM VARIABLE-TEMPERATURE EXPERIMENTS AT LIQUID-SOLID INTERFACES

Oliver Ochs, Wolfgang M. Heckl, and Markus Lackinger (Deutsches Museum and TU Munich, School of Education and Physics Department)

■ [www.wisskom.edu.tum.de](http://www.wisskom.edu.tum.de)

Ochs and coworkers developed the Immersion-Scanning-Tunneling-Microscope (I-STM) for variable-temperature studies up to 120 °C in liquids and defined gas atmospheres. This instrument facilitates high-resolution imaging of thermally activated processes and reactions on surfaces at the molecular level as the basis for obtaining novel insights into the associated kinetics and thermodynamics. This is achieved by integrating the I-STM into a heatable container, whose temperature is stabilized within 0.05 °C by means of a feed-back controller. Thereby the sample is fully immersed into liquid. Hermetic sealing of the container prevents any loss of liquid by evaporation, which normally restricts the duration of more conventional experiments. Hence, prolonged experiments are feasible that allow full thermal equilibration, eventually resulting in very low drifts comparable to cryogenic conditions. Long-term experiments with samples held at elevated temperatures for two weeks were already realized. Particular attention was given to the corrosion resistance of the I-STM to facilitate operation in common acidic solvents.



**Fig. 1.** **Left:** Sectional view of the I-STM showing the heatable container with the STM body (turquoise) mounted on the inside of the hermetically sealing lid, and enlarged sectional view of the STM body with sample stage (lower part); **Right:** High-resolution STM image of a self-assembled monolayer of 2,6-naphthalene dicarboxylic acid molecules on a nonanoic acid-graphite interface at a temperature of 70 °C.

First applications of the I-STM comprise quantitative studies of the thermodynamics of supramolecular self-assembly. The conceptual idea is to assess the position of the thermodynamical equilibrium as a function of temperature by STM imaging. Fitting of the data with appropriate models allows extraction of associated enthalpy and entropy changes. Precise experimental data is invaluable for the advancement of theoretical models, nonetheless for a thorough understanding of self-assembly thermodynamics. In future developments, the I-STM serves as a variable platform for the implementation of further Scanning-Probe-Microscopies as

Electrochemical-STM or Non-Contact Atomic Force Microscope that would similarly benefit from variable temperature long-term experiments with ultralow drift

■ **O. Ochs, W.M. Heckl, M. Lackinger:** *Immersion-Scanning-Tunneling-Microscope for Long-Term Variable-Temperature Experiments at Liquid-Solid Interfaces*; Rev. Sci. Instrum. 89 (2018).

### 3D DNA ORIGAMI CRYSTALS

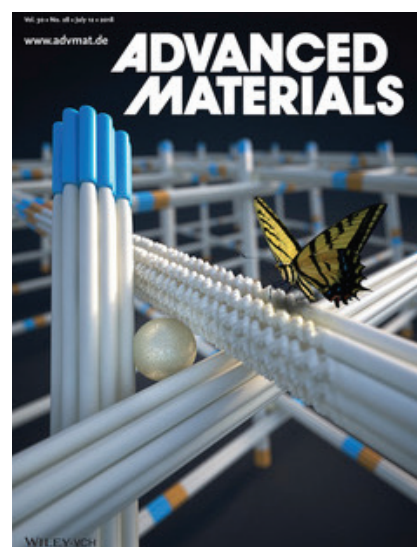
Tao Zhang, Caroline Hartl, Kilian Frank, Amelie Heuer-Jungemann, Stefan Fischer, Philipp C. Nickels, Bert Nickel, and Tim Liedl (LMU Munich, Faculty of Physics)

- [www.softmatter.physik.uni-muenchen.de/liedl\\_group](http://www.softmatter.physik.uni-muenchen.de/liedl_group)
- [www.softmatter.physik.uni-muenchen.de/nickel\\_group](http://www.softmatter.physik.uni-muenchen.de/nickel_group)

More than three decades ago, Nadrian Seeman proposed the co-crystallization of biological macromolecules on self-assembled DNA lattices to solve their structures by X-ray crystallography. This concept has catalyzed the success of the rapidly developing area of DNA nanotechnology and Nadrian Seeman showed in his landmark paper from 2009, that 3D crystals indeed can be rationally designed and built from DNA (doi:10.1038/nature08274). Thus far, however, arranging sizeable guest molecules in three dimensions using DNA frameworks has not been achieved, mainly because the reported DNA lattices either lack the possibility to grow in three dimensions, or lack sufficient rigidity or cavity size to host guest molecules. The groups of Bert Nickel and Tim Liedl together addressed these challenges and showed the crystalline assembly of a DNA origami-based triangular tensegrity structure into rhombohedral lattices. In these lattices, the authors then co-crystallized gold nanoparticles of various sizes.

DNA origami is optically-transparent and almost invisible under X-ray irradiation. This permits structural analysis of the co-crystallized guest molecules and opens up possibilities for a variety of applications that could cross multiple disciplines. Optically-active nanocomponents, such as quantum emitters or plasmonic particles, periodically and precisely arranged in 3D hold great promise for applications in nanophotonics, plasmonics, and metamaterials research. On the other hand, interdependent functional proteins that are brought into defined spatial relation to each other can spur the development of new bioreactors and help to study aspects of fundamental and applied research where spatial correlations between components are key.

- **T. Zhang, C. Hartl, K. Frank, A. Heuer-Jungemann, S. Fischer, P. C. Nickels, B. Nickel, T. Liedl:** *3D DNA Origami Crystals*; *Advanced Materials* 30, 1800273 (2018).



**Fig. 1.** Cover image for *Advanced Materials*: Christoph Hohmann, NIM.

## MOLECULE PENETRATION INTO MUCIN HYDROGELS

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**Ulrich Gerland** (TU Munich, Physics Department)

■ [www.mw.tum.de/de/bme](http://www.mw.tum.de/de/bme)

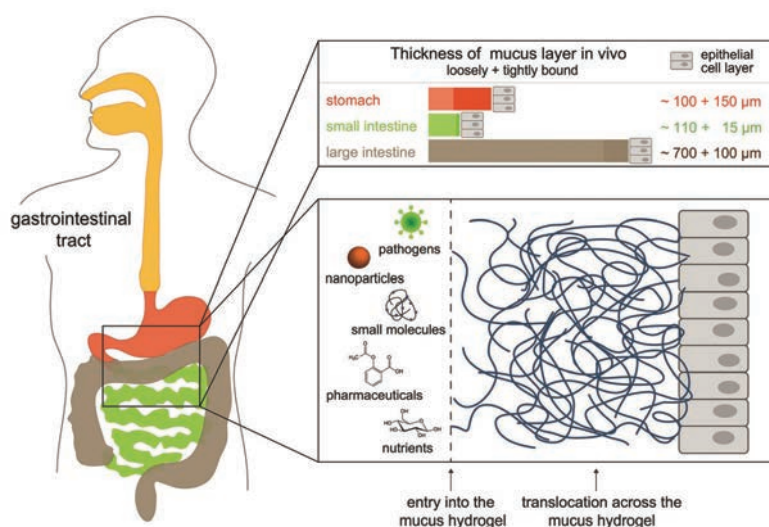
■ [www.qbio.ph.tum.de](http://www.qbio.ph.tum.de)

The human gastrointestinal tract not only regulates the passage of nutrients, growth factors, proteins, hormones, drugs and further beneficial molecules, but also serves as a barrier towards the entrance and distribution of pathogens. To achieve those functions, the apical surface of the mucosal epithelium is lined with a viscoelastic mucus gel, and the macromolecular key components of those gels are mucin glycoproteins. Although lots of research has been devoted to better understand the selective barrier properties of mucin gels and mucus, there are

still puzzling observations which demonstrate that our understanding of the physico-chemical principles governing mucosal permeability are incomplete. In this study, a microfluidics chip platform is employed to study the charge-dependent transport of molecules across the interface of acidic mucin gels. With this setup, a selective accumulation of molecules at the liquid/gel interface of mucin hydrogels is demonstrated that occurs as a function of the molecule charge: this phenomenon is strongly pronounced for cationic molecules, weakly pronounced for

anionic molecules and absent for neutral molecules. The obtained results suggest that molecular transport into and across the gel depends on two main factors, i.e. molecule partitioning from the liquid phase into the gel phase and molecule diffusion throughout the gel. Transient binding of charged molecules to the mucin biopolymers enhances the former process whereas it slows down the latter. This model is supported by a theoretical description of this molecular transport process that is based on diffusion-reaction equations. With this model, the efficiency of the diffusive transport of charged objects across self-renewing physiological mucus barriers can be predicted. Our results challenge the prevailing notion that inert, non-mucoadhesive molecules were always more efficient in penetrating mucin-based hydrogels such as native mucus than charged molecules.

■ **M. Marczynski, B.T. Käs-dorf, B. Altaner, A. Wenzler, U. Gerland, and O. Lieleg:** *Transient binding promotes molecule penetration into mucin hydrogels by enhancing molecular partitioning*; *Biomaterials Science*. 6, 3373 - 3387 (2018).



**Fig. 1.** Mucosal tissues from different compartments of the human body exhibit mucus layers with distinct thicknesses. Those mucosal barriers consist of a thin, tightly bound layer adjacent to the epithelial cell surface (indicated in dark color) and a thick, loosely bound mucus layer located at the luminal end of the mucosal tissue (indicated in lighter color).

## SMALL ROTORS AND FAST SPINNING: SOLID-STATE NMR INNOVATIONS FOR STRUCTURE AND DYNAMICS OF COMPLEX PROTEINS

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■ [www.cup.lmu.de/oc/linser/](http://www.cup.lmu.de/oc/linser/)

Proton-detected solid-state NMR spectroscopy has gained lots of attention recently due to its applicability for proteins tumbling too slowly for solution NMR. In particular by severely reducing the required sample amounts for solid-state NMR spectroscopy, proton detection represents a versatile strategy for structural biology of supra-molecular assemblies or membrane proteins. Methods development by the Linser group in this direction has been able to successfully overcome part of the remaining limitations, such that also complex enzymes or enzyme:small-molecule complexes are now realistically becoming

feasible targets. In 2018, Linser and coworkers were able to demonstrate that near-complete resonance assignments in a 260-amino acids protein (with more than 4000 atoms) are obtainable with tailor-made, novel solid-state NMR experiments. By expanding previously established assignment strategies to four dimensions and developing a series of unprecedented coherence transfer schemes, a complex of the human carbonic anhydrase II (hCAII) and its pharmaceutical ligand dorzolamide could be shown to be fully assessable with respect to residue-specific secondary structure and protein dynamics.

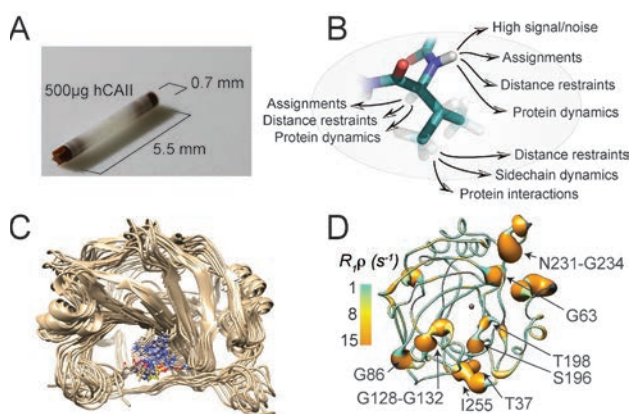
Whereas such assessment has been facilitated by protein deuteration, the group has also shown that comprehensive structural-biology

assessment of an hCAII:small-molecule complex, i. e., access to protein structure, dynamics, as well as sidechain proton parameters of biochemical relevance, is feasible in the absence of protein deuteration. This possibility makes the methodology transferable to many potential target proteins whose recombinant expression in bacteria is impossible. Given the multiple novel strategies composed by the Linser group for facilitated solid-state NMR spectroscopy, an invited compilation of novel methodology for proton-detected solid-state NMR was published in the reputable journal "Accounts of Chemical Research".

■ **S. K. Vasa, H. Singh, R. Linser:** *Assessment of a large enzyme-drug complex by proton-detected solid-state NMR without deuteration;* *Angew. Chem., Int. Ed.,* 58 (17), 5758-5762 (2019).

**S. K. Vasa, H. Singh, P. Rovó, R. Linser:** *Dynamics and interactions of a 29-kDa human enzyme studied by solid-state NMR;* *J. Phys. Chem. Lett.* 9, 1307-1311 (2018).

**S. K. Vasa, P. Rovó, R. Linser:** *Protons as versatile reporters in solid-state NMR spectroscopy;* *Acc. Chem. Res.,* 51 (6), 1386-1395 (2018).



**Fig. 1.** Proton-detected solid-state NMR. A) Fast magic-angle spinning achieved via small sample containers spinning around their own axis with 60-110 thousand rotations per second. B) Benefits of detecting protons: high sensitivity as well as a high diversity of information content. C) Solid-state NMR backbone fold and ligand position in human carbonic anhydrase obtained via fast-MAS ssNMR. D) Backbone dynamics ( $^{15}\text{N}$   $R_{1\rho}$  relaxation) in hCAII obtained via fast-MAS ssNMR.

## TIME-RESOLVED SMALL-ANGLE X-RAY SCATTERING REVEALS MILLISECOND TRANSITIONS OF A DNA ORIGAMI SWITCH

**Jan Lipfert** (LMU Munich, Faculty of Physics) and **Hendrik Dietz** (TU Munich, Physics Department)

■ [www.molecularbiophysics.physik.uni-muenchen.de](http://www.molecularbiophysics.physik.uni-muenchen.de)

An important goal of nanotechnology is the construction of artificial molecular machines that perform specific biological or technological functions in response to external stimuli. A promising approach is the DNA origami technique, in which DNA strands can be precisely folded into complex, three-dimensional objects and can now be used to generate dynamic DNA nanosystems. These structures can reversibly switch between different conformational states. How extraordinarily fast such a structural transition can take place was demonstrated by a CeNS collaboration led by Professor Jan Lipfert (LMU Munich) and Professor Hendrik Dietz (TUM, Munich): Using time-resolved small-angle X-ray scattering (SAXS), the team demonstrated that a DNA origami switch can transition between two defined states within a few milliseconds. In contrast to previous dynamic DNA origami structures, in which conformational changes were mainly caused by the addition of further DNA molecules, the mechanism implemented here is based on the stacking of nucleobases on shape-complementary surfaces.

These structures can "click together" like Lego bricks. Depending on the ionic strength, the DNA origami switch reversibly changes from an X-shaped, open, to a rectangular, closed state. To characterize the dynamics of the DNA origami switch in free solution, the researchers performed time-resolved SAXS measurements with high-brilliance synchrotron radiation at the ESRF in Grenoble (France). With the experimental setup used, the researchers achieved a time resolution in the millisecond range. Based on the X-ray scattering profiles of the DNA origami structures, the global conformations of the origami switch were analyzed. Remarkably, the mega dalton structure can switch within milliseconds, close to the theoretical limit expected from diffusion, highlighting the potential of dynamic DNA nanostructures.

■ **L. K. Bruetzel, P. Walker, T. Gerling, H. Dietz, and J. Lipfert:** *Time-Resolved Small-Angle X-Ray Scattering Reveals Millisecond Transitions of a DNA Origami Switch*; *Nano Letters* 18:2672-2676 (2018).



**Fig. 1.** Artist's rendition of the DNA switch device in its open (front) and close (back) conformation, transitioning within milliseconds. Picture: Christoph Hohmann, NIM.

## TOPOCHEMICAL CONVERSION OF IMINE TO THIAZOLE LINKED COVALENT ORGANIC FRAMEWORKS THAT ENABLE THE INVESTIGATION OF THE REAL SPACE STRUCTURE

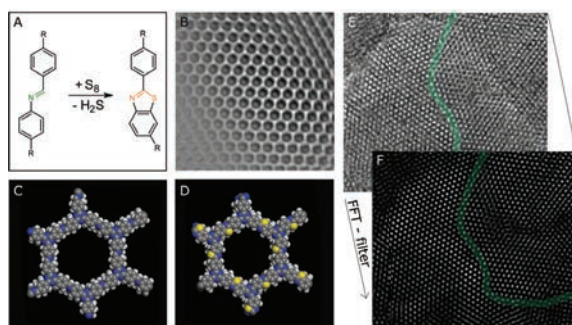
Frederik Haase, Erik Troschke, Gökçen Savasci, Tanmay Banerjee, Viola Duppel, Susanne Dörfler, Martin M. J. Grundei, Asbjörn M. Burow, **Christian Ochsenfeld** (LMU Munich, Faculty of Chemistry and Pharmacy), Stefan Kaskel & **Bettina V. Lotsch** (LMU Munich, Faculty of Chemistry and Pharmacy / MPI for Solid State Research)

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- [www.cup.uni-muenchen.de/pc/ochsenfeld/](http://www.cup.uni-muenchen.de/pc/ochsenfeld/)

Covalent organic frameworks (COFs) are a class of crystalline porous materials that are composed entirely of light elements. These features make them ideal candidates for application in gas separation and storage, catalysis, and solar-to-fuel conversion. However, all these applications require stable frameworks that are difficult to obtain by direct techniques. COF formation proceeds under reversible conditions, which inherently leads to chemical lability. This problem can be addressed by altering the chemical functionalities that are used to construct the COF such that they are no longer prone to hydrolysis and cleavage, while maintaining the signature properties of the COF like porosity and crystallinity.

Most COFs are based on the formation of imines, obtained by condensation of amines with aldehydes. In order to lock these types of COFs in their crystalline state, the imine group was transformed into a thiazole by exposure to elemental sulfur in a topochemical reaction. The subtle change in structure is accompanied by a marked increase in chemical stability in alkaline, acidic, nucleophilic and reducing media, thereby enabling applications that require resistance against such harsh conditions. An intriguing consequence of the described post-synthetic locking process is an improved stability of the COF towards damaging effects of the electron beam in the transmission electron microscope. This

crystalline domains, structural details of the COF could be assessed, such as low- and high-angle grain boundaries with partially coaligned lattice planes that lead to defects such as edge dislocations. Close inspection of these boundaries suggests that a covalent connection between individual crystallites exists, which verifies the previously proposed mechanism for the formation of COFs by crystallization of an initially amorphous polymer. This study not only offers unique insights into the complex structure and defect formation in COFs and how we can tune it, but highlights the application potential of post-synthetically stabilized COFs in general.



**Fig. 1.** Transformation of an imine linked COF by reaction with elemental sulfur leads to the topochemical formation of a thiazole-linked COF, while the order and porosity of the COF is retained.

enabled the investigation of the real structure of the thiazole-COF at an unprecedented level of detail. Apart from featuring large

- **F. Haase, E. Troschke, G. Savasci, T. Banerjee, V. Duppel, S. Dörfler, M. Grundei, A.M. Burow, C. Ochsenfeld, S. Kaskel, B.V. Lotsch:** *Topochemical conversion of an imine- into a thiazole-linked covalent organic framework enabling real-structure analysis;* Nature Comm., DOI: 10.1038/s41467-018-04979-y (2018).

## MORPHOLOGY CONTROL OF LOW TEMPERATURE FABRICATED ZNO NANOSTRUCTURES FOR TRANSPARENT ACTIVE LAYERS IN ALL SOLID-STATE DYE-SENSITIZED SOLAR CELLS

Kun Wang and Peter Müller-Buschbaum (TU Munich, Physics Department)

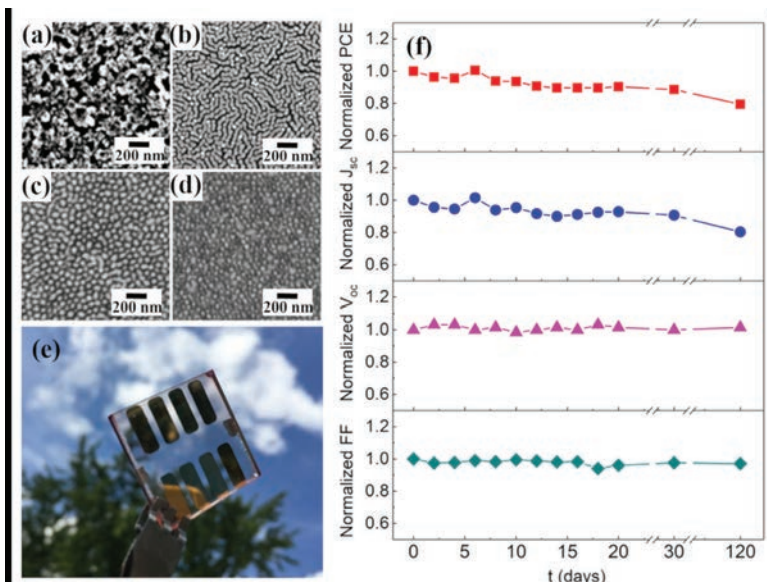
■ [www.groups.ph.tum.de/functmat/homepage/](http://www.groups.ph.tum.de/functmat/homepage/)

Dye-sensitized solar cells (DSSCs), which were pioneered by Grätzel in 1991, show great promise in the photovoltaic field. Above 14% of efficiency has been achieved recently. However, the electrolyte leakage and electrode corrosion make the conventional DSSCs unstable. An efficient way to solve this problem is to use a solid-state p-type semiconductor to replace the liquid electrolyte, leading to a solid-state DSSC (ssDSSC). Generally, a metal oxide is used as an n-type semiconductor, with dye molecules loaded at the

surface. A conducting polymer acts as a p-type semiconductor to transport positive charge carriers. To increase current density, a large surface area is required for the metal oxide to adsorb dye molecules. A mesoporous interconnected network structure is a good alternative to the bilayer or nanorod structure with respect to both large surface and good pathway for charge transport. Moreover, the pore size of the metal oxide films also has a great influence on the penetration of dye and p-type semiconductor to build a

well-connected interface. Therefore, in this project, the morphology of zinc oxide (ZnO) films are finely tuned based on a method using sol-gel chemistry combined with diblock copolymer templating. Under low-temperature annealing, ZnO films with multiple morphologies including foam-like, worm-like and sphere-like structures are fabricated and investigated. Based on controlled nanostructured ZnO films, transparent ssDSSCs are prepared, which demonstrate the possibility for building integrated solar cells. The ssDSSCs with a worm-like ZnO morphology show the highest power conversion efficiencies, which are four times of the devices from sphere-like structure. After 120 days, almost 80% of the initial power conversion efficiency is maintained in ambient air conditions, which demonstrates good long-term stability of the ssDSSCs even without special encapsulation.

■ K. Wang, V. Körstgens, D. Yang, N. Hohn, S. V. Roth and P. Müller-Buschbaum: *Morphology control of low temperature fabricated ZnO nanostructures for transparent active layers in all solid-state dye-sensitized solar cells*; *J. Mater. Chem. A* 6 (10), 4405-4415 (2018).



**Fig. 1.** (a-d) SEM images of mesoporous ZnO films annealed at different temperatures after polymer removal: (a) 80 °C, (b) 120 °C, (c) 160 °C, and (d) 200 °C. (e) Optical images of ssDSSCs based on 120 °C annealed ZnO films. (f) Stability (PCE, J<sub>sc</sub>, V<sub>oc</sub>, and FF from top to bottom, respectively) of ssDSSCs based on 120 °C annealed ZnO films. The lines are guides to the eye.

## THE PHYSICOCHEMICAL BASIS OF ORGANIC SOLID-SOLID WETTING

Alexander Eberle, Thomas Markert, Frank Trixler (LMU Munich, Faculty of Geosciences and TU Munich, School of Education)

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The group of Frank Trixler focuses on the behavior of organic semiconductor particles in contact with inorganic substrates. Their research demonstrated that dispersed particles of polycyclic heteroaromatics are capable of directly generating two-dimensional crystals on inorganic substrates, such as graphene or carbon nanotubes. As the molecular deposition and self-assembly occurs at the solid-solid interface between the insoluble organic particles and the corresponding substrates,

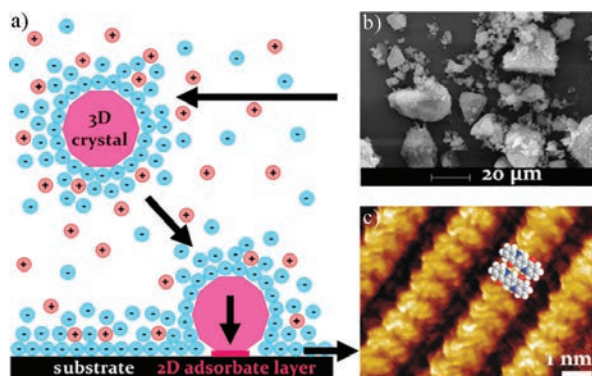
they termed this effect as "Organic Solid-Solid Wetting". The highlight of this deposition process is its ability to grow monolayers and nanostructures under ambient conditions without the need of any solubility, any highly demanding preparation techniques (such as for the case of molecular beam epitaxy) and/or any expensive chemical modifications to achieve the solubility of the molecules. Applications of the Organic Solid-Solid Wetting Deposition (OSWD) have become relevant,

for instance, in the fields of low-dimensional crystal engineering, the surface-transfer doping of graphene, and in the area of field-effect

transistor fabrication. However, to date, lack of an in-depth understanding of the physicochemical basis of the OSWD prevented the identification of important parameters, essential to achieve a better control of the growth of monolayer and supramolecular assemblies with defined structures, sizes, and coverage areas.

In this project, a detailed model for the OSWD was developed, derived from various experimental and theoretical results. The results reveal the vital role of the zeta-potential and indicate the occurrence of different nanoscale effects among particles approaching a substrate, such as the dewetting in hydrophobic nanoconfinements and Casimir-like fluctuation-induced forces. The work substantially enhances the ability to control the OSWD in terms of substrate coverage and adsorbate structure and enables the application of the OSWD of organic semiconductors to environmental friendly and low-cost dispersing agents, such as water.

■ **A. Eberle, T. Markert, and F. Trixler:** *Revealing the Physicochemical Basis of Organic Solid-Solid Wetting Deposition: Casimir-like Forces, Hydrophobic Collapse, and the Role of the Zeta Potential*; *J. Am. Chem. Soc.*, 10.1021/jacs.7b10282 (2018).



**Fig. 1.** Images illustrating the sequence of the OSWD process: (a) Schematic depiction of the formation of electrical double layers as organic particles [shown in (b)] are dispersed in a liquid phase. A complex interplay of various nanoscale forces (arising from electrical double layer forces, Van-der-Waals interactions, Casimir-like fluctuation-induced forces and hydrophobic dewetting) result in an overall increasingly attractive particle-substrate interaction, as the dispersed particles approach the substrate surface. Finally, the forces reach a level where the layer of the inner Helmholtz plane of particles and substrates is expelled. This generates a temporal solid/solid interface where molecules detach from low-energy crystal faces and adsorb via a gradient of the surface free energy onto the substrate surface. Subsequently, supramolecular self-assembly of monolayers occurs; (b) Scanning Electron Microscopy (SEM) image of quinacridone source particles prior to dispersion; (c) Scanning-Tunneling Microscopy (STM) image of a self-assembled quinacridone monolayer grown via OSWD.



## INHERENT INSTABILITY OF RHOMBOHEDRALLY STACKED MULTILAYER GRAPHENE UNDER METAL CONTACT PATTERNING

Fabian R. Geisenhof, Felix Winterer, Tobias D. Gokus, Yasin C. Durmaz, Daniela Priesack, Jakob Lenz, Fritz Keilmann, R. Thomas Weitz (LMU Munich, Faculty of Physics)

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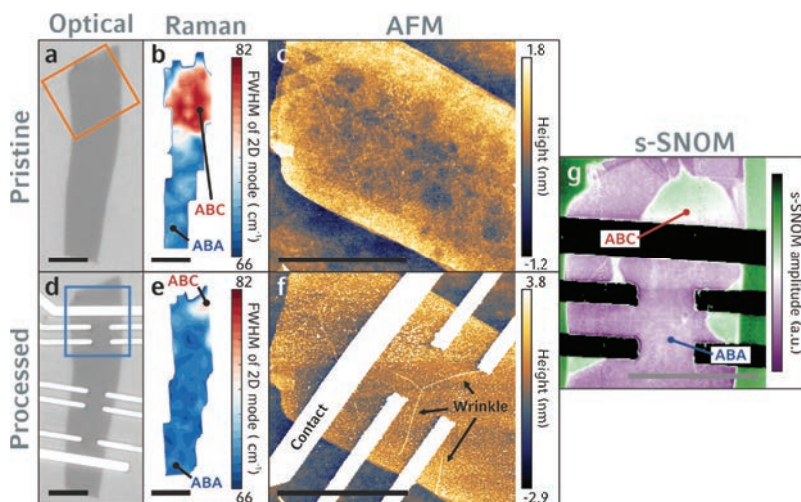
■ [www.softmatter.physik.uni-muenchen.de/personen/guests/fritz-keilmann1/nanoscopy\\_lab](http://www.softmatter.physik.uni-muenchen.de/personen/guests/fritz-keilmann1/nanoscopy_lab)

After the significant excitement about the isolation and electrical measurement of graphene monolayers, the investigation of electrical properties of graphene multilayers is gaining more and more interest in the solid-state community. One of the reasons are the recently discovered flat bands in “magic angle” twisted bilayer graphene. Such flat bands have shown unconventional superconductivity and Mott insulating behavior. In the present work, a further material has been investigated, which exhibits similar flat bands:

multilayer rhombohedrally stacked graphene (also called ABC-stacked graphene). In order to measure low temperature charge transport in exfoliated multilayer flakes that consist partially of ABC and partially of conventional ABA (also called Bernal) stacking, established protocols via electron-beam lithography and lift-off to pattern lateral metal contacts have been followed. Surprisingly, exactly this contact patterning induces a transition from ABC to conventional ABA stacking (see Figure 1). Via scanning Raman spec-

troscopy and scattering scanning near field optical microscopy (s-SNOM) (Figure 1b, e and g) it was identified, that the transition happens continuously across several  $\mu\text{m}$ . The movement of the ABC – ABA domain boundary is accompanied with the appearance of folds in the graphene multilayer (see Figure 1c and f), which is one of the indications that anisotropic strain exerted onto the flake during metal evaporation is causing the transition. Furthermore, by increasing the density of metal contacts to the graphene layer, ABC stacking can be preserved. This stable contacting method should allow contacting and reliable measuring measurement of low-temperature transport in ABC stacked multilayer graphene, and thus may lead to the observation of the surprising phenomena associated with the present flat bands.

■ F. R. Geisenhof, R. Guerrero, M. Pelc, F. Winterer, T. D. Gokus, Y. C. Durmaz, D. Priesack, J. Lenz, F. Keilmann, A. Ayuela, and R. T. Weitz: *Anisotropic strain induced soliton movement changes stacking order and bandstructure of graphene multilayers*; arXiv:1810.00067 (2018).



**Fig. 1.** Stacking transition induced in a tetralayer graphene flake. Optical image of the pristine (a) and processed (d) flake. The orange and blue sections indicate the regions shown in c), f) and g) respectively. b), e) Raman map of the FWHM of the 2D mode in the pristine (b) and processed flake (e), showing the vanishing of the ABC domain. c), f) Topography of the top part of the flake. In the processed flake (f) wrinkles occur. g) s-SNOM image corroborating the stacking transition.

## MECHANISM OF THE SILVER-CATALYZED EPOXIDATION OF ETHYLENE

**Joost Wintterlin** (LMU Munich, Faculty of Chemistry and Pharmacy)

■ <http://wintterlin.cup.uni-muenchen.de>

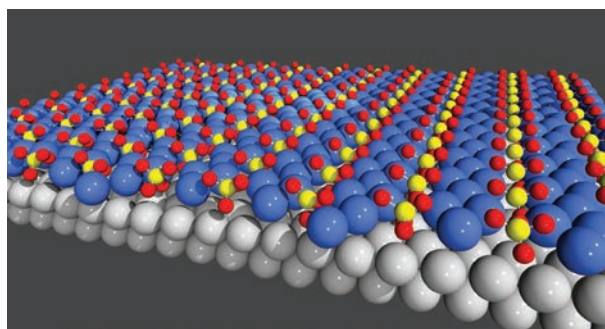
The atomic-scale mechanisms of most catalytic reactions are unknown, and this is even the case for reactions that have been applied on an industrial scale for decades. In particular the chemical species participating in the critical bond breaking and bond making steps on the catalyst surface are often unknown. An emblematic case is the industrial synthesis of ethylene oxide. In this process ethylene reacts with oxygen on Ag catalysts to give ethylene oxide, a major petrochemical product, 34.5 million tons of which are produced per year. An open question has been for a long time which oxygen species on the Ag surface reacts with ethylene to give ethylene oxide - adsorbed oxygen atoms exclusively react to give the total oxidation products CO<sub>2</sub> and

water. It had been known that the active oxygen species showed a clear difference from adsorbed oxygen atoms in x-ray photoelectron spectroscopy, but its nature remained mysterious. In this project, by applying several surface science methods and in collaborations with theorists it could be shown that the active oxygen is actually the oxygen in adsorbed SO<sub>4</sub>, a quite unexpected result. Sulfur is a ubiquitous contaminant in petrochemical processes, but it usually represents a catalyst poison. However, in low amounts it seems to activate the catalyst by reacting with oxygen to give SO<sub>4</sub>. The mechanism by which SO<sub>4</sub> reacts with ethylene is complex: In its stable state SO<sub>4</sub> forms an ordered phase on an Ag(111) surface (s. figure) the structure of which could be

solved by an extensive analysis using low-energy electron diffraction and density functional theory. This phase, in which the SO<sub>4</sub> moieties are imbedded in the first layer of Ag atoms, is not yet active. However, by the action of further oxygen the first layer Ag atoms are displaced, and the resulting less stable SO<sub>4</sub> is the active species. It can, with low activation energy, add an O atom to an ethylene molecule to give ethylene oxide and SO<sub>3</sub> (the SO<sub>4</sub> is regenerated by reaction of SO<sub>3</sub>). This mechanism solved one of the oldest puzzles in heterogeneous catalysis.

■ **T. E. Jones, R. Wyrwich, S. Böcklein, E. A. Carbonio, M. T. Greiner, A. Y. Klyushin, W. Moritz, A. Locatelli, T. O. Menten, M. A. Niño, A. Knop-Gericke, R. Schlögl, S. Günther, J. Wintterlin, S. Piccinin:** *The selective species in ethylene epoxidation on silver*; ACS Catal. 8, 3844 (2018).

**R. Wyrwich, T. E. Jones, S. Günther, W. Moritz, M. Ehrensperger, S. Böcklein, P. Zeller, A. Lünser, A. Locatelli, T. O. Menten, M. A. Niño, A. Knop-Gericke, R. Schlögl, S. Piccinin, J. Wintterlin:** *LEED-I(V) structure analysis of the (7x√3)rect SO<sub>4</sub> phase on Ag(111): precursor to the active species of the Ag-catalyzed ethylene epoxidation*; J. Phys. Chem. C 122, 26998 (2018).



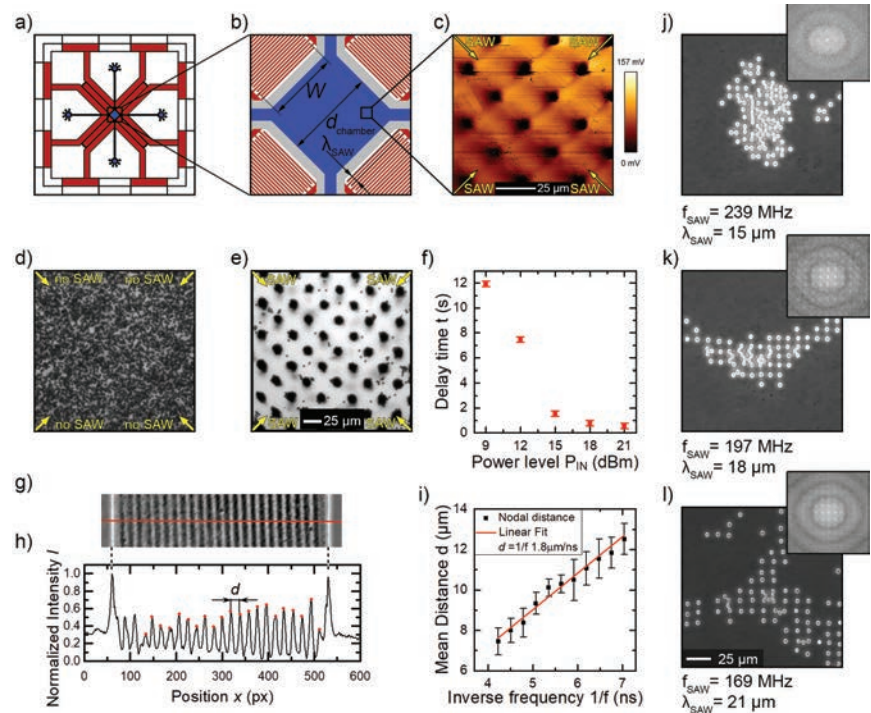
**Fig. 1.** Model of the (7x√3)rect SO<sub>4</sub> structure on Ag(111). S atoms are indicated yellow, O atoms red, first layer Ag atoms blue, and second and third layer Ag atoms grey. Reprinted with permission from R. Wyrwich et al., LEED-I(V) structure analysis of the (7x√3)rect SO<sub>4</sub> phase on Ag(111): Precursor to the active species of the Ag-catalyzed ethylene epoxidation, J. Phys. Chem. C. 122, 26998 (2018). Copyright 2019 American Chemical Society.

## LIVING NETWORKS! – ORCHESTRATING CELLS ON CHIPS TO FORM NETWORKS

Manuel S. Brugger, Sarah Grunden, Adele Doyle, Luke Theogarajan, Achim Wixforth, and Christoph Westerhausen (University of Augsburg, Institute of Physics)

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For the basic investigation of neural communication and for future applications of neural networks performing various tasks, a well-defined network structure is crucial, preferably a very simple one. By combining the wealth of sophisticated microfluidic techniques with Surface Acoustic Waves (SAW) and acoustic streaming, first steps towards the envisioned creation of a simple life-on-a-chip system are presented. Employing standing SAW body force fields, a tunable acoustic pressure field and thus a well-defined potential landscape in a fluid layer on top of a functionalized chip surface is created. The resulting (dynamic) hydrodynamic body force fields acting on living cells residing in the fluid can precisely and deliberately be tuned in space and time by adjusting the SAW amplitudes, wavelengths and phases within a single device. In contrast to all currently existing static approaches to control the precise position of cells on a chip surface, our novel technique allows to dynamically adapt the setup and cell environment to the required needs. Preliminary experiments show the enormous potential of our SAW based acoustic approach: While keeping living neurons trapped in a well defined acous-



**Fig. 1.** The experimental setup, dynamically variable in space in time to allow single particle trapping to align neurons separately. **a) – b)** technical drawing of the SAW-chip with an aligned microchannel. **c)** AFM-micrograph of the SSAW-force field. **d) – f)** SAW mediated alignment of  $d=2\ \mu\text{m}$  diameter polystyrene beads ( $P_{\text{SAW}}=12\ \text{dBm}$ ). Starting from a homogenous suspension at  $t=0\ \text{s}$  (**d**), after  $t=21\ \text{s}$ , the bead accumulation reached a total maximum patterning efficiency (**e**). **f)** Time to accumulate the beads as a function of the applied SAW power level  $P_{\text{SAW}}$ . **g)** Particle accumulation using a ‘chirped’ IDT ( $d=300\ \text{nm}$ ,  $f_{\text{SAW}}=147,9\ \text{MHz}$ ). **h)** Intensity along the red line in (**d**). **i)** Nodal distance as a function of the  $f_{\text{SAW}}$ . **j-l)** single particle trapping of  $d=7.38\ \mu\text{m}$   $\text{SiO}_2$  beads. For  $\frac{\lambda_{\text{SAW}}}{D} \geq 2.4$  the trapping for single particles is achieved.

tic potential landscape, they actually begin to adhere at exactly the desired positions and event grow neural extensions to interconnect. We believe that based on our findings, a whole new field of research for the creation of artificial neural

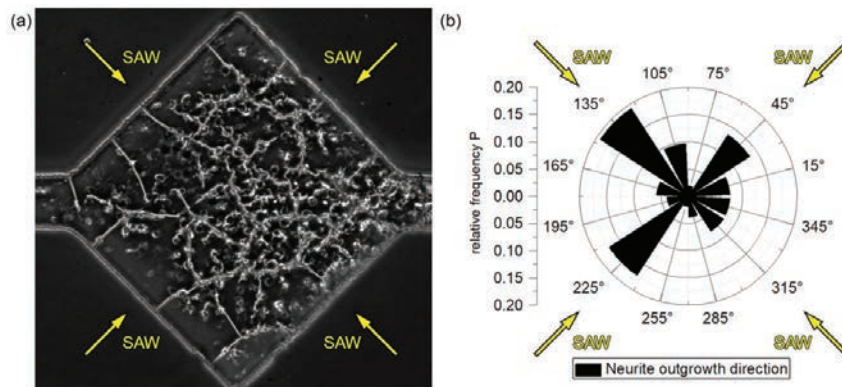
networks on a chip is opened. The main project goal is targeted by addressing the following, crucial tasks:

- explore the limits of biocompatibility and stimulation of cellular activity,

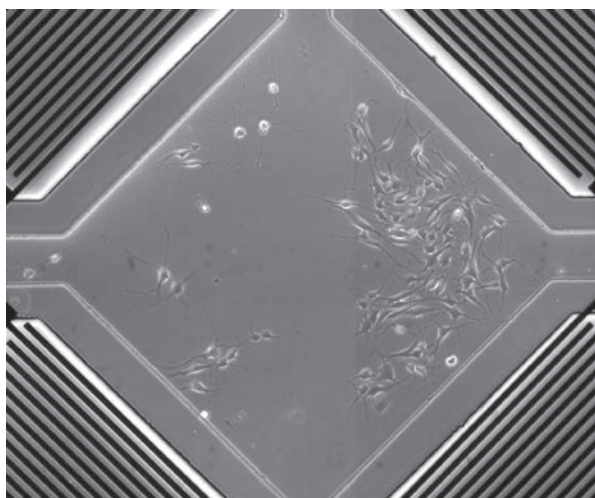
- acoustically actuated manipulation and stimulation of living neurons on a chip to
- finally enable biophysical applications like signal collisions or correlation of network topology and the response of the network to external stimuli.

■ **M. S. Brugger, S. Grundeen, A. Doyle, L. Theogarajan, A. Wixforth, and C. Westerhausen:** *Orchestrating cells on a chip: employing surface acoustic waves towards the formation of neural networks*; Phys. Rev. E 98 (1), 012411 (2018).

**M. Weiß, A. L. Hörner, E. Zallo, P. Atkinson, A. Rastelli, O. G. Schmidt, A. Wixforth, and H. J. Krenner:** *Multiharmonic Frequency-Chirped Transducers for Surface-Acoustic-Wave Optomechanics*; Physical Review Applied 9, 014004 (2018).



**Fig. 2.** a) Neurons after the SAW at  $P_{IN}=18$  dBm was activated for  $t = 11$  hours. The adhered neurons even started growing extensions. b) Relative frequency P of the outgrowth direction.



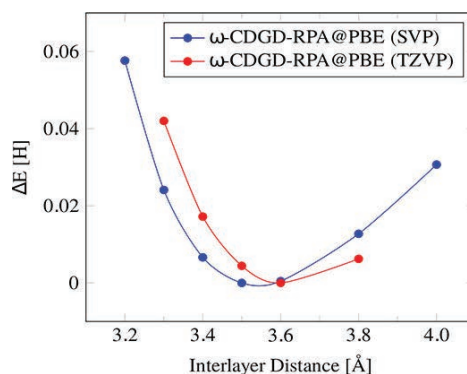
**Fig. 3:** Neuroblastoma B35 cells in a standing SAW field. The trapped cells are growing extensions that are clearly influenced by the dynamic acoustic potential landscape. Experimental parameters are  $\lambda_{SAW}=50 \mu\text{m}$ ,  $P_{SAW}=18$  dBm, SAW pulse frequency  $f_p=1$  Hz, duty cycle  $a=30 \%$ .

## EFFICIENT METHODS FOR THE ACCURATE DESCRIPTION OF ELECTRON CORRELATION IN LARGE MOLECULAR SYSTEMS WITHIN THE RANDOM-PHASE APPROXIMATION

Matthias Beuerle, Daniel Graf, Henry Schurkus, Christian Ochsenfeld  
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Quantum chemical methods based on the random-phase approximation (RPA) represent a promising alternative to conventional density-functional theory (DFT) for computing molecules and solids. RPA methods do not only contain no empirical parameters and are therefore transferable to a wide range of systems, but also provide a good description of dispersion effects. While RPA methods were traditionally limited to small molecules due to their steep computational scaling (conventionally with the sixth-power of molecular size), earlier work of the Ochsenfeld group enabled linear-scaling RPA calculations allowing to treat large systems. In most recent work, an even more



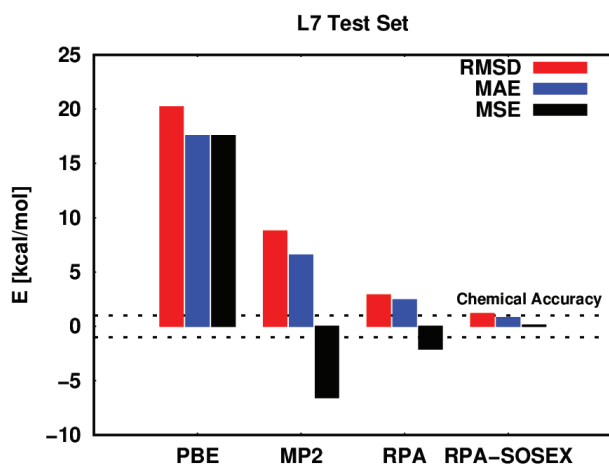
**Fig. 1.** Dimer of two covalent organic frameworks and corresponding interlayer distance potential energy curve determined with the multi-node RPA method.

accurate and multi-node parallel, linear-scaling RPA method was devised [1] that allows to investigate systems of unprecedented size. This opens the way to study for the first time, e.g., the stacking of two covalent organic

frameworks at the RPA level of theory (Fig. 1). Since such systems are dominated by dispersion effects, classical DFT methods fail to describe the interaction between the two layers.

To make RPA methods ubiquitously applicable, properties beyond ground state energies are necessary. Therefore, fast energy gradients were introduced [2] that significantly improve performance and enable, e.g., to perform highly accurate structure optimisations at the RPA level of theory.

Finally, also for even more accurate but at the same time even more costly so-called beyond RPA methods (with exchange), linear- and low-scaling schemes were devised [3].



**Fig. 2.** Performance of RPA and beyond RPA (RPA-SOSEX) methods for the so-called L7 test set (dispersion dominated systems) in comparison to pure DFT (PBE functional) and MP2 theory.

These newly developed methods [3] open the way to benchmark the accuracy of RPA with exchange methods also for large dispersion dominated systems (Fig. 2). The results show that RPA with exchange outperforms not only plain RPA, but also other electron correlation methods such as second order Moeller-Plesset theory.

- [1] **D. Graf, M. Beuerle, H. F. Schurkus, A. Luenser, G. Savasci, C. Ochsenfeld:** *Accurate and Efficient Parallel Implementation of an Effective Linear-Scaling Direct Random Phase Approximation Method;* J. Chem. Theory Comput. (14), 2505 (2018).
- [2] **M. Beuerle, C. Ochsenfeld:** *Low-Scaling Analytical Gradients for the Direct Random*

*Phase Approximation using an Atomic Orbital Formalism;* J. Chem. Phys. (149), 244111 (2018).

- [3] **M. Beuerle, D. Graf, H. F. Schurkus, C. Ochsenfeld:** *Efficient Calculation of Beyond RPA Correlation Energies in the Dielectric Matrix Formalism;* J. Chem. Phys. (148), 204104 (2018).

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## PHOTOSWITCHABLE REAGENTS FOR THE HIGH-SPATIOTEMPORAL-PRECISION CONTROL OF ENDOGENOUS MICROTUBULE FUNCTION

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- [www.phog.physik.uni-muenchen.de/people/project-leaders/lohmueller\\_theobald](http://www.phog.physik.uni-muenchen.de/people/project-leaders/lohmueller_theobald)

The scaffolding protein tubulin forms a complex, highly dynamic network of cellular microtubules - gigantic, noncovalent polymeric assemblies that act as roads for cellular trafficking, parking lots for resting proteins, and dynamic girders that apply or respond to forces within and outside of cells. The microtubules are continuously being built up, torn down, modified with chemical flags (post-translational modifications), and coordinated by a host of proteins into rapidly changing shapes. These dynamics are crucial to the correct functioning of a broad range of anisotropic cellular processes, most famously, to the separation of genetic material and daughter cells during mitosis/meiosis; and many of the most powerful

anticancer drugs (taxanes, vinca alkaloids, discodermolides) work by altering these microtubule dynamics so that cells can no longer divide correctly and instead go into apoptosis.

A series of azobenzene-based microtubule inhibitors have been developed in our group and act as light-regulated inhibitors of endogenous microtubule dynamics. Using precisely-spatiotemporally-targeted illumination to switch these inhibitors on and off in specific cells at precise times, these photoswitchable antimetotics can stop or restart mitosis at will in genetically unmodified animals - and by doing so, study and alter the course of normal embryonic development. This level of

cell-by-cell, reversible control over fundamental biological processes has not previously been possible. This approach is at last permitting the study of the influence of short-term temporal patterning of antimetotic activity (ongoing CeNS project), and is revealing a range of novel organisational features of embryogenesis and morphogenesis.

- **A. Singh, T. Saha, I. Bege- mann, A. Ricker, H. Nüsse, O. Thorn-Seshold, J. Klingauf, M. Galic, M. Matis:** *Polarized microtubule dynamics directs cell mechanics and coordinates forces during epithelial morphogenesis;* Nature Cell Biology 20, 1126 (2018).

## UNDERSTANDING THE ROLE OF CESIUM AND RUBIDIUM ADDITIVES IN PEROVSKITE SOLAR CELLS: TRAP STATES, CHARGE TRANSPORT, AND RECOMBINATION

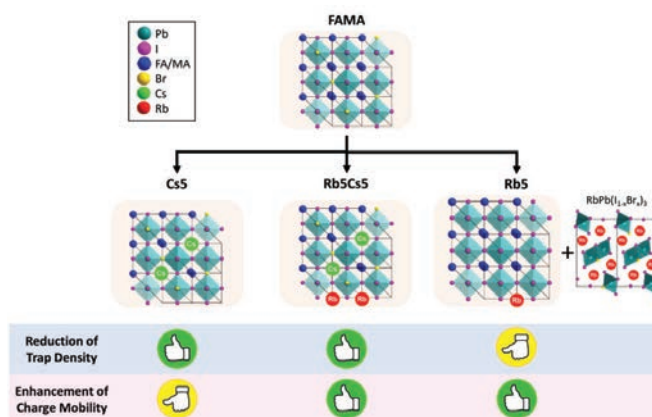
Y. H. Hu, E. M. Hutter, P. Rieder, Irene Grill, J. Hanisch, Meltem F. Ayguler, Alexander G. Hufnagel, Matthias Handloser, **Thomas Bein**, **Achim Hartschuh**, K. Tvingstedt, V. Dyakonov, A. Baumann, T. J. Savenije, Michiel L. Petrus, and Pablo Docampo (LMU Munich, Faculty of Chemistry and Pharmacy)

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Hybrid metal halide perovskite materials have recently attracted enormous attention due to their promising optoelectronic properties, particularly in the context of novel solar cell developments. While several physical properties of these materials such as tunable light harvesting capabilities and high charge carrier mobilities are promising features for a possible revolution in photovoltaics, several important challenges remain.

Recently, the addition of Cs and Rb ions to the synthesis of methylammonium (MA) lead iodide ( $\text{CH}_3\text{NH}_3\text{PbI}_3$ , MAPbI<sub>3</sub>)-type perovskites has attracted much attention due to the observed photovoltaic (PV) efficiency increases. In a collaboration involving several groups in CeNS and at other institutions, the researchers investigated the role of these additives in  $\text{FA}_{0.83}\text{MA}_{0.17}\text{Pb}(\text{I}_{0.83}\text{Br}_{0.17})_3$  hybrid lead halide perovskites (FA = formamidinium) regarding trap states, charge transport, and recombination. A powerful combination of Time-of-Flight (ToF), Time-Resolved Microwave Conductivity (TRMC), and Thermally Stimulated Current (TSC) techniques was employed



**Fig. 1.** Schematic illustration of the hypothesized distribution of the inorganic cation additives within the perovskite crystal and the effect of Cs/Rb addition on the reduction of trap density and enhancement of charge carrier mobility within the perovskite layer. (Hu et al. figure)

to gain the desired mechanistic insights. Here, it could be shown that Cs-incorporation reduces the trap density and charge recombination rates in the perovskite layer, consistent with increased open-circuit voltage and fill factor of Cs-containing devices. On the other hand, addition of Rb causes increased charge carrier mobility within the perovskite, as well as reduced current-voltage hysteresis. The group showed that by mixing Cs and Rb in quadruple cation (Cs–Rb–FA–MA) perovskites, the advantages of both inorganic cations can be combined. This study provides valuable insights into the role of

these additives in multiple-cation perovskite solar cells, which are essential for the design of high-performance devices.

■ **Y. H. Hu, E. M. Hutter, P. Rieder, I. Grill, J. Hanisch, M. F. Ayguler, A. G. Hufnagel, M. Handloser, T. Bein, A. Hartschuh, K. Tvingstedt, V. Dyakonov, A. Baumann, T. J. Savenije, M. L. Petrus, and P. Docampo:** *Understanding the Role of Cesium and Rubidium Additives in Perovskite Solar Cells: Trap States, Charge Transport, and Recombination*; *Advanced Energy Materials* 8 (16), 1703057 (2018).

## NANOPARTICLE MEDIATED DELIVERY AND SMALL MOLECULE TRIGGERED ACTIVATION OF PROTEINS IN THE NUCLEUS

Hsin Yi Chiu, J. A. Bates, Jonas Helma, Hanna Engelke (LMU Munich, Faculty of Chemistry and Pharmacy), Hartmann Harz, Thomas Bein (LMU Munich, Faculty of Chemistry and Pharmacy), and Heinrich Leonhardt (LMU Munich, Faculty of Biology)

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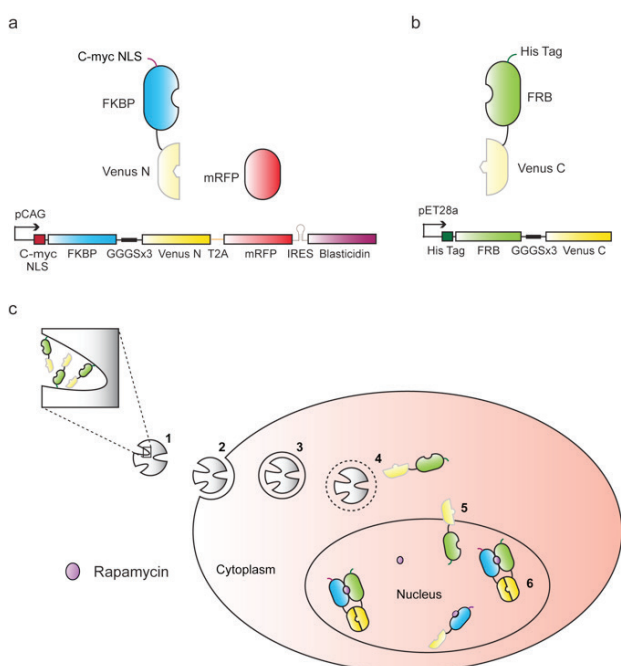
In this project, the groups of Hanna Engelke, Thomas Bein and Heinrich Leonhardt collaborated to develop a method for optimisation and live cell tracking of nanoparticle mediated cytosolic protein delivery based on an inducible split Venus system. This method uses a background free, live-cell Venus complementation-based molecular sensor that exclusively detects delivered protein that is both functionally viable and bioavailable. This molecular sensor was complemented by protein delivered intracellularly with large-pore mesoporous silica nanoparticles (MSNs)

binding the guest through a his-tag methodology, thus allowing for pH dependent binding and release of the his-tagged guest protein. The sensor was applied in parallel with an MTT assay to optimize the protein delivery and biocompatibility of the large-pore multifunctional MSNs. The group could demonstrate highly efficient protein transfection rates of about 80%. Moreover, the sensor approach also allowed for tracking of live cell protein delivery with good temporal resolution, to separate the timing of protein uptake from that of sensor dynamics.

built-in chemically inducible moieties. It is anticipated that the Venus sensor will be suitable for applications with a wide range of protein nanocarriers. Hence, this approach will enable efficient multi-parameter optimization and will allow for a reliable comparison between different nanocarriers for protein delivery.

■ **H. Y. Chiu, J. A. Bates, J. Helma, H. Engelke, H. Harz, T. Bein, and H. Leonhardt:** *Nanoparticle mediated delivery and small molecule triggered activation of proteins in the nucleus*; *Nucleus* 9 (1), 530-542 (2018).

This was achieved by employing



**Fig. 1.** Two-component cytosolic protein delivery detection system. **(a)** Layout of the mammalian expression cassette used to generate the HeLa-FKBP-VN stable cell line. **(b)** Layout of the bacterial expression cassette. **(c)** MSN-mediated application of the cytosolic protein delivery detection system. 1 Purified His-tagged FRB-VC proteins are loaded into MSNs via interaction with Ni-NTA groups on the surface of the MSN pore system. 2 Charged MSN-FRB-VC complexes bind to the cell surface and are 3 endocytosed into the cell. Lower pH in the endosomal system causes accelerated FRB-VC dissociation from the MSN. 4 Chloroquine shock (0.5 mM in the medium, RT, 5 min) triggers endosomal protein release followed by 5 free protein diffusion in the cytoplasm and further into the nucleus. 6 Addition of rapamycin leads to the formation of FRB/rapamycin/FKBP ternary complexes subsequently driving Venus complementation and fluorophore maturation. (Chiu et al. figure)



## CHEMICAL CUTTING OF PEROVSKITE NANOWIRES INTO SINGLE-PHOTON EMISSIVE LOW-ASPECT RATIO CSPBX<sub>3</sub> (X= CL, BR & I) NANORODS

Yu Tong, Ming Fu, Eva Blatt, He Huang, Alexander F. Richter, Kun Wang, Peter Müller-Buschbaum (TU Munich, Physics Department), Sara Bals, Philippe Tamarat, Brahim Lounis, Jochen Feldmann, and Lakshminarayana Polavarapu (LMU Munich, Faculty of Physics)

■ [www.phog.physik.uni-muenchen.de](http://www.phog.physik.uni-muenchen.de)

■ [www.groups.ph.tum.de/polymer/peter-mueller-buschbaum](http://www.groups.ph.tum.de/polymer/peter-mueller-buschbaum)

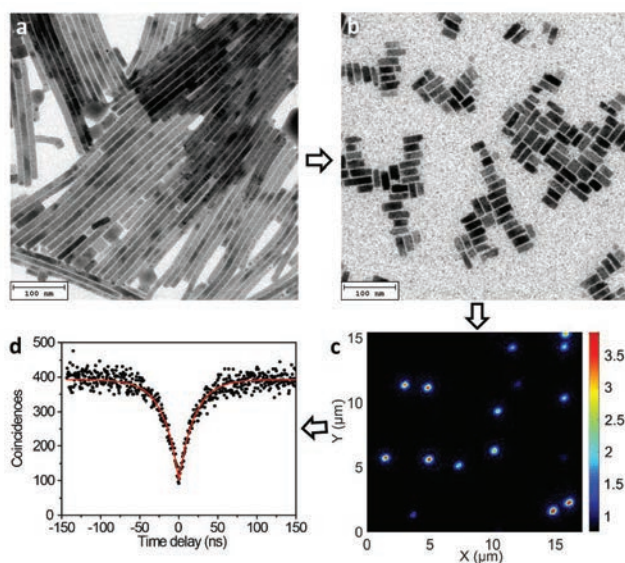
Metal halide perovskites (ABX<sub>3</sub>, A=monovalent cation, B=bivalent cation and X=halide ion) have attracted remarkable attention from chemists, physicists, and engineers because of broad scientific interest not only due to their high power conversion efficiencies but also their fascinating optical properties. In particular, Halide perovskite nanocrystals (NCs) have received significant research interest owing to their extraordinary optical properties as well as their appeal as efficient light sources for technological applications. The optical properties of perovskite NCs are tunable by their dimensions as well as halide composition. It is extremely important to explore how the optical properties can be influenced by the morphology of perovskite NCs for their integration into optoelectronic devices.

In this project, It is found that CsPbBr<sub>3</sub> perovskite NWs fragments into low-aspect ratio CsPbX<sub>3</sub> (X=Cl, Br and I) nanorods (NRs) through so called ligand-induced chemical cutting process upon reaction with PbX<sub>2</sub>-ligand complex. The shape transformation resulted in an increase of photoluminescence (PL) efficiency owing to a de-

crease of non-radiative decay rates. The increase of PL efficiency is attributed to the separation of NWs having traps from the non defective ones when the NW breaks into NRs, otherwise the excitons are likely to find a trap owing to large exciton diffusion lengths of perovskites. Importantly, we discovered that the perovskite NRs can serve as single photon (quantum light) source as revealed by photon antibunching measurements, while it is not detected in parent NWs. This work not only reports on the quantum light

emission of low aspect ratio perovskite NRs, but also expands our current understanding of shape-dependent optical properties of perovskite NCs.

■ **Y. Tong, M. Fu, E. Blatt, H. Huang, A. F. Richter, K. Wang, P. M. Buschbaum, S. Bals, P. Tamarat, B. Lounis, J. Feldmann, L. Polavarapu:** *Chemical Cutting of Perovskite Nanowires into Single-Photon Emissive Low-aspect Ratio CsPbX<sub>3</sub> (X= Cl, Br & I) Nanorods*; *Angew. Chem. Int. Ed.*, *Angew. Chem. Int. Ed.* 57 (49), 16094 (2018).



**Fig. 1.** CsPbBr<sub>3</sub> nanowires (a) transform into CsPbI<sub>3</sub> nanorods (b) upon reaction with PbI<sub>2</sub>-ligand complex solution. (c) Wide field fluorescence image of CsPbI<sub>3</sub> rods dispersed in PMMA. (d) Histogram of time delays between consecutive photon pairs detected from the fluorescence of a single CsPbI<sub>3</sub> rod, the dip at zero time delay is a clear signature of photon antibunching.

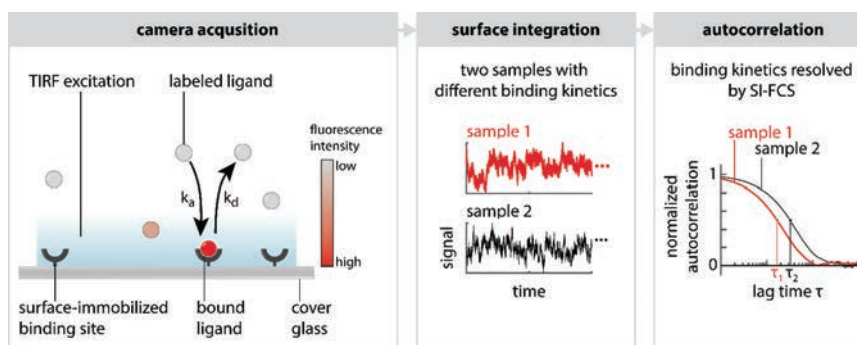
## QUANTIFYING REVERSIBLE SURFACE BINDING VIA SURFACE-INTEGRATED FCS

Jonas Mücke, Philipp Blumhardt, Max Strauss, Eugene Petrov, Ralf Jungmann (Max Planck Institute of Biochemistry and LMU Faculty of Physics), and Petra Schuille (Max Planck Institute of Biochemistry)

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To quantify the reversible surface attachment of fluorescently labeled molecules, we have modified previous schemes for Fluorescence Correlation Spectroscopy with Total Internal Reflection illumination (TIR-FCS) and camera-based detection. In contrast to most modern applications of TIR-FCS, we completely disregard spatial information in lateral direction. In contrast, we perform correlation analysis on a spatially integrated signal, converting the illuminated surface area into a single measurement volume. In addition to providing a high surface selectivity, our new approach resolves association and dissociation rates in equilibrium over a wide range of time scales. We chose the transient hybridization of fluorescently labeled single-stranded DNA to the complementary handles of surface-immobilized DNA origami structures as a reliable and well-characterized test system.



We varied the number of base pairs in the duplex, yielding different binding times in the range of hundreds of milliseconds to tens of seconds, allowing us to quantify the respective surface affinities and binding rates.

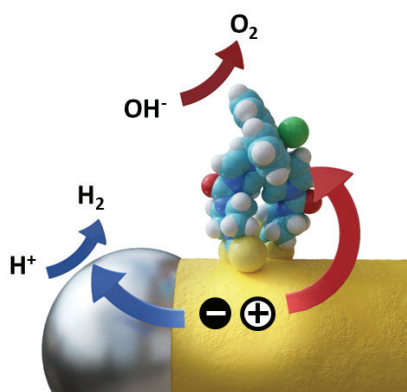
■ **J. Mücke\*, P. Blumhardt\*, M.T. Strauss, E.P. Petrov, R. Jungmann, P. Schuille:** *Quantifying reversible surface binding via surface-integrated FCS*; Nano Lett 18, 3185-3192 (2018).

## ALL-IN-ONE VISIBLE-LIGHT-DRIVEN WATER SPLITTING BY COMBINING NANOPARTICULATE AND MOLECULAR CO-CATALYSTS ON CDS NANORODS

Christian M. Wolff, Peter D. Frischmann, Marcus Schulze, Bernhard J. Bohn, Robin Wein, Panajotis Livadas, Michael T. Carlson, Frank Jäckel, Jochen Feldmann, Frank Würthner, and Jacek K. Stolarczyk (LMU Munich, Faculty of Physics)

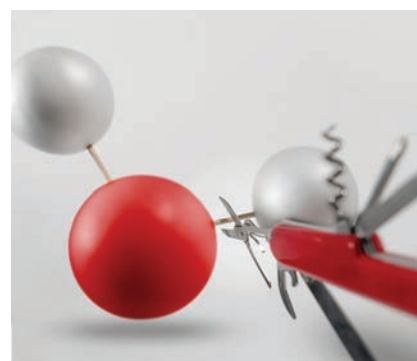
■ [www.phog.physik.uni-muenchen.de](http://www.phog.physik.uni-muenchen.de)

The paper reports, for the first time, the full water splitting to hydrogen and oxygen under visible light using a single particle of a photocatalyst. Such “all-in-one” solution, shown schematically in fig. 1, offers a very simple, and potentially cheap, pathway for the harvesting and storage of solar energy in the form of a solar fuel. This fuel can be combusted without any additional emission to



**Fig. 2.** Schematic illustration of the full water splitting on CdS nanorods where, upon excitation, the photo-generated charges separate. Electrons are transferred to the Pt nanoparticle located at the nanorod tips where they reduce water to hydrogen. Holes transfer to the molecular ruthenium-based oxidation catalyst located at the side surfaces of the nanorods where they oxidize water to oxygen. Picture: Christoph Hohmann, NIM.

recover the energy when needed. Other approaches only work higher energy UV irradiation or involve a more complex two-particle system (so called Z-scheme). Here, the full water splitting is achieved with CdS nanorods by utilizing nanorod morphology to separate the reduction and oxidation sites to reduce charge recombination and by combining nanoparticulate and molecular co-catalysts for water reduction and oxidation, respectively. Specifically, hydrogen is generated on Pt nanoparticles grown at the nanorod tips, while Ru(tpy)(bpy)Cl<sub>2</sub>-based oxidation catalysts are anchored onto the sides of the nanorod for oxygen generation (see fig. 2). The binding of the oxidation catalyst to CdS through dithiocarbamate bonds allows for ultrafast hole transfer to the co-catalysts and prevents the photooxidation of the semiconductor. The system demonstrates that careful management of charge transfer pathways with an appropriate choice of co-catalysts, enables full water splitting on a single photocatalyst particle, significantly simplifying the design of the photocatalyst.



**Fig. 1.** All-in-one water splitting (“a Swiss army knife approach”): using nanoparticles decorated with both oxidation and reduction catalysts for full water splitting on each individual nanoparticle. Picture: Christoph Hohmann, NIM.

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## ON-SURFACE SYNTHESIS OF HIGHLY ORIENTED THIN METAL-ORGANIC FRAMEWORK FILMS THROUGH VAPOR-ASSISTED CONVERSION

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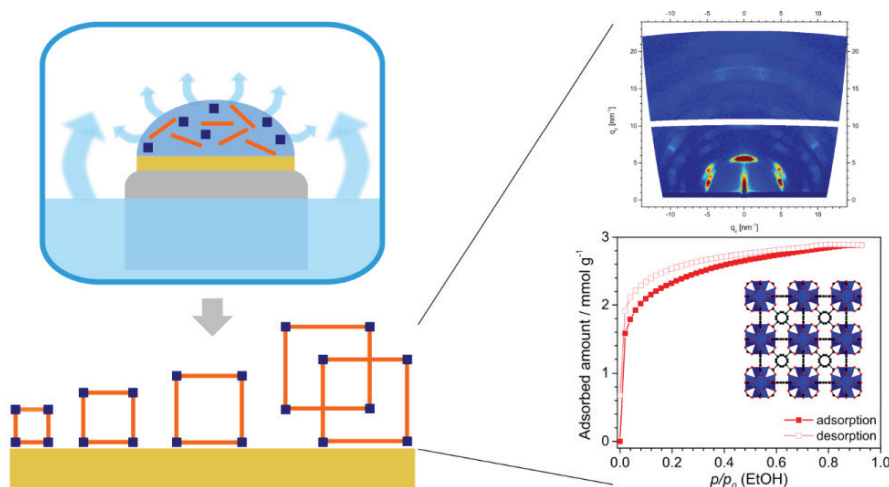
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Metal-organic frameworks (MOFs) are particularly intriguing candidates for the growth of crystalline porous films. MOFs consist of a periodic array of inorganic nodes connected by organic units providing the MOFs with well-defined structures, precise chemical compositions, surface areas and pore sizes. Due to their crystalline nature, the growth of thin films of these materials permits, in principle, a specific crystal orientation and, thereby, an oriented pore system relative to a surface. Several methods have been reported for the growth of oriented thin MOF films. However, these methods are merely suitable for the synthesis of a small number of MOF topologies.

In this context, we presented the synthesis of thin zirconium-based metal-organic framework (MOF) films by vapor-assisted conversion (VAC). We established protocols adequate for the growth of UiO-66, UiO-66(NH<sub>2</sub>), UiO-67, and UiO-68(NH<sub>2</sub>) as well as the porous interpenetrated Zr-organic framework (PPPP-PIZOF-1) as highly oriented thin films. Through the VAC approach, precursors in a cast solution layer on a bare gold substrate are reacting to form a porous continuous MOF film, oriented along the [111] crystal axis by an exposure to a solvent vapor under elevated temperatures of 100 °C and 3 h reaction times. We found that the concentration

of dicarboxylic acid precursors, and modulator, the droplet volume and the reaction time are vital parameters to be controlled for obtaining oriented MOF films. Using VAC for the MOF film growth on gold surfaces modified with thiol SAMs as well as on a bare silicon surface yielded oriented MOF films rendering the VAC process as robust towards chemical surface variations. Ethanol sorption experiments show that a substantial part of the material pores is accessible. Thereby, the practical VAC method is an important addition to the toolbox of thin MOF film synthesis methods. We expect that the VAC approach will provide new horizons in the formation of highly defined functional thin MOF films for numerous applications.

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**Fig. 1.** Schematic representation of the vapor-assisted conversion process for the fabrication of oriented MOF films.



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