LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

20 Years CeNS.

Exploring the Nanoworld Since 1998.

CeNS
Center for NanoScience | LMU

Contents

Congratulatory Message

The Center for NanoScience (CeNS) was founded in 1998 as a network of six research groups at LMU's Faculty of Physics to promote interdisciplinary cooperation in the field of nanoscience. Since then, more than 400 enthusiastic senior and junior scientists, PhD and master's students across many disciplines at LMU as well as from several other institutions have joined the network — united by their research interest in structures and processes at the nanoscale. Today, CeNS is a prime example for a stimulating interdisciplinary research environment. Furthermore, the supportive structures at CeNS are highly successful and have been adapted at many other centers at LMU.

From the very beginning, the research topics at CeNS have been highly multidisciplinary and they have remained so over the years — from semiconductor physics, nano-optics, and photonics to material sciences, biophysics and nanomedicine. CeNS has generated a wide range of success stories as evidenced by a remarkable number of coordinated programs as well as scientific awards won by its members. One example to be named here is the Collaborative Research Centre "Nanoagents for Spatio-temporal Control of Molecular and Cellular Reactions," which is currently in its second funding period by the German Research Foundation (DFG), with 20 of its 21 principal investigators being CeNS members. Further success stories are continuously being written by the — as of now — eleven spin-off companies founded by CeNS scientists as well as by its numerous outreach activities, demonstrating the impact of nanoscience research on high-tech industry and society at large.

Promoting interdisciplinary research by exchanging knowledge, sharing infrastructure and state-of-the-art technologies, as well as actively promoting technology transfer and coordinating a lively external presentation of its research are the hallmarks of CeNS. In addition, CeNS makes great efforts to foster interdisciplinarity in teaching and training through joint courses, seminars, workshops and events, and is extraordinarily dedicated to supporting young scientists and their career development inside and outside academia.

On behalf of LMU, I congratulate all CeNS-affiliated scientists, staff, and students on the 20th anniversary of this exceptional project and wish them and their cooperation partners the best of success for their future joint activities.

Prof. Dr. Bernd Huber
President of LMU Munich

The Spirit of CeNS

Looking back on 20 years of CeNS offers many surprising insights. The first surprise was when we realized that we have been part of CeNS for almost the entire time. For Tim, day-to-day survival as a student depended, to a large part, on the coffee machine in what was then the new CeNS office in the "Sommerfeld cellar". The spirit for which CeNS later became famous was already in evidence here: during chance encounters with students from neighboring groups we discussed scientific problems, often obtaining helpful tips and fresh insights. For Dieter, ongoing experience of learning about other fields, for example, in the proven format of the Venice summer school was the generator of many new ideas. One week away from the usual environment with interesting discussions and challenging new viewpoints has been a source of ideas and the creator of surprising combinations of sometimes distant fields. And his lab continues the tradition of a cellar-based coffee machine providing coffee for everyone who stops by for a discussion. These are just a few of the anecdotes — of which we have many — that have emerged from the fertile environment which CeNS provides for students and group leaders alike. Believing in open structures, enjoying science, and experimenting with unconventional ideas is all part of the spirit of CeNS. No proposal is too outlandish, no project too risky. And there is always a blackboard or a piece of paper ready to sketch out ideas.

Over the years, we have witnessed excellent interdisciplinary science evolve from the interaction between the many talented junior and senior scientists working in the Faculties of Physics, Chemistry and Pharmacy, Biology, and Medicine at LMU and at the partner institutions. This connection of disciplines is often at the heart of experiments that manipulate molecules and systems at the nanoscale level. Thus, it was Christoph Bräuchle as the first CeNS board member and his colleagues from the Faculty of Chemistry who were invaluable in helping CeNS to build bridges across the disciplines and to provide this essential cross-fertilization. CeNS is also a good example of the speed at which innovation can take place if groups join forces and pool their expertise. Importantly, CeNS is not a physical center, but a network of labs that offer their support in mutual collaborations. This structure has the advantage that instruments are in the hands of scientists who are really interested in achieving the best results. With the support of CeNS, instruments are purchased and maintained through shared funding for two or more groups. Instead of individual PIs trying to pursue new directions by themselves, ideas can be tested in discussions, explored at workshops, and then later shaped into a working proposal and successful science. All this is only possible with a network of trust which has emerged within CeNS.

With its many collaborations, CeNS has become a focal point for cluster proposals and collaborative research centers. Researchers can build on the existing interconnections and, with access to previous proposals and expertise, the chances for future success increase significantly. Ideas, which initially sounded impossible, e.g. nanomanipulation, atomic forces, nanobiotechnology, DNA self-assembly, single-molecule experiments, nanoagents, or origins of life, were shaped into working scientific programs and collaborative networks. These projects have, in turn, provided a broad base for diversification into new research topics. We think this is true even in a world in which nanoscience seemingly has grown up and matured into fields represented by, e.g., the new e-conversion and quantum clusters of excellence. These long-term efforts have been shaped out of the Nanosystems Initiative Munich, which in turn grew directly out of the CeNS network. The networking and education formats of CeNS have structured these processes.

It is also worth mentioning that a total of 20 ERC grants went to LMU CeNS members. This is the result of an environment in which individual successes are not considered to be in competition with each other. Instead, such achievements provide a positive stimulus for others to launch their own proposals with helpful support from colleagues who have already been successful in their applications.

The members of CeNS have trained more than 1,000 diploma, master's, and PhD students in workshops and training. Further, the internationalization provided by CeNS through the recruitment program and by the Junior Nanotech Network (JNN) program are essential to make our students fit for worldwide exchange and networking with PhD colleagues from abroad. To the delight of the students, CeNS funds their visits to summer and winter schools. It is in Mauterndorf, Venice and other places that many meet their future PhD supervisor or postdoc adviser—and some of our future nanoscience heroes. Also, the impact of outdoor activities, such as hiking or skiing, should not be underestimated. The next new ideas are often out there to be grabbed while exercising both mind and body in the fresh air. Workshops with an inspiring and interactive atmosphere are a central element in the continuous reshaping of CeNS.

The creation of start-up companies through CeNS is the ultimate result of placing confidence in young scientists and training them to think independently. In the same way that we believe that our PhD students are ready to compete on a global stage with their scientific ideas, we also believe that they are fit to compete in the tough world of business with their bright ideas. As it turns out, the most successful startups from CeNS come from very basic research and focus on the science underlying the products. What is novel and well-understood in science also has a high potential to be successful on the market place. All CeNS spin-offs combined have more than 600 employees to date, many of whom are CeNS alumni. In terms of the tax paid by these companies in the past, we came up with a very conservative estimate of at least €150 million. This is even more impressive when compared with the moderate funding on which CeNS was operating in the same period: about €4.5 million. To honor this convincing leverage, the DPG will give its next Technology Transfer Prize to CeNS, NanoTemper, and the Spin-off Service of LMU in 2019.

Working across the borders of disciplines and faculties and developing new ideas requires trust and long-term support from the university, and we would like to express our gratitude to LMU Munich and the Faculty of Physics for their generous support. We are also grateful to our former and current Advisory Board members David Awschalom, Gerd Binnig, Cees Dekker, Andreas Engel, Teun Klapwijk, Klaus Müllen, and Daniel Müller for their continuous and constructive advice that has helped to develop CeNS over the past years.

Much at CeNS has been achieved with a lean structure and through the use of collaborative networks and a question-focused approach. Thus the center can be seen as an interconnected platform of endless possibilities in which we can explore and test new ideas.

So what is at the heart of CeNS? It is scientific curiosity, interdisciplinarity, and a focus on caring for and supporting our PhD students and postdocs. We believe they will rock the future of science and actively shape their environment, whether as group leader in academia, as researcher in industry, or as part of a start-up company. If we focus on how junior researchers can learn and experience science as a worldwide lab to test the newest and sometimes even crazy ideas, then CeNS has fulfilled its mission.

Prof. Dr. Dieter Braun
Spokesman of CeNS

Prof. Dr. Tim Liedl
Spokesman of CeNS
2016–2018

20 Years of CeNS

1998

CeNS is founded at LMU
by Prof. Jochen Feldmann,
Prof. Hermann Gaub,
Prof. Khaled Karrai,
Prof. Jörg P. Kotthaus,
Prof. Johann S. Peisl, and
Prof. Wilhelm Zwerger


Erstmals Zentrum für Nanoforschung
Interdisziplinäre Arbeitsgruppe gegründet:
Das Kleinste wird ganz groß erforscht
Im »Center for NanoScience« geht es künftig um die Technik der Zukunft
Rosige Zukunft für Nanowissenschaften
Auf dem Weg ins Winzi
Nano-Wissenschaft in München: die nächste technologische Revolution

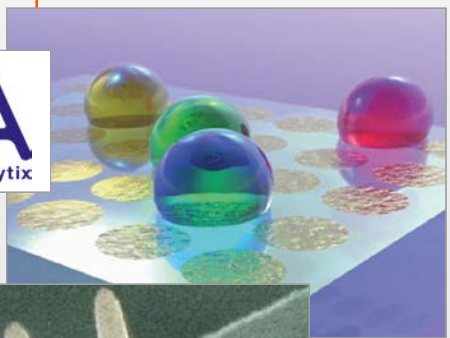
1999

18.01.1999:
CeNS inaugural
ceremony at LMU

First international workshop at Venice International University:
18–23 April 1999
"CeNS Workshop
Nanoscience: Scientific, technological and economic aspects"

2000

Spin-Off
Advalytix
is founded



2000

Funding
SFB486
"Manipulation of matter at
the nanometer length scale"

20 Years CeNS

Exploring the Nanoworld Since 1998.

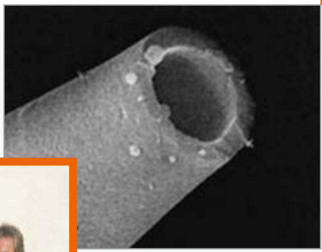
2001

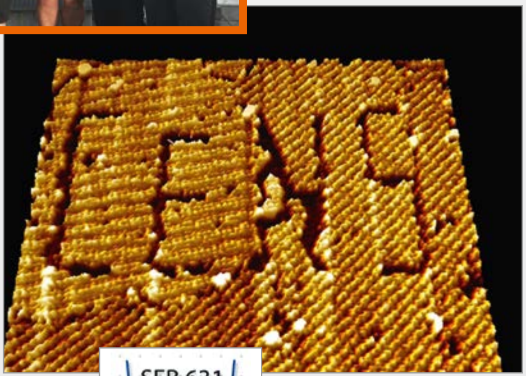
First CeNS Winter School
in Mauterndorf, Austria

First “CeNS meets Industry”
Representatives from industry present their careers

2002

Spin-Off
Nanion Technologies is founded





2001

Spin-Offs
attocube systems, ibidi and NanoScape are founded

2002

Funding
ForNano Research Cooperation funded by the Bayerische Forschungsstiftung

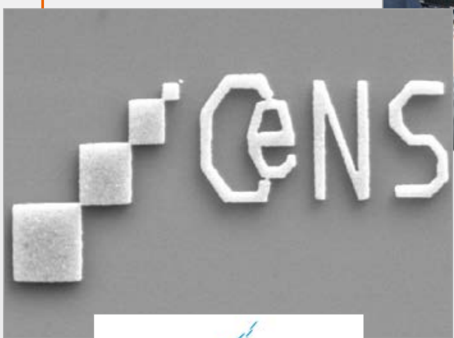
2003

Funding
SFB631
“Solid-State Based Quantum Information Processing: Physical Concepts and Materials Aspects”

2004
Joint CNSI-CeNS Workshop
at the Californian
NanoSystems Institute
in Santa Barbara

2005
Summer school
on "Nanoscience and
Systems Biology" with
IDK NanoBioTechnology

2006
First Junior Nanotech Network
PhD Exchange with McGill
University, Montréal



2004
Funding
International PhD Program
"IDK NanoBioTechnology"
is funded by the Elite Network
of Bavaria

2006
Funding
Nanosystems Initiative Munich (NIM) is funded as a
Cluster of Excellence by the
German Excellence Initiative

2007

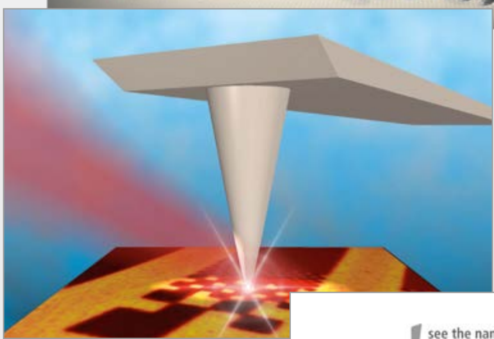
Joint "NINT-CeNS Winter School on Nanotechnology Convergence"
in Edmonton (Alberta), Canada

2008

Ten years of CeNS

International Workshop
"The Global Challenges— How can Nanotechnology help?" with Swiss Nanoscience Institute at Venice International University

10 Years CeNS



2007

Spin-Off
Neaspec is founded

2008

Spin-Offs
NanoTemper Technologies, ChromoTek and Baseclick are founded

2009

8 ERC grants go to CeNS members

PhD exchange program
with University of Bristol

The attocube Research Award
honors outstanding junior scientists for application-oriented research

2010

CeNS has more than 100 members by now

2011

Joint CeNS-NIM Winter School
in St. Christoph (Arlberg)

Undergraduate Exchange
with City University Hong Kong started

ethris ENABLING THERAPIES

GNA Biosolutions

Forces in Biomolecular Systems SFB 863

2009

Spin-Off
ethris is founded

2010

Spin-Off
GNA Biosolutions is founded

Funding
SFB863
"Forces in Biomolecular Systems"

2012

Junior Nanotech Network
with University of California Santa Barbara

2013

First election of CeNS Student Representatives

International Workshop
"Global Challenges—Opportunities for Nanotechnology" with Nobel laureates Gerd Binnig and Jean-Marie Lehn at Venice International University

CeNS Travel Awards
allow CeNS PhD students and postdocs to present their work at conferences

2012

Funding
SFB1032
"Nanoagents for spatiotemporal control of cellular reactions"

Graduate School **"Quantitative Biosciences Munich"** within the German Excellence Initiative

"Solar Technologies Go Hybrid"
funded by the Free State of Bavaria

2014

10th CeNS workshop
at Venice International University

International workshop "Physics of Living Systems"
of the iPOLS network is hosted by CeNS and SFB1032 in Munich

2016

Topping ceremony for the new LMU Nano Institute,
the first building on the future LMU Physics campus near the Englischer Garten

2014

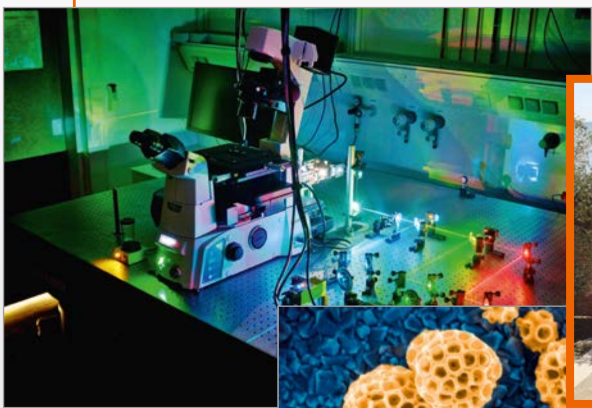
Spin-Off
GATTAquant is founded

2015

The CeNS Innovation Award
honors outstanding PhD and master students for application-oriented research. The awards are financed by attocube systems, ibidi, Nanion Technologies, and NanoTemper Technologies

2017

Junior Nanotech Network
with the University of
Illinois Urbana-Champaign



2018

CeNS Anniversary Workshop
at Venice International University

2018

Funding
Transregio 235
"Emergence of life:
Exploring mechanisms with
cross-disciplinary experiments"

Three new **Clusters of Excellence**
"Munich Center for Quantum Science and Technology", "Origins", and "e-conversion" with CeNS participation

CeNS: How It Was Born — a Personal View at 20 Years of CeNS

In 1998, my colleagues Jochen Feldmann, Hermann Gaub, Johann Peisl and I were thinking about establishing a Center for NanoScience at LMU based on curiosity-driven collaborative research between interested scientists from different faculties. The idea for CeNS was conceived during discussions about an attractive offer I received in 1997 to become the founding director of caesar. This new "center of advanced european studies and research", the aim of which was applied interdisciplinary research centered around nanoscience, was established by the German government to compensate the Bonn area for the government moving to Berlin. The complex negotiations made me realize that LMU would be a much better environment for interdisciplinary research than a new, merely politically motivated and rather isolated institution. We were able to convince the LMU administration that transdisciplinary research needed both some initial investment and a small yearly budget to organize workshops and training, and to initiate new science projects. To circumvent tedious negotiations between different faculties, CeNS was founded as a "non-legal working group" by interested members of the physics faculty in the fall of 1998. Following its opening symposium in January 1999 and with the support of a scientific coordinator and a secretary, it quickly reached out across disciplinary boundaries to chemistry, geosciences, and medicine.

Interactions started with smaller focused workshops and a week with interdisciplinary talks and discussions at Venice International University, now a regular highlight with prominent international participation. The main success, however, was that CeNS gave young scientists from different disciplines the opportunity to meet, discuss, and to jointly try out ambitious high-risk projects that needed some initial investment. This bottom-up strategy resulted not only in new science with many publications in high-impact journals, but also incubated the first spin-off companies Nanotools, Advalytix, attocube, Nanotype, Nanion, and ibidi which were later followed by others. CeNS supports the development of spin-offs by providing training in patent law and entrepreneurship and fosters contacts to industry, for instance with its yearly event "CeNS meets industry". The event, which is followed by a lively summer party with music from the CeNS band "UnCeNSiert", also helps to establish new scientific interactions.

In my opinion, the main success of CeNS results from its unbound grassroots scientific culture, highly motivating young adventurous scientists to reach out into neighboring disciplines. This is quite a contrast to some top-down-directed and concrete and program-confined institutions. The interactive culture initiated other CeNS events such as the biweekly "Science Rocks" for PhD students or the international "Junior Nanotech Network". CeNS has formed the breeding ground for many joint interdisciplinary research projects supported by the European Union, DFG, BMBF, Volkswagen Foundation and others. It also was essential for the successful funding of the NIM cluster of excellence. This multi-cultural spirit of CeNS has enabled many young scientists to develop excellently, as reflected by the reputation of its former and present members and associates, many of whom have now highly attractive positions in science and industry.

Looking back now over 20 years, I must admit that in 1998 I did not anticipate the high impact that CeNS continues to have on both science and technology, particularly considering its still modest organizational base. Since nanoscience has many facets that are now becoming increasingly important in our daily lives, I believe that the slogan "CeNS makes sense and only needs cents" that we used to convince the LMU administration to support the CeNS project in 1998 continues to be valid. I wish CeNS to thrive and keep its adventurous spirit for many years to come.

Prof. Dr. Jörg P. Kotthaus, Emeritus
Spokesman of CeNS
1999–2008

Research
and Collaboration

Research at CeNS

Interdisciplinary research has always been the central idea of CeNS. Nanoscience as such includes a wide range of topics, including nanostructured materials, nano-optics, semiconductor technology, molecular devices, systems biophysics, and nanomedicine, to mention just a few. This diversity of topics and the large number of CeNS members have made it impossible to include all research activities of the last 20 years here. On the following pages, we therefore take a different approach and present a few research highlights along the timeline of the last 20 years. These papers have been compiled following a bottom-up principle that is typical for CeNS: All current ordinary members were asked to send a publication that was of specific importance for them, be it as the starting point for a new research direction, the fundamental idea underlying a later spin-off, or a fruitful CeNS collaboration. We hope you will enjoy this subjective, but very personal short review of 20 years of research at CeNS, even if many other exciting scientific findings, especially by our extraordinary CeNS members, are not depicted here.

The number of scientific publications and their reception in the international scientific community may help to give a more objective picture of the scientific output of CeNS researchers. Since 1998, more than 2,800 publications have been published with the participation of CeNS scientists, equivalent to about two to three publications per week (source: ISI Web of Science; publications where CeNS was mentioned as author's affiliation).

These 2,800 CeNS publications have been cited in over 82,000 papers, including three publications cited over 1,000 times and 293 publications cited 100 times or more (source: ISI Web of Science).

16 publications have been published in *Science*, 19 in *Nature*, and 79 in other series of the *Nature* family (*Nature Physics, Nature Nanotechnology, Nature Materials*, *Nature Photonics*, *Nature Methods*, and *Nature Communications*). 53 articles appeared in *Angewandte Chemie* and 34 in *PNAS*. The most common journals for CeNS publications are *Physical Review Letters* (169 articles), *Physical Review B* (240), *Nano Letters* (128), and *Applied Physics Letters* (127) (source: ISI Web of Science).

Another important aspect is the number of papers jointly published by collaborating CeNS groups. On average, every fourth to fifth CeNS publication results from a collaboration within the Center for NanoScience. This reflects our efforts to strengthen interdisciplinary exchange and cooperation between CeNS members, by providing initial funding for CeNS collaboration projects and by enabling personal contact and scientific discussions at numerous events.

Table 1 — **Numbers of CeNS publications per year**

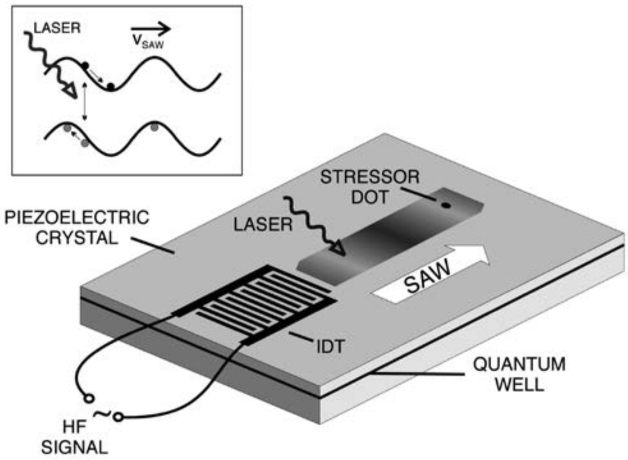
1999	36
2000	67
2001	49
2002	70
2003	86
2004	105
2005	103
2006	117
2007	164
2008	204
2009	177
2010	209
2011	182
2012	181
2013	167
2014	197
2015	168
2016	192
2017	187
2018	185

Photon Trains and Lasing: The Periodically Pumped Quantum Dot

Christian Wiele, Fritz Haake, Carsten Rocke, and Achim Wixforth

Physical Review A 58(4), R2680 (1998)

ABSTRACT We propose to pump semiconductor quantum dots with surface acoustic waves that deliver an alternating periodic sequence of electrons and holes. In combination with a good optical cavity such regular pumping could entail antibunching and sub-Poissonian photon statistics. In the bad-cavity limit a train of equally spaced photons would arise.



Schematic sketch of a SAW sample for the acoustically driven transport of electron hole pairs. The material of the system may be, for example, GaAs for the piezoelectric crystal, InGaAs for the quantum well, and InP for the stressor. The inset depicts the storage of optically generated excitons in the potential of the surface acoustic wave. These spatially separated excitons may recombine at the location of the quantum dot, given rise for the generation of single photons.

1998 1999 2000 2001

> This paper has been written right at the time of the foundation of CeNS. It somehow comprises the research that our group is doing until this date. SAW are employed to acoustically separate and transport charges, convert them into photons after recombination within a quantum dot. Combination of such exciton dissociation, SAW driven charge transport, and quantum dot recombination with sophisticated phoXonic crystals and nanomechanical membranes represented the origin and the basics of worldwide efforts in the field of acoustically mediated light-matter interaction. PROFESSOR ACHIM WIXFORTH

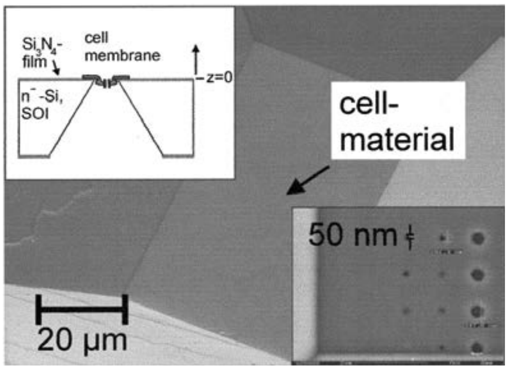
IMPACT The SAW driven transport of charges later resulted in the acoustic actuation of small amounts of fluids, paving the path for the meanwhile well-established research field of acoustofluidics. Such acoustically driven microfluidic systems have been the subject of the group's research for meanwhile 20 years and led to the successful spin-off “Advalytix” in 1999.

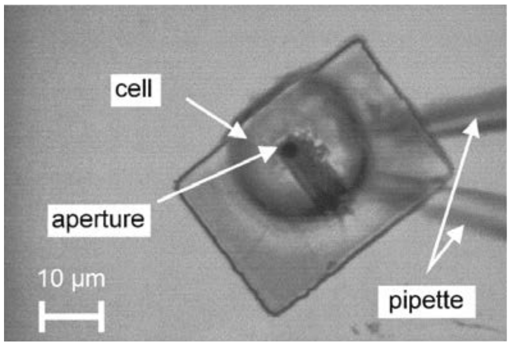
Stable Integration of Isolated Cell Membrane Patches in a Nanomachined Aperture

Niels Fertig, Armin Tilke, Robert H. Blick, Jörg P. Kotthaus, Jan C. Behrends, and Gerrit ten Bruggencate

Appl Phys. Lett. 77, 1218–1220 (2000)

ABSTRACT We present a method for integrating an isolated cell membrane patch into a semiconductor device. The semiconductor is nanostructured for probing native cell membranes for scanning probe microscopy *in situ*. Apertures were etched into suspended silicon-nitride layers on a silicon substrate using standard optical lithography as well as electron-beam lithography in combination with reactive ion etching. Apertures of 1 µm diameter were routinely fabricated and a reduction in size down to 50 nm was achieved. The stable integration of cell membranes was verified by confocal fluorescence microscopy *in situ*.





Top: SEM micrograph of a V-groove in (100) silicon with a suspended Si_3N_4 layer on top. In the central aperture cell material is incorporated. The upper inset depicts the arrangement of the semiconductor–cell hybrid. The lower inset shows a series of holes in a suspended membrane with dimensions down to 50 nm.
Bottom: Photograph of the probe with the cell positioned on top of the aperture.

2000 2001 2002 2003

IMPACT This is the first report on experiments at CeNS to realize patch clamping of cell membranes on nanostructured chips. Based on the interdisciplinary collaboration of scientists from physics and physiology it presents basic research aiming at the analysis of ion channels in a high throughput industrial format. In 2002, Nanion Technologies was founded as a CeNS spin-off. With Niels Fertig as CEO, Nanion is today the international market leader for automated patch clamp systems with daughter companies in the USA, Japan, China, and Denmark and has over 100 highly qualified employees worldwide.

nan]i[on

Real-Time Single Molecule Imaging of the Infection Pathway of an Adeno-associated Virus

Georg Seisenberger, Martin U. Ried, Thomas Endreß, Hildegard Büning, Michael Hallek, and Christoph Bräuchle

Science 294, 1929 (2001)

ABSTRACT We describe a method, based on single-molecule imaging, that allows the real-time visualization of the infection pathway of single viruses in living cells, each labeled with only one fluorescent dye molecule. The tracking of single viruses removes ensemble averaging. Diffusion trajectories with high spatial and time resolution show various modes of motion of adeno-associated viruses (AAV) during their infection pathway into living HeLa cells: (i) consecutive virus touching at the cell surface and fast endocytosis; (ii) free and anomalous diffusion of the endosome and the virus in the cytoplasm and the nucleus; and (iii) directed motion by motor proteins in the cyto-plasm and in nuclear tubular structures. The real-time visualization of the infection pathway of single AAVs shows a much faster infection than was generally observed so far.

Ein echter Thriller: Wenn das Virus dreimal klingelt

Münchner Forscher haben Infektionen live mitverfolgt. Durchbruch im Kampf gegen Krebs?

Wenn das Virus dreimal klingelt – so könnte der Titel lauten. Das Drehbuch zur Aufsehen erregenden Story entstand am High-Tech-Campus der Münchner Uni (LMU) in Martinsried. Es liest sich spannender als mancher Thriller. Und es könnte die medizinische Forschung revolutionieren.

Münchner Wissenschaftler um die Professoren Christoph Bräuchle und Michael Hallek haben erstmals am Spezialmikroskop live mitverfolgt, wie ein Virus eine menschliche Zelle infiziert.

Wenn das Virus dreimal klingelt – der Titel bezieht sich auf ein interessantes Phänomen bei der Annäherung des Erregers an sein Opfer – die lebende Zelle. „Das Virus klopft immer wieder an", sagt Professor Bräuchle. Und dann kann's ganz schnell gehen: Nach zwei, drei oder vier Klopfzeichen flutscht das durch ein fluoreszierendes Molekül markierte Virus durch die Zellhülle, dringt in den Zellkern ein. Und schon ist's passiert.

Was das Münchner Forscher-Team besonders überraschte: Der Vorgang, dessen Dauer bisher auf etwa ein bis zwei Stunden geschätzt wurde, passiert wesentlich schneller. „In durchschnittlich 15 Minuten ist die Infektion passiert", sagt Bräuchle. Faszinierend: Manche Viren setzen sich sogar auf so genannte Motor-Proteine, die sie blitzschnell in den Zellkern transportieren.

Einen „großen Schritt vorwärts" – so sehen die LMU-Physiker und -Genforscher ihre Arbeit. Der praktische Nutzen liegt auf der Hand. Die Wirkung neuer Medikamente gegen Infektionen von der Virusgrippe bis zu HIV kann mit ihrer Technik direkt an einer einzelnen Zelle ausprobiert werden.

Mittelfristig setzen die Forscher noch wesentlich größere Hoffnungen in ihre Erkenntnisse: Sie könnten der Gentherapie gegen Krebs zum Durchbruch verhelfen.

Rudolf Huber

Enträtselt Virus-Infektionen: Prof. Christoph Bräuchlevon der LMU.

2001 2002 2003 2004

> On the occasion of the release of this publication about imaging the infection pathway of a single virus, Science hired the LMU auditorium to hold an international press conference. It gained much publicity in TV and German and international newspapers, as well as in the AZ Munich under the title: "A real thriller: When the virus rings three times".
>
> PROFESSOR CHRISTOPH BRÄUCHLE

IMPACT In a later cooperation with Professor Don Lamb, the formation of a virus in an infected cell and budding of the finished virus from the cell was investigated by live-cell imaging.

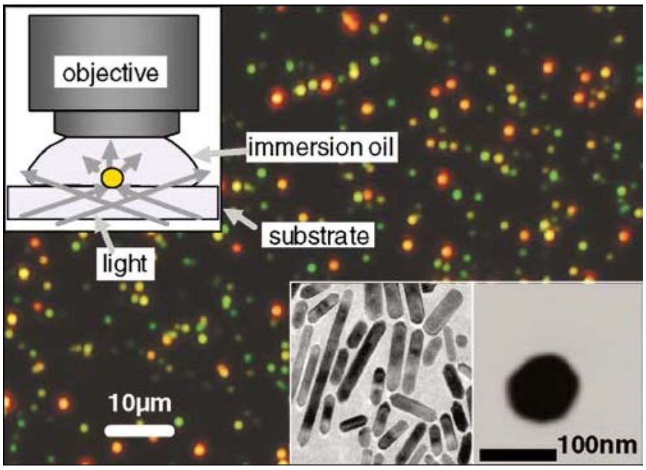
- Baumgärtel V., Ivanchenko S., Dupont A., Sergeev M., Wiseman P.W., Kräusslich H.-G., Bräuchle C., Müller B., Lamb D.C.: Live-cell visualization of dynamics of HIV budding site interactions with an ESCRT component; *Nature Cell Biology* (2011)
- Ivanchenko S., Godinez W.J., Lampe M., Kräusslich H.-G., Eils R., Rohr K., Bräuchle C., Müller B., Lamb D.C.: Dynamics of HIV-1 Assembly and Release; *PLoS Pathogens* (2009)
- Prescher J., Baumgärtel V., Ivanchenko S., Torrano A.A., Bräuchle C., Müller B., Lamb D.C.: Super-Resolution Imaging of ESCRT-proteins at HIV-1 Assembly Sites; *PLoS Pathogens* (2015)

Drastic Reduction of Plasmon Damping in Gold Nanorods

Carsten Sönnichsen, Thomas Franzl, Tatjana Wilk, Gero von Plessen, Jochen Feldmann, Orla Wilson, and Paul Mulvaney

Phys. Rev. Lett. 88, 077402 (2002)

ABSTRACT The dephasing of particle plasmons is investigated using light-scattering spectroscopy on individual gold nanoparticles. We find a drastic reduction of the plasmon dephasing rate in nanorods as compared to small nanospheres due to a suppression of interband damping. The rods studied here also show very little radiation damping, due to their small volumes. These findings imply large local-field enhancement factors and relatively high light-scattering efficiencies, making metal nanorods extremely interesting for optical applications. Comparison with theory shows that pure dephasing and interface damping give negligible contributions to the total plasmon dephasing rate.



True color photograph of a sample of gold nanorods (red) and 60 nm nanospheres (green) in dark-field illumination (inset upper left).
Bottom right: TEM images of a dense ensemble of nanorods and a single nanosphere.

2002 2003 2004 2005

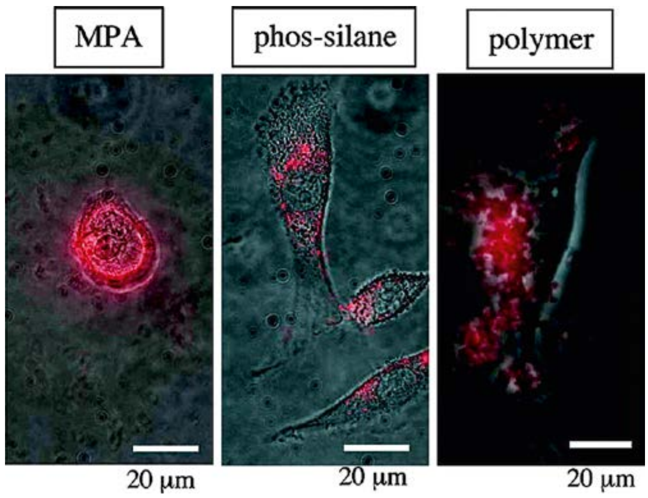
IMPACT This paper has inspired the field of plasmonics, as it reports for the first time on the use of dark field microscopy for the spectral measurement of individual plasmonic nanoparticles, as well as quantitatively recording and explaining the radiating and non-radiative decay channels and thus the line widths of particle plasmons. This fundamental work also motivated a subsequent number of opto-thermal experiments carried out at Professor Feldmann's chair, which i.a. led to the spin-off GNA Biosolutions.

Cytotoxicity of Colloidal CdSe and CdSe/ZnS Nanoparticles

Christian Kirchner, Tim Liedl, Stefan Kudera, Teresa Pellegrino, Amudena Muñoz Javier, Hermann Gaub, Sonja Stölzle, Niels Fertig, and Wolfgang Parak

Nano Letters, 5 (2), 331–338 (2005)

ABSTRACT Cytotoxicity of CdSe and CdSe/ZnS nanoparticles has been investigated for different surface modifications such as coating with mercaptopropionic acid, silanization, and polymer coating. For all cases, quantitative values for the onset of cytotoxic effects in serum-free culture media are given. These values are correlated with microscope images in which the uptake of the particles by the cells has been investigated. Our data suggest that in addition to the release of toxic Cd^{2+} ions from the particles also their surface chemistry, in particular their stability toward aggregation, plays an important role for cytotoxic effects. Additional patch clamp experiments investigate effects of the particles on currents through ion channels.



2005 | 2006 | 2007 | 2008

IMPACT Here one of the first systematic studies on the cytotoxic effects of colloidal nanoparticles has been presented. This particular work investigated particles containing Cadmium and Selenium, both toxic elements in their own rights. As these particles are widely used in biological imaging, a fundamental understanding of the toxic effects on cells is essential. The interdisciplinary infrastructure and the unique combination of bio-nano groups at CeNS was crucial for this success.

Visualizing Single-Molecule Diffusion in Mesoporous Materials

Andreas Zürner, Johanna Kirstein, Markus Döblinger, Christoph Bräuchle, and Thomas Bein

Nature 450, 705 (2007)

ABSTRACT Periodic mesoporous materials formed through the cooperative self-assembly of surfactants and framework building blocks can assume a variety of structures, and their widely tuneable properties make them attractive hosts for numerous applications. Because the molecular movement in the pore system is the most important and defining characteristic of porous materials, it is of interest to learn about this behaviour as a function of local structure. Generally, individual fluorescent dye molecules can be used as molecular beacons with which to explore the structure of—and the dynamics within—these porous hosts, and single-molecule fluorescence techniques provide detailed insights into the dynamics of various processes, ranging from biology to heterogeneous catalysis. However, optical microscopy methods cannot directly image the mesoporous structure of the host system accommodating the diffusing molecules, whereas transmission electron microscopy provides detailed images of the porous structure, but no dynamic information. It has therefore not been possible to 'see' how molecules diffuse in a real nanoscale pore structure. Here we present a combination of electron microscopic mapping and optical single-molecule tracking experiments to reveal how a single luminescent dye molecule travels through linear or strongly curved sections of a mesoporous channel system. In our approach we directly correlate porous structures detected by transmission electron microscopy with the diffusion dynamics of single molecules detected by optical microscopy. This opens up new ways of understanding the interactions of host and guest.

2007 2008 2009 2010

> This paper resulted from a long-standing and successful cooperation with Christoph Bräuchle and later Jens Michaelis on the visualization of single-molecules diffusion in mesoporous materials.
>
> PROFESSOR THOMAS BEIN

IMPACT Further publications from this cooperation:

- Kirstein J., Platschek B., Jung C., Brown R., Bein T., Bräuchle C.: Exploration of Nanostructured Channel Systems by Single Molecule Probes; *Nature Materials* (2007)
- Jung C., Schwaderer P., Dethlefsen M., Köhn R., Michaelis J., Bräuchle C.: Visualization of the Self Assembly of Silica Nanochannels reveals growth mechanism; *Nature Nanotechnology* (2011)

Scanning Tunneling Microscopy of Graphene on Ru(0001)

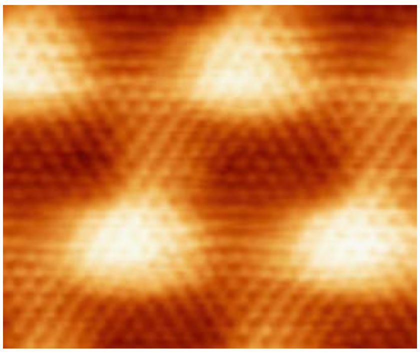
Silvia Marchini, Sebastian Günther, and Joost Wintterlin

Physical Review B 76, 075429 (2007)

ABSTRACT After prolonged annealing of a Ru(0001) sample in ultrahigh vacuum a superstructure with a periodicity of ~30 Å was observed by scanning tunneling microscopy (STM). Using x-ray photoelectron spectroscopy it was found that the surface is covered by graphitic carbon. Auger electron spectroscopy shows that between 1000 and 1400 K carbon segregates to the surface. STM images recorded after annealing to increasing temperatures display islands of the superstructure, until, after annealing to T ≥ 1400 K, it covers the entire surface. The morphology of the superstructure shows that it consists of a single graphene layer. Atomically resolved STM images and low-energy electron diffraction reveal an (11 × 11) structure or incommensurate structure close to this periodicity superimposed by 12 × 12 graphene cells. The lattice mismatch causes a moiré pattern. Unlike the common orientational disorder of adsorbed graphene, the graphene layer on Ru(0001) shows a single phase and very good rotational alignment. Misorientations near defects in the overlayer only amount to ~1°, and the periodicity of ~30 Å is unaffected. In contrast to bulk graphite both carbon atoms in the graphene unit cell were resolved by STM, with varying contrast depending on the position above the Ru atoms. The filled and empty state images of the moiré structure differ massively, and electronic states at −0.4 and +0.2 V were detected by scanning tunneling spectroscopy. The data indicate a significantly stronger chemical interaction between graphene and the metal surface than between neighboring layers in bulk graphite. The uniformity of the structure and its stability at high temperatures and in air suggest an application as template for nanostructures.

2007 2008 2009 2010

> This is an early publication about absorbed graphene on metal surfaces and one of our most-cited papers.
>
> PROFESSOR JOOST WINTTERLIN



Atomically resolved image of the graphene overlayer. The image shows three different levels of apparent heights, namely four bright maxima, a dark minimum in the center between the three maxima on the right hand side, and a less dark minimum between the three maxima on the left hand side. 50 Å × 40 Å, It = 1 nA, V_{sample} = −0.05 V.

Single Molecule Cut and Paste

Stefan Kufer, Elias Puchner, Hermann Gumpp, Tim Liedl, and Hermann Gaub

Science 319 (5863), 594–596 (2008)

ABSTRACT We introduced a method for the bottom-up assembly of biomolecular structures that combines the precision of the atomic force microscope (AFM) with the selectivity of DNA hybridization. Functional units coupled to DNA oligomers are picked up from a depot area by means of a complementary DNA strand bound to an AFM tip. These units are transferred to and deposited on a target area to create basic geometrical structures, assembled from units with different functions. Each of these cut-and-paste events is characterized by single-molecule force spectroscopy and monitored by single-molecule fluorescence microscopy.

2008 | 2009 | 2010 | 2011

> With this pictogram we congratulated our CeNS advisory board member Gerd Binnig for his Kavli Award. It was assembled by single molecule cut and paste from 2100 individual molecules.
>
> PROFESSOR HERMANN GAUB

IMPACT Further publications following the Science paper:

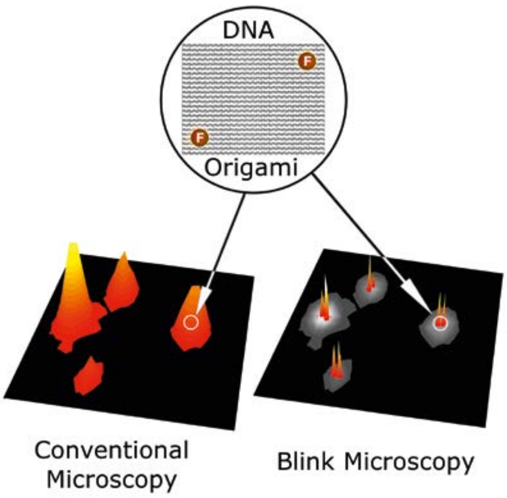
- Pippig, D.A., Baumann, F., Strackharn, M., Aschenbrenner, D. and Gaub, H.E.: Protein-DNA Chimeras for Nano Assembly. *ACS Nano* 8(7), 6551–6555 (2014)
- Strackharn, M., Stahl, S.W., Puchner, E.M. and Gaub, H.E.: Functional Assembly of Aptamer Binding Sites by Single-Molecule Cut-and-Paste. *Nano Letters* 12(5), 2425–2428 (2012)
- Strackharn, M., Pippig, D.A., Meyer, P., Stahl, S.W. and Gaub, H.E.: Nanoscale Arrangement of Proteins by Single-Molecule Cut-and-Paste. *Journal of the American Chemical Society* 134(37), 15193–15196 (2012)

DNA Origami as Nanoscopic Ruler for Superresolution Microscopy

Christian Steinhauer, Ralf Jungmann, Tom L. Sobey, Friedrich C. Simmel, Philip Tinnefeld

Angew. Chem. Int. Ed. 48, 8870–8873 (2009)

ABSTRACT Optical microscopy is one of the key analysis tools in modern life science. However, the resolution of this technique has always been limited by diffraction, that is, a structure which is smaller than about 300 nm cannot be resolved. To overcome this fundamental restriction, a couple of super-resolution methods where developed in recent years, which provide a resolution better than the diffraction barrier. For comparison and evaluation of several super-resolution approaches as well as calibration of each super resolution microscope, a nanoscopic ruler is needed. The basis for such a ruler was found with the so called DNA origami structures, where a long strand of DNA is folded into any desired shape. With a diameter of typically 100 nm and a fully addressable breadboard-like structure, DNA origami can be used to arrange nanoscale objects with nanometer precision. Scientists from the Tinnefeld (LMU) and the Simmel (TUM) group used the origami technique to develop a nanoscopic ruler and applied it to an assortment of super resolution techniques including blink microscopy. Single fluorophores were clearly resolved at a distance of 90 nm showing that fluorescent structures made of DNA origami are the perfect samples to test the resolving power of a microscope and furthermore a formidable tool for fluorescence microscopy in general.



2009 2010 2011 2012

> Interestingly, the starting point of the cooperation with the Simmel Group was a discussion between our PhD students within the framework of the International Doctorate Program NanoBio-Technology. For my group, this was the starting point of working with DNA origami, which has had a lasting impact on our research (meanwhile, a large part of my group is working on DNA nanotechnology).
>
> PROFESSOR PHILIP TINNEFELD

IMPACT This was the first combination of DNA origami with single-molecule fluorescence and super-resolution microscopy. It has been the basis of the world's first commercial application of DNA origami in 2014 (by the Tinnefeld spin-off GATTAquant). Ralf Jungmann (co-author of this study) works on DNA-paint today, combining DNA nanotechnology with single-molecule fluorescence methods. Last but not least, the CeNS start-up DEOXY Technologies currently develops nanometer-scale, DNA-based barcodes for quantitative and ultra-sensitive detection of biomolecules.

GATTAquant DNA NANOTECHNOLOGIES

DEOXY TECHNOLOGIES

Direct Observation of the Myosin-Va Power Stroke and Its Reversal

James R. Sellers and Claudia Veigel

Nature Structural & Molecular Biology 17, 590–595 (2010)

ABSTRACT Complex forms of cellular motility, including cell division, organelle trafficking or signal amplification in the auditory system, require strong coordination of the myosin motors involved. The most basic mechanism of coordination is via direct mechanical interactions of individual motor heads leading to modification of their mechano-chemical cycles. Here we used an optical trap-based assay to investigate the reversibility of the force-generating conformational change (power stroke) of single myosin-V motor heads. By applying load to the head shortly after binding to actin, we found that at a certain load the power stroke could be reversed and the head fluctuated between an actin-bound pre- and a post-power stroke conformation. This load-dependent mechanical instability might be critical to coordinate the heads of processive, dimeric myosin-V. Non-linear response to load leading to coordination or oscillations amongst motors might be relevant for many cellular functions.

2010 2011 2012 2013

> This paper demonstrated how molecular motor proteins involved in a myriad of critical cellular motile functions in health and disease, from cell division and intracellular transport to signal transduction in mammalian vision or hearing, can change and reverse their directionality of movement.
>
> PROFESSOR CLAUDIA VEIGEL

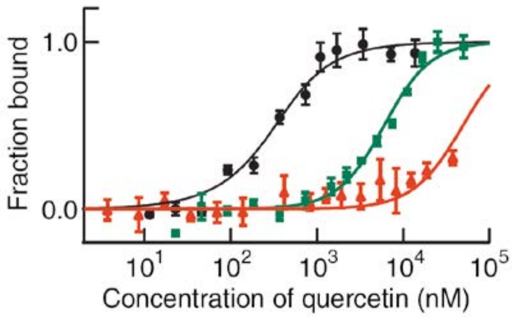
IMPACT The technical breakthrough of this paper was to apply controlled forces in the pico Newton range with millisecond time resolution onto a single motor head, whilst measuring the nanometre conformational changes as the motor protein proceeds through its cyclic biochemical transitions. This achievement made it possible to address the basic mechanism of chemo-mechanical energy transduction of these biological nano-machines, which had remained unresolved since they were first investigated at the single molecule level using optical tweezers technology, an approach for which Arthur Ashkin was awarded the Nobel prize in Physics in 2018.

Protein-Binding Assays in Biological Liquids Using Microscale Thermophoresis

Christoph J. Wienken, Philipp Baaske, Ulrich Rothbauer, Dieter Braun, and Stefan Duhr

Nature Communications 1, 100 (2010)

ABSTRACT Protein interactions inside the human body are expected to differ from the situation *in vitro*. This is crucial when investigating protein functions or developing new drugs. In this study, we present a sample-efficient, free-solution method, termed microscale thermophoresis, that is capable of analysing interactions of proteins or small molecules in biological liquids such as blood serum or cell lysate. The technique is based on the thermophoresis of molecules, which provides information about molecule size, charge and hydration shell. We validated the method using immunologically relevant systems including human interferon gamma and the interaction of calmodulin with calcium. The affinity of the small-molecule inhibitor quercetin to its kinase PKA was determined in buffer and human serum, revealing a 400-fold reduced affinity in serum. This information about the influence of the biological matrix may allow to make more reliable conclusions on protein functionality, and may facilitate more efficient drug development.



Microscale thermophoresis can detect the binding of antibodies and small pharmaceutical compounds in 50% serum and cell lysate. The apparent dissociation constant K_D of the inhibitor quercetin to the cAMP-dependent kinase PKA changes from 0.13μM (black circles) to 6μM in 5% human serum (green squares) and 50μM in 30% human serum (red triangles).

2010 2011 2012 2013

> Our lab in collaboration with its independent start-up Company NanoTemper showed that the nanoscale environment of proteins can be probed very quantitatively with the drift of proteins along a thermal gradient. In this very important publication in Nature Communications, we demonstrated that a wide range of biological bindings can be probed. PROFESSOR DIETER BRAUN

IMPACT This paper was one of the base papers for NanoTemper Technologies, now ten years later a company with more than 150 employees. The microscale thermophoresis technology has been used in many Nature and Science papers since and enabled numerous labs to probe the binding affinity of biomolecules in their natural buffer setting. As of today, scholar google shows more than 5000 papers with the term "microscale thermophoresis" in the abstract or the title.

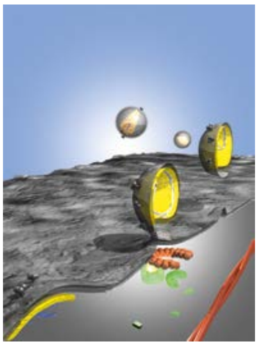
nano TEMPER technologies

Live-Cell Visualization of Dynamics of HIV Budding Site Interactions with an ESCRT Component

Viola Baumgärtel, Sergey Ivanchenko, Aurélie Dupont, Mikhail Sergeev, Paul W. Wiseman, Hans-Georg Kräusslich, Christoph Bräuchle, Barbara Müller, and Don C. Lamb

Nature Cell Biology 13, 469–474 (2011)

ABSTRACT Live-cell visualization of dynamics of HIV budding site interactions with an ESCRT component HIV (human immunodeficiency virus) diverts the cellular ESCRT (endosomal sorting complex required for transport) machinery to promote virion release from infected cells. The ESCRT consists of four heteromeric complexes (ESCRT-0 to ESCRT-III), which mediate different membrane abscission processes, most importantly formation of intralumenal vesicles at multivesicular bodies. The ATPase VPS4 (vacuolar protein sorting 4) acts at a late stage of ESCRT function, providing energy for ESCRT dissociation. Recruitment of ESCRT by late-domain motifs in the viral Gag polyprotein and a role of ESCRT in HIV release are firmly established, but the order of events, their kinetics and the mechanism of action of individual ESCRT components in HIV budding are unclear at present. Using live-cell imaging, we show late-domain-dependent recruitment of VPS4A to nascent HIV particles at the host cell plasma membrane. Recruitment of VPS4A was transient, resulting in a single or a few bursts of at least two to five VPS4 dodecamers assembling at HIV budding sites. Bursts lasted for ~35 s and appeared with variable delay before particle release. These results indicate that VPS4A has a direct role in membrane scission leading to HIV-1 release.



2011 2012 2013 2014

In accordance with the interdisciplinary nature of CeNS, we combined expertise from physics, physical chemistry, biology and virology to gain insights into the lifecycle of one of mankind's nemesis, HIV. Using live-cell imaging, single particle tracking, image correlation spectroscopy and genetically engineered HIV constructs in a collaboration between the groups of Professor Kräusslich (University of Heidelberg), Professor Wiseman (McGill University) and Professor Bräuchle (LMU), we could build on our previous work and show that the ATPase VPS4 plays in active role in the release of new HIV particles.

PROFESSOR DON LAMB

IMPACT My group specializes in the development and adaptation of advanced fluorescence methodologies to investigate biological systems. Through the CeNS network, we have been able to establish a large number of collaborations. These collaborations have resulted in many new insights in a number of different fields, which has been documented by a number of excellent publications with CeNS members including Christoph Bräuchle, Thorben Corbes, Hanna Engelke, Heinrich Leonhardt, Friedrich Simmel, Philip Tinnefeld, Ernst Wagner, Joost Wintterlin, and Stefan Wuttke.

DNA-Based Self-Assembly of Chiral Plasmonic Nanostructures with Tailored Optical Response

Anton Kuzyk, Robert Schreiber, Zhiyuan Fan, Günther Pardatscher, Eva-Maria Roller, Alexander Högele, Friedrich C. Simmel, Alexander O. Govorov, and Tim Liedl

Nature 483, 311–314 (2012)

ABSTRACT Matter structured on a length scale comparable to or smaller than the wavelength of light can exhibit unusual optical properties. Particularly promising components for such materials are metal nanostructures, where structural alterations provide a straightforward means of tailoring their surface plasmon resonances and hence their interaction with light. But the top-down fabrication of plasmonic materials with controlled optical responses in the visible spectral range remains challenging, because lithographic methods are limited in resolution and in their ability to generate genuinely three-dimensional architectures. Molecular self-assembly provides an alternative bottom-up fabrication route not restricted by these limitations, and DNA- and peptide-directed assembly have proved to be viable methods for the controlled arrangement of metal nanoparticles in complex and also chiral geometries. Here we show that DNA origami enables the high-yield production of plasmonic structures that contain nanoparticles arranged in nanometre-scale helices. We find, in agreement with theoretical predictions, that the structures in solution exhibit defined circular dichroism and optical rotatory dispersion effects at visible wavelengths that originate from the collective plasmon–plasmon interactions of the nanoparticles positioned with an accuracy better than two nanometres. Circular dichroism effects in the visible part of the spectrum have been achieved by exploiting the chiral morphology of organic molecules and the plasmonic properties of nanoparticles, or even without precise control over the spatial configuration of the nanoparticles. In contrast, the optical response of our nanoparticle assemblies is rationally designed and tunable in handedness, colour and intensity—in accordance with our theoretical model.

2012 2013 2014 2015

> This paper emerged from merging the disciplines of DNA self-assembly with plasmonics and chirality control. As a result it entailed a whole field of chiral plasmonic structures. Without the encounter of Alexander Högele, Sasha Govorov and myself, this would never had happened.
>
> PROFESSOR TIM LIEDL

IMPACT Here, DNA origami was used for the fabrication of self-assembled chiral nanoscopic plasmonic materials that have strong optical activity in the visible range. This work harvested the full potential of DNA origami for controlled 3D assembly of plasmonic nanostructures and introduced “metafluids” with optical properties defined by design.

Nanosized Multifunctional Polyplexes for Receptor-Mediated siRNA Delivery

Christian Dohmen, Daniel Edinger, Thomas Fröhlich, Laura Schreiner, Ulrich Lächelt, Christina Troiber, Joachim Rädler, Philipp Hadwiger, Hans-Peter Vornlocher, and Ernst Wagner

ACS Nano 6 (6), 5198–5208 (2012)

ABSTRACT Although our understanding of RNAi and our knowledge on designing and synthesizing active and safe siRNAs significantly increased during the past decade, targeted delivery remains the major limitation in the development of siRNA therapeutics. On one hand, practical considerations dictate robust chemistry reproducibly providing precise carrier molecules. On the other hand, the multistep delivery process requires dynamic multifunctional carriers of substantial complexity. We present a monodisperse and multifunctional carrier system, synthesized by solid phase supported chemistry, for siRNA delivery in vitro and in vivo. The sequence-defined assembly includes a precise cationic (oligoethanamino)amide core, terminated at the ends by two cysteines for bioreversible polyplex stabilization, at a defined central position attached to a monodisperse polyethylene glycol chain coupled to a terminal folic acid as cell targeting ligand. Complexation with an endosomolytic influenza peptide-siRNA conjugate results in nanosized functional polyplexes of 6 nm hydrodynamic diameter. The necessity of each functional substructure of the carrier system for a specific and efficient gene silencing was confirmed. The nanosized polyplexes showed stability in vivo, receptor-specific cell targeting, and silencing of the EG5 gene in receptor-positive tumors. The nanosized appearance of these particles can be precisely controlled by the oligomer design (from 5.8 to 8.8 nm diameter). A complete surface charge shielding together with the high stability result in good tolerability in vivo and the absence of accumulation in nontargeted tissues such as liver, lung, or spleen. Due to their small size, siRNA polyplexes are efficiently cleared by the kidney.

2012 | 2013 | 2014 | 2015

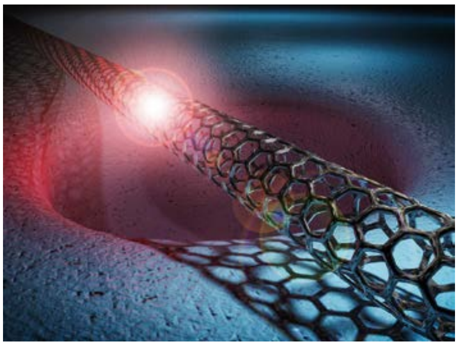
IMPACT This work resulted from a cooperation between the groups of Ernst Wagner (Pharmacy Department) and Joachim Rädler (Faculty of Physics). Beside the highly-cited paper, a patent application was filed together with Roche. Christian Dohmen, PhD student from Ernst Wagner's group, received the attocube research award 2012 for this work. In addition, the project was supported by the m4 network of the BMBF.

Bright, Long-Lived and Coherent Excitons in Carbon Nanotube Quantum Dots

Matthias S. Hofmann, Jan T. Glückert, Jonathan Noé, Christian Bourjau, Raphael Dehmel, and Alexander Högele

Nature Nanotechnology 8, 502–505 (2013)

ABSTRACT Carbon nanotubes exhibit a wealth of unique physical properties. By virtue of their exceptionally low mass and extreme stiffness they provide ultrahigh-quality mechanical resonances, promise long electron spin coherence times in a nuclear-spin free lattice for quantum information processing and spintronics, and feature unprecedented tunability of optical transitions for optoelectronic applications. Excitons in semiconducting single-walled carbon nanotubes could facilitate the upconversion of spin, mechanical or hybrid spin–mechanica degrees of freedom to optical frequencies for efficient manipulation and detection. However, successful implementation of such schemes with carbon nanotubes has been impeded by rapid exciton decoherence at non-radiative quenching sites, environmental dephasing and emission intermittence. Here we demonstrate that these limitations may be overcome by exciton localization in suspended carbon nanotubes. For excitons localized in nanotube quantum dots we found narrow optical lines free of spectral wandering, radiative exciton lifetimes and effectively suppressed blinking. Our findings identify the great potential of localized excitons for efficient and spectrally precise interfacing of photons, phonons and spins in novel carbon nanotube-based quantum devices.



2013 2014 2015 2016

> It was an amazing experience to see the evolution of the project from the first attempts of carbon nanotube synthesis in a Master's thesis project to the controlled realization of suspended nanotubes with unprecedented optical properties.
> PROFESSOR ALEXANDER HÖGELE

IMPACT This work on the exceptional photophysical properties of localized excitons in suspended carbon nanotubes was not only pivotal in securing the ERC Starting Grant 2013 for my research group, it also triggered, at least in part, efforts towards the recent realization of nanotube-based single-photon sources at room temperature and telecom wavelengths[1]. Within collaborative projects at LMU, the nanotubes from our in-house synthesis found applications in optical micro-cavities[2] or were used as truly nanoscaled beam-splitters in electron interferometry[3].

1 X. He et al., Tunable room-temperature single-photon emission at telecom wavelengths from sp3 defects in carbon nanotubes, Nat. Photon. 11, 577–582 (2017).
2 T. Hümmer et al., Cavity-enhanced Raman microscopy of individual carbon nanotubes, Nat. Commun. 7, 12155 (2016).
3 D. Ehberger et al., Highly coherent electron beam from a laser-triggered tungsten needle tip, Phys. Rev. Lett. 114, 227601 (2015).

Microscopic Origin of the '0.7-Anomaly' in Quantum Point Contacts

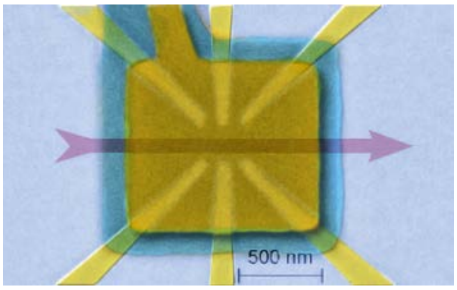
Florian Bauer, Jan Heyder, Enrico Schubert, David Borowsky, Daniela Taubert, Benedikt Bruognolo, Dieter Schuh, Werner Wegscheider, Jan von Delft, and Stefan Ludwig

Nature 501, 73–78 (2013)

ABSTRACT Quantum point contacts are narrow, one-dimensional constrictions usually patterned in a two-dimensional electron system, for example by applying voltages to local gates. The linear conductance of a point contact, when measured as function of its channel width, is quantized in units of $G_Q = 2e^2/h$, where e is the electron charge and h is Planck's constant. However, the conductance also has an unexpected shoulder at $\sim 0.7 G_Q$, known as the '0.7-anomaly', whose origin is still subject to debate. Proposed theoretical explanations have invoked spontaneous spin polarization, ferromagnetic spin coupling, the formation of a quasi-bound state leading to the Kondo effect, Wigner crystallization and various treatments of inelastic scattering. However, explicit calculations that fully reproduce the various experimental observations in the regime of the 0.7-anomaly, including the zero-bias peak that typically accompanies it, are still lacking. Here we offer a detailed microscopic explanation for both the 0.7-anomaly and the zero-bias peak: their common origin is a smeared van Hove singularity in the local density of states at the bottom of the lowest one-dimensional subband of the point contact, which causes an anomalous enhancement in the Hartree potential barrier, the magnetic spin susceptibility and the inelastic scattering rate. We find good qualitative agreement between theoretical calculations and experimental results on the dependence of the conductance on gate voltage, magnetic field, temperature, source–drain voltage (including the zero-bias peak) and interaction strength. We also clarify how the low-energy scale governing the 0.7-anomaly depends on gate voltage and interactions. For low energies, we predict and observe Fermi-liquid behaviour similar to that associated with the Kondo effect in quantum dots. At high energies, however, the similarities between the 0.7-anomaly and the Kondo effect end.

2013 2014 2015 2016

> This was a theory-experiment cooperation with the group of Stefan Ludwig at the chair of Jörg Kotthaus. Together, we were able to explain a phenomenon that had been unexplained for a long time.
>
> PROFESSOR JAN VON DELFT



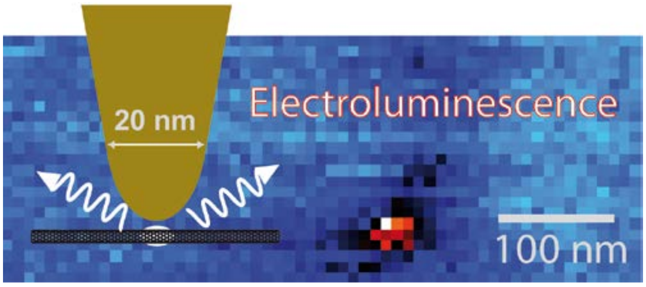
Gate layout of the nanoscale device. Shown is the surface of a GaAs/AlGaAs heterostructure with a high mobility two-dimensional electron system 100 nm beneath the surface. The yellow colored regions are gold gates on the surface including six narrow "side" gates and one large "top" gate. The latter is semitransparent and electrically isolated from the other gates by a thin insulating layer (PMMA, dark shadow). The gates are used to define and finetune a narrow constriction, the quantum point contact, connecting two two-dimensional electrical contacts.

Antenna-Enhanced Optoelectronic Probing of Carbon Nanotubes

Nina Mauser, Nikolai Hartmann, Matthias S. Hofmann, Julia Janik, Alexander Högele, and Achim Hartschuh

Nano Lett. 14, 3773–3778 (2014)

ABSTRACT We report on the first antenna-enhanced optoelectronic microscopy studies on nanoscale devices. By coupling the emission and excitation to a scanning optical antenna, we are able to locally enhance the electroluminescence and photocurrent along a carbon nanotube device. We show that the emission source of the electroluminescence can be pointlike with a spatial extension below 20 nm. Topographic and antenna-enhanced photocurrent measurements reveal that the emission takes place at the location of highest local electric field indicating that the mechanism behind the emission is the radiative decay of excitons created via impact excitation.



2014 2015 2016 2017

> These are the highest-resolved photocurrent and electroluminescence images of an optoelectronic device to date.
> PROFESSOR ACHIM HARTSCHUH

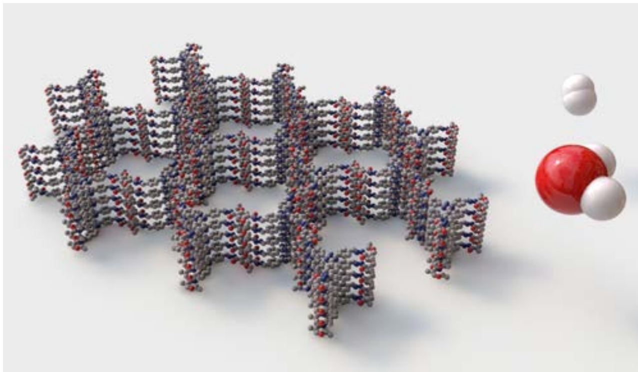
IMPACT This paper showed for the first time that antenna-enhanced microscopy not only provides super-resolution for Raman scattering and photoluminescence but also for photocurrent and electroluminescence images.

A Tunable Azine Covalent Organic Framework Platform for Visible Light-Induced Hydrogen Generation

Vijay S. Vyas, Frederik Haase, Linus Stegbauer, Gökcen Savasci, Filip Podjaski, Christian Ochsenfeld, and Bettina V. Lotsch

Nature Communications 6, 8508 (2015)

ABSTRACT Hydrogen evolution from photocatalytic reduction of water holds promise as a sustainable source of carbon-free energy. Covalent organic frameworks (COFs) present an interesting new class of photoactive materials, which combine three key features relevant to the photocatalytic process, namely crystallinity, porosity and tunability. Here we synthesize a series of water- and photostable 2D azine-linked COFs from hydrazine and triphenylarene aldehydes with varying number of nitrogen atoms. The electronic and steric variations in the precursors are transferred to the resulting frameworks, thus leading to a progressively enhanced light-induced hydrogen evolution with increasing nitrogen content in the frameworks. Our results demonstrate that by the rational design of COFs on a molecular level, it is possible to precisely adjust their structural and optoelectronic properties, thus resulting in enhanced photocatalytic activities. This is expected to spur further interest in these photofunctional frameworks where rational supramolecular engineering may lead to new material applications.



2015 2016 2017 2018

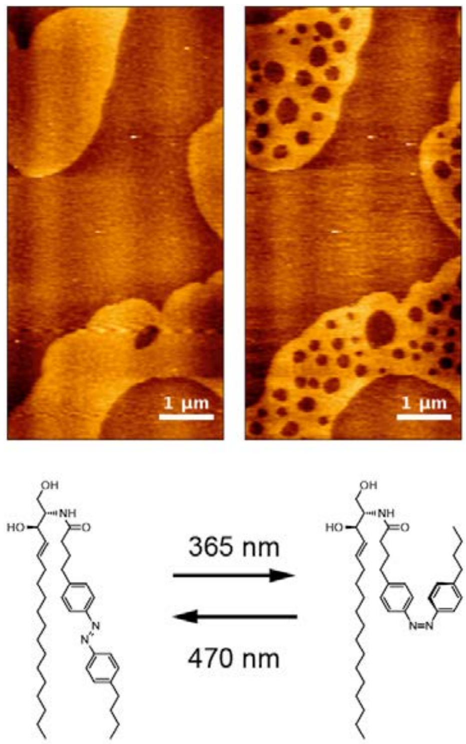
This work gave covalent organic frameworks (COFs) a home in photocatalysis: The marriage of exquisite molecular tunability within a robust heterogeneous backbone set up COFs as a new generation of earth-abundant photocatalysts for the hydrogen evolution reaction. This publication also vividly demonstrates the power of combining experiment and theory to understand complex phenomena in catalysis and beyond. PROFESSOR BETTINA LOTSCH

Control of Lipid Rafts with Photoswitchable Ceramides

James Allen Frank, Henri G. Franquelim, Petra Schwille, and Dirk Trauner

J. Am. Chem. Soc. 138 (39), 12981–12986 (2016)

ABSTRACT Ceramide is a pro-apoptotic sphingolipid with unique physical characteristics. Often viewed as a second messenger, its generation can modulate the structure of lipid rafts. We prepared three photoswitchable ceramides, ACes, which contain an azobenzene photoswitch allowing for optical control over the N-acyl chain. Using combined atomic force and confocal fluorescence microscopy, we demonstrate that the ACes enable reversible switching of lipid domains in raft-mimicking supported lipid bilayers (SLBs). In the trans-configuration, the ACes localize into the liquid-ordered (Lo) phase. Photoisomerization to the cis-form triggers a fluidification of the Lo domains, as liquid-disordered (Ld) "lakes" are formed within the rafts. Photoisomerization back to the trans-state with blue light stimulates a rigidification inside the Ld phase, as the formation of small Lo domains. These changes can be repeated over multiple cycles, enabling a dynamic spatiotemporal control of the lipid raft structure with light.



trans-ACe-1 *cis*-ACe-1

2016 2017 2018 2019

> It has long been suspected that the actual lipid composition of membranes tightly regulates their physical properties, and along with this, their biological functionality. Model membrane systems allow us to visualize the impact of lipid structure on membrane shape and function, but so far it hasn't been possible to reversibly switch the lipid structure in an intact membrane. This very fruitful collaboration between biophysics and chemical biology paves the way for using light as a direct modulator of membrane physiology.
>
> PROFESSOR PETRA SCHWILLE

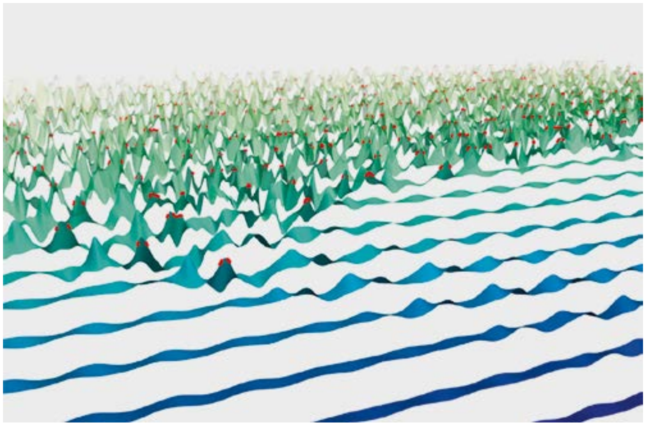
IMPACT The photoswitchable ceramides here developed revealed to be extremely powerful molecules, allowing us for the very first time to control lipid packing in a reversible and spatiotemporal manner using light. Overall, this impactful collaboration (which started within the framework of CeNS) continued, and led to i) the investigation of new photoswitchable sphingolipids for lipid raft optical manipulation (manuscript in preparation), and ii) the optical control of a biological reaction-diffusion system (Glock et al, Angew Chem Int Ed Engl 57 (2018) 2362–2366).

Rethinking Pattern Formation in Reaction-Diffusion Systems

Jacob Halatek and Erwin Frey

Nature Physics 14, 507–514 (2018)

ABSTRACT The present theoretical framework for the analysis of pattern formation in complex systems is mostly limited to the vicinity of fixed (global) equilibria. Here we present a new theoretical approach to characterize dynamical states arbitrarily far from (global) equilibrium. We show that reaction–diffusion systems that are driven by locally mass-conserving interactions can be understood in terms of local equilibria of diffusively coupled compartments. Diffusive coupling generically induces lateral redistribution of the globally conserved quantities, and the variable local amounts of these quantities determine the local equilibria in each compartment. We find that, even far from global equilibrium, the system is well characterized by its moving local equilibria. We apply this framework to *in vitro* Min protein pattern formation, a paradigmatic model for biological pattern formation. Within our framework we can predict and explain transitions between chemical turbulence and order arbitrarily far from global equilibrium. Our results reveal conceptually new principles of self-organized pattern formation that may well govern diverse dynamical systems.



Schematic representation of Min protein patterns at the transition into the chaotic regime.

2018 2019 2020 2021

> This work will fundamentally change how we think about pattern formation in biological systems and beyond. It is a first key step towards a geometric representation of spatio-temporal dynamics in these systems.
> PROFESSOR ERWIN FREY

IMPACT In the same year this paper appeared there were already two papers building on the concepts introduced there.

- MinE conformational switching confers robustness on self-organized Min protein patterns, Jonas Denk, Simon Kretschmer, Jacob Halatek, Caroline Hartl, Petra Schwille, and Erwin Frey, *PNAS* 115 (18), 4553–4558 (2018).
- Self-organization principles of intracellular pattern formation, Jacob Halatek, Fridtjof Brauns, and Erwin Frey, *Phil. Trans. R. Soc.* B 373, 20170107 (2018).

20 Years of CeNS Clean Room

Since the creation of the CeNS statute in 1998, the founding members of the Center for NanoScience have made “the cooperation of different scientific disciplines by sharing knowledge, technologies, facilities and resources” a primary task.

From the very beginning, the clean room at the Kotthaus Chair has been one of the central facilities at the Center for NanoScience. Here, the various scientific disciplines converge by sharing facilities and technologies, develop innovative ideas, collaborate to seek solutions, and finally discover them in close contact with local experts in the respective fields.

The basis for this is two-fold: on the one hand the clean room equipment, and on the other hand the philosophy underlying the clean room use.

The wide-ranging infrastructure — modular and flexible — has always been state-of-the-art. It offers scientists in basic academic research outstanding opportunities to try out or even develop new technologies themselves. Currently, 37 versatile systems and devices for the production and characterization of samples on the micro- and nanometer scale are available to the researchers. Examples include the e-beam and soft lithography, wet or dry etching, and vapor deposition or sputtering of metals and insulators.

But why have the most sophisticated and best equipment if it will not be used? — This is where the philosophy of clean room use comes into play at CeNS: Every scientist, even every advanced student has “open access” to the CeNS clean room and is responsible for producing his or her own samples. However, this only works if the junior researchers are well-instructed in the use of the sometimes very expensive and demanding equipment, and if they handle it carefully and attentively.

If this is taken into account by the users, nothing stands in their way to efficiently produce or optimize complex samples on their own. Anyone who has ever worked in the clean room knows the uplifting feeling of happiness when you see a tiny, self-fabricated nanostructure shine on the screen of the scanning electron microscope at 200,000-fold magnification.

The CeNS clean room serves as a hub for many students from a wide variety of disciplines. Thus, it is a communication platform that promotes collaboration and an interdisciplinary mindset. Currently, 52 people have access to the clean room and can use all facilities and equipment. Over the past 20 years, a total of 106 diploma students, 35 undergraduates, 102 master students, 137 doctoral students, and even 48 postdocs from nine CeNS chairs and 29 CeNS working groups have been trained and educated in nanotechnology.

Many of the group leaders, who have since received a call for a professorship from abroad, still today — sometimes wistfully — think back to the small but refined “CeNS-Reinraum” in which they were able to realize many of their ideas.

Finally, I would like to thank those in charge at the Center for NanoScience for considerable financial support as well as the clean room staff for the reliable and smooth organization of ongoing operations and above all for their commitment to training young researchers.

Dr. Heribert Lorenz
Manager of the clean room laboratory

Third-Party Funding

Many new multidisciplinary research initiatives were established on the fertile soil of CeNS. Some of them were direct descendants of CeNS, such as the Nanosystems Initiative Munich (NIM) Cluster of Excellence, the SFB 1032 Nanoagents, or the International Doctorate Program NanoBioTechnology. In addition, CeNS members coordinate or participate in a range of Collaborative Research Centers (SFBs) as well as further interdisciplinary research projects supported by the BMBF, the Free State of Bavaria, the Volkswagen Foundation, and the European Union, shaping direct links between these initiatives and CeNS. The most prominent examples will be presented briefly in this chapter.

The new funding round of Germany's Excellence Strategy in 2018 has also been very successful for CeNS members. Four Clusters of Excellence submitted by LMU in collaboration with the Technical University of Munich (TUM) have been approved and will receive funding for seven years. Three clusters involve a substantial number of CeNS members: 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. Eleven physicists and chemists from CeNS are part of this initiative. The Origins Cluster of Excellence will study the evolution of the cosmos—from the origin of the universe to the first building blocks of life. This highly interdisciplinary cluster involves six CeNS members working on topics connected to the origin of life. Last but not least, the Munich Center for Quantum Science and Technology (MCQST) aims to further explore the principles of quantum information with a view to the practical application of quantum effects. Six CeNS members from theoretical and experimental physics are participating in this endeavor.

Clusters of Excellence with CeNS Participation (German Excellence Initiative)

Nanosystems Initiative Munich (NIM)

FUNDING PERIOD
2006–2019

COORDINATORS
Prof. Dr. Thomas Bein, CeNS (since 2015)
Prof. Dr. Jochen Feldmann, CeNS (2007–2015)
Prof. Dr. Jörg Kotthaus, CeNS (2006–2007)

INVOLVED CENS MEMBERS
43

INVOLVED INSTITUTIONS
LMU München
TU München
Universität Augsburg
Max Planck Institute of Biochemistry
Max Planck Institute of Quantum Optics
Deutsches Museum
Walther-Meißner-Institute for Low Temperature Research (WMI)
Helmholtz-Zentrum München (2012–2016)
Fachhochschule München (now Hochschule München, 2006–2012)

The Cluster of Excellence "Nanosystems Initiative Munich" (NIM) was among the first scientific clusters to be selected for funding in the initial round of the Excellence Initiative in 2006 and has been successfully renewed for a second funding period in 2012. NIM brings together 64 research groups in the Munich area, covering the fields of physics, biophysics, chemistry, biochemistry, biology, electrical engineering, pharmacy and medicine. NIM merges a broad range of expertise on man-made and biological nanoscale systems into a unique, coherent and focused nanoscience cluster. It has been extremely successful in developing a fundamental understanding and control of nanoscale systems, which range from being dominated by quantum effects to being governed mainly by non-linear and stochastic effects.

Research areas dominated by quantum effects include single-electron and single-spin behavior at low temperatures, nanophotonic experiments, and investigation of practical strategies for quantum computation. Conversion of light to energy and subsequent energy transfer at the nanoscale are being explored by artificial photosynthesis constructs and ordered carbon based interfaces. Moreover, great strides have been made regarding the exploration of extremely sensitive nanosensors and -actuators, both artificial and natural single-molecule machines, nanoscale objects and vehicles in live cells, and drug delivery nanosystems.

These sophisticated experimental studies and technological developments have been complemented by in-depth theoretical investigations of increasingly complex nanosystems in order to create a broad and deep knowledge base, and to establish an exciting research environment that bridges and links traditionally separate disciplines.

nim

Center for Integrated Protein Science Munich (CiPSM)

FUNDING PERIOD
2006–2019

COORDINATOR
Prof. Dr. Thomas Carell, CeNS

INVOLVED CENS MEMBERS
10

INVOLVED INSTITUTIONS
LMU München
TU München
Helmholtz Center München
Max Planck Institute of Biochemistry
Max Planck Institute of Neurobiology

The Munich Center for integrated Protein Science (CiPSM) has become a premier facility for protein research in Germany. The major goal of the cluster is to build up a comprehensive picture of protein functions—as isolated molecules, multisubunit complexes and molecular machines that mediate cell processes. In the first funding period, work at CiPSM focused on the molecular properties of specific proteins. In the second funding period, more emphasis has been placed on understanding their function in cellular networks and on the chemical manipulation of proteins for therapeutic and diagnostic purposes. The Cluster employs a wide range of modern chemical, biochemical, genetic and biophysical methods. In this area the Cluster not only uses and further develops existing methods but has set as a major goal the invention of completely new technologies.

CIPSM

DFG Collaborative Research Centers (SFBs) Connected to CeNS

SFB 486: Manipulation of matter at the nanometer length scale

FUNDING PERIOD

2000–2009

COORDINATOR

Prof. Dr. Hermann Gaub, CeNS

INVOLVED CENS MEMBERS

30

INVOLVED INSTITUTIONS

LMU München
TU München
Universität Augsburg
Max Planck Institute of Biochemistry

This SFB played a key role in the development and in the use of novel molecular tools and models as well as in the investigation of nanoscopic systems from biology, chemistry and physics.

SFB 631: Solid State Based Quantum Information Processing: Physical Concepts and Materials Aspects

FUNDING PERIOD

2003–2015

COORDINATOR

Prof. Dr. Rudolf Gross, TUM

INVOLVED CENS MEMBERS

9

INVOLVED INSTITUTIONS

TU München
LMU München
University of Augsburg
University of Regensburg
Bayerische Akademie der Wissenschaften
Max Planck Institute for Quantum Optics (MPQ)

In this SFB, research activities in the fields of quantum information theory, experimental and theoretical solid state physics, quantum optics, materials science and nanotechnology were co-ordinated, with the goal to develop a deep under-standing of physical concepts of solid state based quantum information processing and to establish the materials and technology basis for a successful implementation of solid state based quantum bits.

SFB 749: Dynamics and Intermediates of Molecular Transformations

FUNDING PERIOD
2007–2019

COORDINATOR
Prof. Dr. Thomas Carell, CeNS

INVOLVED CENS MEMBERS
9

INVOLVED INSTITUTIONS
LMU München
TU München

The researchers of the Collaborative Research Center 749 investigate reaction and folding mechanisms. In all projects chemistry and biochemistry is linked to modern time resolving UV-, fluorescences and IR-spectroscopic methods in order to learn about chemical and biochemical transformations in the domain of time.

SFB 863: Forces in Biomolecular Systems

FUNDING PERIOD
2010–2021

COORDINATOR
Prof. Dr. Matthias Rief, TUM and CeNS

INVOLVED CENS MEMBERS
17

INVOLVED INSTITUTIONS
LMU München
TU München
Max Planck Institute of Biochemistry

The major goal of this collaborative research center is to improve our understanding of force-driven mechanical processes in complex biomolecular networks from the single molecule to the whole cell level.

Forces in SFB 863
Biomolecular Systems

SFB 1032: Nanoagents for the spatiotemporal control of molecular and cellular reactions

FUNDING PERIOD
2012–2020

COORDINATOR
Prof. Dr. Joachim Rädler, CeNS

INVOLVED CENS MEMBERS
19

INVOLVED INSTITUTIONS
LMU München
TU München
Max Planck Institute of Biochemistry

The leading idea of the SFB is to design synthetic biomolecular constructs, nanoagents, which fulfil biomimetic or entirely novel functions. Researchers within the SFB study the artificial combination of molecules, which are capable of carrying out cascaded processes in vitro and investigate how cells react to artificially arranged molecules on surfaces as well as to intracellular nanoagents.

SFB1032 nano agents

Transregio 235: Emergence of life: Explorating mechanisms with cross-disciplinary experiments

FUNDING PERIOD
2018–2022

COORDINATOR
Prof. Dr. Dieter Braun, CeNS

INVOLVED CENS MEMBERS
8

INVOLVED INSTITUTIONS
LMU München
TU München
Helmholtz Center München
Max Planck Institute of Biochemistry
Max Planck Institute for Extraterrestrial Physics
University of Heidelberg
University of Stuttgart

The CRC 235 “Emergence of Life” is a cross-disciplinary network, aiming to experimentally demonstrate a cascade of mechanisms producing life from ordinary matter. The experiments range from the origin of organic molecules, including their long-term survival in rocks or meteorites, volcanic scenarios of molecular synthesis, to the autonomous polymerization and replication of oligonucleotides, the origin of the genetic code, the role of freeze-thaw cycles, mechanisms to amplify chirality, connections to existing metabolic networks and the non-equilibrium chemical physics to form, divide and control protocells.

life CRC 235 Emergence of Life

Collaborative Research Projects Funded by the Free State of Bavaria Connected to CeNS

Bavarian Research Association for Miniaturised Analysis Techniques Using Nanotechnology (ForNano)

FUNDING PERIOD
2002–2004 (Bayerische Forschungsstiftung)

COORDINATORS
Prof. Dr. Jörg P. Kotthaus, Prof. Dr. Christoph Bräuchle, CeNS

INVOLVED CENS MEMBERS
6

INVOLVED INSTITUTIONS
LMU München
TU München
University of Augsburg
University of Würzburg

The scientists in the ForNano research cooperation developed components for analytical laboratories which fit on a thumbnail sized chip, actively researching new methods of analysis that are capable of detecting substances with a high degree of sensitivity using even the tiniest quantities. Alongside the analytical techniques, chips were developed on which liquids can be moved or living cells examined.

Solar Technologies Go Hybrid (SolTech)

FUNDING PERIOD
2012–2022

COORDINATOR
Prof. Dr. Christoph Lambert, Universität Würzburg

INVOLVED CENS MEMBERS
10

INVOLVED INSTITUTIONS
Universität Bayreuth
FAU Erlangen
LMU München
TU München
Universität Würzburg

SolTech is an interdisciplinary project initiated by the Government of Bavaria to explore innovative concepts for converting solar energy into electricity and non-fossil fuels. The SolTech network covers all fields of research on solar energy use, i.e. the conversion of solar energy to electricity for immediate use and the conversion of solar energy into chemical energy for storage and future use. Each of the five universities has set up a well-equipped SolTech key laboratory.

Doctoral Programs with CeNS Participation

International Doctoral Program NanoBioTechnology (IDK-NBT)

FUNDING PERIOD
2004–2012

COORDINATORS
Prof. Dr. Christoph Bräuchle, Prof. Joachim Rädler, CeNS

INVOLVED CENS MEMBERS
49

INVOLVED INSTITUTIONS
LMU München
TU München
Universität Augsburg
Helmholtz Center München

The IDK NanoBioTechnology (IDK-NBT) was an eight-year international doctoral excellence program, administered by the Center for NanoScience. The IDK-NBT offered outstanding graduate students the opportunity to earn their doctoral degree in a stimulating scientific and academic environment providing interdisciplinary research conditions and excellent education. Nanobiotechnology refers to the area of nanotechnology concerned with biological systems, and thus the IDK-NBT involved scientists from biophysics, physical chemistry, biochemistry, biology, and medicine. The program offered students a number of support measures such as administrative support, travel grants, literature grants, and German courses for international students. In addition, doctoral candidates benefited from various scientific events and from co-advisoring. In total, 111 PhD students from 49 CeNS groups participated in the program.

NanoBio Technology
INTERNATIONAL DOCTORATE PROGRAM

Graduate School of Quantitative Biosciences Munich (QBM)

FUNDING PERIOD
2012–2019

COORDINATORS
Prof. Dr. Ulrike Gaul, Prof. Dr. Erwin Frey, CeNS

INVOLVED CENS MEMBERS
8

INVOLVED INSTITUTIONS
LMU München
TU München
Max Planck Institute of Biochemistry

The Graduate School of Quantitative Biosciences Munich (QBM) was founded as part of the German Excellence Initiative. The international PhD training program focuses on communication and collaboration between traditionally separate disciplines, ranging from biochemistry and medicine to bioinformatics, experimental and theoretical biophysics and applied mathematics. With its strong emphasis on anchoring theoretical analysis in advanced quantitative experimentation, and the excellence of the participating scientists, the school has a unique position within the European scientific landscape. The school is home to 93 graduate students, more than half of them having an international background.

QB GRADUATE SCHOOL OF Quantitative Biosciences Munich

Further Doctoral Programs Where CeNS Members Have Been Involved

- Marie Skłodowska-Curie Initial Training Network "MANAS: Manipulation of Matter on the nano-scale" (2003)
- Marie Skłodowska-Curie Initial Training Network "POCAONTAS" (2012–2016)
- Marie Skłodowska-Curie Initial Training Network European School of DNA Nanotechnology (EScoDNA) (2013–2017)
- Marie Skłodowska-Curie Initial Training Network SAW Train (2015–2019)
- DFG-GRK 2062 "Molecular Principles of Synthetic Biology" (since 2015)
- Marie Skłodowska-Curie Initial Training Network DNA Robotics (since 2018)

Funding

- Alexander von Humboldt Foundation
- Bavaria California Technology Center (BaBaTeC)
- Bavarian State Ministry of Sciences, Research and the Arts
- Bavarian-French University Center
- Bayerische Forschungsstiftung
- Bayern Innovativ
- Bayerisches Materialsforschungsprogramm
- Boehringer Ingelheim Fonds
- Carl-Zeiss-Stiftung
- Chinese Scholarship Council (CSC)
- Christiane-Nüsslein-Volhard-Stiftung
- Dr. Klaus Römer-Stiftung
- Dr. Mildred Scheel Stiftung
- EADS
- EMBO Young Investigator Programme
- European Space Agency (ESA)
- European Science Foundation
- European Union/European Research Council (ERC)
- Excellence Initiative of the German Federal Government and the State Governments
- Federal Ministry of Education and Research (BMBF)
- Federal Ministry for Economic Affairs and Energy (BMWi)
- Fonds der Chemischen Industrie
- Friedrich-Baur-Stiftung
- German Academic Exchange Service (DAAD)
- German-Israeli Foundation (GIF)
- German Research Foundation (DFG)
- German Israeli Foundation (GIF)
- Helmut-Fischer-Stiftung
- Human Frontier Science Program (HFSP)
- Innovative Medicines Initiative (IMI)
- Joachim-Herz-Stiftung
- Klaus-Tschira-Stiftung
- Liebig Foundation
- LMUinnovativ
- Max-Planck-Gesellschaft
- Papiertechnische Stiftung (PTS)
- Robert Bosch Foundation
- Simons Collaboration on the Origins of Life
- Sino-German Center
- Stiftung Industrieforschung
- Stiftung der Deutschen Wirtschaft
- Studienstiftung des Deutschen Volkes
- Telekom-Stiftung
- Universität Bayern e.V.
- Verband Deutscher Ingenieure (VDI)
- Verein zur Förderung von Wissenschaft und Forschung
- Volkswagenstiftung
- Wilhelm Sander Stiftung

Interdisciplinary Training and Activities

Events

The Center for NanoScience actively promotes mutual understanding and collaboration between researchers from different disciplines by means of joint seminars, workshops, and schools. Professors, junior group leaders, postdocs, and graduate students interact with each other within this lively network, exchanging scientific ideas and establishing new research collaborations. The topics cover the broad spectrum of nanosciences and nanobiosciences. International exchange programs and soft-skills workshops complete the interdisciplinary program. In addition, the students are encouraged to suggest workshop topics and organize scientific events on their own. Thus, CeNS has been able to offer a comprehensive educational program to its graduate students.

Since 1999, Friday afternoons have been reserved for talks by renowned international speakers and for fruitful discussions within the **CeNS colloquium** (formerly the "Oberseminar"). The joint colloquium of CeNS and the Faculty of Physics aims to foster interdisciplinary exchange and education, and speakers are always invited by several CeNS members to ensure that their research topics are of broad interest to the CeNS community. Coffee, tea, and gummi bears before the talk have become a popular tradition to keep energy levels up.

Right from the beginning, the biennial and later **annual workshops in Venice** with about 100 CeNS participants have been at the heart of CeNS. Venice International University (VIU) provides the perfect setting for this. Founded in 1995, VIU is located on the island of San Servolo, in the building of a former monastery. The small island with its beautiful park, lecture hall, and accommodation in historic buildings is ideally suited for bringing scientists together. At the first workshop in April 1999, the characteristic workshop concept was developed and a broad range of research areas of CeNS was presented. Even within the individual sessions, diverse topics, from nanomedicine to solid state physics, are often mixed.

This differentiates the CeNS workshop from many other topic-focused formats and places relatively high demands on the participants, but it is precisely this format that makes truly interdisciplinary discussions possible. Many speakers, who are attracted by the demanding program and the idyllic location, appreciate this engagement with other topics. For many years, high-ranking speakers, including several Nobel Prize winners such as Konstantin Novoselov, Gerd Binnig, and Ben Feringa, to mention just a few, have accepted the invitation to participate. The five-day program leaves room for scientific discussions, which have been the starting point for new collaborations—be it in the coffee breaks, during the poster sessions or during lunch with a view of the Venetian lagoon. Not only for the group leaders, but also for the PhD students of the various CeNS groups the workshop is a great opportunity to get to know each other better and learn from each other. Most of the CeNS associates attend the workshop at least once during their PhD. Last but not least, the shared train journey from Munich and, of course, Venice itself are always a special experience.

In 2001, the first **CeNS winter school** "Current Issues of Nano-Bio-Science" with about 100 participants was organized in cooperation with SFB 486 and SFB 513 in Mauterndorf, Austria. From a 2018 perspective, the list of speakers is more than impressive, comprising Viola Vogel, Ned Seeman, Cees Dekker, Steven Quake, Joachim Spatz, and later CeNS member Petra Schwille, to name just a few. The densely packed scientific program was divided into a morning and an evening session, leaving some afternoon hours for skiing and even ski-racing.

Castle Mauterndorf remained the place-to-be in the following years—the 2003–2007 CeNS winter schools were held there biennially. In 2009, the first joint winter school of CeNS, SFB 486 NanoMan, and the NanoSystems Initiative Munich (NIM) cluster of excellence was organized in St. Anton, Arlberg. From 2011 to 2017, winter schools were organized by NIM, giving CeNS the opportunity to make the Venice workshops an annual event.

The end of the summer term is always marked by a special seminar: **CeNS meets Industry**. On this day, about six invited speakers from different business sectors present their work, their company, and their professional career to members from CeNS and other interested students. It is fascinating to see how many different career options actually exist—from the more obvious ones, such as in R&D or as a product manager in large companies, e.g. Toptica, Roche, BMW or Wacker, to more unusual ones in start-up companies, the publishing sector, science journalism, or even organ building. Many speakers are CeNS alumni, making their presentations even more true-to-life for the participants.

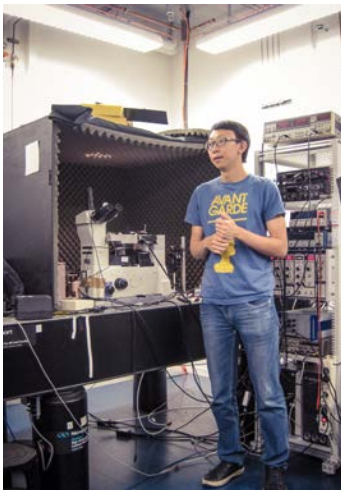
The talks are followed by the presentation of the Nano Innovation Award winners of the year and the traditional CeNS summer party in the Salinenhof—a perfect and relaxed way to meet other CeNS members and alumni and to celebrate the start of the semester break.

Beside these regular events, CeNS and CeNS members have also organized or co-organized a wide range of thematically more **focused workshops**. A few examples are the biennial workshops on "Advanced Fluorescence Imaging and Dynamics" organized by Don Lamb; the student-organized workshop "Energy and Innovation" with the IDK NanoBioTechnology in 2011; the workshop "Probing and Manipulating Biomolecules: From Single Molecules to an Ensemble" organized by Hermann Gaub with researchers from Israel in 2012; or the DNA22 workshop organized by Tim Liedl, Friedrich Simmel, Ralf Jungmann, and Hendrik Dietz in 2016. In addition, technical workshops and seminars on topics such as TEM, Bayesian data analysis, MatLab, or LabVIEW were an integral part of the CeNS calendar.

CeNS Junior Scientists

Nanoscience research is extraordinarily diverse and interdisciplinary. PhD students in these areas must be open-minded and engaged and must constantly acquire new expertise and technical know-how from a variety of disciplines. It has therefore been one of CeNS' most important tasks right from the start to strengthen interdisciplinary exchange and to promote networking between early career researchers by means of various events. However, to avoid the often rigid structures of "graduate schools" with compulsory courses etc., CeNS above all promotes the involvement and active collaboration of all participants.

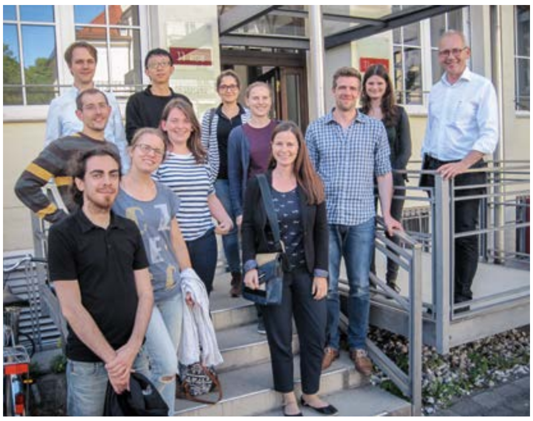
Every junior member of a CeNS group — master's student, PhD student or postdoc — can register as a "CeNS Associate" and benefit from all CeNS offers — be it participating in various workshops, company visits, and exchange programs, or the opportunity to apply for a CeNS Travel Award for attending conferences. These low-threshold offers are very well received, and so the group of associates has grown steadily from the beginnings of CeNS to around 300 today.



Since 2013, the CeNS associates have had a voice to the outside — the CeNS student representatives. The three representatives are elected annually through an online poll. They represent the interests of the associates to the CeNS Board and the CeNS management and are actively involved in the organization of various events. Thus, new series of events are established regularly: "Science in a Nutshell" with lectures by doctoral students and postdocs on various topics from CeNS; CeNS lab tours, where participants get to know the topics and labs of different CeNS groups; visits to CeNS spin-off companies and other companies in the region, and much more. Approximately twice a year, the Student Representatives also invite speakers to the CeNS colloquium, which is accompanied by a shared home-cooked lunch and a subsequent journal club. In addition, a three-day winter retreat for the associates in Kleinwalsertal was initiated.

A special seminar series is the student-organized Science Rocks! initiated by Tim Liedl and Alexander Högele in 2010. Junior researchers from the Faculties of Physics and Chemistry present fascinating aspects of their doctoral research to their peers in an entertaining way.

All of these activities help bring the associates together across the boundaries of their groups and faculties, and create links for new collaborations. CeNS thus serves as a multidisciplinary platform for students and postdocs, allowing access to a large range of research topics, techniques, and expertise.



International Exchange

International Recruiting — the Quest for the Best

From 2008 onwards, PhD positions within the International Doctorate Program in NanoBio-Technology (2004-2012) were advertised internationally and, thanks to the LMU-GraduateCenter, online applications were made possible. These measures led to a significant increase in the number of international applicants. The then established selection procedure served as a best-practice model for application rounds coordinated by CeNS after the end of the IDK. Every CeNS member can advertise open PhD and even postdoc positions in his group and profit from central advertisement, a standardized application procedure, and pre-selection by formal criteria by the CeNS management. The further application process comprises phone interviews and finally an invitation to a selection workshop in Munich. In the last ten years, this process has proven to be efficient, transparent, and useful for both PIs and applicants. Moreover, it has strengthened CeNS' visibility worldwide. Once the international students get started in Munich, they are further supported in administrative issues such as visa applications, enrolment at LMU etc. by program manager Marilena Pinto.

International Networking Activities

Although CeNS is based in Munich, the activities of the network reach well beyond the borders of the city and the country. Intensive contacts to other researchers from all over the world are of the utmost importance not only to the senior scientists, but especially to the junior members of CeNS. Thus, graduate and undergraduate students benefit strongly from early scientific and personal exchange with leading scientists world-wide. Over the past two decades, CeNS has organized regular events like the annual workshop in Venice with strong participation of international speakers, but also joint international workshops such as the 2004 CNSI-CeNS Workshop at the California NanoSystems Institute Santa Barbara. On the initiative of Jochen Feldmann and Andrey Rogach, CeNS graduate students participated in a joint Winter School with the National Institute for Nanotechnology in Edmonton, Canada in 2007. A more recent joint event was the 2014 International Physics of Living Systems Network (iPoLS) Annual Meeting initiated by Don Lamb (LMU) and Zan Luthey-Schulten (UIUC). The meeting was organized by CeNS and SFB1032 and attended by about 200 international participants. This meeting has been the starting point for a regular and ongoing exchange with the US-based Physics of Living Systems Network. In 2019, the iPoLS meeting will take place in Munich for the second time, hosted by Don Lamb and Philip Tinnefeld (CeNS and SFB 1032).

Global Challenges Workshops

A very special meeting was initiated by Hermann Gaub (CeNS) and Christoph Gerber (Swiss Nanoscience Institute) in 2008: an intensive workshop on "Global challenges and how nanotechnology can help". The Swiss Nanoscience Institute (SNI, former NCCR Nano) and CeNS invited young researchers from around the world to Venice International University, San Servolo, to discuss issues of global importance and to initiate a global network. The group consisted of about 50 advanced PhD students and postdoctoral researchers from China, India, Iran, Japan, Pakistan, Russia, Africa, South America, USA, and Europe. In the three-day workshop, the participants identified existing and upcoming global challenges where nanotechnology as a key technology of this century could play a leading role. In the course of the workshop, the junior researchers finally defined central questions and ideas where nanotechnology could provide solutions.

In 2013, a second workshop entitled "Global Challenges — opportunities for nanotechnology" took place on San Servolo. The organizers, Hermann Gaub, Kavli-Award winner Christoph Gerber, and Daniel Müller from ETH Zürich, invited four additional nanotechnology experts to support the participants: Two Nobel laureates, Jean-Marie Lehn and Gerd Binnig, Viola Vogel (the former US presidential nanotechnology advisor) and Adi Scheidemann, a nanotechnology entrepreneur, brought their detailed knowledge and know-how to the discussions. A summary booklet of each workshop was sent to stakeholders in science and politics to raise awareness for future technological solutions.

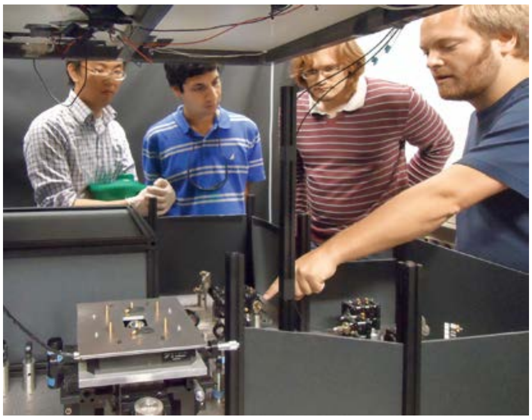
The 2008 and 2013 workshops were realized with substantial external financial support. The first workshop was supported by the National Center of Competence in Research Nanoscience (NCCR Nano) Switzerland. In 2013, the Klaus Tschira Stiftung and the European Science Foundation (ESF) under the EUROCORES Programme generously contributed to this endeavor.

Junior Nanotech Network (JNN)

Exchange of knowledge and collaboration between highly-skilled specialists can lead to top-level research and new scientific developments. While this is a generally accepted statement, it is especially true for nanoscience, an area of research that is interdisciplinary by nature and often relies on merging the expertise of curious scientists from diverse fields, such as physics, chemistry, biology and material sciences. Ways of nurturing scientific exchange can differ but the common method is to organize meetings, at which established researchers present their latest achievements. However, CeNS has been striving to supplement this with another approach that involves the engagement and drive of young and enthusiastic students. The Junior Nanotech Network (JNN) was initiated by Professor Hermann Gaub in 2006 as a collaboration between CeNS and partners at McGill University in Montreal. It has continued with several international partners every two years since.

The unusual and unique program is strongly focused on an intensive exchange on both a scientific and a cultural level — students from both parties are hosts in their labs as well as at their homes. This guarantees strong interactions between all participants and reduces the need for third-party funding. About ten PhD students from each institution individually plan and realize experiments to introduce their research to one another, and spend two weeks each rotating through the laboratories of their foreign counterparts. This direct exchange of knowledge and expertise between PhD students is extremely efficient. Maybe more importantly, it gives students a chance to explore new techniques, solidify their own skills by teaching them to others, and look at their own research and the research of others with fresh eyes.

The success of the JNN stems directly from the diligence, enthusiasm, and open-mindedness of its participants. The students spend many extra hours in their laboratories, host their visiting counterparts in their homes, and give their free time to organize guided trips on the weekends. By opening their labs and sharing their ideas, the participating PIs implement the spirit of open access and scientific exchange on all levels that fosters excellent research. The hospitality and the scientific openness of all partners, both junior and senior, have made the JNN exchanges a true success and an invaluable experience for the participants. The networks that have been formed as a result will aid the students in their further scientific and personal development.



Exchange Programs

The JNNs were financially supported by “Bayern-Québec” by the Bayerisch-Französisches Hochschulzentrum, the BMBF via the International Bureau, the Bavaria California Technology Center, the Deutsch-Israelische Projektkooperation, the DFG via the SFB1032, UCSB’s Materials Research Laboratory, the Californian NanoSystems Institute, and the NSF Physics Frontier Center CPLC and NFS iPoLS grants.

Table 2 — JNN partner institutions

2006 and 2008 McGill University
organized by Prof. Hermann Gaub and Prof. Peter Grutter

2010 Center for the Physics of the Living Cell (CPLC), University of Illinois at Urbana-Campaign
organized by Prof. Philip Tinnefeld, Prof. Klaus Schulten, and Prof. Taekjip Ha

2012 Californian NanoSystems Institute (CNSI), Santa Barbara
organized by Prof. Tim Liedl, Prof. Alexander Holleitner, and Prof. Deborah Fygenson

2013/14 Center for Nanoscience and Nanotechnology, Tel Aviv University
organized by Prof. Hermann Gaub and Prof. Yael Hanein

2015 University of California Santa Barbara
organized by Prof. Tim Liedl and Prof. Omar Saleh

2017/2018 Center for the Physics of the Living Cell (CPLC), University of Illinois at Urbana-Campaign
organized by Prof. Jan Lipfert, Prof. Alek Aksimentiev, and Prof. Zan Luthey-Schulten

In 2009, the Center for NanoScience set up a cooperation agreement for PhD students with the Doctoral Program of the Bristol Centre for Functional Nanomaterials (BCFN) at the University of Bristol. Based on this reciprocal exchange arrangement, each year, one to two doctoral students from each center had the opportunity to spend three weeks in the labs of the respective partner institution to learn new research techniques and perform experiments. In the framework of an ERASMUS agreement, CeNS and the Swiss Nanoscience Institute at the University of Basel (Switzerland) exchange Bachelor and Master’s students who spend between 3 to 6 months at the respective partner university.
In 2011, CeNS member Andrey Rogach initiated a cooperation with the College of Science and Engineering at the City University of Hong Kong. Since then, undergraduate students have had the opportunity to spend one semester in Hong Kong.

Life at CeNS

CeNS brings together doctoral students and senior researchers not only scientifically but also socially. The two annual highlights in the CeNS calendar, the summer party and the get-together party in late November, are an important part of this.

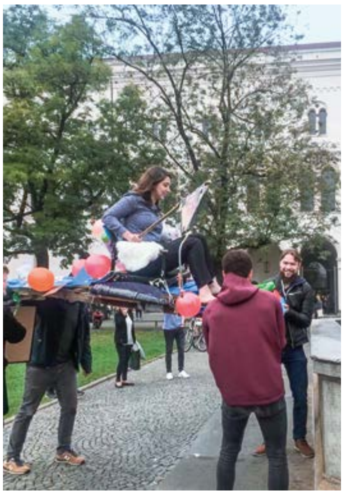
The CeNS summer party takes place in the beautiful Salinenhof on the LMU main campus. Over the years, the party has become a true tradition, starting with the tapping of the beer keg by the CeNS spokesman. Every year about 130 people, professors and students alike, come together after the event “CeNS meets Industry”, and celebrate the winners of the Nano Innovation Award and the completion of the summer semester. Since 2008, the CeNS band “unCeNSiert” has entertained the CeNS guests, helping to create the perfect relaxed party atmosphere. The band, led by Dr. Martin Benoit, consists of ever new researchers from CeNS and students from the LMU physics department, who play music in New Orleans, Klezmer, and Bavarian style.

After the CeNS Annual Assembly at the end of November, the CeNS researchers and alumni gather in the Café at the University (CadU) for an evening of life music by the CeNS band and the presentation of the annual CeNS publication awards. The cozy atmosphere makes the get-together a perfect event for meeting former colleagues and members of different CeNS groups.

A special tradition is also the doctoral celebrations at the Faculty of Physics. After passing the exam, the doctoral students are carried by their colleagues in a home-made palanquin to the fountain in front of the LMU main building where they receive their “scientific baptism”.

About twice a year, the CeNS management arranges a home-cooked lunch for CeNS graduate students and members. This event is usually combined with a peer-to-peer discussion or a journal club with a renowned invited speaker and gives the students an opportunity to exchange ideas and discuss them with each other.

Further activities, such as football matches, the “CeNSation” team at the B2Run company competition in Munich, or skiing at the winter schools help to create a true CeNS community spirit.



CeNS in Public

In the past years, CeNS has presented current topics and developments in nanoscience to the public on multiple occasions. For example, CeNS and its spin-off Advalytix were part of the first Munich Science Days in 2004, a four-day event with about 30,000 visitors and with annually changing topics. Between 2004 and 2017, young scientists from CeNS (mostly together with NIM) presented topics such as "Designing the Future with Nano" or "Nanoparticles—Tiny but Full of Energy!" at the Munich Science Days.

Numerous CeNS members gave talks in lectures open to the public, such as "Wissenschaft für Jedermann" in the Deutsches Museum, "Physik Modern", or the "Münchner Kinderuni". Other activities included the organization of events such as "Nano and the Public" in collaboration with the Institute of Technology Theology (TTN) at LMU, and a CeNS and NIM booth "Ois is Nano!" on nanoscience at the celebration of the 850th anniversary of the City of Munich.

In the exhibition "Kunst^{-9} — nano mal anders", nanoscientists from CeNS and NIM provided insights into a world that is otherwise hidden from our eyes. Images from the nanometer scale were exhibited in the underground gallery of the subway stop "Universität" in 2010. Some images were later selected for the exhibition "nanoArt from Germany" and were shown in the German Center for Research and Innovation in New York and in Japan. Last but not least, the CeNS calendar with current research images from the laboratories of the CeNS groups has been sent to hundreds of recipients all over the world and has helped to increase the visibility of the research at CeNS.

Technology Transfer

CeNS Spin-offs: 20 Years of Active Start-ups

The establishment of the Center for NanoScience was driven by the scientific challenges of nanoscience and the desire to create a culture of interdisciplinary collaboration within the university. Looking back over the past twenty years, we can proudly record an overwhelming success in the application of scientific inventions and the establishment of 14 spin-off companies by CeNS members. But were these start-up ideas planned and predictable? Did researchers at CeNS even focus on industry-related research in the first place? The answer is probably neither of the above. Instead, nanoscience is an undertaking that demands the crossing of borders and innovative solutions, and thus contains inherent economic opportunities. On the other hand, the establishment of CeNS coincided with a start-up friendly investment environment and increasing state funding. Last but not least, the Center for NanoScience also played its part in sensitizing the new generations of doctoral students to entrepreneurship and supporting the founders with advice and technical infrastructure.

The first spin-offs (Advalytix, attocube, ibidi, Nanoscape and Nanion) started in 2000–2002 as part of the Munich business plan competition. Due to the successes in this competition (Advalytix, attocube – award winners 2001), the start-ups became more visible and investors or business angels could be acquired. After the dot-com bubble burst, which was followed by insecurity and the accompanying caution in the new markets, the climate for start-ups became harsher. It was not until 2007–2010 that a second wave of new spin-offs, Neaspec, ChromoTek, NanoTemper, Baseclick, ethris, and GNA Biosolutions, followed. This was triggered by newly initiated public start-up programs that helped these spin-offs to survive the cliffs of the early start-up phase.

The CeNS spin-offs all developed positively and today altogether have more than 600 employees. It is noteworthy that almost all companies are still run by the founders today. Only two companies, Advalytix and NanoScape, were sold. The success of the companies also received nationwide attention. The numerous awards included the "Deutscher Gründerpreis" (attocube 2008, nanion 2009, and Nanotemper 2014), the "Deutscher Innovationspreis" (NanoTemper 2012, ibidi 2013), and the STEP Award (Nanion 2009, NanoTemper 2012). Nanion also reached the final round of the German Future Award 2016 (Deutscher Zukunftspreis), awarded by the German Federal President.

We hope that the success story of innovative spin-offs will continue in the future. Recently, a third wave of founders has emerged. GATTAquant (2014, Tinnefeld Group) was founded, and other teams are in the pre-startup phase. In particular, start-up projects are currently running in the groups of Heinrich Leonhardt (Tubulis Technologies, Exits Grant 2017 and Leibniz Founder Award 2018), Oliver Thorn-Seshold (CytoSwitch, FLÜGGE Grant 2016 and Exist Grant 2018, and with Petar Marinkovic NanoCapture, GO-Bio Award 2018), Ralf Jungmann (DEOXY, GO-Bio Award 2018), and Philipp Paulitschke (PHIO, FLÜGGE Grant 2016 and Exist Grant 2018). The very high success rate in FLÜGGE, EXIST and BMBF funding is also a direct consequence of the helpful support provided by the Spin-Off Service of the LMU Technology Transfer.

According to the founders, the environment of CeNS has helped them in many ways. Over the years, CeNS has established a training program for doctoral students that provides both science-oriented education and the transferable skills necessary to take advantage of opportunities in academic research. The events that shed light on the application and economic aspects of research include regular patent workshops, as well as the annual event "CeNS meets Industry" since 2000. In addition, the cooperation with the LMU Entrepreneurship Center, which offers entrepreneurship seminars for CeNS associates, should be acknowledged here. In addition, the “Münchner Industriegespräche” have been held in cooperation with the German Physical Society since 2013.

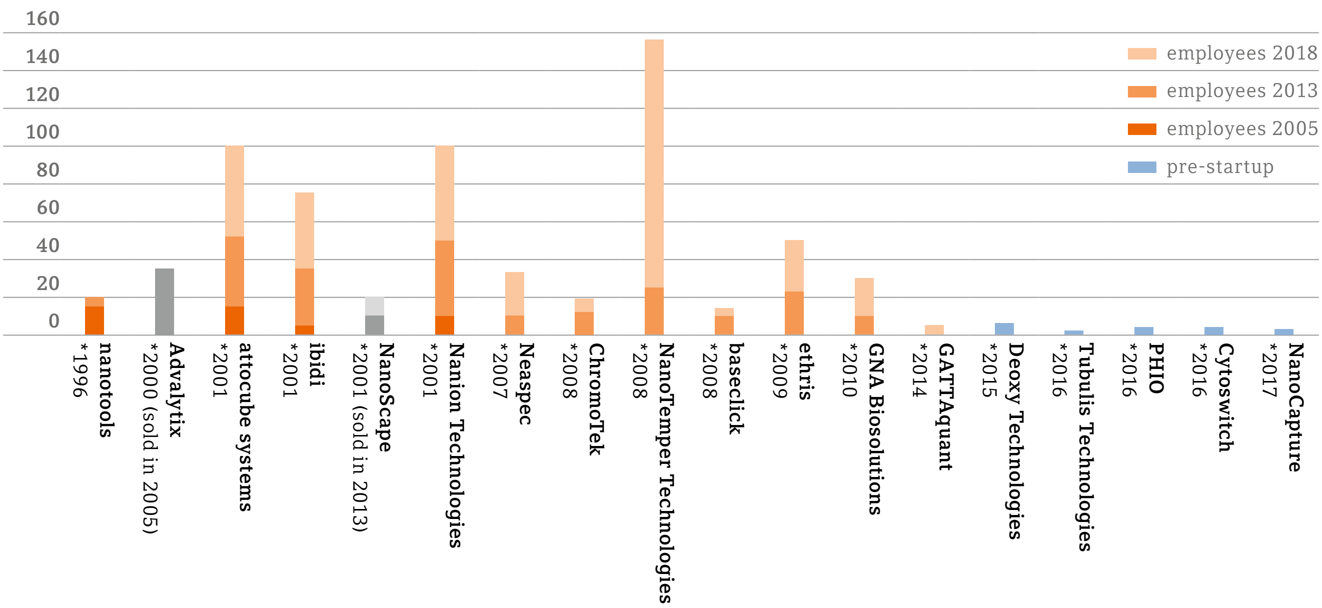
Meanwhile, the CeNS spin-offs have become popular employers for CeNS alumni, and we are proud of the success of many former CeNS associates who are contributing to the achievement of nanotechnology within the spin-off companies. Moreover, the companies are partners in scientific projects and active supporters of CeNS: From 2009 to 2013, attocube donated an award for the best master’s and doctoral thesis at CeNS. Since 2015, this prize has been generously sponsored jointly by attocube, Nanion, NanoTemper, and ibidi.

Very recently, NanoTemper, together with CeNS and the LMU Spin-off Service, received the DPG Technology Transfer Award 2019. This award illustrates that for the successful realization of innovative ideas in products, not only an idea, but also a fertile environment are of great importance. CeNS has shaped this environment over the past 20 years.

On the following pages, ten companies founded by CeNS members will be presented in more detail. Looking at these success stories, I would like to express my gratitude to all founders and CeNS scientists involved, for their openness, their entrepreneurial spirit, and their ongoing support of the idea of CeNS.

Prof. Dr. Joachim Rädler
CeNS board member 2002–2006,
Spokesman of CeNS 2012–2014

Figure 1 — **Headcount of spin-offs and pre-startups from CeNS groups**



nanotools GmbH

FOUNDED BY
Dr. Bert Lorenz, Dr. Martin Wendel, Dr. Bernd Irmer, Klaus Werhahn, Armin Kriele

FOUNDING YEAR
1996

CEO
Dr. Bernd Irmer

EMPLOYEES
18

LOCATION
München

TECHNOLOGY
FEBIP (electron beam induced processing), nano-MEMS

MARKET
Semiconductor industry

AWARDS
McKinsey Business Plan Competition

NANOTOOLS IN BRIEF
nanotools designs, develops and mass-produces high quality nano-MEMs components. Taking advantage of our patented electron beam processing, 3D structures are directly formed in diamondlike material quality, with ultra-high precision and reproducibility. Founded and based in Munich/Germany in 1996 we have constantly extended our core competences in the field of nanofabrication and have achieved scale as one of the leading experts in the production of atomic force microscopy (AFM) tips. Since more than 20 years, we supply the world’s leading semiconductor, nanoelectronics and metrology system suppliers.

Advalytix AG

FOUNDED BY
Prof. Dr. Achim Wixforth, Dr. Jürgen Scriba, Eckart Neuhaus, and Dr. Christoph Gauer

FOUNDING YEAR
2000

CEO
Dr. Christoph Gauer

EMPLOYEES
35 (2005)

LOCATION
München

TECHNOLOGY
Acoustic-driven microfluidics, biochips, lab-on-a-chip

MARKET
Point-of-care diagnostics, pharma research, academic research

AWARDS
Bavarian Innovation Award 2002: Recognition Award; Innovation Award 2002 of Volksbanken and Raiffeisenbanken in Bavaria; 1. BioTrends Award 2003 for Achim Wixforth and Advalytix; Innovation Award for Medical Engineering 2007 of the BMBF for Matthias Schneider and Advalytix; C.B. Sawyer Memorial Award 2011 for Achim Wixforth and Advalytix

ADVALYTIX
Advalytix AG developed solutions for single cell molecular diagnostics, and the miniaturisation of diagnostic and biological tests for research and development. Advalytix offered a portfolio of products for these applications, based on proprietary microelectronics technologies, such as surface acoustic waves (SAW). As of March 2005, Advalytix AG operated as a subsidiary of Olympus Life and Material Science Europa GmbH. In 2007, parts of Advalytix were acquired by Beckman Coulter Beckman Coulter (USA).

ibidi GmbH

FOUNDED BY
Dr. Roman Zantl, Dr. Valentin Kahl, Dr. Ulf Rädler, and Prof. Dr. Joachim Rädler

FOUNDING YEAR
2001

CEOS
Dr. Roman Zantl, Dr. Valentin Kahl

EMPLOYEES
75

LOCATION
Martinsried

TECHNOLOGY
Functional (phenotypic) cell-based assays. Systems imply native environment for analyzing living cells. Cell biochips, reagents, and equipment for analyzing living cells.

MARKET
The ibidi product lines are sold worldwide to customers in scientific institutions, industrial pharmacology, and biotechnology. ibidi's products are also used in the field of immunocology.

AWARDS
Germany Land of Ideas 2016; Winner in the 2012/13 German Economy Innovation Award Competition; 2012 Deloitte Technology Fast 50; 2011 Top 10 finalist in the "STEP Award" competition

IBIDI IN BRIEF
ibidi GmbH, a spin-off from TUM and CeNS at LMU Munich, is a leading supplier of functional cell-based assays and advanced products for cell microscopy. The company develops cutting-edge solutions for classic cell culture, as well as complex assays (e.g., angiogenesis, chemotaxis, and wound healing). The primary business idea was to produce microfluidic cell chambers for use in microscopy. With unique cell biochips made from high-performance polymers, ibidi has pioneered the use of plastic as a material for bio-slides that can be used to simulate an organ-like environment. Over the past 17 years, ibidi has managed to become the leading international provider of disposables for cell-based microscopy assays — a fact that has been acknowledged in more than 15,000 scientific publications.

attocube systems AG

FOUNDED BY
Prof. Dr. Khaled Karrai, Dr. Dirk Haft

FOUNDING YEAR
2001

CEOS
Peter Kraemer, Dr. Martin Zech

EMPLOYEES
100

LOCATIONS
München (headquarters), New York, Berkeley

TECHNOLOGY
Components and systems for nanoscale applications at extreme environments

MARKET
Scientific analysis, synchrotrons, quality assurance & control, precision engineering

AWARDS
Bavarian Innovation Award 2006; German Startup Award 2008; Deloitte Fast 50 (2008, 2009, 2010); Bavarian Award for Medium-Sized Businesses; TOP100 Innovation Award 2013

ATTOCUBE IN BRIEF
As a pioneer in the field of nanotechnology applications, attocube systems is the partner of choice for cutting edge solutions for industry and research. The portfolio includes nanopositioners, an ultra-precise displacement sensor as well as microscope and cryostat systems, all of which work at the limit of what is technically and physically feasible. The products are compatible with extreme environmental conditions such as ultrahigh vacuum, high magnetic fields, radiation exposure, as well as cryogenic to elevated operating temperatures. The far superior technology is revolutionizing existing applications and guarantees lasting competitive advantages for customers.

CeNS was the birth cradle of attocube. The spirit of the company "DNA" is certainly very much CeNS inspired and this explains the close ties both organizations enjoy today. CeNS and attocube both share the pioneering spirit that permeate their members and this makes the partnership so natural. When attocube was able to "stand on its legs and walk" it contributed back by bringing to life the actual CeNS nano award which in turn emulated several CeNS startups to join in the action. That was the beginning of a long friendship … PROF. KHALED KARRAI

Nanion Technologies GmbH

FOUNDED BY
Dr. Niels Fertig, Prof. Dr. Robert Blick, and Prof. Dr. Jan Behrends

FOUNDING YEAR
2001

CEOS
Dr. Niels Fertig (CEO), Dr. Andrea Brüggemann (CSO), and Michael George (CTO)

EMPLOYEES
100

LOCATIONS
München (headquarters), Peking, Livingston (US), Newark (US), Tokio

TECHNOLOGY
Automated Electrophysiology, Cell-based Assays, Membran Protein Analysis (Ion Channels and Transporters)

MARKET
Drug Discovery, Safety Pharmacology, Drug Screening, Academic Research

AWARDS
Deutscher Gründerpreis 2009, Step Award 2009; Nominated for Deutschen Zukunftspreis 2007 and 2014

NANION IN BRIEF
Nanion Technologies is a leading provider of instrumentation for ion channel drug discovery and screening. Founded in 2002, Nanion has grown over the last 16 years to a company with over 100 employees worldwide. With headquarters in Munich, Germany, Nanion has subsidiaries in the USA, Denmark, Japan and China, as well as distribution partners in seven other countries. The Nanion team has developed and successfully established four generations of automated patch clamp instruments for sophisticated and high throughput applications in ion channel research and drug discovery.

For us at Nanion, CeNS not only is advancing science and contributing cutting edge scientific research, but also created an incredibly inspiring environment with lots of entrepreneurial spirit. Nanion wouldn't have been founded without that environment and spirit, and hence our founders are deeply rooted in and still today feel strongly connected to CeNS. To me, CeNS with all its many spin offs and startup success stories is the perfect breeding ground for early startup days, sort of a pre-incubator! DR. NIELS FERTIG

neaspec GmbH

FOUNDED BY
Prof. Dr. Rainer Hillenbrand, Dr. Fritz Keilmann, Dr. Nenad Ocelic

FOUNDING YEAR
2007

CEO
Dr. Stefan Schiefer

EMPLOYEES
33

LOCATION
Haar

TECHNOLOGY
Nanoscale analytics with background-free optical, infrared and THz near-field microscopy

MARKET
Academic materials research; semiconductor, chemical, pharma, solar, biotech industries

AWARDS
Münchner Business Plan Wettbewerb; Microscopy Today Innovation Award; Step Award; Prism Award; iF DESIGN AWARD; Deloitte Technology Fast 50 Award

NEASPEC IN BRIEF
neaspec has gained worldwide attention for commercializing its proprietary NeaSNOM nanoscope in 2007. The leading experts of near-field microscopy at the Max-Planck-Institute of Biochemistry combined the best of two worlds, the nanoscale resolution of atomic force microscopy (AFM) with the analytical power of visible, infrared and THz imaging & spectroscopy. At up to 10.000-times better resolution compared to conventional optical/infrared imaging, NeaSNOM revolutionizes light microscopy and enables novel nano-analytics such as chemical identification, plasmon-field mapping and free-charge-carrier mapping.

By joining CeNS (2001) our research gained from communication with enthusiastic nanoscientists, and spinning-off benefitted from CeNS entrepreneurs. We now collaborate with CeNS groups and see CeNS as a crucial local academic partner for testing ideas, finding personnel, and exploring new opportunities of our nano-scale analytic platform, biology being one example. DR. FRITZ KEILMANN

NanoTemper Technologies GmbH

FOUNDED BY
Dr. Stefan Duhr and Dr. Philipp Baaske

FOUNDING YEAR
2008

CEOS
Dr. Stefan Duhr and Dr. Philipp Baaske

EMPLOYEES
156

LOCATIONS
München (headquarters), San Francisco, Boston, Cambridge (UK), Peking, São Paulo, Bangalore, Krakau, Kopenhagen

TECHNOLOGY
Optical, biophysical characterisation techniques such as MST (MicroScale Thermo Optics), nanoDSF, backreflection

MARKET
Pharma research, biotechnology, academic research

AWARDS
German Innovation Award 2012; Deutscher Gründerpreis 2014; TOP100 Innovator 2017 and 2018; DPG Technology Transfer Award 2019

NANOTEMPER IN BRIEF
NanoTemper Technologies is a globally operating high-tech company that develops, produces and markets technologies and instruments for biomolecular analytics. The company was started in 2008 after Stefan Duhr and Philipp Baaske met in the group of Prof. Dieter Braun at CeNS/LMU. The company's focus is on high quality products made in Germany that enable researchers to easily, efficiently, and accurately perform protein characterization. With a broad offering of systems, software and consumables for evaluating binding affinities, protein stability and protein quality, NanoTemper has become the partner of choice for thousands of researchers worldwide in pharmaceutical and biotechnology industries as well as in academic settings.

Ethris GmbH

FOUNDED BY
Dr. Carsten Rudolph and Prof. Dr. Christian Plank

FOUNDING YEAR
2009

CEOS
Dr. Gita Dittmar, Dr. Carsten Rudolph, and Prof. Dr. Christian Plank

EMPLOYEES
50

LOCATION
Planegg

TECHNOLOGY
Stabilized non-immunogenic mRNA (SNIM® RNA), polymer and lipid nanoparticles for inhalational mRNA therapy

MARKET
Pharma research, biotechnology

AWARDS
GO-Bio Award 2011

ETHRIS IN BRIEF
Ethris GmbH is a leading innovation company in the emerging field of mRNA biopharmaceuticals. Stabilized non-immunogenic messenger RNAs (SNIM® RNAs) contain the genetic information for the production of therapeutic proteins directly in the patient's body. Ethris has developed nanoparticle ferries that can deliver SNIM® RNAs to cells in diseased tissue. Based on these platform technologies, Ethris develops so-called mRNA transcript therapies for serious diseases. In the broad field of possible applications, Ethris has specialized in lung diseases and intends to develop a therapy for primary ciliary dyskinesias for the first time. Currently, there are no therapeutic options for these rare genetic diseases.

GNA Biosolutions GmbH

FOUNDED BY
Dr. Joachim Stehr, Dr. Federico Bürsgens, and Dr. Lars Ullerich

FOUNDING YEAR
2010

CEOS
Dr. Joachim Stehr, Dr. Federico Bürsgens, and Dr. Lars Ullerich

EMPLOYEES
30

LOCATION
Martinsried

TECHNOLOGY
Pulse Controlled Amplification

MARKET
Diagnostics, nucleic acid analysis

AWARDS
First or first group placements: Münchener Businessplan Wettbewerb; German Venture Award; Science4Life; Disruptive Technology Award (AACC)

GNA BIOSOLUTIONS IN BRIEF
GNA Biosolutions is a molecular technology company based in Martinsried, Germany. Our breakthrough technology, Pulse Controlled Amplification, is based on local heating of nanometer to micrometer scaled structures. It transforms molecular testing by combining ultrafast nucleic acid amplification with intrinsic sample preparation, to enable powerful solutions for the diagnostic laboratory and on-site applications. The Center for NanoScience was not only the scientific starting point for our endeavor — all its previous start-ups were highly inspirational for our own entrepreneurial path. For us, CeNS stands for scientific excellence and successful technology transfer.

The Center for NanoScience was not only the scientific starting point for our endeavor — all its previous start-ups were highly inspirational for our own entrepreneurial path. For us, CeNS stands for scientific excellence and successful technology transfer. DR. LARS ULLERICH

GATTAquant GmbH

FOUNDED BY
Dr. Jürgen Schmied, Dr. Carsten Forthmann, Dr. Max Scheible, and Prof. Dr. Philip Tinnefeld

FOUNDING YEAR
2014

CEO
Dr. Jürgen Schmied

EMPLOYEES
5

LOCATIONS
Hiltpoltstein, München

TECHNOLOGY
DNA nanotechnology, super-resolution microscopy

MARKET
Manufacturer and users of high- and super-resolution fluorescence microscopes

AWARDS
optecnet Startup Challenge (2016); KfW Gründerchampion (Landessieger, 2016); TUBS Entrepreneurship Award (2016); IHK Technologietransferpreis (2017)

GATTAQUANT IN BRIEF
GATTAquant develops calibration and test samples for fluorescence microscopy, with a focus on products for super-resolution techniques. Starting from the concept of so-called nanometer rulers based on DNA origami nanotechnology, published in 2009 by Tinnefeld (LMU) and Simmel (TUM), we were able to develop a broad product portfolio of such test samples, serving as a simple positive control to test, optimize and monitor the resolution of microscopes. Based on the same technology, fluorescent beads were presented as a new product category in 2016. They are ideal for calibrating fluorescence microscopes and are superior in many respects to competing products. Meanwhile, GATTAquant has become a much valued partner for microscope manufacturers and users around the world.

CeNS has been the framework in which the different disciplines (microscopy / DNA nanotechnology) came together and finally led to our crossover products. DR. CARSTEN FORTHMANN

Facts and Figures

CeNS Members

Founded in September 1998 at the Faculty of Physics, the Center for NanoScience has grown steadily ever since *(see table 3)*. The six "ordentliche" (ordinary) founding members (Jochen Feldmann, Hermann Gaub, Jörg Kotthaus, Khaled Karrai, Johann Peisl and Wilhelm Zwerger) were joined at that time by 17 "außerordentliche" (extraordinary) members, above all young junior research group leaders.

Soon members of the Faculty of Chemistry joined CeNS and expanded the CeNS network. Over time, members of other faculties who were interested in the interdisciplinary cooperation in CeNS filled up the ranks *(see table 4)*. In addition, the CeNS network serves as a link in the Munich area to colleagues at the TUM, the University of Augsburg, the Deutsches Museum, the Munich University of Applied Sciences and the MPI who can join CeNS as extraordinary members *(see figure 2)*.

Due to their excellent scientific achievements, many CeNS members received calls to German and foreign universities *(see figure 3)*, in total more than 60 to date. While most of these calls have been accepted and are natural steps in the careers of young scientists, most of these colleagues continue to be associated with CeNS as extraordinary CeNS members and continue their fruitful collaborations. Other members have continued their research at CeNS and LMU, despite calls to other universities, which is very pleasing. And some, such as Philip Tinnefeld and Thorben Cordes, have returned to LMU and CeNS after a few years away.

An essential part of CeNS are the junior researchers, doctoral students, masters and postdocs *(see figure 4)*. The about 300 "CeNS associates" make up a large fraction of the CeNS community. With their cutting-edge research and their numerous activities, they contribute significantly to the success of CeNS.

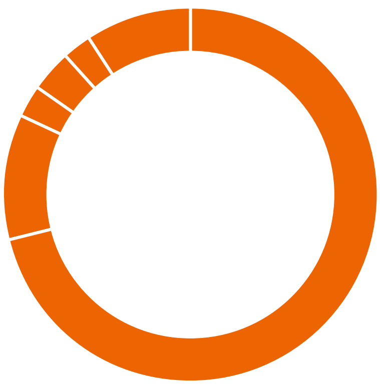
Table 3 — **CeNS memberships 1998–2018**

Year	Ordinary Members	Extraordinary Members	Total
1998	6	15	21
2002	13	33	46
2006	19	57	76
2010	30	74	104
2014	28	73	101
2018	39	67	104

Table 4 — **Faculties**

Faculty	CeNS members
Physics	56
Chemistry	21
Medicine	4
Biology	4
Pharmacy	5
other	13

Figure 2 — **CeNS members' and associates' affiliations**



LMU	284
TUM	43
Uni Augsburg	12
MPI	14
Hochschule München	10
Other	36

Figure 3 — Appointments of CeNS members (2000–2018)

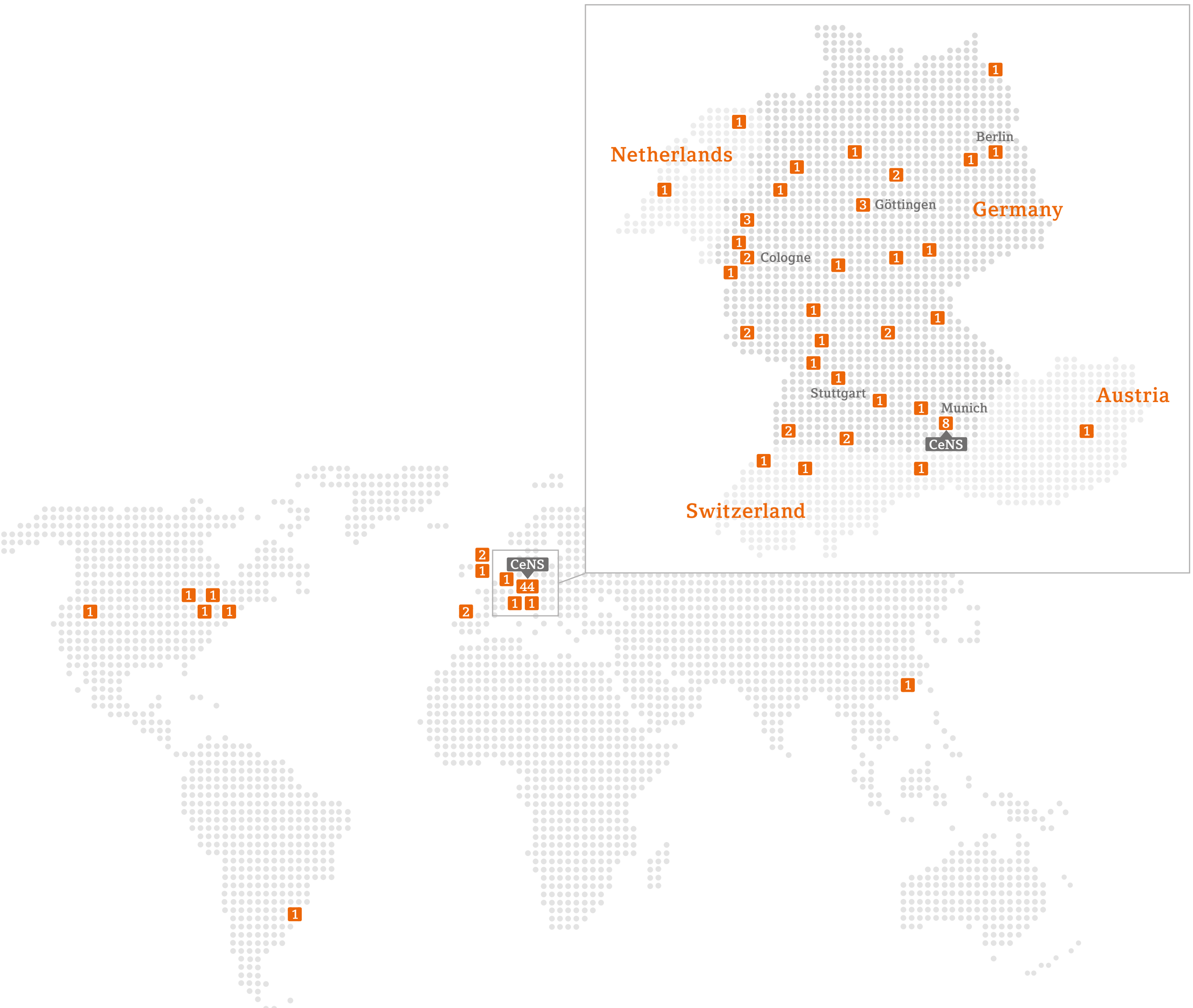
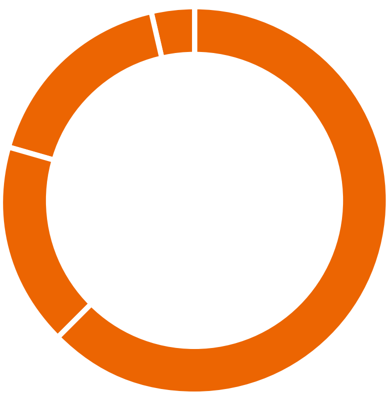


Figure 4 — CeNS members' and associates' qualification level



Graduate students	250
Junior group leaders & postdocs	68
Professors	67
Spin-off companies & Technicians	14

Table 5 — **Ordinary members (2018)**

CeNS member	Affiliation	Research topic	Member since
Prof. Dr. Thomas Bein	LMU Faculty of Chemistry and Pharmacy	Cellular and Molecular Biophysics	1999
Prof. Dr. em. Christoph Bräuchle	LMU Faculty of Chemistry and Pharmacy	Physical Chemistry	1999
Prof. Dr. Dieter Braun	LMU Faculty of Physics	Systems Biophysics	2004
Prof. Dr. Chase Broedersz	LMU Faculty of Physics	Theoretical Statistical & Biological Physics	2015
Prof. Dr. Thomas Carell	LMU Faculty of Chemistry and Pharmacy	Nucleic Acid Chemistry	2004
Prof. Dr. Thorben Cordes	LMU Faculty of Biology	Physical and Synthetic Biology	2009
Prof. Dr. Jochen Feldmann	LMU Faculty of Physics	Photonics and Opto-electronics	1998
Prof. Dr. Erwin Frey	LMU Faculty of Physics	Statistical and Biological Physics	2004
Prof. Dr. Hermann Gaub	LMU Faculty of Physics	Biophysics and Molecular Materials	1998
Prof. Dr. Ulrike Gaul	LMU Faculty of Chemistry and Pharmacy	Systems Biology of Gene Regulation	2010
Prof. Dr. Achim Hartschuh	LMU Faculty of Chemistry and Pharmacy	Nanooptics	2006
Prof. Dr. Alexander Högele	LMU Faculty of Physics	Nanophotonics	2009
Prof. Dr. Ralf Jungmann	LMU Faculty of Physics	Molecular Imaging and Bio-nanotechnology	2014
Prof. Dr. Khaled Karrai	attocube	Solid State Physics	1998
Prof. Dr. Roland Kersting	LMU Faculty of Physics	THz Spectroscopy	2004
Prof. Dr. em. Jörg P. Kotthaus	LMU Faculty of Physics	Nanophysics	1998
Prof. Dr. Don C. Lamb	LMU Faculty of Chemistry and Pharmacy	Fluorescence Applications in Biology	2003
Prof. Dr. Heinrich Leonhardt	LMU Faculty of Biology	Human Biology and Bio-imaging	2006
Prof. Dr. Tim Liedl	LMU Faculty of Physics	Molecular Self-Assembly and Nanoengineering	2009
Prof. Dr. Rasmus Linser	LMU Faculty of Chemistry and Pharmacy	NMR Spectroscopy	2016
Prof. Dr. Jan Lipfert	LMU Faculty of Physics	Molecular Biophysics	2013
PD Dr. Theobald Lohmüller	LMU Faculty of Physics	Plasmonics and Nano-chemistry	2011

Table 5 — **Ordinary members (2018)**

CeNS member	Affiliation	Research topic	Member since
Prof. Dr. Bettina Lotsch	LMU Faculty of Chemistry and Pharmacy	Nanochemistry	2009
PD Dr. Bert Nickel	LMU Faculty of Physics	X-ray Diffraction and Electronics	2004
Prof. Dr. Christian Ochsenfeld	LMU Faculty of Chemistry and Pharmacy	Theoretical Chemistry	2010
PD Dr. Madeleine Opitz	LMU Faculty of Physics	Ecology of Bacterial Communities	2010
Prof. Dr. Matthias Punk	LMU Faculty of Physics	Strongly Correlated Quantum Systems	2015
Prof. Dr. Joachim Rädler	LMU Faculty of Physics	Soft Condensed Matter Physics	2001
PD Dr. Markus Rehberg	LMU Faculty of Medicine	In vivo Microscopy	2013
Prof. Dr. Ulrich Schollwöck	LMU Faculty of Physics	Theoretical Nanophysics	2009
Prof. Dr. Petra Schwille	Max-Planck-Institut für Biochemie	Cellular and Molecular Biophysics	2013
Prof. Dr. Philip Tinnefeld	LMU Faculty of Chemistry and Pharmacy	Single Molecule Techniques	2007
Prof. Dr. Oliver Trapp	LMU Faculty of Chemistry and Pharmacy	Organic Chemistry	2018
Prof. Dr. Alexander Urban	LMU Faculty of Physics	Nanospectroscopy	2015
Prof. Dr. Claudia Veigel	LMU Faculty of Medicine	Cellular Physiology	2010
Prof. Dr. Jan von Delft	LMU Faculty of Physics	Theoretical Solid State Physics	2001
Prof. Dr. Ernst Wagner	LMU Faculty of Chemistry and Pharmacy	Pharmaceutical Biotechnology	2005
Prof. Dr. Thomas Weitz	LMU Faculty of Physics	Physics of Nanosystems	2015
Prof. Dr. Joost Wintterlin	LMU Faculty of Chemistry and Pharmacy	STM of Surface Reactions	2005

Table 6 — **Extraordinary members (2018)**

CeNS member	Affiliation	Member since
Dr. Tayebeh Ameri	LMU Faculty of Chemistry and Pharmacy	2018
Dr. Martin Benoit	LMU Faculty of Physics	2001
Dr. Hanna Engelke	LMU Faculty of Chemistry and Pharmacy	2015
Dr. Heinrich Grabmayr	LMU Faculty of Physics	2018
Dr. Robert Grummt	LMU Faculty of Physics	2018
Dr. Fritz Keilmann	LMU Faculty of Physics	2001
Dr. Ulrich Lächelt	LMU Faculty of Chemistry and Pharmacy	2017
Dr. Heribert Lorenz	LMU Faculty of Physics	1998
Stephan Manus	LMU Faculty of Physics	1998
Dr. Petar Marinkovic	LMU Faculty of Chemistry and Pharmacy	2018
Dr. Christof Mast	LMU Faculty of Physics	2017
Dr. Philipp Paulitschke	LMU Faculty of Physics	2014
Dr. Lakshminarayana Polavarapu	LMU Faculty of Physics	2018
Dr. Petra Rovó	LMU Faculty of Chemistry and Pharmacy	2018
Dr. Jacek Stolarczyk	LMU Faculty of Physics	2015
Dr. Oliver Thorn-Seshold	LMU Faculty of Chemistry and Pharmacy	2016
Dr. Johannes Wöhrstein	LMU Faculty of Physics	2018
Prof. Dr. Andreas Bausch	TUM Faculty of Physics	2006
PD Dr. Anna Cattani-Scholz	TUM Faculty of Physics	2016
Prof. Dr. Hendrik Dietz	TUM Faculty of Physics	2010
Prof. Dr. Ulrich Gerland	TUM Faculty of Physics	2003
Prof. Dr. Alexander W. Holleitner	TUM Faculty of Physics	2004
Prof. Dr. Oliver Lieleg	TUM Department of Mechanical Engineering	2012
Prof. Dr. Peter Müller-Buschbaum	TUM Faculty of Physics	2013
Prof. Dr. Christian Plank	TUM Faculty of Medicine	2009
Prof. Dr. Matthias Rief	TUM Faculty of Physics	2003
Prof. Dr. Friedrich Simmel	TUM Faculty of Physics	2002
Prof. Dr. Marc Tornow	TUM Department of Electrical and Computer Engineering	2004
Prof. Dr. Peter Hänggi	Universität Augsburg Faculty of Physics	2002
Prof. Dr. Hubert Krenner	Universität Augsburg Faculty of Physics	2011
Dr. Christoph Westerhausen	Universität Augsburg Faculty of Physics	2016
Prof. Dr. Achim Wixforth	Universität Augsburg Faculty of Physics	1998
Prof. Dr. Wolfgang Heckl	Deutsches Museum	2009

Table 6 — **Extraordinary members (2018)**

CeNS member	Affiliation	Member since
PD Dr. Markus Lackinger	Deutsches Museum	2006
Dr. Frank Trixler	Deutsches Museum	2008
Prof. Dr. Hauke Clausen-Schaumann	Hochschule München	2002
Dr. Ferdinand Jamitzky	Leibniz-Rechenzentrum	2003
Dr. Dirk Haft	attocube systems AG	2003
Dr. Zeno Guttenberg	ibidi GmbH	2001
Dr. Valentin Kahl	ibidi GmbH	2002
Dr. Roman Zantl	ibidi GmbH	2011
PD Dr. Stefan Thalhammer	Heidenhain GmbH	2001
Dr. Niels Fertig	Nanion Technologies GmbH	2002
Dr. Philipp Baaske	NanoTemper Technologies GmbH	2011
Dr. Stefan Duhr	NanoTemper Technologies GmbH	2010
Dr. Bernd Irmer	nanotools GmbH	2005
Prof. Dr. Andrey Rogach	City University Hong Kong	2002
Prof. Dr. Christina Scheu	MPI for Eisenforschung	2008
PD Dr. Stefan Ludwig	Paul-Drude-Institut für Festkörperelektronik	2004
Prof. Dr. Gregor Cevc	The Advanced Treatments Institute	2016
Prof. Dr. Matthias Schneider	TU Dortmund	2007
Prof. Dr. Dina Fattakhova-Rohlfing	Universität Duisburg-Essen	2016
Prof. Dr. Jan Behrends	Universität Freiburg	1998
Prof. Dr. Irmgard Frank	Universität Hannover	1999
Prof. Dr. Thomas Franosch	Universität Innsbruck	2006
Prof. Dr. Lukas Schmidt-Mende	Universität Konstanz	2011
Prof. Dr. Eva Weig	Universität Konstanz	2008
Prof. Dr. John Lupton	Universität Regensburg	2002
Prof. Dr. Ulrich Rothbauer	Universität Tübingen	2009
Prof. Dr. Jens Michaelis	Universität Ulm	2003
Prof. Dr. Manfred Ogris	Universität Wien	2009
Prof. Dr. Thomas Franke	University of Glasgow	2009
Dr. Stefan Wuttke	University of Lincoln	2013
PD Dr. Ján Minár	University of West Bohemia	2017

Awards

Prizes, Recognitions and ERC Grants

The high quality of the scientific work at CeNS is reflected by the large number of awards and distinctions awarded to CeNS associates and members. Since 1998, CeNS PhD students have been awarded four times the "Promotionspreis" of the Munich University Society, which is awarded annually for the six best dissertations at LMU. At the Faculty of Chemistry, numerous CeNS doctoral candidates and postdocs have been honored with the Dr. Klaus Römer-Awards. In addition, CeNS associates received various prizes for outstanding research at international conferences. These awards are an expression of the excellent skills and dedication of all CeNS Associates.

Many prestigious awards went to the senior CeNS members, and only a few of them can be mentioned here as examples. The Gottfried Wilhelm Leibniz Prize of the DFG was awarded to Jochen Feldmann (2001), Thomas Carell (2004), and Patrick Cramer (2006), the Federal Cross of Merit to Jörg Kotthaus (2001), Jochen Feldmann (2001), Wolfgang Heckl (2008), Thomas Carell (2010), and Patrick Cramer (2012). Jochen Feldmann and Ulrich Lemmer (1999), Thomas Carell (2006), and Patrick Cramer (2007) received the Philip Morris Research Award.

Particular successes have also been achieved by the younger CeNS members, some of whom will be listed here. The Max Auwärter Prize 2006 went to John Lupton, and the Walter Schottky Prize of the German Physical Society (DPG) 2009 to Florian Marquardt. Jens Michaelis received the 2010 Nernst-Haber-Bodenstein-Award from the German Bunsen Society, Dieter Braun the Klung-Wilhelmy-Weberbank-Prize 2011 and Carsten Grashoff (MPI of Biochemistry) the Leopoldina Early Career Award 2014. All these prizes are explicitly addressed to young scientists under the age of 40.

In addition, the CeNS scientists were particularly successful in winning the prestigious ERC Grants. A total of 29 ERC grants from all categories were awarded to CeNS members between 2009 and 2018, 20 alone to LMU *(see table 7)*.

The efforts of the CeNS members in the field of teaching should also be underlined. Joost Wintterlin (2009) and Christian Ochsenfeld (2016) received the Teaching Award at Bavarian Universities. Jan Lipfert was awarded the Teaching Prize of the Chemistry and Biochemistry Department in 2018.

Last but not least, CeNS has established a range of its own awards. The annual CeNS publication award distinguishes excellent publications from co-operation projects within CeNS as well as outstanding research of individual research groups in the categories "Best Interdisciplinary Publication", "Scientific Breakthrough" and "Best Junior Scientist Publication". The number of excellent submissions has been steadily rising, which results in a demanding selection process. In 2018, three Science papers and three publications in Nature journals were selected by the CeNS board. Since 2013, the Center for NanoScience has been announcing a limited number of Travel Awards for LMU CeNS associates. The travel awards are granted for active participation (talk or poster) in a scientific conference or workshop.

Table 7 — **ERC grants at LMU**

CeNS member	Year
Advanced Grant	
Dieter Braun	2018
Thomas Carell	2017
Thomas Bein	2012
Hermann Gaub	2011
Jochen Feldmann	2010
Dirk Trauner	2010
Patrick Cramer	2010
Consolidator Grant	
Tim Liedl	2018
Alexander Högele	2017
Proof of Concept Grant	
Ralf Jungmann	2017
Starting Grant	
Alexander Urban	2017
Michael Nash	2016
Ralf Jungmann	2015
Bettina Lotsch	2014
Alexander Högele	2013
Tim Liedl	2013
Achim Hartschuh	2011
Dieter Braun	2010
Philip Tinnefeld	2010
Jens Michaelis	2009

From fundamental research to application: Attocube Research Award and CeNS Innovation Award

In 2009, the CeNS spin-off attocube systems AG and CeNS established a new kind of award for junior scientists: the attocube Research Award. While most scientific prizes honor achievements in fundamental research, this award focused particularly on innovative ideas and the potential applicability of excellent research. Prof. Khaled Karraï from attocube had a clear motivation for sponsoring this specific award: "It is essential for attocube to promote the interdisciplinary exchange between science and industry, thus opening up new potentials which will create opportunities we can't even detect today. The attocube Research Award rewards young scientists opening up their minds to application-oriented approaches and facilitating the exchange of different disciplines."

The prize money reflected the significance of the award: The winner in the "PhD thesis" category won €5,000 and the supervising laboratory received €10,000 for its contribution to the successful thesis. In the "Master's thesis" category, the prize money was €2,500. The winners were chosen by a jury composed of three professors from CeNS and a representative from attocube systems. The scientific background of the submitted applications has always been broad—from quantum technology to nanomedicine, nanomaterials, or DNA origami. Due to this diversity and the high quality of applications, the jury chose to share the annual award between multiple winners on several occasions.

A few years later, the basis of the attocube Research Award was broadened and it was transformed into the CeNS Innovation Award. Three further CeNS spin-offs (ibidi, Nanion Technologies, and NanoTemper Technologies) joined attocube and together they have sponsored the award with €10,000 since 2015. In addition, the jury was expanded to include an external member from industry, a member from another university, and one representative from the four sponsoring spin-offs. Two years later, the award was opened to applicants from all Bavarian research institutions and became the Nano Innovation Award. These measures led to a significant increase in the numbers of applications—and made it even harder for the jury to select the winners from the many excellent candidates.

The Nano Innovation Award fosters the balance between high-quality fundamental research and real life applications that may arise from cutting-edge laboratory work. As such, the award perfectly reflects the philosophy of CeNS. We are grateful to attocube systems, ibidi, Nanion technologies, and NanoTemper Technologies for their continued generous support.

Table 8 — **attocube Research Award and CeNS/Nano Innovation Award 2009–2018: Awardees**

Year	Category	Name	Group
2009	Diploma thesis	Sebastian Stapfner	Eva Weig (LMU)
2009	PhD thesis	Elias Puchner	Hermann Gaub (LMU)
2009	PhD thesis	Qian Huihong	Achim Hartschuh (LMU)
2010	Diploma thesis	Thomas Faust	Eva Weig (LMU)
2010	PhD thesis	Jan Vogelsang	Philip Tinnefeld (LMU)
2010	PhD thesis	Franz Weinert	Dieter Braun (LMU)
2012	Master’s thesis	Adriano de Andrade Torrano	Christoph Bräuchle (LMU)
2012	PhD thesis	Christian Dohmen	Ernst Wagner (LMU)
2013	Master’s thesis	Friederike Möller	Dieter Braun (LMU)
2013	Master’s thesis	Eva-Maria Roller	Tim Liedl (LMU)
2013	PhD thesis	Johann Feckl	Thomas Bein (LMU)
2013	PhD thesis	Thomas Faust	Eva Weig/Jörg Kotthaus (LMU)
2015	Master’s thesis	Aurora Manzi	Jochen Feldmann (LMU)
2015	PhD thesis	Christof Mast	Dieter Braun (LMU)
2017	Master’s thesis	Florian Schüder	Ralf Jungmann (LMU)
2017	PhD thesis	Stefan Datz	Thomas Bein (LMU)
2017	PhD thesis	Peter Röttgermann	Joachim Rädler (LMU)
2017	PhD thesis	Patrick Vogel	Peter Jacob (Universität Würzburg)
2018	Master’s thesis	Konstantin Ditzel	Philipp Paulitschke (LMU)
2018	PhD thesis	Klaus Wagenbauer	Hendrik Dietz (TUM)

NANO INNOVATION AWARD 2018

Imprint

Contact

Center for NanoScience
LMU Munich
Schellingstrasse 4
80799 Munich
■ www.cens.de

Scientific Board

Prof. Dr. Dieter Braun (spokesman)
Prof. Dr. Tim Liedl
Prof. Dr. Ulrich Schollwöck
Prof. Dr. Philip Tinnefeld
Prof. Dr. Claudia Veigel

Management

Dr. Susanne Hennig
Phone +49-89-2180-5791
E-mail ■ hennig@cens.de

V.i.S.d.P.

Dr. Susanne Hennig

Editors

Prof. Tim Liedl and Dr. Susanne Hennig

Layout and Typesetting

Sebastian Lehnert, Leipzig
■ www.deskism.com

Isabel Zeiselmair, Munich (pages 6–13, 75)
■ www.locomoto.de

Printing

FIBO Druck, Neuried

Published

January 2019

Photo Credits

Page 3: LMU Munich
Page 5: Christoph Hohmann (NIM)
Page 6: CeNS, Advalytix, AG Jörg Kotthaus
Page 7: CeNS, Nanion
Page 8: CeNS, AG Jörg Kotthaus, NIM
Page 9: CeNS, neaspec
Page 10: CeNS, AG Jochen Feldmann/AG Andrey Rogach, private photograph Christian Westermeier, Christoph Hohmann (NIM)
Page 11: CeNS, Audrey Fischer, Philipp Paulitschke
Page 12: CeNS, Christoph Hohmann (NIM), AG Bettina Lotsch
Page 13: CeNS, Petra Rovó, AG Ralf Jungmann, AG Thomas Bein
Page 14: Private photograph Jörg Kotthaus
Page 30: CeNS
Page 31: Christoph Hohmann (NIM)
Page 34: Christoph Hohmann (NIM)
Page 37: Christoph Hohmann (NIM)
Page 38: Marilena Pinto, Christoph Hohmann (NIM)
Pages 48–56: CeNS and private photographs
Page 50: Christoph Hohmann (NIM)
Page 58: Christoph Hohmann (NIM)
Page 61: Christoph Hohmann (NIM)
Page 62: Private photograph Bernd Irmer
Page 63: Advalytix
Page 64: ibidi
Page 65: attocube
Page 66: Nanion
Page 67: Private photograph Fritz Keilmann
Page 68: NanoTemper
Page 69: Ethris
Page 70: GNA Biosolutions
Page 71: Gattaquant
Page 80: Christoph Hohmann (NIM), CeNS
Page 82: Christoph Hohmann (NIM)

www.cens.de