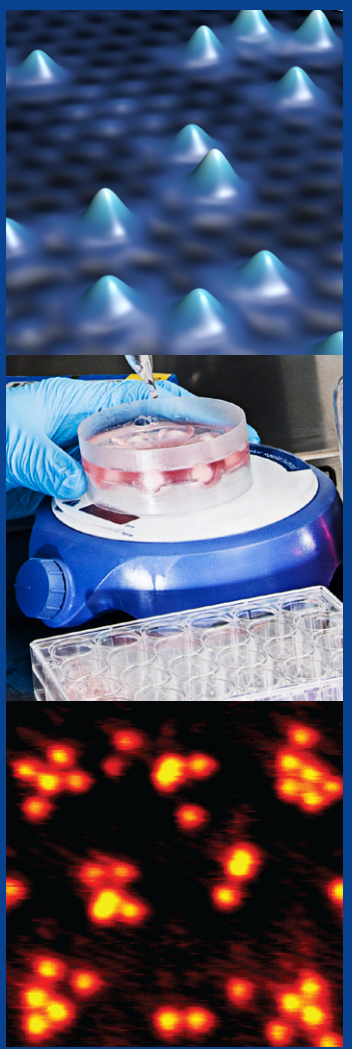
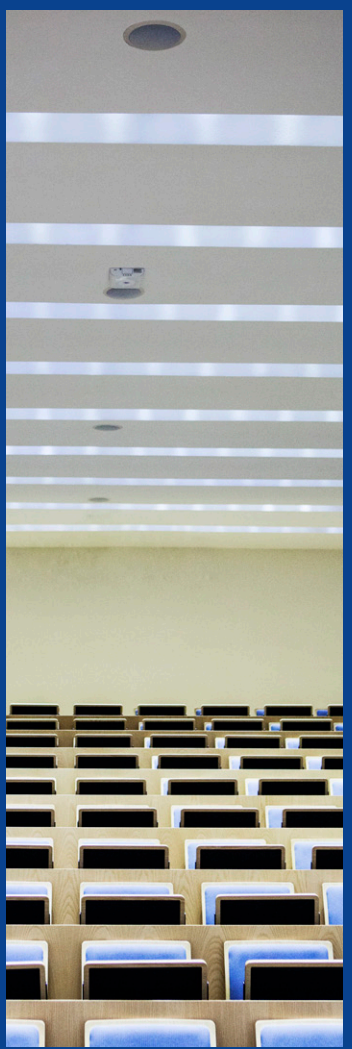
AARHUS
UNIVERSITY

# iNANO
# ANNUAL REPORT
# 2012

EDUCATION · RESEARCH · INNOVATION



iNANO

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# CONTENTS

As of February 2012, I took over the position as Director of the iNANO Center, following in the footsteps of Proffessor Flemming Besenbacher, who was elected as Chairman of the Board of Trustees of Carlsberg Brewery. In spite of his engagement in Carlsberg, Flemming Besenbacher is still active within the research community, both internationally and here at iNANO. I am completely confident that Prof.Flemming Besenbacher will be able to further strengthen Carlsberg Brewery's position as one of the world's largest breweries while still acting as an active researcher and great supporter of iNANO.

With a new director many could speculate that iNANO would move in a new direction. However, as iNANO director - but also as longstanding member of the iNANO leadership – it has been one of my cardinal points to ensure that the iNANO mission continues to rest on the three equally strong pillars, namely excellent science, world-class education, and highest-level technology transfer to society. This mission not only fits excellently with the strategy of Aarhus University, highlighting iNANO as a role model for large interdisciplinary research centers, but also the capabilities of Denmark to participate efficiently as a provider of solutions to global challenges. Interdisciplinary research, education, and innovation have never been more important than now. As one of the largest interdisciplinary research centers in Denmark, iNANO has a clear mission and responsibility in this regard.

It has been a true pleasure taking over iNANO with the enormous support and contributions from the many iNANO researchers, administrative and technical staff, and students at all levels. iNANO is borne by an overwhelming support to our fundamental value; an uncompromised focus on excellence in the true deliverables of a strong university. In a year with many challenges, as described below, the maintenance of high quality in the operation could not have been accomplished without support from the iNANO secretariat and the many people participating in our various committees (e.g. research, educational, cooperation and safety committees to name a few). I full-heartedly thank you all for your contribution to the daily operations of iNANO.

2012 was a very busy year with a lot of changes at iNANO and at Aarhus University in general. The world around iNANO changed with the restructuring of the University and the preparation of a new financial model. On the internal front, the move of many of our activities to the new iNANO House (see article elsewhere in the Annual Report) obviously required a lot of focus and resources and as I am writing this message, the final logistic and infrastructural knots are being untied. This means that we now have a fantastic platform for educating nanoscience students, carrying out excellent interdisciplinary research and just as important: Improved networking conditions for the iNANO research groups and our many academic and industrial partners. I truly believe that Aarhus University and Danish science will benefit from this beautiful building and the world-class instrumentation and laboratories assembled in the iNANO House.

In 2012, we finished also the iNANO strategy report that sums up the visions, strengths and future focus areas of the whole organization. The iNANO strategy aims to instill a strong sense of scientific social responsibility into our researchers. Our aim is to improve awareness

# MESSAGE FROM THE DIRECTOR

> In 2012, we witnessed exciting research being performed by the iNANO scientists. I find particular pleasure in the high number of our outstanding young researchers who were recognized for their scientific abilities and potential

that interdisciplinarity is essential for and a potential key provider of solutions to numerous important Grand Challenges of our time. Embedded within a broad palette of research areas, we have increased focus on three strategic research areas, namely nanomaterials, nanomedicine, and nanofood. The three strategic areas will be supported by three key platforms: nanosynthesis, nanoanalysis, and nanomodelling. My hope and expectation is that iNANO can contribute significantly to the solution of global challenges based on nanoscience and interdisciplinarity.

To conduct the above-mentioned research, iNANO currently has 59 associated permanent professors, 60 postdocs, and around 150 PhD students. These numbers underline that the iNANO family is large, and we are always thrilled to welcome new family members as a central part of our recruitment strategy.

In 2012, we witnessed exciting research being performed by the iNANO scientists. I find particular pleasure in the high number of our outstanding young researchers who were recognized for their scientific abilities and potential by attracting prestigious awards in tough competition with their peers. In January 2012, Professor Bjørk Hammer (iNANO and Dept. of Physics & Astronomy) was awarded the very prestigious Advanced grant ("Topforsker") by the Danish National Research Council. This award will allow Bjørk Hammer to expand his research group and strengthen his position as an internationally recognized researcher within the field of theoretical modelling of chirally modified heterogeneous catalysis. (See elsewhere in this Annual Report). Doctor Mogens Christensen received a Sapere Aude Starting Grant, making it possible for him to establish his own research group. This award is only given to young, outstanding scientists, emphasizing his scientific talent. (The project is described elsewhere in the Annual Report).

To my great pleasure Megan Ho, Eva Arnspang Christensen, and Maria Andreasen all received a Sapere Aude Young Elite researcher grant, which will undoubtedly act as a stepping stone towards their establishment as group leaders. They certainly have the talent.

As you all are aware of, iNANO does not only consist of bright, young talents, we also have a large group of outstanding well-established scientists associated with the center. These experienced scientists often attract a lot of attention by receiving numerous awards. Among these, Professor Flemming Besenbacher has been one of the more active scientists in this particular area, and I feel that a big congratulation is on order for being the first Dane to receive the International Science and Technology Cooperation Award of the People's Republic of China.

One thing is to receive awards by performing great science, another important aspect is the ability to attract funding from various private and public sources. In that respect, 2012 was a record-breaking year: we received more than DKK 226 million from foundations such as The Danish Council for Strategic Research (DSF), The Danish Council for Independent Research (DFF) and The Danish National Research Foundation (Danmarks Grundforskningsfond). This is simply impressive and it goes without saying that I am extremely proud of and thankful for this result mediated by the world-class researchers at iNANO.
To me, all of the above clearly demonstrates that the interdisciplinary approach to scientific work indeed works very well – and that it is being increasingly recognized by the university, funding agencies, and the public.

iNANO is more than established scientists on the verge of taking the next steps in their scientific careers. Our Bachelor's, Master's and Ph.D. programs are crucial to us, because without the next generation of talents we are not able to continue to make great science, since the actual work is often carried out by the young people. I am proud to say that the future of iNANO is in great hands. As an example I will mention the 3 young people, Signe Grønborg, Simon Frølich, and Irene Hansen, who recently won the regional Grundfos Challenge and who have now qualified for the global final to be held in March 2013. I am very much looking forward to following their progress during the final week at the Poul Due Jensen Academy.

Overall, 2012 was a very busy year, and I definitely feel that is a year which we all can be very proud of and I am looking forward to the challenges and great science which 2013 will undoubtedly bring. I am very much looking forward to the continued collaboration with all members of the iNANO family.

# AN INTERDISCIPLINARY **CURRICULUM** FOR **NANOSCIENCE**

Interdisciplinarity lies at the core of nanoscience and nanotechnology. Many of the most groundbreaking current developments take place at the boundaries between the traditional disciplines of physics, chemistry, molecular biology, and biology. This observation, along with the fact that the years of undergraduate education define our mental framework and approach to science to a large extent, calls for an early introduction to *all* the core disciplines of nanoscience.

At iNANO, we offer dedicated Bachelor's and Master's programmes in Nanoscience where the goal of disciplinary breadth has been realized without sacrificing scientific depth. This has been accomplished by developing a fixed course programme involving carefully selected elements from the core disciplines in combination with dedicated nanoscience courses and elective specialisation modules during the last years of study. Since its introduction in 2002, the annual intake of this new study programme has counted 40-60 highly motivated and dedicated young students.

## Bachelor's programme

During the first three years, students receive basic interdisciplinary training in physics, chemistry, biology, molecular biology, mathematics, and computer science. Many courses are followed along with students from these core disciplines. In addition, several courses address issues specific to the nano area. In the course *Introduction to Nanotechnology*, the first-year students are introduced to key nano concepts such as scanning probe techniques and bottom-up/top-down synthesis of nanostructures, e.g. involving an experimental exercise on DNA origami. They also make a first contact with research groups at iNANO through a two-week project. In subsequent courses more advanced experimental exercises and an extensive project are carried out. Elective course modules during the third year of study allow fine-tuning of the course programme to the particular interest of individual students. The Bachelor's degree programme is concluded by an individual Bachelor's project.

## Master's programme

During their Master's study the students are required to specialize in either of three different directions: *nano-physics*, *nano-chemistry*, or *nano-molecular biology*. Here they follow course programmes developed through individual counselling and can choose Master's courses such as *Bio-Nanotechnology*, *Current Nanoscience*, *Nanomedicine*, or *Science-based Innovation and Entrepreneurship*, offered by iNANO, as well as from a large suite of courses in the course catalogue of the Faculty of Science and Technology.

In the compulsory "Student's Colloquium" course the students gain experience in presenting a subject of their own choice to fellow students. The specialisation courses followed during the fourth year of study enable the students to commence their one-year Master's project or alternatively to seek admittance to the PhD programme of iNANOschool.

| | | | |
|---|---|---|---|
| 5th year | Master project in nanotechnology | | |
| 4th year | Current Nanoscience | Innovation and Enterpreneurship | Specialisation |
| | Specialisation | Specialisation | Specialisation |
| | Bio-nanotechnology | Specialisation | Specialisation |
| | Student Colloquia | Specialisation | Specialisation |
| 3rd year | Bachelor project | Elective | Elective |
| | Bachelor project | Molecular structure | Elective |
| | Solid state physics | Nanocharacterisation | Elective |
| | Statistical physics | Fourier analysis | Elective |
| 2nd year | Quantum mechanics | Statistics and data analysis | Advanced molecular biology |
| | Non-classical physics | Linear algebra | Theory of science (Nano) |
| | Experimental nano-project | Numerical physics | General molecular biology |
| | Experimental nano-exercises | Physical chemistry | General biochemistry |
| 1st year | Waves and optics | Organic chemistry | Nano intro |
| | Electromagnetism | | General biology |
| | Mechanics/thermodynamics | Inorganic chemistry | Calculus 2 |
| | Introductory mechanics | Introductory chemistry | Calculus 1 |

**Course programme for the interdisciplinary Bachelor's and Master's degree in nanoscience offered at iNANO in 2012.**
**Each academic year (starting from the bottom) is divided into four 7-week quarters and three courses are followed in each quarter.**

**Legend**
- **Physics courses**
- **Chemistry courses**
- **Molecular biology courses**
- **Mathematics/computer science courses**
- **Compulsory nanoscience courses**
- **Selected elective courses**
- **Specialisation modules**

# GRADUATE STUDIES – **iNANOschool**

With currently 150 PhD students enrolled, iNANOschool is a graduate school of international stature. A broad range of specialized graduate courses are offered alongside access to highly advanced research facilities. This combination makes iNANOschool a nexus of interdisciplinary competences in nanoscience and nanotechnology at the highest international level.

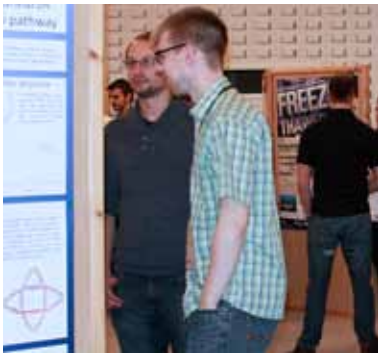
More than ten years after the establishment of iNANOschool (www.iNANOschool.au.dk), the main objectives remain the same. The major driving force is the education of highly qualified, internationally competitive PhDs with a broad range of interdisciplinary competences within nanoscience and nanotechnology. The research areas of iNANO and iNANOschool are highly integrated as well as truly interdisciplinary and cover at present such diverse research fields as functional nanomaterials, nano-energy materials, nanomedicine, self-assembled molecular nanostructures, nanofood, nanophotonics and -electronics, nanotoxicology, and nanoethics. Many of the PhD research projects involve more than one research group, and in frequent cases also industrial research laboratories. Overall, the research activities are at the international forefront of science and serve as an ideal framework for education and industrial collaboration. In addition to research, iNANOschool offers several PhD courses within nanoscience and nanotechnology and provides access to facilities for and supervision of more than 150 PhD students. During 2012, 35 new PhD students were enrolled in iNANOschool and 31 PhD students completed their PhD studies. In addition to the focused PhD courses, activities include a major annual meeting, an autumn school, student networks, and initiatives to promote exchange with other international institutions.

**Courses in 2012**

In addition to education in high-priority research fields, an important task for iNANOschool is to educate the students in other aspects important to a top researcher. This includes topics such as innovation, commercialization, and ethical aspects of nanoscience and nanotechnology. Courses are either offered as intense one- or two-week courses or classic 7-week courses. The advantage of the intense courses is to ensure that interference between course attendance, research activities, or travelling is kept to a minimum.

During 2012, iNANOschool offered courses in Data Visualization, Managing and Organizing Scientific Innovation, Science-based Innovation and Entrepreneurship, Bionanotools, Drug Delivery, and the annual iNANO Autumn School.

Data Visualization taught the students how to improve and manage visual strategies for scientific data. By analyzing visual design and implementing different tools and techniques, the students learned how to distinguish between good and bad visualization, and how to optimize visual representations of their own data. The course was a mixture of lectures presenting a wide range of examples of visual solutions to presentation of scientific data, and practical exercises concentrated on improving the students' own scientific graphics. It was held as an intense course at Aarhus University.



Managing and organizing scientific innovation aimed at providing the students with an understanding of how an organization functions and how knowledge and methodologies from natural sciences can create innovation and be applied in a business context. The course was developed especially for iNANO by teachers from Aarhus School of Business and Social Sciences. In addition, a course in science-based innovation and entrepreneurship complemented the students' skills by enabling the students to leverage their learning from prior courses in novel ways. This was done by teaching the students how to construct and act upon their own opportunities for entrepreneurship as well as to see how their own disciplinary background could create value through collaboration in an entrepreneurial process. Both courses were held during the spring semester at Aarhus University.

As in previous years, the courses Bionanotools and Protein Structure, Drug Delivery, and the annual Autumn School were held with a great number of participants.

**iNANO Autumn school 2012**

Again this year more than 100 iNANO PhD students were brought together for an extended weekend at Kystvejens Hotel & Conference Center in Grenaa.

The overall intention of the iNANO Autumn Schools is to expose the students to varying themes from year to year. In 2011, the students participated in the first ever iNANO Challenge, while the 2012 edition was held as a classic conference with plenary sessions by invited speakers from the fields of nanomedicine, nanofood, and nanomaterials. In addition to guest speakers, the PhD students gave oral presentations in a number of parallel sessions. Their presentations were rated by their peers by means of a clicker system. In addition to the scientific program, the students met under more informal circumstances during a quiz night and a gala dinner. In 2013, the Autumn School will focus on extracurricular skills, to prepare the students for life after academia.

# NANORAMA – STUDENTS ORGANIZATION

Since the spring of 2005, Nanorama has represented the interests of the students at iNANO. Nanorama is a student-run organization that organizes social and academic events for the nanoscience students at AU.

After iNANO moved to the new iNANO House, Nanorama has grown bigger and taken on more responsibilities and is now a much larger part of the nanoscience education.

The aims of Nanorama are to create opportunities for our members to interact with people associated with the nanoscience education at Aarhus University. In 2012, this objective was achieved through Friday bars, various field trips, a pub crawl, interesting lectures, and much, much more!

The second half of 2012 saw many exciting highlights for Nanorama. With the move to the new nanohouse, Nanorama became a more serious organization with additional resources. However, the most important effect of the move has been the increase in the concentration of nanoscience students and groups in one location. This has created a market for more Friday bars and more events, which, fortunately, we can arrange in the foyer of the iNANO House.

In connection with the move to the new iNANO House, Nanorama made a deal with Carlsberg to be our supplier of beer and soft drinks. This collaboration has proven very beneficial for Nanorama, as Carlsberg has supplied us with a brand new fridge and taps for draft beer. Nanorama also applied for funding for new items for our organization at the Tuborg Foundation. We were fortunately granted a sum of money, which meant that we were able to purchase a variety of items to use for social events. For our Friday bars, we purchased a football table, a projector with a large screen, and a Nintendo Wii with four remotes and a few games. All of this was bought with the aim of making the best Friday bar on Campus. And we think we are getting very close.
We also wanted to be able to arrange outdoor social events, so we purchased a barbeque, two outdoor heaters, and a pavilion/tent. The idea is that the inhabitants of the house can borrow it for events on the lawn of the nanohouse.

2012 was also the year where the Nanorama-TIMINI relationship flourished. TIMINI is the nanoscience student organization at NTNU (Norges Tekniske og Naturvidenskabelige Universitet) in Trondheim. The collaboration was initiated in 2011. In 2012, Nanorama sent a small group to Trondheim on a short-term exchange program. The group experienced how they "do nano" in Trondheim and attended lectures and tours at university and Trondheim city. In the beginning of 2013, Trondheim is sending a delegation on a short-term exchange stay to Aarhus, where Nanorama will show them nano in Aarhus and what it is like to be a student at iNANO.

We, the board of Nanorama, are very much looking forward to 2013, which will see more collaboration between students and Nanorama and iNANO and Nanorama, and Nanorama already has plenty of interesting events on the drawing board.

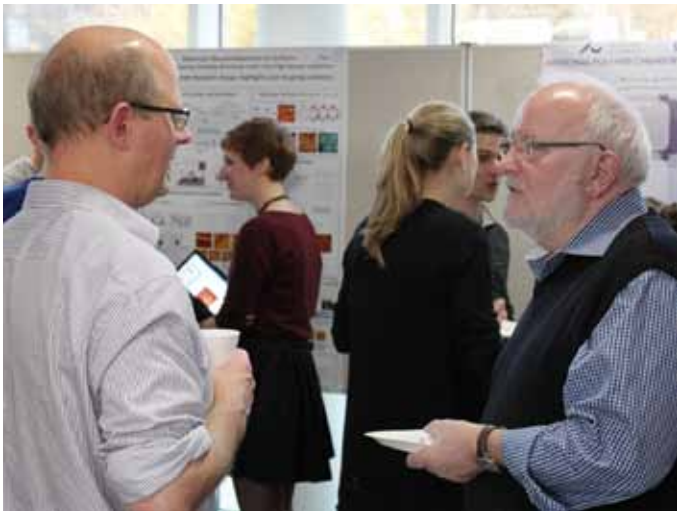
JESPER RAIS/AU KOMMUNIKATION

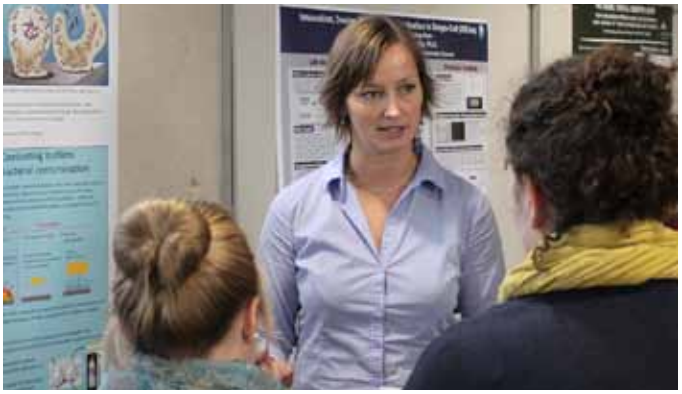
# STUDENT/RESEARCHER **MATCHMAKING**

On Friday 16 November, 2012, iNANO held its first Student/Researcher Matchmaking Event in the foyer of the iNANO House. 35 of iNANO's senior researchers joined the event, where they all brought a poster explaining their groups' activities.

The purpose of the event was for the group leaders to recruit students to their research groups and to give the students an opportunity to talk informally with the group leaders, and thereby potentially find the right supervisor for their Bachelor's-, Master's- or PhD project. The event was established after requests from both the researchers and the students. A student competition was setup to encourage the students to talk to as many group leaders as possible – a competition which was fortunately not really needed because of the strong student interest in the event. The group leaders were very pleased with the possibility to talk to the students about their activities and show their passion for their work to the students. The researchers also used this opportunity to talk to each other and gain insight into iNANO's interdisciplinary activities.

The event lasted for two hours and afterwards the student organization Nanorama arranged a Friday bar where the informal talks between students and researchers continued in a less formal setting.





BY ANDREAS BOVIN,
MILENA LABAN,
CAROLINE KNABE,
and JULIE SCHMØKEL,
iNANO STUDENTS

# THE ANNUAL **STUDY TOUR**

In 2012, as in previous years, iNANO students who had just finished their second-year nanoscience studies went on an international study tour, seeking inspiration for their continued nanoscience studies and hoping to gain insight into the scientific environments of some of iNANO's international scientific partners. This year's destination was the inspiring nanoscientific environments of Grenoble, France, and Geneva, Switzerland.

On the 19 June 2012 the scientific program began with a visit to Institut Néel, an institute for fundamental research. Here we were given an overview of the scientific research performed at the Institute. Subjects included cryonanotechnology, magnetics, spintronics, and surface chemistry. In addition, we were given an exciting tour of various laboratories and were presented with a great buffet during which we had the opportunity to speak with members of the scientific staff. Afterwards, we drove to Minatec, a high-security research facility, which meant that we had to go through thorough security checks of passports and backgrounds. Inside, we were shown state-of-the-art microscopes such as High-Resolution TEMs and an Ion-Etching 3D-SEM, and given a presentation of some of the fundamental research projects in, e.g., quantum computing.






On the second day we crossed the border to Switzerland, as we drove to visit the University of Geneva and CERN. The University of Geneva showed us their physics show and afterwards we spent most of the morning playing with static-electric devices and superconducting lev-trains. Here we were also introduced to a laboratory working with research on high-pressure optics.

In the afternoon we drove to CERN, where we were given the official guided tour of the facility. Driving around in minibuses, stopping and watching from time to time, we learned about particle physics, synchrotron construction, and data analysis. We were shown part of their humongous server park, used for storage and data handling, and were taught about the invention and development of computer technology and networking throughout the last century.

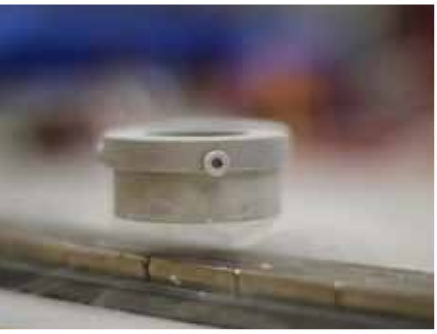
On the third and last day of the academic program we visited European Molecular Biology Laboratorie. We were shown several bio-laboratories working with protein crystallization and various sample testings using a pipette robot. From a distance, we also saw the construction site for a newly built synchrotron, which will be used for crystallography measurements.

Finally, we visited the Institut Laue-Langevin, a facility focused on research based on their neutron source. We were given a tour of the facilities and visited the nuclear reactor building, where we learned about the reactor itself and how to extract neutrons for usage as probes in diffraction techniques.

With the academic program completed, most students took the opportunity to experience France and the surrounding countries and extended their stay by a few days to enjoy each other's company.

All in all, we had a very educational trip, which was also highly entertaining and fun.

The trip was made possible thanks to the generous support from iNANO. A special thanks to Leif Schauser, scientific coordinator at iNANO, for organizing the scientific program and participating in our study trip. A student committee helped with the fundraising and organization of hostels and plane tickets.







# STUDENT **AWARDS**

Each year the Institute of Nanotechnology (IoN) awards one Master's level student the international IoN Student Award. The Institute of Nanotechnology is one of the global leaders in providing information about nanotechnology.

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February 1, 2012, iNANO student Marie Krogsgaard was selected as the winner of the IoN award 2012. She impressed the review panel, consisting of experts from academia and industry, with her submission on "Mussel Inspired Potential Tissue Adhesives – Design, Synthesis and Characterization" in terms of technical depth and creativity, and the quality of her research.
Her project aims at designing and synthesizing new multifunctional molecules with blue mussel treads as the point of inspiration. These treads use a specific chemical functionality called DOPA, which is excellent at binding to metal ions. By incorporating DOPA into smart polymers, it may be possible to create adhesives that could work as tissue "glue". Marie was enrolled as a PhD student in the iNANOSchool in the spring of 2012, where she has continued her work on the mussel project together with her supervisor Associate Professor Henrik Birkedal, iNANO and Department of Chemistry. Currently, she is doing a research stay in Professor Joanna Aizenberg's lab at Harvard University, who is one of the pioneers of the rapidly developing field of biomimetics.

Dorthe Ravnsbæk received the Danish Academy of Science's PhD Award 2012 for her PhD thesis entitled "Synthesis, structure and properties of novel metal borohydrides". The research was conducted at the Center for Materials Crystallography at iNANO and the Department of Chemistry under the supervision of Associate Professor Torben R. Jensen and Professor Flemming Besenbacher. The PhD award is given for an excellent thesis and is only awarded to one former PhD student each year. Dorthe's PhD work resulted in 22 publications.
Currently, Dorthe Ravnsbæk has left the field of metal borohydrides and is now working on another form of energy storage, namely lithium-ion batteries. This work is being carried out in the laboratory of Professor Yet-Ming Chiang at the famous Massachusetts Institute of Technology (MIT) and is funded by a postdoctoral stipend from the Carlsberg Foundation.

In the spring of 2012 Lasse Arnt Straasø was awarded the Danish Young NMR Researcher Prize 2012 for his contributions to solid-state NMR methods for internuclear distance measurements. Potentially, these improvements can increase the resolution of protein structures determined by solid-state NMR spectroscopy, including the structures of amyloid fibrils.
The work of Lasse Arnt Straasø was carried out under the supervision of Prof. Niels Christian Nielsen at the Center for Insoluble Protein Structures (inSPIN) located at iNANO and Department of Chemistry, Aarhus University. The project comprised all aspects from theoretical development, numerical optimizations and experimental implementation.

Lasse received the award the day after defending his PhD thesis at the annual NMR symposium held at the Carlsberg Laboratory.The picture shows Associated Professor Anders Malmendal, Copenhagen University and chairman of the users group at the Carlsberg NMR Center (left) handing over the prize to Lasse Arnt Straasø (right).

# 11TH iNANO **ANNUAL MEETING** 2013

The 11th iNANO Annual Meeting took place on 16 January 2013. For the first time this year's Annual Meeting was held in the iNANO House, thus taking advantage of the excellent auditorium, meeting rooms, and the Foyer.

Distinguished high-profile speakers from all over the world were invited to talk about nanoscience. 250 people attended these inspiring talks and in addition the iNANO PhD students presented their research at a poster session. The day was rounded off by the inauguration of the new iNANO House and an evening dinner in the canteen at the Department of Chemistry.

From left to right: Thomas Carell, Stephen Turner, Niels Chr. Nielsen, Christopher Dobson, Mercouri G. Kanatzidis, Clare Grey.
Absent: Peter Fratzl

PHOTO: LISE BALSBY/AU COMMUNICATION

**Understanding and preventing neurodegenerative diseases: a grand challenge for the modern biomolecular sciences**
Prof. Christopher Dobson from the Department of Chemistry, University of Cambridge, was the first speaker of the day. His talk concerned neurodegenerative disorders such as Alzheimer´s and Parkinson's diseases and how these are associated with misfolding and aberrant self-assembly of peptides and proteins into nanoscale 'amyloid' structures. His talk described our present state of knowledge and current attempts in the development of novel approaches to inhibit the progression of dementia.

**Atomic-, Nano-, Meso Scale and beyond: a panoscopic view of thermoelectrics**
Prof. Mercouri G. Kanatzidis from the Department of Chemistry, Northwestern University, gave a talk on why there is a compelling need for high performance thermoelectrical materials that can directly and reversibly convert heat to electrical energy, because more than 2/3 of utilized energy is being lost as waste heat. The talk highlighted the role of panoscopic strategy to bulk thermoelectrics.

**DNA bases beyond Watson and Crick**
Prof. Thomas Carell from the Faculty of Chemistry and Pharmacy, Ludwig-Maximilians Universität, Munich, talked about how chemistry leads to new insight into the biology of stem cell development processes. He described the distribution of carboxylcysteine in somatic tissue and in stem cells and provided new quantitative data from a detailed mass spectrometric analysis.

**The development of single molecule, real-time sequencing: history and prospects for the future**
Dr. Stephen Turner from Pacific Biosciences presented a talk on DNA polymerases, viewed as a molecular nanomachine. These molecules are actually sequencing instruments, which can sequence the entire human genome in minutes. This remarkable potential has been harnessed in Single Molecule Real Time sequencing. His talk followed the history of this technology and concluded with an overview of prospects for future development.

**Are nano-structure important for chemical energy storage?**
Prof. Clare Grey from the Department of Chemistry, University of Cambridge, presented her work on the characterization of materials for chemical energy storage, with particular focus on batteries and supercapacitors. She described the advantages and disadvantages of nano-sizing material for these applications. A major focus has been on the development of NMR methodologies that allow devices or materials to be probed while they are operating.

**Nature´s nanocomposites as inspiration for materials science**
Prof. Peter Frätzl from the Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Berlin, addressed the topic of natural materials with outstanding mechanical properties, including wood, grasses, silk bone sea shells or sponges.

Unraveling the structural principles of unexpected material properties may indicate ways towards the development of nanocomposite materials with adaptive capabilities.

# THE **iNANO HOUSE**

More than three years after the first sod was cut, the iNANO House was finally completed and ready to receive its new inhabitants during the late summer and autumn of 2012.

Several research groups packed their labs and offices into moving boxes, and with great anticipation (and a bit of nerve) moved through AU Campus and into the iNANO House on Gustav Wieds Vej 14, where they unpacked in completely new facilities. The main driving force behind the move is, contrary to popular belief, not only excellent new laboratory facilities, but perhaps even more so, new neighbors. A common denominator for many of the moved groups is their deep involvement in interdisciplinary research and education, where they benefit at least as much from collaboration with peers in their home departments as with scientists from other departments at Science & Technology.

Two good examples are the Danish National Research Foundation centers inSPIN (Center for Insoluble Protein Structures) and CDNA (Center for DNA Nanotechnology) both involving researchers from several departments, including Department of Chemistry, Department of Molecular Biology and Genetics, and Department of Physics and Astronomy. In both cases all or a major fraction of the research and training activities have moved to the iNANO building, thereby improving access to key laboratories, easy exchange of ideas, and improved interactions with their new neighbors on novel research themes.

Currently, the following research areas are being investigated by research groups in the iNANO House:

- Homogenous transition metal catalysis, organic synthesis, isotope-labeling (Prof. Troels Skrydstrup, iNANO and Department of Chemistry)
- Organic nanochemistry and DNA nanotechnology (Professor Kurt Gothelf, iNANO and Department of Chemistry).
- Biological solid- and liquid-state NMR spectroscopy and MRI (Professor Niels Chr. Nielsen, iNANO and Department of Chemistry, Professor Thomas Vosegaard, iNANO, Department of Engineering and Department of Chemistry, and Associated Professor Frans Mulder, iNANO and Department of Chemistry)
- Biological and bioinspired materials (Assocociated Professor Henrik Birkedal, iNANO and Department of Chemistry)
- Soft materials science (Professor Jan Skov Pedersen, iNANO and Department of Chemistry)
- Biophysics and single molecule fluorescence (Assocciated Professor Victoria Birkedal, iNANO)
- Biomedical surfaces (Senior Researcher Morten Foss, iNANO)
- Nanobiointerfaces (Assocociated Professor Duncan Sutherland, iNANO)
- Scanning Probe Microscopy (AFM and STM) studies of nanocatalysis and self-assembled nanostructures, biomolecule-surface interactions: (Professor Flemming Besenbacher, iNANO and Department of Physics and Astronomy, Assocociated Professor Trolle Linderoth, iNANO and Department of Physics and Astronomy, Senior Researcher Stefan Wendt, and Assocociated Professor Jeppe Vang Lauritsen, iNANO, Assocociated Professor Mingdong Dong, iNANO)
- Semiconductor physics (Professor Arne Nylandsted Larsen, iNANO and Department of Physics and Astronomy)
- Bioelectrochemistry and bioelectrocatalysis, biosensors, nanoelectrocatalysis (Assocociated Professor Elena Ferapontova, iNANO)
- Nanomedicine (Professor Jørgen Kjems, iNANO and Department of Molecular Biology and Genetics and Associated Professor Ken Howard, iNANO)









BY LINDSAY R. MERTE and
FLEMMING BESENBACHER

# WATER MEDIATED HYDROGEN TRANSPORT MAY IMPROVE CATALYSTS AND HYDROGEN STORAGE

The transport of hydrogen across oxide surfaces is essential for the function of hydrogen storage materials and various catalysts. At iNANO we aim to understand this transport at the atomic level so that functional materials can be designed and operated as efficiently as possible.
A recent study showed how water molecules dramatically accelerate hydrogen diffusion on an iron oxide surface.

The diffusion of atoms and molecules across surfaces is a fundamental topic of tremendous importance in science and technology. These moving atoms and molecules can determine the morphologies of growing thin films and crystals, the rates of metal corrosion, the efficiency of fuel cells, and the lifetime of catalysts. In order to control diffusion processes, we need to understand what happens on the atomic and molecular scales when bits of material travel from one point on a surface to another.

The movements of atoms or molecules may not be simple jumps. In fact, the diffusing species interact with other atoms and molecules adsorbed on the surface and these interactions often exert huge effects on the microscopic hopping rates. In order to understand the fundamental steps in the diffusion process, it is crucial to investigate it directly at the atomic level.

**Diffusion by reactive surface ions**

We use scanning tunnelling microscopy (STM) to investigate hydrogen diffusion, which is important in hydrogen storage, metal corrosion, and catalytic hydrogenation reactions. The hydrogen diffusivity on oxide materials can be enhanced by the presence of trace amounts of water, and this is related to the acid/base character of the water molecule ($H_2O$), which can both donate and accept hydrogen ions ($H^+$) and thereby act as a carrier for hydrogen.

A previous study at iNANO on a titanium dioxide ($TiO_2$) surface has demonstrated one mechanism for this process: A water molecule bound to an exposed surface titanium ion ($Ti_4^+$) dissociates and loses a hydrogen ion to a neighbouring oxygen atom to form a hydroxide ion ($OH^-$). This ion then reacts with another hydrogen atom to form water and the net result is the movement of a hydrogen atom from one site to another. The water-mediated movement occurs much faster than the intrinsic mechanism where hydrogen atoms jump by themselves.

However, the accelerated diffusion requires the presence of an exposed titanium ion at the oxide surface to stabilize the hydroxide ion, which forms as an intermediate stepping stone in the diffusion process. But what happens on a surface without reactive ions?

**Speeding up on an unreactive surface**

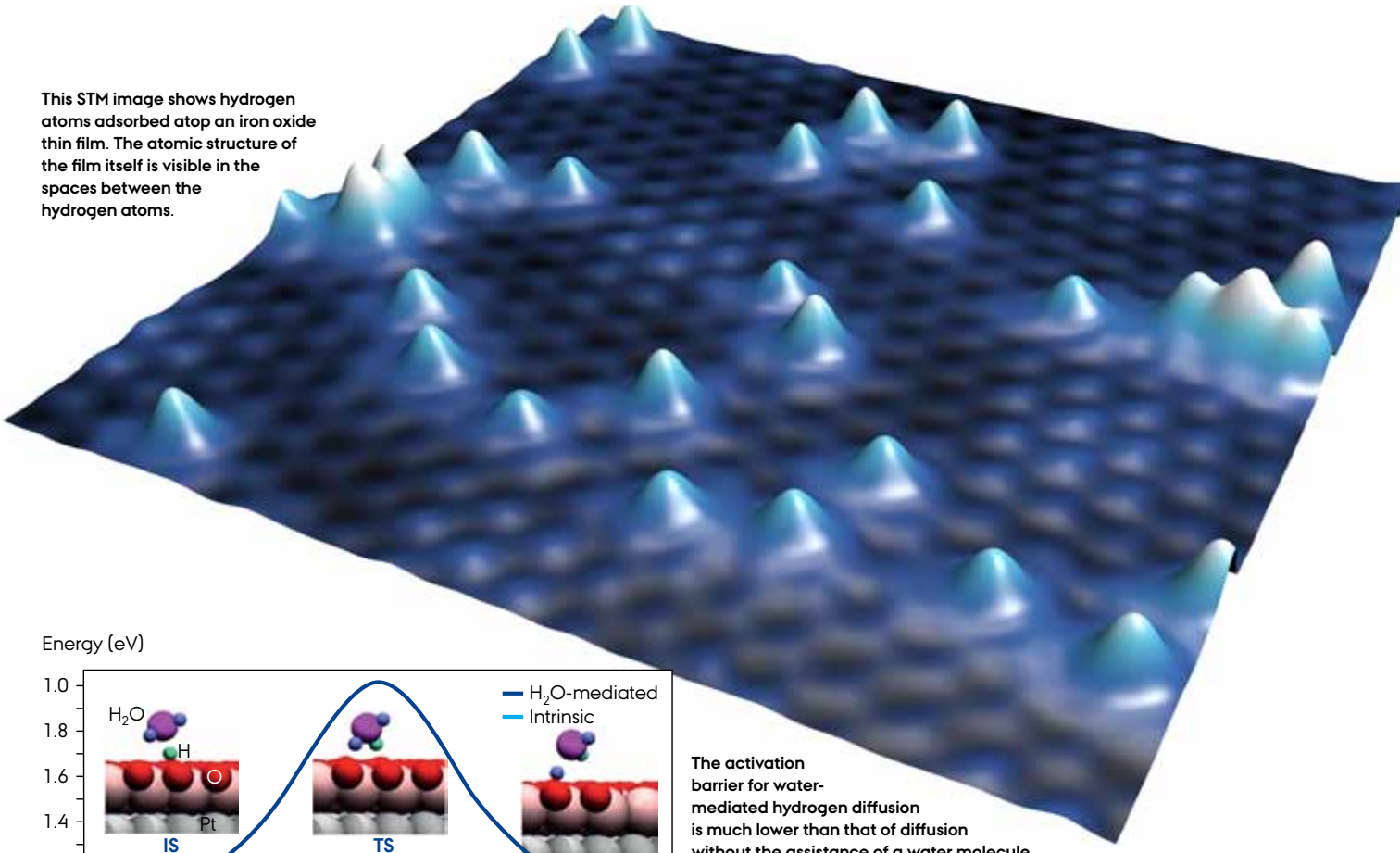
To study this, we used a thin iron oxide film grown on a platinum surface, which is unreactive towards water. After depositing hydrogen atoms, we recorded STM movies to capture their motion — with and without water — over a wide range of temperatures.

At temperatures below -110 °C the hydrogen atoms were almost completely immobile without the aid of water, but after dosing water onto the surface they began to diffuse rapidly. At the lowest temperature we studied, -168 °C, we were able to follow a single water molecule as it moved across the surface, causing nearby hydrogen atoms to jump between different sites. The experiments showed that water-promoted hydrogen diffusion in the absence of reactive metal is in fact even more rapid than what was observed on the titanium dioxide surface.

**Lowering the activation barrier**

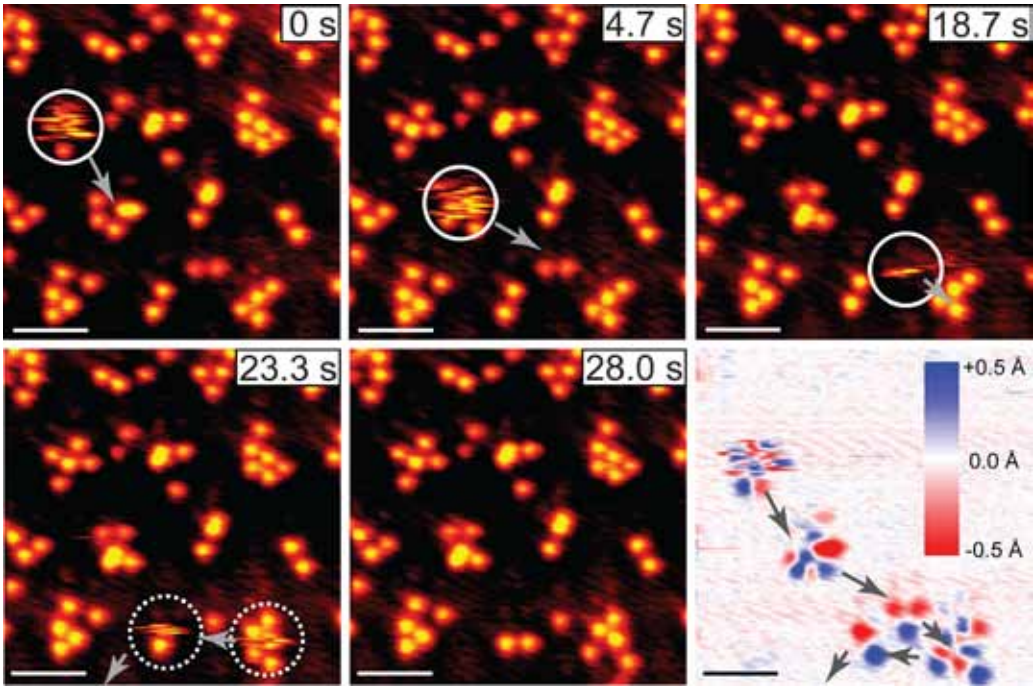
Our collaborators at the University of Wisconsin-Madison in the USA explained this through computer simulations. They found that the presence of a water molecule lowers the activation barrier for diffusion by about 80 per cent, causing a huge increase in the diffusion rate. Rather than first losing a hydrogen atom and then picking up another, the water molecule first picks up one hydrogen atom, then donates another to the surface. The intermediate state is not hydroxide but hydronium ($H_3O^+$). Therefore, water can promote hydrogen surface diffusion by acting either as an acid or a base, depending on the nature of the surface. Such direct, atomic-scale insight into diffusion processes provides a basis for design of intelligent materials.

This STM image shows hydrogen atoms adsorbed atop an iron oxide thin film. The atomic structure of the film itself is visible in the spaces between the hydrogen atoms.






The activation barrier for water-mediated hydrogen diffusion is much lower than that of diffusion without the assistance of a water molecule. The inserts show snapshots of the water-mediated process, including the formation of hydronium ($H_3O^+$) at the transition state. Water picks up the extra hydrogen atom from the surface and donates another hydrogen atom back to the surface at an adjacent site.




These snapshots from an STM movie show hydrogen atoms (bright dots) diffusing in the presence of a water molecule (circled) as it moves across the surface. When the water molecule is near a group of hydrogen atoms they move about rapidly. The frame to the lower right shows the difference between the first and last images of the sequence, with red and blue indicating the positions of hydrogen atoms before and after encountering the water molecule. The path taken by the water molecule is indicated with arrow.

## Designing hydrogen storage materials at the atomic level

Efficient hydrogen storage materials remain a key challenge for developing compact and safe tanks for hydrogen cars.

These materials may be based on metals – such as metal oxides or metal hydrides – which are able to adsorb hydrogen reversibly to their surfaces and release the gas quickly when needed. In this context fast hydrogen diffusion is paramount. In order to design hydrogen storage materials at the atomic level, instead of simply using trial-and-error, researchers need to understand how the structure of the surface influences the rate of hydrogen diffusion.

Our study showed that water-assisted hydrogen diffusion can be very rapid for oxide surfaces without reactive metal sites, which may actually slow the diffusion process by binding water molecules strongly.

# BOTTOM-UP DESIGN OF **HIGH PERFORMANCE PERMANENT MAGNETS**

**From left to right: Mogens Christensen, Post Doc Marian Stingaciu and PhD Student Matilde Saura.**

PHOTO: JESPER RAIS/AU COMMUNICATION

In recent years the world market for high performance permanent magnets has been dominated by neodymium rare-earth magnets. Unfortunately rare-earth minerals are found only in few geographical areas. This is a huge geopolitical and strategic issue and new magnetic materials without rare-earth elements are urgently needed. The aim of our research is to design and produce improved permanent magnetic materials that do not include rare-earth elements.

Many great discoveries by mankind have been enabled by magnetic materials. In the early days the compass allowed explorers such as Christopher Columbus to navigate the seas and find new continents. Later on Hans Christian Ørsted discovered electromagnetism and, hence, the nature of electricity using permanent magnets. Today, magnets are everywhere in our daily lives. They run the compressors in our refrigerators, convert electrical signals into sound in our loudspeakers, and the improved performance of magnets has been essential for the size reduction of the mobile phones in our pockets. In general, high performance magnets facilitate the interconversion between electrical energy and motion. Some examples are the propulsion of electrical cars and power production in gearless wind turbines.

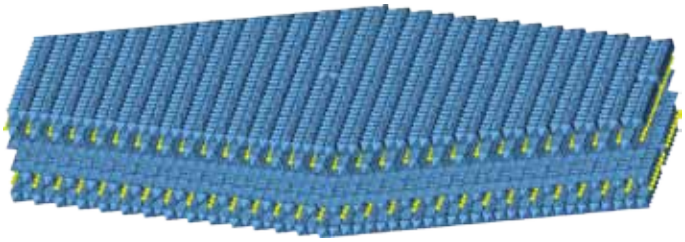
Globally, the high performance permanent magnet market is dominated by neodymium rare-earth magnets and 97 per cent of world's production of neodymium is controlled by China, which has imposed export restrictions on rare-earth metals in spite of

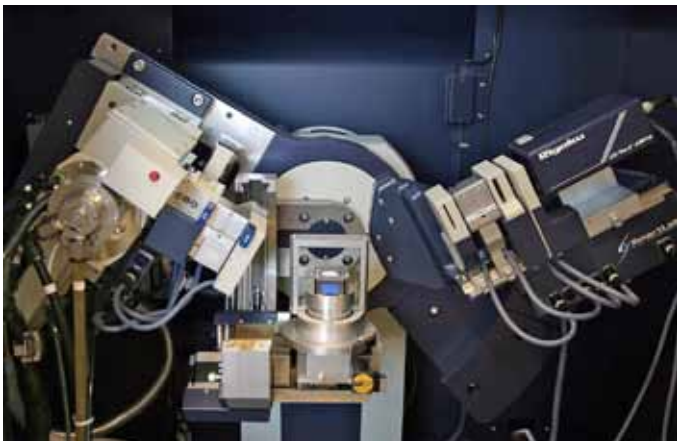
complaints to the World Trade Organisation by the USA, Europe, and Japan. Therefore, new magnetic materials without rare-earth elements are urgently needed.

The task set out by our research group is to create improved magnetic materials based on cheap and common metals such as iron. The Danish Council for Independent Research, Technology and Production Science has allocated a Sapere Aude Advanced Grant of 7.0 million DKK for the project, which is carried out in collaboration with Sintex, a Danish company specializing in the production of permanent magnetic systems and subcomponents. The research will focus on the application of transition metal oxides for producing improved high performance permanent magnets.

### Structural control from sub-nanometer to bulk

The design of permanent magnets is challenging as it involves structural control at all levels from atomic positions to the macroscopic arrangement of nanoparticles with a specific size and shape. On the sub-nanometer scale ferromagnetism predominantly originates from the self-rotation of unpaired electrons in atoms and quantum mechanical interactions may cause the magnetic spin of many atoms to align with respect to each other. For small particles all spins can be easily rotated by thermal energy and such compounds are known as superparamagnetic. At a specific size, which depends on the material, the spins become increasingly difficult to rotate and the particle becomes a single domain magnet.



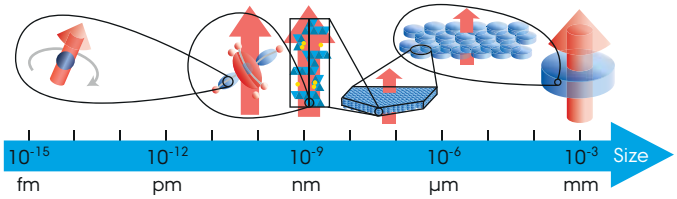


**The instrument is a Rigaku X-ray diffractometer. The X-ray source is mounted on the left hand side and the sample is found in the middle, while the detector is seen to the right. The emitted X-rays are reflected by the atomic planes in the nanocrystals and the angular positions and intensities of these reflections gives information about their structures at the atomic level. A structure of a single domain magnetic nanocrystal is shown above**

Nanoparticles smaller than 25 nm are often superparamagnetic, while particles in the range of 25-250 nm are single domain magnets. Upon further size increase multiple domains with different magnetic orientations are introduced and this reduces the magnetic energy of the system. Thus, a collection of oriented single domain nanoparticles can produce a larger net magnetisation than a bulk material containing multiple magnetic domains.

The challenge of the research project can be divided into different size domains: atomic, nanometre and micrometre length scales. At the atomic scale the goal is to synthesize structures giving rise to strong quantum mechanical interactions aligning the magnetic spins. The next step is to ensure that these atomic structures are reproduced in nanoparticles of appropriate size and shape. Finally, a large number of nanoparticles with perfected atomic structure, size, and shape must be compacted into a bulk material, where the individual nanoparticles are ordered with respect to each other. Control at all length scales is essential for making such high performance permanent magnets.


**Production (left to right) of magnetic pellets: cheap metallic salts are dissolved in water and crystallized. The resulting magnetic nanoparticles are imaged by AFM microscopy and TEM microscopy. Photographs show the nanopowder and final mm-cm sized pellets.**




**The figure illustrates the design of a permanent magnet on a logarithmic scale from femtometres to centimetres. Starting to the left is shown an unpaired electron spinning, which gives rise to the magnetic moment. Next an iron atom is coordinated to oxygen and this structure is placed in a nanometre sized unit cell.**
**The size and shape of the nanoparticles are controlled to create a single domain magnetic particle measuring 25-250 nm. These single domain particles are compacted into micrometre sized particles with their magnetic axis pointing along the same direction. The final magnetic sample is in the mm-cm range.**

### Production of nanoparticles and compaction into magnets

The atomic structure including size and shape of the nanoparticles is controlled in a single synthesis step. Cheap metallic salts are dissolved in water and crystallized by fast heating and subsequent cooling.

To obtain the right crystalline product a number of parameters must be accurately controlled. Key parameters are the reactor pressure, temperature, heating rates, and reaction time, but other parameters are also important such as pH, concentration, stoichiometry, and nature of the ingredients of the metal ion solution. We follow the synthesis continuously using X-ray diffraction as a function of time, which gives insight into some of the growth parameters.

# MAKING CHIRALLY PURE MOLECULES BY RATIONAL DESIGN

Drug molecules often exist in two forms, which are mirror images of each other like the right and the left hand. One form may cure a disease, while the other may lead to serious side effects. We aim to enable production of pure pharmaceuticals with the desired handedness by rational design as opposed to the trial and error approach that the field relies on at present.

When you brush your teeth in the morning try to compare the toothbrush with its counterpart in the mirror. Surely, they appear identical in the sense that a turn and a rotation would make the real toothbrush look exactly like its mirror image. However, if you try the same thing with your hands it doesn't work. Even though the mirror image of your right hand looks like a left hand no twisting and turning will ever make your two hands identical – it is simply impossible.

The presence or absence of handedness is a property of objects of all sizes, ranging from galaxies to molecules. Objects with two mirror images that resemble the right and the left hand are called chiral, while objects like the toothbrush that exist in just one shape are called achiral.

### Chirality matters

If chiral molecules enter a combustion process leading to simple exhaust gasses, it doesn't matter which chiral form was burned. This is because the stored chemical energy and the oxidation reaction routes are the same for both forms. However, for other reactions the role of handedness may become very important.

One example is the chiral scent molecule carvone which interacts with protein receptors in the human olfactory system. Such receptors are also chiral and hence the left-handed and right-handed forms of carvone interact with different receptors. One receptor senses the left handed form of carvone as caraway scent, but is oblivious to its mirror counterpart. Meanwhile, a completely different receptor senses the right handed form as the smell of spearmint, but does not recognize the caraway form.

### Effects and side effects of drugs

The chirality of pharmaceuticals is even more critical. One chiral form of a drug may interact exclusively with a specific receptor leading to an efficient treatment of a disease. Conversely, the other chiral form may not interact with the target receptor because of geometrical mismatch – similar to how the right hand does not fit in to a left handed glove. Instead, this chiral form of the drug may bind to other receptors and cause potential hazards for the patient. As a consequence, many pharmaceuticals must be manufactured chirally pure.

### Producing chirally pure chemicals

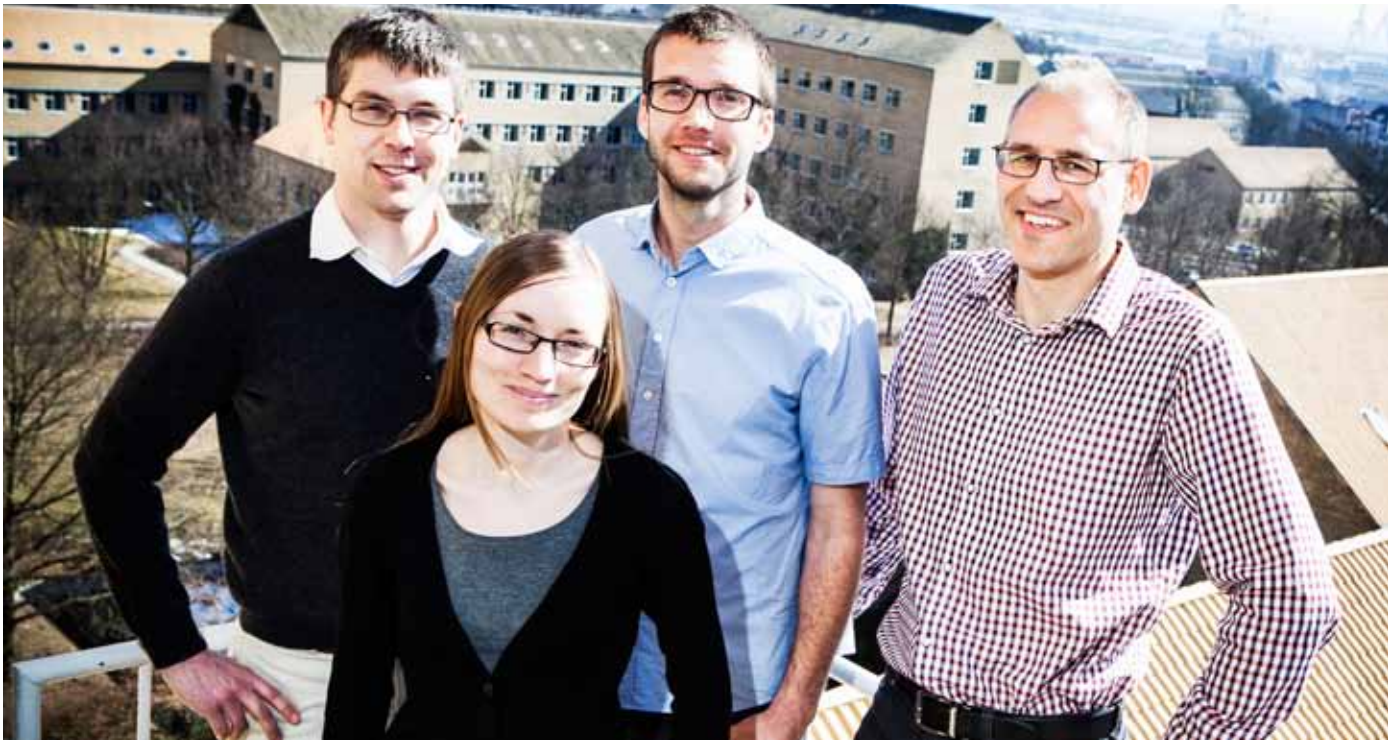
When producing chirally pure chemicals, it is paramount to control a critical chemical reaction step in which achiral reagents become chiral. In our approach, we assume that solid surfaces are required for speeding up the reaction in the first place and, thus, the purpose of our project is to develop methods to control chirality in surface reactions.

Returning to the toothbrush analogy, once it is placed on a table it must lie on one of its two sides. However, when the toothbrush is placed on its right hand side it would appear to lie on its left hand side in a mirror and vice versa. Consequently, by placing the toothbrush on the table we change it from being an achiral object into a chiral object. Likewise, when achiral reagent molecules interact with surfaces their symmetry is broken and a chiral form is adopted. Therefore, if gaseous achiral molecules can be steered into binding exclusively to a catalyst surface in one molecular form, the subsequent chemical reactions may produce chirally pure substances.

### Applying chiral modifiers

One strategy for chiral steering of the adsorption process involves the introduction of chiral modifiers on the surface. These are chirally pure molecules that do not undergo a reaction, but merely alter the chirality of the reagents that are adsorbed afterwards.

In recent years we have worked with an experimental group lead by Peter McBreen at Laval University in Quebec. Together we have demonstrated how pairwise complex formation involving one modifier and one reagent molecule can be steered into adopting one chiral form on a catalytic surface. In our present project, we will investigate these structures systematically in order to unravel which interactions are responsible for the complex formation and how the subsequent chemical reactions may proceed.



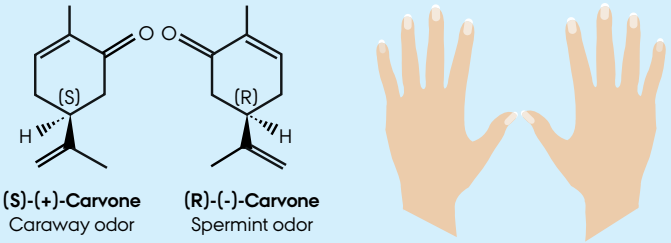
**From left to right: Post Doc Michael Groves, PhD Student Katrine Louise Svane, PhD Student Anton Rasmussen and Professor Bjørk Hammer.**

PHOTO: JESPER RAIS/AU COMMUNICATION

## Computational modelling

A Sapere Aude grant funds our project's computational modelling efforts. At iNANO we will perform so-called van der Waals-density functional theory calculations. These quantum mechanical calculations will provide us with information on the potential energy landscape of the molecular structures on a surface. Furthermore, the computations also reveal the delocalized electron clouds of the complexes, which may allow us to reach a fundamental understanding of the origin of the computed energy landscapes.

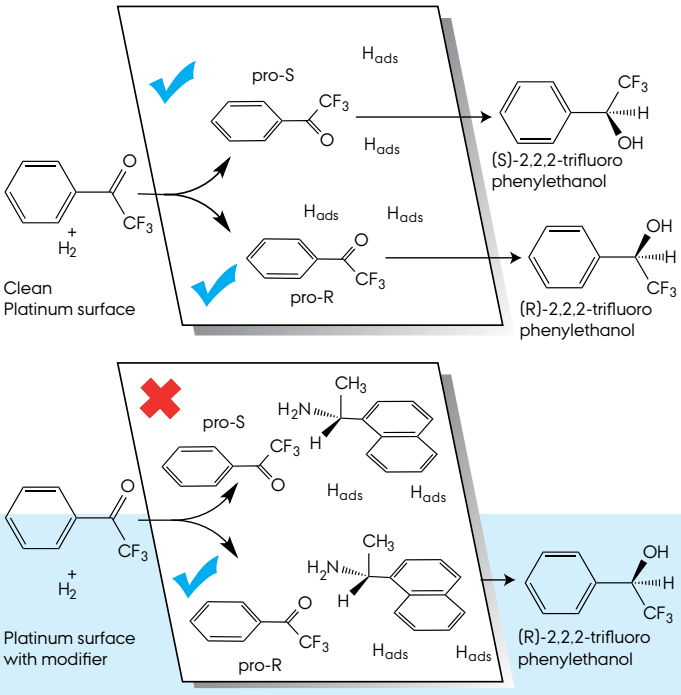
The project aims to discover the basic principles for symmetry breaking through the application of chiral surface modifiers. We hope to obtain a theoretical understanding that will greatly facilitate future developments of surface modifiers by rational design as opposed to the trial and error approach that the field relies on at present.




**(S)-(+)-Carvone**
Caraway odor

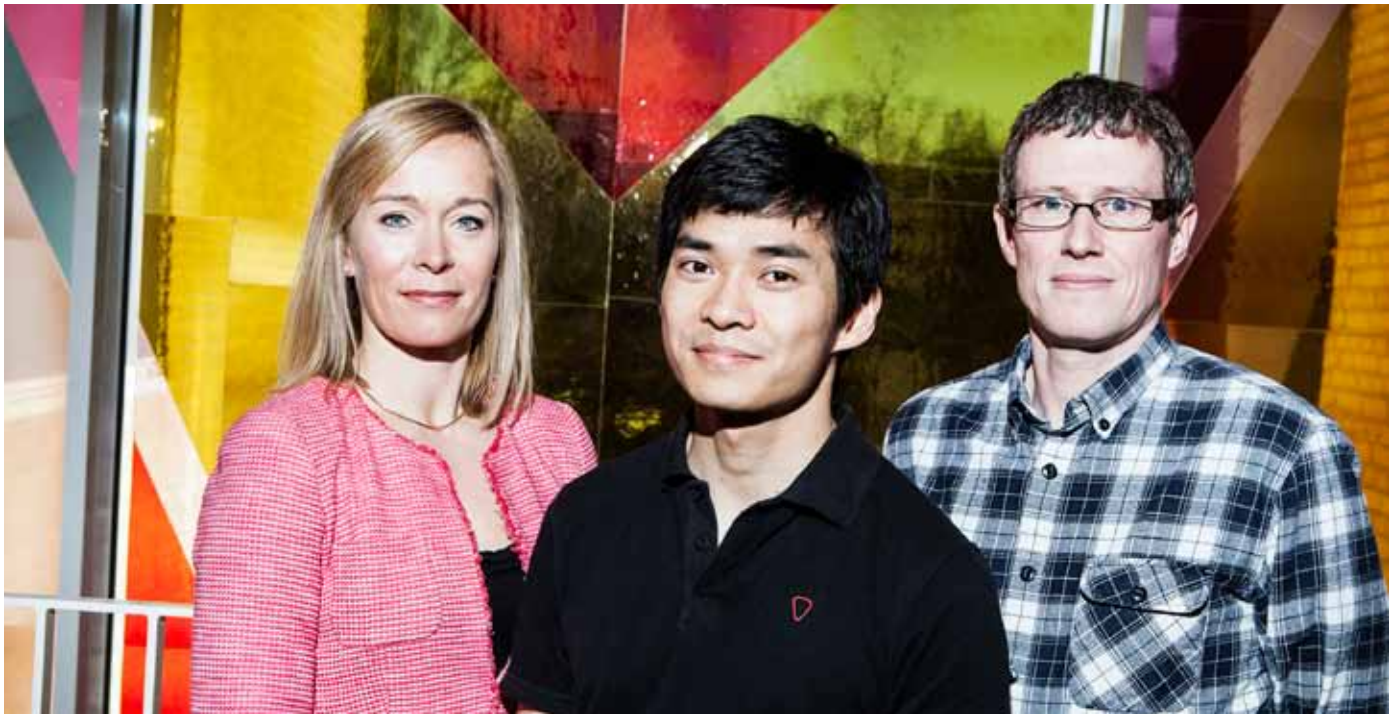
**(R)-(-)-Carvone**
Spermint odor

**Chiral molecules are structurally different like the right and the left hand. An example is the scent molecule carvone. The left handed form (S) smells like caraway, while the right handed form (R) smells like spearmint.**




**When the achiral 2,2,2-tri-fluoroacetophenone molecule is adsorbed to a platinum surface (top) it undergoes symmetric hydrogenation into trifluorophenylethanol (TFPE) and becomes chiral in the process. If a chiral surface modifier is present (bottom) the reagent undergoes complex formation with the modifier. This results in a disparity in the production of the two chiral forms of TFPE.**

# CREATING A THIRD DIMENSION IN CELL CULTURE: **SCAFFOLDS AND BIOREACTORS**



**Left to right: CEO Lone Jager Lindquist, Post Doc Dang Quang Svend Le and Senior researcher Morten Foss.**

PHOTO: JESPER RAIS/AU COMMUNICATION

Tissue engineering is an emerging multidisciplinary field involving nanoscale material engineering, molecular biology, cell biology, and medicine. It holds promise to greatly improve the health of millions of people worldwide by restoring or enhancing the function of damaged tissue. A key challenge is to create three dimensional porous scaffolds aimed at specific tissue engineering applications.

Tissue engineering is the process of organizing human or other mammalian cells into forming functional tissue. Future advances in the field may very well provide economically sound alternatives to donor tissue and eliminate the risk of disease transmission. To accomplish this we need to find suitable cell sources, explore the optimal culturing conditions, and develop compatible materials with tailored chemical, topographical, and mechanical aids for cell support. Ultimately, in the case of regenerative medicine, doctors must devise the least invasive surgical method for implantation into the patient.

### 3D cultures for drug screening

Three dimensional cell cultures may also serve as practical alternatives to natural tissue in pharmaceutical research. These systems provide an environment where one or more cell types can be encouraged to form tissue-like constructs using synthetic scaffolds for structural support. Notably, 3D cell culture models can provide a platform for improved screening of candidate drugs. This reduces the need for animal testing and permits a more straightforward understanding of the relationship between cause and effect in drug safety and efficacy studies.

Until now, the industrial standard has been two dimensional cell cultures grown in Petri dishes or animal models. Both have major disadvantages. Drug toxicity responses from 2D cell cultures of human cells are often misleading, while animal models are expensive, time consuming, ethically problematic, and may give aberrant, species specific results.

3D cell culture systems provide a promising solution because they combine the cell-cell and cell-drug interactions observed in animal models with the reproducibility and scalability of laboratory cultures. Therefore, 3D cell cultures are increasingly being applied, e.g. for screening of potential anti-cancer drugs and for testing of tissue specific toxicity.

### A scaffold for accelerated bone formation

The key challenge is to create porous scaffolds that are useful for, e.g. bone tissue engineering. These scaffolds are designed with focus on their biocompatibility, mechanical properties, porosity, and a well-controlled microstructure and nanostructure. One route to build them is 3D printing. This technique makes it possible to fabricate scaffolds and implants from computer generated drawings, which offer clinicians the option of implants that are custom-made for the individual patient.

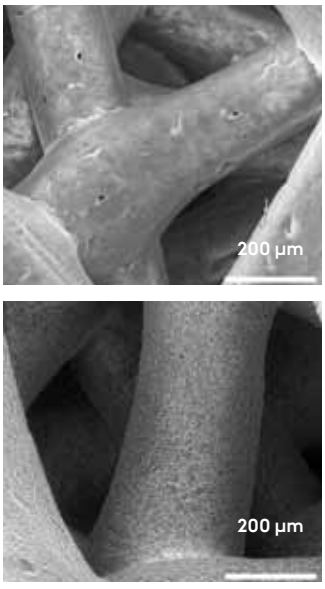
However, one drawback of printed scaffolds is the lack of surface features on the micrometre and nanometre scale, which is vital for cellular attachment and stem cell differentiation. Furthermore, functionalization of the scaffold with drug nanoparticles is impaired because the available area on a smooth surface is insufficient. To counter these limitations, we have developed a new solvent-based technique to add micro- and nano-roughness to virtually all types of porous polymer scaffolds. This method is very effective for organizing mesenchymal stem cells and growing bone tissue.

### The new CarouCELL perfusion bioreactor

The remaining challenge for shifting cell culture procedures from flat Petri dishes to 3D scaffolds is to ensure perfusion of fresh medium throughout the scaffold in order to maintain a viable and homogenous cell population. This can be achieved by using perfusion bioreactors, which applies motorized pumps for moving the cell culture media through the scaffold.

However, conventional perfusion bioreactors are big and require careful maintenance by skilled operators. Therefore, a cheaper, smaller, and better system is desirable, particularly in the clinical setting. To satisfy this need we have developed a downsized perfusion bioreactor, which lowers the costs of growing 3D cell cultures while fulfilling the need for disposability and flow reproducibility in biomedical research and clinical applications.

The new CarouCELL perfusion bioreactor has been patented and a new company CarouCELL ApS was established in April 2012 in collaboration between Aarhus University and the regional innovation incubator, Oestjysk Innovation A/S. The company is now taking the bioreactor product to the market.



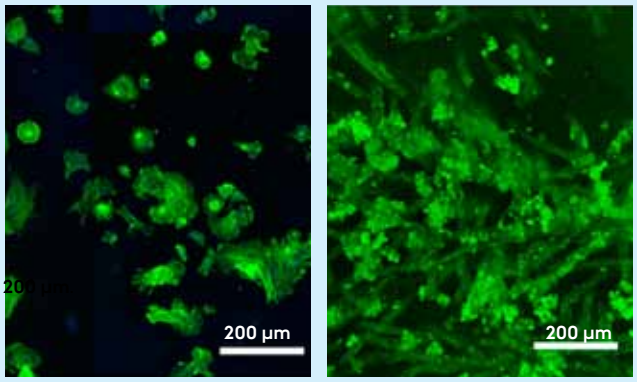

**The scanning electron micrograph (top) shows an untreated 3D scaffold made from a bioerodible polymer with a smooth surface.
The surface of the treated scaffold (bottom) is structured both on the micrometre and nanometre scales.**

**This texture provides a potent stimulus for the growth and differentiation of mesenchymal stem cells into bone tissue. The modified scaffold is also well suited for drug nanoparticle loading for screening of drugs.**

### Human stem cells for regenerative medicine

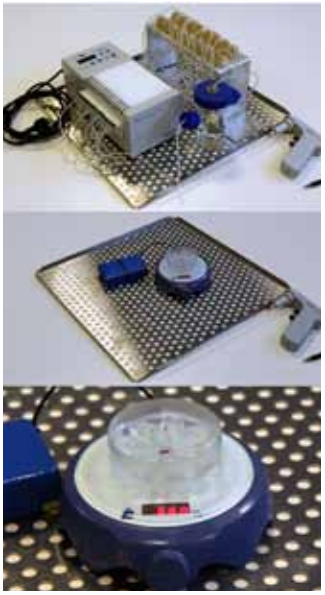
**Human mesenchymal stem cells are adult stem cells, which are accessible in the bone marrow, fatty tissue, skin, and gums. These cells have the ability to form several types of tissue including bone, fat, and cartilage.**

**Mesenchymal stem cells have become popular for biomedical research because of their broad potential and the ease with which they can be grown and expanded in a laboratory setting. With few ethical dilemmas attached and low risk of tumour development these stem cells are among the most promising cells for regenerative medicine.**




**2D versus 3D: Mesenchymal stem cells in a Petri dish (left) show a morphology resembling a cracked egg. This is a far cry from natural tissue where cells connect to each other or to their surroundings in three dimensions.**

**Liver cells in a fibrous polyester scaffold (right) show a vastly improved organization featuring aggregates of cells packed together around the fibres.**



**The conventional perfusion bioreactor (top) almost fills the 50×50 cm incubator tray.**

**In comparison, the compact CarouCELL bioreactor (middle) is easy to handle. The inside of the reactor (bottom) with the magnetic stirrer bar that generates a unidirectional flow through the peripheral scaffolds. As the bioreactor is fully submerged the fluid circuit (blue arrow) is closed by the container.**

# EVERY CELL MATTERS: PROBING **CANCER** FROM **SINGLE CELLS**

Cancer cells differ from each other, and whether a tumour grows or dies after a treatment depends on a small fraction of the cells. By studying individual cancer cells we aim to elucidate how cellular heterogeneity affects the efficacy of cancer therapy. This may lead to fundamental new insights into cancer as well as clinical applications in therapeutics and treatment evaluation.

Individual cancer cells in a tumour do not only carry different genetic information, but also behave differently from the majority of the tumour cells. Moreover, whether a tumour flourishes or dies after a given treatment depends on the small fraction of cells in the tumour, rather than the whole population. Currently scientists can only obtain general information from the entire population of cells in a bulk tumour, but our goal is to develop an effective and user-friendly platform capable of interrogating single cells.

Spotting the unique quirks of individual cancer cells could solve long-standing medical mysteries. How do cancer cells differ from normal cells? How will a specific tumour respond to a specific treatment? What methods should doctors use to predict the outcome of a therapy? And why is the efficiency of a given treatment inconsistent in different patients? Answers to these questions could have profound effects on the success of future cancer therapy.

### Interrogating individual cells

Cellular heterogeneity – the variation among seemingly identical cells – has a huge impact on the outcome of cancer treatments, such as chemotherapy. For instance, the prognostics of an important group of anti-cancer drugs, camptothecins, are hampered by the high heterogeneity of tumour cells. These drugs target the human enzyme topoisomerase, but previous studies have been unable to map out the relationship between enzyme activity and drug response at cellular level, which is critical for understanding the true effectiveness of the drugs.

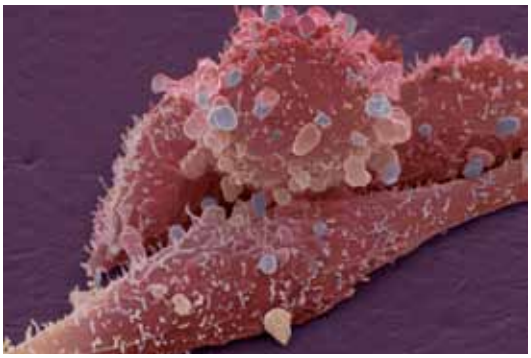
In order to investigate this relationship, we are building an integrated system to study the enzymatic activity of cancer cells quantitatively and dynamically at a single-cell level. Such analyses will remove the heterogeneity limitation imposed on traditional ensemble studies and so far our platform is the only system capable of resolving the enzymatic activity of individual cancer cells. The research project is supported by a Sapere Aude grant from the Danish Council for Independent Research, Technology and Production Sciences (FTP), and by Karen Elise Jensens Fond.

### Isolation in micro-droplets

An ideal single-cell assay requires high spatiotemporal resolution and high throughput, but no single experimental technique fulfills all these goals. We approach the problem from an engineer's perspective and work to utilize picoliters-sized droplets to assure uniform single cell encapsulation, proper reagents mixing, and reliable droplet incubation with therapeutic stimuli.

The small droplets measure 50-100 micrometers in diameters, while cells measure 10-20 micrometers across, and thus, each droplet contains a small number of cancer cells. A major research task is to develop methods to ensure most of the droplets contains just one cancer cell.

Having done that, variations of therapeutic stimuli, in particular different combinations of drugs, can be applied to single cells within a well-controlled micro-environment. With this set-up any differences in the response to a treatment can be directly attributed to heterogeneous cellular processes of individual cells. Our strategy combines a range of recent engineering developments in nanophotonics and microfluidics, and the experimental platform will not only allow spatial organization of single cells, but also temporal tracking of cellular responses during a drug screening. The exiting new possibility of resolving single-cell dynamics will ultimately lead to clinical applications in cancer therapeutics and treatment evaluation.

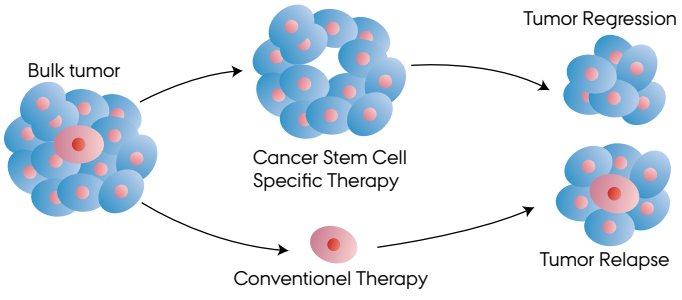


**One size does not fit all. Cancer cells in a tumour are as different from each other as humans in a population.**

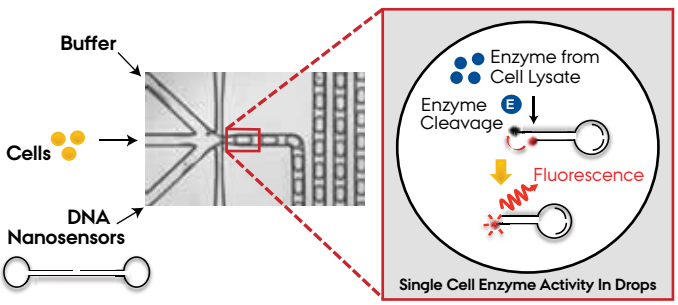
PHOTO: XXXX

Back row: Emil Laust Kristoffersen, Morten Leth Jepsen. Front row: Megan Yi-Ping Ho, Birgitta R. Knudsen.

PHOTO: JESPER RAIS / AU COMMUNICATION



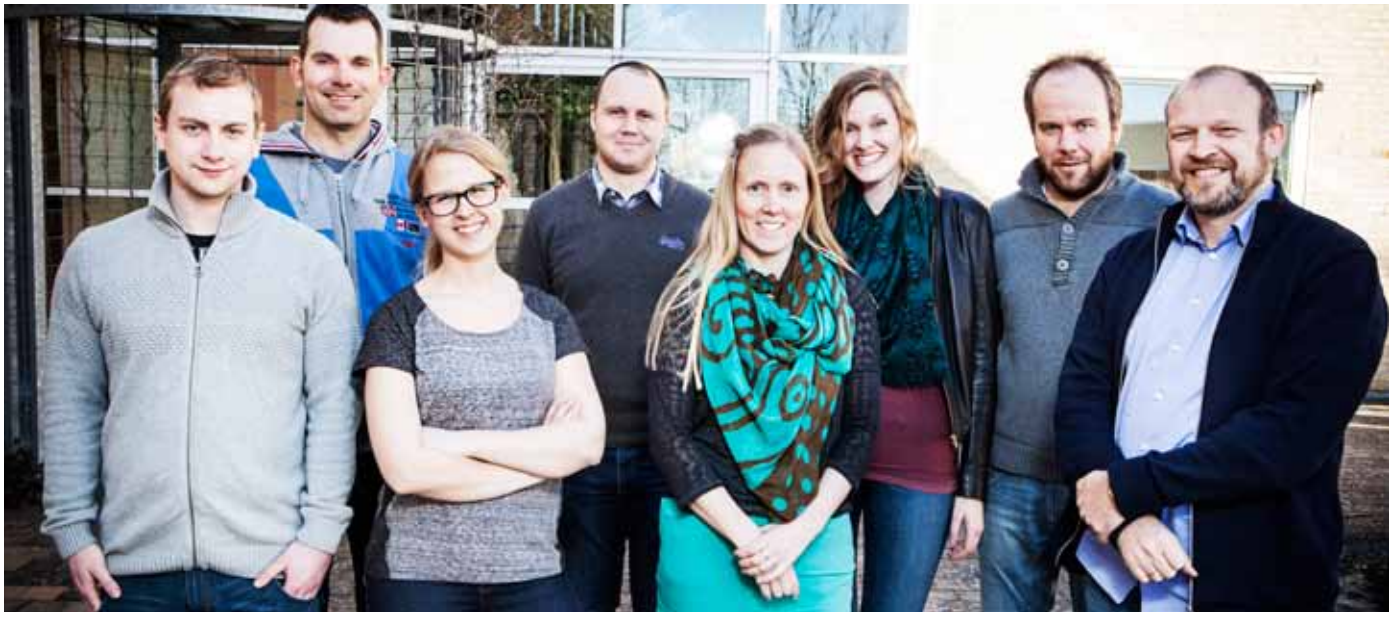

Why it is important to study individual cells in cancer therapy? Current theory suggests that cancer stem cells are the major cause of tumour relapse. However, while the bulk tumour is suppressed through conventional approaches, the cancer stem cells may be left unharmed. For a complete cure of cancers, it is of critical importance to locate the stem cells, which have unique characteristics compared to the majority of the tumour cells.




Generation of microfluidics-based droplets enables confinement of a controlled number of cells in a small volume of an incubator. Therefore, information extracted from each droplet can reflect the cellular processes from individual cells. This microfluidics-mediated assay enables a highly sensitive and simultaneous analysis of single cell enzymatic activities.

BY HENNING TIDOW,
JACOB LAUWRING ANDERSEN
and POUL NISSEN

# A TURBO **SWITCH** SPEEDS UP A **CRUCIAL CALCIUM PUMP**



**On the right: Professor Poul Nissen with postdoctoral fellow Henning Tidow, PhD student Sigrid Thirup and chief technician Anna Marie Nielsen. Furthermore, people of the drug discovery team are present in this picture (from left): Jens Christian Bredahl Sørensen, Claus Olesen, Christine Juul Fælled Nielsen and Jacob Luawring.**

PHOTO: JESPER RAIS/AU COMMUNICATION

In plant and animal cells calmodulin-stimulated calcium pumps are key regulators of the calcium concentration inside the cells and therefore essential to life. If they fail, the intracellular calcium concentration rises pushing the cell to commit suicide. The pump contains a previously unknown third gear that makes it flush calcium out of the cell. These three stages of progressive activation enables tight control of cellular calcium and reveals new drug targets.

Calcium plays a central role in most signalling processes of life such as changes in cell activity or cell division. Calcium signalling derives from the 20.000-fold gradient between the high concentration outside the cells and the low intracellular level. For example, during signalling or under stress the calcium concentration inside the cells increases due to opening of calcium channels and triggers a corresponding reaction.

Afterwards, the intracellular concentration must be lowered again. This task is carried out by a calcium pump known as PMCA. These high-affinity pumps are situated in the cell membrane and they export calcium ions (Ca2+) from the cytoplasm to the extracellular environment. The pumps are crucial for controlling the overall balance of calcium inside cells and for local intracellular calcium ion signalling.

### A regulatory switch

Export of calcium out of the cell requires a lot of energy due to the high concentration gradient. Thus, it is important that the pump is activated only when needed and cannot go in reverse. Therefore, the pump has a regulatory switch, which is actuated by the protein calmodulin. When calcium binds to calmodulin, the protein changes its shape, which enables it to dock onto the switch and activate the pump. If the intracellular calcium concentration keeps on rising, more and more pumps are turned on. However, until recently the detailed mechanism of this regulation was unknown due to the lack of structural information.

### Determining the atomic structure

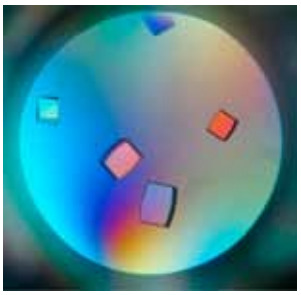
We determined the structure of a complex between the regulatory domain of the calcium pump and calmodulin by X-ray crystallography and small-angle X-ray scattering. To our great surprise, we found that the calcium pump has two binding sites for calmodulin and not just one as always thought. While the first site had been previously mapped by mutational studies the second binding site has never been discovered before. The SAXS studies confirmed this unexpected result from the crystal structure.

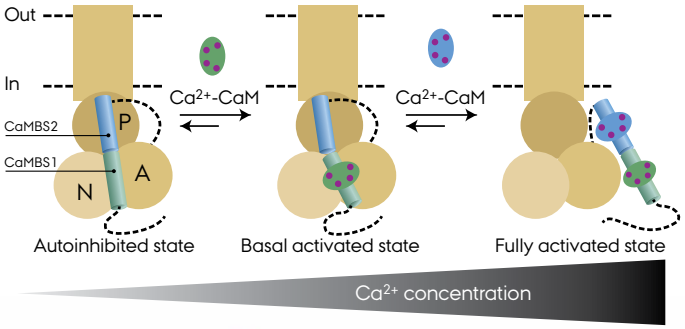
### Progressive activation in three steps

The next step was to determine whether the newly discovered second binding site for calmodulin has biological significance, which was studied in yeast and the model plant thale cress. In combination with mathematical modelling the experiments revealed that pumps in which one of the two calmodulin binding sites was disabled could not reach full power.

The results show that the calcium pump is controlled in three steps: Under very low intracellular calcium concentrations the pump is completely inactive. When the concentration increases calmodulin binds to one site within the regulatory domain, which leads to moderate pumping. When the concentration rises to even higher levels calmodulin complexes bind to both sites and the pump rapidly transports large amounts of calcium out of the cell.

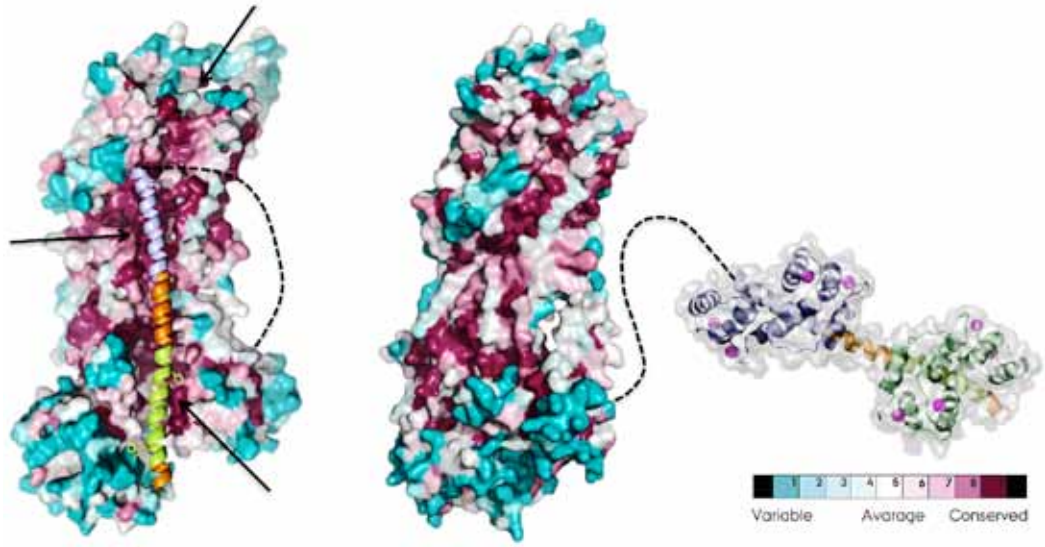
In conclusion, we have developed a general structural model for calmodulin-mediated regulation of PMCA calcium pumps involving a turbo switch. This mechanism allows for a stringent and highly responsive control of the intracellular calcium concentration in plant and animal cells. This discovery improves our understanding of a fundamental biological mechanism in all higher organisms. In the future the discovery could allow for better treatments of certain diseases in which the calcium balance is disturbed. An example is chronic kidney disease.






**Left: We used crystals of the regulatory domain of calcium pumps from thale cress (*A. thaliana*) in complex with calmodulin and $Ca^{+2}$ for structure determination. The crystals were obtained by the sitting-drop vapour diffusion method and grew to dimensions of up to 0.7 x 0.35 x 0.2 mm.**

**Right: The schematic shows the three stages that enable the calcium pump to respond progressively to rising intracellular calcium concentrations: The inactive stage. The basal activated stage with one calmodulin molecule bound to the pump. The fully activated stagewith two calmodulin molecules attached to the pump. The dotted lines represent the cell membrane in which the calcium pump is situated.**




**Structural models of the calcium pump during its inactive stage and fully activated stage. Drug sites of interest are marked with arrows.**

### New targets for chemotherapeutics

**The SERCA calcium pump is related to the PMCA calcium pump and it is present in all higher cells, where it pumps calcium from the cytoplasm into internal stores, e.g. when muscles are relaxed.**

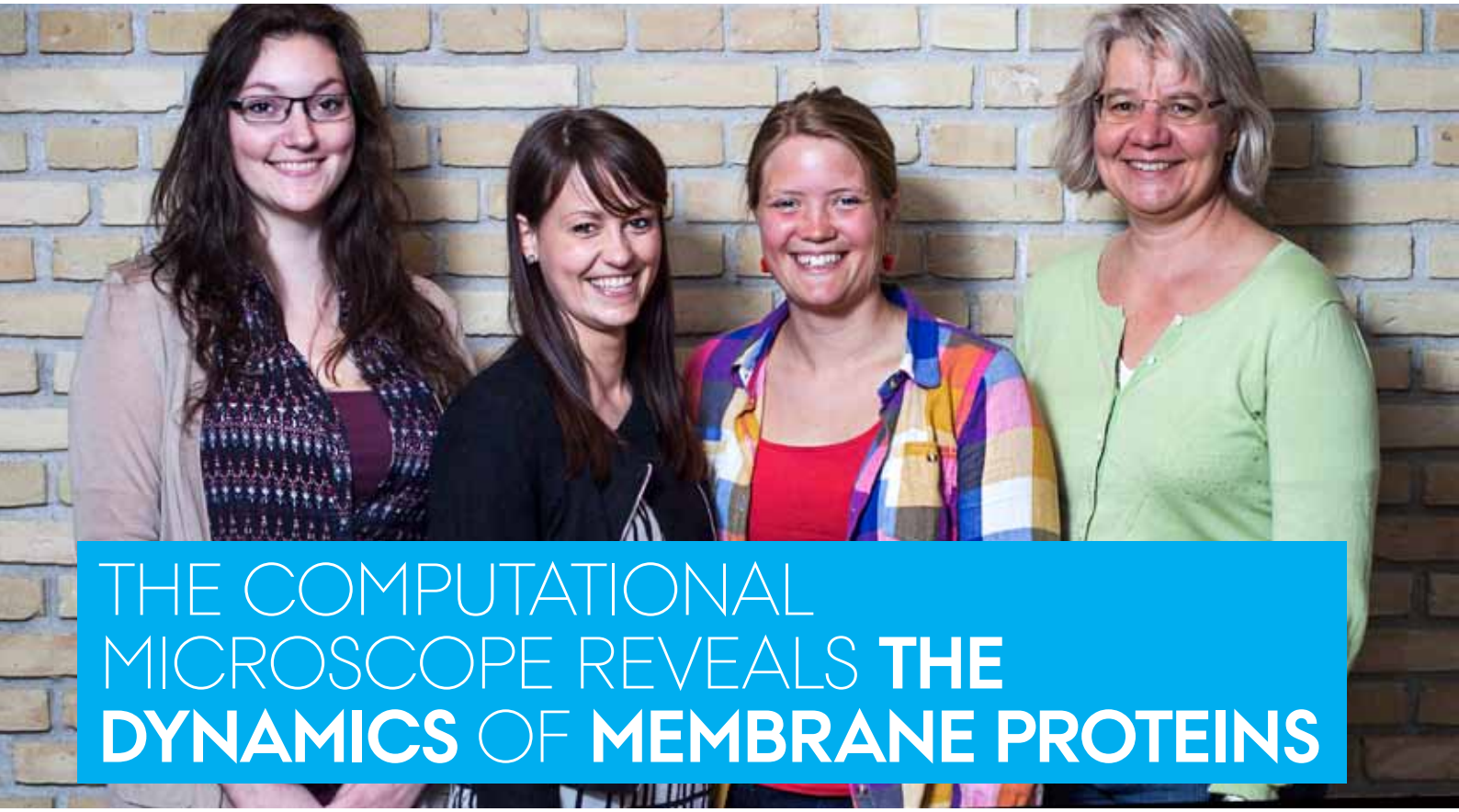
**This calcium pump has been extensively studied in our lab with structure determination of several high-resolution crystals structures in different functional stages as well as in complexes with inhibitors and regulatory proteins.**

**These structures do not only enable detailed insight into the functional reaction cycle of ion pumps like PMCA and SERCA, but also provide a basis for drug discovery. If drugs can be targeted specifically towards tumours the calcium pumps of the cancer cells are promising targets for chemotherapeutics since the cells commit suicide by apoptosis if the pumps are blocked.**

### Bacterial ion pumps and new antibiotics

**Bacteria also possess calcium pumps as revealed by the increasing number of sequenced bacterial genomes. Their functions are still poorly understood, but a calcium pump from *Streptococcus pneumonia* has been shown to be vital for the survival of the pathogen in the infected host. Similarly, bacterial copper pumps from the same protein family are critically important for pathogenic organisms.**

**These bacterial ion pumps are attractive targets for new antibiotics. Their activity is easily monitored in high-throughput assays that facilitate powerful drug discovery programs in combination with structural studies.**



# THE COMPUTATIONAL MICROSCOPE REVEALS **THE DYNAMICS** OF **MEMBRANE PROTEINS**

Access to large computer clusters at supercomputing facilities has opened a new avenue for molecular dynamics simulations of biological systems at relevant timescales. This is extremely helpful in connection with linking different pieces of experimental data and developing improved drugs, diagnostic tools, and commodity enzymes for industrial use.

From left to right:
MSc. student Lucy-Kate Ladefoged
Post Doc Heidi Koldsø
PhD-student Julie Grouleff
Professor Birgit Schiøtt

PHOTO: JESPER RAIS / AU-COMMUNICATION

Cells communicate with their environment through proteins embedded in their encapsulating membranes. An example is the transmission of nerve signals by neurotransmitters. These compounds are released from the presynaptic neuron, while specific proteins situated in the membrane of the postsynaptic neuron act as receptors for the neurotransmitters and transfer the signals along the nerve cells.

With the appearance of high resolution 3D-structures of membrane proteins over the last decades, it has become possible to describe the underlying mechanisms of these vital signalling processes at the atomic level. However, structures obtained from protein crystallography only provide snapshots of stages in the transport process, thereby leaving the dynamics of working membrane proteins open for hypotheses.

Molecular dynamics simulations provide a powerful tool for exploring the dynamical properties of membrane proteins at an atomic level. With the appearance of large supercomputing facilities interconnecting thousands of CPUs, it is possible to perform simulations of important molecular processes at biologically relevant timescales and sizes. Molecular dynamics simulations are often phrased as a computational microscope because they allow researchers to follow molecular events at a spatiotemporal resolution that has yet to be achieved experimentally.

### A bio-nano-machine at work

Secondary active transporters are membrane proteins responsible for the transport of molecular cargo – such as a neurotransmitter – through the cell membrane against its concentration gradient either into or out of cells. This process is fuelled by simultaneous transport of ions across the membrane exploiting ion concentration gradients.

The human serotonin transporter belongs to this class of membrane proteins and its function is re-uptake of the neurotransmitter serotonin into the presynaptic neuron after a nerve signal has been passed along. In this way the transporter acts as an off switch during nerve signalling. The serotonin transporter plays a key role in maintaining correct synaptic concentrations of the neurotransmitter, and thus, it

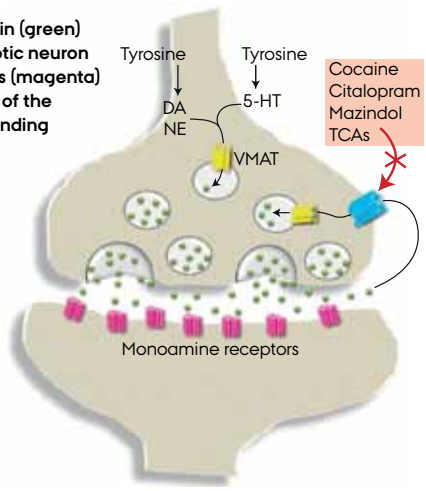
constitutes a target for the treatment of several psychiatric diseases related to serotonergic dysfunction such as depression, obsessive compulsive disorder, and post-traumatic stress disorder. It is assumed that this class of transport proteins works through an alternating access mechanism, where they are open either to the extracellular side or to the intracellular side, but never to both sides simultaneously. The transporter is able to exchange the cargo with its surroundings both in the outward-facing and in the inward-facing conformation.

In 2005, the first crystal structure of a similar bacterial membrane protein became available. The structure revealed an open conformation that is outward-facing, but yet occluded in such way that the substrate binding pocket is shielded from the extracellular and intracellular medium. This discovery enabled us to computationally explore the 3D-structure of the human homologues and we proposed structural models of the human serotonin transporters bound to either the neurotransmitter or to an inhibitor. These models were later experimentally validated by our collaborators.

In order to relate the physiological function of the human serotonin transporter to its dynamical properties, we set out to use molecular dynamics simulations. For the first time ever, we were successful in simulating a transition of the protein from an outward-facing conformation into an inward-facing conformation. During the conformational change it was observed how a sodium ion is released to the intracellular side of the cell, and how the lipids of the membrane bilayer smoothly adapt to the conformational change of the protein. Our simulations suggest that a delicate hydrogen bonding network just below the substrate binding site may serve as a molecular trigger for the conformational transitions to occur.

## Rational drug design

Since the human serotonin transporter and two other similar human transporters, the dopamine and norephinephrine transporters, are major drug targets for treatment of several psychiatric diseases, the knowledge gained with the computational microscope can be exploited in the rational drug design of future medicines targeting these membrane proteins.




**The neurotransmitter serotonin (green) is released from the presynaptic neuron and binds to protein receptors (magenta) embedded in the membrane of the postsynaptic neuron. After sending the signal along the neuron through the serotonin transporter (cyan) and restored in vesicles for future use by the vesicular monoamine transporter (yellow). This membrane protein is a major drug target for a range of psychiatric diseases.**

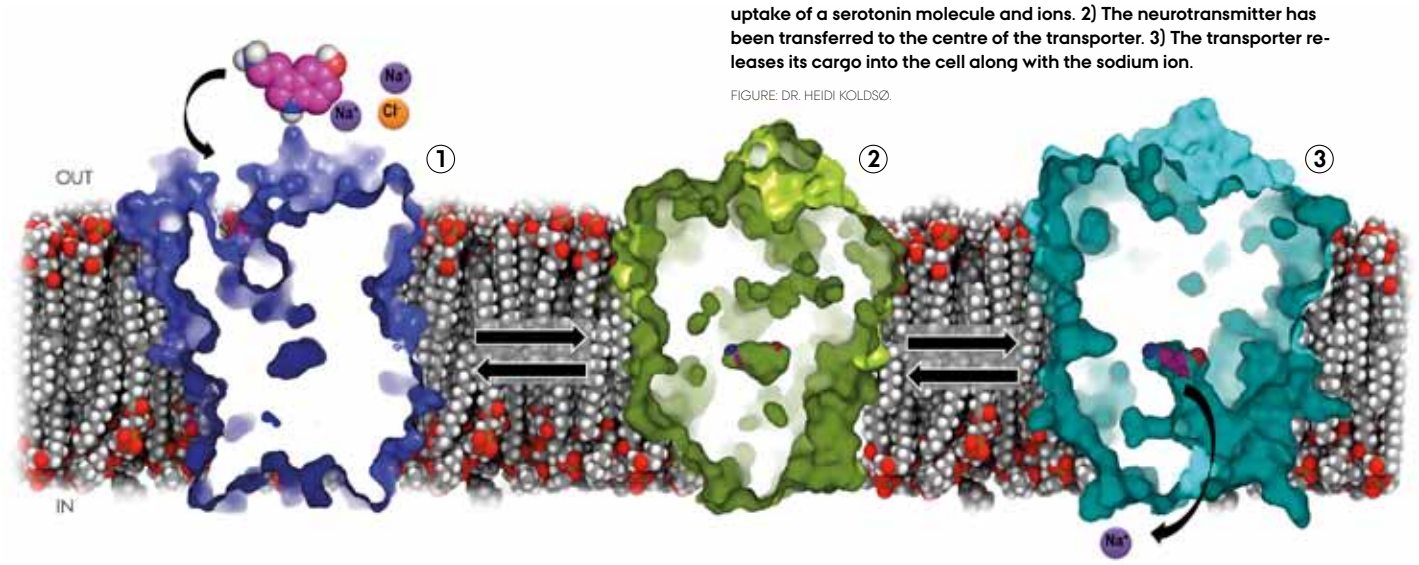
FIGURE: DR. HEIDI KOLDSØ.

Rational drug design depends on reliable structural models of the protein targeted, accessible from either protein crystallography or NMR. The use of molecular dynamics simulations widens the protein ensemble to consider for targeting in drug design studies and enables the design of small molecules that can bind to different conformations of a given protein. In most cases such information is not available from experiments. Therefore, the obtained knowledge could be beneficial for limiting side effects of drugs, optimizing drug selectivity, and targeting membrane proteins from the extracellular side of a membrane in order to eliminate issues related to moving the drug across the cell membrane.

We are currently involved in several studies along these lines. We are exploring at an atomic level how a known non-competitive inhibitor, ibogaine, may bind to the human serotonin transporter and influence its dynamics differently than current drugs on the market, which are competitive inhibitors. The results of these studies may be useful in connection with designing drugs to treat addiction of illicit drugs such as cocaine in the future.

**The first glimpse of the human serotonin transporter at work at an atomic level obtained through molecular dynamics simulations. From the left: 1) The transporter is open to the extracellular medium ready for the re-uptake of a serotonin molecule and ions. 2) The neurotransmitter has been transferred to the centre of the transporter. 3) The transporter releases its cargo into the cell along with the sodium ion.**

FIGURE: DR. HEIDI KOLDSØ.



# INTRINSICALLY DISORDERED PROTEINS: A **NEW PARADIGM** IN **STRUCTURAL BIOLOGY**

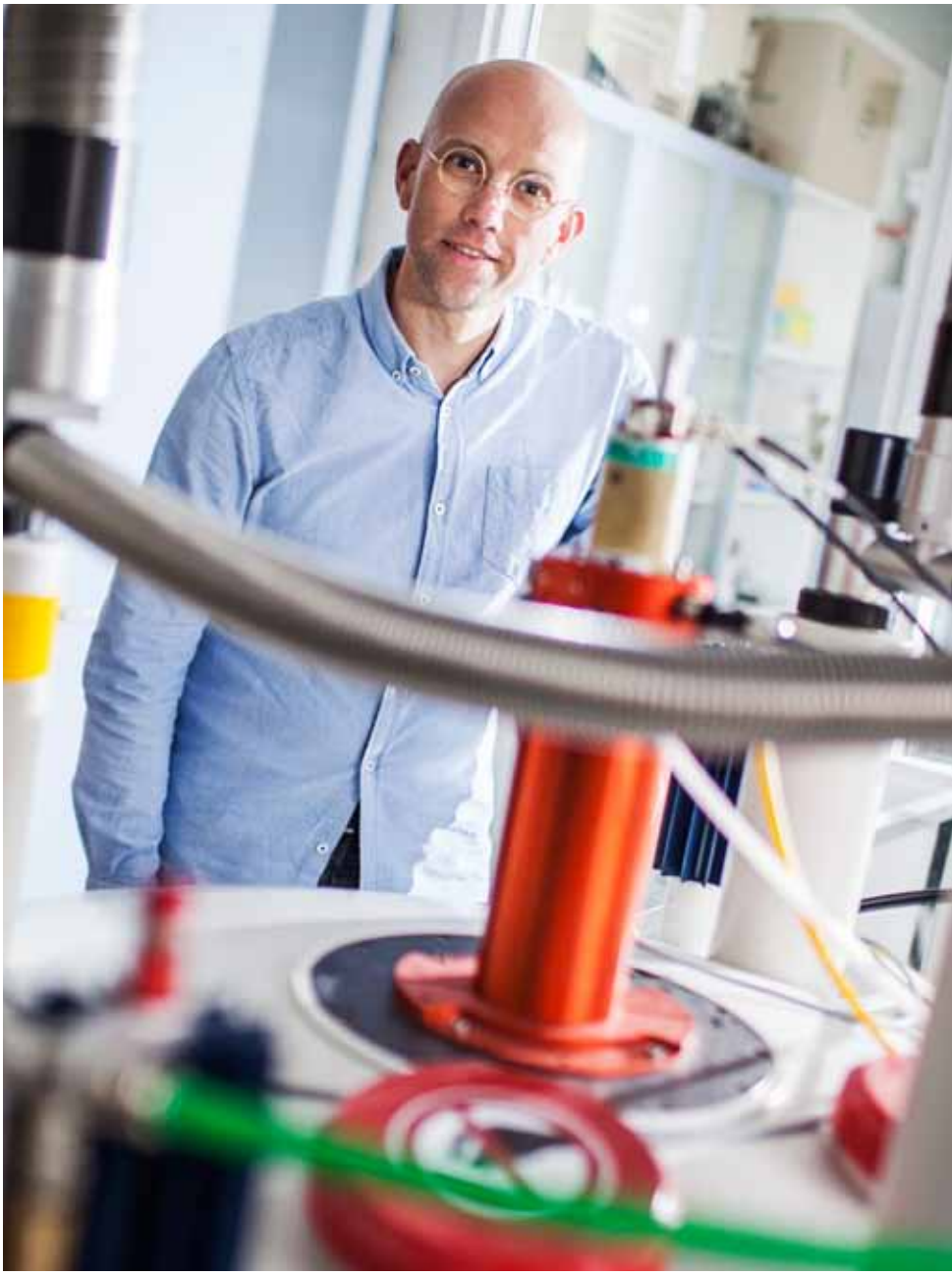


PHOTO: JESPER RAIS / AU COMMUNICATION

It is estimated that more than a third of eukaryotic proteins contain long intrinsically disordered regions and such proteins are involved in all kinds of human diseases. Therefore, ensemble-based views of protein disorder are a necessity for improving our understanding of molecular biology and for developing new drugs that target networks and pathways rather than single proteins.

Pro teins are the building blocks and workhorses of all living organisms. For decades it has been a central dogma that the function of a protein is determined by its fully folded three-dimensional structure. But recently it has become increasingly clear that many regulatory proteins are unfolded or only partially folded.

Such intrinsically disordered proteins can adopt a wide range of conformations in solution, and despite the lack of a well-defined structure these disordered proteins possess a functional repertoire that complements the functions of ordered proteins. Because of their inherent plasticity intrinsically disordered proteins are uniquely suited as hubs in protein networks, where they may interact with many different partner molecules using adaptable surfaces.

Phylogenetic analyses have demonstrated that disordered proteins play prominent roles in cell signalling and regulation, and they have been implicated in all human diseases including cancer, diabetes, and cardiovascular disease. In particular, disordered proteins are causative agents in neurodegenerative diseases such as Alzheimer's and Parkinson's.

The famous 1894 lock-and-key model of drug action by Emil Fischer has no validity for intrinsically disordered proteins and needs to be replaced by more complex models that take disorder, dynamics, and entropy into account. New, ensemble-based views of proteins are a necessity for identifying suitable drugs.

### The nuclear pore complex

Recently, a study of intrinsically disordered proteins was carried out in collaboration with Liesbeth Veenhoff and Bert Poolman at the University of Groningen in the Netherlands. The results shed new light on the transport of cellular material into and out of the cell nucleus, which is essential for eukaryotic cells and hence for the existence of higher organisms.

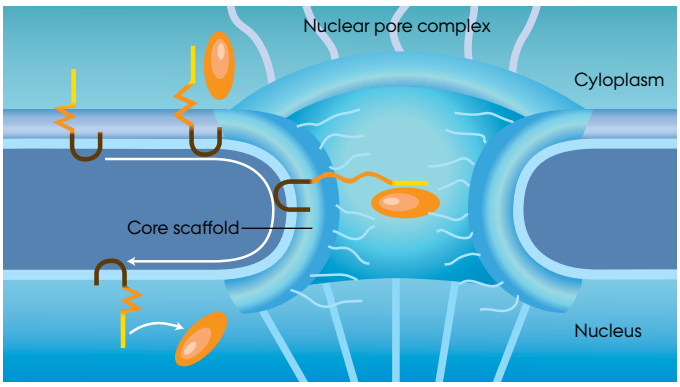
The cell nucleus is surrounded by an envelope that consists of an inner and an outer membrane. The two membranes are connected by pores through which the transport of cargo takes place and these pores are made up by a very large protein assembly called the nuclear pore complex. This complex is shaped as a doughnut with a central region that functions alike a semi-permeable membrane.

Cellular proteins destined for the interior of the nucleus carry a specific address label in the form of a stretch of amino acids. Helper proteins bind to these amino acids and assist in the delivery of proteins from the cytoplasm through the pore and into the cell nucleus.

### Transport of membrane proteins

However, it has been unclear how membrane proteins situated in the outer membrane are able to reach the inner membrane. Based on the form of the pore complex it was tempting to assume that the entire membrane protein would be transported in between the lipid membrane and the doughnut shape. This is possible because the outer membrane and the inner membrane connect around the pore. But surprisingly, our experiments showed something entirely different.

While the transmembrane region of the protein stays in the nuclear membrane, the terminus containing the address label passes through the semipermeable centre of the pore. Throughout the transport process an intrinsically disordered domain, placed between the terminus and the transmembrane region of the membrane protein, stretches out and keeps these domains connected. Our results indicate that at the atomic level the doughnut shape of the nuclear pore complex cannot stay intact, but has to allow the passage of the intrinsically disordered region of the protein cargo. This domain slices through the doughnut, just like a cutting knife. A minimum length of the intrinsically disordered domain was found to be essential to sustain membrane protein transport.




**The cell nucleus is surrounded by an envelope with two membranes. The schematic shows how a membrane protein is transported from the outer to the inner membrane. The terminus (white line) of the membrane protein forms a complex with a helper protein (yellow oval). As this complex move through the central hole of the pore an intrinsically disordered domain of the membrane protein (orange line) stretches out and pulls the transmembrane region (brown line) along with it. This tether slices through the nuclear pore complex like a cutting knife.**

ILLUSTRATION AFTER: B. STRAUCH/SCIENCE

### NMR experiments

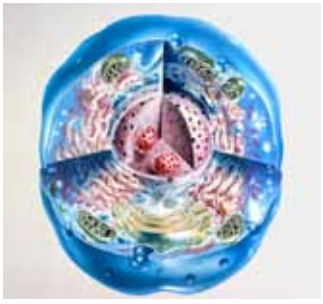
The intrinsic disorder of the linker region was elucidated by protein NMR spectroscopy, which records signals coming from the atomic nuclei of a sample. We can measure the distance between atoms and thereby build three-dimensional models of the atomic structure of a protein. We can also measure how a protein interacts with a drug and determine how the drug molecule may be refined in order to bind stronger or more specifically to its target. Furthermore, we can study various dynamic events, such as enzyme catalysis and protein folding.

Speaking of versatility, NMR spectroscopy is not just applicable in solution, in crystals, and in powders, but also in living plant, animal, and human cells. With its exquisite sensitivity for the chemical identity of molecules, it is a vital analysis tool for synthetic organic chemists, and increasingly so for the clinic and drug discovery.

### A bright future with ultra-high-field NMR spectroscopy at iNANO

In 2013 a new state-of-the-art 950 MHz NMR spectrometer will be installed at iNANO, boasting the highest field in Scandinavia. This investment has been made possible through a research infrastructure grant from the Danish Agency for Science, Technology and Innovation. The new machine will be the core of a Danish and European high-field NMR instrument centre that will involve collaborations between academia and industry.


**For experimentalists the new ultra-high-field NMR spectrometer at iNANO is a dream coming through.**



**Artist's impression of an animal cell. The cell nucleus is seen in the centre**

ILLUSTRATION: WWW.SCIENCEPHOTO.COM/

BY MINGDONG DONG AND
RIKKE LOUISE MEYER

# THE ROAD TO NANOCABLES:
## FROM NANOFABRICATION TO CHARACTERIZATION OF NEWLY DISCOVERED CABLE BACTERIA

Nanowires show great potential for applications in electronic and optical devices. Thus, fabrication of long nanowires and insulated nanocables are key research targets at iNANO. Inspiration can be found in nature. Recently discovered cable bacteria in the sea floor are forming centimetre long conductive filaments that are only a few hundred nanometres wide.

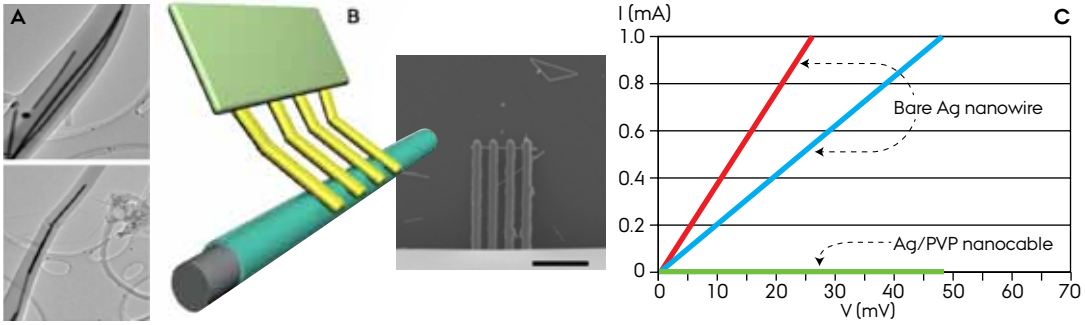
Electrical wires and cables are everywhere in our daily life. They conduct electric currents and transmit electronic signals. A global trend in the development of improved conducting wires is downscaling of the diameter. This miniaturization is much desired by industry and a promising technology is fabrication of nanowires, which are one-dimensional nanomaterials with sufficient conductivity and low production costs. Nanowires demonstrate extraordinary properties compared to macro scale wires due to their high aspect ratios. Therefore, nanowires possess a huge potential for applications in electronic, optic, and sensing devices.

### Metallic nanocables with an insulating sheath

However, many challenges must be overcome before it will be possible to transfer recent scientific results into industrial technology. A particularly important challenge arises from contaminants, oxidation, and leaky insulation between the nanowires in a cable.

The conventional solution is to enclose metallic nanowires in an insulating sheath. Unfortunately, the traditional methods for fabricating core-sheath nanocables are often costly and time-consuming. Hence, they require a complicated multi-step process, which limits their suitability for industrial scale applications. Furthermore, integration of nanowires into consumer electronics is possible only if their length is increased.

Fabrication of long nanowires and nanocables is a key research area at iNANO. Our nanowires are characterized by state-of-the-art methods in order to explore their properties and realize their future applications.




**We have developed a new route to fabricate silver nanowires (A with a polymer sheath using a one-step electrospinning method. Four probe measurements (B) indicate that the single crystal nanowires show excellent conductivity (diagram – C). In contrast, it was impossible to pass any current between the insulated nanowires in the cable.**

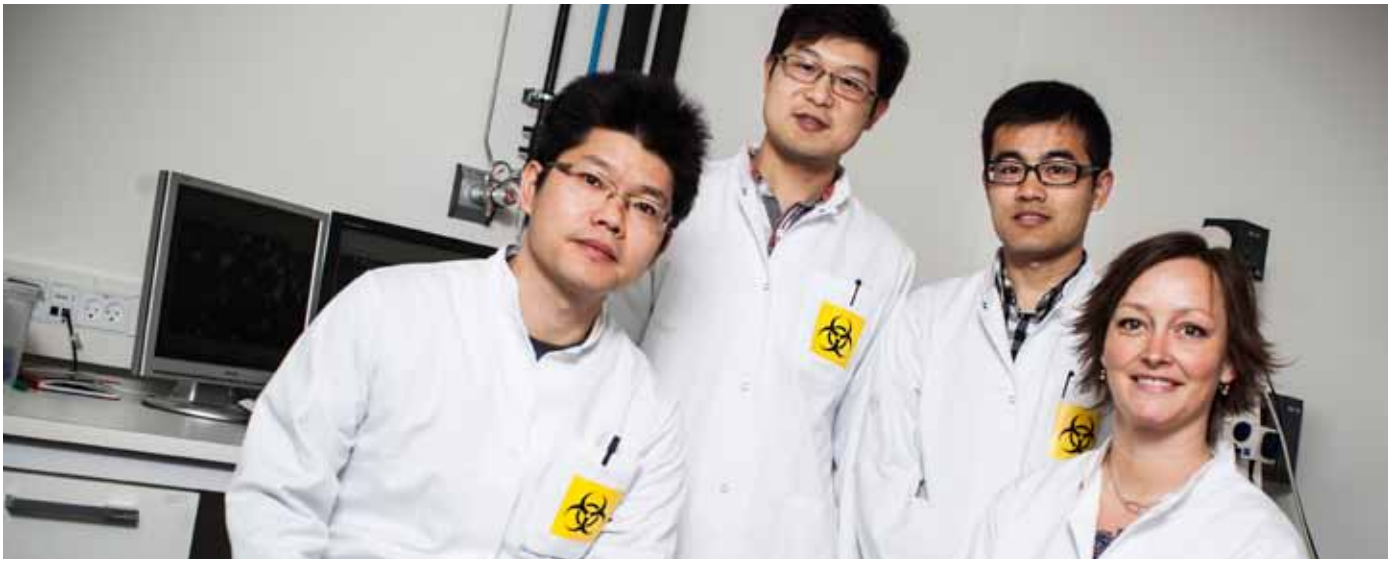
### Nanofabrication in a single step

Recently, we have developed a one-step process to produce silver nanowires with well-defined dimensions. Because of their intriguing electrical, thermal, and optical properties, nanocables with silver nanowires in the core present very exciting properties for a broad range of applications. The new route to production of silver nanowires with an insulating polyvinylpyrrolidone sheath is based on a one-step electrospinning process. Electrospinning is a straightforward, robust, and low-cost method that is suitable for industrial scale production.

The successful synthesis of nanocables has been confirmed by scanning electron microscopy (SEM) and transmission electron microscopy. Furthermore, the conductivity of the nanocables has been tested using an auto-mechanical arm with four probes placed along the cable in a SEM chamber. These measurements indicate that the single crystal silver nanowires are excellent conductors. In contrast, it was not possible to pass any current between the insulated wires. This shows that the silver nanowires are effectively insulated and perform as an ideal nanocable. However, the current fabrication method limits the length of the nanocables to micrometre distances. Further development is under way at iNANO with the aim of fabricating longer nanocables.

### The discovery of natural nanocables

Inspiration for new materials can often be found in nature. Some bacteria are able to respire solid minerals, such as manganese oxide, and they form extracellular protein fibres in order to transport electrons from the cell to the mineral. These fibres essentially work as microbial



**Left to right: Assistent. Prof. Mingdong Dong, Post Doc Guanghong Zeng, PhD Student Qiang Li and Assoc. Prof. Rikke Louise Meyer.**

PHOTO: JESPER RAIS / AU COMMUNICATION

nanowires, providing a direct electrical connection between the bacterium and the mineral. This concept is being exploited in the development of microbial fuel cells. Biological nanowires may also allow nanoelectronic devices to operative in aqueous and moisture environments.

All microbial nanowires described previously have fundamental limitations because they do not appear to be insulated and only conduct electrons over micrometre distances. Therefore it was a great surprise when Lars Peter Nielsen's group at Aarhus University discovered a few years ago that electrons are conducted over centimetre distances in the seafloor by bacteria. In this way oxygen reduction at the sediment surface is coupled with sulphide oxidation occurring more than a centimetre below the depth where oxygen disappear.

### Unveiled by the SEM microscope

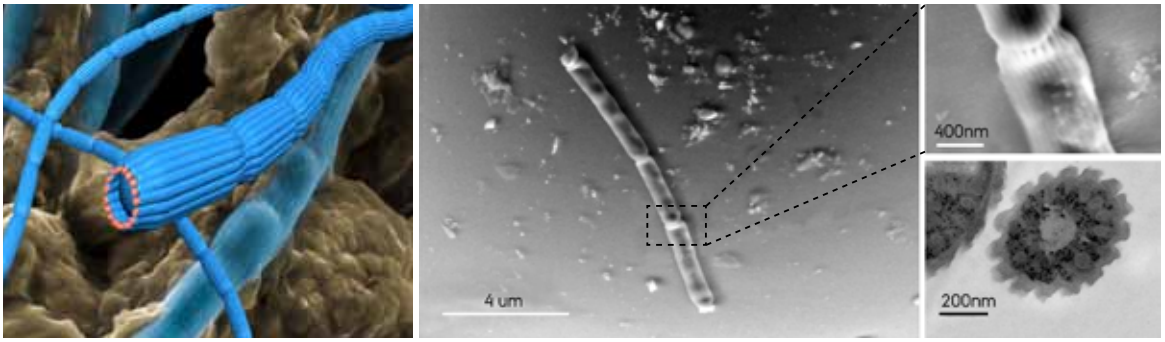
This discovery initiated an intensive hunt for the mechanism behind this surprising long-distance electron transport. At iNANO we used scanning electron microscopy to magnify the mud of the seafloor thousands of times in order to look for important clues.

By chance, our eyes caught some rather unusual looking bacteria, which were forming filaments with strings along the surface – a phenomenon that had never been seen before. The culprit turned out to be thousands of cells connected with an array of membrane insulated strings providing unbroken electron transport from one end of the filament to the other.

These filaments attained individual lengths beyond 1.5 centimetres confirming that single filaments could span the gap between oxygen and sulphide in the sediment. The bacterial cables were highly abundant – the sum of filaments accumulated to a total length of 117 meters per cm3 in the sediment layers where the electron transport takes place.

### Biocompatible and biodegradable devices

The cable bacteria present a previously unknown lifestyle, and many questions remain unanswered as to how energy is conserved along the length of the conductive wires, how the wires are produced, and what they are made of. As we learn more about them, we may find applications in biocompatible and biodegradable devices, biosensors, and soft electronics as well as novel applications that may arise from so far unexplored optical, magnetic, thermal, mechanical properties of these living electrical cables.




**Left: an artist's impression of the bacterial nanocables in the mud of the sea bottom.**

**Right, the grey colored photo: the real thing – living electric cables pictured by scanning electron microscopy at iNANO.**

# MESSAGE FROM THE CHAIRMAN

2012 was another exciting year for iNANO. The highlights were certainly the initial opening of the iNANO house in August 2012 and the official inauguration on January 16th, 2013.

The idea of an iNANO house was born more than seven years ago and only through a persistent and concerted effort from professor Flemming Besenbacher and his team (among them Brian Bech Nielsen, now the Dean at Science and Technology) and the great support from others at Aarhus University (in particular building director Bent Lorenzen) did this fantastic building become reality.

The idea to gather a large part of the iNANO "family" under one roof is as evident as it is promising. The possibility to interact informally and reshape the future of research together is the natural next step in a continuing process of breaking down barriers and working together in a truly interdisciplinary environment.

The moving process seemed like a daunting task with many pitfalls but I have heard nothing but praise for the almost military-style (but still flexible and user-oriented) precision employed. The new management headed by Director Niels Christian Nielsen and the team around him should be praised for a job well done now that the relocation process is coming to a close.

With the new house in operation and an impressive history of numerous successful projects in collaboration with industry, many of which seek to meet global Grand Challenges, iNANO is in a unique position to tap into the new national innovation strategy proposed by Minister for Education Morten Østergaard just before Christmas 2012. iNANO's three equally important pillars (education, research, and innovation) indeed fit right into the new innovation strategy so I have high hopes for extensive iNANO participation in the funding programs, which will become the concrete manifestations of the innovation strategy.

Thank you for an adventurous year; I am proud and excited to be part of the iNANO family and look forward to seeing more exciting science and innovation emerge throughout 2013.

Bjerne Clausen
Chairman of the iNANO Board
Chief Executive Officer
Haldor Topsoe A/S


ALFA LAVAL
ALK ABELLÓ
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CHR. HANSEN
CLC bio
Coloplast
Danfoss
Danfoss BIONICS
DPA MICROPHONES
DUPONT
DYRUP
Elkem
ELOS PINOL
eva
fef Preserving Your Quality
FERRING PHARMACEUTICALS
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Fibertex
FLSmidth
Fresenius Kabi Caring for Life
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Gram Equipment
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H2 Logic
HALDOR TOPSØE CATALYSING YOUR BUSINESS
Ibsen photonics
Ignis
image Metrology
IDT INTEGRATED DNA TECHNOLOGIES
ipht jena
JPK Instruments
KinaseDetect
KOHERAS
LEO Pharma Nordic
Gerstenberg Schröder
LU-VE GROUP
MANKIEWICZ
MERCK
MERCK SERONO
molegro
NanoNord A/S
NIL TECHNOLOGY
NILAN OUTSTANDING INDOOR CLIMATE
NKT Photonics the power of light
novo nordisk
Novosense
novozymes Rethink Tomorrow
ofs A Furukawa Company
oticon PEOPLE FIRST
pBeSt coating
PANCO GmbH
PCOVERY MEMBRANE PROTEIN DRUG DESIGN
PEPSCAN
Pipeline Biotech A/S
Polyplus transfection
POLYTEKNIK HOUSE OF COATING TECHNOLOGY
qsense
Quantum Wise
RA CELL
Regulon
RiboTask
RiNA
Roche
VARIAN
sanofi aventis
SANTARIS PHARMA
SP Group
specs
SÜD-CHEMIE
SUNSIL PHOTOVOLTAIC PRODUCTS
SYSTEMATIC
TEKNOLOGISK INSTITUT
TOPOTARGET
TOPSIL
TOPSOE FUEL CELL
UNISENSE
VARO Process Equipment
Vestas
WIDEX HIGH DEFINITION HEARING
Wyeth
aalborgportland CEMENTIR HOLDING

# INDUSTRIAL TECHNOLOGIES **CONFERENCE 2012**

In the summer of 2012 iNANO co-organized the Industrial Technologies 2012 conference (IT 2012) together with Spinverse Oy and Aalborg University. The conference took place in Aarhus during the period June 19-21, 2012, and was supported by the European Commission

The main purpose of the conference was a discussion of the vision of European Industry and research within the framework of Horizon2020 and the signing of The Industrial Technologies Declaration. Representatives from industries employing over 19 million Europeans were present at the conference , thus underlined the critical importance of industrial innovation as a route to European economic recovery, and stating their willingness to contribute and engage with governments and the research community in ensuring that this goal is achieved.

The Declaration states that to meet the objectives of smart, sustainable, and inclusive growth, the future European research and innovation funding program (Horizon2020) should stimulate and strengthen excellence in tackling Grand Challenges, strengthening competitiveness and Europe's science base by implementing key recommendations. (see box)

Niels Christian (left) Rudolf Strohmeier Deputy Director General, DG Research and Innovation, European Commission.

PHOTO: MARTIN GRAVGAARD

From left to right: Klaus Sommer, Ignacio Calvo, Massimo Mattuci and Flemming Besenbacher.

PHOTO: MARTIN GRAVGAARD

From left to right: Massimo Mattuci, Ignacio Calvo, Klaus sommer, Flemming Besenbacher and Herbert Von Bose.

PHOTO: MARTIN GRAVGAARD

"Frontier and high-risk, curiosity driven research and innovation must focus on the excellence of people, with special focus on interdisciplinarity. There was consensus that we need a European Research Area of excellence that is interconnected and efficient; a research area that brings together people and ideas in a way that catalyze excellent science and world-leading innovation. This European Research Area of excellence should be implemented by a small set of simple, broad, and non-thematic instruments free of bureaucratic procedures. Greater flexibility must be allowed for curiosity-driven research activities, including flexibility in forming the best teams, attracting the best minds, mobility and destination of choice and research grants.

Trust stimulates creative research. By recognizing and trusting outstanding researchers' talents, society should expect them to deliver results that may make a difference. The assessment and selection processes of such researchers must be transparent. In order to be successful in face of the global competition, Europe needs to strengthen its science base, allowing Europe to be at the very frontier of research and to address the challenges, which have not yet been imagined."

The conference program was very diverse in order to appeal to the different sectors present at the conference, such as researchers, CEOs, and legislators. There were 5 Plenaries, 18 Sessions, 15 Workshops and 60+ Exhibitors, a Matchmaking Event, a Poster Session, and an Award Gala Dinner.

The venues were Musikhuset Aarhus and Scandinavian Congress Center, as well as the sites of different Danish companies of interest to the participants. There was even a showroom on wheels, the Manufacturing Transporter (MANTRA) truck, parked outside Musikhuset Aarhus, a travelling exhibition from the University of Sheffield's Advanced Manufacturing Research Center (AMRC) and Boeing and Rolls Royce.

The conference, which was opened by the Minister for Science, Innovation and Higher Education, Morten Østergaard, was a great success with close to 900 participants. The specific aim of the 2012 event was to bring together representatives of the NMP field: cutting-edge nanotechnology (N), advanced materials (M), and innovative production technologies (P).

# **PRESTIGIOUS AWARDS** FOR PROFESSOR FLEMMING BESENBACHER

In January 2012 Professor Flemming Besenbacher was awarded "The Award for International Scientific Cooperation "by the Chinese Academy of Sciences, which is the highest award of the Chinese Academy of Sciences (CAS), People's Republic of China.

This award honors the eminent foreign experts who have made outstanding contributions to facilitate cooperation with CAS.

The award is given to encourage further efforts that will strengthen CAS' innovation capacity and lead to improvements in its research performance, education & training, management, and reputation within the international scientific community.

Professor Besenbacher is a pioneer in the development of scanning probe microscopy and its application to the fields of nanoscience and nanotechnology. His relationship with China can be traced back to the early 1990s, when he first visited China to foster a cooperative link between Denmark and China, actively promoting academic cooperation and exchanges in science and technology.

Since 1990 he has collaborated with the Institute of Chemistry, CAS, and the scanning tunneling microscopy laboratory lead by Professor Chun Li Bai, carrying out academic exchange, student transfer and publishing joint papers.

In 2009 the Sino-Danish Self-assembly and Nanostructure Functional Materials Center was established and as Director of the Center, Professor Besenbacher has promoted the center to a world-leading center performing high-level research in the field of self-assembly.

Professor Besenbacher has been involved in the advocacy and promotion of the Sino-Danish Center for Education and Research (SDC), in particular, the direction of the nanoscience education program, actively discussing the promotion of the interdisciplinary curriculum.

SDC has subsequently helped with the exchange of science and technology personnel and cooperation on jointly sponsored projects between the two countries. Professor Besenbacher has played a major role in promoting high level interactions for strategic development of science and technology between Denmark and China.

In October 2012 Professor Flemming Besenbacher received the Chinese Friendship Award – the People's Republic of China's highest award for foreign experts.

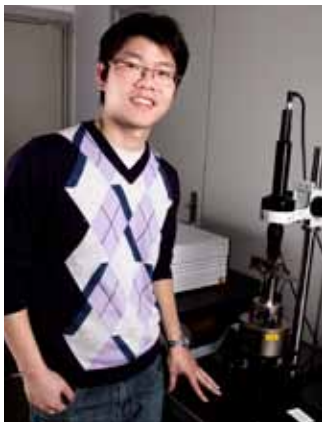
This award is an acknowledgement of Flemming Besenbacher's long-running efforts in strengthening the research collaboration between the People's Republic of China and Denmark, e.g., the research collaboration between iNANO at Aarhus University and the National Nanoscience Center in Beijing and the Harbin Institute of Technology. In addition, Flemming Besenbacher has previously received the Einstein Professorship from the Chinese Academy of Sciences.

The distinction is awarded by the State Council once a year to 40 foreign experts who have made outstanding contributions to China's economic and social progress. The winners accepted the award during a solemn ceremony in connection with the National Day of the People's Republic of China on 1 October 2012.

Professor Besenbacher displaying his gold medal with Chinese Academy of Sciences president Bai Chunli.

# HIGHLIGHTS 2012

2012 was another rewarding year where iNANO scientists received an impressive number of awards and prizes. Here is a look back at some of the most spectacular grants and awards in 2012.



**Dr. Mingdong Dong receives prestigious grant from the VILLUM FOUNDATION**

In January Mingdong Dong received a Young Investigator Grant from the VILLUM FOUNDATION for his project entitled "Combined real-time Atomic Force Microscopy and Force Spectroscopy". This project will investigate the dynamic conformation changes and measure the mechanical responses of biological systems in real time. By combining two new techniques (high-speed atomic force microscopy and microsecond force spectroscopy), complementary information about the studied samples will be obtained. The grant amounts to DKK 4 million.


**Jakob Kibsgaard wins AkzoNobel Nordic Prize for Surface and Colloid Chemistry**

iNANO postdoc Jakob Kibsgaard received the AkzoNobel Nordic Prize for Surface and Colloid Chemistry for his excellent work and independent research in the area of surface and colloid chemistry.

The price has been awarded since 1985 to outstanding young researchers in this field and consists of up to SEK 50 000 to be used for travelling scholarships or similar.

**Recently knighted professor**

As of 14 September 2012, Troels Skrydstrup is a Knight of the Order of the Dannebrog. Professor Skrydstrup is an extremely productive scientist and he is the author of 175 international publications, including scientific articles, reference articles, book chapters and the book Organic Synthesis Using Samarium Diiodide.

Professor Skrydstrup is head of Aarhus University's research group in Organic Synthesis with about 20 members, and he is also affiliated with the Interdisciplinary Nanoscience Center (iNANO) and the Danish National Research Foundation's Centre for Insoluble Protein Structures (inSPIN).

**Brigitte Städler awarded the L'Oreal-UNESCO fellowship "For Women in Natural Science"**

The L'Oréal-UNESCO fellowship is an annual acknowledgement established to promote scientific careers and identify outstanding women in natural science. It is supported by the Danish National Commission for UNESCO and the Royal Danish Academy of Sciences and Letters. The fellowships are each valued at DKK 100,000 and are awarded to three extremely promising female researchers. These top-ranking scientists embrace universal challenges ranging from health to environment, and represent hope for the future.

**New nember of The Young Academy of Denmark**

The Young Academy is a new independent platform for young scientists from all branches of science and thus a new institution in Danish academia. The purpose of The Young Academy is to strengthen basic research and the interdisciplinary exchange, bridging the gap between science and society - and to give a united voice to some of the most excellent young scientists in Denmark.

Rikke Schmidt Kjærgaard is one of the 8 new members of The Young Academy of Denmark. Her research covers data visualization and visual scientific communication at the nanoscale. She came to iNANO in 2011 after postdoctoral years at Harvard Medical School and University of Cambridge, working with cutting-edge visual communication of molecular science.

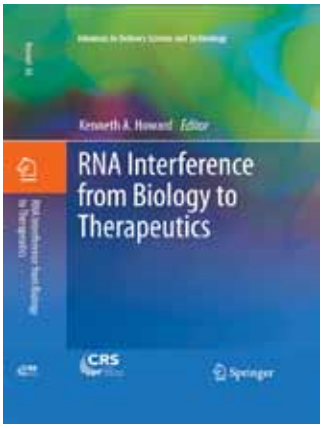

**iNANO Students win Grundfos Challenge, regional competition**

Simon Frølich, Signe Grønborg, and Irene Hansen won the regional competition of Grundfos Challenge 2012/2013.

The three brilliant iNANO students came up with a solution to the overall question ..develop a way to meet and solve the current challenges related to the world's scarce water resources. The solution was so good that they became 1 of 2 teams from Denmark to progress to the Global Grundfos Challenge competition, scheduled to take place in the spring of 2013. Here they will meet the best teams from USA and China in the first ever Global Grundfos Challenge.

**Powerful infrared light sources for the development of analytical instruments for the analysis of food**

In another project, LIGHT & FOOD, iNANO's Søren Keiding and partners from Foss Analytical A/S, NKT Photonics A/S, DTU and Copenhagen University will use novel, powerful infrared light sources to develop analytical instrumentation for the analysis of food quality. The project, LIGHT & FOOD, is funded by the Danish Advanced Technology Foundation and will receive DKK 15 million over the next four years.

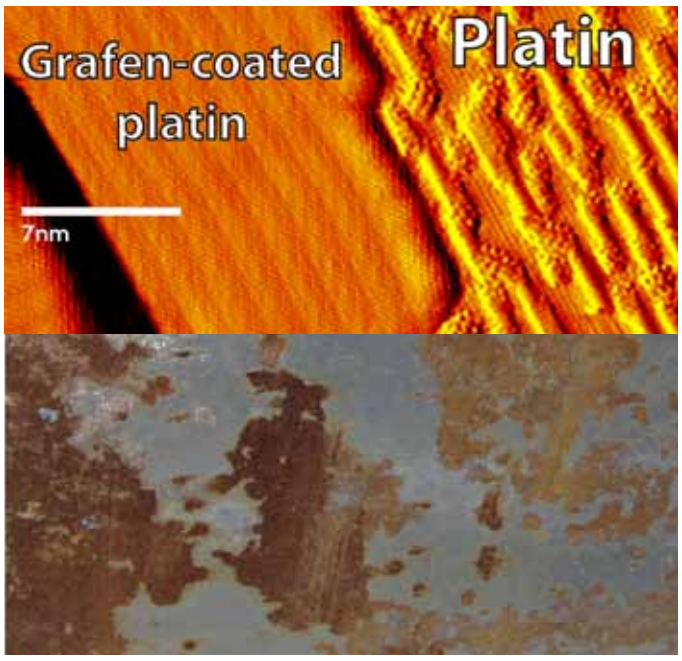



**New book from iNANO scientist**

Associate Professor Ken Howard edited a book "RNA interference from biology to therapeutics" published by Springer.

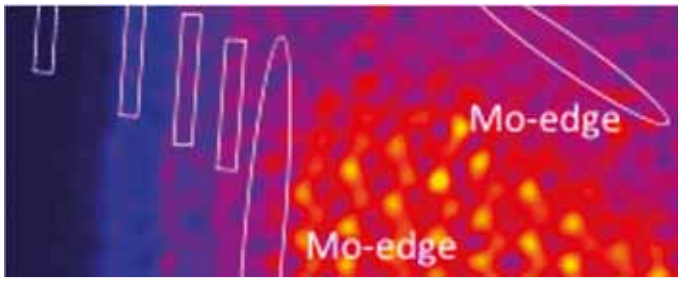
The book is part of the controlled release society advances in delivery science and technology series and includes contributions from global leaders in the field including iNANO scientists.

Topics covered in the book include miRNA biology and therapeutic exploitation, exosome delivery, and clinical translation.




**A graphene platform and a photonics project from the Danish Advanced Technology Foundation headed by iNANO researchers**

Liv Hornekær, Kim Daasbjerg and Philip Hofmann from iNANO established a consortium with SP Group A/S, LEGO SYSTEM A/S, Mekoprint A/S, Newtec A/S, Welltec A/S, DTU Nanotech and Copenhagen University. The "National Initiative for Advanced Graphene Coatings and Composites (NIAGRA)" will receive DKK 24 million in support from the Danish Advanced Technology Foundation for R&D efforts towards graphene and polymer applications for industry over the coming five years.




**Grant for Clean-Air-Technologies by development of new catalysts**

The Danish Strategic Research Council, Program Committee for Sustainable Energy and Environment, granted DKK 15 million to a project headed by iNANO researchers.

Together with partners at Lund University and Haldor Topsøe A/S Jeppe V. Lauritsen and Flemming Besenbacher were granted a research project from The Danish Council for Strategic Research for the development of new catalysts for pollution control from exhaust gases in industry and automotive applications.

The DKK 35.6 million project, which also includes top researchers from Lawrence Berkeley National Laboratories, STFC Daresbury Laboratory and University of Wisconsin-Madison, will run for five years.

# PUBLICATIONS 2012

In 2012 iNANO published 309 peer-reviewed articles. A complete list of both iNANO publications and specialized lectures can be found at our homepage.
**Publications 2012**: http://inano.au.dk/research/publications/2012/
**Specialized lectures 2012**: http://inano.au.dk/news-events/distinguished-inano-lectures/2012/

## iNANO LECTURES 2012

**January 13**. *Professor Clemens Kaminski, Department of Chemical Engineering and Biotechnology, Laser Analytics group, University of Cambridge, Cambridge, United Kingdom:* Visualising protein function in living cells

**January 20**. *Professor Henny van der Mei, Department of Biomedical Engineering, W.J. Kolff Institute, University Medical Center Groningen and University of Groningen, Groningen, The Netherlands:* New strategies to fight against biomaterial associated infections

**January 27**. *Professor Susan Stipp, NanoGeoScience, Copenhagen University, Copenhagen, Denmark*: More oil, less $CO_2$, cleaner water, how organisms make shells – the secrets of nature at the nanoscale

**February 3**. *Professor David A. Leigh FRS, The Edinburgh and St. Andrews Research School of Chemistry University of Edinburgh, Edinburgh, Scotland:* Making the Tiniest Machines

**February 10**. *Professor Tobias Wang, Department of Biosciences – Zoophysiology, Aarhus University, Aarhus, Denmark:* Darwinian physiology: How to choose appropriate animal models

**February 24**. *Professor Hans Hebert, Department of Biosciences and Nutrition, Karolinska Institutet, Stockholm, Sweden:* Electron cryomicroscopy of membrane proteins and complexes from the cyclooxygenase/lipoxygenase pathways

**March 30**. *Professor Birger Lindberg Møller, Department of Plant Biology and Biotechnology, Section for Plant Biochemistry, University of Copenhagen, Copenhagen Denmark:* Light driven synthesis using cytochrome P450s – from plant chemical defences to synthetic biology

**April 16**. *Michael Grätzel, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland:* Nanostructured Photosystems for the Generation of Electricity and Fuels from Sunlight

**April 18**. *Professor Gu Binglin, President of Tsinghua University and Member of Chinese Academy of Sciences, Tsinghua University, Tsinghua , China:* Inaugural lecture of Honorary Professor Gu Binglin, former President of Tsinghua University

**April 20**. *Professor Zicai Liang, Laboratory of Nucleic Acid Technology, Institute of Molecular Biology, Peking University, Beijing, China:* Technology innovation to facilitate the development of siRNA-based therapeutics

**April 27**. *Academic Research Leader Fritz Vollrath, Department of Zoology, University of Oxford, Oxford, United Kingdom:* Unravelling Spider' Silks

**May 3**. *Professor Greg G. Goss, Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada:* Nanotoxicology is not your average toxicology

**May 3**. *Professor Richard D. Handy, School of Biomedical and Biological Sciences, University of Plymouth, Plymouth, England:* Toxic Effects of Nanoparticles on the Body Systems of Fishes

**May 11**. *Professor Kees de Kruif, Van 't Hoff Laboratory for Physical and Colloid Chemistry, Debye Institute, Utrecht University, Utrecht, The Netherlands:* Milk Nanotubes

**May 24**. *Dr. Robert Tycko, Laboratory of Chemical Physics, NIDDK, National Institutes of Health, Bethesda, MD, USA:* Amyloid Structures In Vitro and In Vivo: Insights from Solid State NMR

**June 1**. *Professor Karl-Petter Lillerud, Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Oslo, Oslo, Norway:* Crystalline Nanoporous Materials; Catalysis from a Material scientist perspective

**June 8**. *Researcher Martin Lindahl, Department of Biochemistry and Structural Biology/Karolinska Institutet, Department of Biosciences, Lund University, Lund, Sweden: Single particle cryo electron microscopy:* A tool for seamless integration of length-scales in structural biology

**June 15**. *Assistant Professor Ümit Akbey, FMP, NMR Supported Structural Biology, Leibniz-Institute for Molecular Pharmacology, Berlin, Germany:* Solid-State NMR Studies on Functional & Biological Materials

**June 22**. *Professor, Dr. Urs Staufer, Delft University of Technology, Department of Precision and Microsystems Engineering, Delft, The Netherlands:* Nanoscience and Planetology – AFM measurements on Mars

**June 29**. *Emeritus Professor & Honorary Professor at the Faculty of Science, Allan S. Hoffman, Bioengineering Department, University of Washington, Seattle, WA, USA:* Biomaterials in the Nano-Era

**August 24**. *Creative Director Bang Wong of the Broad Institute of MIT and Harvard, Cambridge, MA, & adjunct Assistant Professor in the Department of Art as Applied to Medicine at the Johns Hopkins University School of Medicine, Baltimore, Maryland, USA:* Visual Representation for Communication and Discovery

**August 31**. *Senior Manager Claus Hviid Christensen, Research and Development, Innovation Center, DONG Energy, Gentofte, Denmark:* Biorefining: From Science to Business

**September 7**. *Professor Robert Tampé, Institute of Biochemistry, Biocenter Goethe-University Frankfurt, Frankfurt, Germany:* In situ assembly of macromolecular complexes in four dimensions triggered by light

**September 14**. *Farshad Moradi, Integrated Circuits and Electronics Lab. (ICE-LAB), Department of Engineering, Aarhus University, Aarhus, Denmark:* Spin-Transfer Torque Random Access Memory

**September 21**. *Professor Troels Skrydstrup, The Center for Insoluble Protein Structures (inSPIN), Department of Chemistry and the Interdisciplinary Nanoscience Center, Aarhus University, Aarhus, Denmark: The Development and Application of Carbon Monoxide Releasing Molecules:* From Accident to Research to Business

**September 28**. *Research Associate Professor (Docent) Esben Thormann, PhD, KTH, Royal Institute of Technology, School of Chemical Science and Engineering, Department of Chemistry, Surface and Corrosion Science, Stockholm, Sweden:* Colloidal Probe Atomic Force Microscopy – A method for Direct Measurements of Colloidal interactions

**October 5**. *Visiting Professor Peter Gaiduk, Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark:* Nanovoids in Strained Layers and Nanodots: Self- Assembled Formation and Prospects for Applications

**October 12**. *Professor Jonathan S. Dordick, Rensselaer Polytechnic Institute,Troy, NY, USA:* Nanobiocatalysis for Sustainable Bioprocessing

**October 26**. *Assistant professor Rikke Schmidt Kjærgaard, PhD, MSc, Interdisciplinary Nanoscience Center, iNANO, Aarhus University, Aarhus, Denmark: 3D Science Animation:* applicable software solutions for bio-nanoscience visualization in Autodesk Maya

**November 2**. *Professor of Structural Biology Fei Sun, Institute of Biophysics, Chinese Academy of Sciences, Beijing, China:* Studying biological macromolecular structures by three dimensional electron microscopy

**November 9**. *Christophe Demaille, Laboratoire d'Electrochimie Moléculaire, UMR 7591 CNRS, Univ Paris Diderot, Sorbonne Paris Cité, Paris Cedex 13, France:* Probing the Distribution and Conformational Dynamics of Surface-Immobilized Redox-Tagged Macromolecules using Electrochemical-Atomic Force Microscopy (AFM-SECM)

**November 16**. *Centre Manager Lars Pleth Nielsen, Tribology Centre, Materials and Production, Danish Technological Institute, Aarhus, Denmark:* Solution driven R&D of novel nanostructured coatings meeting industrial demands

**November 23**. *Center Director Charles Marcus, Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark:* Magnetic Resonance Imaging with Silicon Nanoparticles

**November 30**. *Professor, dr. med. Søren Nielsen, Institute of Biomedicine, Health, Aarhus University, Aarhus, Denmark:* From Basic Science to Big Business in Drug Development

**December 14**. *Holger Bech Nielsen, Professor emeritus, Niels Bohr Institute and Mette Høst, Artist-in-residence at the Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark:* A conversation about science and art

## PHD THESES PUBLISHED 2012

**Johan Frederik Kraft**. Computational studies of membrane mimics and peptides – A study on interactions

**Nina Kerting Iversen**. Distribution and cardiovascular effects of metal and magnetic nanoparticles

**Christoffer Nielsen**. Using antibodies for targeted delivery of therapeutic small interfering RNA

**Geanna Kay Min. Enamides**. Synthesis and application in Rh-catalyzed hydrosilylations – The facile assembly of silicon-based peptidomimetics

**Lasse Arnt Straasø**. Novel recoupling solid-state NMR experiments for accurate distance measurements in proteins

**Jakob Rostgaard Eltzholtz**. Nucleation, growth and morphology of nanoparticles

**Jon Gade Hansted**. Aggregation of whey proteins – and their interactions with amphiphiles

**Malgorzata Maria Pakula**. Improvement of siRNA performance with chemical modifications and Targeted delivery of anti-CD44Ab/siRNA conjugates to breast cancer stem cells

**Mads Sloth Vinding**. Fast Optimal Control in MRI

**Viduthalai Rasheedkhan Regina**. Microbial fouling in dairy production: Characterization of biofilm formation and development of anti-fouling coatings

**Zhuo Liu**. Inhibitory mechanisms of peptides and antibodies targeting murine urokinase-type plasminogen activator

**Mads Wraa Hyttel**. Wear resistant materials for the cement and minerals industries

**Kristian Sneskov**. The polarizable embedding coupled cluster method: exciting news from beyond the vacuum

**Jonas Lerche Hansen**. Imaging molecular frame dynamics – using spatially oriented molecules

**Thomas Kollin Nielsen**. Nano-confined Hydrides for Energy Storage

**Helene Zeuthen**. Atomic Scale Investigation of Ultra-Thin Iron Oxides Supported on Pt(111) and Pd(111)

**Darius Kavaliauskas**. FRET-based structure-function studies of translation elongation factor Tu

**Søren Porsgaard**. Model catalysts studies by photoemission spectroscopy at elevated pressures

**Ren Su**. TiO2 based photocatalyst – from synthesis and characterization to optimization and design

**Thomas Franck Dyrlund**. Proteomics and Data Mining – Study of the human cornea proteome and the human embryo secretome

**Line Holdt Rude**. Anion Substitution in metal borohydrides

**Joachim Møllesøe Vinther**. Sensitivity enhancement in solid-state mgic-angle spinning NMR spectroscopy

## PATENTS 2012

**Birkedal, H., Krogsgaard, M.**, Multi-responsive muslingeinspirerede hydrogeler (1), Priority Application, PA 2012 70266

**Birkedal, H., Krogsgaard, M.**, Multi-responsive muslingeinspirerede hydrogeler (2), Priority Application, PA 2012 70080

**Foss, M., Ogaki, R.**, Long-term zero-fouling poly (ethylene glycol) surfaces, PCT/DK2013/050088

**Meyer, R.L., Olsen, J., Skovgaard, J., Nyvad, B., Sutherland, S.D., Wejse, P.L., Birkedal, H., Schlafer, S.**, Anti-biofilm protein/inorganic nanoparticle formulation, Priority Application, 12161802.9

**Gothelf, K.V., Zhang, Z.**, Detection of biomolecular interactions by DNA strand displacement exchange reactions, Priority Application, PA 2012 70555

**Foss, M., Andersen, O.Z., Bøttiger, J., Sillassen, M.B.**, Strontium based coating for body implants, Priority Application, 61/614,798

**Thomsen, C.S., Foss, M., Andersen, O.Z.**, Priority Application, 61/710,103

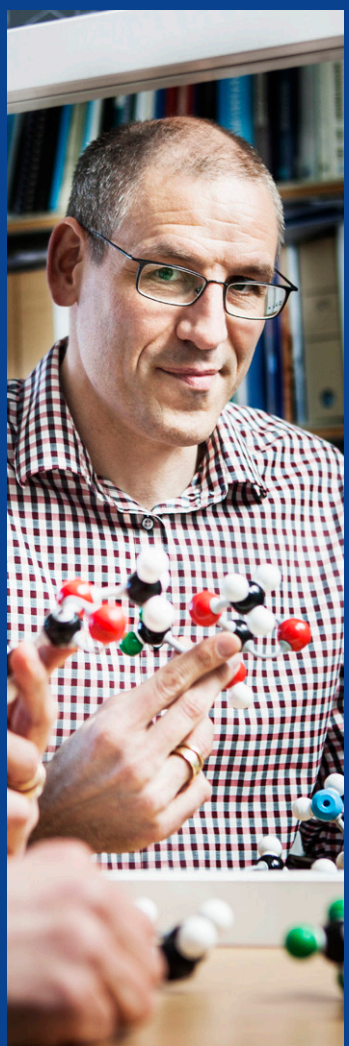
**iNANO administration. Back row: Rebeca Thostrup, Kaj Jensen, Leif Schauser and Peter Thostrup. Front row: Trine Møller Hansen, Annette Wandahl and Gry Westergaard Hansen.**

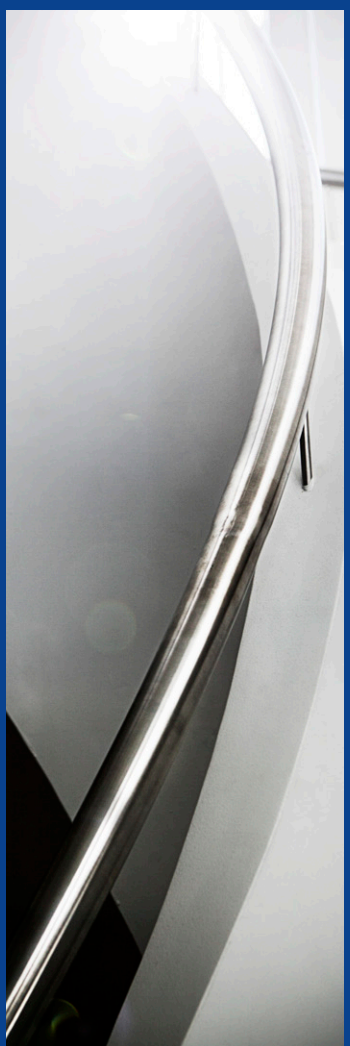
## SENIOR STAFF

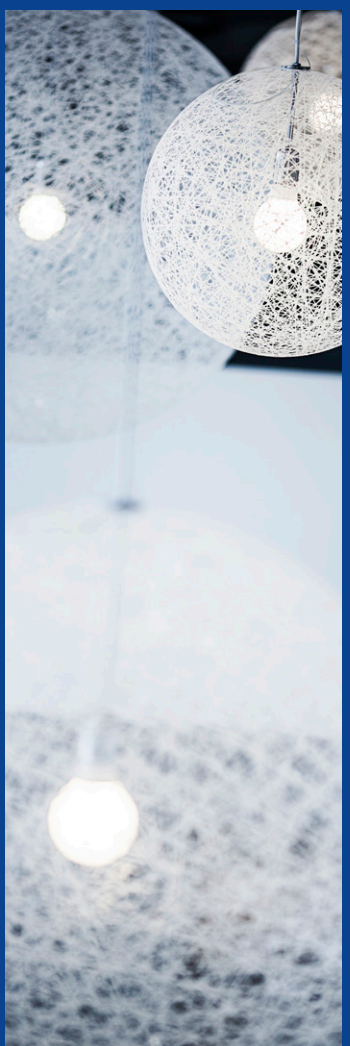
Andreasen, Peter
Baatrup, Erik
Balling, Peter
Besenbacher, Flemming
Birkedal, Henrik
Birkedal, Victoria
Bøttiger, Jørgen
Christensen, Mogens
Daasbjerg, Kim
Dong, Mingdong
Enghild, Jan Johannes
Ferapontova, Elena
Foss, Morten
Gao, Shan
Glasius, Marianne
Gothelf, Kurt Vesterager
Hammer, Bjørk
Ho, Megan
Hofmann, Philip
Hornekær, Liv
Howard, Ken
Iversen, Bo Brummerstedt
Jensen, Jan Egebjerg
Jensen, Torben René
Keiding, Søren
Kjems, Jørgen
Knudsen, Birgitta
Knudsen, Charlotte Rohde
Larsen, Arne Nylandsted
Lauritsen, Jeppe Vang
Linderoth, Trolle René
Lægsgaard, Erik
Meyer, Rikke L.
Mulder, Frans
Nielsen, Niels Chr.
Nissen, Poul
Ogilby, Peter Remsen
Otzen, Daniel
Pedersen, Finn Skou
Pedersen, Jan Skov
Pedersen, Steen Uttrup
Revsbech, Niels Peter
Schiøtt, Birgit
Skibsted, Jørgen
Skrydstrup, Troels
Stadler, Brigitte
Sørensen, Esben Skipper
Stapelfeldt, Henrik
Sutherland, Duncan
Vosegaard, Thomas
Wendt, Stefan
Xu, Xuebing
Zelikin, Alexander

## APPOINTMENTS OF STAFF ASSOCIATED WITH iNANO in 2012

**Dr. Megan Ho** was employed as an Assistant Professor at iNANO





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**Faculty of Science & Technology**

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