NTNU Nano 2021

Photo: Geir Mogen / NTNU NanoLab – NTNU Grafisk senter

NTNU
Norwegian University of Science and Technology

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Introduction

John de Mello
Photo: Thor Nielsen / NTNU

Two issues of tremendous global importance loom large as I write this introduction. The first is COVID-19 which -- despite the unprecedented speed of vaccine development and the identification of increasingly effective therapeutic treatments -- continues to ravage communities across the world. The competing challenges of maintaining an active economy and protecting the population from runaway infection have pulled countries in very different directions, and the outcomes have been strikingly different. Norway has so far managed this balancing act comparatively well but, with new COVID variants emerging each month and restrictions greatly relaxed, the future is anything but clear.

The second big issue is the Climate Crisis which, despite overwhelming scientific evidence, is still treated with a worrying lack of urgency by governments around the world. Perhaps the United Nations Climate Change Conference (COP26), taking place in Glasgow as I write, will mark the turning point where governments finally start taking the painful actions needed to avert future catastrophe. Time will tell.

When it comes to COVID, the Climate Crisis and numerous other areas of public concern, universities have a critical role to play. It is our job to acquire and assimilate the scientific evidence that's needed for informed decision making and to present this evidence to policy makers, clearly and dispassionately. It also falls to us to find workable, technical solutions to the major societal challenges of our time, and this of course is where nanotechnology comes in. As Director of NTNU Nano, I have been privileged to witness first-hand how NTNU's own nano-research is addressing issues of huge societal importance. Examples from the past year include promising drug delivery techniques for tumour treatment, new lab-on-a-chip technologies for modelling degenerative brain conditions like Parkinsons and Alzheimer's, and the successful development of a COVID test – now actively used by several countries around the world. Nanotechnology also underpins large swathes of NTNU's activities in sustainability, including a wide range of renewable energy technologies, energy-efficient electronics, and green manufacturing. You can read about some of these activities in the pages that follow, and on our website https://www.ntnu.edu/nano.

On a practical level NTNU, like other universities, has been greatly affected by the pandemic, with lab closures, enhanced safety procedures and travel restrictions determining what we have been able to do and how we have been able to do it. An undoubtedly positive aspect has been a substantial reduction in unnecessary travel (and associated carbon emissions) through increased use of virtual on-line meetings, while a significant downside has been the cancellation of the workshops, conferences and exchange visits that that are the lifeblood of scientific knowledge sharing and collaboration. As we move forward, we will hopefully be able to strike a better balance between the two – avoiding travel where a virtual meeting will suffice, while still allowing the in-person meetings that fuel scientific progress.

Despite the challenges that COVID has created, the past year has been a time of significant productivity for our nano-researchers. NTNU has published over 300 papers spanning virtually all areas of nanoscience (see https://www.ntnu.edu/nano/publications for an up-to-date list of this year's publications). Funding highlights include two European Research Council (ERC) grants: an ERC Starting grant on electrochemical flow energy conversion devices awarded to Jan Torgersen from the Department of Mechanical and Industrial energy, which began in May 2021; and an ERC Advanced Grant on cavity quantum electrodynamics awarded to Henrik Koch from the Department of Chemistry, which begins next month.

I hope you will enjoy reading this year's annual report, and very much hope that NTNU Nano will be able to assist you with your research in the year to come.

John de Mello, Director of NTNU Nano

NTNU Nano Impact Funds

One way in which NTNU Nano supports nanoscience at NTNU is through its Impact Funds, which offer small-scale support for activities that are likely to raise the visibility and impact of NTNU's work in the area of nanoscience, nanotechnology and functional materials. Since launching the fund, we have supported a wide variety of activities, including conference organisation, networking, research collaborations, open science projects, cover article production, and the establishment of new experimental facilities. Other potential uses of the fund include photography and artwork, prototype development, and the preparation of publicity materials.

The application process involves a simple online form, and most funding decisions are made within a month of applying. There are three schemes within the Impact Fund, depending on the intended use of the funding: (i) the cover-article fund, which contributes up to 15000 NOK towards the production costs of cover articles; (ii) the product fund, which contributes up to 100000 NOK for the development of a tangible product, e.g. software or a device; and (iii) the standard fund, which typically contributes up to 20000 NOK for purposes not covered by the other two schemes. You can read more about the Impact funds, examples of previously funded activities, and find the application form here: *https://www.ntnu.edu/nano/ntnu-nano-impact-fund*

Prizes and awards

A number of current and previous NTNU Nano members have been recognised for their contributions to nanoscience in the past year. Jabir Ali Ouassou (now at SINTEF Energy Research) received Yara's 2021 Birkeland Prize in physics for his PhD thesis "Manipulating superconductivity in magnetic nanostructures in and out of equilibrium", completed under the supervision of Jacob Linder. Ine Larsen Jernelv (now at the UiT Arctic University of Norway) was awarded the 2021 Chorafas Prize for her PhD research on "Mid-Infrared Tuneable Laser Spectroscopy for Glucose Sensing", carried out under the supervision of Astrid Aksnes and Dag Roar Hjelme. Magnar Bjørås (Department of Clinical and Molecular Medicine) and Sulalit Bandyopadhyay (Department of Chemical Process Technology) accepted NTNU's "award for innovation and collaboration with working life" on behalf of the research teams behind the NTNU Covid-19 test. They also received the Research Council of Norway's Innovation Award for 2021.

In May 2021, Jan Torgersen began a European Research Council (ERC) Starting grant "ELECTRODE" that aims to understand and improve the operation of electrochemical flow conversion devices like fuel cells, electrolysers and flow batteries using 3D printed carbon microsctructures to monitor transport kinetics and improve performance at high current density" (www.ntnu.edu/nano/qa_articles).
In January 2022 Henrik Koch will begin an ERC Advanced Grant Quantum Light that will investigate at a quantitative level how the chemical properties of molecules are changed when they are placed between highly reflective mirrors.

Congratulations to all the award winners for their outstanding achievements!

New Staff

We are delighted to report the appointment of several new professors to NTNU, who are working in the general area of nanoscience and advanced materials. Daniel Rettenwander (battery materials) and Julian Walker (green chemistry, ferroics and functional materials) have joined the Functional Materials and Materials Chemistry group in the Department of Materials Science and Engineering as associate professors. Jacob Lamb (sustainable energy systems) and Sulalit Bandyopadhyay (particle engineering and hydrometallurgy) have respectively joined the Department of Energy and Process Engineering and the Department of Chemical Engineering as associate professors. We offer them our sincere congratulations on their new appointments, and warmly welcome them into the NTNU Nano community.

Over the coming months, we will be running a series of Q&A-style interviews with new professors where you can learn more about their backgrounds and research interests. You can already find interviews with some of our recent appointees on our website at: *https://www.ntnu.edu/nano/qa_articles*

The Kavli Prize laureates 2020. From the left: Knut Urban (Photo: Research Center Juelich), Ondrej Krivanek (Photo: © Michelle Krivanek), Maximilian Haider (Photo: © "Bilderfest" Germany) and Harald Rose. (Photo: © private)

Kavli Prize Winners

In the ten years since their inception, the biennial Kavli Prizes have established themselves as some of the most important prizes in the international scientific calendar. Founded in 2008 by the Norwegian-born businessman-turned-philanthropist Fridjtof ("Fred") Kavli, the prizes recognise exceptional breakthroughs in the fields of astrophysics, nanoscience and neuroscience. The 2020 astrophysics prize was awarded to Andrew Fabian "for his ground-breaking research in the field of observational X-ray astronomy, covering a wide range of topics from gas flows in clusters of galaxies to supermassive black holes at the heart of galaxies"; the neuroscience prize was awarded to David Julius and Ardem Patapoutian "for their transformative discovery of receptors for temperature and pressure"; and the nanoscience prize was awarded to Harald Rose, Maximilian Haider, Knut Urban and Ondrej Krivanek "for sub-ångström resolution imaging and chemical analysis using electron beams" (see box).

NTNU is fortunate to play a key role in the Kavli prize celebrations, acting as the official host for the Prize Lectures in nanoscience and neuroscience. Owing to COVID-19, the 2020 lectures were unfortunately postponed until 2022 where they are due to take place alongside those of the 2022 awardees. We are very much looking forward to hosting the 2020 and 2022 Prize winners on September 8, 2022.

The 2020 Kavli Prize in Nanoscience

The ultimate goal of microscopy has always been to image matter at the atomic scale. The resolution of conventional microscopy is limited by Abbe's theorem of diffraction which, broadly speaking, states that it is not possible to resolve features that are much smaller than one-half the wavelength of the illuminating radiation. For ordinary optical microscopy based on photon radiation, this means it is difficult to view anything less than 200 nm, which is about 2000 times greater than the size of an atom. In electron microscopy, long-wavelength photons are replaced by very short-wavelength electrons, leading to a massive improvement in the theoretically achievable resolution. However, for many years, atomic resolution remained beyond reach due to the poor quality of the lenses needed to focus the electrons. Innovations by the Kavli prize winners led to the development of improved (aberration corrected) lenses that dramatically improved focusing quality and made possible sub-ångström (i.e. sub-atomic) imaging and chemical analysis for the first time. You can find out more about their work here: *https://tinyurl.com/h54kn8zy*

Rector's Prize Studentships in Nanoscience, Nanotechnology and Functional Materials

Each year the Rector sponsors a university-wide competition for PhD positions in nanoscience, nanotechnology and functional materials, open to nano-active research groups in all faculties. In 2021 one position was awarded to Henrik Koch and Ida-Marie Høyvik from the Department of Chemistry to transform chemical behaviour via polaritonic chemistry. The other was awarded to Nuria Espallargas and Astrid de Wijn from the Department of Mechanical and Industrial Engineering, together with Solon Oikonomopoulos from the Department of Chemistry. They will investigate the use of carbon nanostructures and ionic liquids as green, multifunctional lubricants. We wish both research teams success with their projects, and look forward to reporting on their progress in future news items.

The 2022 call will be announced in December 2021 and, exceptionally, will provide funding for four PhD positions in nanoscience. The application deadline will be in January 2022, and we encourage you to consult the NTNU Nano website for further details.

Sustainability

In April 2021 NTNU announced a major initiative to investigate the changes that will be needed to make a successful transition to a fully sustainable society. The goal was to bring together researchers from multiple disciplines (natural scientists, engineers, industrial ecologists, economists etc.) to provide a more holistic understanding of sustainability issues. As part of this initiative, NTNU Nano held a webinar on 23rd June 2021, covering sustainability issues in nanoscience and nanotechnology. Johan Pettersen, Bjørn Munro Jensen and Helge Brattebø (Director of NTNU sustainability) presented on life-cycle analysis, nanotoxicology and NTNU's sustainability strategy. The webinar is still available online, and you may access it here: *https://www.ntnu.edu/nano/events*
Nine projects received funding across NTNU, including one project with a strong focus on nanoscience and advanced materials: "Developing a Holistic Ecosystem for Sustainable Repurposing and/or Recycling of Lithium-ion Batteries (LIBs) in Norway and the EU" led by Sulalit Bandyopadhyay from the Institute of Chemical Process Technology. The project aims to "develop a holistic understanding of the fate of end-of-life electric vehicle batteries by addressing technical, economic, and design perspectives along the battery value chain, complemented by evaluation of sustainable business model scenarios within reuse, repurposing and recycling." The project is a multi-disciplinary research collaboration across six departments and four faculties at NTNU.

Norwegian Nano Symposium 2021

Nicolai Winter-Hjelm and Katharina Zürbes accepting their respective prizes for best contributed talk and best poster. Photo: Per Henning/NTNU

The Norwegian NanoSymposium is a national meeting organised by NTNU that aims to bring together students and researchers in nanoscience and nanotechnology from across Norway. The meeting is jointly arranged by master and PhD students at NTNU, and has a broad scope that encompasses all aspects of nano research. The meeting has traditionally been a physical one but, owing to COVID restrictions, it was held online for the first time this year. The organizing committee made excellent use of the online format, deciding that all contributed talks should be delivered in a "high-octane" Pecha Kucha format, where each speaker is required to present exactly twenty slides at a rate of twenty seconds per slide.

Other highlights of the meeting included a terrific line-up of technical talks from invited speakers across Norway and Europe, presentations from Andreas Dahlin and Nancy Bazilchuk on visualising science and presenting research to the media and the public, and a fascinating panel debate on the future of nanotechnology, deftly hosted by Ida Breivik. Congratulations to Nicolai Winter-Hjelm and Katharina Zürbes for winning the prizes for best contributed talk and best poster on the respective topics of "information flow in neuronal networks" and "tuning anisotropic gold nanoparticles for bio-medical applications."

We are immensely grateful to our organising committee members Nicolai Winter-Hjelm, Daniel Tveit, Elinor Lindstrøm and Hanna Gautun for arranging the meeting and putting together such a strong programme. COVID-permitting, the 2022 meeting will revert to being a physical meeting.

Covid Testing

Responding to a global shortage of COVID-19 tests in the early days of the pandemic, research teams led by Magnar Bjørås at the Department of Clinical and Molecular Medicine and Sulalit Bandyopadhyay at the Department of Chemical Engineering worked together with clinicians from St. Olavs hospital to develop and validate a new COVID test based on readily available reagents. The test uses a mixture of polar solvents, buffers, salts and other chemicals to crack open the virus and release its genetic material without damaging the viral RNA molecule. The RNA is subsequently removed from the test mixture by magnetic iron-oxide nanoparticles that capture the RNA and allow it to be removed using a magnet for subsequent analysis by conventional PCR technology. The COVID-19 test is currently approved for use in Norway, and has been exported to countries including India, Brazil and Denmark. The technology behind the test has recently been licensed to a new NTNU spin-out company Lybe Scientific, who aim to use it for testing other viruses and diagnostic applications.

You may read more about Lybe Scientific here: *https://s.ntnu.no/NSciTec_Lybe*

In the background (from the left): Professor Magnar Bjørås from the Department of Clinical and Molecular Medicine at NTNU and Associate Professor Sulalit Bandyopadhyay from the Department of Chemical Engineering at NTNU have been central to the development of a new test method for SARS-CoV-2 virus (corona test). Photo: Geir Mogen/NTNU

Particle Engineering Centre

The Particle Engineering Centre is a new centre at the Department of Chemical Engineering, established in March 2021. Drawing on the department's extensive experience in particle synthesis and characterisation, the Centre aims to advance the state of the art in fundamental and applied particle engineering. The Centre is closely linked to the department's Particle Engineering "Core Facility", which provides a wide range of techniques for studying nano and micro particles in dispersion. Ongoing research activities focus on the synthesis and characterisation of particles, and their optimisation for applications such as nanomedicine and environmental science. You can find out more about the Centre and the Core Facility here:
https://www.ntnu.edu/chemeng/particle-engineering-centre

https://www.ntnu.edu/web/chemeng/particle-engineering-core-facility

Timini

Timini is the association of students on NTNU's master program in nanotechnology. We aim to create a social arena for the students, and to help them build links with academia and industry. Lunch talks are arranged regularly in collaboration with NTNU NanoLab, where PhD-candidates in the field of nanotechnology present their research, followed by scientific discussions and servings of coffee and buns. One of the highlights in our calendar is the annual Grey Goo symposium, where companies get to meet students on the nanotechnology program. The aim of the symposium is to promote exchange of knowledge and ideas, and to encourage collaborative master projects with industry. Both students and industry representatives are given the opportunity to present their expertise, creating an atmosphere for further talks during the breaks. This year, around ninety students from NTNU participated, together with representatives from five Norwegian companies. The symposium was organised by Timini and sponsored by NTNU Nano.

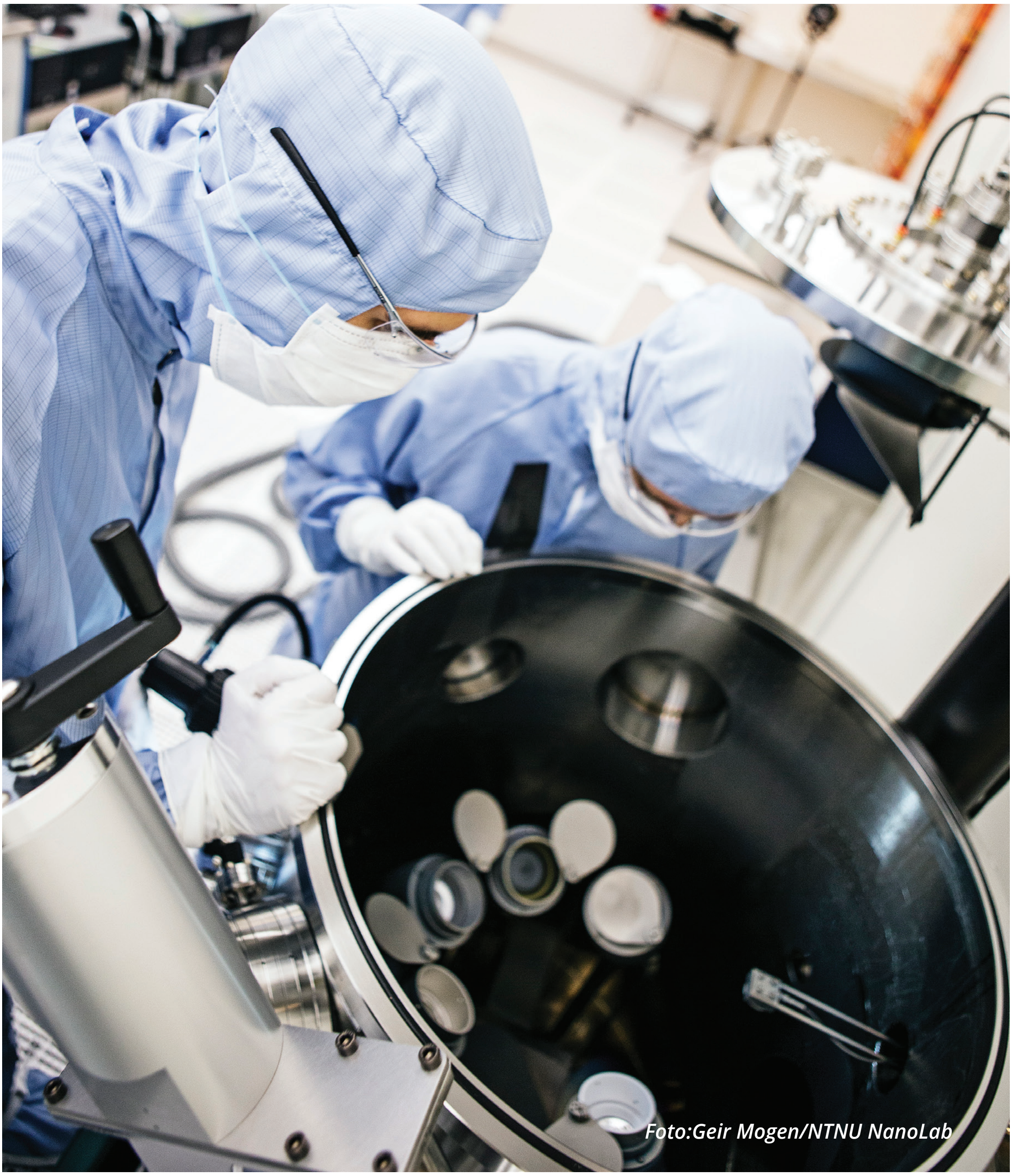

Foto:Geir Mogen/NTNU NanoLab

INFRASTRUCTURE

NTNU is fortunate to have many excellent infrastructures for micro- and nano-scale fabrication and characterisation. We have listed some of the most important facilities below with a brief description of what they do. If you want to learn more, you can find further details on the NTNU Nano website and at the websites of the individual infrastructures.

NTNU NanoLab

NTNU NanoLab is a 700 m^2 cleanroom, providing general purpose equipment for the fabrication and characterization of complex systems on the micro- and nanoscale.

The cleanroom is an open-access user-operated facility, managed by a staff of nine full-time engineers. As part of the "Norwegian Infrastructure for Micro- and Nanofabrication" (NorFab), NanoLab is open to researchers from across Norway, independent of their academic, institutional or company affiliation. International researchers are also welcome to use the facility.

The lab offers a wide range of thin-film deposition methods (evaporation, sputtering, chemical vapour deposition and atomic layer deposition), covering metals, insulators, semiconductors and piezo-electrics. It also offers a broad range of etching methods, including wet and dry etching chemical techniques and ion-milling. NanoLab provides extensive optical and e-beam lithographic equipment, enabling patterning of features down to 1 μm and 6 nm, respectively. Two maskless aligners are available within the lab for rapid optical lithography.

"Bottom-up" preparation of nanomaterials can be carried out in NanoLab's chemical cleanroom, which is equipped with fumehoods, laminar flow benches, a nitrogen glovebox, Schlenk line, ovens, autoclaves, dip-coaters and a Langmuir Blodgett trough.

A wide range of state-of-the art characterization equipment is available. The NanoLab's Scanning Transmission Electron Microscope (S(T)EM) provides imaging resolution below 1 nm, and includes a highly sensitive windowless Energy Dispersive X-ray (EDX) detector for chemical analysis. Our Focused Ion beam (FIB) systems enable serial tomography, TEM/ATP preparation and other sub-surface investigations at the nm-scale. The characterisation tool park also includes a scanning electrochemical microscope, a particle size analyser, absorption spectrometer, Atomic Force Microscopes (AFMs), a 3D profilometer, a contact angle measurement system, and two Scanning Electron Microscopes (SEMs). Compositional analysis may be carried out using X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES) or μ-Raman spectroscopy.

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Photo: Geir Mogen/NTNU NanoLab

Report from Peter Köllensperger, Director of NTNU NanoLab and NorFab

In 2021 we have had the pleasant task of using funds awarded to us by The Research Council of Norway to upgrade several of our facilities.

An early investment saw the replacement of our aging and troublesome S(T)EM with a new and improved model. The installed Hitachi SU9000 is the best commercially available S(T)EM of its kind and can be used to resolve structures down to 0.4 nm. In addition, the attached EDX-system is optimised for the SU9000 which results in around ten times better collection efficiency for X-Rays (compared to regular SEM's). Consequently, acquisition of elemental maps now just takes a couple of minutes instead of hours. The windowless design also allows the mapping of light elements such as lithium and is the only SEM with this capability at NTNU as far as we are aware. The NFR funds will also be used to strengthen our etching capabilities. These investments are due to occur in 2022.

NTNU NanoLab managed to remain open and operational throughout COVID-19, having to close our doors for only three days (Friday-Sunday) as we were putting in place infection-control related safety measures. The team of engineers at NanoLab did an exceptional job to keep our users safe, the lab open and the equipment running despite challenging circumstances!

Two of our engineers have left for new opportunities recently: Amin Zavieh, who was in charge of the AES/XPS lab and characterisation, has started work at Nordic Semiconductor. And Svenn Ove Linde has moved from the thin-film and dry etch area to the Norwegian Armed Forces. I would like to thank them both for their work on behalf of the NanoLab and its users, and I wish them all the best in their new positions.

The Nordic Nano Network User Meeting which was due to be held in Gothenburg in May 2021 was postponed to 2022, and instead we arranged a very well received webinar with 186 participants on the topics of maskless aligners as well as more exotic lithography techniques in use within our network. From NTNU, Jens Høvik, Mark Chiappa and Sihai Luo shared their expertise with the community in a series of informative and entertaining sessions.

Two important and interlinked topics for the medium to long-term future of the NanoLab are the availability of expansion areas and the Campus project. The planned construction works and concentration of activity at Gløshaugen will certainly influence research activity going forward. The NanoLab hosts several vibration sensitive instruments. Whilst it is built to handle the current level of vibrations, the placement of construction works, their duration and timing may affect the use of sensitive equipment. We are working with the faculty to mitigate the impact as far as possible. If you have input or concerns you would like to discuss, please let us know.

As we move towards the NorFab IV Infrastructure funding application for 2024 and beyond, I would also encourage all our users to let us know your equipment needs, your priorities and how you envisage using the NanoLab facilities going forward so that we can develop an investment plan that best suits our community.

I look forward to meeting existing and welcoming new members at NorFab and NTNU NanoLab in 2022.


Photo: Geir Mogen/NTNU NanoLab

The Norwegian Laboratory for Minerals and Materials Characterisation (MiMaC)

MiMaC is a Norwegian national infrastructure, and all instruments are accessible for both Norwegian and international users. The centre is a collaboration between NTNU, SINTEF and the Geological Survey of Norway (NGU).

MiMaC is an infrastructure for characterising the structure and chemical composition of minerals, metals and advanced nanomaterials. The laboratory can map structural features from atomic to micrometre scale in 1–3 dimensions, and allows sensitive compositional analysis down to the parts-per-billion level. The instruments available within the centre include the following: an Atom Probe Microscope, see below; an Electron Probe Microanalyser which provides compositional information by exciting a sample with an electron beam and using the spectral characteristics of the emitted X-ray photons to identify elemental species; a Field Emission Scanning Electron Microscope equipped with an electron backscatter diffraction (EBSD) detector for microstructural-crystallographic analysis, and an energy dispersive X-ray (EDX) detector for high resolution compositional analysis; a split-stream laser ablation instrument with parallel mass spectrometry (MS) and tandem MS detection channels for simultaneous analyses of elemental and isotopic compositions in minerals and materials; and a laser ablation system with triple quadrupole Inductively Coupled Plasma mass spectrometer (Agilent 8900 ICP-QQQ-ICP-MS) for direct surface analysis of elements in solid samples.

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The Atom Probe Laboratory

Recently installed in the department of materials technology, the Cameca LEAP 5000 XS Atom Probe Tomography (APT) setup allows 3D imaging and chemical composition measurements to be carried out at the atomic scale.

The atom probe forms part of the newly established Norwegian national centre for Minerals and Materials Characterisation (MiMaC) – a collaboration between NTNU, SINTEF and the Geological Survey of Norway that aims to establish a world-class facility for the structural characterisation and chemical analysis of minerals, metals and advanced nanomaterials.

In brief, APT is based on field evaporation of atoms located at the surface of a sample that has previously been shaped into a sharp needle. By detecting the emitted ions with a time- and position-sensitive detector, it is possible to estimate their chemical composition by time-of-flight mass spectrometry and to calculate their initial position in 3D by means of a reconstruction algorithm. A wide range of materials may be analysed by Atom Probe Tomography, including metals, alloys, semiconductors, oxides and thin films. Key applications include: chemical analysis of nanoparticles; nanoscale compositional analysis and 3D imaging of grain boundaries in metals and alloys; investigation of interfaces in multilayer structures; analysis of phase separation in complex media; and spatial mapping of trace elements or dopants.

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NTNU Nanomechanical Lab

The nanomechanical lab specialises in techniques for investigating the deformation and degradation of materials, interfacial mechanics and adhesion, and interactions between materials on the nanoscale.

The lab is equipped with a variety of instruments for nanomechanical and nanotribological testing, including: two Hysitron TriboIndenters, which allow Young's modulus, hardness and fracture toughness to be measured by nanoidentation and allow scratch resistance, critical delamination forces and friction coefficients to be quantified by scratch testing; a dynamic tensiometer for the weight-based measurement of contact angle, surface tension, interfacial tension, and critical micelle formation concentration; an environmental SEM equipped with an electron backscatter diffraction (EBSD) detector for microstructural-crystallographic analysis; an in-situ picoIndenter for nanomechanical testing; and an in-situ tensile module for tensile, and compression tests of specimens.

Detailed experimental investigations are supported by simulations involving ab-initio calculations, molecular dynamics and finite element methods.

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The Norwegian Centre for Transmission Electron Microscopy (NORTEM).

NorTem is a nationally coordinated initiative that makes state-of-the-art transmission electron microscopy (TEM) facilities available to Norwegian and international researchers.

The Centre has two nodes, in Oslo and Trondheim, and is a collaboration between NTNU, the University of Oslo and SINTEF. The Trondheim activity is run by the TEM Gemini Centre – a research team specialising in TEM from the Department of Physics, the Department of Materials Science and Engineering, and SINTEF Industry. The Centre is part of the EU TEM network ESTEEM3.

The following TEMs are available within the Centre:

1. a **Jeol JEM-2100 LaB6**, which is our work-horse for routine TEM studies, optimised for conventional TEM techniques such as bright-field (BF) and dark-field (DF) TEM and selected area electron diffraction (SAED).

2. a **Jeol JEM-2100F** equipped with a field-emission gun (FEG), which is optimized for advanced materials studies, with a special focus on tomography and scanning precession electron diffraction (SPED). In 2020 we installed a direct electron detector on this instrument, which provided a substantial improvement in detection of diffraction patterns.

3. a **Jeol JEM-ARM200F**, which is one of the best specified microscopes in Europe, capable of atom-by-atom imaging and chemical analysis. The system has aberration correction for the probe and image forming lenses. It also has a large, efficient Energy-Dispersive X-ray (EDX) detector and Electron Energy Loss Spectroscopy (EELS) for atomic scale spectroscopy.

The centre is equipped with extensive specimen preparation facilities and a computer room for data processing. Each TEM has its own set of single and double tilt holders. Other options include cold-stage holders, heating holders, environmental cell holders, transfer holders, tomography holders and two tilt-rotation holders. Specimen preparation facilities include different types of dimplers, saws, ultrasonic cutters and other tools for the preparation of cross-sectional specimens. The Centre has three precision ion-polishing systems, while an ultramicrotome is available for thinly slicing soft specimens. For applications requiring sample preparation on the nanoscale, there are two focused ion beam systems available at NTNU NanoLab.

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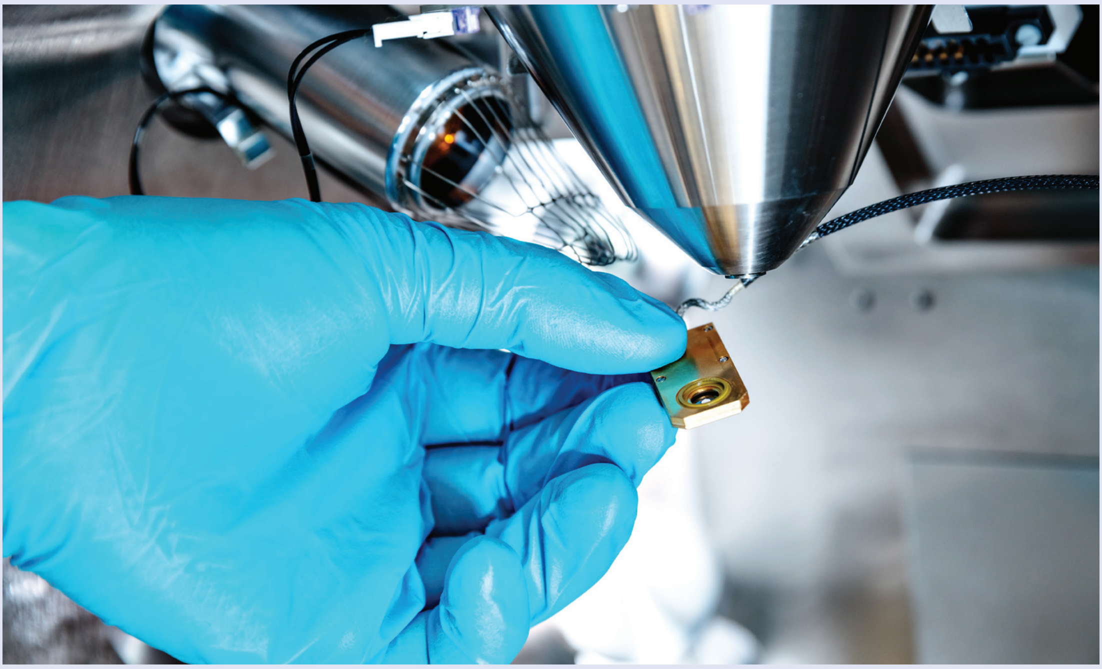

Nanoindenter at the NanoMechanical Lab, photo : Geir Mogen / NTNU

INFRASTRUCTURE

The X-ray Physics Laboratory

The X-ray Physics Laboratory is headed by the X-ray Physics Group at the Department of Physics, NTNU. The lab is an integral part of the nationally coordinated Norwegian Centre for Nanoscale X-ray Tomography, which has a second node at the University of Oslo.

The lab is well equipped for X-ray imaging and scattering, which are non-destructive techniques to study the internal nano- and microstructure of materials. The lab has particular expertise in porous media and mesoscale physics, with applications in the fields of geophysics, biophysics, and materials physics. It coordinates and participates in several national and international research projects, and is part of the EU H2020 network project EXCITE.

The facility includes a Nikon 3D scanner for imaging with resolution down to about 5 micrometres, which is extensively used by both internal and external users. Adequate sample environments are available for in-situ thermal and mechanical loading.

The lab further contains a unique X-radiography facility for dynamic imaging of evolving microstructures during solidification in alloy samples. A custom-built setup is available for small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS) analysis – built with a focus on flexibility for physics experiments. Finally, a phase-contrast computed tomography (CT) instrument based on a partially coherent nano-focus source is currently under construction and will be commissioned early 2022, aiming for sub-micron resolution and improved contrast for studies of soft and organic materials.

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The Ugelstad Laboratory

The Ugelstad lab was established in 2002 in memory of Professor John Ugelstad, and provides a wide range of experimental techniques for colloid, polymer and surface chemistry.

The lab has a strong focus on complex interfaces (especially in relation to dispersion stability and multiphase flow), and addresses application areas such as sustainable production and processing of oil and food, water treatment, and materials science.

The laboratory uses a wide range of techniques for investigating solid/liquid, liquid/liquid, gas/liquid and gas/solid interfaces. Listed below are some of the key methods available within the lab that may be of interest to nano-researchers: (i) tensiometry for measuring dynamic and equilibrium surface tensions; (ii) methods for characterisation of dispersions; (iii) microfluidic platforms, primarily used for studying dispersion stability and flow in porous media; (iv) differential scanning calorimetry (DSC); (v) methods for surface and particle characterisations; (vi) a wide range of ultra-violet (UV), visible, near infra-red (IR) and mid IR spectroscopies; (vii) instrumentation for high performance liquid chromatography, using UV- and IR-detection plus a combined GC-MS instrument. A full list of equipment is available on the laboratory web site: *https://www.ntnu.edu/chemeng/research/ugelstad*

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The Molecular Beam Expitaxy (MBE) lab

The MBE lab specialises in epitaxial growth (deposition) of III-V semiconductors in ultrahigh vacuum (UHV). The UHV condition allows evaporated materials to behave like molecular beams that can be easily interrupted by the use of shutters, permitting the fabrication of multi-layer structures with atomically sharp interfaces. The use of elemental sources whose deposition rates can be individually adjusted (by changing the source temperature) allows alloys such as $Al_xGa_{1-x}N$, $Al_xGa_{1-x}As_ySb_{1-y}$ and $In_xGa_{1-x}As_ySb_{1-y}$ to be fabricated. Layers can be doped by co-deposition of a doping material, with a wide range of doping concentrations being possible. Growth of both thin-film structures and nanostructures, like nanowires and quantum dots, is possible. The lab usually stocks GaAs, GaSb, InAs, InP, Si and sapphire as substrates.

The lab consists of two MBE systems, one of which is dedicated to full nitrides and the other of which is used for arsenides and antimonides. In addition, there is a CV-profiler in the lab that can be used to determine doping profiles in samples by destructive etching (while measuring the capacitive response of the semiconductor-electrolyte interface).

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FEATURE ARTICLES

How researchers solved a decade-long puzzle about friction

Sometimes, when it comes to friction, less is more – at least that's what several experiments over the last decade seem to have shown in the case of friction caused by layered materials. But it wasn't until recently that researchers at NTNU figured out what was actually going on.

Astrid de Wijn
Photo: Thor Nielsen/NTNU

David Andersson
Photo: Marcus Gidekull

Friction probably isn't something you think about on a daily basis, but as anyone who's ever slipped over on an icy pavement could tell you, it can play a crucial role in many situations. The downside of friction, though, extends far beyond icy pavements: along with wear, it is responsible for approximately 23% of the world's energy consumption.

"Friction is a huge technological problem," says Astrid de Wijn, a professor in the department of mechanical and industrial engineering at NTNU. "In industrialised societies, where we have machines that are moving constantly or very fast, friction is enormously costly."

Studying friction is not as simple as classroom physics demonstrations involving a wooden block on a ramp suggest. "What is really happening is that the surfaces are rough and they meet at some points that are typically quite small," says de Wijn. "When we study friction we are thinking about these contact points and how they behave."

In order to really understand what they can see happening at the real world macroscale, researchers need to be able to explain the complex behavior of the materials at the nanoscale. "Many different things are happening at different length and time scales, and it makes friction very interesting," says de Wijn.

Layered materials – such as graphene, which is a single layer of carbon atoms arranged in a honeycomb pattern – generally have low friction. They are already used in lubricants, but learning more about how they work could enable us to make the world's machinery run more smoothly and reduce our energy bill on a global scale.

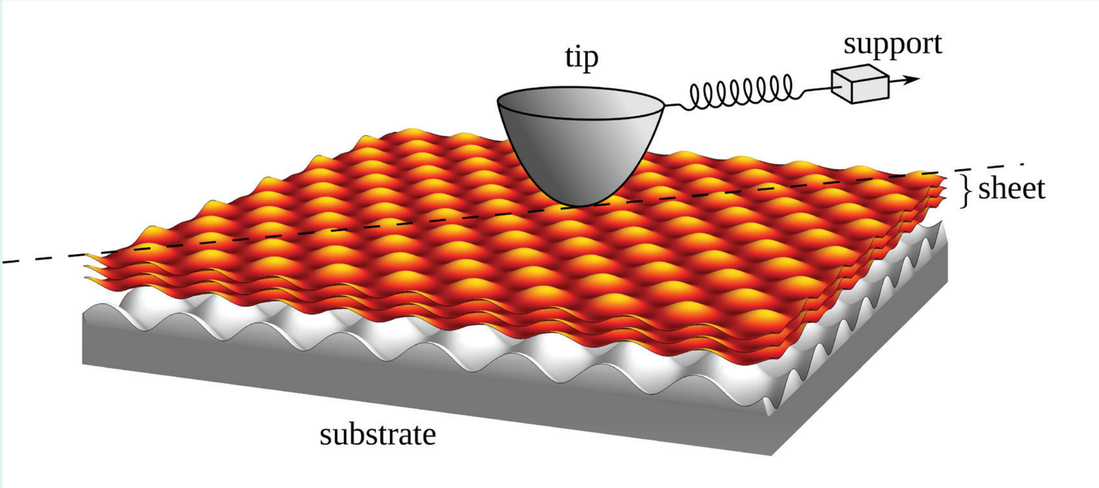
But in the last decade, researchers studying how friction works in materials like graphene have found that a single layer actually creates more friction than several layers. "People didn't understand that, and for years they were struggling with it," says de Wijn. "They did simulations and they reproduced this behaviour but couldn't figure out what was really happening."

The problem was, while there were plenty of results apparently showing what was causing the material to behave like this in particular situations, the explanations proposed by different researchers seemed to contradict each other, and nothing stood out. "They all had good arguments and evidence that, in their system, it was their suggested mechanism that was doing it, says de Wijn.

In a recent paper published in Nature Communications, de Wijn and PhD student David Andersson solved the problem. It turns out that all of the proposed solutions are, in a way, right.

One existing model that often proves helpful for understanding friction was first proposed in 1928 and consists of three elements: a support, a spring and a tip. The friction is then the force required to pull the tip across a sheet. While that works well for explaining many situations, it falls apart when layered materials are involved. So de Wijn and Andersson added just one variable to describe what is happening inside the layers of the sheet that the tip is being pulled across. "We didn't specify what that variable meant exactly – if it was a scrunching up of some kind, or some bending or one of the many possible things that people had proposed," she says.

That simple tweak turned out to be the key to explaining several previous results, both from real world experiments and computational models. "Suddenly all the pieces fell into place and we understood what was happening," says de Wijn. "It could be different mechanisms giving rise to the same kind of dynamics."



SOURCE: https://www.nature.com/articles/s41467-019-14239-2/figures/1

Unfortunately, because of travel restrictions due to the coronavirus pandemic, de Wijn and Andersson have not been able to present the work at many conferences or discuss it with colleagues as widely as they would otherwise have done – at least not in person. Nevertheless, now this puzzle has finally been solved, it opens up new avenues for investigating how friction works in layered materials, and could pave the way for new technology to reduce it.

The work is not over yet, though. The next step for de Wijn is to figure out how thermal fluctuations affect the system. "It's not just an academic puzzle for us," she says. "Solving this means that we are one step closer to making friction lower."

Kelly Oakes

DOI: 10.1038/s41467-019-14239-2

Engineering materials for a new generation of electronics

Modern-day computers rely on the fact that electrons have charge. But electrons have another fundamental property called spin – a measure of magnetic orientation – that researchers hope to harness to create a new generation of computer chips. Spintronics – short for spin transport electronics – could lead to faster, more stable, and less power-hungry devices.

Thomas Tybell in the lab. Photo: Geir Mogen

An electron's spin is a bit like a compass needle that points north or south. Magnetic hard drives already use the spin of electrons to store information in the form of binary 0s and 1s, which your computer can then translate back into human-readable information. But traditional computer processing ignores spin entirely. Using spin for computation would mean processing and storage could happen on the same chip.

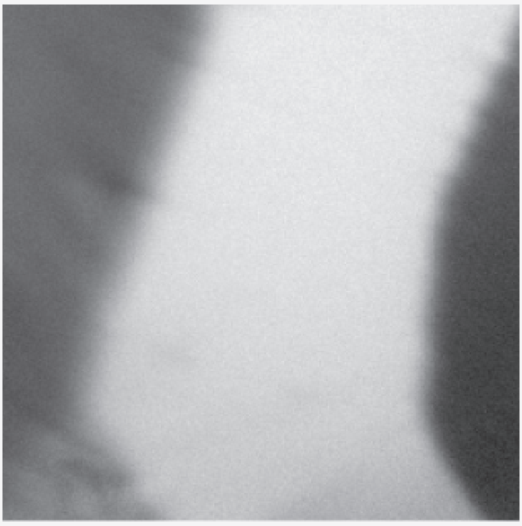
In most materials, there are equal numbers of electrons with spins that point in opposite directions, so from the outside they all appear to cancel out. These materials are known as antiferromagnetic, and Thomas Tybell, a professor in the department of electronic systems at NTNU and his colleagues are looking for ways to engineer them for use in future spintronic devices. "If we use antiferromagnetic materials, where the spins cancel, they are very robust against perturbations," he says.

That stability is a big plus. Let's say you're working on an important document, and just before you hit save there's a power cut. With conventional computing, you have probably just lost your work. But the spin of an electron stays the same even when the power is lost, so on a spintronic computer your work would be preserved.

But to create spintronic devices, we first need materials that allow us to reliably control spin. One big challenge is engineering materials without internal boundaries that could mess with the spin of electrons and result in lost information. These boundaries – called domain walls – occur where the repeating pattern of atoms in the material doesn't quite match up.

Recently, Tybell and his colleagues have found a way to make thin films from antiferromagnetic materials that look like they have no domain walls at all. By changing the arrangement of atoms – known as the lattice – in the substrate onto which the thin film is deposited, they can ensure the crystal grows in such a way as to avoid creating those internal boundaries. "Our key to controlling the physical properties is the lattice," says Tybell. "Previously we did see contrast between different magnetic regions as in the figure here. By controlling the lattice we suddenly got a grey, boring image with only one contrast, but actually what's important is that each pixel has the same magnetic axis," he says. "Suddenly you have no domain walls."

In recent years other researchers have shown that it's possible to create a single crystal that doesn't have domain walls. This new work shows it is possible in thin films, too. "That's important because suddenly you have unprecedented new possibilities for devices," says Tybell. "If you want to make a device that works you can't work on a single crystal, you have to make thin films."



The white and dark regions represent different magnetic regions, having their 'compass needle' pointing in different directions. The present study shows how to engineer materials with only one magnetic ordering. Data taken in collaboration with Ingrid Hallsteinsen, Rajesh Chopdekar (SLS), Erik Folven and Jostein Grepstad. Ref. I. Hallsteinsen, E.Folven, F. Olsen, R.V.Chopdekar, M.S. Rzchowski, C.B. Eom, J.K. Grepstad and T. Tybell, APL Matr. 3, 062501 (2015); licensed under a Creative Commons Attribution (CC BY) license.

There are still a number of challenges to overcome before spintronics goes mainstream, and Tybell says he can't be sure how long it will be until you'll be able to hold an entirely spintronic computer in your hand. "It will depend on how well we can control the materials to allow them to be mass produced," he says. "I hope it's soon, but I fear it's quite in the future."

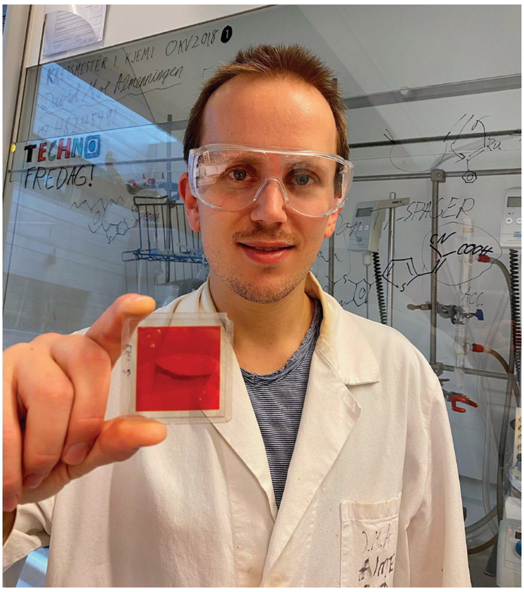
But, he points out, the concept behind the transistors that are present in every computer around the world was first patented in 1925. It then took two decades until the first working transistor was realised by researchers working at Bell Labs in the US, and several more years until they were in widespread use. In the meantime, the materials Tybell and his colleagues are developing will not go to waste: they can also be used by researchers studying quantum objects from a fundamental physics point of view. And while it's not easy to predict where that could lead, there's always a chance it might prove vital in the future, one way or another.

"We should not forget that if you can grow single crystalline thin films, it opens up new avenues to study quantum phenomena and learn about these materials in a way that might be important for quantum technologies in the future," he says. "I am sure there are many things still to discover."

Kelly Oakes

DOI: 10.1038/s41467-020-17999-4

Capturing energy from sunlight with dyes inspired by nature



David Moe Almenningen. Photo: Vilde Bråten.

As sunlight filters through a forest canopy, chlorophyll is hard at work capturing the energy of photons. Inspired by nature, researchers at NTNU are working on light-capturing dyes for solar cells to generate electricity.

These aren't the kind of solar cells you'll see on the roof of a building. In those silicon solar cells, light hits one of two semiconductor layers and frees up electrons to jump between the layers. It's the movement of these electrons that creates an electrical current. A dye-sensitised solar cell (DSSC) works in a similar way, but one of the semiconductor layers is replaced with a photosensitive dye that absorbs the light and releases electrons instead.

Dye-sensitised solar cells tend not to be as efficient at converting light into electricity as their silicon counterparts. But they work in low light conditions, and can be transparent and flexible, so are better suited to some applications. To really take full advantage of DSSCs, a research project partially funded by the Research Council of Norway (RCN)* is looking for ways to step up their efficiency.

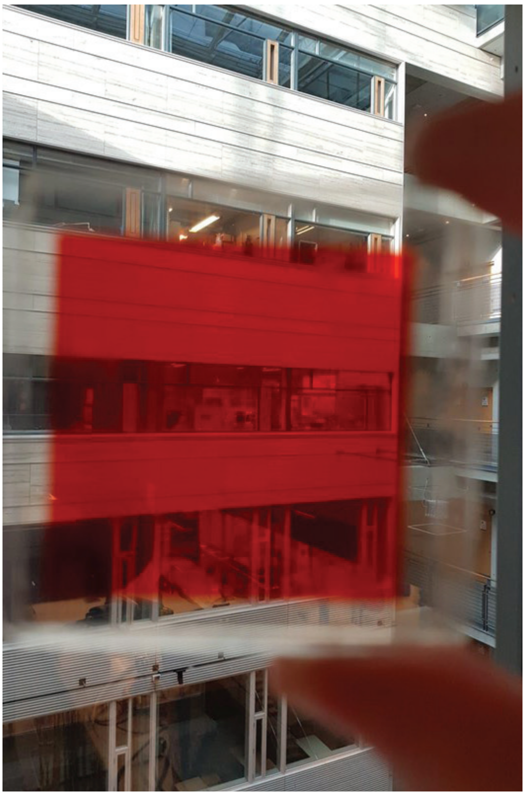
In a paper published recently in the journal Dyes and Pigments, NTNU PhD candidate David Moe Almenningen and colleagues, Odd Reidar Gautun, Bård Helge Hoff and Svein Sunde have shown that adding a particular molecule to the dyes can increase its light harvesting properties – though so far the additional light comes at a cost.

To harvest light a dye needs to act as an electron donor and an electron acceptor. "When this molecule is struck by a ray of sunlight, then the electron moves from the electron-rich part to the electron-poor part," says Almenningen. By adding something in-between the donor and acceptor, chemists are able to increase the amount of light the cell harvests.

Almenningen's research is investigating the addition of compounds featuring thiophenes, a molecule similar to benzene but containing sulphur. Thiophenes are electron-rich, so would be expected to increase the light harvesting properties of the dye, he says. And recent experiments show that they do: the dye with the most thiophenes was the one that harvested most light.

However, it turns out that increasing the amount of light a dye captures doesn't automatically mean better solar cells. Put simply: you might get more electrons, but they don't necessarily go where you want them to.

In his experiments, Almenningen found that though it absorbed the most light, the dye with the most thiophenes actually made the least efficient solar cell. "You think you're doing something brilliant by increasing the light harvesting ability, but then there are other reactions going on in the solar cell that are negatively affected by these modifications," he says.



Transparent solar cells could be used as part of a building's window or facade. Photo: David Moe Almenningen

He and his colleagues hope to find a way to avoid those counterproductive effects and take advantage of the improved light collection. Their next step is to try modifying the dye chemically so the electrons can only go in one direction. If this is successful, it could lead to more efficient solar cells.

Finding a way to increase the efficiency of DSSCs is one of the roadblocks to widespread use. The current highest efficiency is around 12%, compared with closer to 20% for a traditional commercial silicon solar cell.

If researchers are able to harness the light captured by dyes in these solar cells more effectively, DSSCs would potentially offer an advantage over traditional crystalline solar cells when it comes to scaling up: they are cheap to make, because they don't need a clean room or vacuum technology.

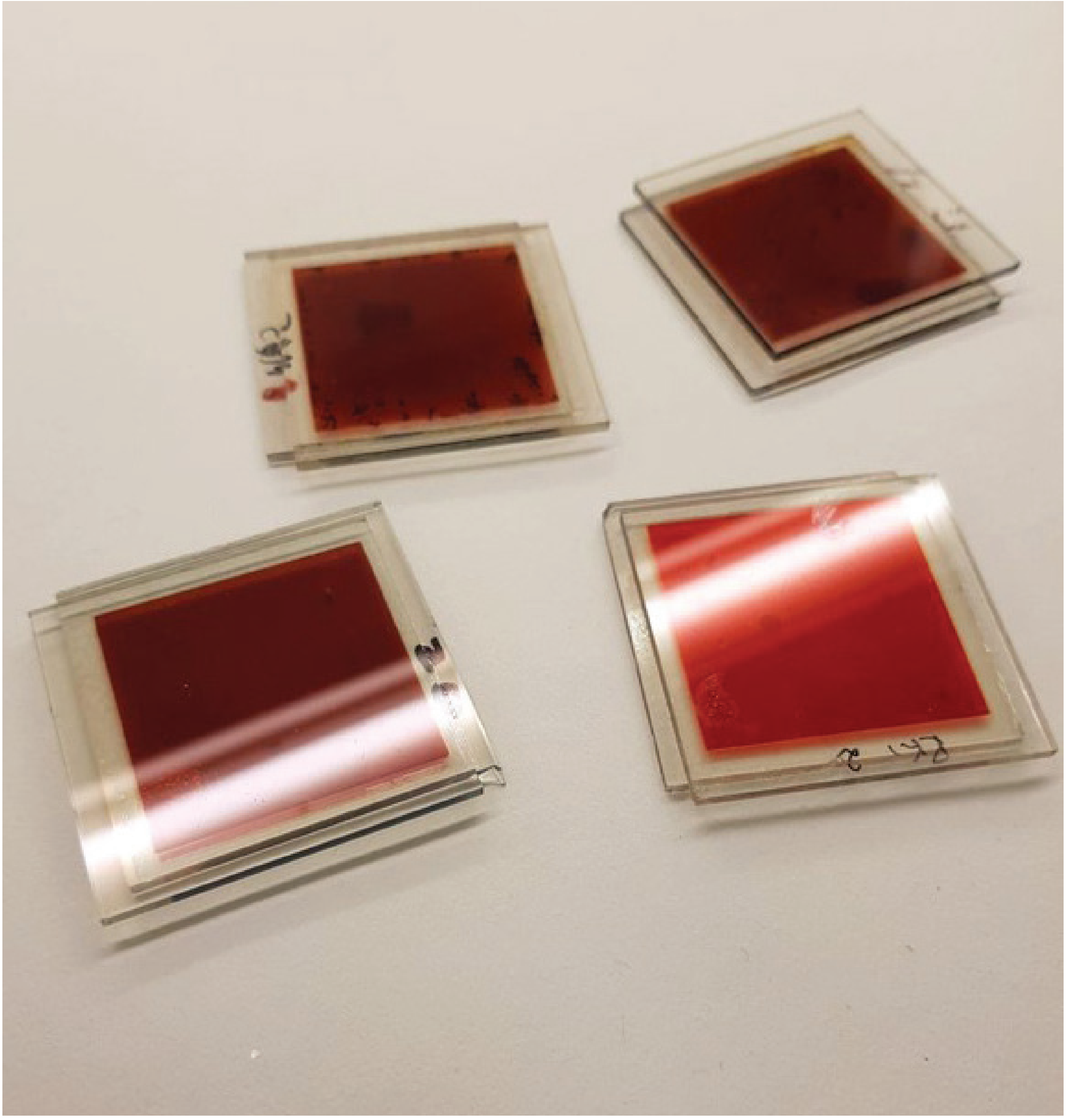
One promising avenue for DSSCs would be to integrate them into buildings to capture the dimmer light that is typically found indoors. "That's where these solar cells shine," says Almenningen. "Also they look quite pretty. You can customise any colour you want, they can be see-through."

For Almenningen, though, the reward is in figuring out how changing the chemical structure affects the performance of the dye: "The chemistry in itself is what's fascinating."

Kelly Oakes

RCN project numbers: 262152, 226244 and 295864

DOI: 10.1016/j.dyepig.2020.108951



Transparent solar cells, photo David Moe Almenningen

FEATURE ARTICLES

A new way to look at the inner workings of tiny magnets

Researchers from NTNU are shedding light on magnetic materials at small scales by creating movies with the help of some extremely bright x-rays.

Einar Standal Digernes
Photo: Kai T. Dragland

Erik Folven, Photo: Terje Trobe

Erik Folven, co-director of the oxide electronics group at NTNU's Department of Electronic Systems, and colleagues from NTNU and Ghent University in Belgium set out to see how thin-film micromagnets change when disturbed by an outside magnetic field. The work, partially funded by NTNU Nano and the Research Council of Norway, was published in the journal Physical Review Research.

Tiny magnets
The tiny square magnets, created by NTNU PhD candidate Einar Digernes, are just two micrometers wide and split into four triangular domains, each with a different magnetic orientation pointing clockwise or anti-clockwise around the magnet. These domains meet at a central point – the vortex core – where the magnetic moment points directly in or out of the plane of the material.

"When we apply a magnetic field, more and more of these domains will point in the same direction," says Folven. "They can grow and they can shrink, and then they can [merge] into one another."

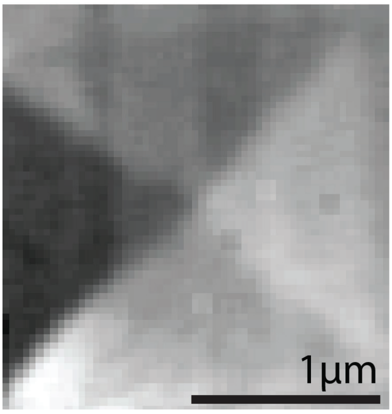
Electrons almost at the speed of light
Seeing this happen isn't easy. The researchers took their micromagnets to an 80m-wide donut-shaped synchrotron, known as BESSY II, in Berlin, where electrons are accelerated until they are travelling at almost the speed of light. Those fast moving electrons then emit extremely bright x-rays. "We take these x-rays and use them as the light in our microscope," says Folven.
Because electrons travel around the synchrotron in bunches separated by two nanoseconds, the x-rays they emit come in precise pulses. A scanning transmission x-ray microscope, or STXM, takes those x-rays to create a snapshot of the material's magnetic structure. By stitching these snapshots together, the researchers can essentially create a movie showing how the micromagnet changes over time.

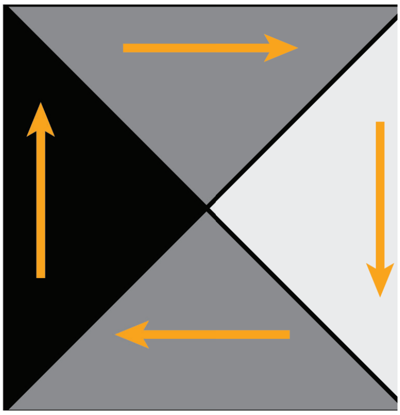
With the help of the STXM, Folven and his colleagues disturbed their micromagnets with a pulse of current that generated a magnetic field, and saw the domains change shape and the vortex core move from the centre.
"You have a very small magnet, and then you poke it and try to image it as it settles again," he says. Afterwards, they saw the core return to the middle – but along a winding path, not a straight line. "It will kind of dance back to the centre," says Folven.

One slip and it's over
The team's biggest challenge was making the samples in the first place. "We were very, very uncertain whether it would even be possible when we started out," says Folven.

That's because they study epitaxial materials, which are created on top of a substrate that allows researchers to tweak the properties of the material, but would block the x-rays in a STXM.

To solve the substrate problem, the researchers buried their micromagnet under a layer of





Scanning transmission X-ray microscopy image showing how the micromagnets are split into four triangular domains, each with a different magnetic orientation. Photo: Einar Digernes, NTNU

carbon to protect its magnetic properties. Then they carefully and precisely chipped away the substrate underneath with a focused beam of gallium ions until only a very thin layer remained. The painstaking process could take eight hours per sample – and one slip up could spell disaster.
"The critical thing is that, if you kill the magnetism, we won't know that before we sit in Berlin," he says. "The trick is, of course, to bring more than one sample."

From fundamental physics to future devices
Thankfully it worked, and the team used their carefully-prepared samples to chart how the micromagnet's domains grow and shrink over time. They also created computer simulations to better understand what forces were at work.

As well as advancing our knowledge of fundamental physics, understanding how magnetism works at these length and time scales could be helpful in creating future devices.

Magnetism is already used for data storage, but researchers are currently looking for ways to exploit it further. The magnetic orientations of the vortex core and domains of a micromagnet, for example, could perhaps be used to encode information in the form of 0s and 1s.
The researchers are now aiming to repeat this work with anti-ferromagnetic materials, where the net effect of the individual magnetic moments cancels out. These are promising when it comes to computing – in theory, anti-ferromagnetic materials could be used to make devices that require little energy and remain stable even when power is lost – but a lot trickier to investigate because the signals they produce will be much weaker.

Despite that challenge, Folven is optimistic. "We have covered the first ground by showing we can make samples and look through them with x-rays," he says. "The next step will be to see whether we can make samples of sufficiently high quality to get enough signal from an anti-ferromagnetic material."

Kelly Oakes

RCN project numbers: 221860 and 295864

DOI: 10.1103/PhysRevResearch.2.043429

Using real neural networks to pinpoint the start of brain disease

Researchers at NTNU are studying brain cells in the lab to investigate the foggy beginnings of diseases like Parkinson's and Alzheimer's.


Ioanna Sandvig
Photo: Angella Niarou

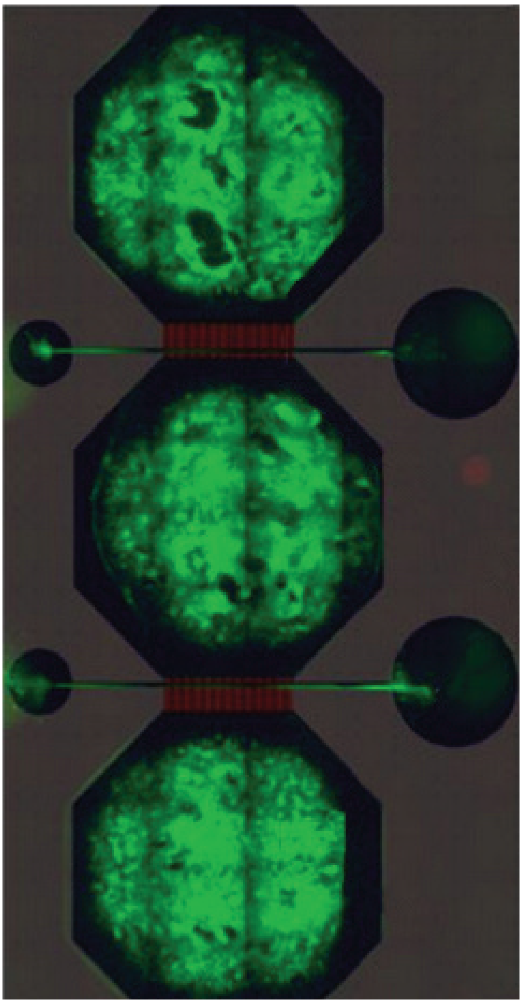
When the symptoms of neurodegenerative diseases like Parkinson's become clear enough to make a diagnosis, there have already been significant changes in a person's brain. That's why researchers believe that finding a way to identify this turning point could be the key to better treatments.

"In theory, if you can pinpoint the onset of the disease, you might be able to stop it or reverse some of its effects," says Ioanna Sandvig, co-leader of the integrative neuroscience group at NTNU's Department of Neuromedicine and Movement Science. "By the time you actually have very strong indications that something is wrong, then it's a bit too late."

Sandvig and her colleagues are growing interconnected brain cells in the lab, to study how these neural networks evolve and what happens when things go wrong. The research, supported by NTNU Nano, could help to pinpoint the very beginnings of neurodegenerative diseases.

Chip that mimics connectivity
Each neural network contains bundles of neurons – the cells that carry messages in our brains – housed in a microfluidic chip, the prototype of which was designed by Rosanne van de Wijdeven during her PhD at NTNU. These nodes are connected by tunnels in the chip through which axons – the wire-like protrusions of a neuron – can grow, but the main body of a neuron cannot.

By connecting three nodes together the researchers can mimic the connectivity inside the human brain. But Sandvig is keen to stress that these neural networks are not in any way real brains. "We don't have brains in the lab," she says. "But we do have networks that are



A neural network in a microfluidic chip.
Photo: NTNU

representative, and are very malleable to the perturbations we want to introduce."

The chips contain microelectrode-arrays made in NTNU's NanoLab that enable the researchers to measure the electrical activity of the network and gain insight into how signals are passing between the neurons.

In one recent study, led by Vibeke Devold Valderhaug and detailed in a paper uploaded to the pre-print server bioRxiv, the researchers cultivated two groups of neural networks in parallel, one of which housed neurons with a gene mutation that has been linked to Parkinson's disease known as LRRK2 G2019S. They saw that, in the network with the mutation, neurons grew and formed connections in a markedly different way, and displayed different electrical activity, to the healthy network. Neurons typically navigate their environment in a very specific manner, says Sandvig, but in the network with the mutation the cells didn't have the kind of directionality you would expect – they seemed confused. "The LRRK2 mutated networks seem to have some kind of aberrant growth," says Sandvig. "They seem to interpret exactly the same cues – because it's the same substrate – in a totally different way than the healthy network."

As well as those findings, Sandvig was pleased to see how clearly the subtle changes showed up in the team's experimental set up. "What was surprising was how well we could pick it up with this interface," she says. The interface also allowed the researchers to look at the connectivity within the nodes as well as between them.

Studying these brain changes in a neural network has advantages over studying them in animals, though each method can inform the other. "You can have these snapshots of changes in the structure and function of the network much more easily than in animal models," says Sandvig.

With neural networks, it's also possible to take cells from the same individual and derive them in two separate ways to compare how the networks evolve when age-related effects are removed. In fact, one of the follow up projects Sandvig is developing with integrative neuroscience group co-leader Axel Sandvig alongside colleagues at the Kavli Institute for Systems Neuroscience does exactly this for Alzheimer's disease. "Diseases like Parkinson's, ALS, Alzheimer's are all different, but they share some very fundamental characteristics," she says.

By providing new insights into how our brains change in the early days of neurodegenerative disease, real life neural networks could set us on a path to new understanding, and perhaps, eventually, even new treatments.

Kelly Oakes

RCN project number: 295864

DOI: 10.1101/2020.05.02.073726

A new way to get cells to spill their secrets

Countless potentially useful enzymes are hidden all around us. Now a team of researchers at NTNU have developed a new method that could help us find them.

Rahmi Lale (personal photo)

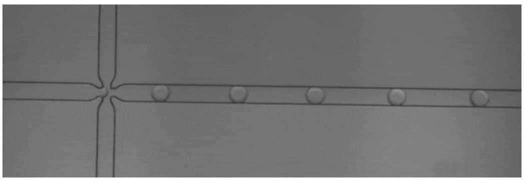
The natural world is a treasure trove of potentially useful enzymes, hidden in microorganisms living all around us. But finding them is tricky. A team of researchers at NTNU have developed a new method to break open cells that could help in the quest.

Enzymes are biological catalysts that can make industrial processes cheaper, less toxic, and more sustainable – and researchers are discovering new ones all the time. For example, a bacteria that uses two enzymes to break down plastic was found outside a plastic bottle recycling facility by Japanese researchers in 2016. "Nature has a vast capacity for producing enzymes," says Rahmi Lale, a synthetic biologist at NTNU's Department of Biotechnology and Food Science.

Now, Lale and his colleagues have developed a new technique to break open cells in a controlled way – a vital step in screening for helpful enzymes. Crucially, the method leaves some cells intact, allowing them to be recovered and investigated further. The work, partly funded by the Research Council of Norway and the EU HORIZON 2020 programme, has been published in the journal ACS Synthetic Biology.

Millions of different cells

To find a new enzyme in nature, the first step is to identify an environment where microbes that need such an enzyme might live. Heat-resistance is likely to be prized in the desert, for instance, whereas carbohydrate-degrading enzymes are more likely to be found in the human gut. Next researchers sift through material from that environment, such as a soil sample, to find genetic material. After isolating this environmental DNA, researchers cut it up into smaller pieces in the lab and paste it into well-studied microorganisms like E. coli (a process known as cloning) to screen for enzymatic reactions



The lysis-on-demand system works with microfluidic screening to find useful enzymes (Image credit: Husnain Ahmed)

This leads to countless microbes, each of which could contain what the researchers are looking for. From this point the search becomes a "needle in a haystack problem," says Lale. "It's easy to collect DNA, it's easy to clone them, and it's easy to introduce them into these microorganisms," he says. "But all of a sudden you have hundreds of millions of different cells. Every one of them carries something unique, but you don't know which carry things that you are interested in."

Screening the candiates

Using microfluidics – liquids flowing through tiny channels etched into a chip – allows researchers to screen the microbes 10,000 times faster than previous methods. The microbes are contained in water droplets that sit within an oil-based carrier fluid. But because most of the potentially useful enzymes are made inside those microbes, the cells have to be opened up in order to test them. To do this, Lale and his colleagues have developed a system that deliberately punctures the membrane of a cell, so its insides leak out into its surroundings. There, it can be tested for the presence of whatever kind of enzyme the team are looking for. "We have a substrate that waits for the enzyme to come and interact with it," says Lale. If there's a positive match, it will trigger a reaction.

Controlling the holes

The standard way to break down the membrane of a cell, a process known as lysis, involves a chemical solution that is all but guaranteed to kill every cell in the droplet. But this presents a problem for researchers who, after finding an enzyme of interest, want to probe the microbe it came from further.

In contrast to chemical lysis, the "lysis-on-demand" system can be controlled by adjusting the concentration of the substance that induces lysis, meaning the researchers can deliberately leave some cells intact so they can be recovered later on. "Because we can control how many holes we're introducing, we can also control how many cells die," says Lale. "We're not killing them all, and that's important."

"If something of interest happens in one particular droplet, then we can recover that droplet," he says. "Thanks to cells growing so quickly, we can take the droplet, put it in a growth medium and the next day have a billion cells again. Then recovery of DNA becomes a really simple task." The researchers confirmed their new technique in microfluidic chips they made in NTNU NanoLab.

From northern Norway to a UK compost heap

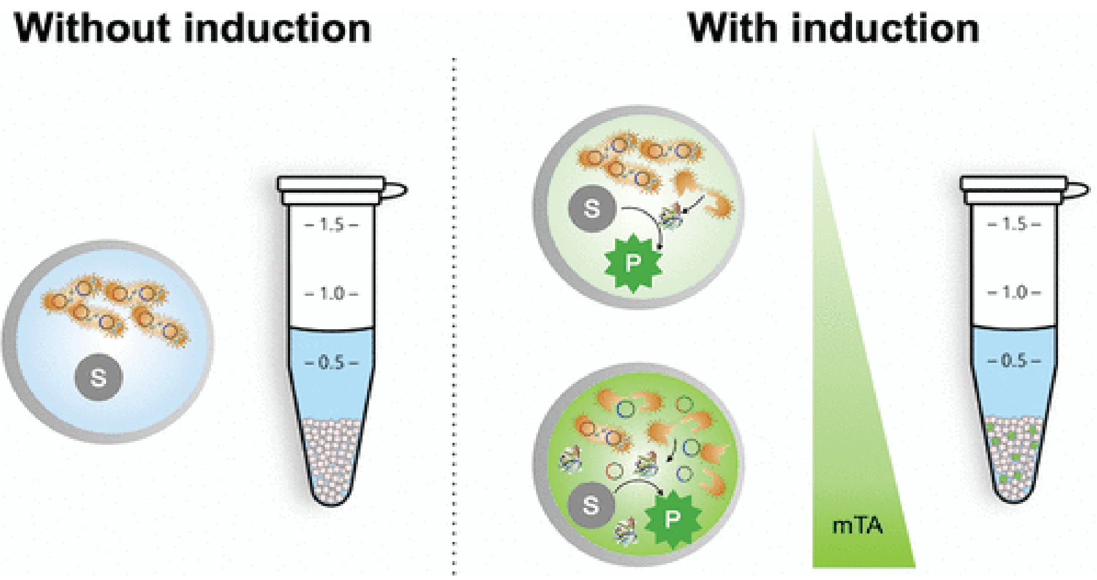
As well as boosting the search for useful molecules in nature, the technique could give a helping hand to researchers attempting to steer microbes towards making enzymes with particular traits. By introducing genetic mutations in the lab, researchers can nudge the microbe in numerous different directions – then use microfluidic screening combined with the lysis-on-demand system to find the microbe that was nudged closer to making the kind of enzyme they want.

Lale and his colleagues have applied for a grant to explore this aspect of the research further, as part of a consortium led by colleagues at the University of Cambridge, UK. The researchers plan to use the system to sift through environmental DNA samples from various locations that could yield interesting enzymes, including the cold of northern Norway, the hot climate of southern Spain, and a UK compost heap. "If you look into these interesting environments, the chances of finding something is higher," says Lale.

Kelly Oakes

RCN project number: 295864

DOI:10.1021/acssynbio.1c00084



The lysis-on-demand system can control how many cells are broken open (Credit: Wong et al. 2021) https://pubs.acs.org/doi/10.1021/acssynbio.1c00084

How spider silk inspired a new material with extraordinary mechanical properties

Researchers at NTNU have developed a new elastomer with unprecedented stiffness and toughness, inspired by spider silk

Zhiliang Zhang
Photo: Jianying He

Inspired by extremely strong spider silk, researchers at NTNU have developed a new material that defies previously seen trade-offs between toughness and stiffness.

The material is a type of polymer known as an elastomer because it has a rubber-like elasticity.

The newly developed elastomer features molecules that have eight hydrogen bonds in one repeat unit, and it is these bonds that help to evenly distribute stress put on the material and make it so durable.

"The eight hydrogen bonds are the origin of the extraordinary mechanical properties," says Zhiliang Zhang, professor of mechanics and materials at NTNU's department of structural engineering. The material was developed at NTNU NanoLab and partially funded by the Research Council of Norway.

The idea to introduce a higher than usual number of hydrogen bonds came from nature. "Spider silk contains the same kind of structure," says Yizhi Zhuo, who developed the new material as part of his PhD and postdoc work. "We knew it could result in very special properties."

Scientists have previously noted that spider silk – specifically dragline silk, which provides the spokes and outer rim of a spider's web – is both exceptionally stiff and tough.

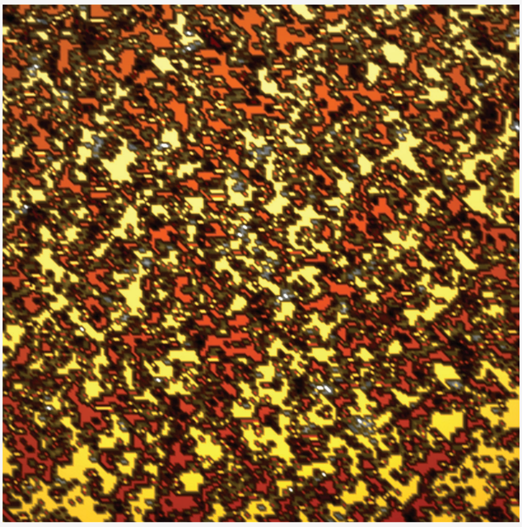
Stiffness and toughness are distinct properties in engineering and are often in opposition. Stiff materials can withstand a lot of stress before deforming, whereas tough materials can absorb a lot of energy before they break. Glass, for example, is stiff but not tough.

Until now, replicating the dual stiffness and toughness of spider silk in synthetic elastomers has not been possible. "With commercial materials, if you want to have higher stiffness, you have lower toughness. It's a trade off. You cannot have both," says Zhang.

The team's new elastomer features distinct hard and soft domains. After devising and making it, the team used an atomic force microscope – with a resolution of fractions of a nanometre – to look at the underlying structure of the material, and observe the interface between the hard and soft regions.

They saw that as well as the eight hydrogen bonds distributing stress, the mismatch in stiffness between the hard and soft domains helped to dissipate energy further by encouraging any cracks to branch off instead of continuing along a straight path. "If you have a zig-zag, you create a large fracture surface and dissipate more energy, so you have higher toughness," says Zhang.

Alongside it's mechanical properties, the material is optically transparent and research suggests it could even self-heal at temperatures higher than 80 °C. If production can be scaled up, the new material could one day be used



The researchers looked at the interface between the hard and soft domains using an especially powerful microscope called an atomic force microscope. Image size: 200 x 200 nm. Credit: Zhang et al (2021)

in flexible electronics – particularly wearable devices that are more prone to damage and breakages.
Zhang and his colleagues filed a patent for their material in March, but they continue to work on introducing other desirable properties to it. The soft domains in their material are made up of a silicon-based polymer known as PDMS, but the researchers suspect they could improve the mechanical properties even further by experimenting with other substances.

They would also like to extend the material's properties to include anti-icing – stopping ice sticking to it at low temperatures – and anti-fouling – preventing aquatic organisms like mussels and algae attaching to it – so it could be used in extreme conditions, such as the Arctic. "This material is a good starting point, but we want to add some other functionality," says Zhang.

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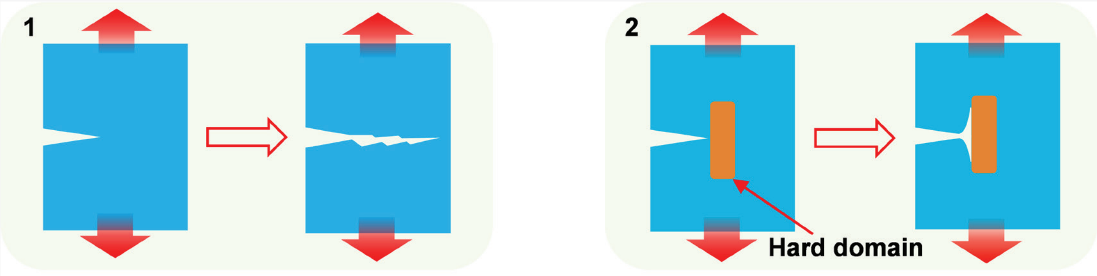

The hard domains (shown here in orange) prevent cracks from propagating through the material Credit: Zhang et al (2021)

Magnetic lamella in a 300 nm thin film of Fe_3Sn_2. Photo: Erik Dobloug / NTNU NanoLab.