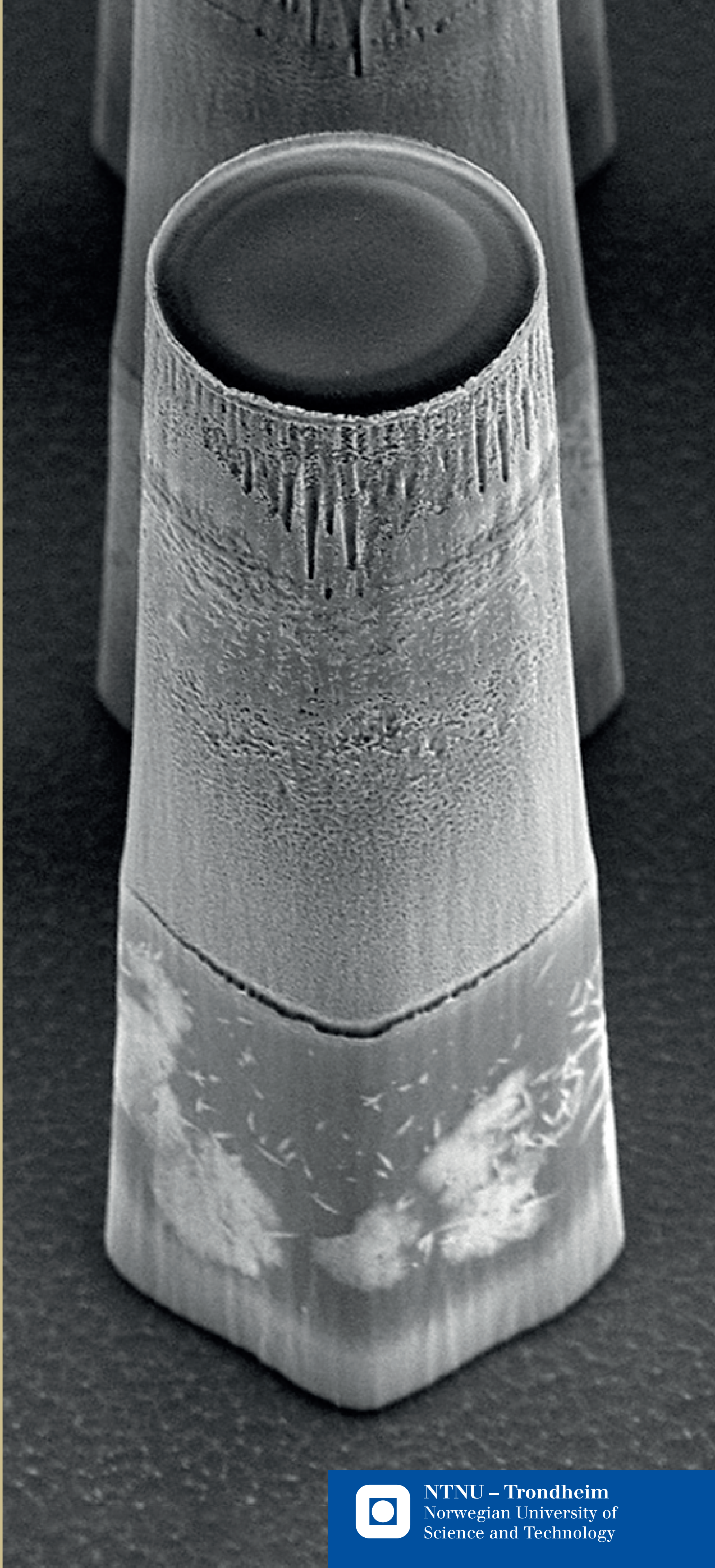
Annual Report Nano@NTNU 2016



NTNU – Trondheim
Norwegian University of
Science and Technology

Nano@NTNU 2016

2016 has been a good and busy year for NTNU´s nano community, both on the scientific side and for NTNU´s cleanroom research infrastructure, NTNU NanoLab.

The nano community is growing, in particular at the Faculty of Engineering. Several new faculty members have been recruited at different departments, among them, two participants of the Onsager fellowship programme for young, internationally recognized researchers. Also, the number of PhD degrees related to nanotechnology, nanoscience and functional materials has increased by 35% the last year, demonstrating increased activity in the field.

The NorFab II project was initiated, which together with NTNU´s own financial contribution, ensures new investments in state of the art equipment in NTNU NanoLab. A process group, that will reduce the time for new users to get up-and-running in cleanroom fabrication technologies at NTNU NanoLab has been established. New this year is also that we have prepared a separate annual report for NTNU NanoLab featuring fabrication results and infrastructure related topics. Have a look!

In 2016, we have focused on the development of long term international relations. The Nano@NTNU board visited MESA+ at the University in Twente, the Netherlands, in February. The purpose of this visit was to explore the possibilities for scientific collaboration and in particular, to learn about the excellent innovation ecosystem in Twente. Furthermore, Nano@NTNU established a close cooperation with NTNU's office in Brussels. Together with its Director, Massimo Busuoli, we have initialised activities to increase the number of EU projects within Horizon 2020. Finally, the Kavli Nanoscience Symposium was arranged at NTNU with presentations of Nobel Prize laureate Shuji Nakamura and several other international recognised scientists. This symposium increases the visibility of NTNU within the international nano community and gives an excellent possibility to establish strategic collaborations.

On the research infrastructure part of the initiative we have intensified our cooperation within the Nordic NanoLab Network (NNN) where we cooperate on a Nordic level to increase competence among cleanroom users, engineers and managers. One of the largest achievements in 2016 was the more formal establishment of EuroNanoLab network. Together with seven other European partners, we aim at increasing collaboration between cleanroom infrastructures in Europe with the goal to improve and accelerate the research of our scientific users.

International success will be one of the main key performance indicators for Nano@NTNU in the coming years. In 2016, we have established a sound fundament to build on in the coming years.

Kay Gastinger
Director of Nano@NTNU

NORWEGIAN MICRO- AND NANOFABRICATION FACILITY NorFab

The Norwegian Micro- and Nanofabrication Facility, NorFab was established in 2010 by The Research Council of Norway (RCN) as a national infrastructure with four partners; NTNU, the University of Oslo, SINTEF Digital - Microsystems and Sensors and the University College of Southeast Norway. In 2016, the RCN granted NorFab a new project period (NorFabII), which will run until 2019.

In 2016, NorFab has undertaken several networking initiatives. The Nordic Nanolab Network (NNN) includes Myfab (Sweden), DTU Danchip (Denmark) and VTT Micronova (Finland) and NorFab. This year, NNN has had two meetings at the leader group level to exchange best practice experiences.

In addition, the Nordic Nanolab Expert Network (NNEN) constitutes a forum for exchange of experiences within micro- and nanofabrication among engineers. In 2016, NNEN organized four workshops; one in thin film and dry etching, two in lithography and one focusing on facility operation issues. The workshops had between 15-20 participants from 19 cleanrooms in the Nordic countries. Between the meetings the experts exchange experiences in an online forum.

Website: www.norfab.no

NanoNetwork
Norwegian PhD Network on Nanotechnology for Microsystems

The Norwegian PhD Network on Nanotechnology for Microsystems was established in 2009, with the objective to coordinate, integrate, and strengthen PhD programs in the field of nanotechnology and microsystems in Norway. The partner institutions are NTNU, the University of Oslo, University of Bergen, the University College of Southeast Norway, and SINTEF Digital - Microsystems and Sensors. The network is funded by the Research Council of Norway, Division of Science, Program for National Graduate Schools.

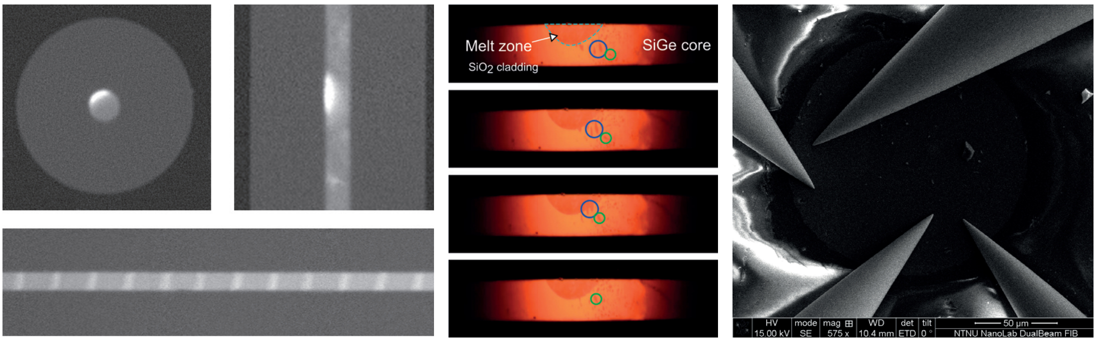
In 2016, the Network offered 8 PhD courses on compact format and provided travel support for the candidates to attend these courses. The network has allocated funding for laboratory and processing expenses (activity grants) to 21 PhD candidates and travel support for 25 candidates to present their work at international conferences. Our 2016 annual workshop was held in Trondheim, June 13th to 15th, gathering 93 participants from the network partnership research communities.

Website: www.nano-network.net

Front page: Silicon micropillars fabricated by cryogenic dry etching with SU-8 as mask material. At the lower part of the pillars the etch is crystallographic where the etch is directed by the crystal orientation of the (100) Silicon substrate. The image was taken with a FEI APREO SEM at NTNU NanoLab. Photo: Espen Rogstad/NTNU. Contact: Carlos Dorao, NTNU.

Structured SiGe fibers have a bright future

Glass fibres with semiconductor cores have emerged as a versatile platform for all-optical processing, sensing and microscale optoelectronic devices. Using SiGe in the core extends the accessible wavelength range and potential optical functionality because the bandgap and optical properties can be tuned by changing the composition. We have fabricated SiGe-core optical fibres, using CO_2 laser irradiation to heat the glass cladding and recrystallize the core, improving the optical transmission. We have observed the ramifications of the classic models of solidification at the microscale, and demonstrated suppression of constitutional undercooling at high solidification velocities. Tailoring the recrystallization conditions allows formation of long single crystals with uniform composition, as well as fabrication of compositional microstructures, such as gratings, within the fibre core. This work is related to the vertical rod and horizontal wire silicon solar cells produced at NTNU NanoLab and the Department of Physics at NTNU in the last years, and has led to an RCN project to further explore the solar prospects of the alloy microwires.



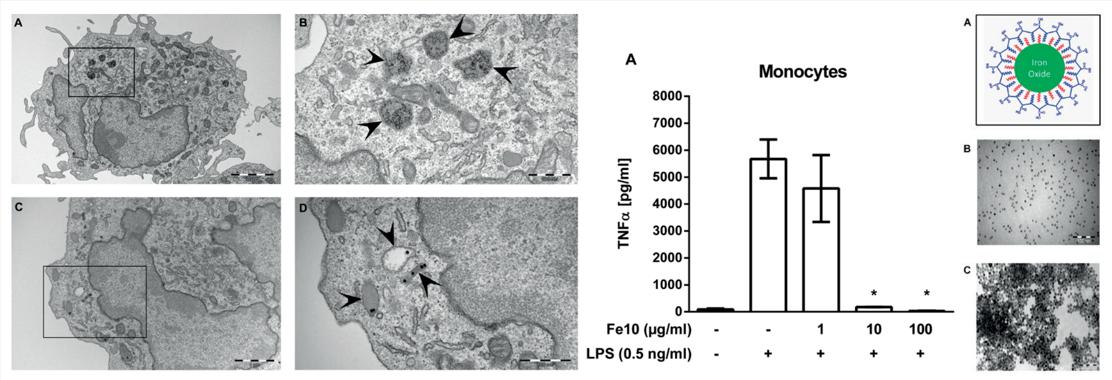
From the left: Cross section and side view of a Ge-rich lobe formed by melting the core and gradually reducing the laser power density and a Ge-rich grating formed in the fibre core by periodically interrupting the laser beam. Scale bars 200 µ. Visible emission during CO_2 laser treatment showing aggregation of Ge. Electrical properties measured using the Mibots at NTNU NanoLab. Scale bar 50 µm.

Reference: D.A. Coucheron, M. Fokine, N. Patil, D.W. Breiby, O.T. Buset, N. Healy, A. Peacock, M. Jones, T.A. Hawkins, J. Ballato, U. Gibson, *Nature Communications* 7 (2016) 13265.

Contact: Ursula Gibson, Dept of Physics, NTNU.

Immunological effects of iron oxide nanoparticles

Considering the increasing exposure of humans to engineered nanomaterials, it is relevant to study the effects of these materials on the human immune system. Moreover, as co-stimulation of the immune system to more than one agent concomitantly is very common in real life, there is a need to assess the potential effects of nanomaterials on immune stimulants, like e.g. bacterial components. We have characterized the physicochemical properties of 10 nm and 30 nm iron oxide nanoparticles (IONPs) and ensured that the nanoparticles were free from biological contamination. Using primary human monocytes as a model system, we found that the IONPs were taken up by the cells, but did not induce an immune response (measured by TNFα production). However, the IONPs suppressed the immune response induced by the bacterial component lipopolysaccharide (LPS). Using confocal microscopy, we have shown that this effect correlated with impaired LPS internalization by monocytes in the presence of IONPs, which could be partly explained by LPS adsorption onto the nanoparticles surface.



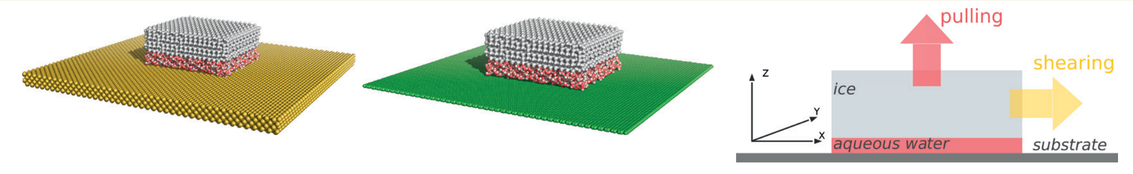
TEM images of 10 nm (A,B) and 30 nm (C,D) IONP uptake in monocytes. IONPs suppress LPS-induced TNF . B:10 nm, C:30 nm

Reference: S. Grosse, J. Stenvik, A.M. Nilsen, *Int J Nanomed*. 11 (2016) 4625.

Contact: Asbjørn Nilsen, Dept of Cancer Research and Molecular Medicine, NTNU.

Nanoscale deicing by molecular dynamics simulations

Deicing is important to human activities in low-temperature circumstances, and is critical for combating the damage caused by excessive accumulation of ice. The aim of creating anti-icing materials, surfaces and applications relies on the understanding of fundamental nanoscale ice adhesion mechanics. In this study, atomistic modelling and molecular dynamics simulation were employed to investigate ice adhesion. Pulling and shearing forces were applied to detach and shear nano-sized ice cubes on different surfaces for probing the determinants of ice adhesion mechanics. The results show that high interfacial energy restricts ice mobility and increases both ice detaching and shearing stresses. Interestingly, a sandwiched aqueous water layer between ice and substrates was found to drastically alter ice adhesion mechanics, which can result in up to a 60% decrease in ice adhesion strength. This study has not only provided atomistic details for interpreting previous experimental anti-icing experiments, but also for the first time contributed quantitative theoretical references for understanding the mechanics of macroscale ice adhesion at the atomistic origins.

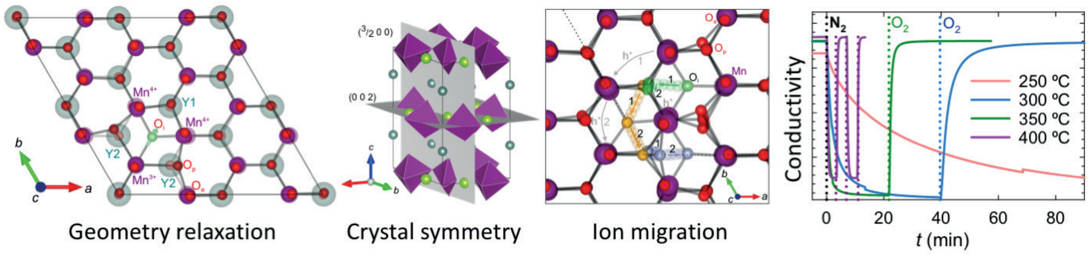


Atomistic models of ice-cube with a sandwiched water layer on silicon and graphene substrates

Reference: S. Xiao, J. He and Z. Zhang, *Nanoscale* 8 (2016) 14625.
Contacts: Jianying He and Zhiliang Zhang, Dept of Structural Engineering, NTNU.

p-Type conductivity controlled by oxygen interstitials

Hexagonal manganites are among the most studied multiferroic materials. Their domain walls (DW) display electronic properties with great potential for nanoelectronics, but the source of this conductivity has proven elusive. Using a combination of density functional theory (DFT) calculations and experiments on nanoparticles of $YMnO_3$, we have shown that p-type conductivity can be reversibly tuned by thermal and atmospheric history, without impeding the ferroelectric properties. This opens the possibility for reversibly controlling the DW conductivity without destroying the ferroelectricity or DWs. Oxygen interstitials (Oi) have not previously been demonstrated in ABO_3 oxides, and the charge compensation by holes gives rise to the p-type conductivity. Transport of Oi takes place through an interstitialcy mechanism with an unusually low migration energy barrier comparable to the best known oxygen anion conductors. As Oi cause only subtle perturbations of the structure, experimental detection in small concentrations is challenging, demonstrating the great value of the 'DFT microscope'.



Reference: S.H Skjærvø, E.T. Wefring, S.K. Nesdal, N.H. Gaukås, G.H. Olsen, J. Glaum, T. Tybell and S.M. Selbach, *Nature Comm.* 7 (2016) 13745.
Contact: Sverre M. Selbach, Dept of Materials Science and Engineering, NTNU.

Micro-nanoscale strategies for cellular heterogeneity

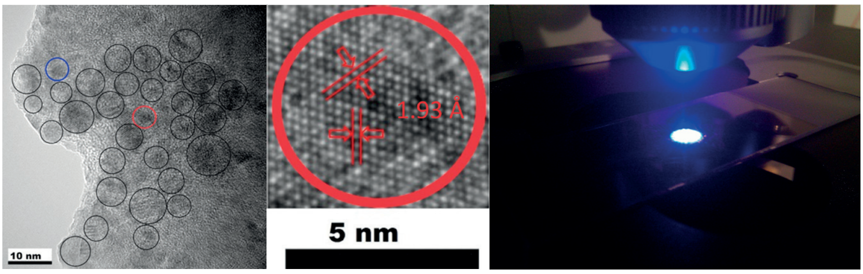
There is an increasing awareness of the importance of cellular heterogeneity, e.g., significant variability in gene expression at the single cell level in microbial populations. Bulk measurements yielding data averaged over the populations (still the most widespread, standard approach for characterization of such populations) do not provide the optimal information for characterization of cellular heterogeneity. To address this challenge, we have established two microdevice based strategies to facilitate such studies. Thus, droplet based microfluidics for encapsulation of microorganisms in micron sized alginate microbeads and the subsequent microbead immobilization on microarrays on glass surfaces by virtue of micro contact printing was developed. A double emulsion (W/O/W) micro-array arrangement strategy for the investigation of swimming microorganisms with a focus on the widely studied *P. putida* was also demonstrated. The work has been carried out at the Departments of Physics and Biotechnology and Food Science, and the steps in the device fabrication in NTNU NanoLab.

Schematic illustration of microgel bead synthesis and subsequent immobilization on PEI microcontact printed array.

Reference: A.G. Håti, N.B. Arnfinnsdottir, C. Østevold, M. Sletmoen, G. Etienne, E. Amstad, and B.T. Stokke, *RSC Advances* 6 (2016) 114830.
Contact: Bjørn Torger Stokke, Dept of Physics, NTNU.

White light emitting silicon nano-crystals-polymeric hybrid films

Si nano-crystals have exceptional optical and electronic properties due to their size and surface dependent tunable light emission, and possible applications in new generation opto-electronic devices are fascinating. Their importance in lighting and display technologies is increasing due to the abundance and non-toxicity of silicon. At NTNU NanoLab, we have established a single batch solution based synthesis route to Si nano-crystals (~2-10 nm) polymeric hybrid films exhibiting white light photoluminescence at room temperature upon excitation by ultraviolet light. These hybrid films are new candidates for down-shifting layers with the ability of spectral-shifting control.

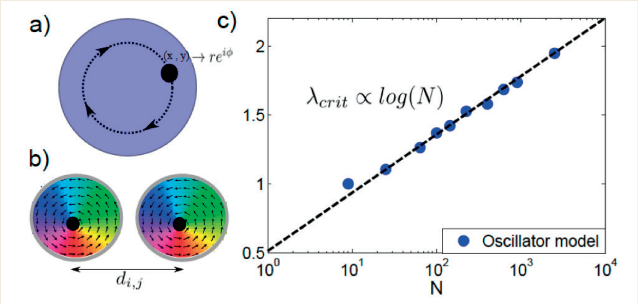


Luminescent hybrid films

Reference: M.H. Balci, L.M.S. Aas, M. Kildemo, R. Sæterli, R. Holmestad, M. Lindgren, T. Grande, M.-A. Einarsrud, *Thin Solid Films* 603 (2016) 126.
Contact: Mari-Ann Einarsrud, Dept of Materials Science and Engineering, NTNU.

Synchronization of nanoscale magnetic spin-torque oscillators

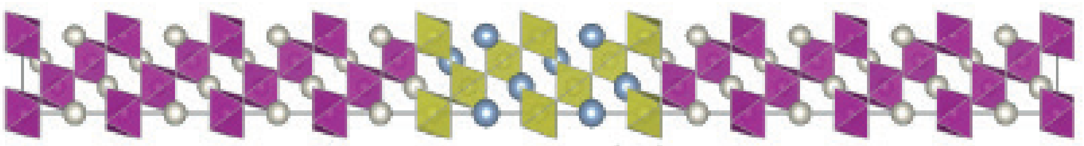
Spin-torque oscillators (STO:s) are microscale magnetic pillars driven to oscillate at GHz frequencies by passing spin polarised currents through them. STO:s are strongly non-linear magnetic oscillators that are envisaged to be useful for a variety of advanced nanodevices, as microwave sources and for signal processing. For applications, however, the ability of STO:s to be frequency and phase locked to external oscillatory signals or other STO:s is considered crucial to archive signal strength and usability. We have studied possible synchronization od large ensembles of STO:s through numerical/analytical models of systems that are currently too complicated and time consuming to realize experimentally. Our results shed new light on the limitations of the collective behavior of coupled STO:s, which might prove to be useful in designing new approaches to synchronize several oscillators, one of the main challenges to overcome to fabricate useful devices.



Ref. V. Flovik, F. Macià, E. Wahlström. Scientific Reports 6 (2016) 32528
Contact: Erik Wahlström, Dept of Physics, NTNU.

Functional interfaces – the role of structural reconstructions

Recent focus on epitaxial interfaces between strongly correlated oxides has revealed a large spectrum of exotic physical phenomena not present in bulk. Central to functional oxide interfaces are possible structural reconstructions. To elucidate the role of such structural reconstructions on emerging interface magnetism we have investigated the non-charge transfer system (111)-oriented epitaxial La0.7Sr0.3MnO3/LaFeO3 thin films. By combining magnetic XAS, spin-polarized neutrons, STEM/EELS with theoretical DFT studies we show that structural reconstructions at an interface can be accompanied by a change in electron localization, resulting in new magnetic phases.



Reference: I. Hallsteinsen, M. Moreau, A. Grutter, M. Nord, P.E. Vullum, D.A. Gilbert, T. Bolstad, J. Grepstad, R. Holmestad, S.M. Selbach, A.T. N'Diaye, B.J. Kirby, E. Arenholz and T. Tybell, Thomas, *Phys. Rev.* B 94 (2016) 201115
Contact: Thomas Tybell, Dept of Electronic Systems, NTNU.

Grey Goo Symposium, NTNU, 07.02.2016

The annual Grey Goo Symposium is a meeting place for companies and students enrolled in the master program in nanotechnology at NTNU. The aim of the symposium is to promote exchange of knowledge and ideas, and to prepare the ground for an increased number of collaborative master projects with the industry. Both students and industry representatives were thus given the opportunity to present their expertise, creating an atmosphere for further talks during the breaks. Around 115 students from NTNU, 7 guest students from China and 4 from the University of Oslo participated together with representatives from 7 Norwegian companies.

The symposium was organised by Timini, the association of the nanotechnology students, and was sponsored by Nano@NTNU.

Nano@NTNU Symposium, Trondheim, 17-18.11.2016

For the first time, the annual Nano@NTNU Symposium was organized as a two-day meeting. The event took place at Scandic Nidelven Hotel in Trondheim and gathered 130 participants.

The objective of the symposium was to feature nanorelated research at NTNU in at cross-disciplinary forum. The scientific program consisted of 34 oral presentations, four of which were given by invited plenary speakers from NTNU. The meeting also offered an "open space" platform for discussions of specific problems and challenges in an interdisciplinary forum. The poster session exhibited 32 posters. This year's prizes for the best oral presentation and poster were afforded to Aleksander B. Mosberg (best oral presentation) and Marieke Olsman (best poster). The symposium also included a social dinner.

Kavli Prize Lectures and Kavli Nanoscience Symposium, NTNU 08.09.2016

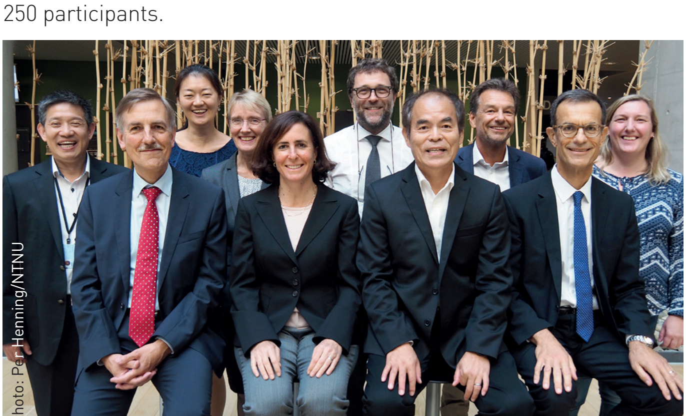
The Kavli Prizes in nanoscience 2016 were awarded to Calvin Quate, Gerd Binnig and Christoph Gerber *"for the invention and realization of atomic force microscopy, a breakthrough in measurement technology and nanosculpting that continues to have a transformative impact on nanoscience and technology"*. After the celebrations in Oslo, the laureates came to Trondheim to give their prize lectures at NTNU.

In affiliation with the prize lectures, Nano@NTNU organized the half day Kavli Nanoscience Symposium featuring the following international speakers:

- Shuji Nakamura, University of California, Santa Barbara
- Stacey Bent, Stanford University
- Krijn de Jong, Utrecht University
- Dimos Poulikakos, ETH Zürich

The prize lectures and symposium gathered more than 250 participants.

Kavli prize winners with their hosts. From the left: Ole Mathias Sejersted, Christoph Gerber, Anne Borg, Gunnar Bovim, Kay Gastinger and Gerd Binnig. Not present: Calvin Quate.



Speakers at the Kavli Nanoscience Symposium together with their hosts at NTNU.
From the left side, front row: Krijn de Jong, Stacey Bent, Shuji Nakamura, Dimos Poulikakos.
Second row: De Chen, Jianying He, Anne Borg, Kay Gastinger, Helge Weman and Hilde Lea Lein.

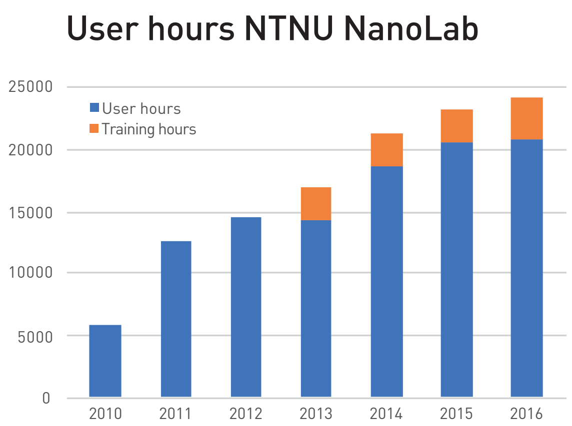
NTNU NanoLab

2016 was a year of cleanroom reorganization and start-up of the processing group to provide an even better service to our users.

The new Electron Beam Lithography system has become the heart of the cleanroom activities, and the nanostructuring fabrication line has been further strengthened through a purchase of an electron beam simulation software (Beamer). Furthermore, a maskless aligner (Heidelberg, MLA150) has been aquired to increase flexibility and efficiency of our lithography processes. A new dual-beam Focused Ion Beam instrument (FEI, Helios G4 UX) and a process characterization SEM (FEI, Apreo) have removed important bottle necks in the nanofabrication line and strengthened our national responsibility for this technology within NorFab.

Along with the installation of the new instruments, the cleanroom staff has been busy with the first major reorganisation of the cleanroom since the construction in 2009. The lithography and wet etch area has been completely reorganised to improve workflow, efficiency and safety. Also, the characterisation area has been extended and given a new footprint to give space for the new instruments as well as improvement of the vibration and acoustic noise properties of the area.

The employment of a leader for the processing group has boosted the activities of this group. The aim of the group is to give better user support to existing users and getting new users faster up-and-running.



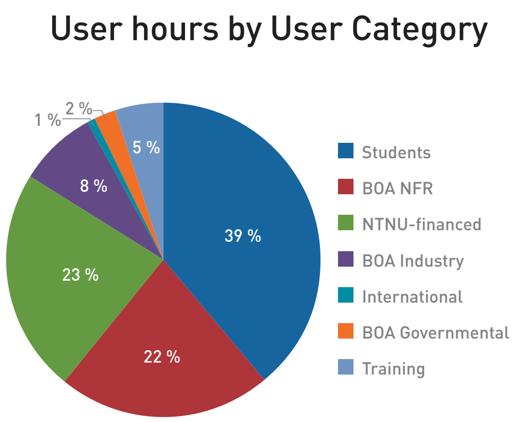


Photo: Geir Mogen/NTNU NanoLab

Dissertations

The following candidates obtained a PhD degree at NTNU in fields related to nanoscience,nanotechnology and functional materials in 2016. Highlighted candidates have carried out part of their work in NTNU NanoLab.

- **Nina Bjørk Arnfinnsdottir, *Microscale tools for the development of bacterial microarrays***
- **Habib Baghirov, *Nanoparticle uptake by brain endothelial cells and ultrasound-mediated transport across the blood-brain barrier***
- **Sulalit Bandyopadhyay, *Smart and multifunctional core shell nanoparticles (NPs) for drug delivery***
- **Zhongde Dai, *Combination of ionic liquids with membrane technology: a new approach for CO_2 separation***
- **Vidar Tonaas Fauske, *Electron microscopy based characterization of semiconductor nanowires***
- Vegard Flovik, *Magnetization dynamics in nanostructures*
- **Zhiwei He, *Nanotechnology for anti-icing application: from superhydrophobic surfaces to super-low oce adhesion surfaces***
- **Armend Gazmeno Håti, *Nano- and microscale control of alginate interactions and assembly***
- **Håkon A. Holm Gundersen, *Natural Superhydrophobic Surfaces: nanostructures and wetting states on Collembola cuticle***
- **Katherine Inzani, *Structure-Property Relations of Reduced MoO_3***
- Iryna Kulagina, *Magnetization Dynamics and Spinsuper-currents in Superconducting and Multiferroic Systems*
- Sigrid Lædre, *Bipolar Plates for PEM Systems*
- **Federico Mazzola, *Photoemission spectroscopies and their application in solid state and material physics***
- **Magnus Nord, *EELS and STEM studies of perovskite oxide heterostructures***
- Gerhard Henning Olsen, *Ferroelectric tungsten bronzes*
- Anna Maria Padol, *Influence of oligoguluronates on alginate gelation and on alginate gel properties*
- **Saroj Kumar Patra, *Antimonide-based mid-infrared laser structures: Growth and characterization***
- **Sigurd Pettersen, *Conduction mechanisms in conductive adhesives with metal-coated polymer spheres***
- **Rajesh Raju, *L-tartaric acid derived surfactants and N-isopropylacrylamide based core-shell nanogels***
- Isha Savani, *Non-equilibrium statistical mechanics of two-phase flow in porous media*
- **Tatjana Sherstova, *Quantitative atomic force microscopy and light microscopy of hydrogels and cells***
- Hans Langva Skarsvåg, *Normal and Superfluid Spin Dynamics in Magnetic Insulator Heterostructures*
- Jørgen Sundby, *Electrochemical Characterisation of Carbon-Supported Ru@Pt Core-Shell Catalyst for the Direct-Methanol Fuel Cell*
- Belma Talic, *Metallic interconnects for solid oxide fuel cells-High temperature corrosion and protective spinel coatings*
- Erlend Grytli Tveten, *Manipulating Spins in Antiferromagnets with External Forces*
- Nils Peter Wagner, *Alternative Li-ion Cathodes based on Transition Metal Orthosilicates*
- Xuehang Wang, *Porous carbon prepared by chemical activation for high-energy supercapacitors in ionic liquid electrolyte*

Marieke Olsman (best poster) and **Aleksander B. Mosberg** (best oral presentation)

Board of NTNU NanoLab

- Prof. Anne Borg,dean of the Faculty of Natural Sciences, NTNU (head of the board)
- Prof. Bjørn Gustafsson, dean of Faculty of Medicine and Health Sciences, NTNU
- Prof. Ingvald Strømmen, dean of the Faculty of Engineering, NTNU
- Prof. Geir Øien, dean of the Faculty of Information Technology and Electrical Engineering, NTNU.
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- Senior engineer Dr. Birgitte McDonagh
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