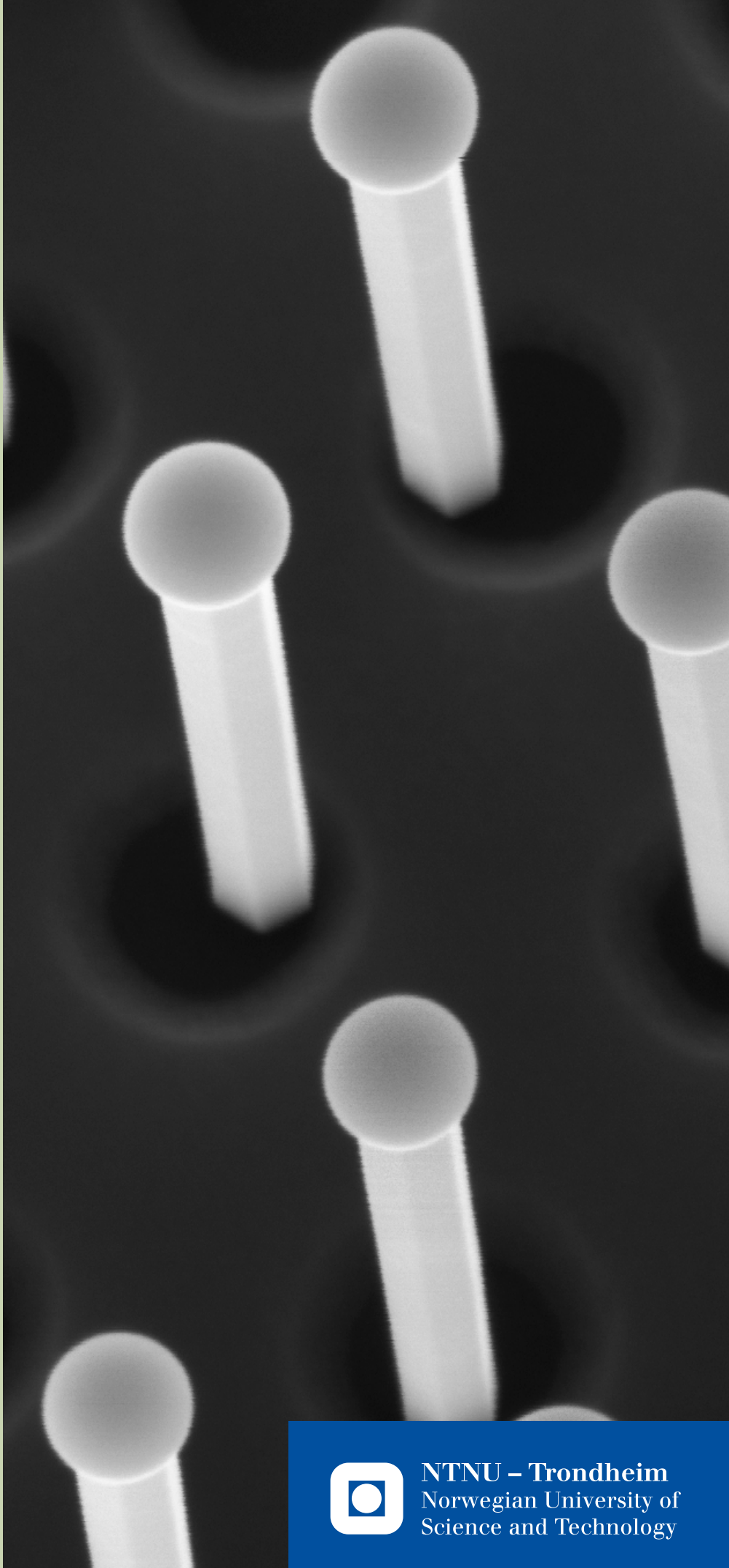
Annual report NTNU NanoLab 2010



NTNU – Trondheim
Norwegian University of
Science and Technology

NTNU NanoLab 2010

Erik Wahlström – director of NanoLab.

2010 marked the transition of NTNU NanoLab's cleanroom into a participating part in everyday science and education at NTNU. From the cleanroom perspective, there has been an increasing number of researchers and students using the equipment, ending the year with over 200 users, approximately 75 registered activities, and a steadily increasing activity in the laboratory. With the establishment of a full engineering staff, the key prerequisites for the infrastructure to be used to its full potential are fulfilled. During the year, a large number of techniques and processes have been established, forming a sound basis for further development of the infrastructure. The organisation of three new module courses at Master level has been especially demanding. These courses will, however, turn out to be invaluable for building future competence within nanotechnology in Norway.

Nationally, NTNU NanoLab attained the status as national infrastructure through the establishment of NorFab. In addition to supporting the development of the laboratory, this opens up an important gateway for researchers to collaborate and enrich our environment.

One of the main success criteria for NTNU NanoLab as a strategic effort is the degree of interdisciplinary collaboration. During 2010 we experienced increased interaction with all the involved faculties, mainly through the activities in the cleanroom. The establishment of a permanent position in nanomedicine / bionanotechnology at the Faculty of Medicine will promote this development further. At the beginning of the year, Rector of NTNU implemented a new organisation of NTNU NanoLab, including a full-time director. I am confident that the recruitment of a new competent director and the build-up of further arenas for interaction, both within NTNU and with collaborators in science and industry will form a firm ground for further development of NTNU NanoLab.

New director at NTNU NanoLab in 2011

Dr.Kay Gastinger (43) was hired in 2010 as the new director of NTNU NanoLab from January 1st 2011. Dr. Gastinger obtained a PhD in Physics in 2006 at the University of Oldenburg in Germany. He has been employed in SINTEF for the last 13 years within optical metrology. "I'm looking forward to this exciting task. I wish to establish NTNU NanoLab as one of the leading European research laboratories within nanotechnology. To obtain this, we will focus on establishing a large user group and a reliable financing model for NTNU NanoLab." Gastinger states.

Kay Gastinger.

NORWEGIAN MICRO- AND NANOFABRICATION FACILITY
NorFab

The national infrastructure NorFab (The Norwegian Micro- and Nanofabrication Facility) was started up in 2010.

NorFab (www.norfab.no) provides access to state-of-the-art laboratories for Norwegian researchers, independent of their academic, institute or company affiliation.

The infrastructure includes three nodes: NTNU NanoLab in Trondheim (project leader), SINTEF MiNaLab and UiO MiNaLab in Oslo, and MST- Lab at Vestfold University College in Horten.

NorFab offers open access to 2000m^2 of cleanroom laboratories with advanced equipment for nanoscale synthesis and analysis.

The Norwegian Research Council supports the project with 71MNOK over 4 years.

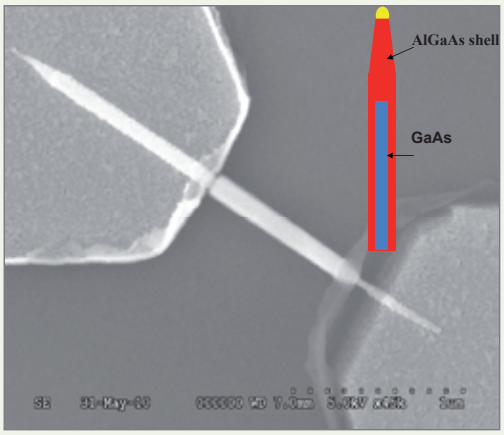
NanoNetwork

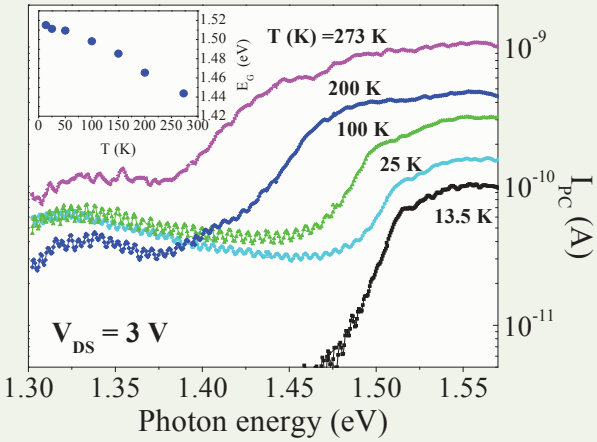
The Norwegian PhD Network on Nanotechnology for Microsystems (www.nano-network.net) has been established to coordinate, integrate, and strengthen PhD programs in the field of nanotechnology and microsystems in Norway. Partners are NTNU, University of Oslo, Vestfold University College, SINTEF ICT Microsystems and Nanotechnology, and NCE Micro- and Nanotechnology. The project is managed by the Faculty of Information Technology, Mathematics and Electrical Engineering at NTNU. In 2010, the PhD Network offered 5 PhD courses taught on compact format to network candidates. The number of courses is expected to grow to 9 in 2011. The network´s first annual workshop was organized in Tønsberg in June 2010 and gathered more than 90 participants.

Front page SEM image of positioned self-catalyzed GaAs nanowires grown on a silicon substrate. The diameter of the nanowires are about 100 nm. Copyright: Helge Weman.

Single GaAs/AlGaAs nanowire photodector

Using e-beam lithography and other facilities in NTNU NanoLab, single wurtzite GaAs/AlGaAs core-shell nanowire devices with electrical contacts have been fabricated. The nanowires were grown by Au-assisted molecular beam epitaxy at the Dept of Electronics and Telecommunications (DET) (Prof. Fimland's lab) and their electro-optical properties were investigated in the Nanophotonics lab (Prof. Weman's lab, DET). A high photo-response with more than two orders of magnitude increase of current at room temperature showed promise for nanoscale photo-detectors and solar cells. Photocurrent spectroscopy enabled investigation of the optical absorption of the nano-wires, giving important information about the fundamental physical properties of its unique wurtzite crystal phase.

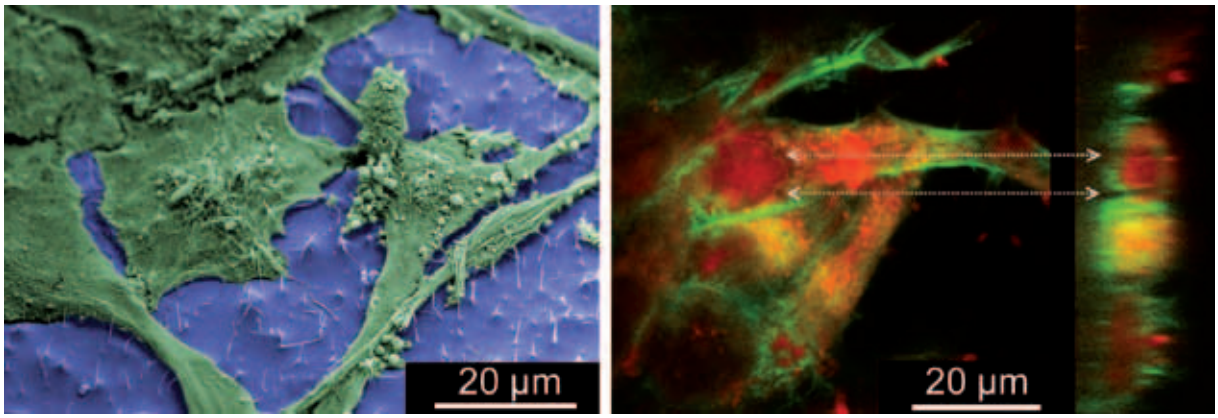




SEM image of a GaAs nanowire photodetector (left) and the energy dependence of the photocurrent response (right).
"Photocurrent spectroscopy of single wurtzite GaAs nanowires", D.C. Kim, L. Ahtapodov, A.B. Boe, J.W. Choi, H. Ji, G.T. Kim, A.F. Moses, D.L. Dheeraj, B.O. Fimland, and H. Weman, Proc. 30th ICPS, Seoul, Korea, July 25-30, 2010.

Transfection by cell impalement on nanostructures

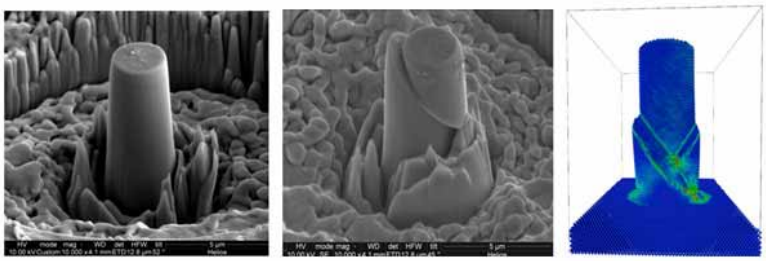
Analogous to the way hypodermic needles are used in macroscopic medicine to transport drugs or diagnostic agents into living tissue, nanotubes and nanowires can be used in microscale systems to transport molecular cargo directly into living cells. The much smaller diameter of the nanostructures (~100nm) compared to cells (~10 µm) allows the wires or tubes to impale the cells without causing internal damage, as indicated in the images below. In this research project conducted at the Department of Physics and in NTNU NanoLab, arrays of vertically aligned nanowires or nanotubes were fabricated on a transparent, cell-friendly surface with the aim to non-invasively transport materials such as DNA, RNA, or proteins attached to the nanowires or inside of the nanotubes across the cell membrane into the interior of the cells. The arrays are aimed at applications in high throughput screening, for example in molecular medical research, where response of cells to many agents can be investigated in parallel. The project utilizes a variety of NTNU NanoLab instrumentation e.g. photo-lithography, thin film deposition, chemical surface modification and micro- and nanoscale characterisation.



Coloured SEM (left) and fluorescent image of cervical cancer cells impaled on nanowires (indicated with arrows) (right).
Contact: P. Sikorski, Department of Physics, NTNU, pawel.sikorski@phys.ntnu.no.

Nanomechanical testing and modeling of pillars

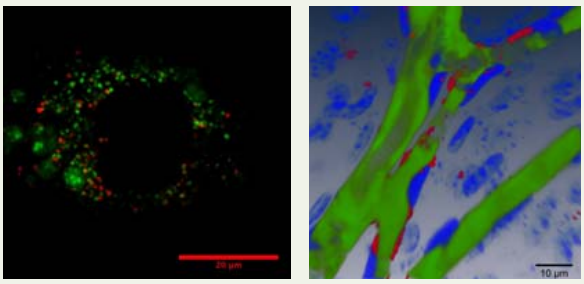
The rapid developments within nanotechnology have made it possible to machine very small test specimens from selected areas within crystalline materials: located at a grain, across a grain boundary or at specific microstructural constituents. In this way very precise mechanical properties can be obtained. The specimens are machined with Focused Ion Beam at NTNU NanoLab and subsequently tested with a Nanoindenter. From the compression testing of the pillars we obtain the stress-strain relationships at the nano level and can examine details of the deformation mechanisms. In parallel with the testing we also perform atomistic modeling of the pillars on the supercomputer at NTNU. The work is carried out at the Department for Engineering Design and Materials.



Specimens machined with Focused Ion Beam (left and centre). Atomistic modelling of pillars (right).
Contact: Christian Thaulow, Dept of Engineering Design and Materials, NTNU, christian.thaulow@sintef.no

Theranostics: Multifunctional nanoparticles

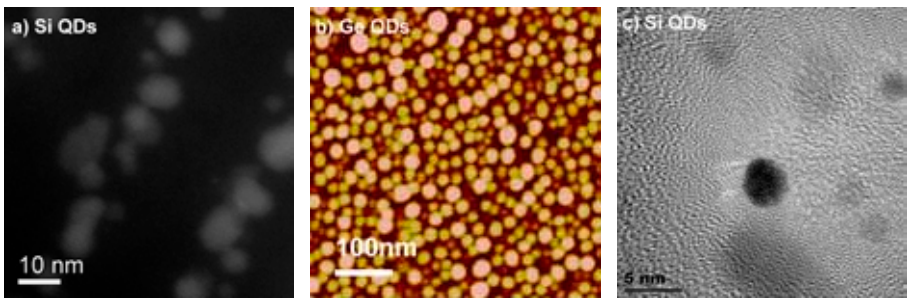
Nanoparticles are used in the clinic to improve cancer-specific therapy by targeting the drug-carrying nanoparticles to the tumor cells. They also have great potential to improve early detection of cancer and monitor therapy efficacy. At Department of Physics and Department of Circulation and Medical Imaging we are optimizing and characterizing targeted multifunctional nanoemulsions for MRI, optical imaging and drug delivery. Using confocal laser scanning microscopy the cellular uptake and intracellular trafficking of nanoemulsions in cell culture were studied, and in tumours growing in mice the distribution of nanoemulsions was characterized. Together with SINTEF Material and Chemistry who makes gas bubbles stabilized with nanoparticles containing a drug, we study how these bubbles can improve early detection of cancer by ultrasound and how ultrasound can be used to improve the delivery of the nanoparticles and the drug they carry.



Left: Targeted nanoemulsions (red) in endothelial cell in vitro was shown to avoid lysosomes (green). Right: Vasculature (green) in tumor growing in mouse. Nanoemulsions targeted to the vessel wall (red). Cell nuclei in blue.
Hak, S., Reitan NK, Haraldseth O, Davies C deL. Intravital microscopy in window chambers: a unique tool to study tumor angiogenesis and delivery of nanoparticles. Angiogenesis, 13, (2010) 113-130.

Quantum dots for solar cells

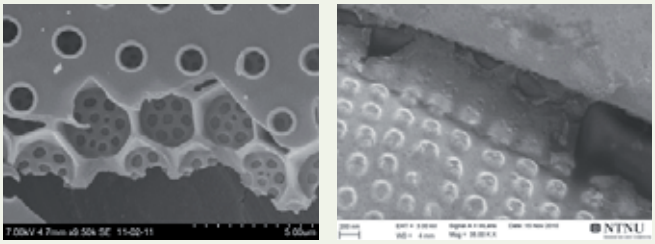
A quantum dot (QD) is a nanometre sized semiconductor with electronic and optical properties that can be tailored by varying the size of the QDs. The Department of Physics, and the Department of Materials Science and Engineering at NTNU, and SINTEF are working together in *The Norwegian Centre for Solar Cell Technology* to make QD materials in NTNU NanoLab. QD materials can be used to enhance the performance of solar cells by modifying the solar spectrum so that a better match with the solar cell properties is obtained. The QD materials are also used for new solar cell concepts, such as tandem cells and intermediate band solar cells. These cells have potential efficiencies that are twice that of conventional cells.



QD s fabricated using vapor deposition (a) and (b) or wet chemistry (c).
Contact: Turid Worren Reenaas, Dept of Physics, NTNU, turid.reenaas@ntnu.no.

Use of biomaterials in solar cell structures

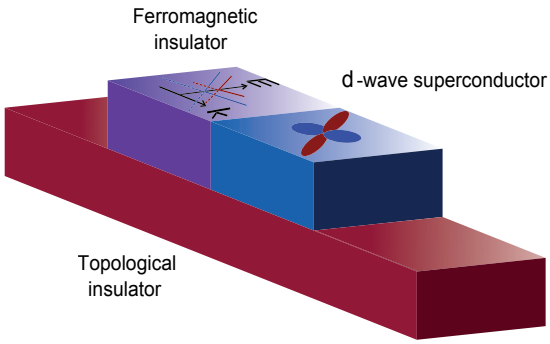
Diatoms are unicellular algae encased in an ornate amorphous silica cell wall *(frustule)*. The nanostructured frustule is suggested to possess optical properties making diatoms attractive for application, directly or indirectly, in solar cells in order to increase the amount of solar light harvested by the solar cell. Two diatom species, *Pinnularia sp* and *Cosinodiscus* were studied with respect to their structural properties in the Focused Ion Beam and the FEG-SEM at Nanolab. Templates of the two diatom structures were also manufactured by depositing a gold film, using the Electron Beam Evaporator in Nanolab. The work is carried out in a collaborative project between the Department of Materials Sciences and Engineering and Department of Biotechnology at NTNU and SINTEF Materials and Chemistry.



Frustule structure of Cosinodiscus (left) and gold template of Pinnularia sp. structure (right).
P. Ottesen, A.K. Noren, G. Tranell, A. Røyset, M. Juel and I. Kaus.

Topological edge-states and Majorana fermions

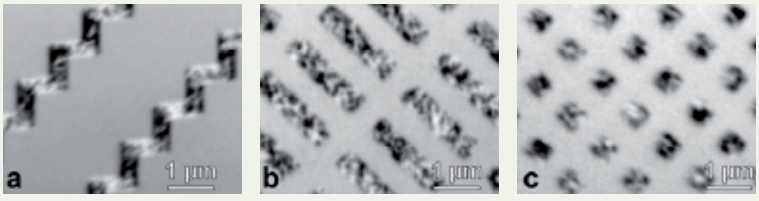
The recent discovery of a class of materials known as topological insulators offer a rich perspective on both fundamental physics and in terms of possible applications. These materials represent a new quantum state of matter with a bulk that remains electrically insulating whereas the edges have electrons which are spin-polarized and robust towards disorder. We have studied how topological insulators respond when placed in proximity to ferromagnetic and superconducting materials, and found a number of novel effects. Among the most exciting of these, we find that such hybrid structures may support so-called Majorana fermions which are their own anti-particles. They may find potential use in terms of fault-tolerant quantum computing due to their non-Abelian statistical nature. The work is carried out at the Department of Physics, NTNU in collaboration with theoretical physicists in Japan.



Hybrid structure of a ferromagnet and superconductor deposited on a topological insulator.
J. Linder, Y. Tanaka, T. Yokoyama, A. Sudbø, N. Nagaosa, Phys. Rev. Lett. 104, (2010) 067001.

Domain ordering in antiferromagnetic nanostructures

In a PhD project at Department of Electronics and Telecommunications, NTNU, E. Folven *et al*. have proven that – contrary to conventional wisdom – the domains in antiferromagnetic oxide thin film nanostructures may be influenced by size, shape, and orientation with respect to the film crystalline axes, i.e., despite the lack of magneto-static forces responsible for the domain formation in ferromagnetic nanostructures. The results were published in the Nov. 2010 issue of Nano Letters, and may prove important to fabrication of memory, logic, and sensor devices relying on exchange-biased magnetic nanostructures.



XPEEM images of the antiferromagnetic domain structure in $LaFeO_3$ thin film nanostructures embedded in a paramagnetic matrix. (Advanced Light Source, LBNL).
Erik Folven, Thomas Tybell, Andreas Scholl, Anthony Young, Scott Retterer, Yayoi Takamura, and Jostein K. Grepstad. Nano Letters 10.1021/nl1025908 (2010).

Kavli Prize Lectures at NTNU

The Kavli Prize in nano-science was awarded in Oslo on the 7th of September 2010 to Prof. Donald M. Eigler, IBM Research Center, USA and Prof. Nadrian Seeman, New York University, USA. Prof. Eigler gave his official Kavli lecture, "The Small Frontier" at NTNU on the 9th of September.

Kavli Prize laurates Prof. Donald Eigler (left) and Prof. Nadrian Seeman.

2nd Nanotechnology@NTNU

In conjunction with the Kavli Prize Lectures given in Trondheim on the 9th of September, NTNU NanoLab organized a half-day international symposium which gathered around 200 participants. The following international speakers were invited to give presentations:

- Kavli Prize Laureate Prof. Nadrian Seeman; *Using Chemical Information to Control the Structure of Matter*
- Prof. Anja Boisen, Technical University of Denmark; *Miniaturised Mechanical Sensors for Molecular Recognition and Nanoparticle Detection*
- Prof. Charles Lieber, Harvard University, USA; *Semiconductor Nanowires: Platform of Nanotechnology*
- Prof. Lars Samuelson, Lund University, Sweden; *Semiconductor Nanowires: a Generic Approach Towards Novel Materials Physics and Devices*

5th NTNU NanoLab User Meeting

This one-day seminar was organized on the 10th of September at NTNU. The aim of the meeting was to portray the various activities within nanoscience and nanotechnology at NTNU and to facilitate cross disciplinary contacts. The programme consisted of 21 lectures presenting different infrastructures and research projects at NTNU and SINTEF. The meeting gathered 80 participants.

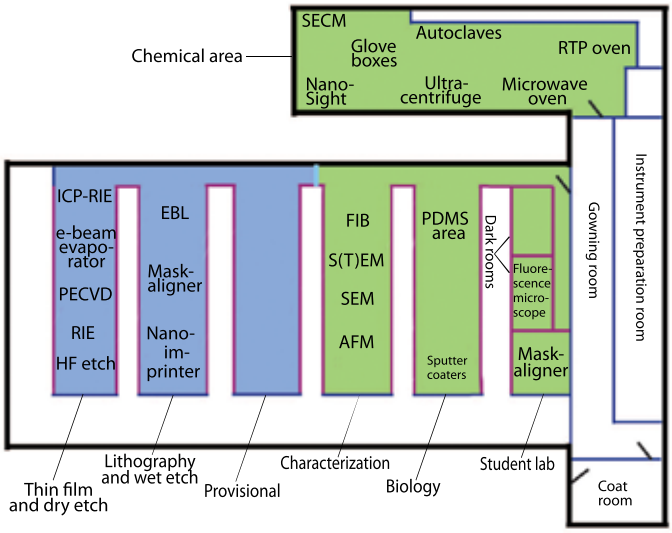
The NTNU NanoLab Lunch Seminars

These weekly seminars gathered 20 – 50 participants.

- Mohamed Asbahi, *Introduction to Nanoimprint Lithography: Methods and Material Requirements. Tore Syversen, Nanotoxicology – perceived or real health hazard?*
- Kåre Tvedt, *Possibilities for preparation of soft samples for TEM and SEM at DMF.*
- Ole Martin Løvvik, *Nano-structured heat engines – thermoelectricity for energy production and waste heat recovery.*
- Erik Wahlström, *Possibilities/ organisation of tuition in NTNU NanoLab's cleanroom.*
- Alex Winkel, *AFM with advanced optics and spectroscopy: from single molecule mechanics to chemical fingerprinting.*
- Erik Folven, *Nanoscale structuring and domain structure of magnetic oxide thin films.*
- Bjørn Soleim, *FIB-TEM sample preparation.*
- Øystein Dahl, *PECVD options in NTNU NanoLab's cleanroom.*
- Per Martin Rørvik, *Hydrothermal synthesis of nanomaterials – possibilities and limitations.*
- Ulf Österberg, *Pump-probe spectroscopy of Nanostructures.*
- Vidar Beisvåg, *Challenges within the Norwegian Microarry Consortium (NMC) that nano-technology may solve.*
- Erik Andreassen, *Micro- and nano-structured polymer components fabricated by injection moulding.*
- Andy Stamm, CAIBE, *Chemically Assisted Ion Beam Etching – a general overview nanowire optoelectronic devices.*
- Irina Sorokina, *Optical fibers: opening new opportunities.*
- David Barriet, *SU-8 Photoresist – Applications and Practical Issues.*

NTNU NanoLab's Cleanroom

2010 may be considered as the first year of full operation of the cleanroom. All major installations of acquired equipment, including a Flex AFM, sputterer and a Nanosight for characterisation of nanoparticles were completed. A separate area for work with polydimehtysiloxane (PDMS) has also been set up. Information regarding the equipment available in NTNU NanoLab's cleanroom can now be found at www.norfab.no.

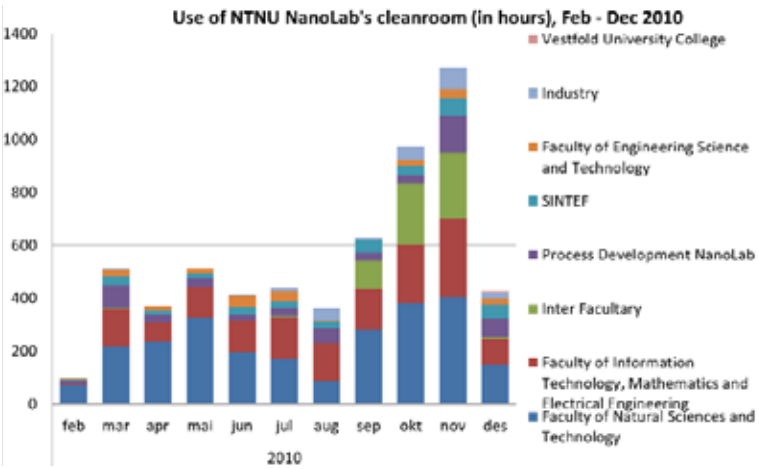


Along with the installations, standard procedures for most of the equipment have been set up in a UserWiki which is available to all users. Parallel to this, HSE routines have been defined. As part of this work, all registered activities at NTNU NanoLab are risk evaluated prior to start-up. In addition, courses in cleanroom behaviour, handling of chemicals (eg. HF) and instruments are offered regularly.


Photo: Geir Mogen

2010 was the first year with organized courses for Master students. As a result we have observed a marked increase in the number of students working on master projects in the cleanroom.

As may be seen from the figure below, the overall activity in the cleanroom increased considerably through 2010. By the end of the year NanoLab had 215 registered users and more than 75 activities.



Training offered by NTNU NanoLab in 2010

- HSE/intro course
- Scanning Electron Microscopy (SEM)
- Focused Ion Beam (FIB)
- Thin film deposition
- Lithography
- E-beam lithography
- Nanoimprinting
- Dry etch/PECVD
- Atom Force Microscope (AFM)
- Bio-functionalization
- Particle synthesis
- Particle analysis


Photo: Geir Mogen

Module courses at Master level in NTNU NanoLab's cleanroom

- TFE4575 Physical Methods for Nanostructuring and Characterization
- TMT4515 Chemical Methods for Synthesis and Characterization of Nanomaterial
- TFY4525 Bionanotechnology
- TFY4335 Nano Life Science
- TFE 4180 Semiconductor Manufacturing Technology

Nasjonalt sertifikat: 1660
Layout and print: Tapir Uttrykk

Visit by the Minister of Trade and Industry, Trond Giske and County Mayor of Sør-Trøndelag, Tore O. Sandvik


Photo: Pernille Fellberg Langeland/NTNU

The Minister of Trade and Industry, Trond Giske and County Mayor of Sør-Trøndelag, Tore O. Sandvik visited NTNU and SINTEF in Trondheim on the 12th of February 2010. The programme included a guided tour of the NTNU NanoLab cleanroom and presentations regarding industrialisation of Norwegian technology on handling of CO_2 and solar energy, as well as strategic measures to commercialise new technology. NTNU NanoLab collaborated with NTNU central organization in organising the meeting.

PhD Dissertations related to nanoscience and nantochnology at NTNU in 2010

- Tone Borge, *Development of hybride membrane materials (mixed matrix membranes)*
- Øystein Dahl, *Measurements and Modelling of Effect of Interface on Ferroelectricity in Lead Titanate Thin Films*
- Sara Boullosa Eiras, *Comparative study of selected catalysts for methane partial oxidation*
- Ingrid Anne Lervik, *Electrocatalysis of the Oxygen Evolution Reaction – A comparative study of Anodically Formed and Nanostructured Iridium Oxides*
- Håvard Haugen, *Spin and Charge Transport in Two-dimensional Electron Gases*
- Francesco Madaro, *Synthesis of textured KxNa1-xNbO$_3$ materials*
- Florian Mumm, *Interactions of High Aspect Ratio Nanostructures and Biological Systems*
- Dheeraj Dasa Lakshmi Narayana, *Growth and Structural Characterization of III-V Nanowires Grown by Molecular Beam Epitaxy*
- Ørnulf Nordseth, *Ferroelectric Thin Films for Planar Photonic Device Applications*
- Axel Baumann Ofstad, *Increasing the Lifetime of PEM Fuel Cells: A Characterization of some Degradation Mechanisms*
- Ragnhild Sæterli, *Electronic structure of thermoelectric and ferroelectric materials – Advanced transmission electron microscopy studies*
- Chang Chuan You, *Fabrication and Characterization of Ferroelectric Nanomesas: A Scanning Probe Approach*

Management
Director: Associate Prof. Erik Wahlström
Coordinator: Hanna Gautun

Permanent Technical Staff
- Head of Laboratory Søren Heinze
- Staff engineer Ida Noddeland
- Staff engineer Trine Østlyng
- Senior engineer Dayong Zhou

Leader Group, established in 2010
- Associate Prof. Erik Wahlström (leader)
- Prof. Duan Chen
- Associate Prof. Marit Sletmoen
- Professor Chritstian Thaulow
- Associate Prof. Fride Vullum-Bruer
- Prof. Helge Weman
- Research manager Ragnar Fagerberg
- Coordinator Hanna Gautun
- Head of Laboratory Søren Heinze

Awards

The I. K. Lykke's prize to young researchers within natural sciences and physics for 2010 was awarded to Dr. Jacob Linder

The Exxon Mobile prizes within basic and applied research 2010 was awarded to Dr. Jacob Linder for his thesis: *Quantum transport and proximity effects in unconventional hybrid systems* and Dr. Jianying He for the thesis: *Nanomechanics of Polymer and Composite Particles.*


Photo: Thor Nielsen/NTNU Info

Board of NTNU Nano-Lab, established in 2010

- Prof. Bjørn T. Stokke, Faculty of Natural Sciences and Technology, NTNU (head of the board).
- Prof. Thomas Tybell, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU.
- Prof. Roy Johnsen, Faculty of Engineering Science and Technology, NTNU.
- Astrid Bjørnetun Haugen, Department of Materials Science and Engineering, NTNU.
- Prof. Svanhild Schønberg, The Medical Faculty, NTNU.
- Kai Beckwith, student, Master's degree programme in nanotechnology, NTNU.
- Lotte Skolem, student, Master's degree programme in nanotechnology, NTNU.
- Rudie Spooren, SINTEF Materials and Chemistry, Research Director.
- Per Gløersen, Sensonor, Senior R&D Adviser.
- Bjørn Fuglaas, GE Healthcare, Director, Security and Internal Services.
- Randi Haakenaasen, Norwegian Research Defense Establishment, Principal Scientist.

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