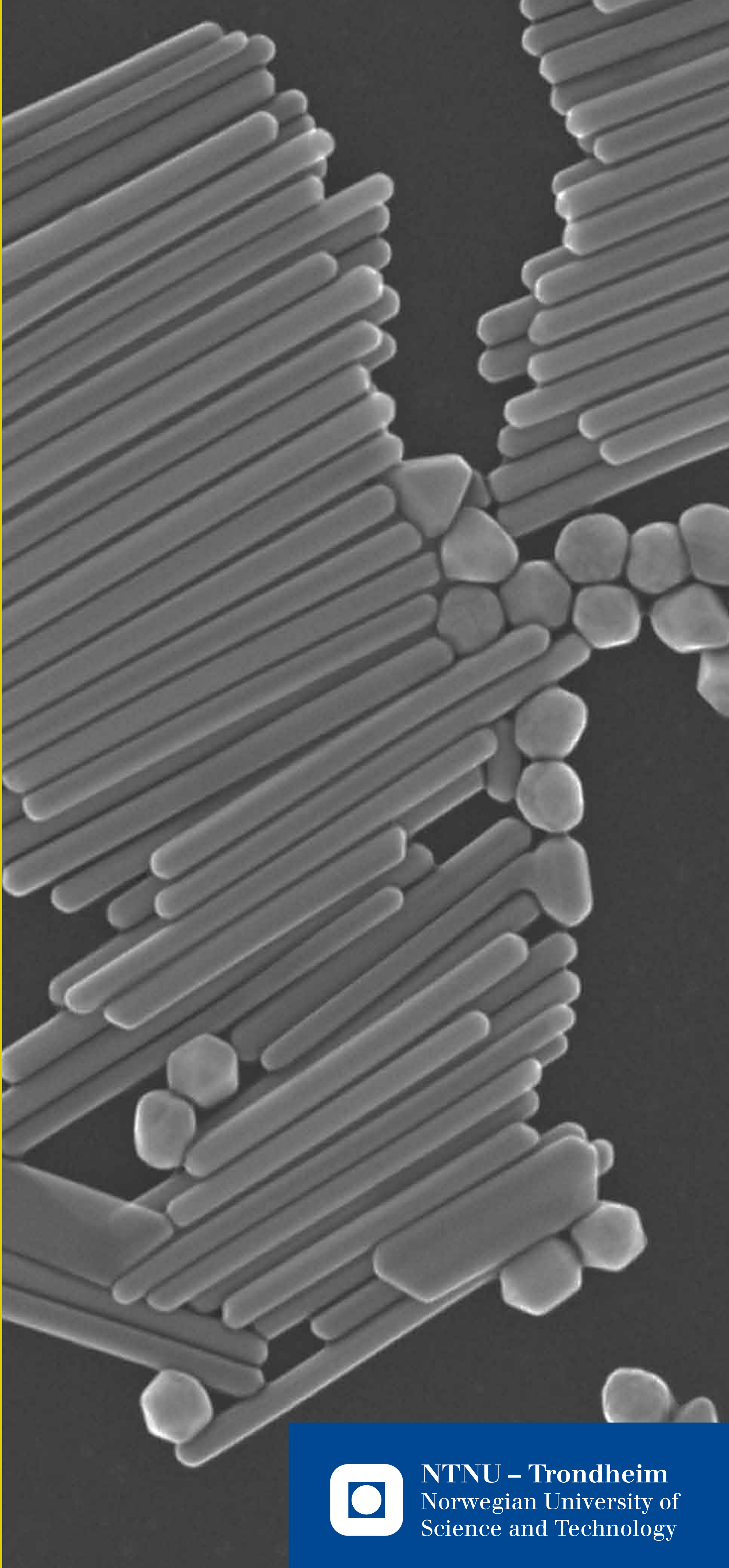
Annual report NTNU NanoLab 2011



NTNU – Trondheim
Norwegian University of
Science and Technology

NTNU NanoLab 2010

2011 has been an exciting year for NTNU NanoLab. At the beginning of the year, our aim was to double the activity in the cleanroom compared to 2010. This goal was indeed achieved with nearly 13.000 user hours registered by the end of 2011.

The first class of Masters in Nanotechnology graduated from NTNU in the summer of 2011. These students used the cleanroom extensively. They have a broad theoretical expertise, hands-on experience from the cleanroom, they are talented and enthusiastic. I am convinced that they will contribute in the promoting of nanotechnology applications in traditional industry and also to the establishment of start-up companies based on nanotechnology research in Norway.

After a period of 10 years, the NanoMat program of the Research Council of Norway was finished in 2011. The final report shows that NTNU was one of the largest participants within nanotechnology research in Norway, as 25% of the project funding from NanoMat was allocated for research projects led by NTNU.

In 2012, the Research Council of Norway will launch a new research program, Nano2021. With a funding of around 92MNOK per year this program will be a great opportunity for nano-related research groups. We are confident that the scientific groups at NTNU and SINTEF will submit excellent proposals to the program. NTNU NanoLab will contribute with a professionally run infrastructure with state-of-the art equipment.

New possibilities abound through the national infrastructure,NorFab, which was officially opened in 2011 (see separate article). In the past year, NorFab started the establishment of a common price policy. With this work successfully completed, NorFab will offer access to the common facilities for all researchers from universities and colleges, institutes and industries in Norway at common conditions and prices.

After the first two start-up years NTNU NanoLab now offers state of the art equipment in a interdisciplinary and proffesionell environment. For the years to come we welcome established and new users to carry out innovative and in particular interdisciplinary projects so that NTNU NanoLab emerges as an important infrastructure for new nanotechnological research and -products in Europe!


Photo: Renate Wahlström

Kay Gastinger
Director of NTNU NanoLab

NORWEGIAN MICRO- AND NANOFABRICATION FACILITY
NorFab

The Norwegian Micro- and Nanofabrication Facility, NorFab was officially opened by the Minister of Research and Higher Education Tora Aasland on the 16th of June 2011.

The opening of NorFab was organized in Oslo as a one-day meeting with invited speakers. The meeting gathered 170 participants and was arranged in collaboration with the annual meeting of the Norwegian PhD Network on Nanotechnology for Microsystems.

In the autumn of 2010, The Research Council of Norway assigned NTNU NanoLab, SINTEF MiNaLab, UiO MiNaLab and HiVE MST-lab status as a united, national infrastructure for micro- and nanotechnology in Norway. Together they offer more than 2300 m^2 of cleanroom areas for both academic and industrial users. A common web-page, www.norfab.no with information regarding equipment, prices and options for support has been established. In 2011, NorFab granted support for use of the infrastructure to 20 short term projects and 20 long term projects.


Photo: Erik Poppe fra SINTEF

NanoNetwork

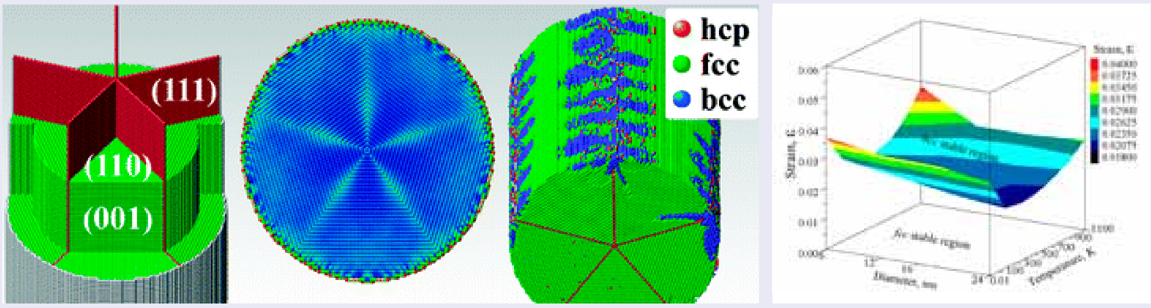
The Norwegian PhD Network on Nanotechnology for Microsystems was established in 2009, and aims to coordinate, integrate, and strengthen PhD programs in the field of nanotechnology and microsystems in Norway.

In 2011 University of Bergen joined the network, which already had NTNU, University of Oslo, Vestfold University College, SINTEF ICT Microsystems and Nanotechnology as partners. The project is funded by the Norwegian Research Council's NANOMAT-program and is managed by NTNU. The PhD Network offered 8 PhD courses on compact format in 2011. The network has provided financial support for laboratory and processing expenses to 17 PhD candidates in the network, and granted travel support to 31 candidates presenting their work at international conferences as well as 12 candidates on extended research visits abroad.
The 2011 annual workshop was held in Oslo the15th–17th of June, and gathered 70 participants from the research community of nanotechnology and microsystems in Norway.
Website: **www.nano-network.net**

Front page S(T)EM image of gold nanostructures prepared by a seed-mediated wet chemical approach using ~4 nm gold nanoparticles as the seeds and subsequent reduction of metal salt with a weak reducing agent (ascorbic acid) in the presence of cetyltrimethylammonium bromide (CTAB) as a cationic surfactant. The aspect ratio and shape of these nanostructures can be tuned by controlling the concentration of surfactant and halide ions. Copyright: Wilhelm R. Glomm and Gurvinder Singh, NTNU.

Enhanced mechanical properties of five-fold twin fcc Fe nanowires

The five-fold twinned fcc Fe nanowire shows significant increase in Young's modulus of the smaller nanowires, resulting from the central area of quinquefoliolate-like stress-distribution over the five-fold twins, rather than from the surface tension that is often considered as the main source of such size-effects found in nanostructures. The yield strength of the nanowire is enhanced by the twin boundary that suppresses dislocation nucleation within a fcc twin-domain; consequently, the plasticity of the nanowire is initiated by strain-induced fcc-to-bcc phase transformation that destroys the twin structure. The nucleated bcc phase immediately spreads to the entire area and forms a multigrain structure to realize ductile deformation followed by necking. As the temperature is elevated close to the critical temperature between the bcc and fcc phases, the increased stability of the fcc phase competes with the phase transformation under tension, and hence dislocation nucleation in the fcc phase is observed exclusively at the highest temperature tested. This study was carried out at the Dept. of Structural Engineering, NTNU.

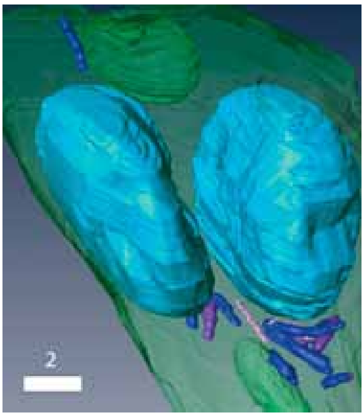


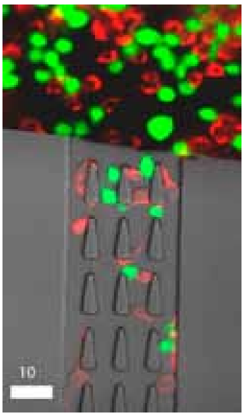
Structure of five-fold twinned fcc Fe Nanowire (left) and its critical strain surface (right)

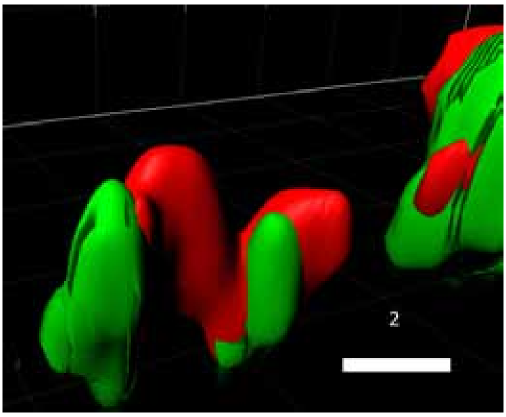
"Role of Five-fold Twin Boundary on the Enhanced Mechanical Properties of fcc Fe Nanowires", J. Y. Wu, S. Nagao, J. Y. He, Z. L. Zhang, ***Nano Letters***, 2011, 11(12), 5264-5273.

New eyes on ancient disease

Tuberculosis is still a major global health problem, having infected two billion people, with more than 1.8 million deaths annually, mostly in developing countries. A group at the Dept. of Cancer Research and Molecular Medicine has, together with researchers at the Dept. of Physics and the Dept. of Circulation and Medical Imaging, turned to NTNU NanoLab to gain new insight in the mycobacterial pathology, to develop new research tools to study the immune reactions of the infection, and to develop nanoparticles for drug delivery to mycobacteria. The left figure shows a representation of a green cell infected with purple mycobacteria dissected by ionabrasion electron microscopy with 10nm resolution (FIB-SEM). The middle figure shows movements of different immune cells towards mycobacteria in a microdevice made by soft lithography. The right figure shows accumulation of green drug loaded nanoparticles to red mycobacteria inside a cell.



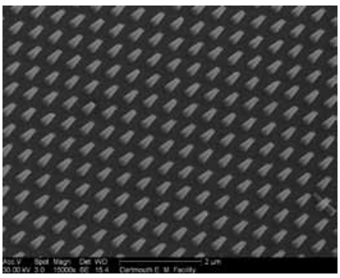


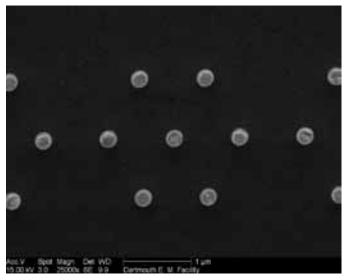


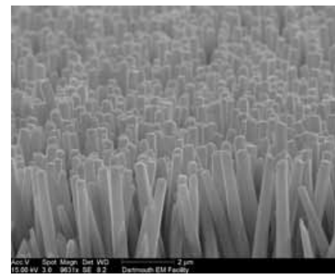
Contacts: Øyvind Halaas, Dept. Cancer Research and Molecular Medicine, NTNU. Pawel Sikorski, Dept. Physics, NTNU. David Barriet, Dept. Physics, NTNU. Sjoerd Hak, Dept. Physics /Dept. Circulation and Medical Imaging, NTNU.

Zinc oxide nanopillars

ZnO is a wide band gap semiconductor that can be grown in nanopillar form by electrodeposition from non-toxic solutions. The left and center images show arrays of pillars fabricated using electron beam lithography that demonstrate photonic bandgap behavior. Such materials permit improved redirection of light in waveguides for optical communications. The randomly positioned single crystal pillars shown to the right were grown as part of a heterojunction solar cell, with copper oxide as the p-type material. The large aspect ratio of the nanopillars increases both solar absorption and the short-circuit current of the cell. ter. 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.

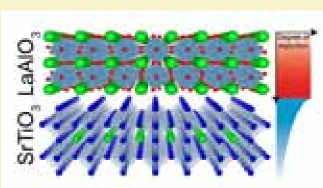






This work is a collaboration between Prof. Ursula Gibson at the Dept. of Physics, NTNU and Prof. Jingbiao Cui at the University of Arkansas.

Structural effects at epitaxial interfaces

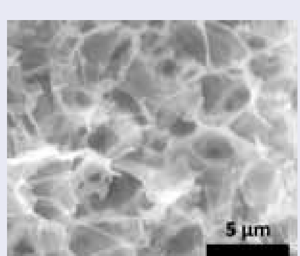


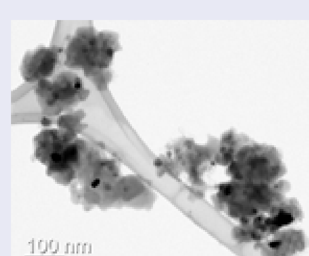
J.E. Boschker et al. Structural coupling across the LaAlO3/SrTiO3 interface: High-resolution x-ray diffraction study. Physical Review B, 2011 **84**, 205418.

Advanced heteroepitaxy, relying on correct use of substrates, is a formidable tool for controlling the properties of epitaxial perovskite oxide thin films. Structural and electronic reconstructions at interfaces between different perovskite oxides have been shown to result in novel functional properties, such as the 2-dimensional electron gas at the interface between SrTiO3 and LaAlO3. However, the strong structure – property coupling in perovskites makes it important to understand possible structural effects across such interfaces. In a combined pulsed laser deposition and x-ray diffraction study of thin epitaxial LaAlO3 films on SrTiO3, has demonstrated that periodic lattice distortions in thin films can couple into the substrate. That is, the properties of thin films do not only depend on the substrate, but the structural properties of the substrates also depend on the epilayers on top of it. This has implications for novel devices that are based on functional interfaces, and future studies will encompass how this type of coupling affects device performance. This study is carried out at the Dept. of Electronics and Telecommunications and the Dept. of Physics at NTNU, in collaboration with researches at the Dept. of Materials Science and Engineering at University of Madison.

Nanostructured Li_2FeSiO_4/C synthesized by a modified sol-gel method

Li_2FeSiO_4/C composites used as cathode materials in Li-ion batteries have been synthesized by a modified sol-gel method. The process is water-based and uses environmentally friendly precursors. By careful control of synthesis parameters a highly porous material built up from 20–50 nm sized crystallites is obtained. A SEM image of the porous material and a TEM image of the nanosized crystallites comprising the walls of the pores are shown below. The nanostructuring combined with a thin layer (2–5 nm thick) of carbon coating provides high conductivity and gives high discharge capacity, close to the theoretical values, when applied in a Li-ion battery. This work is carried out at the Dept. of Materials Science and Engineering.



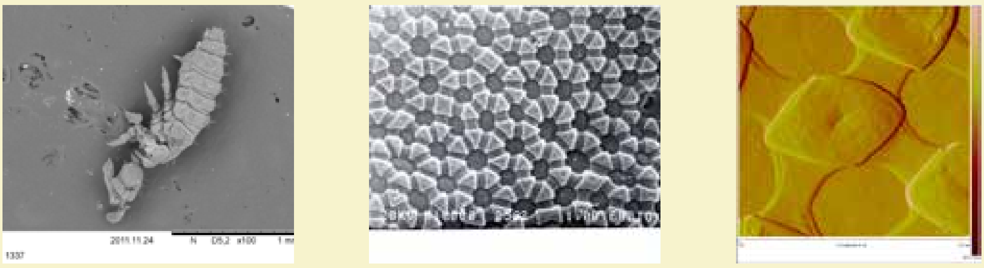


SEM image (left) and TEM image (right) of the Li_2FeSiO_4/C composite

H. Zhou, M.-A. Einarsrud and F. Vullum-Bruer, Solid State Ion., 2012, doi:10.1016/j.ssi.2011.12.008

Nanostructured springtail cuticles

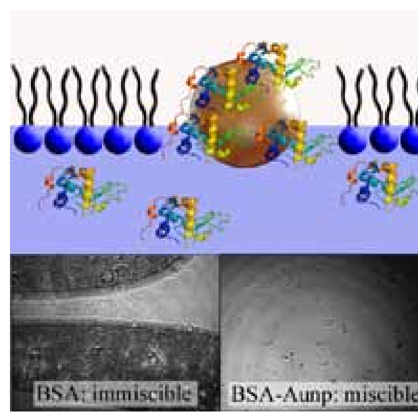
Springtails are tiny earth dwelling arthropods whose skin has amazing properties. PhD-candidate Håkon Gundersen and Prof. Christian Thaulow at the Dept of Engineering Design and Materials (NTNU) are cooperating with Prof. Hans Leinaas (UiO) in an effort to evaluate the springtail cuticle as a model for superhydrophobic, self-cleaning and air-retaining surfaces. It is the characteristic cuticle structure of the springtail that gives rise to its extremely robust water repellent properties. Sample preparation and surface imaging has been performed at NTNU NanoLab in an ongoing effort to characterize this little studied nanostructured surface.



Hypogastura viatica(right), a close up of the cuticle of Vertagopus westerlundi (center) and a detail of a single granule from the cuticle of Folsomia quadriocculata (left).
Hobæk T.C., K.G. Leinan, H.P. Leinaas and C. Thaulow Surface Nanoengineering Inspired by Evolution, BioNanoScience, 2011, **1**(3), 63-77.

Emergent membrane-affecting properties of BSA–gold nanoparticle constructs

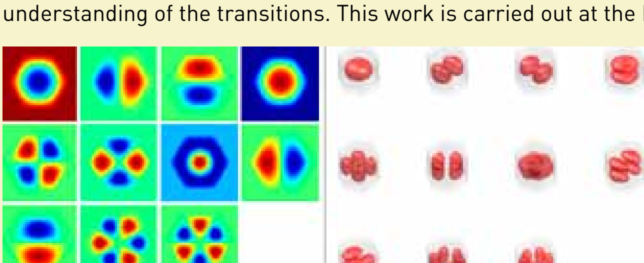
Gold nanoparticles possess unique optical and surface properties and represent promising materials as e.g. drug delivery vectors, biomarkers and folding templates for proteins. The conformation of the protein dictates protein function and interaction with interfaces. Such manipulation of the protein-fold might invoke emergent properties useful for improved understanding and potential treatment of protein misfolding diseases such as Alzheimer's and Parkinson's. Adsorption of bovine serum albumin (BSA) onto gold nanoparticles (Aunps) results in partial unfolding of the protein. The resulting BSA–Aunp constructs induce miscibility with phospholipid monolayer films, a trait not seen for BSA or Aunps alone, as well as disruption of liquid crystalline domains in the film. These protein-Aunp constructs might improve interaction with cell membranes and hence intracellular delivery. This work is carried out at the Dept. of Chemical Engineering, NTNU.



Lystvet S. M., Volden S., Yasuda M., Halskau Ø., and Glomm W. R. Nanoscale, 2011, **3**, 1788–1797.

Modelling of quantum dots within semiconductor nanowires

Semiconductor nanowires are of large fundamental and technological interest due to a high level of flexibility in the material and structural composition. The electro-optical properties of the nanowires can be modified by growing quantum dots (QDs) within the wires. Such QDs are especially promising as single photon sources, due to good control of their size and shape. To predict the optical transition probabilities, the wavefunctions of the electrons and holes in GaAs QDs in an AlGaAs nanowire are calculated using the k.p method. The QDs are highly symmetric with hexagonal cross sections. Tools from group symmetry can therefore be used to obtain better understanding of the transitions. This work is carried out at the Dept. of Electronics and Telecommunications and UniK (Kjeller), in collaboration with EPFL (Switzerland).



Electronic wavefunctions in GaAs QDs in an AlGaAs nanowire.

Contacts: Guro Svendsen or Helge Weman, Dept. of Electronics and Telecommunications, NTNU

6th Annual NTNU NanoLab Meeting

A one-day seminar portraying various activities within nanoscience and nanotechnology at NTNU was held at the Medical Faculty of NTNU on the 16th of November 2011. The aim of the meeting was to portray local research activities and to facilitate cross-disciplinary contacts between scientists. The program consisted of 20 lectures presenting available infrastructure and research projects at NTNU and SINTEF and gathered 72 participants.

Nano-Techniques for Characterizing Materials and Surfaces

An open one and a half day seminar/workshop with focus on scanning probe microscopy (AFM/STM), X-ray diffraction and crystallography as well as electron microscopy and microanalysis was organized at NTNU by Bruker, in cooperation with NTNU NanoLab, on the 20th–21st of September. The first day of the program offered three parallel sessions of seminars dedicated to scientific developments and user experiences in the fields in question. The day was rounded off with an informal dinner downtown in Trondheim. The second day offered of workshops/demonstrations of state-of-the-art tools. The meeting gathered around 40 participants.

Norway-China Workshop on Nanotechnology for (Renewable) Energy Materials


Photo: Hein Johnson, NTVA

As part of an effort to build a Chinese - Norwegian network for renewable energy nanomaterials a workshop was held at Lerchendal Gård in Trondheim on the 31st of August – 1st of September. The aim of the meeting was to foster knowledge within nanotechnology and materials for energy applications and to promote bilateral research projects. The meeting was opened by the Rector of NTNU and offered 17 presentations from both countries and. The program gathered 66 participants, of which 16 came from China and 48 from NTNU. Generous support from the Norwegian Research Council via the RENERGI program, Norwegian Academy of Technological Science, NTNU NanoLab and NTNU Strategic Areas Materials made the meeting possible.

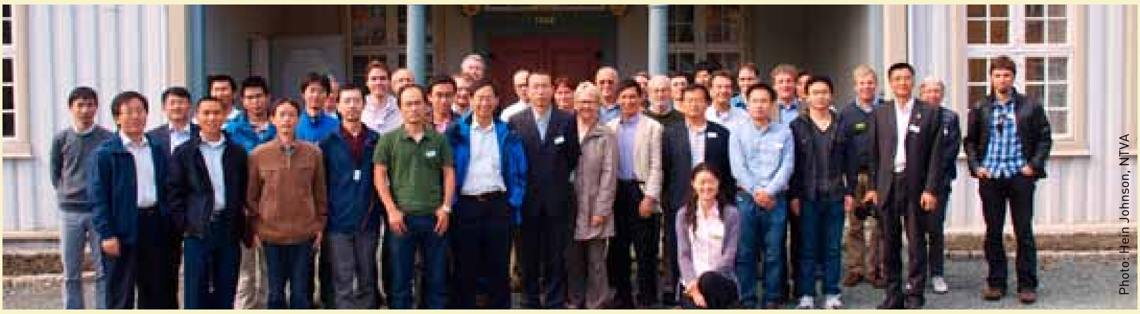


Photo: Hein Johnson, NTVA

The NTNU NanoLab Lunch Seminars

These informal, weekly were given in NTNU NanoLab's lecture area during the spring and autumn semesters, gathering 20-50 participants.

- *New possibilities at NTNU NanoLab and NorFab: access, support and equipment,* Kay Gastinger / Erik Wahlström
- *Atomistic- and Multiscale Material Modeling and Testing,* Christian Thaulow
- *Nanotechnologi in The Norwegian Research Centre for Solar Cell Technology,* Turid Worren Reenaas
- *Bionanotechnology Research at the Ugelstad Laboratory,* Wilhelm R. Glomm
- *E-beam lithography in NTNU NanoLab,* Dong Chul Kim
- *Biomedical characterization using FIB and STEM,* Pawel Sikorski
- *Scanning Electrochemical Microscopy in NanoLab's cleanroom,* Øyvind Mikkelsen
- *Increasing light harvesting by using Algae in Solar Cells? - The Solbiopta project,* Gabriella Tranell
- *Nanomaterials for Energy Storage,* De Chen
- *Nanomechanical Technology,* Zhiliang Zhang
- *MBE growth and processing of mid-IR diode lasers,* Magnus Breivik

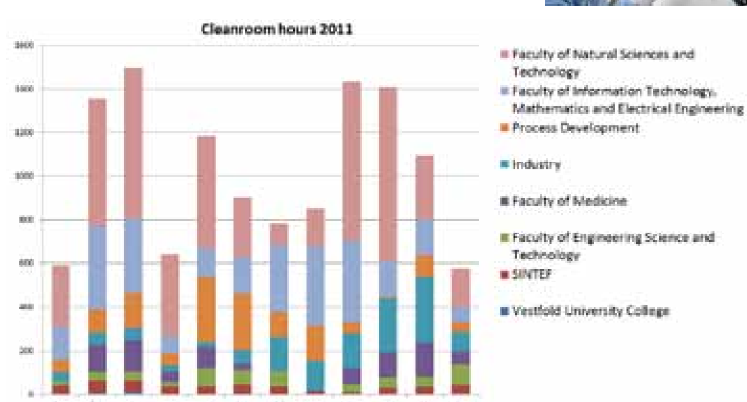
NTNU NanoLab's Cleanroom

The use of the cleanroom increased significantly in 2011 compared to the startup year 2010. Around 100 new users received access to the cleanroom and many of the existing users extended their activities. In addition to researchers from NTNU, the facility hosted users from other Norwegian universities and several companies including SINTEF. In particular master students have discovered the possibilities of NTNU NanoLab's infrastructure. In 2011, around 80 master theses and student projects contributed heavily to the increase of the user hours in the cleanroom. Thus, about 43% of the cleanroom activity was generated by students. The industry and SINTEF contributed with 11% and university researches (mainly PhD and post doctors) with 37% of the user hours. About 9% of the cleanroom activities were related to process development by NTNU NanoLab's staff.

In 2011, two new staff members were hired with responsibility for the thin film area and the lithography area, respectively. In addition to the regular staff, a number of student assistants supported the daily running of the cleanroom.

During 2011 emphasis was put on establishing a quality system to ensure a safe working environment, improved information to all users and maximum instrumentup-time. HSE has been in focus, and all instruments in the clean-room have been evaluated for potential risks.

Descriptions for all instruments are now available on www.norfab.no and information about the cleanroom courses and access procedures can be found on NTNU NanoLab's homepage, www.ntnu.no/nanolab.



Training offered by NTNU NanoLab

- Cleanroom course
- Scanning (Transmission) Electron Microscopy (S(T)EM)
- Focused Ion Beam (FIB) with SEM
- Atomic force microscopy (AFM)
- Thin film deposition
- Dry etching
- Wet etching
- Photolithography
- E-beam lithography
- Nanoimprinting
- Particle synthesis
- Particle analysis

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 Nanomaterials
- TFY4525 Bionano-technology
- TFY4335 Nano Life Science
- TFE4180 Semiconductor Manufacturing Technology

Integrated Optoelectronics; a start-up company using NTNU NanoLab's cleanroom

Integrated Optoelectronics develops lasers and optical devices in III-V materials. The driver for the interest in these new components is the gas sensor market. Higher accuracy and lower cost of Mid-IR gas sensors require improved laser sources. The company uses NTNU NanoLab's facilities in order to increase resolution and accuracy of the optical devices. To obtain this, lithographic, thin film and dry etch tools are applied. Nanoimprinting is, in this context, an important tool to ensure the scalability of the fabrication of nanostructures. Integrated Optoelectronics uses NTNU NanoLab's cleanroom because of the access to high-quality and cutting-edge equipment, the interdisciplinary environment and cost efficiency. For more information, see www.intopto.com or contact post@intopto.com.

Photo: Optical grating in a 400nm thick … layer fabricated by nanoimprinting and dry etching (specifications: line width: 124nm, period: 248nm, required accuracy of grating period: <2nm)

Produksjon: www.fagtrykk.no Miljømerket trykkeri, lisensnr. 241 811

Board of NTNU NanoLab

- Prof. Bjørn T. Stokke, Faculty of Natural Sciences and Technology, NTNU (head of the board)
- Prof. Svanhild Schønberg, The Medical Faculty, NTNU
- Prof. Thomas Tybell, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU / Prof. Jostein Grepstad, Faculty of Information Technology, Mathematics and Electrical Engineering, NTNU (from 01.07.)
- Prof. Roy Johnsen, Faculty of Engineering Science and Technology, NTNU / Prof. Zhiliang Zhang, Faculty of Engineering Science and Technology, NTNU (from 01.07.)
- Astrid Bjørnetun Haugen, Dept. of Materials Science and Engineering, NTNU
- Kai Müller Beckwith, student, NTNU / Frank Johansen, student, NTNU (from 01.07.)
- Lotte Skolem, student, student, NTNU / Mira Thoen Feiring, student, NTNU (from 01.07.)
- Bjørn Fuglaas, GE Healthcare, Director, Security and Internal Services
- Per Gløersen, Sensonor, Senior R&D Adviser
- Randi Haakenaasen, Norwegian Research Defense Establishment, Principal Scientist
- Rudie Spooren, SINTEF Materials and Chemistry, Research Director

Management
Director: Dr. Kay Gastinger
Coordinator: Dr. Hanna Gautun

Permanent Technical Staff
- Head of Laboratory Dr. Søren Heinze
- Staff engineer Mark Chiappa
- Senior engineer Ida Noddeland
- Staff engineer Espen Rogstad
- Senior engineer Trine Østlyng

Leader Group
- Kay Gastinger (head of the leader group)
- Associate Prof. Erik Wahlström / Prof. Ursula Gibson (from 01.07.)
- Prof. Duan Chen / Associate Prof. Øyvind Halaas (from 01.07.)
- Prof. Bjørn Ove Fimland / Prof. Helge Weman (from 01.07.)
- Associate Prof. Marit Sletmoen
- Prof. Christian Thaulow
- Associate Prof. Fride Vullum-Bruer
- Research manager Ragnar Fagerberg
- Coordinator Hanna Gautun
- Head of Laboratory Søren Heinze

Awards

Best Master of Technology, nanotechnology in 2011 was awarded to Kai Müller Beckwith at Dept. of Physics for the thesis: "A Study of Cultured Cells on a Nanowire-based Reverse Transfection Device"

Photo: Kai Müller Beckwith

Prof. Arne Brataas at the Dept. of Physics, NTNU was appointed **Fellow at the American Physical Society (APS)**. The appointment was based on his ho work within spintronics: "Spin transport and dynamics in magnetic nanostructures and mesoscopic systems".

Photo: Geir Mogen / NTNU Info

Dissertations

The following candidates obtained a PhD degree at NTNU in fields related to nanoscience and nanotechnology in 2011.

- Ruben Bjørge: *Scanning transmission electron microscopy studies of precipitation in Al-Mg-Ge alloys.*
- Linga Reddy Cenkeramaddi: *Nanoscale Analog Front-end Amplifiers for Medical Ultrasound Imaging.*
- Yunhan Chu: *Developments of Methods for De novo Design of Functional Drugs and Catalyst Compounds.*
- Kjetil Magne Dørheim Hals: *Current-Induced Dynamics in Ferromagnets and Antiferromagnets.*
- Espen Eberg: *Interface Effects in PbTiO3 Thin Films and Nanostructures: A Transmission Electron Microscopy Study.*
- Erik Folven: *Antiferromagnetic Domain Structure in LaFeO3 Thin Films and Nanostructures.*
- Hassan Gueleruz: *Investigation of the mechanisms governing the deposition of sol particles on a substrate.*
- Xuezhong He: *Development of Hollow Fiber Carbon Membranes for* CO_2.
- Fan Huang: *3D carbon-conductive polymer nanostructures for energy storage.*
- Udit Monga: *Modeling and Characterization of SOI Multigate MOSFETs.*
- Ingar Stian Nerbø: *Real-time study of the formation of GaSb nanopillars by spectroscopic Mueller matrix ellipsometry.*
- Magnus Østgård Olderøy: *Bioinspired mineralization of alginate hydrogels.*
- Lars-Erik Owe: *Characterization of Iridium Oxides for Acidic Water Electrolysis.*
- Xuyen Kim Phan: *Catalyst formulations for use in microstructured reactors for conversion of synthesis gas to liquids.*
- Andrey Andreevich Poletaev: *Hydrogen Storage in Mg-based Alloys Nanostructured by Rapid Solidification.*
- Ionna Sandvig: *The role of olfactory ensheathing cells, MRI, and biomaterials in transplant-mediated CNS repair.*
- Nikolaos Tsakoumis: *Deactivation of Cobalt based Fischer-Tropsch Catalysts.*