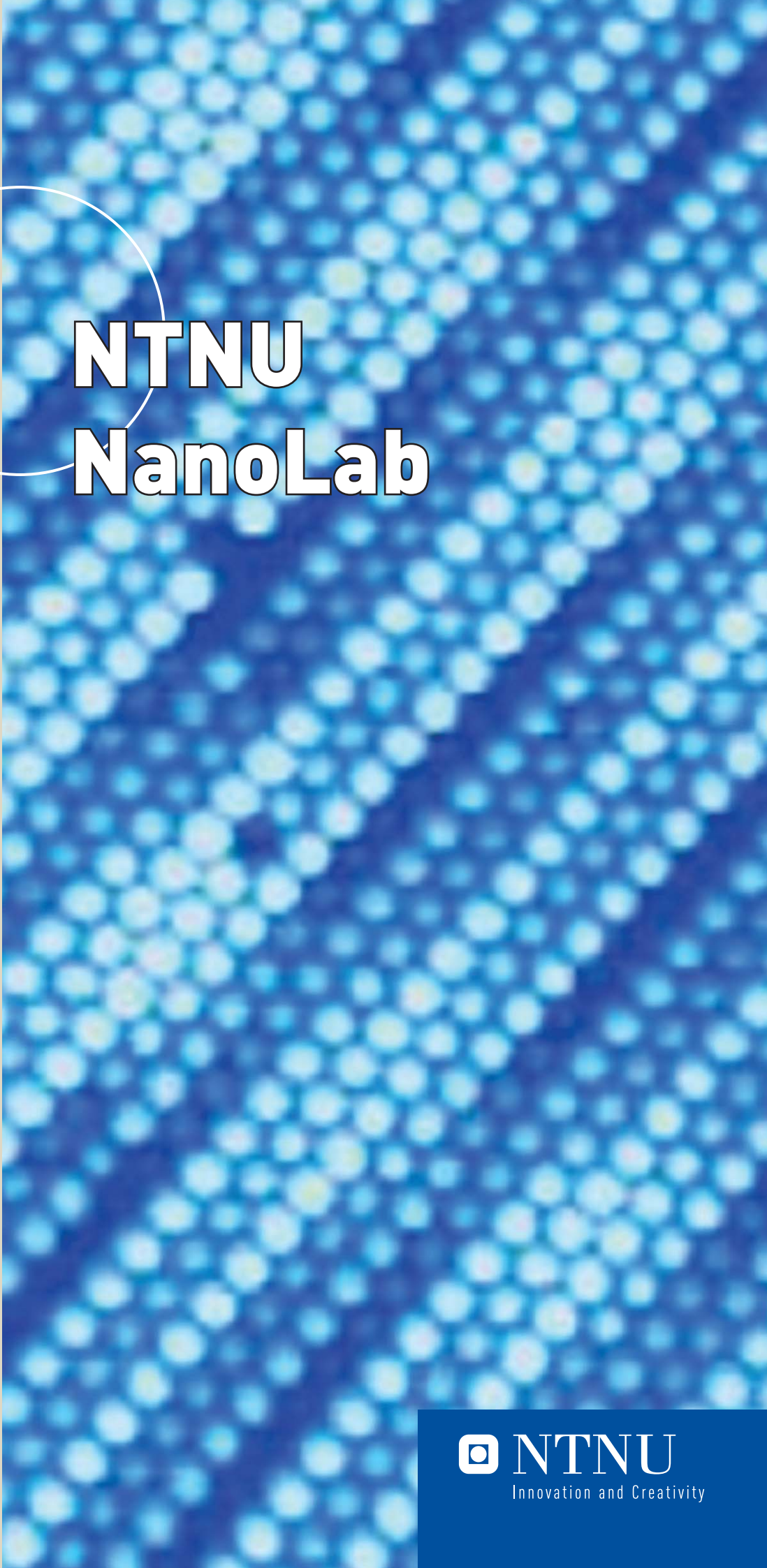
NTNU NanoLab

Annual Report 2006



NTNU
Innovation and Creativity

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NTNU
Innovation and Creativity

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COVER PAGE (Photo: Anne Borg)
Atomic structure of a clean reconstructed Pt(100)-surface
Editor: Hanna Gautun

NTNU NanoLab

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Introduction

The year 2006 can be characterized as a turning point in the nanotechnology era at NTNU. The main contribution to this was the start of the new master programme in nanotechnology. The programme is cross disciplinary. From the first semester the students are introduced to current challenges and possibilities in different fields such as nanoelectronics and bionanotechnology, as well as ethical and health issues. 30 students were admitted. They rapidly picked up speed, not only with the curriculum, but also with extra curricular activities such as forming a student association, Timini, hosting new "classical festivities" such as the Bucky Ball.

To promote nanotechnological activities at NTNU, we hosted the first NTNU NanoLab User Meeting. The meeting focused on the cross-disciplinary possibilities nanotechnology can offer and gathered more than 40 researchers from different faculties at Jægtvolden Fjordhotel. We also used the meeting to discuss the new laboratory under construction in detail. The meeting was well appreciated and we shall continue with yearly user meetings in order to display scientific progress and to explore future possibilities in nanotechnology.

Although most of our attention has been focused on science and the construction of the new cross-disciplinary clean-room laboratory, we have also focused on out-reach activities. I would especially like to mention Researcher's Night, where NTNU NanoLab displayed possibilities of nanotechnology to high schools students of the region.

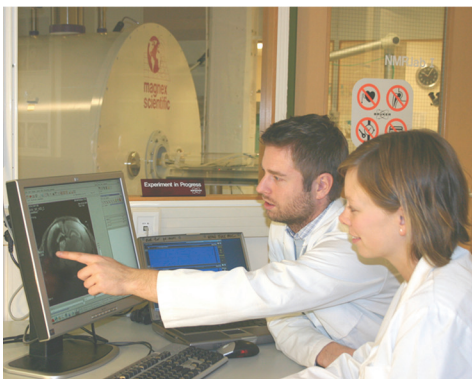
Thomas Tybell
Director NTNU NanoLab

High Lights of 2006

MR AND ULTRASOUND RESEARCH WITHIN BIONANOTECHNOLOGY

Molecular imaging using MR and ultrasound permits analysis and monitoring of biomolecular processes in normal and sick tissues of intact organisms without invasive operations. The techniques often make use of nanostructured "smart contrast agents" (also called tracers and biomarkers), which may give indirect information regarding biomolecular relations.

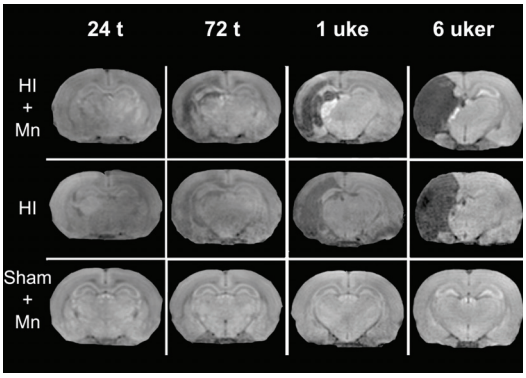
The MR and ultrasound research groups at NTNU have a defined strategy to establish a complete research line for synthesis, validation, in-vivo testing, development of methodology and evaluation of the feasibility of such smart contrast agents. Today's research activity is mainly concentrated around preclinical studies of animal models of diseases and transgenic mice in order to survey *in-vivo* effects of gene modifications. The goal is to transfer the best ideas into clinical use, opening up for substantial industrial opportunities. This strategy includes the Functional Genomics (FUGE) technology platform within molecular imaging in Norway, and Molecular Imaging Centre (MIC), which is a collaboration between the University of Bergen and NTNU.



PhD students at FUGE MIC Trondheim, Marius Widerøe and Marte Thuen. Post.doc. Christian Brekken at FUGE MIC Trondheim and PhD-student Yrr Mørch at Department of Biotechnolgy have recently patented a new type of nanostructured contrast agents, designed for studies of brain damage as shown here, as well as for studies of nerve damage, which cannot be detected by other imaging techniques. Photo: FUGE MIC Trondheim.

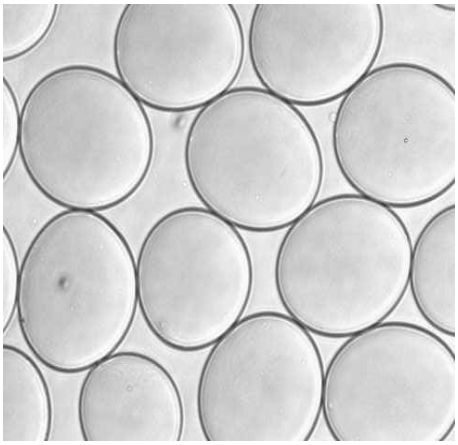
The bionano-imaging activity at NTNU is also a part of the new Centre for Research-based Innovation (CRI) called MI Lab (Medical Imaging Laboratory for Innovative Future Healthcare), which was awarded to the MR and Ultrasound groups at NTNU in 2006 by the Norwegian Research Council. Being one of only three CRIs in biomedicine and health in Norway, it is a token of the high level research carried out in these scientific groups. MIC Trondheim and MI Lab is lead by Professor Olav Haraldseth, who is also NTNU's official contact towards the European Technology Platform (ETP) in Nanomedicine.

One of the ongoing projects in bionano-imaging in Trondheim focuses on the use of manganese-releasing MR contrast agents for monitoring cell activity in the brain and heart. Manganese is a calcium analogue. Thus, uptake and accumulation of manganese in the cells can constitute an indirect measure of the activity of the calcium channels in cell membranes. The calcium channel activity is the most important biomolecular indicator of cell activity in the brain and heart.



MR-image of developing stroke (time after stroke) in 3 newborn rats. The research gives new knowledge on brain damage at birth and its treatment. In this case manganese ions (Mn) are used as an MR-contrast agent for visualising cells activated by brain damage. In the top row the damaged cells are visualized by Mn contrast enhancement. The middle row shows a damaged rat brain without contrast agent present. The bottom row shows the brain of a sham-operated rat with Mn-enhancement. Photo: FUGE MIC Trondheim.

Professor Per Jynge is an international pioneer in this field and has an ongoing activity in heart research. In the area of brain research Dr. Christian Brekken has, in cooperation with Professor Gudmund Sjåk-Bræk and Yrr Mørch at the Department of Biotechnology, recently patented an alginate-based capsule with manganese incorporated in the structure, allowing controlled release of manganese for optimized delivery to brain and heart tissues.



Manganese-containing alginate capsules produced by Yrr Mørch and Christian Brekken. The capsules have a diameter of 300 micrometer and may be structured at a nano-level. Photo: Yrr Mørch

Another project makes use of a combination of contrast agents and teragnostics with ultrasound. This is a concept where the therapeutic molecule is encapsulated in an air bubble attached to a ligand designed for targeting a specific receptor, e.g. in cancer cells. Ultrasound can then be used for ensuring delivery of drug to the desired cells by detection of the air bubbles. The drug is then released by breaking the air bubbles applying ultrasound waves of another frequency.

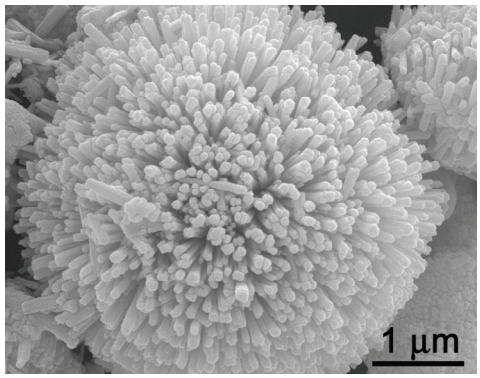
An important reason enabling this research to take place at NTNU is the development of a new ultrasound imaging method (SURF) by Professor Bjørn Angelsen's group. This method increases the sensitivity of the detection of the air bubbles by a factor of 10 compared to conventional methods.

Olav Haraldseth

SELF-ASSEMBLED GROWTH OF NANORODS

There is a great interest in nanostructured materials with various functional properties today. Thus, particles, nanorods and thin films of a whole range of metals, semiconductors and magnetic materials have been fabricated by many groups. Particularly the oxide thin film technology has become very advanced. However, the production of one-dimensional (1D) complex oxide nanomaterials has lingered far behind the preparation of particles and thin films, and to date only a limited number of papers have been published on 1D nanomaterials of complex oxides.

The "Inorganic materials and ceramics research group" at Department of Materials Science and Engineering at NTNU have recently started a programme on the synthesis of low dimensional ferroelectric oxides such as $PbTiO_3$. These efforts have resulted in the development of a novel route to $PbTiO_3$ nanorods. The method utilises a precursor prepared by sol-gel technology onto which the bur-like structures were shown to be formed under hydrothermal conditions, in the presence of a surfactant containing phenyl sulfonic groups. These conditions promoted self-assembly of $PbTiO_3$ nano-crystals resulting in growth of the nanorods.



Bur-like structures of $PbTiO_3$, Photo: Guoxhong Wang

The bur-like structures were found to consist of a core of aggregated nanocrystals of $PbTiO_3$ surrounded by nanorods of $PbTiO_3$ growing out of the core. The fundamentals of the growth process are currently being investigated.

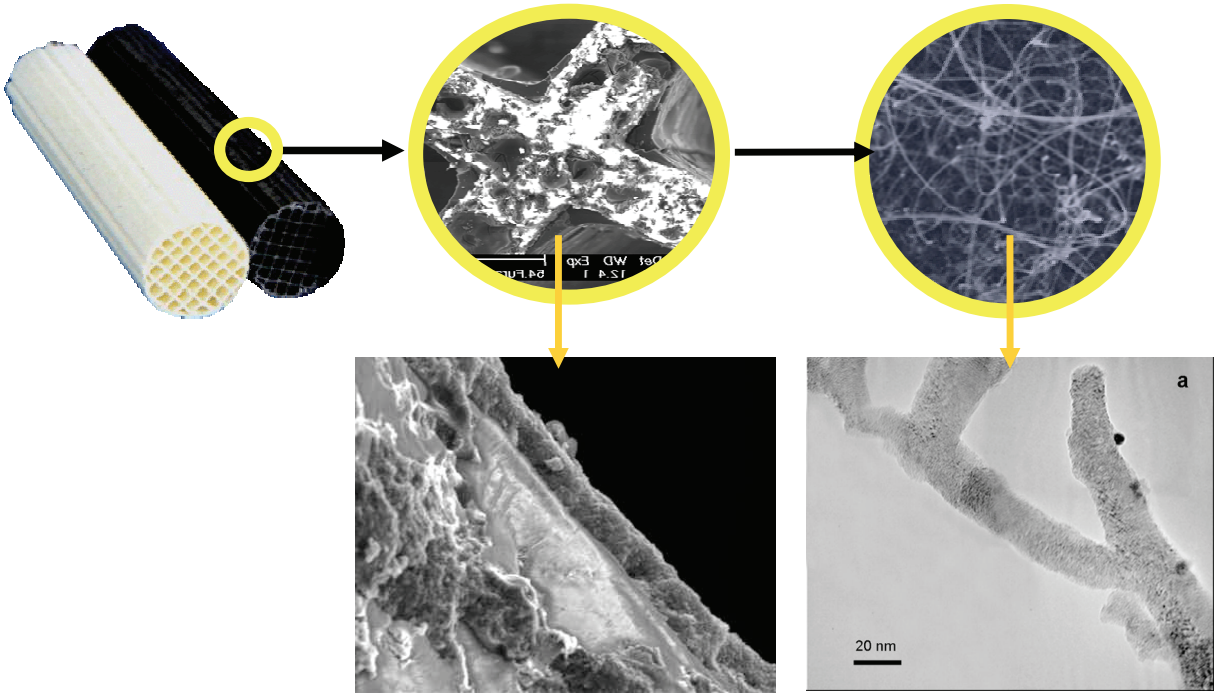
Tor Grande

CARBON NANOTUBE MONOLITHS

Carbon nanotubes (CNT) or carbon nanofibers (CNF) are normally produced in the form of light, fragile and isotropic soot. This soot is of limited use in industrial catalysis and there is a great challenge to fabricate CNT for practical use. Considerable research efforts have been dedicated to the immobilization of CNFs on macroscopic supports. Recently, a catalytic Chemical Vapour Deposition (CVD) method has been developed at the "Catalysis group" in Department of Chemical Engineering at NTNU to grow uniform CNF layers inside the channels of ceramic monoliths.

The key feature of the new method is to control the growth rate by adjusting the growth conditions to grow a uniform layer with cracking the monolith. The mechanical strength of the CNF/monolith composite was found to be better than the ceramic monolith. The composite has many unique properties such as high surface area, mesoporous structure, tuneable thickness of the CNF layer, tuneable graphite sheet orientation in the CNF, tuneable functionality of the CNF surface and good flow ability. These properties will facilitate many applications in (bio) chemical process, especially for process intensification. Applications in multiphase reactions such as Fischer-Tropsch synthesis, filtration, bioreactors with immobilization of bioactive compounds on CNFs are some examples.

De Chen



Meetings and Seminars

1ST NTNU NanoLab USER MEETING

The 1st NTNU NanoLab User Meeting took place March 9-10, 2006, at Jægtvolden Fjordhotel. The objective of the meeting was to promote the development of cross disciplinary networks within the field of nanotechnology at NTNU, and to present the plans for the new clean rooms facilities, as well as the new MSc study programme in nanotechnology. All together, the meeting gathered 44 participants representing 3 faculties and 8 departments at NTNU, as well as SINTEF. In addition, the vice rector of NTNU and representatives from the Norwegian Research Council were especially invited.

The first day of the meeting focused on strategic issues, opening with the leader of NTNU NanoLab, prof. Thomas Tybell's presentation of the "Nanotechnology initiative at NTNU". Aase Marie Hundere from the Norwegian Research Council followed up by focusing on national opportunities for "Future funding of strategies for nanotechnology and new materials". After lunch the overall plans for the clean rooms for chemical, physical and bionanotechnological methods were presented in a plenary session, followed by detail discussions in groups. This revealed a wide variety of interests regarding research fields and equipment among the participants. The final session of the first day was devoted to "Ethical challenges related to nanotechnology" which were debated by ass. prof. Rune Nydal, and a presentation of the new MSc. study programme in nanotechnology by the Dean of the MSc. study programs at NTNU, prof. Bjørn Torger Stokke. The first day was rounded off with a dinner, followed by enthusiastic discussions around 21 scientific posters.

The second day of the meeting was dedicated to scientific presentations. In all, 12 lectures were given, covering the following topics:

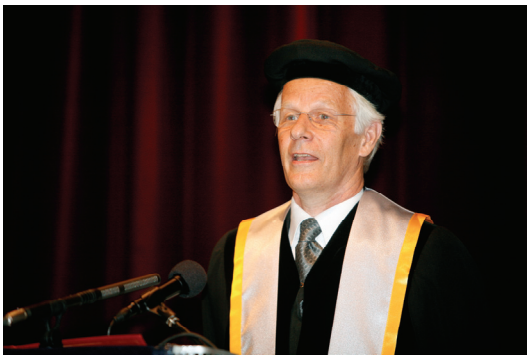
- *Z. Zhang*, "NTNU Nanomechanical Lab and Nanomechanic Research".
- *De Chen*, "Nanomaterials for Energy Production".
- *A. T. J. Van Helvoort*, "Characterization of Materials at the (sub) nanometer scale".
- *J. O. Fossum*, "Nanolayered Silicates (Clays) as Examples of Soft and Complex Matter".
- *S.F. Thomassen*, "Quantum Dot Intermediate Band Solar Cells".
- *T. O. Leiknes,* "Application of Membrane Technology in Environmental Engineering".
- *K. I. Draget*, "Modification of Gelling Kintetics and Elastic Properties by Nanostructuring of Alginate Gels Exploiting the Properties".
- *M. Sletmoen*, "Manipulation of Single Biological Macromolecules Using AFM".
- *K. O. Kongshaug*, "Nanoporous Coordination Polymers".
- *P. Sikorski*, "Bioinspired Nanostructured Materials".
- *H. Weman*, "Fabrication and Characterization of Nanophotonic Structures and Devices".
- *R. W. Bernstein*, SINTEF MiNaLab; "Activities within Nanotechnology and Novel Materials".

The overall impression from the meeting covered high hopes and expectations for the coming facilities and an expressed wish for future workshops to explore possible cross disciplinary contacts and opportunities.

The meeting received economic support from the Strategic Areas "Materials", "Information and Communication Technology" and "Medical Technology" at NTNU. Their generous support is gratefully acknowledged.

PROFESSOR J. E. MOOIJ NANOSCIENCE – NANOTECHNOLOGY SEMINAR

On the 31st of May 2006 Professor J. E. Mooij was appointed *Doctor Technicae Honoris Causa NTNU*.



Doctor Technica Honoris Causa NTNU, Professor J. E. Mooij. Photo: Thor Nielsen/NTNU Info

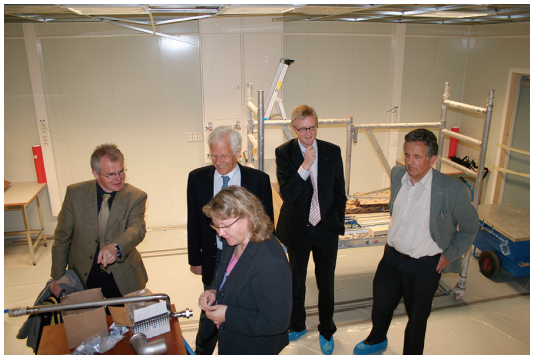
Prof. E. J. Mooij (born 1941) obtained his "ingenieur" and PhD (1970) in applied physics at Delft University in The Netherlands. He was appointed professor in the Department of Applied Physics at TU Delft in 1980. Prof. Mooij has spent a sabbatical year at Stanford University, had three consecutive appointments as visiting professor at MIT, and been the Loeb lecturer at Harvard University in 1998.

The main topics of Prof. Mooij's research are single electron manipulation and behaviour of superconducting nanostructures. More recently, his research interests have been directed towards superconducting quantum circuits, and development of quantum bits for a future quantum computer.

NTNU benefited especially from his scientific vision and wisdom when he as a member of an external committee, appointed by the rector of NTNU, advised on intensive development of nanoscience at the university.

In the honour of Prof. J. E. Mooij's appointment, a one-day seminar focusing on nanoscience and nanotechnology was arranged on.May 30th at NTNU. Prior to the seminar, a small tour of the construction site of the future clean room facilities of NTNU NanoLab was offered. The seminar, which attracted 53 participants, was officially opened by the Chairman of NTNU NanoLab, Prof. Bjørn Torger Stokke, presented high lights of nano-relevant activities at NTNU:

- *Prof. J.E. Mooij*, Delft University of Technology, the Netherlands: "Superconducting nanocircuits for quantum computing".
- *A. K. Fahlvik*, The Research Council of Norway: "Nanotechnology in Norway – Current Status and Future Plans"
- *Prof. T. Tybell*, NTNU NanoLab: "NTNU NanoLab 2003-2006 and Beyond"
- *Prof. M.-A. Einarsrud*, NTNU: "Master of Science, Nanotechnology at NTNU"
- *Prof. A.Brataas*, NTNU: "Nanoelectronics - Theoretical Perspectives".
- *Prof. H. Weman*, NTNU: "Semicoductor Quantum-wires and nano-wires for photonic applications".
- *Prof. Z. Zhang*, NTNU: "NTNU Nanomechanical Lab and Nanomechanics Research".
- *Ass. Prof. W. R. Glomm*, NTNU: "Lanthanide-cored Fluorinated Dendrimers at the Air-water Surfaces".
- *Dr. D. Klein*, NTNU: "Moleular Interactions that Trigger the Innate Immune System Probed at the Nanometer Scale".



Inspection of the construction of the "Clean room for chemical methods". From the left: Bjørn T. Stokke, E. J. Mooij, Mari-Ann Einarsrud, Thomas Tybell and Eivind Hiis Hauge. Photo: Marianne Sjøholtstrand

NTNU NanoLab COLLOQUIAL SERIES 2006

As a means for developing existing and establishing new contacts with internationally respected nanoscientists, the following speakers were invited to present their activities at NTNU in 2006. The presentations were intended as a source of information and inspiration for a broad audience and was sought to cover the various scientific fields in focus at NTNU NanoLab.

- *Prof. Roland A. Fischer*, Ruhr-Universität Bochum, Germany: "The Cu/ZnO Methanol Catalyst: Opportunities for Inorganic Nanochemistry"
- *Prof. Thomas Laurell*, Lund University, Sweden: "Proteomic sample preparation and MALDI-TOF MS interfacing for improved biological readout".
- *Prof. Clément Sanchez*, Université de Pierre de Marie Curie, Paris, France: "Designed construction of nanostructured functional inorganic and hybrid organic-inorganic materials".
- *Prof. Roland Wiesendanger*, University of Hamburg, Germany: "New Trends in Ultra-high Density Magnetic Data Storage".
- *Dr. Emmanuel Hadjii*, French Atomic Energy Commission, Grenoble, France: "Silicon Based Nanostructures for Nanoelectronics and Nanophotonics".
- *Prof. Harald Brune*, EPFL, Lausanne, Switzerland: "Self-Assembly and Magnetism of Metallic Nanostructures at Surfaces".
- *Prof. Suzi Jarvis*, The University of Dublin, Irland: "Using nano-mechanics to explore biological function".
- *Prof. David Haviland*, KTH, Stockholm, Sweden: "Quantum Electrodynamcis with Nano-Scale Superconducting Circuits" and "The Albanova Nano Fabrication Facility - Nano technology for research and small commercial enterprises".

OPENING OF NTNU NANOMECHANICAL LABORATORY

A new lab - NTNU Nanomechanical Laboratory was officially opened on August 29th 2006 by the rector of NTNU, Prof. Torbjørn Digernes. The laboratory is equipped with a state-of-the-art Hysitron TriboIndenter, which based on ultra-sensitive depth sensing techniques provides unique capabilities for studying the mechanical properties of nanomaterials, biomaterials, nano-devices and surfaces as well as conventional materials at nanometer scale. It offers a quantitative tool for exploring the microstructure-property relationships of the materials. Static and dynamic nanomechanical properties can be accurately measured both at high and low temperatures.

Prof. Zhiliang Zhang presents the Hysitron Triboindenter. Photo: Hege Tunstad/NTNU info.

In connection with the opening of the laboratory a day-long seminar was arranged on nanoindentation technology and nanomechanics. Academic and industrial experts from China, Finland, France, Germany and USA as well as Norway were invited to present their recent results and in-house experiences in the new field. More than 70 people attended the opening of the NTNU Nanomechanical Laboratory

NANOETHICS – AVOIDING ETHICS LAGGING BEHIND

A half day seminar on nanoethics was arranged at NTNU on November 21st, 2006.

The launching of NTNU NanoLab and the new MSc programme in nanotechnology motivated a seminar on the ethics of nanotechnology. The current discussions within nanoethics are marked by nanotechnology being at an early stage of development, nationally as well as internationally. Discussing ethical issues at this stage, highlights the challenge of discussing the implications of an emerging technology. The discussions are in danger of being scientifically uninformed. On the other hand, ethics, as it is often said, generally lags behind the science and technology development. This problem now seems to have become acknowledged by both scientist and ethicists.

The seminar focused on the role and place of nanoethical components of nanoinitiatives. Questions of the novelty of ethical challenges related to nanotechnology were not in focus, nor was the question of why we need an ethics of nanotechnology. Ethical-political discussions were taken as important due to the field's potential for radical societal transformations. The speakers of the seminar addressed various aspects of how to pursue on-going ethical discussion in parallel to the developments of nanotechnology. The need for integrating ethics into professional training as well as research founding programmes in order to motivate and secure scientifically informed debates, was argued. Moreover, discussing ethics at an early stage calls for a strengthening of the cooperation of nanoscientist and professional ethicists. This needs to be done in order to find ways of identifying and stimulating preferable developments of nanotechnology. The following speakers represented points of views of students, nanoscientists, founding authorities as well as philosophers and sociologists:

- *John Weckert*, Charles Sturt University, Australia: "Nanotechnology, values and the good life".
- *Roger Strand*, the University of Bergen: "Mapping ethical challenges".
- *Hans Fogelberg*, the University of Gothenburg: "Nanorobustness, co-producing science and society".
- *Thomas Tybell*, NTNU NanoLab: "What is science – what is fiction?"
- *Marit Sletmoen*, NTNU: "Ethics courses – a newly graduated PhD student's point of view".
- *Karin Totland*, the Norwegian Research Council: "NANOMAT and ELSA activities".

The three main speakers, Wecker, Strand and Fogelberg, are all trained in a field of science as well as philosophy. Weckert is editor in chief of the journal NanoEthics (Springer), and has edited and written a number of books and articles in the ethics of nanotechnology. Strand runs a NANOMAT financed research project aiming at identifying ethical challenges of nanotechnology. Fogelberg studies innovation processes of nanotechnology in Sweden.

The seminar, which gathered around 50 participants, was jointly organized by NTNU NanoLab and the Programme for Applied Ethics at NTNU. This programme is governed by a board drawn from the various faculties at NTNU. One of its missions is to create arenas for ethical reflections at NTNU, preferably in cooperation with the research fields under discussion.

Rune Nydal

New Study Programme in Nanotechnology

In the autumn semester of 2006 a new 5 year study programme in nanotechnology was launched at NTNU. The programme attracted 1430 applicants for the 30 available positions, demonstrating a vast interest in nano-technology among young people today.

A characteristic feature of this study programme is the clear emphasis on cross disciplinary and practical skills. The students will acquire basic knowledge in mathematics, physics, electronics, chemistry, and life sciences during the first two years. In addition, nano-related courses will be given from the first semester and continue throughout the entire study. The students will also be challenged in ethical aspects as these issues will be incorporated into the nano-related subjects. In the 4th semester the students will choose to specialize within one of the following four focus areas of NTNU NanoLab:

- Nanostructured materials
- Nanoelectronics, nanophotonics and nanomagnetism
- Bionanotechnology
- Nanotechnology for energy and environment

In order to ensure the cross disciplinary profile the members of the "study programme council" for nanotechnology have been recruited from different departments covering the focus areas of NTNU NanoLab:

- Bjørn E. Christensen – Dept. of Biotechnology
- Finn Drabløs – Dept. of Cancer Research and Molecular Medicine
- Mari-Ann Einarsrud - Dept. of Materials Science and Engineering
- Erik Wahlstrøm – Dept. of Physics
- Helge Weman – Dept. of Electronics and Telecommunications
- Zhilian Zhang – Dept. of Structural Engineering
- Gisle Øye - Dept. of Chemical Engineering
- Andreas Bertheussen - student representative
- Karl Fosli – student representative
- Lars Kilaas – SINTEF Materials and Chemistry
- Ellen Tuseth – Norspace

Each study programme at NTNU has, according to long traditions, their own student association. Consequently, the first class of MSc of nanotechnology students founded their association "Timini" in 2006. They quickly started establishing their own profile, organizing various festivities such as "the Bucky ball".

Enthusiastic students outside Timini's office. Photo: Dale Nichols

Seed Funding

As a strategic action for developing and strengthening cross disciplinary networks at NTNU, as well as between NTNU and external scientific communities, *NTNU NanoLab* announced seed funding in the spring of 2006. Priority was given to development of collaborations, preparation of applications to European commission's 7th Framework Programme for Research and preliminary investigations within nanostructured materials and bionanotechnology. The supported projects were expected to lead to applications for further funding from external sources. In addition to the projects awarded in 2006, several projects were continued with support given in 2005.

Prof. David Embury (visiting professor from McMaster University, Canada) was granted 50.000 NOK in 2005 for organizing a series of seminars related to nanostructured materials. This was a joined initiative between the Dept. of Materials Science and Engineering and NTNU NanoLab, which was continued in 2006.

The series comprised lectures by researchers at NTNU as well as institutions elsewhere in Europe and was kept at an informal level to encourage discussions. The speakers invited in 2006 were:

- *Prof. Dave Embury*, McMaster Univ., Canada: "Ultra-High Strength Materials".
- *Prof. II Ola Jensrud*, NTNU: "Aluminium alloy development and product performance".
- *Prof. II Olaf Engler*, Hydro Aluminium Deutschland GmbH: "Modelling of microstructure and Texture and the Resulting Properties during the Thermo-mechanical Processing of Aluminium Sheets".
- *Prof. Lifeng Zhang*, NTNU: "Transport Phenomena and CFD Application during Process Metallurgy".

Prof. Stefan Jacobsen (Dept. of Structural Engineering) received 50.000 NOK in 2005 as start-up support for the project "Nanoindenting of concrete based materials"

The project was a collaboration between Prof. Jacobsen, Prof. Mari-Ann Einarsrud (Dept. of Materials Sciences and Engineering) and Prof. Zhiliang Zhang (Dept. of Structural Engineering)

A major part of this start-up project was devoted to establishing a network within this scientific field. Personal contacts with Dr. Acker at the Lafarge Research Centre, prof. Ulm at MIT and Dr. Wang in Shanghai have been established and will be further developed in 2007. Parallel to this, introductory studies of preparation of samples of cement and concrete pastes for nanoindenting have been carried out. Test runs of these samples and reference samples will be run in the new Hysitron TriboIndenter at the NTNU Nanomechanical laboratory in 2007.

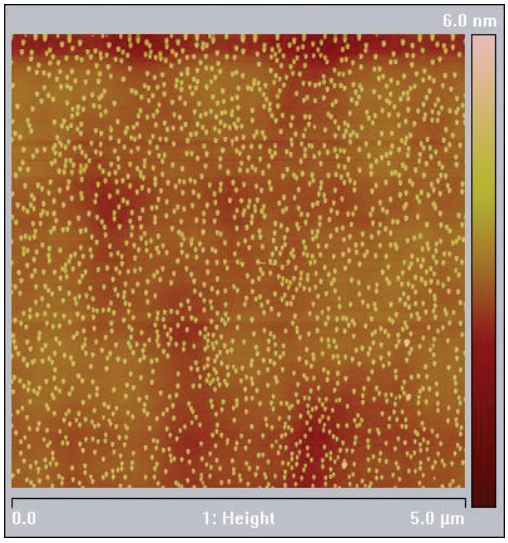
Prof. Mikael Lindgren and Ass. Prof. Morten Kildemo (Dept. of Physics) were granted 25.000 NOK in 2006 as support for "Network building initiatives towards the 7th Framework Programme for Research" of the European Commission.

The recipients of these incentive funding have participated at the annual meeting of the European Technology Platforms annual conference "Photonics 21" in Brussels and visited École Polytechnique in Paris.

Ass. Prof. Turid Worren (Dept. of Physics) and Prof. Bjørn Ove Fimland (Dept. of Electronics and Telecommunications) were granted 50.000 NOK in 2005 as start-up funding for a project on "Growth and Characterization of Quantum Dots for Intermediate Band Solar Cells (QD-IBSCs)"

The aim of the project was to conduct introductory studies on growth parameters of multilayer quantum dots by molecular beam epitaxy (MBE). Suitable characterization methods would be sought in collaboration with the groups of Prof. Bjørn T. Stokke (atomic force microscopy, AFM) and Prof. Randi Holmestad (transmission electron microscopy, TEM).

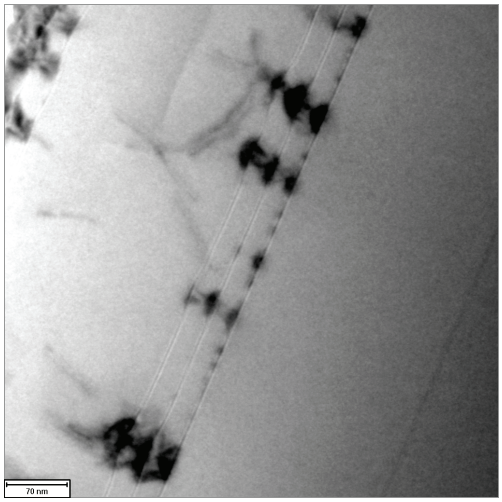
The first two attempts at growing quantum dots did not succeed due to inadequate growth parameters and technical problems with the MBE equipment. The third attempt, however, gave single layer InAs quantum dots on a GaAs substrate, as intended.



AFM picture of InAs quantum dots grown on a GaAs substrate. Photo: Sedsel Fretheim Thomassen

AFM studies of the samples indicated an average height of 3 nm, 50 -70 nm diameter and $8x10^9$ cm^{-2} density of the dots. A quantum dot density of 10^{11} cm^{-2} is foreseen necessary in order to achieve sufficient absorption for the use in solar cells. The growth process will therefore be optimized further in order to increase the dot density and the number of layers.

TEM analyses of the samples will be of great importance in the study of the relative position of dots grown in subsequent layers and how the dots affect each other. Initial test analyses of samples of InAs quantum dots grown in three layers with AlAs barriers at the MC2 laboratory at Chalmers University of Technology in Sweden have been carried out. The distance between the quantum dot layers was 20 nm. The TEM analyses showed that the dots were located on top of each other and tend to be of similar size, giving the same size distribution throughout each layer. As may be seen in the picture below, the quantum dots appeared as dark spots.



TEM picture of three layers of InAs quantum dots grown on GaAs, with AlAs barriers. Photo: Rune Strandberg

However, mechanical strain also gave dark marks, as may be seen as dark stripes on the picture. Such shades interfere with the interpretation of the shape and extent of the dots. Application and refinement of advanced TEM techniques in order to minimize the contrasts due to mechanical strain in the samples will therefore be carried out in the future.

Based on these introductory studies an extensive application to the Norwegian Research Council has been filed.

Turid Worren

Construction of Clean Room Facilities

During 2006 the establishment of an efficient infrastructure for nanotechnological research at NTNU has progressed. The foreseen facilities will constitute an integrated entity situated in Chemistry buildings 1 and 2, as well as the connecting building "Mellombygget". Great emphasis has been put on designing a flexible infrastructure that may easily be adapted to future demands. The entire clean room area will be GMOII:2 compatible. The laboratories will be furnished with state-of-the-art equipment for nanotechnological research within prioritized areas that will complement the facilities of SINTEF's MiNaLab in Oslo. In addition to specialized laboratories, the facilities will include general support laboratories, offices and meeting areas. The laboratories will be open to all researchers interested in nanotechnology, both at NTNU, SINTEF and other Norwegian research establishments.

The first phase involving the construction of a class 10.000 laboratory for synthesis by chemical methods in Chemistry building 2 is in progress and will be completed in 2007.

Construction workers in the Chemical clean room of NTNU NanoLab. Photo: Marianne Sjøholtstrand

This will be a multipurpose laboratory, which will be equipped for synthesis and characterization of nanostructured materials and nanoparticles by various chemical techniques, including specialised equipment for:

Nanosyntheses:

- Wet chemical methods (dip / spin / spray coaters, microwave oven)
- Hydrothermal syntheses (high temperature ovens, autoclaves)
- Nanoparticle separation (centrifuges, ultrasound)
- Chemical Vapour Deposition

Nanoscale characterisation:

- AFM (atomic force microscope; morphology / electrochemical)
- SECM (Scanning electrochemical microscope)
- Particle size determination (from 2 nm)

The planning and furnishing of this laboratory has been undertaken by *The planning committee for the "Chemical clean room":*

- Mari-Ann Einarsrud (Dept. of Materials Science and Engineering, leader)
- Astrid Ramstad (Dept. of Chemistry)
- May-Britt Hägg (Dept. of Chemical Engineering)
- Arne Petter Ratvik (SINTEF Materials and Chemistry)

The scientific equipment has been financed by the Norwegian research council and the board of NTNU. This support is greatly acknowledged.

In the second phase of the construction work the adjacent clean room facilities for physical and bionanotechnological methods will be constructed. The foreseen facilities will include areas holding clean room classes 100 and 10.000 and local vibration free zones down to VC-E. The laboratory has been designed aiming at flexibility and diversity in research with an infrastructure allowing for demanding high resolution work.

The "Clean room for physical methods" has been planned as a fully equipped thin film growth/processing laboratory with emphasis on diversity in materials and high resolution work. The following methods will be available in the fully furnished laboratory:

- Thin film growth: sputter deposition, PECVD, e-beam deposition, metallisation.
- Lithography methods: Dual beam focused ion beam etching system, DUV-lithography, e-beam lithography and nanoimprint lithography.
- Etching methods: wet etching, dry etching (RIE, ICP-RIE, IBE, CAIBE, PE).

The metrology section will offer an excellent environment for characterisation and vibration isolation. This area is planned to host among others, the following facilities:

- High resolution SEM
- Two darkrooms for optically demanding characterisation and manipulation (combined AFM/optical microscopy, spectroscopy, optical tweezers).
- AFM suitable for wafer inspection.

The part dedicated to bionanotechnology will provide class 10.000 cleanliness and incorporate tools for nanoscale fabrication based on biological methods or fabrication using biological materials. Key activities will include work on biopolymers, nanostructured surfaces, studies related to drug delivery and fabrication of new contrast agents for medical imaging. The facilities will also allow work with cells and micro-organisms.

Two planning committees have been involved in defining the future needs regarding the infrastructure and scientific equipment for the remaining clean rooms:

The planning committee for "Clean room for physical methods":

- Erik Wahlstrøm (Dept. of Physics, leader)
- Bjørn Ove Fimland (Dept. of Electronics and Telecommunications)
- Otto Lone (Dept. of Materials Science and Engineering)
- Dag T. Wang (SINTEF ICT)

Planning committee for "Clean room for bionanotechnological methods":

- Tore Lindmo (Dept. of Physics, leader)
- Pawel Sikorski (Dept. of Physics)
- Bjørn Christensen (Dept. of Biotechnology)
- Christian Brekken (NTNU MR centre)
- Lars Kilaas (SINTEF Materials and Chemistry)

Consultants Bo Bengtson and Robert Otterlei seek optimum solutions for the new clean room facilities. Photo: Thomas Tybell

Economy

The overall budget for 2006 was 20.778 MNOK, including 9.431 MNOK allocated for future obligations including wages and scientific equipment.

	Budget	Consumption	Surplus
Administrative running costs	200 000	214 679	(14 679)
Chemical clean room running costs	300 000	31 828	268 172
Strategic / Incentive means	300 000	147 860	152 140
NTNU NanoLab Colloquial Series	100 000	61 977	38 023
Studyprogr. Nanotechnology	400 000	400 000	-
Salaries academic positions	2 060 000	1 179 601	880 399
Salaries leader / coordinator	900 000	848 651	51 349
Establishment of infrastructure	2 087 000	1 896 500	190 500
Scientific equipment	5 000 000	4 579 433	420 567
	11 347 000	9 360 529	1 986 471
Allocations for future obligations			
Wages 2008-2009	3 431 000	-	3 431 000
Equipment to be delivered in 2008	6 000 000	-	6 000 000
Totalt	**20 778 000**	**9 360 529**	**11 417 471**

Media coverage

Activities related to NTNU NanoLab have been presented in the media on several occasions:

- Adresseavisen 24.11.06:
  "Djupedal gir millioner til nanoteknologi"
- Universitetsavisa 23.11.06
  "Ekstramillioner til Nanolab"
- www.Adresseavisen.no, 23.11.06
  "4.7 millioner til NTNU Nanolab"
- Adresseavisen, 09.11.06
  "Forskerne skal møtes i nanoverden"
- Universitetsavisa 29.08.06
  "Maskinen som måler mikrokrefter"
- NRK Midt-Nytt 29.08.06
- NRK radio 29.08.06
- TV Adressa 29.08.06
- Adresseavisen 30.08.06
  "Tester de minste ting"
- www.TU.no; 05.04.06
  "Ta en nano-master på atomsløyden"
- Adresseavisen 1.04.06
  "Studieplass sikres i påsken-kjempeinteresse for nano"

Dissertations

The following candidates have defended their thesis for a PhD degree at NTNU within fields related to nanotechnology in 2006.

Paul Inge Dahl*: Synthesis and Characterization of Ionic Conductors on ZrO_2, $BaZrO_3$ and $SrCeO_3$ and Preparation of $LaFeO_3$ and $LaCoO_3$ Thin Films*

Florian Huber: *Nanocrystalline Copper-based Mixed Oxide Catalysts for Water-gas Shift*

Steinar Kragset: *Phase Transitions in Effective Lattice Models for Strongly Correlated Systems*

Johann Mastin: *Structure, Ferroelastic Properties and Mechanical Behaviour of $LaCoO_3$-based Materials*

Tommy Mokkelbost: *Synthesis and Characterization of CeO_2- and $LaNbO_4$-based Ionic Conductors*

Kanak Pal Singh Parmar: *Oil Dispersions of Nano-layered Silicaters in an External Electric Field: An Experimental Study*

Roman Scheluskin: *Spin-orbit Coupling Induced Transport in Normal Metals and Ferromagnetic Semiconductors*

Marit Sletmoen: *Structure, Dynamics and Force-induced Dissociation of Biomacro-molecular Complexes Involving Polysaccharide*

Marit Sletmoen (right) receives the Faculty of Science and Technology's award for Best PhD Thesis 2006 by Vice Dean Åse Krøkje (left). Photo: Kenneth Stoltz/ NTNU Info

Sondre Volden: *Preparation and Characteristics of Novel Silica-based Materials and Adsorbed Macromolecules*

Publications

The scientific community within nanotechnology at NTNU as published a significant number of articles in 2006. In the following a few selected publications are sited within the four prioritized areas of *NTNU NanoLab.*

Nanostructured materials

Fossum, J.O. Meheust, Y., Parmar, K.P.S., Knudsen, K.D., Maloy, K.J., and Fonseca, D.M., *Intercalation-enhanced electric polarization and chain formation of nano-layered particles*, **Europhysics Letters**, 74(3), 438, 2006.

García-Bordejé, E., Kvande, I., Chen, D., Rønning, M., *Carbon Nanofibers Uniformly Grown On Alumina Washcoated Cordierite Monoliths*, **Adv. Materials**, 18, 1589, 2006.

Hasting, H.S., Walmsley, J.C., van Helvoort, A.T.J., Marioara, C.D., Andersen S. and Holmestad, R., *Z-contrast imaging of the arrangement of Cu-precipitates in 6xxx-series aluminium alloys,* **Philosophical Magazine Letters,** 86, 589, 2006.

Johannessen, E. and Bedeaux, *D. Integral Relations for the Heat and Mass Transfer Resistivities of the Liquid-Vapor, Interface*, **Physica A,** 370, 258, 2006.

Nakajima, H., Nohira, T., Ito, Y., Kaus, I., Dahl, P.I., Mastin, J., Grande, T. and Einarsrud, M.-A. *Synthesis and Characterization of Nanocrystalline YSZ powder by Smoldering Combustion Synthesis*, **J. of Nanomaterials**, Article ID 49283, 1, 2006.

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Magnusson, H., Øye, G., Glomm W.R., and Sjoeblom, J., *Synthesis of Mesoporous Alumina Using Carboxyl Functional, Hyperbranched Polyesters as Templates,* **J. of Dispersion Science and Technology**, 27(4), 547, 2006.

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Petersson L. and Oksman, K. *Biopolymer based Nanocomposites: Comparing Layered Silicates and Microcrystalline Cellulose as Reinforcement*, **Composites Science and Technology**, 66 (13), 2187, 2006.

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Rubi, J.M., Bedeaux D. and Kjelstrup, S., *Thermodynamics for small molecule stretching experiments*, J**. Phys. Chem. B**, 110, 12733, 2006.

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Brataas, A., Tserkovnyak Y., and Bauer, G.E.W., *Current-induced Macrospin Versus Spin-wave Eexcitations in Spin Valves*, **Physical Review B,** 73 (1), 014408, 2006.

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Annual Report for NTNU NanoLab

NTNU
Innovation and Creativity

NTNU – Innovation and Creativity

The Norwegian University of Science and Technology (NTNU) in Trondheim represents academic eminence in technology and the natural sciences as well as in other academic disciplines ranging from the social sciences, the arts, medicine, architecture to fine arts. Cross-disciplinary cooperation results in ideas no one else has thought of, and creative solutions that change our daily lives.

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