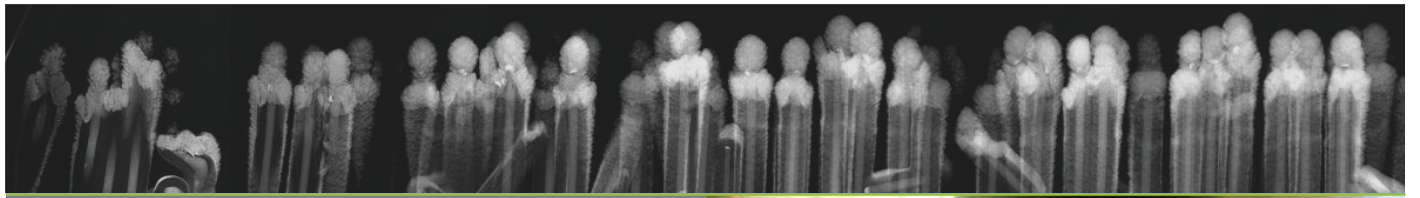


Annual Report





Annual Report 2010

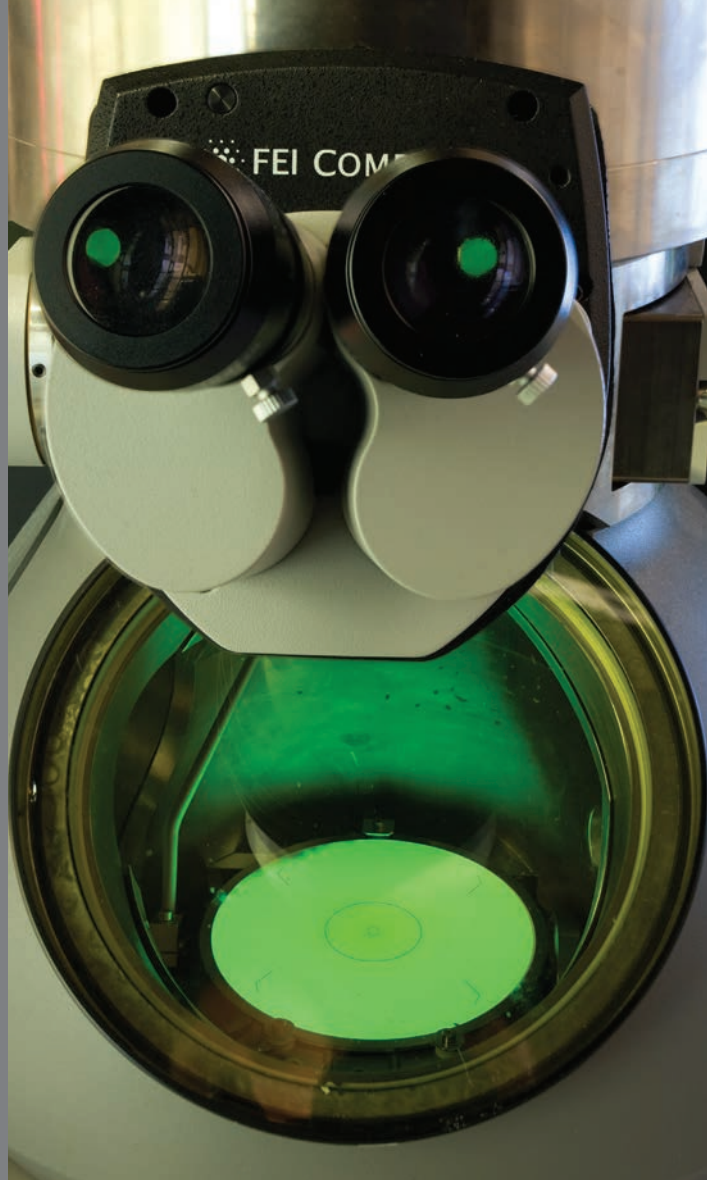
The Center for Electron Nanoscopy - DTU Cen, 2011

Written and edited by DTU Cen

Photographs and supplementary text
Carsten Broder Hansen · ScienceComm

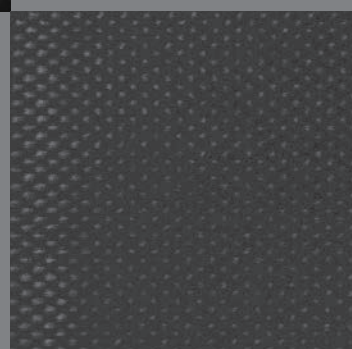
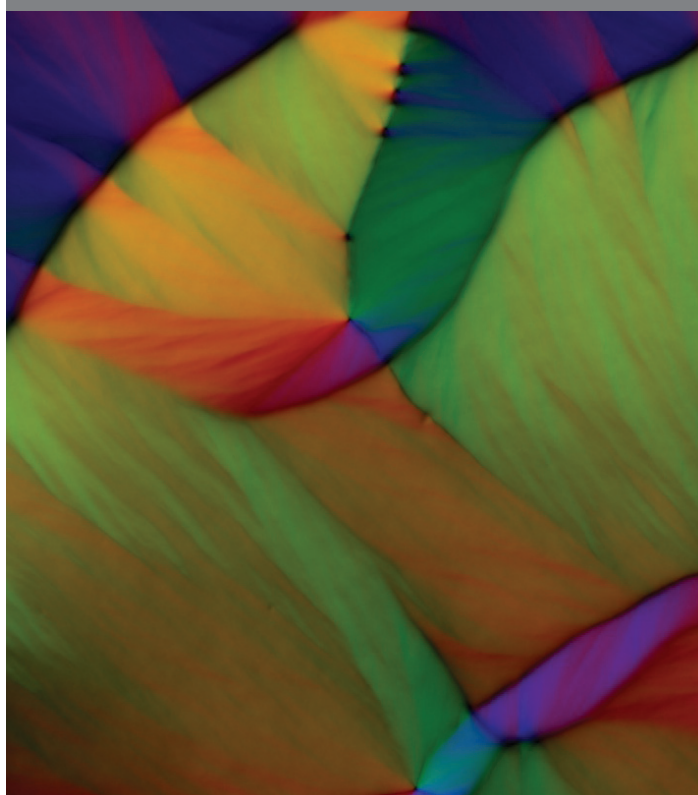
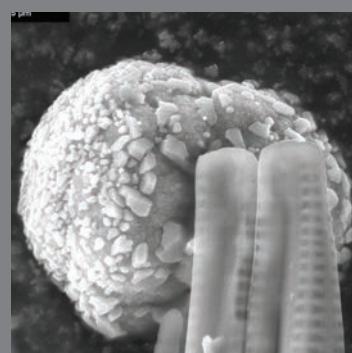
Graphic design · Anne F. Juhl-Schmidt

Printed in Denmark by Kailow Graphic



2010

4	Preface
5	Executive summary
7	The essentials of gas-solid interactions
8	External grants
11	Meeting the need for sustainable energy
12	Teaching activities
14	Project description - CASE
16	Project description - SILICON-Light
18	Projects
27	Events at DTU Cen
28	Publications and presentations
34	Every day I get a little closer
36	Sample preparation room
38	Scanning electron microscopes
42	Transmission electron microscopes
46	Research partners
47	Advisory board
48	Staff



Preface

The Center for Electron Nanoscopy in the Technical University of Denmark (DTU Cen) was established in December 2007 following a generous donation of 102.6 M DKK by the A.P. Møller and Chastine Mc-Kinney Møller Foundation.

DTU Cen contains seven electron microscopes in a purpose-built high-specification building. Three years after its inauguration, it is a successful and dynamic unit at DTU, in which a team of core staff have established close working relationships with other departments at DTU and with national and international partners.

Core staff at DTU Cen also supervise students and scientists, deliver lecture courses, organize workshops, secure external grant funding and host national and international visitors.

Research is carried out in collaboration with scientists from DTU and with external partners, and centres on studies of nanoscale materials at the highest spatial resolution and in three dimensions using techniques that include aberration-corrected electron microscopy, electron tomography, environmental (gas reaction) electron microscopy, electron holography, slice and view imaging in the scanning electron microscope and three dimensional electron backscatter diffraction.

We warmly welcome enquiries about scientific collaborations and both academic and commercial partnerships.

Rafal E. Dunin-Borkowski
Center Director



Rafal E. Dunin-Borkowski



Three years after its inauguration, the Center for Electron Nanoscopy in the Technical University of Denmark is a fully operational unit at DTU.

A core team of experienced scientific and technical support staff is active in research, teaching, service and outreach.

The Center's seven electron microscopes are in daily use, and the microscope building provides an ideal environment for research and teaching.

The Center works alongside other departments at DTU and with other universities and industry, and it has a strong international profile, with a wide range of research and service activities with academic and industrial partners, a good record of publishing research articles in scientific and popular journals and frequent visits to the Center by visiting scientists and industrialists.

The Center's success is demonstrated by the frequent invitations to speak at international conferences that are received by the Center's staff and by the extent of additional European and Danish grant funding that has been secured for specific projects.

This report contains a description of the Center's electron microscopes, examples of research and teaching activities, a summary of events and research output for 2010, and profiles of the Center's research scientists and technical and administrative staff.





The essentials of gas-solid interactions

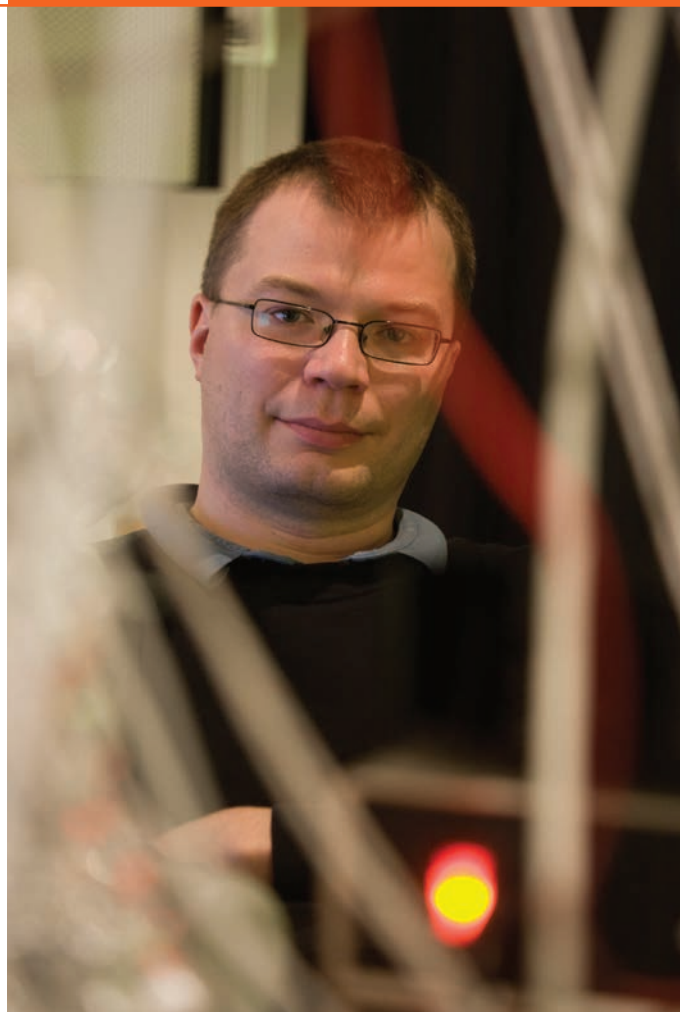
Jakob Wagner held a position as a Post Doctoral Researcher at Lund University before he arrived at DTU Cen. One of a very select few in the world, Jakob had previous experience in the field of Environmental Transmission Electron Microscopy (ETEM) acquired through a PhD study he conducted at Haldor Topsøe A/S.

Indeed, Jakob can be considered as one of the pioneers in the development of ETEM at Haldor Topsøe A/S.

ETEM makes it possible to carry out detailed investigations of samples *in-situ* in gaseous atmospheres. The microscope at DTU Cen is used for a range of purposes and many of these have marked potential for industrial applications.

When the centre was established it was logical to take advantage of Jakob's experience with ETEM and thus he was appointed to take charge of activities in this area; including the responsibility of developing and expanding the whole research field as a priority area for the university. Jakob has maintained this responsibility since the launch of DTU Cen in December 2007.

According to Jakob, state of the art ETEM is a very rare area of expertise in the microscopy world and goes on to explain: "ETEM enables visual disclosure of crystalline structures of individual nanoparticles and the specific, important, gas-solid interaction(s) of such structures. In a traditional electron microscope the sample is observed in vacuum, but of course this does not allow studies and analysis of gaseous



Jakob B. Wagner

processes at, e.g. high temperatures, which is particularly important in catalysis. Using ETEM we are able to perform exactly that kind of analysis and this is a contributing factor to DTU's position as one of the leaders in catalysis research. Hence when DTU Cen began to materialize it is not surprising that the centres at DTU involved in catalysis research were among the prime lobbyists for the acquisition of an ETEM.

It is impressive that of the very few ETEMs of the highest quality that exist in the world today, no less than three are found here in Lyngby; one at DTU Cen and two at Haldor Topsøe A/S just across from the university campus. Together they form a unique concentration of such capacity."

It is understood that an additional European ETEM is on the way and some ETEMs are found in the USA as well as a few in Japan. The coming European ETEM indicates an increasing importance and international focus on the field.

Jakob elaborates: "We have visiting researchers from all over the world participating in collaborative projects. ETEM has huge potential in the industrial world as evidenced by the high priority placed on the technique at Haldor Topsøe A/S.

It is however important to emphasize that at DTU Cen our main objective is to perform fundamental research which indeed also happens to be my main interest. As a consequence there is a wide gap between the subjects and catalyst composites I investigate and, e.g. a shippable product.

My research is centred on materials and crystal structures and how temperature and various gases may affect them. It is all about creating a visual impression of the critical processes that take place. Although this kind of research only offers limited and stepwise breakthroughs, our results may in fact rapidly help narrow down a wide range of possibilities.

An additional bonus is the chance to do something that no one else is capable of doing".

External grants

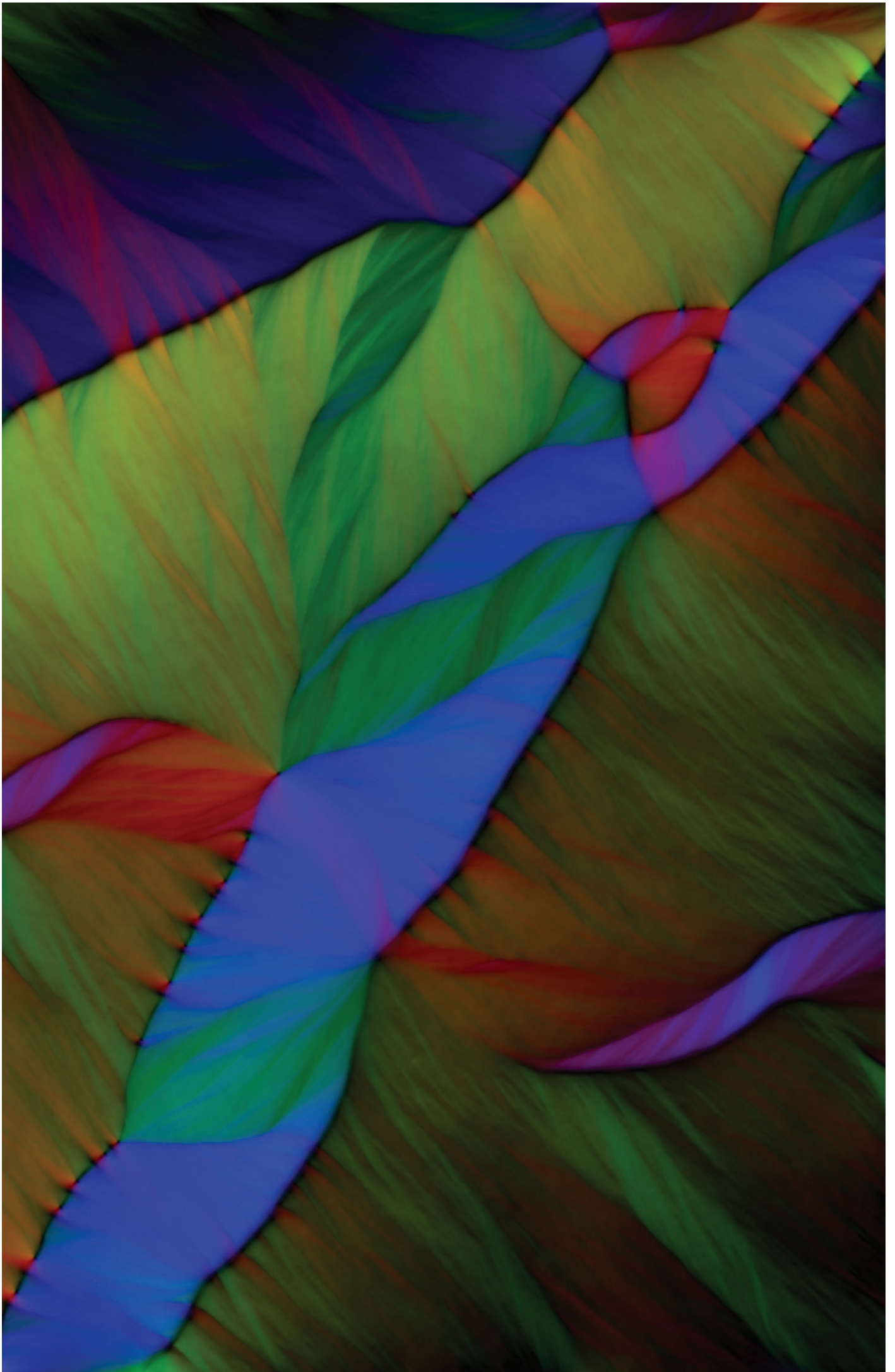
DTU Cen is responsible for work packages in the following grants, which total €27.75M:

2009 - 2014	UNIK grant with Prof. J Nørskov (PI), Prof. I Chorkendorff, Prof. J Grunwaldt, Prof. C Christensen and Prof. M Mogensen. Title: "The Catalysis Discovery Initiative: Sustainable Energy Solutions".	120M DKK (€16.1M).
2009 - 2014	ERC-2008-AdG grant (project number 227690) with Prof. T Dietl (PI), Dr A Bonnani, Prof. J Gaj and Prof. J Majewski. Title: "FunDMS - Functionalisation of Diluted Magnetic Semiconductors".	EC contribution: €2.44M.
2010 - 2013	FP7-ENERGY-2009 -1 grant (project number 241277) with Dr W Soppe (PI), Dr D Fischer, Dr W Schipper, Prof. M Topič, Dr G Sánchez Plaza, Dr K Leitner and others. Title: "SILICON-Light - Improved material quality and light trapping in thin film silicon solar cells".	EC contribution: €5.98M.
2008 - 2011	FP7-NMP-2007-SMALL-1 grant (project number 214814) with Prof. K Deppert (PI), Dr F Dimroth, Prof. B Witzigmann, Dr M Magnusson and Dr J Stangl. Title: "AMON-RA - Architectures, Materials and One-dimensional Nanowires for Photovoltaics - Research and Applications".	EC contribution: €3.2M.
2010 - 2011	Otto Mønsted fellowship to support a three month visiting Professorship in the Technical University of Denmark for Prof. G Pozzi from the University of Bologna.	186k DKK (€25k).



DTU Cen is a named partner on the following grants, which are administered by other departments at DTU and by other universities and total €29.55M:

2010 - 2013	NorTEMnet (Nordic transmission electron microscopy network) NordForsk grant with Prof. R Holmestad, Prof. E Olsson and Prof. J Ruokolainen.	900k NoK (€113k).
2010 - 2013	NERC grant (EACPR_P26419) with Dr A Muxworthy (PI) and Dr W Williams entitled "The effect of chemical alteration on the fidelity of palaeomagnetic pseudo-single-domain recorders".	£399k (€460k).
2010 - 2013	Swiss National Science Foundation grant with Prof. J Van herle and Dr A Hessler Wyser. Title: "IN Situ TEM study of reduction and reoxidation of Ni(O)-ceramic composite (INSITE)".	225k SFr (€170k).
2010 - 2013	FP7 grant (project number 245162) with Dr S Weigel, Prof. E Huusfeldt Larsen (DTU Food), Dr K Mølhav (DTU Nanotech) and others entitled "NanoLyse - Nanoparticles in food: analytical methods for detection and characterisation".	EC contribution: €2.95M.
2008 - 2011	FTP grant with Dr P Bøggild (PI), Prof. A-P Jauho, Prof. T Garm Pedersen and Dr M Brandbyge entitled "Nanoengineered graphene devices".	5.6M DKK (€750 k).
2008 - 2011	Villum Kann Rasmussen Center of Excellence headed by Prof. J Mørk (PI). Title: "NANophotonics for Tera-bit Communications (NATEC)".	25M DKK (€3.35 M).
2011 - 2014	FTP grant entitled "Imaging nanoelectronics live by transmission electron microscopy" awarded to Dr K Mølhav (DTU Nanotech).	5.7M DKK (€765 k).
2011 - 2015	Grant entitled "Functional Electrospun Nanostructures and Microstructures for Food and Bioengineering Applications (FENAMI)" with Dr. I Chronakis, Prof. A Meyer and Prof. K Qvortrup.	14.9M DKK (€2.0M).
2009 - 2013	Danish Natural Science Research Council grant entitled "Fysiske principper for selvorganiserede materialer" awarded to Dr C Frandsen (DTU Fysik).	4.05M DKK (€545k).
2009 - 2012	FP7 grant entitled : "Technotubes (Technology for Wafer-Scale Carbon Nanotube Applications)" awarded to Dr P Bøggild and Dr K Mølhav (DTU Nanotech) and colleagues.	EC contribution: €8.12M.
2008 - 2012	FP7-NMP-2007 grant entitled "NANOTOUGH - Nanostructured toughened hybrid nanocomposites for high performance applications" awarded to Dr A Horsewell (DTU Mek) and Dr M E Vigild (Danish Polymer Center).	EC contribution: €5.09M.
2008 - 2011	FP7-NMP-2007 grant entitled : "Understanding interactions between cells and nano-patterned surfaces" awarded to Dr K Mølhav (DTU Nanotech) and colleagues.	EC contribution: €3.96M
2008 - 2011	FTP grant entitled "Grain boundary engineering of functional thin films" awarded to Dr K Pantleon and Prof. M Somers (DTU Mek).	4.1M DKK (€550k).
2008 - 2011	FTP grant entitled "Micro alloyed high strength net shape components" awarded to Dr N Tiedje, Dr A Horsewell, and Dr J Hattel (DTU Mek).	1.3M DKK (€175k).
2008 - 2011	Fødevareforskningsprogrammet grant entitled "Omega-3 food emulsions. Control and investigations of molecular structure in relation to lipid oxidation" awarded to Dr A Horsewell (DTU Mek) and Dr C Jacobsen (DTU Aqua).	1.3M DKK (€175k).
2008 - 2010	FTP grant entitled "The influence of stress on growth- and transformation kinetics of interstitial alloys" awarded to Thomas Lundin Christensen, Prof. M Somers and Dr K Pantleon (DTU Mek).	2.7M DKK (€360k).



Meeting the need for sustainable energy

In January 2010 Linus Daniel Leonhard Duchstein arrived from Berlin to begin his Ph.D. study at DTU Cen.

Linus had worked in a research group using electron microscopy at the Helmholtz Zentrum Berlin when he noticed the advertisement for a vacant PhD position at DTU.

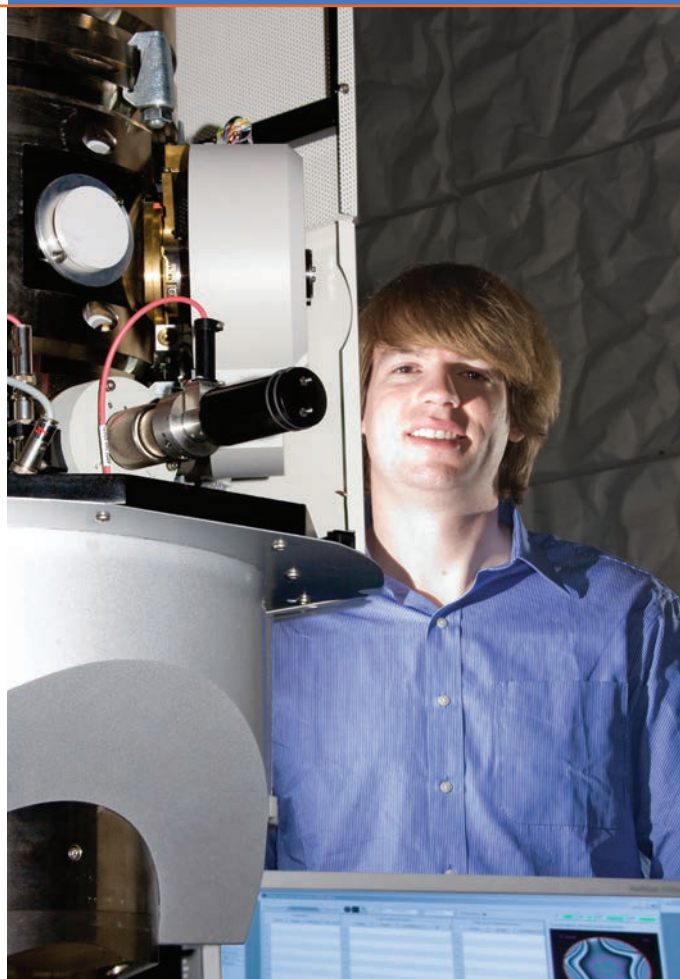
After Linus found out what kind of facilities were available at DTU Cen, he immediately applied.

Linus works in the field of catalysis; specifically in the CASE project (Catalysis for Sustainable Energy).

CASE is the largest project ever financed by the Danish Ministry of Science, Technology and Innovation and the project involves many DTU departments.

The main objective of CASE is the discovery of new solid catalysts and processes for energy conversion for a spectrum of energy sources. The central idea is to develop a science-based rational design strategy for new catalysts.

Linus' field of interest is the characterization of such catalysts using the ETEM to disclose how the catalyst is working. Linus explains: "The ETEM enables me to apply gases and heat to a sample, thus creating a controlled working environment for the particular process. I can then look and observe single nanoparticles and see what specific



Linus Daniel Leonhard Duchstein

changes are caused by changing, among other parameters, pressure or temperature. By using the ETEM I can perform direct observations of segregation or a transition from oxide to metal.

Such information provides feedback to the researchers involved in the design and synthesis of the catalysts.

Our ultimate goal is to find a catalyst capable of efficient production of bioethanol.

Ethanol can be made from organic waste products and is one of the better options for a potential breakthrough in finding a sustainable energy source that meets the needs of society."

Teaching activities

DTU Cen offers a broad range of training and educational opportunities for students and scientists who need to employ electron microscopy in their research.

Any engineer or physicist graduating from DTU with a project involving nanoscience, who moves on to a career in industry or academia, will require tools to quantify the structure and properties of the materials and devices they will deal with.

DTU Cen is responsible for and is actively involved in the following courses:

10710 – Transmission Electron Microscopy for Nanoscience
41690 – Electron Microscopy and Analysis for Materials Research
33257 – Visualization of Micro and Nano Structures.
10510 – PhD course in Catalysis for Sustainable Energy

Beside the courses mentioned above, CEN staff present guest lectures in other DTU courses. Furthermore, CEN staff supervise Bachelor, Master and PhD students.

Bachelor courses

33257 Visualization of Micro and Nano structures

Bachelor course, 5 ECTS points
Course responsables: Rodolphe Marie (DTU Nanotech), Sebastian Horch (DTU Physics) and Jakob B. Wagner (DTU Cen).

General course objective

The goal of this course is to provide an overview of methods for visualization of micro and nano structures and understand the underlying physics of those methods. Such structures are central elements in a large range of research and industrial projects and products.

The knowledge gained from the course will enable the student to choose the techniques best suited for a given task and to diagnose and further develop the appropriate visualisation techniques.

Furthermore, the student will be able to interpret the information provided by these techniques; in the form of the shape of the sample (topography) and its material properties for example.

Master/PhD courses

10710 Transmission Electron Microscopy (TEM) for Nanoscience

PhD course (open to final year MSc), 5 ECTS points
Course responsible: Marco Beleggia (DTU Cen)
DTU Cen staff involved: András Kovács, Thomas W. Hansen, Chris Boothroyd.

General course objective

This course will enable the student to interpret electron micrographs of various types in order to extract quantitative data on the materials or structures he or she is interested in. The course is not for those who wish to train to become electron microscope operators, rather it aims at providing a theoretical understanding of the principles of electron optics, image formation, data acquisition, and image processing relevant to TEM.

The course will enable the participants to understand and interpret TEM images, diffraction patterns, and phase contrast images (commonly known as “high resolution” images). Problems and examples are chosen from current research in nanoscience, materials science and engineering at DTU and will focus on nanostructured materials. The course participants will be PhD and Master students who need to employ TEM methods in their own research.



41690
Electron Microscopy and Analysis for Materials Research

PhD course (open to final year MSc), 5 ECTS points

Course responsible: Andy Horsewell (DTU Mechanical Engineering and DTU Cen).

DTU Cen staff involved: Chris Boothroyd, Jakob B. Wagner, Berit Wenzell and Ramona Matieu.

General course objective

The course aims at providing a basic theoretical understanding of the principles of electron microscopy. The course will enable the participants to understand and interpret images, diffraction patterns and spectra obtained from both scanning and transmission electron microscopes. Specimen types and problems are selected from current research in Materials Science and Engineering at DTU and will cover metals and alloys, ceramics, polymers, composites and nanomaterials.

The course participants will exclusively be PhD and final year Master project students. An active learning approach is adopted with considerable input from the students' own research projects.

10510
PhD course in Catalysis for Sustainable Energy

PhD course, 5 ECTS points

Course responsible: Søren Dahl (DTU Physics), DTU Cen staff involved: Thomas W. Hansen and Jakob B. Wagner.

General course objective

To give the students the scientific background to the process of Solar Fuels production with special emphasis on the catalytic materials required.

The content of the course will cover the framework that underpins the research initiative "Catalysis for Sustainable Energy" which is running at DTU in the period 2009 - 2014. This involves an introduction to the scientific methodology that is used to design new catalytic nano materials. It is a methodology that seeks to improve materials design through a combination of theoretical materials investigations, materials synthesis, materials characterization, and materials testing. Furthermore an introduction to the three catalytic routes to solar fuels is provided: direct fuels synthesis by photo electro catalysis, conversion of sustainable electrical energy to fuel using electro catalysis and transformation of biomass to fuels.

The final evaluation of the course consists of making a contribution to a web-book associated with the Catalysis for Sustainable Energy project. This text is then presented and defended in plenum as an oral presentation by each student.

Project description - CASE

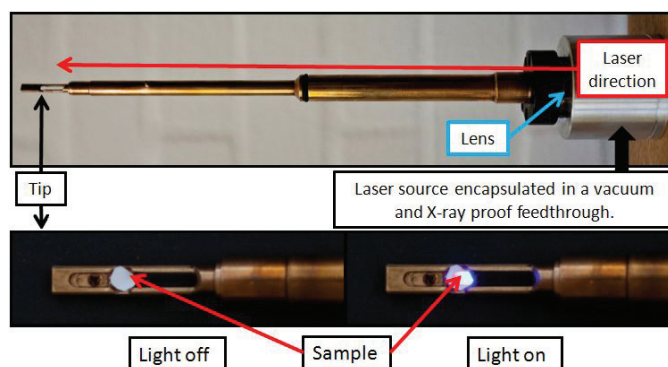
In 2009 the Danish Ministry of Science, Technology and Innovation funded the CATalysis for Sustainable Energy (CASE) initiative at DTU. In total the initiative involves more than 20 PhD students and Post Doctoral positions both in theoretical and experimental based projects coordinated from several institutes at DTU.

The aim of the initiative is to harvest solar energy more efficiently in a sustainable way to provide an alternative to fossil fuels. Fossil fuel resources are limited and will come to an end within the not too distant future. To minimize the costs of changing energy resources on a large scale it is beneficial to be able to use the existing infrastructure of energy distribution. In that respect the formation of energy carriers in chemical bonds from solar energy is an efficient way of changing the primary energy source.

One of the projects funded by the CASE initiative started in 2010 is entitled '*In-situ* characterization of photocatalysis for sustainable energy applications'. The project is coordinated by DTU Cen and carried out by Filippo Cavalca.

The aim of the project is to develop a sample holder that can integrate the capability of shining visible light onto a photocatalyst while simultaneously examining the sample in the environmental transmission electron microscope (ETEM). By means of TEM it is possible to obtain an insight into the structure, composition and operation of such photocatalysts. In particular, a controlled gaseous environment in the ETEM means real time *in-situ* experiments in the presence of light and gas are possible.

The holder is developed to be used in different TEMs to increase flexibility. Furthermore, the laser light source is made changeable to cover the visible light range. The figure below shows the holder with the laser diode source encapsulated in a vacuum sealed and X-ray proof feedthrough.



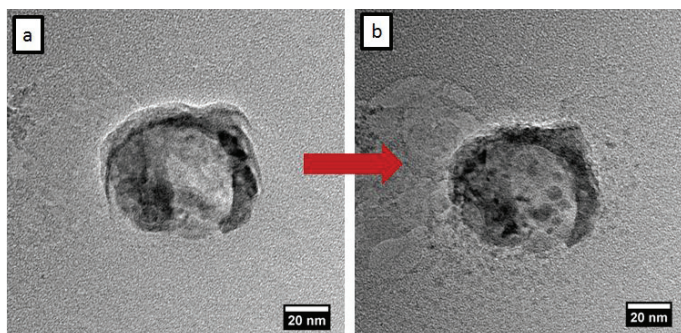
In-situ TEM characterization of photocatalysts for sustainable energy applications



From the numerous catalytic materials of interest, cuprous oxide, Cu_2O is being studied using the in-house developed holder. Cu_2O is a photocatalyst for water splitting under visible light illumination [1]. Photo-catalytic water splitting is used for hydrogen production, a process that is intended to produce a viable fuel source in the future.

However, Cu_2O undergoes photodegradation under an aqueous environment [2]. In order to study the photo-degradation, Cu_2O nanocubes have been synthesized and loaded onto the TEM holder to monitor the process in-situ.

The degradation is investigated by observing morphology changes and using spectroscopy techniques to study any chemical changes.



One of the challenges when studying the effects of visible light in the electron microscope is to differentiate between the effect caused by visible light and by the high energy electron beam. The photon energy density of the laser diode used in this experiment is approximately six orders of magnitude less than the electron beam.

As a result of the high energy density of the electron beam the Cu_2O cubes undergo a rapid degradation when exposed to water in the presence of the electron beam. In contrast, the cubes are stable under the electron beam in vacuum conditions.

Time resolved studies of the degradation process are performed by imaging the cubes using the electron beam in vacuum and then blanking the electron beam during exposure to water and visible light. In the figure a Cu_2O nanocube is imaged before (a) and after (b) illumination by light (405 nm) and exposure to 5 mbar of H_2O for 3 hours.

The degradation of the Cu_2O cubes appears as morphology changes and the formation of smaller particles nearby on the support (in the present case amorphous carbon). The copper oxide is thought to be partly reduced when exposed to visible light in an aqueous environment. The reduction leads to the morphological changes observed in the TEM images. To be able to follow the time-resolved degradation a 'stop-motion'-type experiment has to be performed.

[1] Hara, M., Kasama, T., Chem. Commun., 1998, 3, 357-358.

[2] Nagasubramanian, G., A. S. Gioda, J. Electrochem. Soc., 1981, 128(10), 2158-2164.

Project description - SILICON-Light

The SILICON-Light consortium consists of eight partners, seven European and one from China, and is subsidized by the European Commission within the framework of the thematic research programme Energy in FP7.

The aim of the project is to increase the efficiency of thin-film silicon solar cells on a cheap and flexible substrate thus enabling lower production cost per Watt-peak.

Despite their low production cost, thin-film silicon solar cells represent only 15% of the total solar cell market, mainly because of their lower than 10% yield on the industrial scale.

Therefore, the general technological objectives of the project are to develop better quality materials to enhance light trapping efficiency of thin-film silicon solar cells and then to transfer the know-how into industrial production.

The project is divided in work packages with specific goals in areas such as optical modeling, optimization of the growth processes, incorporation of cheaper material for the current collection and industrial scale integration of the newest innovations.

DTU Cen is part of the work package Silicon layers for which the main objective is to develop silicon deposition processes that prevent or mitigate defect formation in microcrystalline silicon when grown on texturized substrates.

Martial Duchamp and Ramona Mateiu are actively involved at the scientific level. Their task is to provide comprehen-

sible feedback on structure and material characterization using advanced electron microscopy (EM) techniques.

The material characterization includes 3D mapping of defects, interface characterization, elemental mapping as well as *in-situ* EM to understand the behavior of working solar cells. In order to enhance the overall solar cell efficiency, light absorption, photo-generated current and open-circuit voltage need to be optimized simultaneously, which implies a permanent interaction between all the project partners.

The work at DTU Cen has focused on the following points:

- Development of a high throughput transmission electron microscopy sample preparation technique by means of focused ion beam thinning. The samples so prepared are dedicated to a systematic study of material growth processes (Figure 1).
- Characterization of substrate roughness to provide feedback to the “light trapping” work package (Figure 2).
- Structural characterization of the micro-crystalline and amorphous silicon active layer of solar cells fabricated on steel, plastic and glass substrates using transmission electron microscopy (Figure 3).
- Nano-scale chemical analysis using Electron Energy Loss Spectroscopy (EELS) to map dopant concentrations (Figure 4).

Improved material quality and light trapping in thin film silicon solar cells

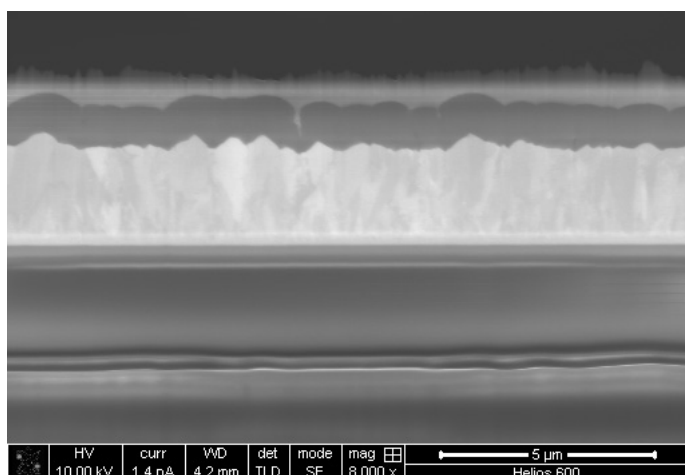


Figure 1
Scanning electron micrograph of a solar cell TEM lamella prepared by focused ion beam thinning using the Quanta 3D and Helios FIB-SEM microscopes.

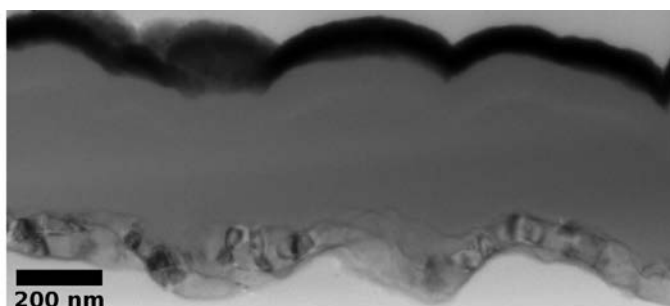


Figure 2
TEM cross-section of an industrial-scale produced solar cell fabricated on a plastic substrate produced by VHF-technologies (Switzerland). The sample has been prepared for light trapping analysis.

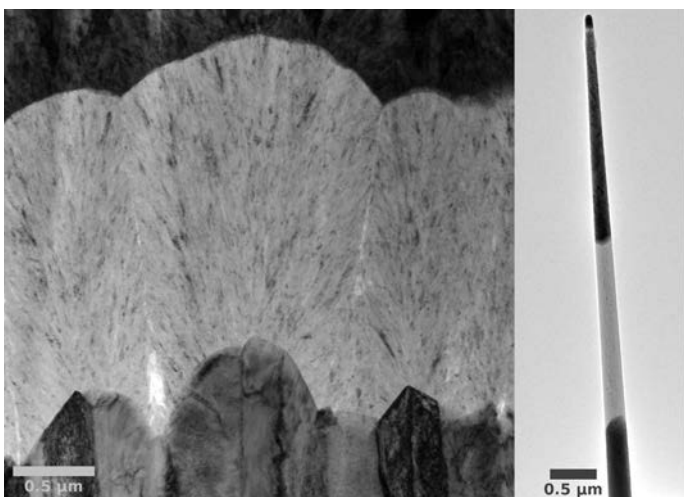
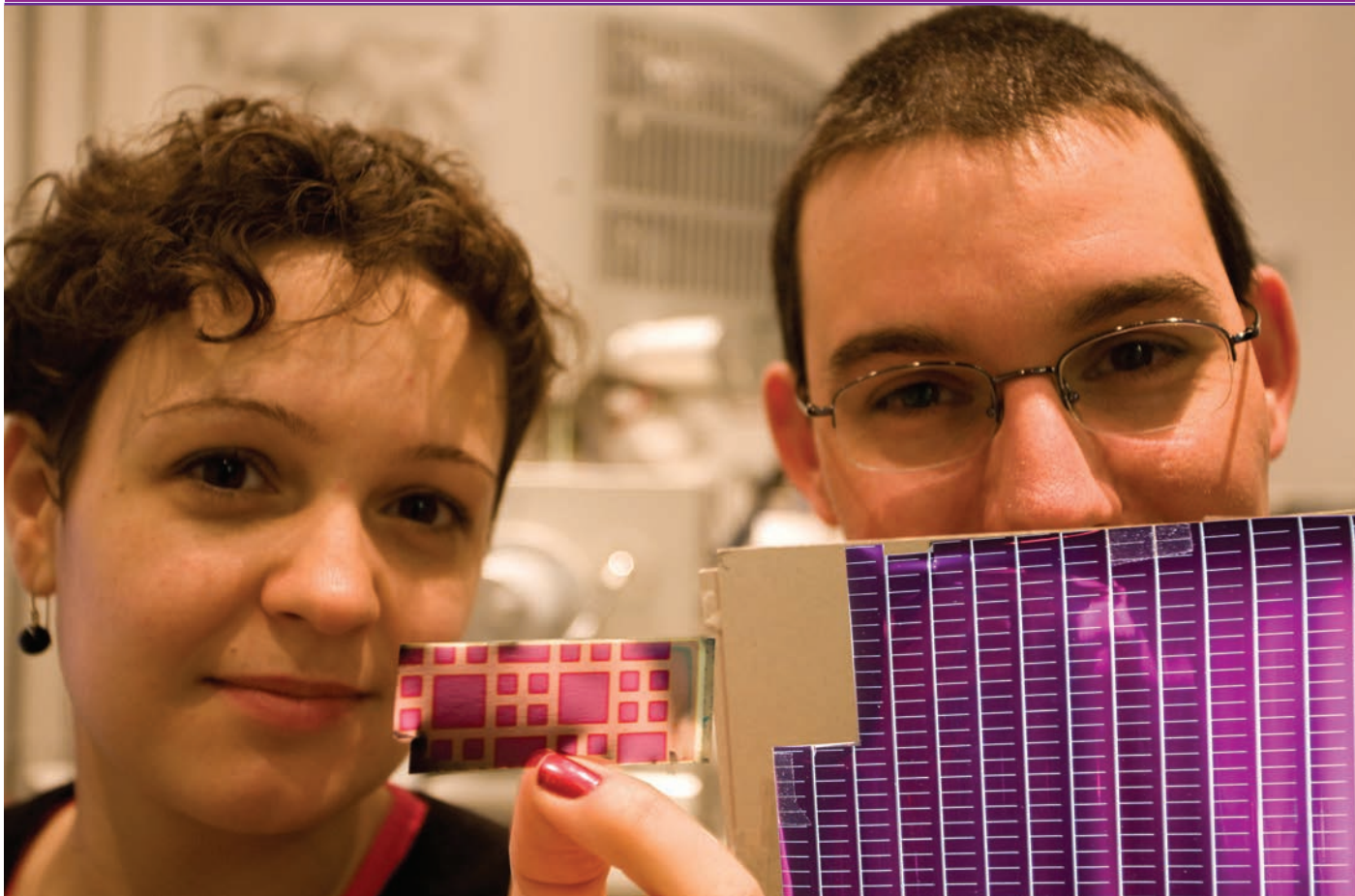


Figure 3
Bright field TEM images of a microcrystalline thin-film silicon solar cell grown on glass substrate by the Institute of Microengineering in Switzerland. (a) TEM lamella and (b) 200 nm wide needle. The gray regions correspond to the active silicon layer, where the light is converted in current. The needle sample is used for tomography experiments for the purposes of 3D image reconstruction.

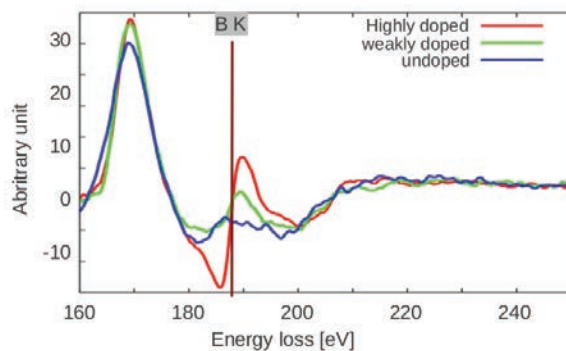
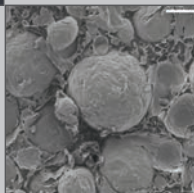
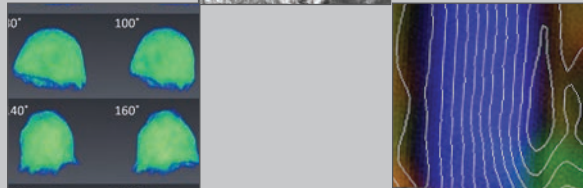
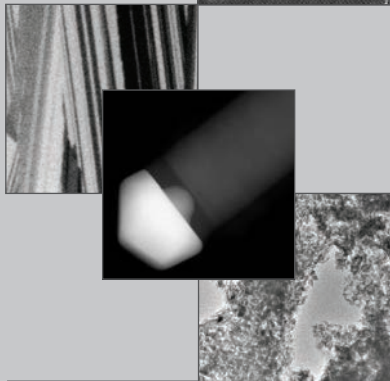
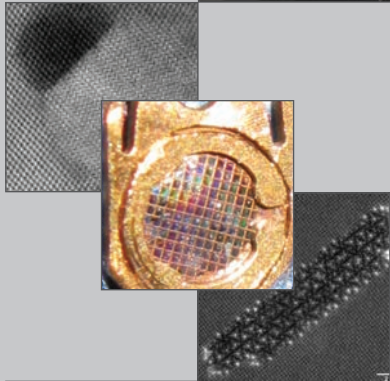
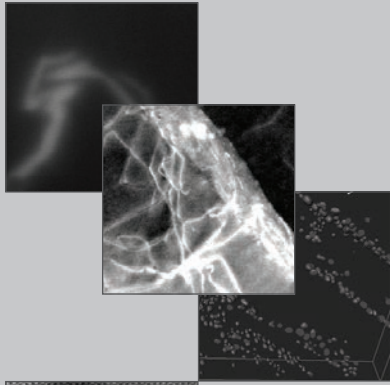


Figure 4
Electron energy loss spectra of silicon-doped layers. The intensity of the Boron peak (labeled B K) reflects the amount of boron contained in the three different layers. The EELS technique allows mapping of low boron concentration at a spatial resolution of less than 20 nm.



Projects

Nanostructured Toughened Hybrid Nanocomposites for High Performance Applications

Funding: **European Union NMP3-2008-213436**

Principal investigator: **Prof. Andy Horsewell**

Staff at DTU Cen: **Dr. Alessandra Mosca**

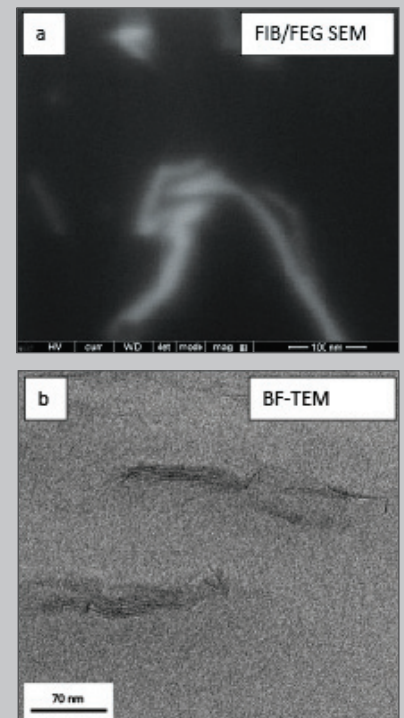
Nanotechnology requires imaging on the nanoscale and electron microscopy is a powerful technique for achieving this. The aim of this project is thus to use electron microscopy techniques to characterize polymer nanocomposites, used for the development of automotive and aerospace components.

Work at DTU Cen focuses on sample preparation, scanning electron and transmission electron microscopy of polymers reinforced with clay or silver nanoparticles. Sample preparation using ultramicrotomy (cryo, i.e. at liquid nitrogen temperature, and at room temperature), chemical etching (with KMnO_4 and H_2SO_4) and staining (with 1wt% RuO_4 solution), is a critical step and standard procedures have been developed for microtoming nanocomposites based on semi-crystalline or amorphous polymers.

The morphology and topology of the samples is studied using scanning electron microscopy on chemically etched samples.

In particular, the slice-and-view technique using selective carbon etching, performed in a focussed ion beam (FIB) with field emission gun (FEG) scanning electron microscope, is used to characterize the particle size distribution and interparticle distance in very thin slices (2 nm). The most important advantages of these techniques are a larger field of view, the possibility to measure the real interparticle distance of the clay nanofillers, and a resolution overlapping with that of bright field (BF) transmission electron microscopy (TEM).

The dispersion of the clay and silver nanoparticles and the exfoliation of the clay in the polymeric matrix is studied by BF-TEM and high angle annular dark field (HAADF) in scanning transmission electron microscopy (STEM) mode. In addition, microchemical analysis with energy electron dispersive X-ray spectroscopy (EDXS) is performed in HAADF-STEM mode, providing valuable information on the presence of oxide layers or residual precursor in the material.



Cross sectional scanning electron micrograph obtained with the slice-and-view method and in-lens detector in a FIB/FEG SEM (a) and bright-field transmission electron micrograph (BF-TEM) (b) of a clay-polypropylene nanocomposite.

Characterization of Iron inclusions in Olivine ($\text{Mg, Fe}_2\text{SiO}_4$)

Principal investigator: **Dr. Richard Harrison (Cambridge University)**

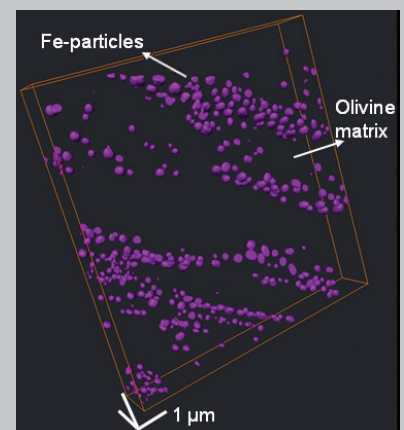
Staff at DTU Cen: **Dr. Alice Bastos da Silva Fanta**

This project aims to study the composition and crystallographic relationship between iron inclusions and olivine matrix in meteorites.

Work at DTU Cen focuses on applying electron backscatter diffraction (EBSD) in combination with energy dispersive spectroscopy (EDS) to study of the phase and distribution of Fe particles and relate this to the compositional zoning of the olivine.

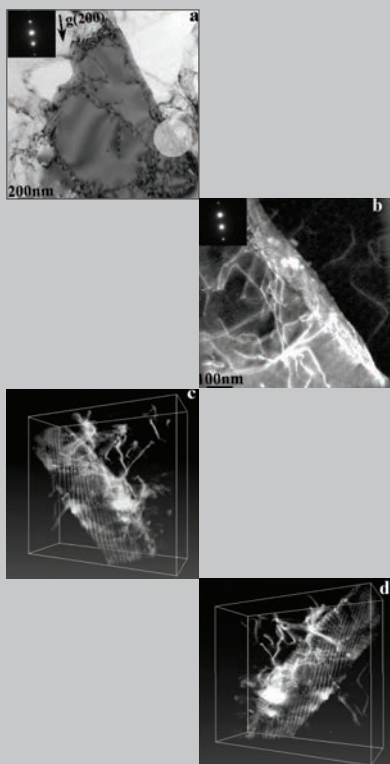
Furthermore, perform 3D characterization of the samples by serial sectioning on a dual beam microscope to investigate the grain boundary relationship between the olivine and Fe particles.

Prepare site specific transmission electron microscope (TEM) specimens using a focused ion beam (FIB) for further magnetic investigation.



3D reconstruction of Fe-nanoparticles in olivine. Data acquired by serial sectioning on the Helios. Slice thickness of 20 nm.

Projects



(a) Bright field image showing planar and cell boundary in tensile deformed Al. (b) annular dark-field image of a Planar boundary. (c + d) 3D of the planar boundary after reconstruction.

Dislocation Tomography and Holography

Funding: **Ørsted Fellowship**

Principal investigator: **Prof. Rafal E Dunin Borkowski**

Staff at DTU Cen: **Dr. Amuthan Ramar**

This project aims to understand the 3D structure of dislocation networks at the grain boundaries and inner cell boundaries of a tensile deformed aluminum using the electron tomography technique.

The task is to acquire a tilt series using annular dark field imaging of dislocations with a controlled diffraction condition experiment using the High Angle Triple Axis (HATA) sample holder.

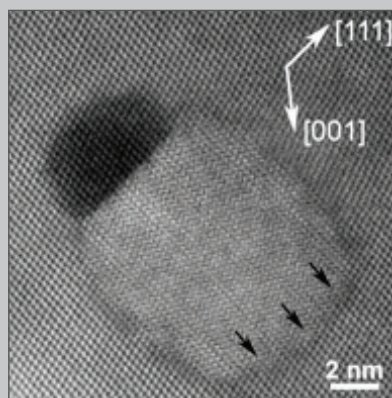
Software is then used to reconstruct the obtained tilt series and its 3D view.

Also, in collaboration with University of Munich, we are now developing new software for the reconstruction of line defects.

The off axis electron holography technique is used to acquire phase images of dislocations in aluminium in a variety of diffraction conditions.

Experimental electron-optical phase images are compared quantitatively with simulations:

- in part to investigate the information about the phase contrast across the dislocations, that are of different types, such as interstitial or vacancy type
- to investigate dislocations that are not visible using conventional diffraction contrast techniques for a particular diffraction condition.



High-resolution aberration-corrected high-angle annular darkfield (HAADF) image of a hexagonal (Ga,Mn)As cluster in GaAs acquired using DTU Cen's Analytical Titan TEM. Arrows indicate misfit dislocations.

FundMS - Functionalisation of Diluted Magnetic Semiconductors

Funding: **European Union ERC-2008-AdG grant**

Principal investigator: **Prof. Tomasz Dietl (University of Warsaw)**

Staff at DTU Cen: **Dr. András Kovács**

This project aims to combine advanced characterisation with epitaxial growth and theoretical modelling to understand the ferromagnetic properties of transition metal doped III-V and II-VI compounds.

Work at DTU Cen focuses on transmission electron microscopy of Fe-doped GaN, Co-doped ZnO and Mn-doped GaAs.

High-resolution electron microscopy, annular dark-field imaging and electron energy-loss spectroscopy are used to characterize nano-scale crystallographic and chemical phases and defects in each material.

Off-axis electron holography is used to measure the local magnetic properties of individual nanocrystals and defects.

Projects

Precipitates in Al alloys containing Si, Mg, Cu and Ag

Funding: **SINTEF**

Principal investigator: **Dr. Calin Marioara (SINTEF, Trondheim)**

Staff at DTU Cen: **Dr. Chris Boothroyd**

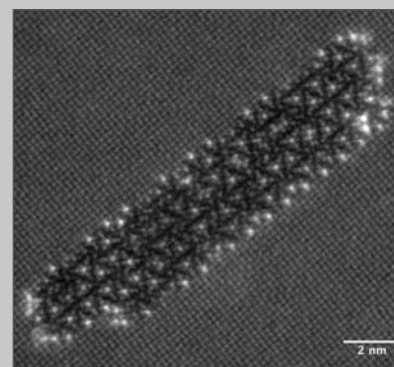
The aim is to determine the atomic structure of the nanometre-sized precipitates formed in aged Al alloys.

Characterisation is performed using high-resolution high-angle annular dark-field scanning transmission electron microscope images (HAADF STEM).

Atomic columns appear bright and intensity increases with atomic number and there is no ambiguity about the position of the atomic columns as there is with HREM.

The Mg atoms are arranged in a triangle around the Si atoms and these groups are arranged in a disordered hexagonal lattice.

The bright columns throughout the precipitate are Cu atomic columns and the brightest columns at the top-right are Ag.



High-resolution aberration-corrected HAADF STEM image of an Al-Si-Mg-Cu-Ag precipitate in a [001] Al matrix. The brightest dots at the top-right are Ag atomic columns and the bright dots are Cu columns. The image was acquired using DTU Cen's Analytical Titan TEM.

In situ measurements of dynamic effects in heterogeneous catalysis

Funding: **CASE**

Staff at DTU Cen: **Dr. Christian D. Damsgaard**

This project aims to perform in-situ measurements of dynamic effects in heterogeneous catalysis.

Work at DTU Cen focuses on constructing a controlled in-situ transfer interface between an environmental transmission electron microscope (ETEM) and other in-situ characterization systems. As a first choice an interface to an in house in-situ X-ray diffractometer analysis system (in-situ XRD) is currently being designed and constructed.

The transfer interface consists of a specially built sample holder sealing the sample in a controlled gas environment at a given pressure. Furthermore, the sample holder controls the sample temperature during transport between the in-situ XRD and the ETEM.

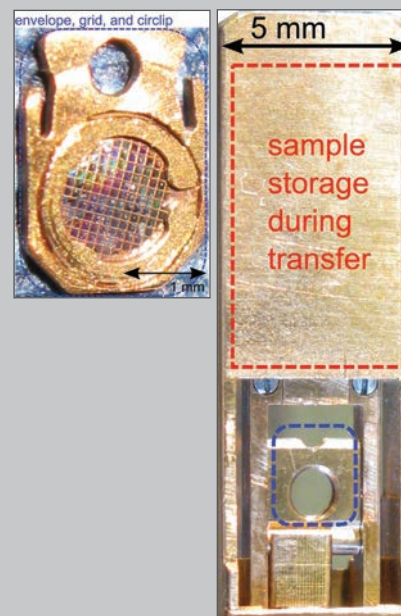
By establishing such an interface it is possible to bridge some of the gaps between ETEM and experiments carried out at conditions

close to the operating environment.

For example it is possible to perform sample preparation at higher pressures while obtaining structural information on larger sample volumes prior to TEM characterization.

Furthermore, it is possible to do experiments over a long period of time to reveal effects such as sintering and aging of catalysts in the in-situ XRD system.

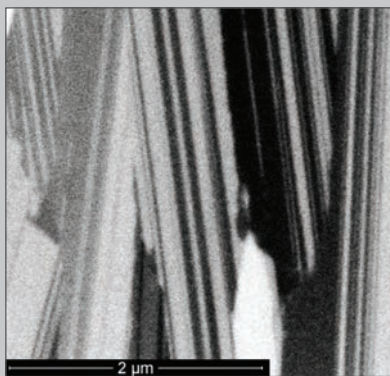
Samples can subsequently be transferred to the ETEM under controlled conditions for further inspections at various stages of the process.



Sample grid mounted in the sample envelope by a circlip (left).

The TEM sample holder designed for transport of a sample under a controlled environment. The blue square indicates the position of the sample envelope. The red square shows where the sample is stored during transfer (right).

Projects



Focused Ion Beam (Channeling Contrast) micrograph of the cross section of an electrodeposited nickel film.

Grain Boundary Engineering of Functional Thin Films

Funding: Danish Research Council

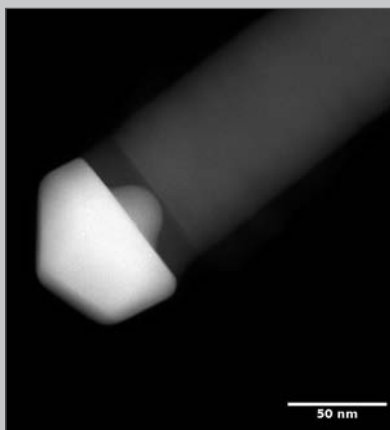
Principal investigators: **Dr. Karen Pantleon (DTU Mek)**, PhD student **Hossein Alimadadi**, Staff at DTU Cen: **Dr. Alice Bastos da Silva Fanta**

This project aims to tailor the internal structure, especially grain boundaries, of thin electrochemically deposited films by cross-linking between targeted thin film processing and thorough microstructure characterization.

Work at DTU-Cen focuses on 3 Dimensional - Electron BackScatter Diffraction (3D-EBSD), 2D-EBSD and Focused Ion Beam (FIB) imaging.

By applying 3D-EBSD, complete three-dimensional quantitative information on the internal structure and grain boundary character can be assessed.

Furthermore, 2D-EBSD in combination with channeling contrast imaging by means of FIB facilitates conventional studies of the microstructure in 2 dimensions.



STEM HAADF image of the growth catalyzing gold particle of a GaAs Nanowire, using DTU Cen's Analytical Titan TEM.

AMON-RA Architectures, Materials, and One-dimensional Nanowires for Photovoltaics - Research and Applications

Funding: European Commission 7th Framework Programme

Project Coordinator: **Prof. Knut Deppert (Lund University)**
Staff at DTU Cen: **PhD Student Johan M. Persson**

Semiconductor nanowires could potentially be used for harvesting of solar light for energy uses.

The aims of the AMON-Ra project are to find ways of overcoming the problems with these structures and develop novel concepts for engineering them into solar cells.

Work at DTU Cen focuses on characterization of semiconductor nanowires grown at Lund University, using mainly transmission electron microscopy.

Morphological and crystallographic information as well as chemical composition is acquired through the use of high resolution transmission electron microscopy and X-ray spectroscopy.

Tomographic information is acquired using scanning transmission electron microscopy.

Projects

Advanced electron microscopy of catalysts for the synthesis of methanol and higher alcohols

Funding: **CASE**

Principal investigator: **PhD Student Linus D. L. Duchstein**

Staff at DTU Cen: **Prof. Rafal E. Dunin-Borkowski, Dr. Jakob B. Wagner and Dr. Thomas W. Hansen**

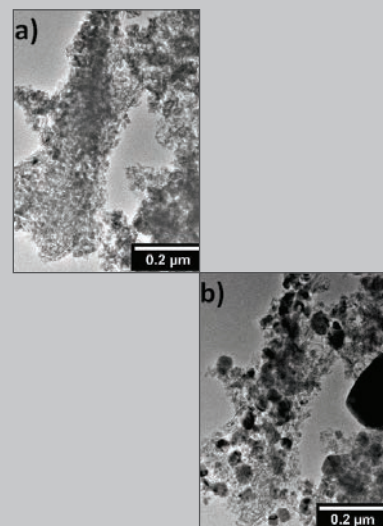
Increasing pollution and a foreseeable shortage of fossil fuels have created an interest in developing transportation fuels from sustainable resources.

Characterization of catalysts for synthesis of methanol and higher alcohols and their dynamic responses to changes in environment are investigated. At DTU Cen this is done using the ability of the environmental Titan TEM (E-TEM) to expose the catalysts to different gas atmospheres and temperatures while studying by means of electron microscopy.

Combining results from conventional electron microscopy techniques with E-TEM leads to further understanding of the catalyst state near working conditions.

The focus so far is lying in the investigation of Cu and MoS₂ based catalysts.

This Ph.D. project is part of the CAtalysis for Sustainable Energy (CASE) initiative, which is funded by the Danish ministry of Science and Technology and aims at improving and understanding catalytic reactions involved in the conversion and storage of energy.



Brightfield images of CuSn catalyst on a Al₂O₃ support nanoparticles acquired using DTU Cen's Environmental Titan TEM both

a) in high vacuum and
b) with exposure to hydrogen atmosphere at a temperature of 600K. The dark particles observed are sintered CuSn crystals.

Omega-3 food emulsions. Control and investigation of molecular structure in relation to lipid oxidation.

Funding: **Ministry of Food, Agriculture and Fisheries**

Principal investigator: **Dr. Charlotte Jacobsen (DTU Food)**

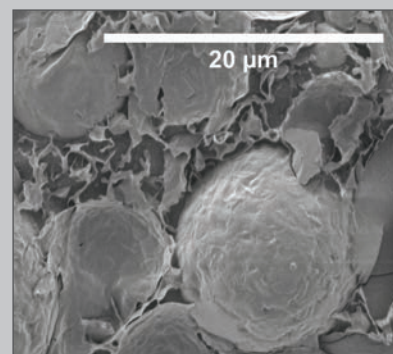
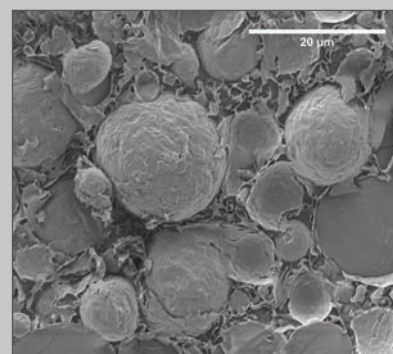
Staff at DTU Cen: **PhD Student Louise H. Sogaard Jensen**

This project aims to elucidate the structure of oil-in-water emulsions consisting of fish oil, different emulsifiers and a water phase.

These are intended for the addition of omega-3 polyunsaturated fatty acids to food products. Features such as oil droplet size, distribution and the structure and thickness of the emulsifier layer are of interest.

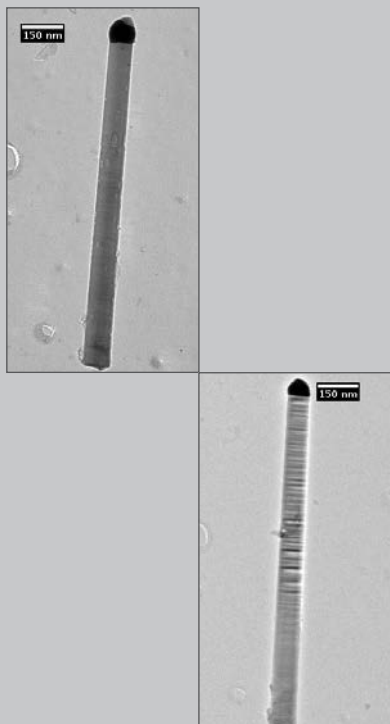
Work at DTU Cen focuses on cryo-Scanning Electron Microscopy (cryo-SEM) of freeze-fractured samples. Freeze-fracture of fast-frozen samples is a method to gain access to the internal structure of bulk samples for cryo-SEM.

If performed on vitrified samples the method is virtually artifact free. The method can clearly elucidate the microstructure of emulsions with respect to distribution, droplet size and possible deformations.



Cryo-SEM micrographs of an emulsion containing fish oil.

Projects



Bright-field TEM images of Au-catalyzed GaAs nanowire before (left) and after (right) a high-temperature in-situ dissolution experiment showing secondary nucleation and structural degradation.

Advanced Quantitative Transmission Electron Microscopy of Semiconductor Nanowires

Funding: **DTU PhD Project**

Staff at DTU Cen: **PhD Student Robert Pennington**

This project develops and applies advanced experimental transmission electron microscopy techniques to the characterization of III-V semiconductor nanowires.

The information gathered through these experiments allows for both improved quantification of characterization techniques and for feedback information about growth conditions, chemical composition, and electrostatic fields to be provided to the nanowire growers.

Work at DTU Cen uses transmission electron microscopy on both the analytical Titan and the environmental Titan of doped and undoped GaAs and InAs nanowires, as well as Si and GaAs FIB-prepared p-n junctions for additional information and calibration.

Among other techniques, high-resolution annular dark-field imaging, electron holography, and in-situ high-resolution transmission electron microscopy are used to measure nanoscale crystallographic and chemical information in the material.

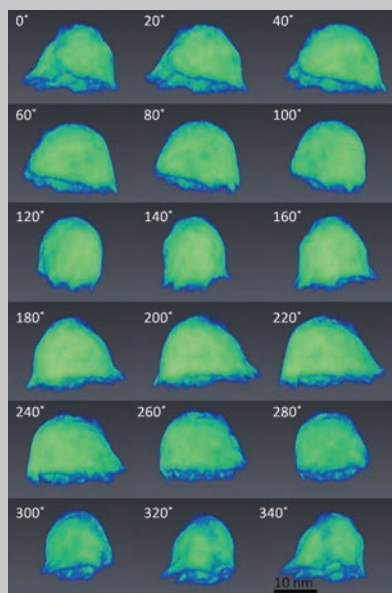


Figure: Tomographic reconstruction of a buried InAs - InGaAsP quantum dot. The montage shows snapshots of the dot being rotated around its vertical axis.

NATEC - NANophotonics for TErabit Communications

Funding: **Villum Kann Rasmussen Fonden**

Principal investigator: **Prof. Jesper Mørk (DTU Fotonik)**

Staff at DTU Cen: **Dr. Shima Kadkhodazadeh**

This project aims to understand the fundamental physics and the technological aspects of materials and devices suitable for communication systems capable of operating in the terabit per second data rate regime.

It is a collaboration between five departments at DTU, each focussing on different aspects of the project.

DTU Cen is involved in structural characterisation of III-V semiconductor quantum dots in order to understand the relationship between the structural and optical properties of the quantum dots.

The characterisation work includes morphological investigations using high resolution scanning transmission electron microscopy and electron tomography as well as chemical composition investigations using electron energy-loss spectroscopy and energy-dispersive X-ray spectroscopy.

Atom probe tomography will be used as an alternative technique to understand the 3-dimensional chemical composition of the quantum dots.

Projects

How do magnetic interactions in nanoscale intergrowths affect palaeomagnetic interpretations?

Funding: **NERC/ EPSRC grant (NE/D002036/1)**

Principal investigator: **Dr Wyn Williams (University of Edinburgh)**

Staff at DTU Cen: **Dr. Takeshi Kasama**

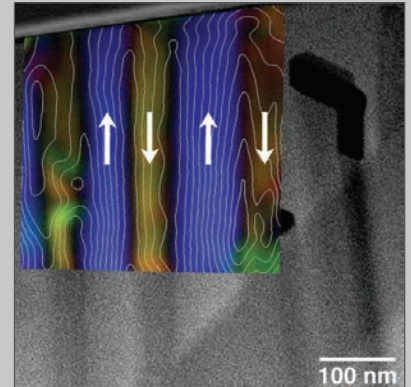
The aim of this project is to understand the effect of exchange and magnetostatic interactions in nanoscale-intergrown magnetic phases on recording and maintaining magnetic fields.

Our contribution is to yield experimental results and parameters that can be used to make theoretical modeling in each system, where different magnetic interactions are considered.

We use transmission electron microscopy to examine their magnetic structures, crystal structures and chemical compositions.

Particularly for magnetic characterization, off-axis electron holography and Lorentz electron microscopy are used to image magnetic structures at the nanometer scale.

The figure indicates magnetic interactions in a magnetite/ilmenite specimen, measured using electron holography, showing that the stray fields from magnetite domains stabilize the magnetizations in ilmenite domains.



Magnetic contour map of a magnetite/ilmenite intergrowth superimposed on a high-angle annular dark field (HAADF) image. In the HAADF image, magnetite has brighter contrast. The arrows show local magnetization directions.

Microstructure Evolution During Friction Stir Spot Welding of TRIP steel

Funding: **Danish Research Council for Technology and Production Sciences**

Principal investigator: **PhD Student Trine C. Lomholt**

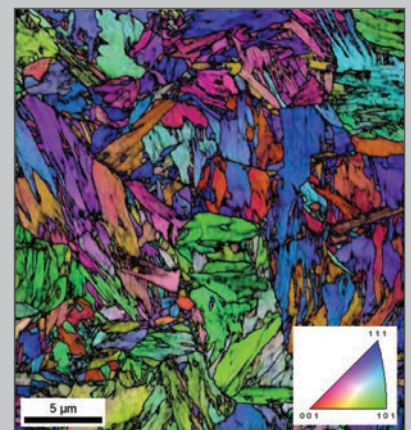
Staff at DTU Cen: **Dr. Alice Bastos da Silva Fanta**

The aim of this project is to characterize the microstructure evolution during friction stir spot welding of TRIP steel. The material characterization involves investigation of the microstructure in the various zones of the welds, to determine the effect of temperature and deformation during welding.

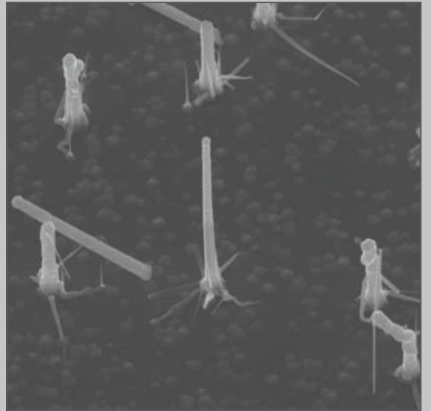
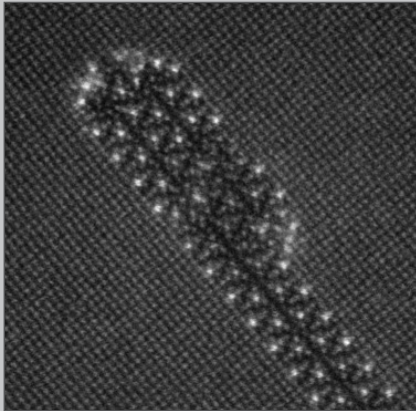
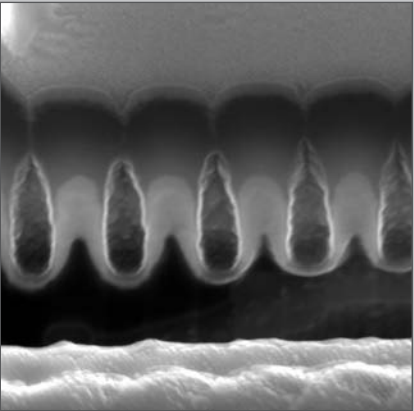
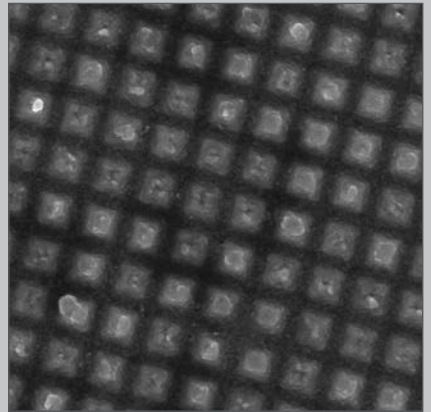
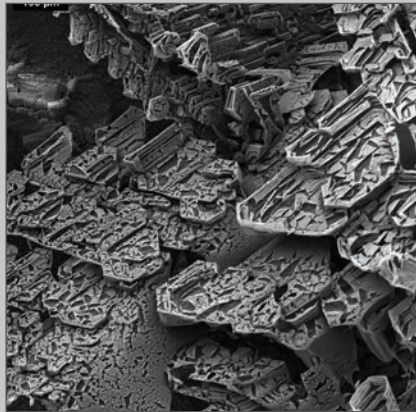
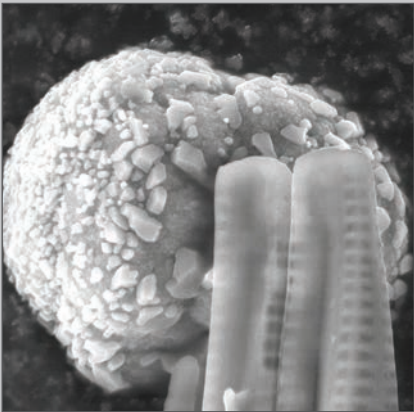
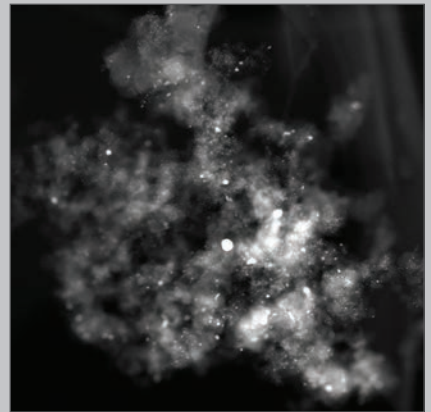
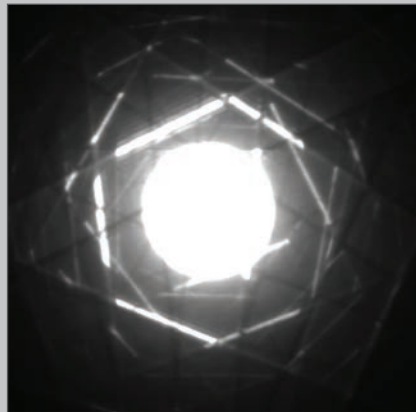
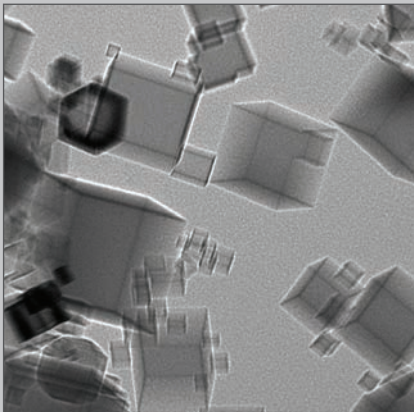
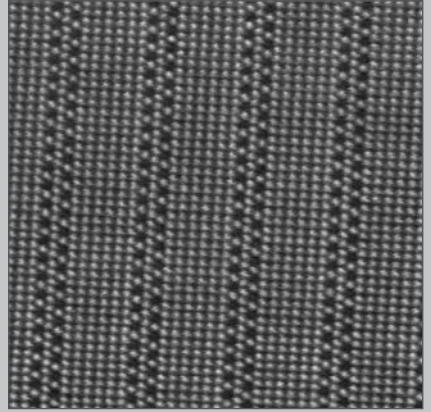
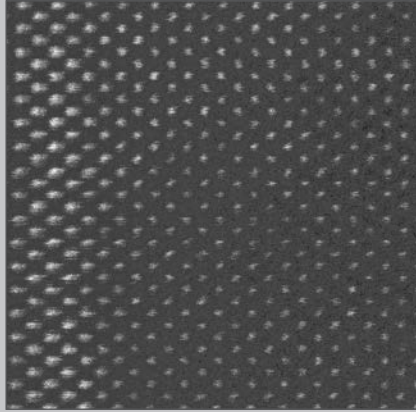
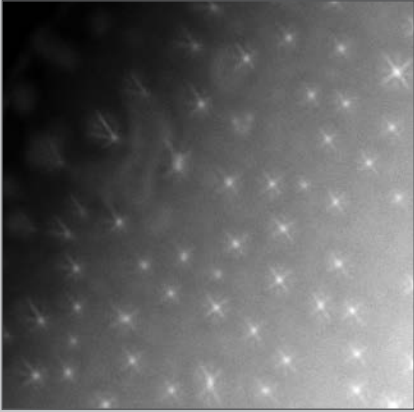
The overall aim is to get a fundamental understanding of the phase transformations occurring during the very complex welding process that friction stir welding is.

Reflected light microscopy, scanning electron microscopy, electron backscattered diffraction (EBSD), and X-ray diffraction will be the main methods applied for the microstructure characterization. Tensile tests and hardness measurements will be used to evaluate the mechanical properties of the welds.

The work at DTU Cen involves EBSD measurements and for this, the Helios EBS3 Dual-beam FIB-SEM will be used.



EBSD map showing [001] Inverse Pole Figure coloring of welded region of TRIP steel acquired using DTU Cen's Helios EBS3 Dual-beam FIB-SEM with EBSD detector.



Events at DTU Cen

FIMIN Workshop
31 May 2010 – 04 June 2010

Oxford Instruments EDS/WDS Workshop
02 November 2010 – 03 November 2010

NorTEMnet Workshop on Advanced TEM
15 November 2010 – 19 November 2010



Oxford Instruments EDS/WDS Workshop

NorTEMnet Workshop on Advanced TEM



Publications and presentations

Conference papers/abstracts not published in proceedings

Progress towards quantitative off-axis electron holography of charges, mean inner potentials and magnetic moments

M Beleggia, T Kasama, C B Boothroyd, G. Pozzi and R E Dunin-Borkowski. Paper presented at the International Conference on Advances in Electron Microscopy and Related Techniques and the 31st Annual Meeting of the Electron Microscopy Society of India, Bhabha Atomic Research Centre, Mumbai, India, 8-10 March, 2010. Invited paper.

Real-time Observations of Metal Nanoparticle Etching in Ultra-clean Suspended Graphene

Booth, Tim; Andersen, Henrik; Jinschek, Jörg R.; Hansen, Thomas Willum; Wagner, Jakob; Bøggild, Peter; Dunin-Borkowski, R E; Presented at: MRS Spring Meeting. San Francisco, 2010.

Illuminating Electron Microscopy of Photocatalysts

Cavalca, Filippo. Presented at: Scandem. Stockholm, 2010 SCANDEM 2010 Proceedings.

Implementation of a light source in a TEM sample holder for studies of photocatalytic materials

F Cavalca, T W Hansen, J B Wagner and R E Dunin-Borkowski Paper presented at Scandem 2010, Stockholm, Sweden, 8-10 June 2010.

Illuminating Electron Microscopy of Photocatalysts

Cavalca, Filippo. Presented at: European Graduate School for Sustainable Energy, Munich, 2010.

Implementation of a light source in a TEM sample holder for photocatalytic materials characterization applications

Cavalca, Filippo; Hansen, Thomas Willum; Wagner, Jakob; Dunin-Borkowski, R E; Presented at: EGS Meeting . Stockholm, Sweden, 2010.

Characterization of an innovative method for RuO₂ deposition using Electron Microscopy

Cavalca, Filippo; Presented at: European Graduate School for Sustainable Energy . Nyborg, 2010.

Illuminating Electron Microscopy of Photocatalysts

Cavalca, Filippo; Laursen, Anders Bo; Hansen, Thomas Willum; Wagner, Jakob Birkedal; Kardynal, Beata; Dahl, Søren; Dunin-Borkowski, R E; Presented at: SCANDEM. Stockholm, Sweden, 2010.

Using environmental transmission electron microscope to study the in-situ reduction of Co₃O₄ supported on α -Al₂O₃

Dehghan-Niri, R; Hansen, Thomas Willum; Wagner, Jakob Birkedal; Holmen, A; Rytter, E; Borg, Ø; Walmsley, J. C; Presented at: International Microscopy Congress. Rio De Janeiro, Brazil, 2010 IMC17

Mapping boron in silicon solar cells using electron energy-loss spectroscopy

M Duchamp, A Kovács, S Kadkhodazadeh, C B Boothroyd, R V Matheiu, B B van Aken, S B Newcomb and R E Dunin-Borkowski. Paper presented at a Workshop on EELS/EFTEM, Zürich, Switzerland, 27-29 October 2010.

Characterization of Catalysts for Synthesis of Higher Alcohols using Electron Microscopy

Duchstein, Linus Daniel Leonhard; Wagner, Jakob Birkedal; Hansen, Thomas Willum; Dunin-Borkowski, R E; Presented at: SCANDEM . Stockholm, Sweden, 2010.

Characterization of Catalysts for Synthesis of Higher Alcohols using Electron Microscopy

Duchstein, Linus Daniel Leonhard; Wagner, Jakob Birkedal; Hansen, Thomas Willum; Dunin-Borkowski, R E; Presented at: EGS Meeting, 2010.

Prospects for electron holography of nanoparticle catalysts

Dunin-Borkowski, R E.; Gontard, Lionel Cervera; Kasama, Takeshi; Beleggia, Marco; Boothroyd, Chris; Pennington, Robert S; Wagner, Jakob Birkedal; Hansen, Thomas Willum; Jinschek, Jörg R.; Presented at: International Symposium on Advanced Electron Microscopy for Catalysis and Energy Storage Materials . Berlin, Germany, 2010.

Quantitative and new approaches for measuring magnetic fields in nanocrystals and devices

R E Dunin-Borkowski, M Beleggia and T Kasama Paper presented at the 1st Workshop on Advanced Transmission Electron Microscopy, Zaragoza, Spain, 12 May 2010.

Prospects for electron holography of atomic moments and potentials

R E Dunin-Borkowski, M Beleggia, C B Boothroyd and T Kasama Paper presented at the Tonomura FIRST Meeting, Tokyo, Japan, 8-10 November 2010.

Non-adiabatic spin torque investigated using thermally activated magnetic domain wall dynamics

M Eltschka, M Wötzel, J Rhensius, S Krzyk, T Kasama, R E Dunin-Borkowski, L J Heyderman, H J van Driel, R A Duine, C Moutafis, U Nowak and M Kläui. Paper presented at the 55th Annual Conference on Magnetism and Magnetic Materials, Atlanta, Georgia, 14-18 November 2010.

Dynamic Observation of Catalysts in the Environmental Transmission Electron Microscope

Hansen, Thomas Willum; Wagner, Jakob Birkedal; Dunin-Borkowski, R. E; Presented at: EGS Meeting . Munich, Germany, 2010.

Electron Energy-Loss Spectroscopy in an Environmental TEM

Hansen, Thomas Willum; Wagner, Jakob; Beleggia, Marco; Boothroyd, Chris; Dunin-Borkowski, R E; Presented at: Symposium "Frontiers in EELS". Vienna, Austria, 2010 Frontiers in EELS.

Aberration Corrected Monochromated Environmental TEM Progress, Prospects and Challenges

Hansen, Thomas Willum; Wagner, Jakob Birkedal; Cavalca, Filippo; Duchstein, Linus Daniel Leonhard; Gontard, Lionel Cervera; Dunin-Borkowski, R E;

Presented at: IMC17 . Rio De Janeiro, Brazil , 2010 International Microscopy Congress.

Dynamics of supported metal nanoparticles observed in a Cs corrected environmental transmission electron microscope

T W Hansen, J B Wagner and R E Dunin-Borkowski

Paper presented at the Materials Research Society Fall Meeting 30 November - 2 December 2010.

In situ redox cycle of a nickel-YSZ fuel cell anode in an environmental transmission electron microscope

Q Jeangros, A Faes, J B Wagner, T W Hansen, U Aschauer, J Van herle, A Hessler-Wyser and R E Dunin-Borkowski

Paper presented at the International Symposium on Transport in Porous Materials, Villigen, Switzerland, 19-20 August 2010.

Electron holography of Fe-N precipitates in epitaxial GaN layers

A Kovács, T Kasama, M Beleggia, R E Dunin-Borkowski,

A Navarro-Quezada, B Faina, A Bonanni and T Dietl

Paper presented at the 39th International School and Conference on the Physics of Semiconductors "Jaszowiec", Krynica-Zdrój, Poland, 19-24 June 2010, p 131.

Electron microscopy of nano-inclusion formation in (Ga,Mn)As magnetic semiconductors

A Kovács, T Kasama, J Sadowski, J Domagala, R Mathieu, R E Dunin-Borkowski and T. Dietl

Paper presented at the E-MRS Fall Meeting, Warszawa, 13-17 September 2010.

Search for ferromagnetism origin in (Zn,Co)O

M I Jukaszewicz, E Guziejewicz, M Godlewski, B S Witkowski, K Kopalko, W Paszkowicz, J Wachnicki, R Jakiela, T A Krajewski, M Sawicki, A Kovács, R E Dunin-Borkowski and T Dietl

Paper presented at the 39th International School and Conference on the Physics of Semiconductors "Jaszowiec", Krynica-Zdrój, Poland, 19-24 June 2010, p 71.

Catalytic methane reduction in the exhaust gas of combustion engines

P Mauermann, M Wittler, S Pischinger, C Belle, U Simon, A Reinholdt, T Weirich, J Wagner, R. E. Dunin-Borkowski, D Röhrens, G Wesch, M Martin, J Dornseiffer and F Amkreutz

Paper presented at the International Symposium on Advanced Electron Microscopy for Catalysis and Energy Storage Materials, Berlin, Germany, 17-20 January 2010.

Variable Inner Detector Angle STEM - Visualising diffraction contrast in semiconductor nanowires

Persson, Johan Mikael; Pennington, Robert S.; Wagner, Jakob Birkedal; Boothroyd, Chris; Dunin-Borkowski, R E;

Presented at: SCANDEM. Stockholm, Sweden, 2010.

Advanced quantitative transmission electron microscopy of semi-conductor nanowires for solar cell applications

R S Pennington, J M Persson, J B Wagner, C B Boothroyd and R E Dunin-Borkowski

Paper presented at the European Graduate School in Sustainable Energy Technology Winter Meeting, Nyborg, 9-11 Dec 2010.

Biominerall attractions: magnets in organisms

M Pósfai, T Kasama, E T Simpson, D Faivre, D Schüler and R E Dunin-Borkowski

Paper presented at the 2010 International Mineralogical Association Conference, Budapest, Hungary, 21-27 August 10.

In-situ Measurements of the Effect of Au Doping in Ni Catalysts on the Yield of Tubular Carbon Nanostructures

Sharma, Renu; Chee, S.; Rez, P.; Wagner, Jakob Birkedal; Treacy, M. M;

Presented at: MRS Spring Meeting. San Francisco , 2010.

In situ TEM studies of supported palladium catalysts for the oxidation of methane

Wagner, Jakob Birkedal; Grunwaldt, Jan-Dierk; Hansen, Thomas Willum; Dunin-Borkowski, R E;

Presented at: MRS Fall Meeting, 2010.

Probing Catalysts Under Working Conditions using Environmental Transmission Electron Microscopy

Wagner, Jakob Birkedal; Grunwaldt, Jan-Dierk; Hansen, Thomas Willum; Beleggia, Marco; Boothroyd, Chris; Dunin-Borkowski, R E;

Presented at: Titan User Club meeting, 2010.

High Performance Single Nanowire Tunnel Diodes

Wallentin, Jesper; Persson, Johan Mikael; Wagner, Jakob Birkedal; Deppert, Knut; Samuelson, Lars; Borgström, Magnus T.;

Presented at: MRS Spring Meeting . San Francisco, 2010.

Characterization of nanostructured materiel by EBSD: possibilities, compromises and limits

Fanta, A.B.

Presented at: 17th International Microscopy Conference (IMC17). Rio de Janeiro, Brazil, 19-24 September 2010.

Conference papers/abstracts published in proceedings

The quantitative measurement of magnetic moments from phase images of nanoparticles and nanostructures

M Beleggia, T Kasama and R E Dunin-Borkowski Proceedings of the 17th International Microscopy Congress, Rio de Janeiro, Brazil, 19-24 September 2010

Measurement of the charge distribution along an electrically biased carbon nanotube using electron holography

M Beleggia, T Kasama, R E Dunin-Borkowski and G Pozzi Microscopy and Microanalysis 16 Suppl. 2 (2010), 562-563. Paper presented at Microscopy and Microanalysis, Portland, Oregon, 1-5 August 2010.

Quantitative magnetization states of colloidal systems via simplified-LLG and model-based fitting of phase images

M Beleggia, A Alpers, T Kasama, H F Poulsen and R E Dunin-Borkowski Paper presented at the 2nd International Workshop on Advanced Microscopy and Theoretical Calculations (AMTC2), Nagoya, 24-26 June 2010.

Oxidation of Filled Carbon Nanotubes Inside a Transmission Electron Microscope

Costa, P. M. F. J.; Hansen, Thomas Willum; Wagner, Jakob Birkedal; Dunin-Borkowski, R. E. Presented at: International Microscopy Congress . Rio De Janeiro, Brazil , 2010 IMC17. Proceedings of the 17th International Microscopy Congress, Rio de Janeiro, Brazil, 19-24 September 2010.

Towards quantitative aberration-corrected monochromated environmental high-resolution transmission electron microscopy of dynamic processes

R E Dunin-Borkowski, T W Hansen and J B Wagner Proceedings of the 17th International Microscopy Congress, Rio de Janeiro, Brazil, 19-24 September 2010. Invited paper.

Coherent Foucault imaging in light of recent electron phase plate developments

M. Beleggia. Paper presented at the International Microscopy Congress (IMC-17), Rio de Janeiro, Brazil, September 19-24, 2010.

Origin of bright-field TEM contrast enhancement by a hole-free phase plate

M. Malac, M. Beleggia, M. Kawasaki, R.F. Egerton, P. Li. Paper presented at the International Microscopy Congress (IMC-17), Rio de Janeiro, Brazil, September 19-24, 2010.

Dynamical effects in the study of supported nanocrystals using electron holography

R E Dunin-Borkowski, C B Boothroyd and M Beleggia Paper presented at Microscopy and Microanalysis, Portland, Oregon, 1-5 August 2010. Microscopy and Microanalysis 16 Suppl. 2 (2010), 572-573. Invited paper.

Dynamical Response of Catalytic Systems in a Cs Corrected Environmental Transmission Electron Microscope.

Hansen, Thomas Willum; Dunin-Borkowski, R. E.; Boothroyd, Chris; Beleggia, Marco; Wagner, Jakob Birkedal. Presented at: Microscopy and Microanalysis . Portland OR, USA, 2010 Microscopy and Microanalysis ; 16, suppl. 2 , 292.

Aberration corrected monochromated environmental transmission electron microscopy – progress, prospects and challenges

T W Hansen, J B Wagner and R E Dunin-Borkowski Paper presented at the 2nd International Workshop on Advanced Microscopy and Theoretical Calculations (AMTC2), Nagoya, 24-26 June 2010. Invited paper.

Quantitative transmission electron microscopy of magnetic minerals

T Kasama, R E Dunin-Borkowski and others Proceedings of the 17th International Microscopy Congress, Rio de Janeiro, Brazil, 19-24 September 2010. Invited paper.

Quantitative electron diffraction and electron holography of magnetite at low temperature

T Kasama, R J Harrison, N S Church, M Nagao, J M Feinberg and R E Dunin-Borkowski Acta Mineralogica-Petrographica Abstract Series 6 (2010), 650 Paper presented at the 2010 International Mineralogical Association Conference, Budapest, Hungary, 21-27 Aug 10.

Microfabricated systems for electron microscopy of nanoscale processes: In-situ TEM creation of Si nanowire devices and in-situ SEM electrochemistry

K Mølhave, C Kallesøe, C Y Wen, F M Ross, T J Booth, T Kjølner Nelleman, E Jensen, C F Elkjær, J L Rasmussen, P S Jensen, P Bøggild and R E Dunin-Borkowski Paper presented at Microscopy and Microanalysis, Portland, Oregon, 1-5 August 2010. Microscopy and Microanalysis 16 Suppl. 2 (2010), 322-323. Invited paper.

The role of iron-bearing minerals on the Earth's surface and crust

Pennington, Robert S.; Mortensen, Jens Jørgen; Kasama, Takeshi; Boothroyd, Chris; Dunin-Borkowski, R. E.; (2010) Theoretical and experimental factors affecting measurements of semiconductor mean inner potentials . Presented at: International Conference on Microscopy of Semiconducting Materials. University of Oxford, United Kingdom , 2009 Journal of Physics: Conference Series (Online) , 209(1), 012030.

Convenient contrast enhancement by hole-free phase plate in a TEM

M. Malac, M. Kawasaki, M. Beleggia, P. Li, R.F. Egerton. Microsc. Microanal. 16, Suppl. 2, 526-527 (2010).

Dislocation electron tomography of boundaries in deformed aluminium

Ramar, Amuthan; Hata, Satoshi; Huang, Xiaoxu; Dunin-Borkowski, R. E.; Winther, Grethe; Presented at: Risø International Symposium on Materials Science. Risø (DK), 6-10 Sep. , 2010 Challenges in materials science and possibilities in 3D and 4D characterization techniques: Proceedings , 397-404 / Editor: Hansen, Niels; Juul Jensen, Dorte; Nielsen, Søren Fæster; Poulsen, Henning Friis; Ralph, B.

Exchange interactions in exchange biased polycrystalline/amorphous bilayers

J. Dean, A. Kovacs, A. Kohn, A. Goncharov, M.A. Bashir, G. Hrkac, D.A. Allwood, T. Schrefl, "Applied Physics Letters 96 (2010) 072504

Enhanced exchange anisotropy in IrMn/CoFeB systems and its correlation with uncompensated interfacial spins

Y. Du, G. Pan, R. Moate, H. Ohldag, A. Kovacs and A. Kohn.
Applied Physics Letters 96 (2010) 222503

Interpretation of electron beam induced charging of oxide layers in a transistor studied using electron holography

Ubaldi, F; Pozzi, G; Kasama, Takeshi; McCartney, M R;
Newcomb, S B; Dunin-Borkowski, R. E; (2010).
Presented at: International Conference on Microscopy of Semiconducting Materials . University of Oxford, United Kingdom , 2009
Journal of Physics: Conference Series (Online), 209(1), 012064.

Publications in journals

Selective side-chain oxidation of alkyl aromatic compounds catalyzed by cerium modified silver catalysts

Beier, Matthias Josef; Schimmoeller, Bjoern;
Hansen, Thomas Willum; Andersen, Jens Enevold Thaulov;
Pratsinis, Sotiris E; Grunwaldt, Jan-Dierk; (2010).
Journal of Molecular Catalysis A: Chemical, 331, 40-49.

Image simulations of Kinked vortices for transmission electron microscopy

M. Beleggia, G. Pozzi, A. Tonomura.
Ultramicroscopy 110, 1428-1433 (2010).

Phase shift of charged metallic nanoparticles

Beleggia, Marco; Pozzi, Giulio. (2010).
Ultramicroscopy , 110(5), 418-424.

Occurrence and restoration of vortex state in nanorings for phase plate development

M. K. Hari, M. Beleggia, R.M.D. Brydson.
J. Phys: Conf. Ser. 241, 012069 (2010).

The quantitative measurement of magnetic moments from phase images of nanoparticles and nanostructures – I. Fundamentals

Beleggia, Marco; Kasama, Takeshi; Dunin-Borkowski, R. E; (2010).
Ultramicroscopy , 110(5), 425-432.

Thermal modification of hematite-ilmenite intergrowths in the Ecstall pluton, British Columbia, Canada

Brownlee, S.J; Feinberg, J.M; Harrison, R.J; Kasama, Takeshi;
Scott, G.R; Renne, P.R; (2010). American Mineralogist , 95(1),
153-160.

Resolving the Structure of Active Sites on Platinum Catalytic Nanoparticles

Chang, Lan Yun; Barnard, Amanda S.; Gontard, Lionel Cervera;
Dunin-Borkowski, R. E; (2010). Nano Letters , 10(8), 3073-3076.

Sol-gel nanocoating on commercial TiO₂ nanopowder using ultrasound

Chen, Quan; Boothroyd, Chris; Soutar, Andrew McIntosh; Zeng,
Xian Ting. (2010). Journal of Sol-Gel Science and Technology,
53(1), 115-120.

Dopant profiling of focused ion beam milled semiconductors using off-axis electron holography; reducing artifacts, extending detection limits and reducing the effects of gallium implantation

Cooper, David; Ailliot, Cyril; Barnes, Jean-Paul; Hartmann,
Jean-Michel; Salles, Phillipe; Benassayag, Gerard;
Dunin-Borkowski, R. E; (2010).
Ultramicroscopy, 110(5), 383-389.

Imaging the oxidation of ZnS encapsulated in carbon nanotubes

Costa, Pedro M. F. J.; Hansen, Thomas Willum;
Wagner, Jakob Birkedal; Dunin-Borkowski, R. E; (2010).
Chemistry: A European Journal, 16(39), 11809-11812.

Nonadiabatic Spin Torque Investigated Using Thermally Activated Magnetic Domain Wall Dynamics

Eltschka, M.; Woetzel, Mathias; Rhensius, J.; Krzyk, S.; Nowak, U.;
Kläui, M.; Kasama, Takeshi; Dunin-Borkowski, R. E; (2010).
Physical Review Letters, 105(5), 056601.

Near-Curie magnetic anomaly at the Ni-C interface observed with Electron Holography

Ferrari, Loris; Matteucci, Giorgio; Schofield, Marvin A; Beleggia,
Marco; Zhu, Yimei. (2010).
Journal of Magnetism and Magnetic Materials, 322(7), 858-865.

Aberration corrected and monochromated environmental transmission electron microscopy – challenges and prospects

T W Hansen, J B Wagner and R E Dunin-Borkowski
Materials Science and Technology 26 (2010), 1338-1344.

Ferromagnetic domain structures and spin configurations measured in doped manganese

He, J.Q; Volkov, V.V; Beleggia, Marco; Asaka, T; Tao, J;
Schofield, M.A.; Zhu, Y.. (2010).
Physical Review B (Condensed Matter and Materials Physics),
81(9), 094427.

The effect of atmospheric corona treatment on AA1050 aluminium

Jariyaboon, Manthana; Møller, Per; Dunin-Borkowski, R. E;
In, Su-il; Chorkendorff, Ib; Ambat, Rajan. (2010).
Corrosion Science , 52(6), 2155-2163.

In situ redox cycle of a nickel-YSZ fuel cell anode in an environmental transmission electron microscope

Jeangros, Quentin; Faes, Antonin; Wagner, Jakob Birkedal;
Hansen, Thomas Willum; Aschauer, Uli; Van herle, Jan;
Hessler-Wyser, Aïcha; Dunin-Borkowski, R. E; (2010).
Acta Materialia , 58(14), 4578-4589.

Direct observation of ferrimagnetic/ferroelastic domain interactions in magnetite below the Verwey transition

Kasama, Takeshi; Church, Nathan S.; Feinberg, Joshua M;
Dunin-Borkowski, R. E; Harrison, Richard J.. (2010).
Earth and Planetary Science Letters , 297(1-2), 10-17.

Publications and presentations

Localized magnetic fields in arbitrary directions using patterned nanomagnets

McNeil, Robert P G; Schneble, Jeff; Kataoka, Masaya; Ford, Christopher J. B.; Kasama, Takeshi; Dunin-Borkowski, R. E.; Feinberg, Joshua M.; Harrison, Richard J.; Barnes, Crispin H. W.; Tse, Desmond H. Y.; Trypiniotis, Theodossis; Bland, J. Anthony C.; Anderson, David; Jones, Geb A. C.; Pepper, Michael. (2010) *Nano Letters* , 10(5), 1549-1553.

Sheet-like carbon particles with graphene structures obtained from a Bunsen flame

Ossler, Frederik; Wagner, Jakob Birkedal; Canton, Sophie E.; Wallenberg, L. Reine. (2010). *Carbon* , 48(14), 4203-4206.

The influence of magnetostatic interactions in exchange-coupled composite particles

Vokoun, D.; Beleggia, Marco; De Graef, M.; Hou, H.C.; Lai, C.H.; (2010). *Journal of Physics D: Applied Physics* , 43(27).

Growth and segregation of GaAs-Al_xIn_{1-x}P core-shell nanowires

Wagner, Jakob Birkedal; Sköld, Niklas; Wallenberg, L. Reine; Samuelson, Lars; (2010). *Journal of Crystal Growth* , 312(10), 1755-1760.

High-Performance Single Nanowire Tunnel Diodes

Wallentin, Jesper; Persson, Johan Mikael; Wagner, Jakob Birkedal; Samuelson, Lars; Deppert, Knut; Borgström, Magnus. (2010). *Nano Letters* , 10(3), 974.

Dynamical Effects in the Study of Supported Nanocrystals using Electron Holography

R. E. Dunin-Borkowski, C. Boothroyd, and M. Beleggia, *Microscopy and Microanalysis*, vol. 16, 2010, pp. 572-573.

Invited talks

M. Beleggia, "Imaging shape effects in nanomagnetism with electrons", Risø DTU, Denmark, May 25, 2010

M. Beleggia, "Electron holography of magnetic nanostructures", U. Hamburg, physics colloquium Germany, Nov 2, 2010

R E Dunin-Borkowski, SFB workshop on "Understanding materials using in-situ electron microscopy", Göttingen, Germany: "Quantitative and in situ TEM of chemical reactions and magnetization reversal processes in materials". 10-12 Nov 10

R E Dunin-Borkowski, Tonomura FIRST International Workshop on "Challenges to New Developments in Electron Microscopy", Tokyo, Japan: "Prospects for off-axis electron holography at (2 π /1000) levels". 8-10 Nov 10

R E Dunin-Borkowski, SCAN (Synthesis, characterization and applications of nanomaterials) 2010 school, Ankara, Turkey: "Off-axis electron holography of magnetic nanoparticles, nanostructures and devices". 4-6 Oct 10

R E Dunin-Borkowski, SCAN (Synthesis, characterization and applications of nanomaterials) 2010 workshop, Ankara, Turkey: "In situ transmission electron microscopy of growth processes and chemical reactions". 30 Sep – 2 Oct 10.

R E Dunin-Borkowski, 17th International Microscopy Congress (IMC17), Rio de Janeiro, Brazil: "Aberration corrected monochromated environmental TEM. Progress, prospects and challenges". 19-24 Sep 10.

R E Dunin-Borkowski, Microscopy and Microanalysis 2010, Portland, U.S.A: "Prospects for electron holography of nanoparticle catalysts". 1-5 Aug 10.

R E Dunin-Borkowski, Session on "Carbon and oxide based nanostructured materials" at the 6th International Conference on Diffusion in Solids and Liquids, Paris, France: "Towards quantitative aberration-corrected monochromated environmental high-resolution transmission electron microscopy of dynamic processes". 5-7 Jul 10.

R E Dunin-Borkowski, Workshop on TEM and Microanalysis, Institute of Materials Research and Engineering, Singapore: "Quantitative and new approaches for measuring magnetic fields in nanocrystals and devices using electron holography". 1 Jul 10.

R E Dunin-Borkowski, 2nd International Symposium on Advanced Microscopy and Theoretical Calculations (AMTC2), Nagoya, Japan: "Aberration corrected monochromated environmental transmission electron microscopy – progress, prospects and challenges". 24-26 Jun 10.

R E Dunin-Borkowski, Workshop entitled "Possibilities and limitations of characterization and modeling of defects, interfaces and phase transformations", Bernkastel, Germany: "Electron holography: status, roadblocks and opportunities". 17-19 May 10.

R E Dunin-Borkowski, INA-LMA inauguration and 1st workshop on advanced transmission electron microscopy, Zaragoza, Spain: "Quantitative and new approaches for measuring magnetic fields in nanocrystals and devices". 11-12 May 10.

R E Dunin-Borkowski, EMSI-2010: International Conference on Advances in Electron Microscopy and Related Techniques and 31st Annual Meeting of the Electron Microscopy Society of India, Bhabha Atomic Research Centre, Mumbai, India. Plenary invited talk: "Progress towards quantitative off-axis electron holography of charges, mean inner potentials and magnetic moments". 8-10 Mar 10.

R E Dunin-Borkowski, Solid State Day, Center for Solid State Chemistry and New Materials, Leibnitz University Hanover, Germany. Seminar: "Quantitative and in situ transmission electron microscopy of functional materials". 29 Jan 10.

R E Dunin-Borkowski, International Symposium on Advanced Electron Microscopy for Catalysis and Energy Storage Materials, Berlin, Germany: "Prospects for electron holography of nanoparticle catalysts". 17-20 Jan 10.

T Kasama, The role of iron-bearing minerals on the Earth's surface and crust (2010). Annual Meeting of Japan Association of Mineralogical Sciences, Shimane, Japan.

András Kovács, "Materials research by advanced electron microscopy". Annual Meeting of Microscopy Society of Hungary, Siófok, 14 May 2010.

Thomas Willum Hansen, Microscopy and Microanalysis 2010, Portland, Oregon: "Dynamical Response of Catalytic Systems in a Cs Corrected Environmental Transmission Electron Microscope", August 1-5 2010.

Invited seminars

C Boothroyd, "Quantitative HRTEM & HRSTEM". Invited talk, SCAN 2010, Bilkent University, Ankara, Turkey.

R E Dunin-Borkowski, Centro Atomico Bariloche, San Carlos de Bariloche, Argentina. Seminar: "Electron holography in the TEM: a unique view of magnetism at the nanoscale". 16-18 Sep 2010

R E Dunin-Borkowski, Mini-Symposium, Center for Solid State Science, Arizona State University, U.S.A. Seminar: "Towards quantitative aberration-corrected monochromated environmental high-resolution TEM of dynamic processes". 6 Aug 2010

R E Dunin-Borkowski, Ångström Laboratory, Uppsala, Sweden. Seminar: "Towards quantitative and in situ transmission electron microscopy of nanoscale magnetic materials and supported catalysts". 25 Jan 2010

T Kasama, The application of electron microscopy to the study of geoscience materials. Nanomineralogy seminar, Kyushu Univ., Fukuoka, Japan, 30 September 2010.

T Kasama, Quantitative off-axis electron holography and Lorentz electron microscopy of nanostructured materials. HVEM seminar, Kyushu Univ., Fukuoka, Japan, 1 October 2010.

T Kasama, Nanoscale mineralogy – transmission electron microscopy study. Environmental mineralogy seminar, Hokkaido Univ., Hokkaido, Japan, 21 December 2010.

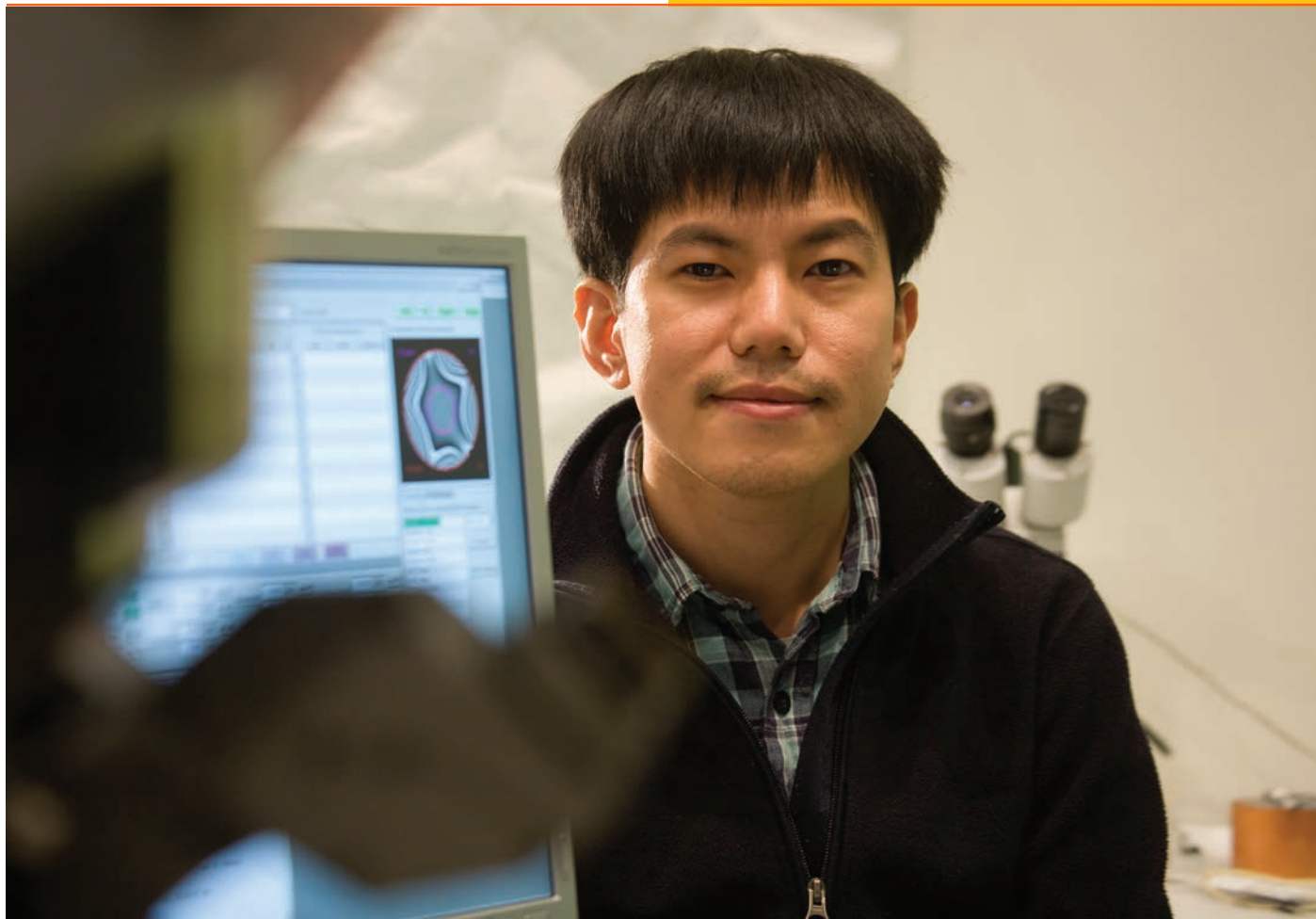
András Kovács, "Advanced electron microscopy of magnetic semiconductors" at Institute for Materials Research, Tohoku University, Sendai, Japan, 15 July 2010.

Other talks

R E Dunin-Borkowski, CASE-Helios workshop: Co-catalysts in photochemical fuel production, Technical University of Denmark: "Progress towards quantitative electron microscopy of catalysts". 17-18 May 10

R E Dunin-Borkowski, European Graduate School on Sustainable Energy Technology Spring Meeting, Freising, Germany: "Dynamic observations of catalysts in the environmental transmission electron microscope". 7-9 Apr 10

Every day I get a little closer



Takeshi Kasama

Senior Scientist Takeshi Kasama came to DTU Cen from the Department of Materials Science and Metallurgy, University of Cambridge.

Takeshi was part of a group working to understand the magnetic and electrostatic fields in nanostructured materials using transmission electron microscopy (TEM).

The research at Cambridge was often conducted in close collaboration with DTU Cen using equipment similar to the electron microscopes at DTU, so it was a natural step for Takeshi to continue his work at DTU when he in 2008 was offered the possibility of a transfer to what he refers to as “probably the best Microscope Center in the world”.

At DTU Cen Takeshi has been able to initiate an even deeper investigation into the fundamental magnetic properties of materials at the nanometer scale using off-axis electron holography, which is a highly specialised TEM technique.

He explains: “I try to understand the magnetic origins and the interactions that take place between grains of the finest size possible. Furthermore, experiments are carried out in the TEM with a biasing specimen holder that allows us to study in-situ the interactions of magnetic and electric fields.

Access to advanced equipment is only one of the advantages of working at DTU Cen. One of the best things about being here is that there are knowledgeable and friendly researchers and staff, who know what we should do and have the ability to achieve it!

Every day I feel a little closer to fulfill my dream of being able to see the magnetic moments from individual atoms.

My primary interest is to understand nanoscale magnetism in materials using TEM, which would contribute to the construction of future spintronic devices such as magnetic random access memory.”

Max Hey Medal 2010

The Mineralogical Society of Great Britain and Ireland (UK) 11 November 2010

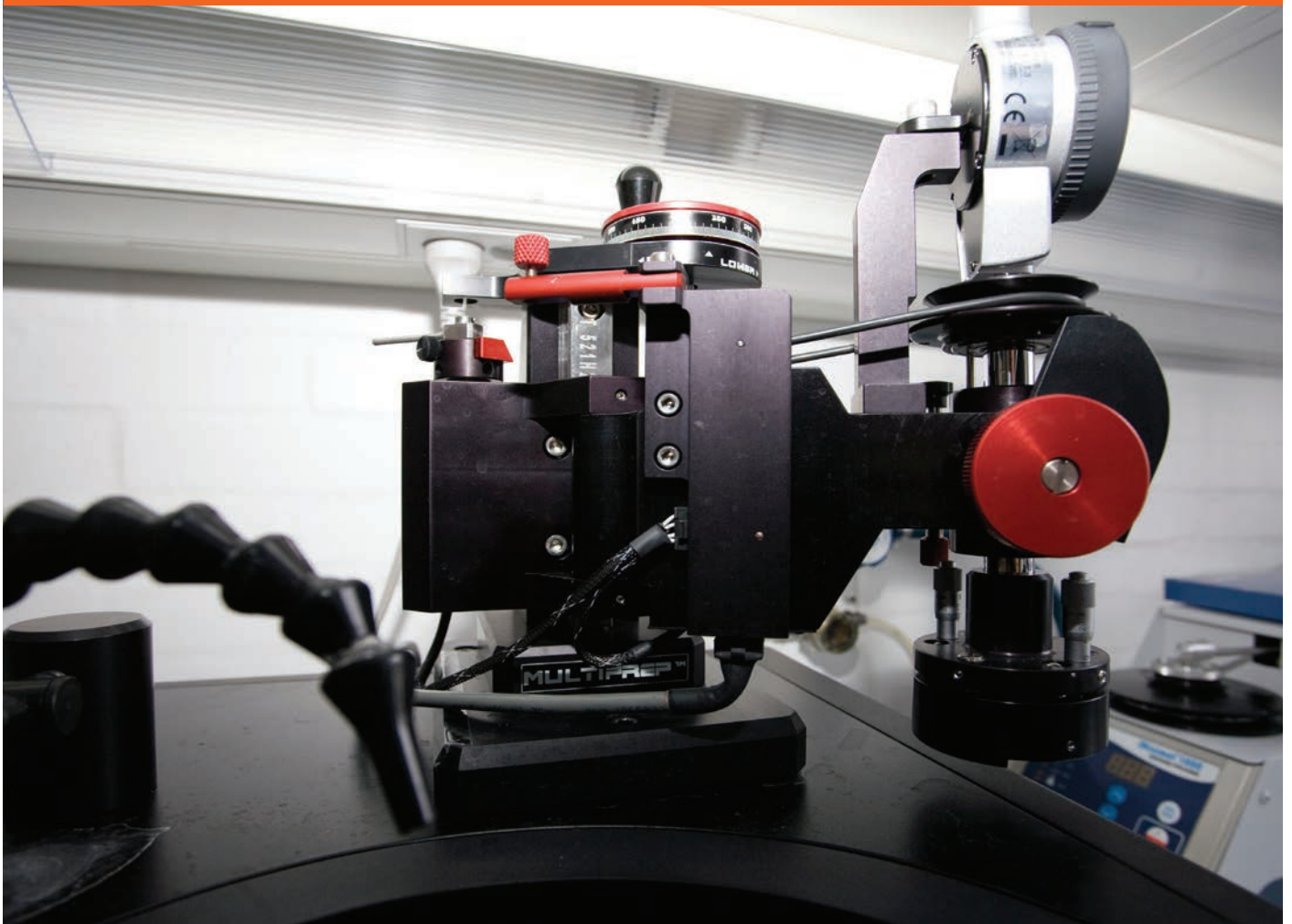
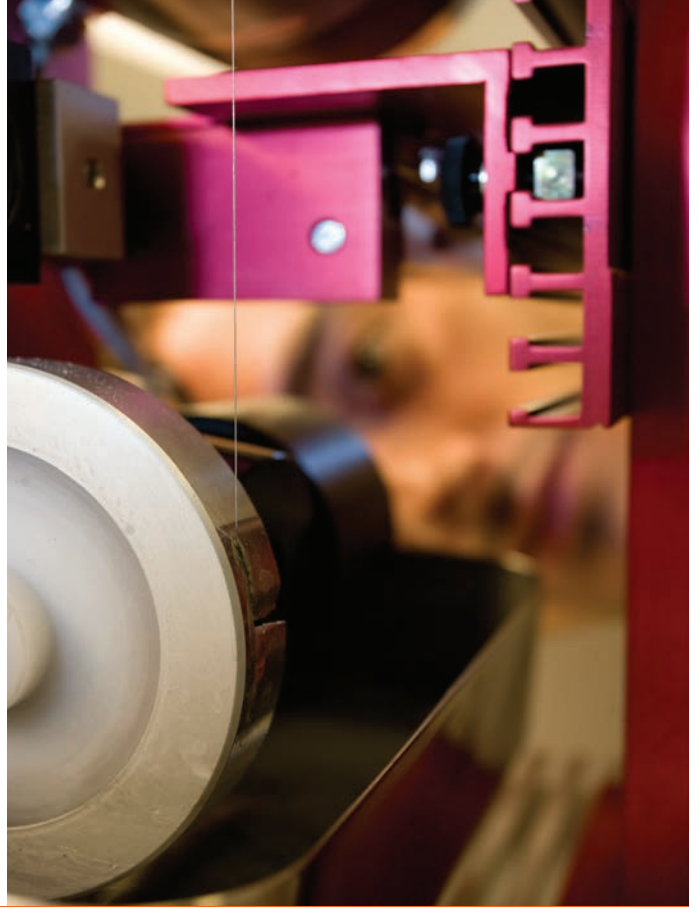
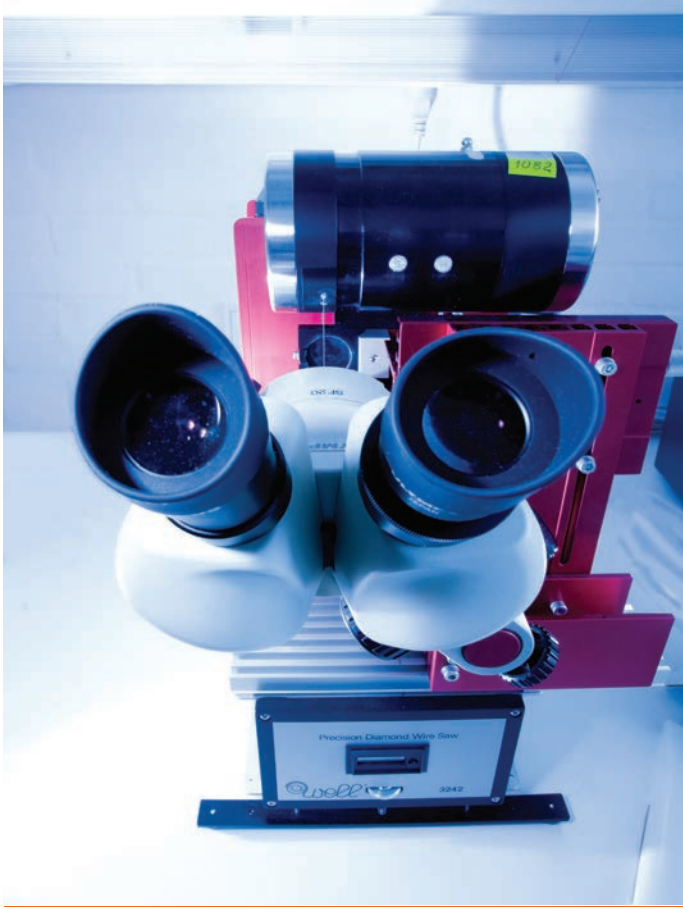
Japan Association of Mineralogical Sciences Award for Young Scientists 2010

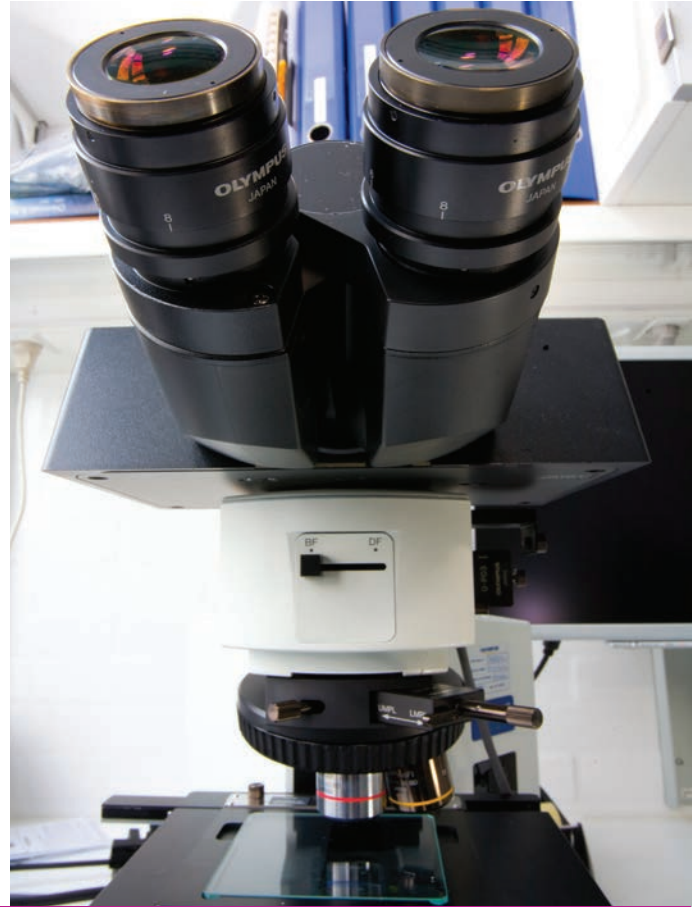
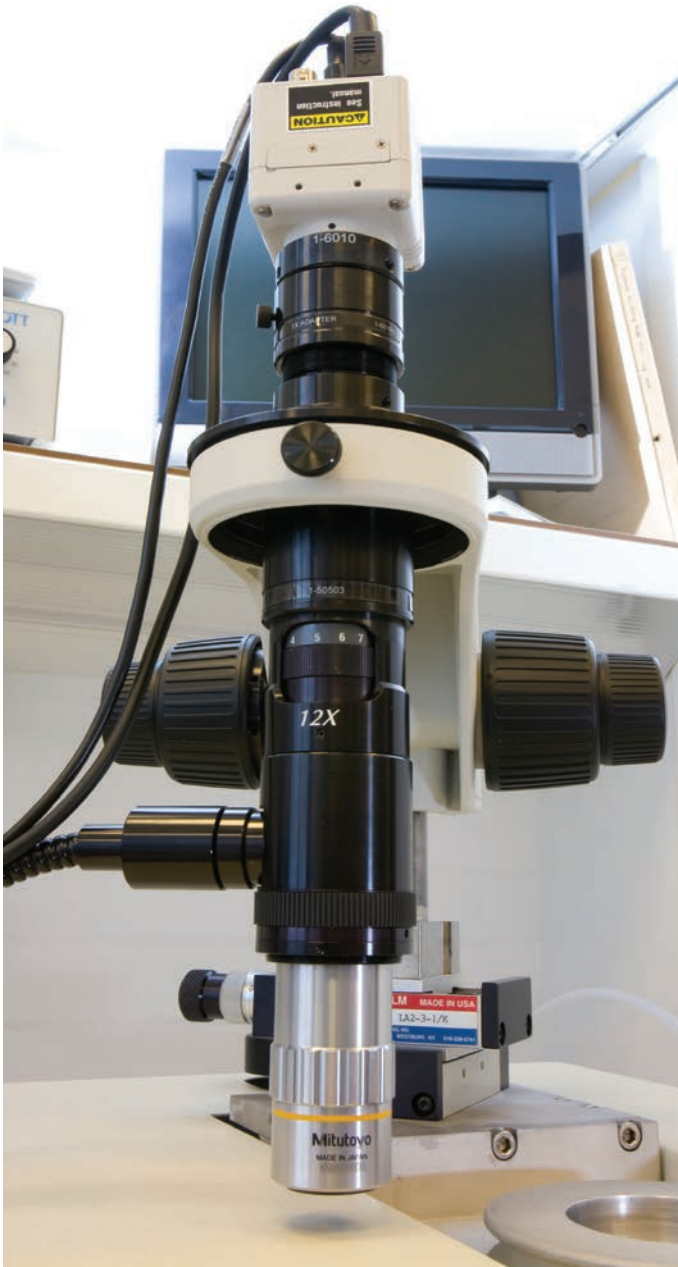
Japan Association of Mineralogical Sciences (Japan) 24 September 2010

Awards



Sample preparation room





The facility also has comprehensive specimen preparation facilities located in Buildings 307 and 314 which includes the following pieces of equipment:

- Diamond wire saw
- Diamond circular saw
- Dimpler
- An extensive suite of grinders and polishing wheels for preparing metallic samples
- Allied MultiPrep polishing system
- Olympus light microscope with CCD camera
- Fischione ion mill
- Fischione plasma cleaner
- Cressington 208HR Sputter Coater
- Cressington 208carbon Coater

In addition, there are a number of computers available for off-line image and spectral data analysis, image simulation, and image reconstruction.

Scanning electron microscopes

Notable acronyms

BSE - Back Scattered Electron(s)

SE - Secondary Electron(s)

Inspect S

The Inspect S is an instrument employed primarily for teaching and training users in basic SEM techniques. However, it can also be used as an analytical tool in its own right.

Electron source

Thermionic - tungsten filament

Accelerating voltage

200 V- 30 kV

Resolution

50 nm at 30 kV (SE)

Imaging detectors

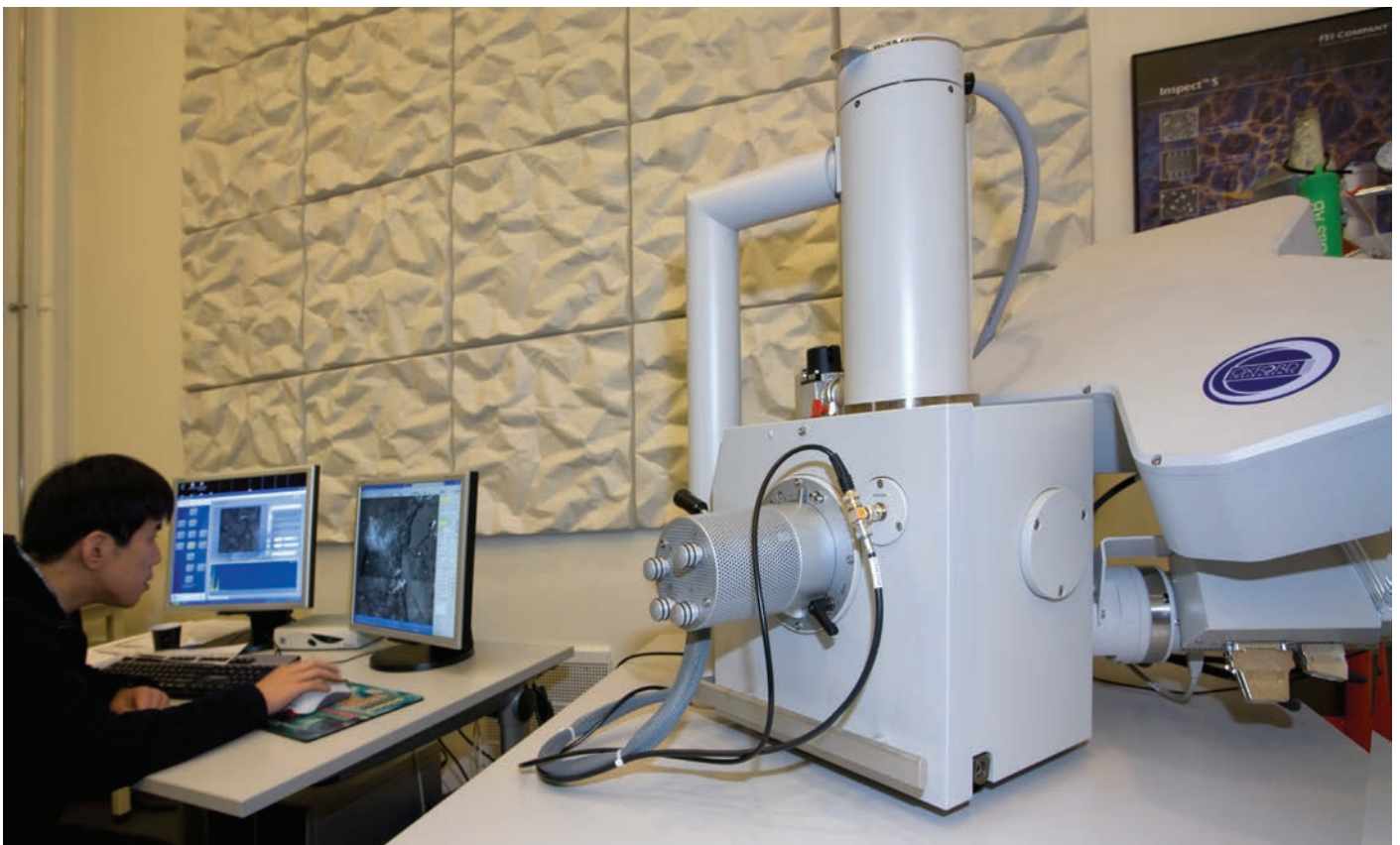
Everhart-Thornley (SE/BSE), Solid state BSE, Large Field, CCD Camera

Imaging modes

High and low vacuum

Analytical Capabilities

Energy Dispersive X-ray Spectroscopy, EDS (Oxford Instruments 50 mm² X-Max silicon drift detector (SDD), MnK_α resolution at 124 eV), Oxford Instruments Wavelength Dispersive X-ray Spectroscopy (INCAWave 500, analysis for all elements down to boron, spectral resolution 2 eV).



Scanning electron microscopes

Quanta 200 ESEM FEG

This microscope is generally used when information is required at the nm scale and can operate in several modes depending on the nature of the sample. In combination with the analytical capabilities and other specialised attachments, the microscope is a highly versatile instrument.

Electron source

Field emission gun

Accelerating voltage

500 V- 30 kV

Resolution

2 nm at 30 kV (SE)

Imaging detectors

Everhart-Thornley (SE/BSE), Solid State BSE, Large Field, Gaseous SE, Gaseous BSE, Gaseous Analytical, CCD Camera

Imaging modes

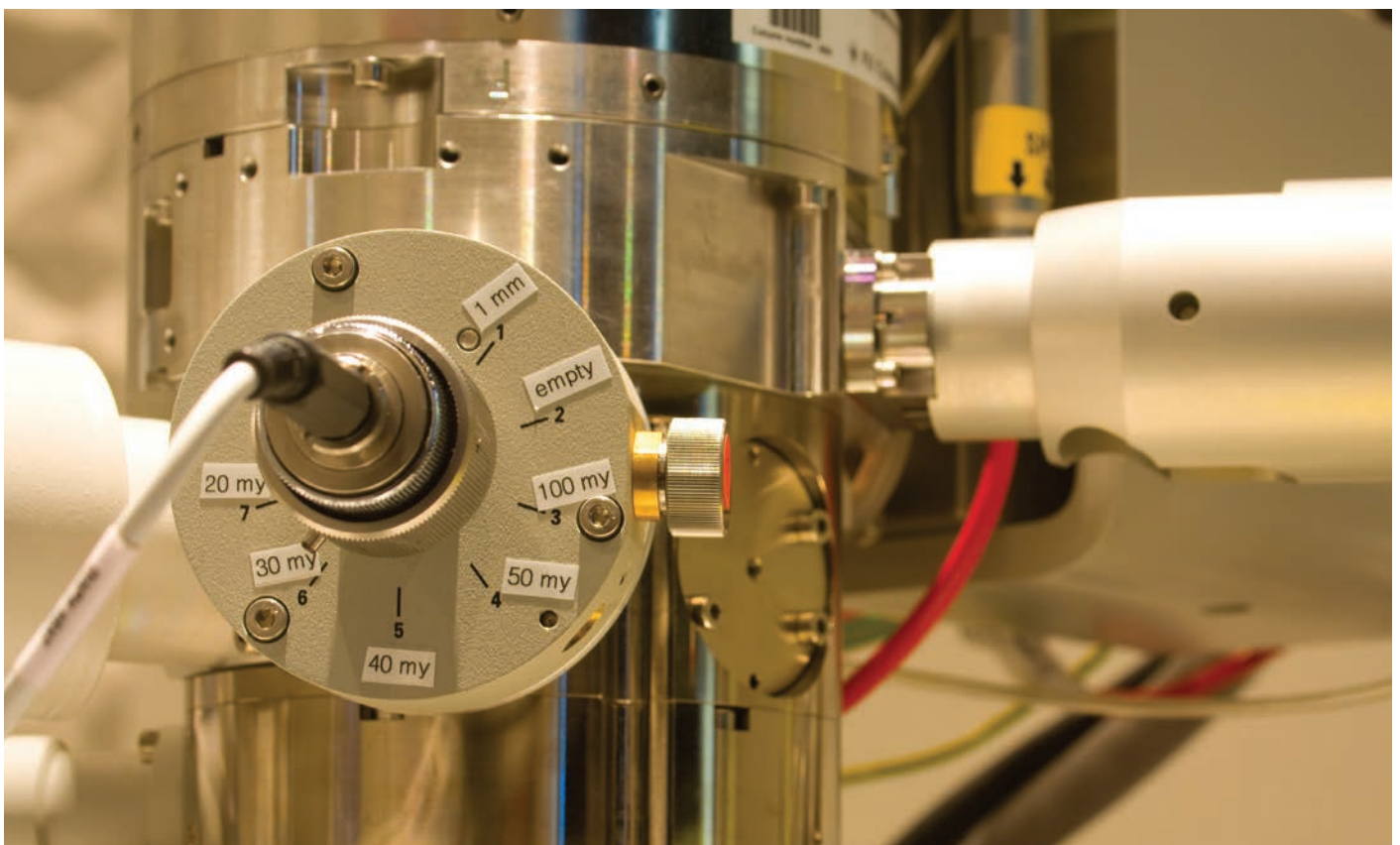
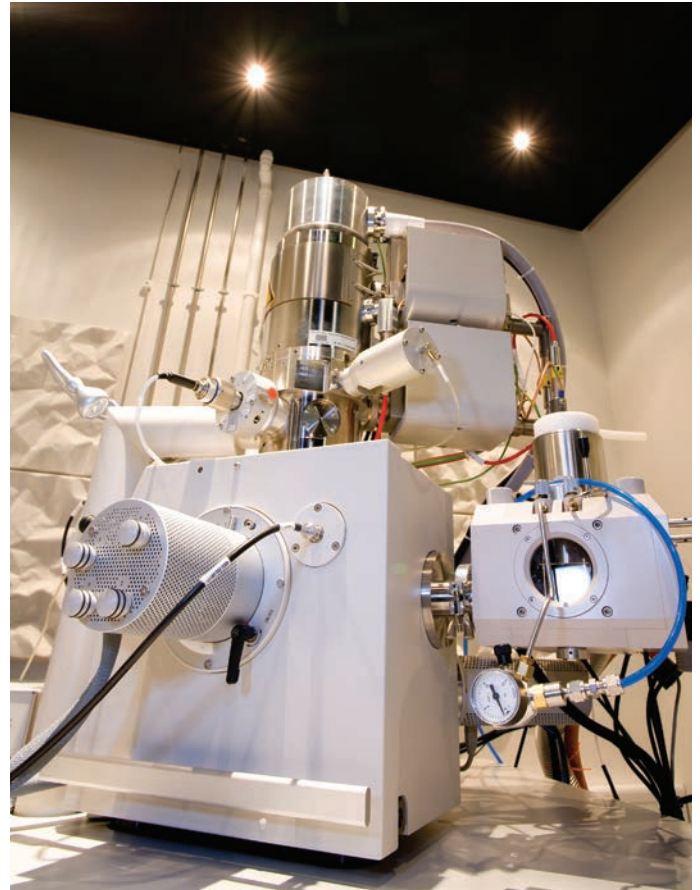
High, low vacuum and environmental

Analytical Capabilities

EDS (Oxford Instruments 80 mm²
X-Max SDD, MnK_α resolution at 124 eV)

Attachments

Quorum PP2000 Cryo System, FEI Peltier stage (-10°C to 22°C).



Scanning electron microscopes

Quanta 200 3D SEM-FIB



The Quanta 200 3D is a dual-beam scanning electron microscope (SEM) which combines normal SEM mode functionality with the capability of using a focused ion beam for removing material by ion milling. This microscope is mainly used for preparing site-specific cross sectional specimens for transmission electron microscopes (TEM) analysis.

Electron source

Thermionic - tungsten filament

Ion source

Ga⁺ ions

Accelerating voltage

500 V- 30 kV

Resolution

50 nm at 30 kV (SE)

Imaging detectors

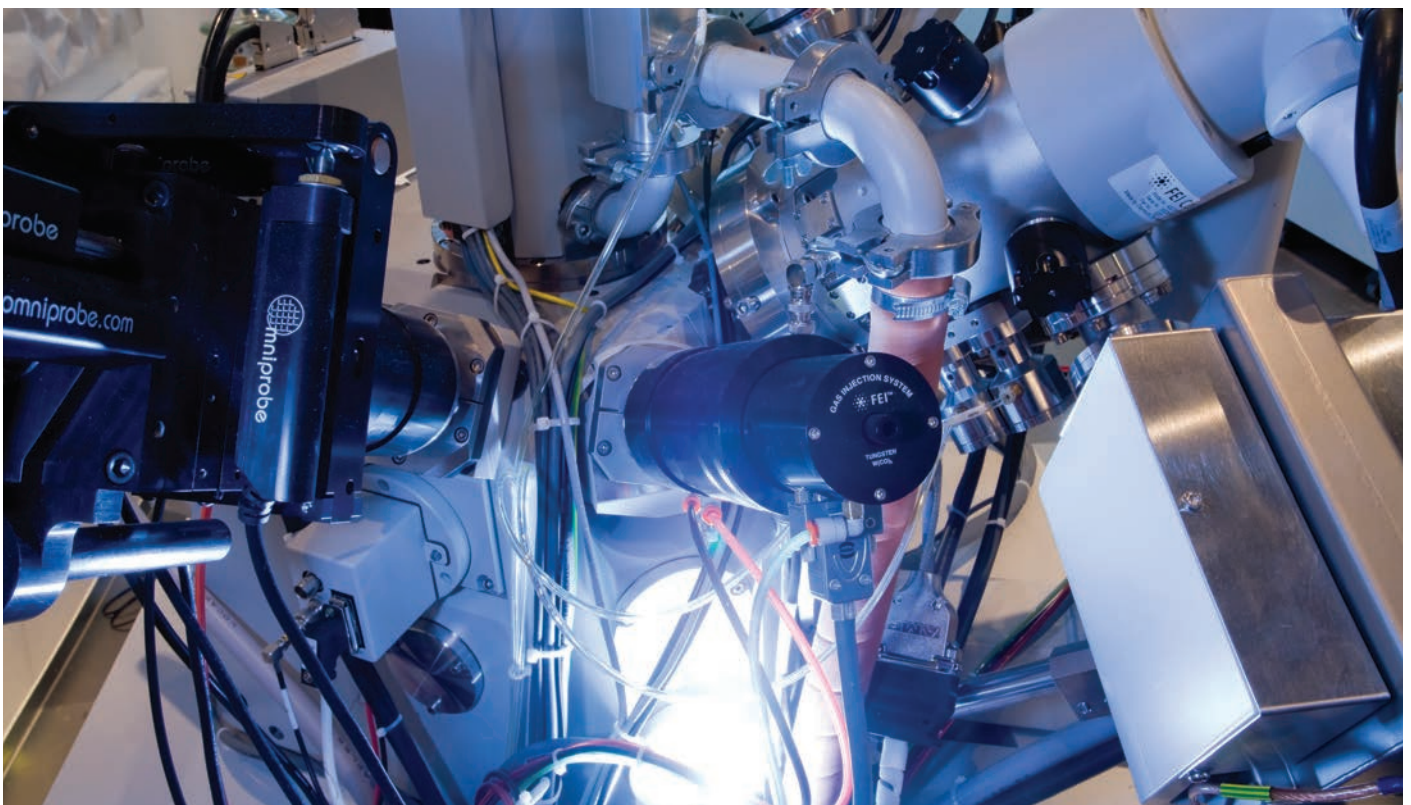
Everhart-Thornley (SE/BSE), Large Field, CCD Camera

Imaging modes

Electron and Ion beams, high and low vacuum

Attachments

Gas Injection System (GIS) for tungsten and platinum deposition and an in-situ Omniprobe micromanipulator.



Helios EBS3

The Helios EBS3 is a dual beam electron microscope used primarily for electron back-scatter diffraction (EBSD) investigations in 2D and 3D. However it is also a tool that can be utilised to prepare high quality TEM lamellas via FIB milling, for chemical characterization via EDS, and to produce very high spatial resolution images at low voltages.

Electron source

Field emission gun

Ion source

Ga⁺ ions

Accelerating voltage

500 V- 30 kV

Resolution

Better than 1.5 nm at 1 kV (SE)

Imaging detectors

Everhart-Thornley (SE/BSE), Thru-the-Lens, Large Field, CCD Camera

Imaging modes

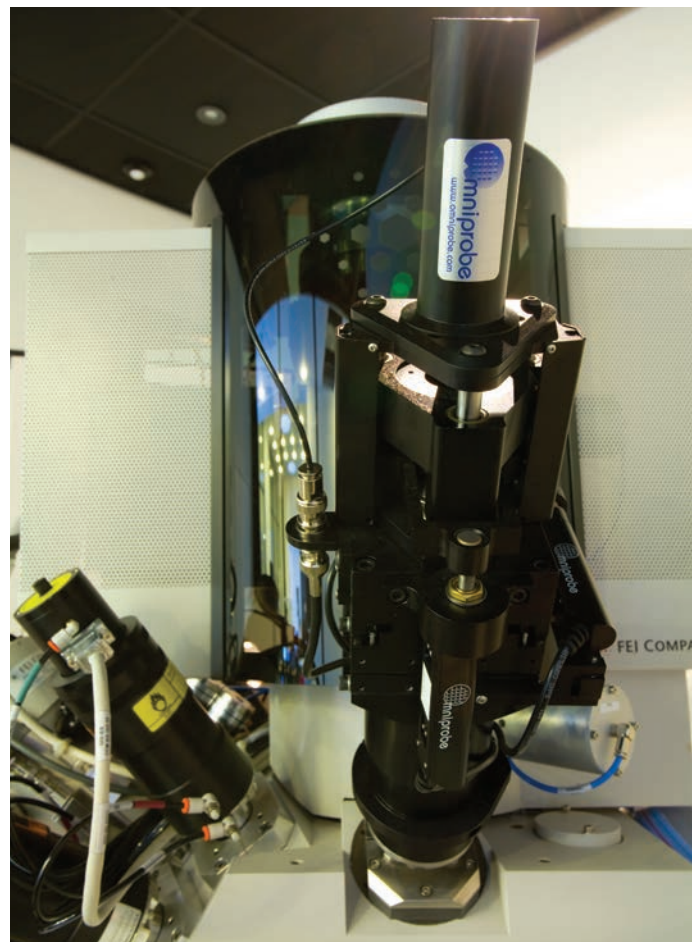
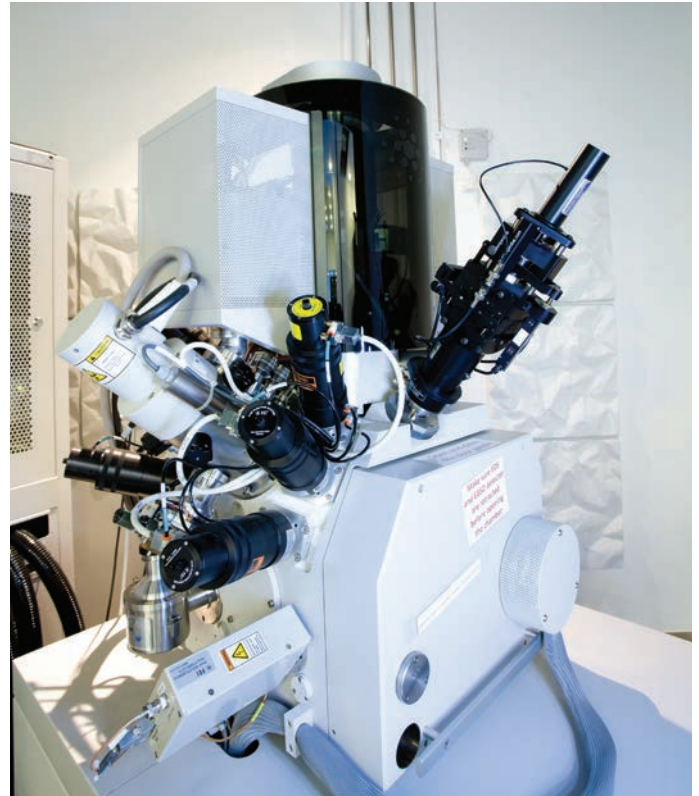
Electron and ion beams at high vacuum

Analytical capabilities

2D and 3D EBSD (EDAX Hikari Camera, TSL EBSD Software Suite), EDS (EDAX SD Apollo 10 Pegasus System, resolution 131 eV)

Attachments

Gas Injection Systems (GIS) for tungsten and platinum deposition, selective carbon etch and delineating etch, in-situ Omniprobe micromanipulator and a cryo can for minimizing contamination.



Transmission electron microscopes

Notable acronyms

BF - Bright Field
DF - Dark Field
HAADF - High Angle Annular Dark Field
HRTEM - High Resolution Transmission Electron Microscopy
SAED - Selected Area Electron Diffraction
STEM - Scanning Transmission Electron Microscopy

The Tecnai is used for performing both conventional and high resolution TEM measurements. It is also equipped to carry out chemical analysis when chemical composition is more important than the spatial resolution.

The Tecnai is a very stable and robust platform which makes it the ideal tool for training users new to the TEM technique.

Tecnai T20 G2

Electron source
Thermionic - LaB₆

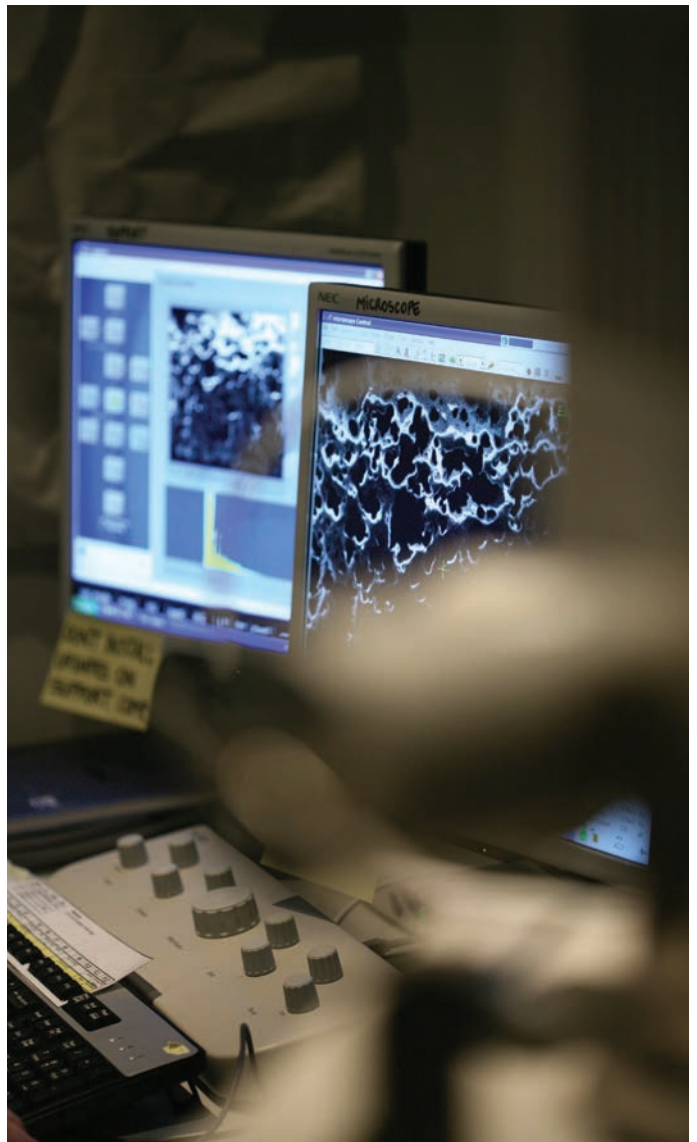
Accelerating voltage
80-200 kV

Resolution
Point resolution of 0.24 nm at 200 kV

Imaging detectors
Gatan 894 2K UltraScan 1000 camera, 2K UltraScan 1000 FT camera

Imaging modes
BF, DF, SAED, Energy filtered TEM, HRTEM, electron diffraction

Analytical capabilities
Gatan 865 GIF Tridiem energy filter, EDS (Oxford Instruments 80 mm² X-Max SDD, MnK_α resolution at 124 eV).



Titan Analytical 80-300ST TEM

The Titan Analytical is a 300kV transmission electron microscope fitted with a field emission gun, a monochromator and a spherical aberration corrector on the condenser system (CESCOR unit from the CEOS Company), i.e. the microscope is probe corrected.

The instrument is used primarily for high spatial resolution chemical analysis and is excellent for applications requiring a small probe size, such as high resolution scanning transmission electron microscopy (HR-STEM) and chemical mapping at the atomic level.

Electron source

Field emission gun

Accelerating voltage

120 and 300 kV

Resolution

TEM information limit < 0.1 nm, STEM resolution ~ 0.08 nm

Imaging detectors

Gatan 894 2K UltraScan 1000 camera, 2K UltraScan 1000 FT camera, Fischione annular dark field 3000

Imaging modes

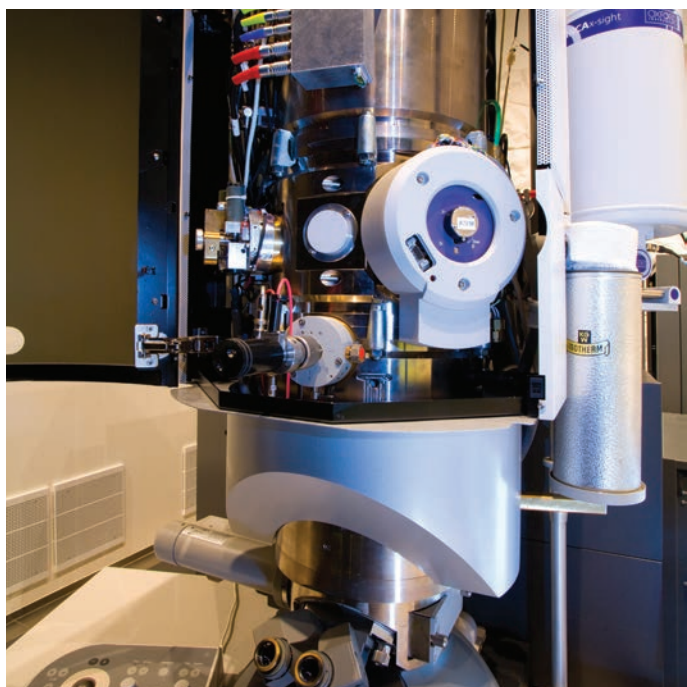
TEM, STEM, DF, HRTEM, HAADF, Energy filtered TEM, electron diffraction

Analytical Capabilities

Gatan 865 GIF Tridiem energy filter, EDS (Oxford Instruments INCAx-sight, resolution 136 eV)

Attachments

Biprism wire for electron holography and Lorentz lens for magnetic imaging.



Transmission electron microscopes

Titan E-Cell 80-300 ST TEM

The Titan E-Cell is a 300kV transmission electron microscope with a spherical aberration corrector on the objective lens (CETCOR unit from the CEOS Company), i.e. the Titan E-Cell is image corrected. It is used primarily for high resolution TEM imaging of nanostructures and interfaces. Where this microscope stands out though is in the area of *in-situ* studies.

By virtue of the presence of a differential pumping system, imaging of samples in gaseous environments up to pressures of 1000 Pa and temperatures of 1000°C are possible (depending on gas composition). Dynamic events at the atomic level can thus be recorded in real time.

Electron source

Field emission gun

Accelerating voltage

80, 200 and 300 kV

Resolution

TEM information limit <0.08 nm, STEM resolution <0.14nm

Imaging detectors

Gatan 894 2K UltraScan 1000 camera, 2K UltraScan 1000 FT camera, Fischione 3000 annular dark field detector

Imaging modes

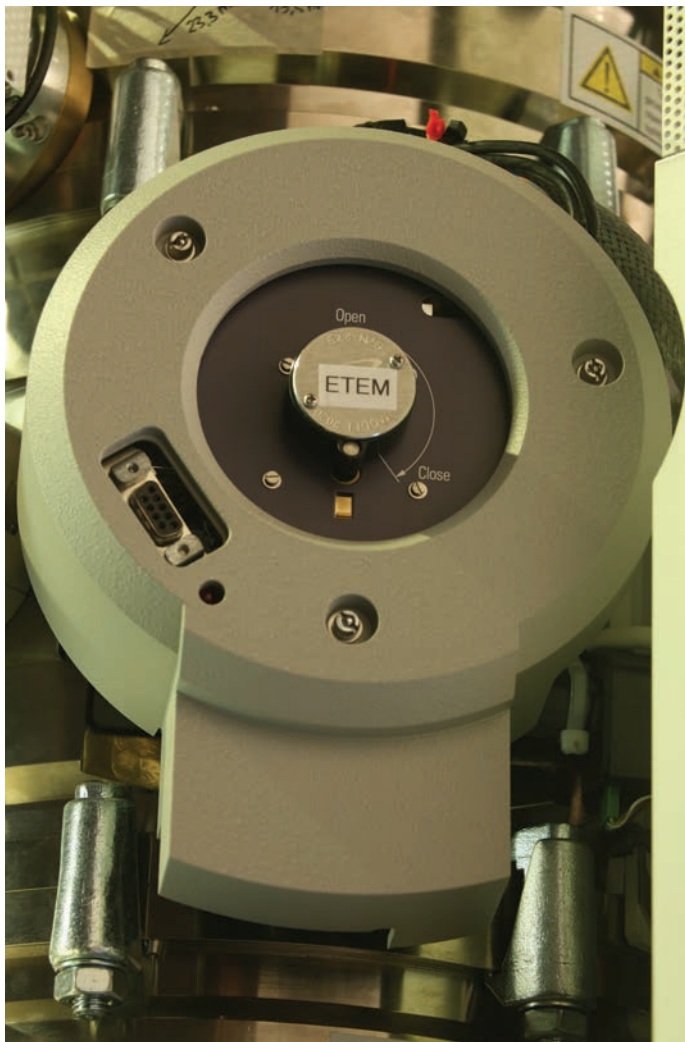
TEM, DF, HRTEM and STEM Energy filtered TEM, electron diffraction

Analytical capabilities

Gatan 865 GIF Tridiem energy filter, EDS (Oxford Instruments INCAx-sight, resolution 136 eV)

Attachments

Lorentz lens



TEM Holders

In order to carry out the broadest range of sophisticated experiments in a TEM it is necessary to have a variety of sample holders that are designed for a specific purpose.

In this respect DTU Cen is equipped as follows:

- Three single tilt Fischione tomography holders (2020, 2040 and 2050)
- FEI single tilt holder
- FEI double tilt holder
- Gatan Be double tilt holder
- Gatan Be double tilt LN₂ cooling holder
- Gatan 652 Tantalum heating holder (up to 1000°C)
- Gatan 652 Inconel heating holder (up to 800°C)
- Vacuum transfer heating holder
- Two-contact biasing TEM specimen holder with capability for electron tomography. The maximum applied current is ~100 mA.
- Three-contact biasing TEM specimen holder with capability for electron tomography. The third contact is movable towards the two contact side using micrometers and piezoelectric drives and can be used as a probe for electric measurements. The maximum applied current is ~100 mA.



Aalto University (Finland) - Tiina Paivarinne
Cambridge University (UK) - Paul Midgeley
Cambridge University (UK) - Richard Harrison
Centro Atomico Bariloche (Argentina)
Civen (Italy)
CNST (USA) - Wade Aaron Hall
Danish Polymer Centre
Danish Technological Institute
Delft University of Technology (The Netherlands) - Cornelis W. Hagen
Departamento de Estratigrafía y Paleontología (Spain) - Antonio Chea
DFM - Kai Dirscherl
DTU Cen - AmonRa
DTU Cen - CASE
DTU Cen - FunDMS
DTU Cen - Silicon Light
DTU Danchip - Peixiong Shi
DTU Danchip - Jonas Lindhard
DTU Food - Jens Adler-Nissen
DTU Fotonik - Beata Kardynal
DTU Fotonik - Haiyan Ou
DTU Fotonik - Jørn Marcher Hvam
DTU Fotonik - Kresten Yvind
DTU Fysik - Cathrine Frandsen
DTU Fysik - Ib Chorkendorff
DTU Fysik - Jane Nielsen
DTU Fysik - Ole Trinhammer
DTU Fysik - Steen Mørup
DTU Fysik - Søren Dahl
DTU Fysik - Ulrik Lund Andersen
DTU Kemi - Anders Riisager
DTU Kemi - Jens Ulstrup
DTU Kemi - Kenny Ståhl
DTU Kemi - Niels Bjerrum
DTU Kemi - Qingfeng Li
DTU Kemi - Rasmus Fehrmann
DTU Kemiteknik - Søren Hvilsted
DTU Kemiteknik - Anker Degn Jensen
DTU Kemiteknik - Anne Juul Pedersen
DTU Kemiteknik - Anne Meyer
DTU Kemiteknik - Kim Dam Johansen
DTU Kemiteknik - Martin Vigild
DTU Kemiteknik - Peter Arendt Jensen
DTU Kemiteknik - Peter Glarborg
DTU Kemiteknik - Weigang Lin
DTU Mek - Marcel Sommers
DTU Mek - Per Møller
DTU Mek - Andy Horsewell
DTU Mek - Flemming Bjerg Grumsen
DTU Mek - Hilmar Kjartansson Danielsen
DTU Mek - Karen Pantleon
DTU Mek - Leonardo De Chiffre
DTU Mek - Rajan Ambat
DTU Miljø - Anders Baun
DTU Miljø - Dimitar Borisov Karakashev
DTU Miljø - Irimi Angelidaki
DTU Nanotech - Mette Skovgaard
DTU Nanotech - Anja Boisen
DTU Nanotech - Eric V Thomsen
DTU Nanotech - Joerg Kutter
DTU Nanotech - Kristian Mølhav
DTU Nanotech - Max Chen
DTU Nanotech - Ole Hansen
DTU Nanotech - Oliver Geschke
DTU Nanotech - Peter Bøggild
DTU Nanotech - Zachary James Davis
DTU Space - Finn E Christensen
EPCOS (Denmark)
EPFL (Switzerland)
Freiburg University (Germany)
GLO A/S (Sweden)
GEUS (Denmark)
Glaxo Smith Kline (UK)
Haldor Topsøe A/S (Denmark)
Helsinki University of Technology (Finland)
Imperial College (UK) - Dave McComb
IMRE (Singapore)
JFE Steel (Japan)
Johnson Matthey Technology Centre (UK)
KU - Jes Christian Knudsen
KU Life - Jens Risbo
KU - Hans Christian Bruun Hansen
KU - Christian Bender Koch
KU - SusanStipp
LEGO (Denmark)
Max Planck Gesellschaft (Germany) - Wilder Carillo Cabrera
Monash University (Australia) - Shery Chang
Mærsk (Denmark)
Nagoya University (Japan)
Nanolyse Project - Erik Huusfeldt Larsen
National Veterinary Institute (Denmark)
NINT (USA)
Nokia (Denmark/Finland)
Nordisk AeroForm Aps (Denmark) - Erik Grove-Nielsen
NRCWE (Denmark) - Keld Alstrup Nielsen
PoLight (Norway)
Radiometer (Denmark)
Risø DTU - Ruth Knibbe
Risø DTU - David Plackett
Risø DTU - Henning Friis Poulsen
Risø DTU - Xiaoxu Huang
Risø DTU - Yi Lin Liu
Rockwool (Denmark)
RWTH Aachen University (Germany) - Thomas Weirich
SCF Technologies (Denmark) - Steen Brummerstedt Iversen
Simon Fraser University (Canada) - Karen Kavanagh
SINTEF Materials and Chemistry (Norway) - John Walmsley
SINTEF Materials and Chemistry (Norway) - Yanjun Li
The University of New Mexico (USA) - Abhaya Datye
Trinity College Dublin (Ireland)
Ulm University (Germany) - Ute Kaiser
University of Aviero (Portugal)
University of Cadiz (Spain)
University of Edinburgh (UK)
University of Groningen (The Netherlands) - Willem van Dorp
University of Kyushu (Japan)
University of Liverpool (UK) - Miroslava Schaffer
University of Rostock (Germany) - Guido Walther
University of Stavanger (Norway) - Ingunn Oddsen
University of Trondheim (Norway) - Randi Holmstad
Vestas Wind Systems (Denmark)

Board

Provost Knut Conradsen (Chairman)
CASE Project Director Søren Dahl, DTU Fysik
Director Mogens Rysholt Poulsen, DTU Danchip
Director Henrik Carlsen, DTU Mek
Director Henrik Bindslev, Risø DTU

Scientific Advisory Board

Professor Archie Howie, Cambridge University (UK)
Professor David J. Smith, Arizona State University (USA)

Center for Electron Nanoscopy at DTU.



Staff

DTU Center for Electron Nanoscopy Administration



Rafal E. Dunin-Burkowski
DTU Cen Director



Andrew Burrows
Deputy Director



Anna Rink Baagøe
DTU Cen Administrator

Administration

How to find us

Center for Electron Nanoscopy
Technical University of Denmark
Fysikvej
Building 307 and 314



www.cen.dtu.dk

Core Scientific Staff



Adam Fuller
Lab Manager
Dual-beam operation and development, facilities logistics



Alice Bastos da Silva Fanta
Scientist
3-D electron backscatter diffraction of metals, advanced SEM development



Marco Beleggia
Associate Professor
Teaching, modeling, image simulation and interpretation



Ramona Valentina Matieu
Technical Support Staff
Scanning electron microscopy service and applications, dual beam operation



Thomas W. Hansen
Senior Scientist
Environmental transmission electron microscopy of catalysts



Chris Boothroyd
Senior Scientist
Quantitative transmission electron microscopy, teaching



Jakob B. Wagner
Senior Scientist
Environmental transmission electron microscopy, teaching



Berit Wenzell
Technical Support Staff
Scanning electron microscopy service and applications



Takeshi Kasama
Senior Scientist
Electron holography of magnetic nanostructures

Core Scientific Staff

Staff

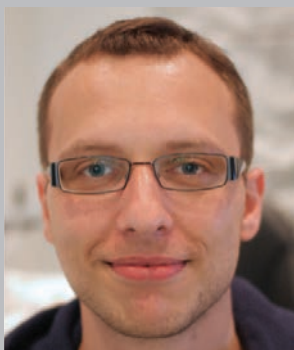
Scientific Staff



Robert Pennington
PhD Student (to 12/2011)
Quantitative electron microscopy of semiconductor nanowires



András Kovács
Postdoctoral Fellow
Electron microscopy of magnetic nanostructures, conventional sample preparation



Zoltan Balogh
Technical Assistant
Focused ion beam specimen preparation and assistance



Johan Persson
PhD Student (to 04/2012)
Electron microscopy of semiconductor nanowire heterostructures



Alessandra Mosca
Postdoctoral Researcher
Scanning electron microscopy polymer studies



Filippo Cavalca
PhD Student (to 12/2012)
In-situ laser holder development and implementation



Shima Kadkhodazadeh
Postdoctoral Researcher
STEM and EELS of FIB-prepared semiconductor quantum dots



Lars Schulte
Scientific Researcher
Scanning electron microscopy, specimen preparation, microtomy



Martial Duchamp
Postdoctoral Researcher
Transmission electron microscopy of silicon solar cell devices, FIB preparation



Andy Horsewell
Affiliated Senior Scientist (DTU Mek)
SEM of polymers and soft materials, teaching



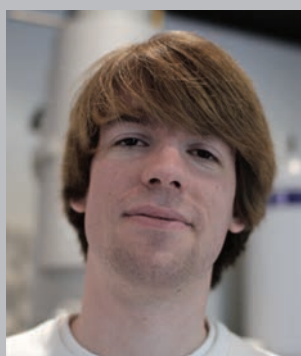
Amuthan Ramar
Ørsted Postdoctoral Fellow
Electron holography and tomography of dislocation networks



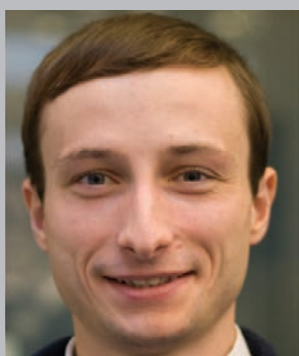
Christian D. Damsgaard
Assistant Professor
In situ measurements of dynamic effects in heterogeneous catalysis



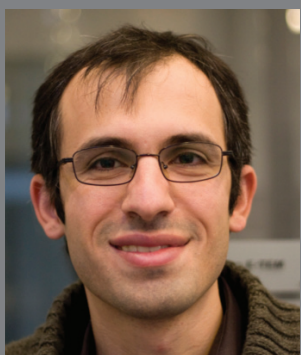
Louise H. S. Jensen
PhD Student (to 10/2012)
Scanning electron microscopy of soft materials and cryo-applications



Linus Duchstein
PhD Student (to 12/2012)
Environmental transmission electron microscopy of catalysts



Alexey Savenko
Scientific Researcher
Focused ion beam applications



Sadegh Yazdi
(Imperial College London)
Holography of FIB-prepared p-n junction membranes

Visitor



A. Nicole Macdonald
Technical Support Staff
Focused ion beam operation and development

Recent Staff

Scientific Staff

Center for Electron Nanoscopy
Technical University of Denmark
Fysikvej
Building 307
2800 Kgs. Lyngby
Denmark

Phone +45 45 25 64 74
www.cen.dtu.dk