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Annual Report 2008

DTU Cen
Center for Electron Nanoscopy

Mærsk Mc-Kinney Møller and DTU's president Lars Pallesen at the inauguration of the Center for Electron Nanoscopy

Preface

Note From the Director
This is the first annual report of the Center for Electron Nanoscopy in the Technical University of Denmark (DTU Cen), which was established in 2007 following a generous donation of 102,6M DKr by the A.P. Møller and Chastine Mc-Kinney Møller Foundation.

The facility contains seven new electron microscopes in a purpose-built high-specification building. Two of the microscopes are state-of-the-art monochromated aberration-corrected instruments. The remaining instruments include two dual-beam focused-ion-beam microscopes and three smaller microscopes.

This report contains an outline of the establishment and inauguration of the facility. It also provides an account of the Center's events and achievements in the calendar year 2008, which have included:

· Completing the hiring of core research and technical support staff;
· Establishing activities in research, education, service and outreach;
· Completing the commissioning and testing of DTU Cen's seven new electron microscopes and ancillary equipment;
· Training new users of the microscopes;
· Developing close working relationships and collaborations with other departments at DTU and with national and international academic and industrial partners;
· Organizing student evenings, demonstrations, tours and seminars;
· Securing national and European research funding for projects;
· Organizing the annual meeting of the Scandinavian societies for electron microscopy in June 2008.

I am grateful to all of our core staff, colleagues and equipment manufacturers, as well as to DTU's management and the A.P. Møller Foundation, for their hard work in the establishment of the Center.
I particularly welcome and encourage contact from potential collaborators to work with us to make the best possible use of the new equipment and resources.

June 2009
Rafal E. Dunin-Borkowski
Center Director

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DTU Cen, Center for Electron Nanoscopy, 2009 · Editor, Anna Rink Baagøe · Scientific Editor, Andy Burrows
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Executive Summary

Within the space of one year, the Center for Electron Nanoscopy in the Technical University of Denmark has become a fully operational facility at DTU in the areas of research, teaching, service and outreach.

Following its inauguration in December 2007, much effort has been devoted to hiring experienced staff and to optimizing the operation of the Center's seven electron microscopes. The microscopes are now used by bachelor students, master students, Ph.d students and post docs, by scientific and technical staff from DTU and other universities, and by industrial partners, while the microscope building provides a pleasant environment for carrying out research and teaching.

By working together with other departments at DTU and with other universities and industry, both in Denmark and abroad, the Center has established itself rapidly as a state-of-the-art electron microscopy facility.

The rapid development of the Center's national and international profile is reflected by:

- the collaborative research activities that have been established with other departments, universities and industry;
- the research articles that have been published in peer-reviewed scientific journals;
- the invitations that are received by the Center's staff to speak at international conferences;
- the frequency of visits to the Center by leading scientists and industrialists;
- the substantial additional grant funding that has been secured for specific projects.

This report begins with a brief history of the facility. It then contains an introduction to electron microscopy and a description of the Center's seven new electron microscopes. Following a presentation of examples of recent research, the report contains an account of the Center's teaching activities, examples of articles about the facility that have appeared in the popular and scientific press, and a summary of the Center's events, seminars and research output for 2008. Finally, profiles of the Center's research scientists and technical and administrative staff are presented.

We hope that the report is informative.

History

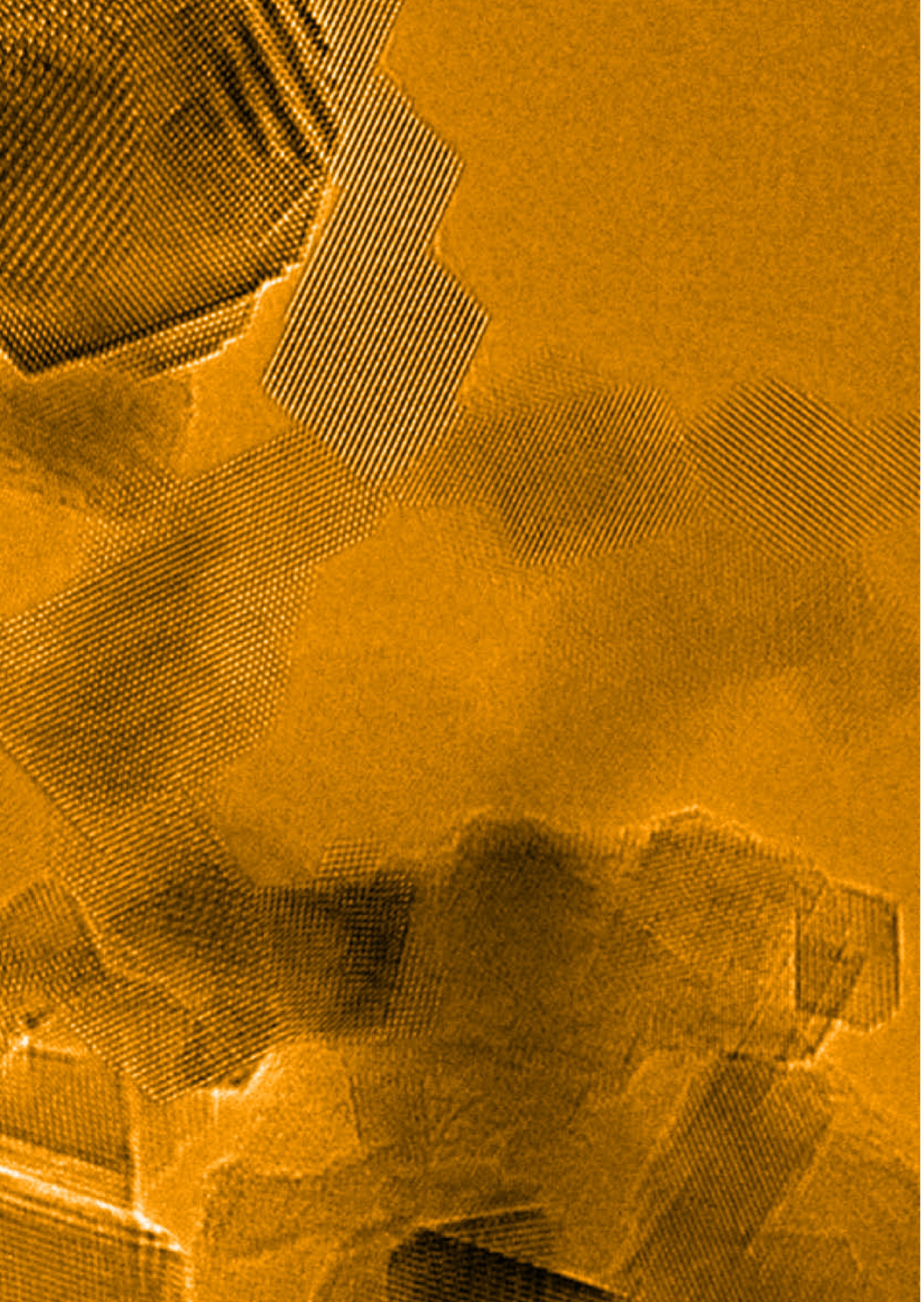
DTU's Center for Electron Nanoscopy (DTU Cen) would not exist without a generous donation from the Møller Foundation, which DTU received in January 2006. The amount, 102,6M DKr helped "establish a world-class facility with a unique suite of advanced electron microscopes in a purpose-built building."

The proposal was set forth in March 2005 and the application for a major foundation was then written. The lengthy process of ordering highly specialized microscopes began in September 2006, and exactly one year later they were installed. The microscope building, building 314, was started in December 2006 and the center was inaugurated within two years from the time DTU received the Møller Foundation's donation.

The microscope building is a specifically designed building which was established for the electron microscopes at DTU. Due to the sensitive nature of the microscopes, three major factors needed to be taken into account when the building was designed. These were ground vibrations, temperature variations and magnetic fields. Ground vibrations and acoustic vibrations of all frequencies were factors in the design of building 314 because of the high magnifications used in electron nanoscopy research. The foundation had to be a meter thick and the rooms vibrationally isolated with both wall and ceiling isolations. Magnetic fields which can be induced by the surrounding power lines were tested and found to be less than 20 nT. Temperature variations, which can also affect electron beam stability, must be constant with less than 0.5 Celsius variation over 30 minutes.

The microscope building

The inauguration was held on the 7 of December, 2007 as the culmination of a scientific conference with presentations from 11 different invited speakers.



Microscopy and microscopes

What is Electron Microscopy?

The word microscopy is derived from the Greek 'mikros' (small) and 'skopeo' (look at). Ever since the dawn of science there has been an interest in being able to look at smaller and smaller details. Biologists have wanted to examine the structure of cells, bacteria, viruses and colloidal particles. Materials scientists have wanted to see inhomogeneities and imperfections in metals, crystals and ceramics. In the diverse branches of geology, the detailed study of rocks, minerals and fossils could give valuable insight into the origins of our planet and its valuable mineral resources.

Why use electrons instead of light?

A modern optical microscope has a magnification of about 1000x and enables the eye to resolve objects separated by 0.0002 mm. In the continuous struggle for better resolution, it was found that the resolving power of the microscope was not only limited by the number and quality of the lenses but also by the wavelength of the beam used for illumination. It was impossible to resolve points in the object that were closer together than a few hundred nanometres. Using light with a short wavelength (blue or ultraviolet) gave a small improvement; immersing the specimen and the front of the objective lens in a medium with a high refractive index (oil) gave another small improvement but these measures together only brought the resolving power of the microscope to just under 100 nm.

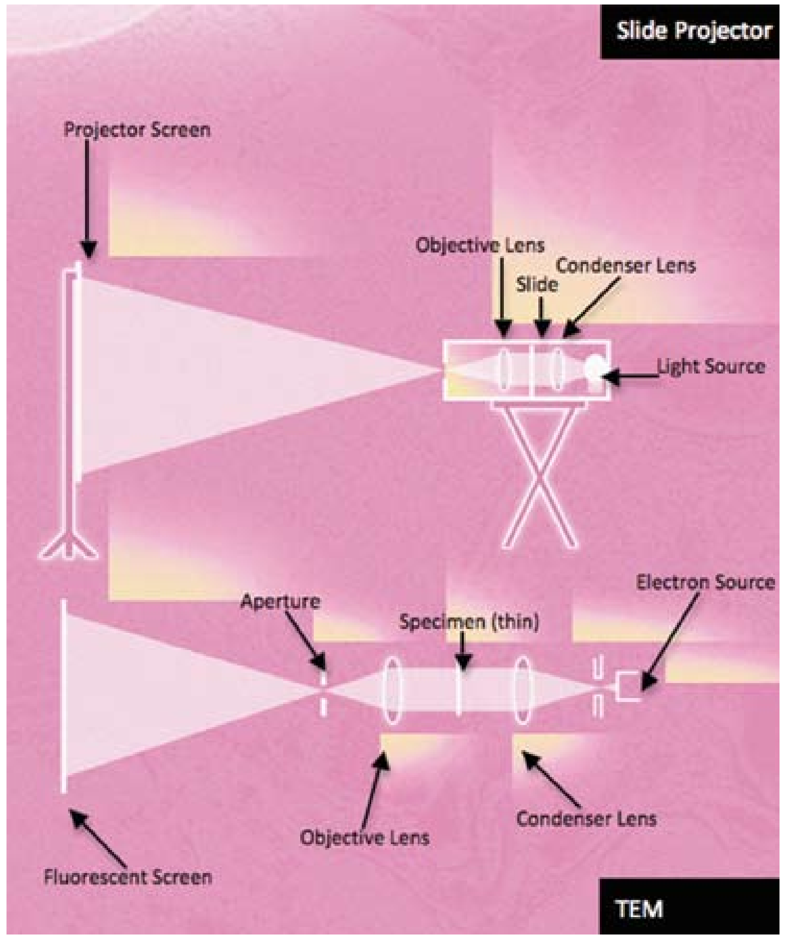


Figure 1: The transmission electron microscope compared with a projector

In the 1920s it was discovered that accelerated electrons behave in vacuum just like light. That is to say, to most intents and purposes they travel in straight lines, and have a wavelength which is about 100000 times smaller than that of light. Furthermore, it was found that electric and magnetic fields have the same effect on electrons as glass lenses and mirrors have on visible light. Dr Ernst Ruska at the University of Berlin combined these characteristics and built the first transmission electron microscope (TEM) in 1931.

For this and subsequent work on the subject, he was awarded the Nobel Prize for Physics in 1986. The first electron microscope used two magnetic lenses and three years later he added a third lens and demonstrated a resolution of 100 nm, twice as good as that of the light microscope at that time. Today, using five magnetic lenses in the imaging system, a resolving power of 0.1 nm at magnifications of over 1 million times can be achieved.

The Transmission Electron Microscope (TEM)
The transmission electron microscope can be compared to a slide projector. In the latter, light from a light source is made into a parallel beam by the condenser lens; this passes through the slide (object) and is then focused as an enlarged image onto the screen by the objective lens. In the electron microscope, the light source is replaced by an electron source (for example, a tungsten filament), the glass lenses are replaced by magnetic lenses and the projection screen is replaced by a fluorescent screen which emits light when struck by electrons. The whole trajectory from source to screen is under vacuum and the specimen (object) has to be very thin to allow the electrons to penetrate it. Ultimately, with a suitably electron transparent sample, the TEM can form images from a specimen right down to the atomic scale, giving new insights into the structure of materials. Furthermore, the strong interaction between electrons and the specimen gives rise to many "secondary" effects in such a form to be detected by appropriate hardware. The signals generated can then be used to provide, for example, chemical information at very specific locations in the sample.

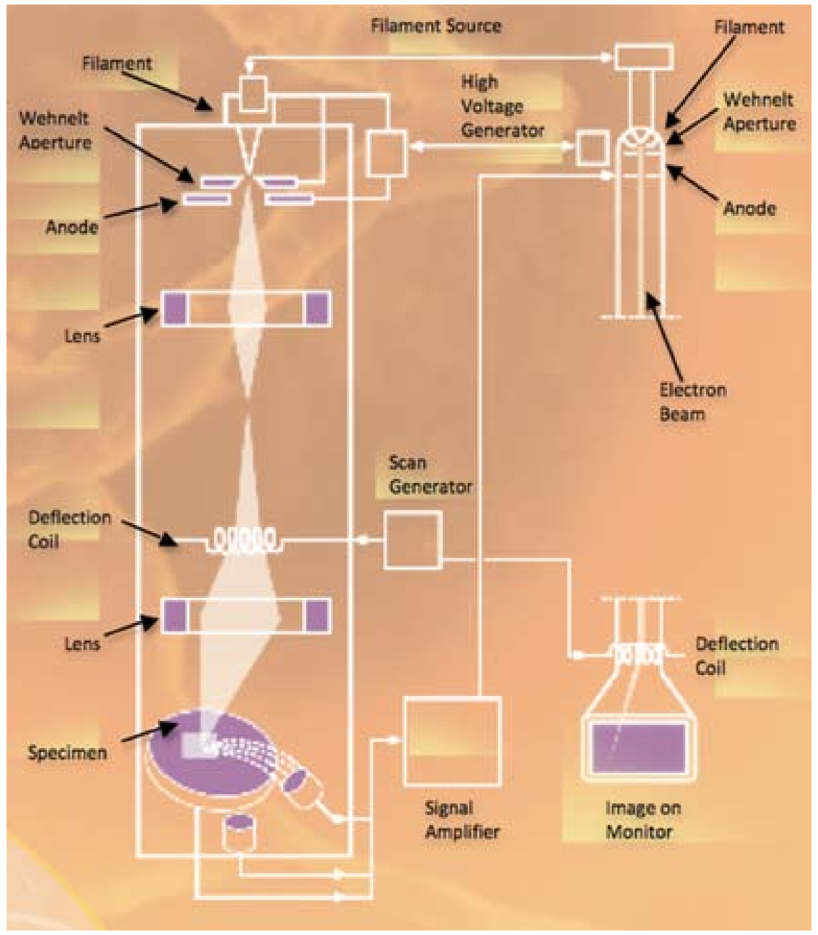


Figure 2: Schematic diagram of an SEM showing the column and how the image is formed on the monitor

The Scanning Electron Microscope (SEM)
It is not completely clear who first proposed the principle of scanning the surface of a specimen with a finely focused electron beam to produce an image. However, in 1942 three Americans, D. Zworykin, Dr Hillier and Dr Snijder first described a "true" SEM with a resolving power of 50 nm and a magnification of 8000x. Nowadays SEMs can have a resolving power of 1 nm and can magnify over 400 000x.

A scanning electron microscope, like the TEM, consists of an electron optical column, a vacuum system and control electronics. The column is considerably shorter because there are only three lenses to focus the electrons into a fine spot onto the specimen; in addition there are no lenses below the specimen. The specimen chamber, on the other hand, is larger because the SEM technique does not impose any restriction on specimen size other than that set by the size of the specimen chamber.

The electron gun at the top of the column produces an electron beam which is focused into a fine spot less than 4 nm in diameter on the specimen. This beam is scanned in a rectangular raster over the specimen. Apart from (several) other interactions at the specimen, secondary electrons are produced and these are collected by a suitable detector. The amplitude of the secondary electron signal varies with time according to the topography of the specimen surface. The signal can be amplified and used to cause the brightness of the electron beam in a cathode ray tube (CRT) to vary synchronously. There is a one to one relationship between each point on the CRT screen and a corresponding point on the specimen. Thus a picture is built up rather like that on a TV screen.

The Microscopes at DTU Cen

In the following sections each of the seven microscopes is described.

Adapted from an article written by FEI company and reproduced with their kind permission.

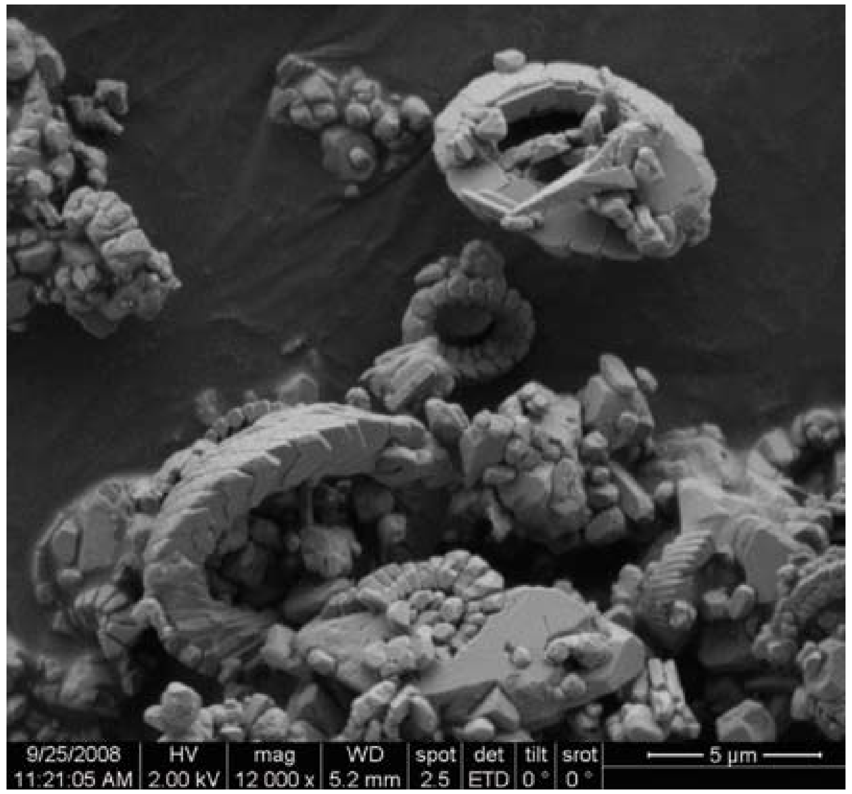
Inspect ’S’

Anne Marie Rasmussen explaining the principles of a SEM to a group of students.

What is it?
The Inspect ‘S’ is a scanning electron microscope (SEM) with a tungsten filament electron source. It has several detector types, including an X-ray detector, and is capable of imaging samples in the following modes: high vacuum, low vacuum (up to 200 Pa) and environmental (up to 4000 Pa).

How are the samples imaged?
The SEM sweeps a fine probe of electrons over the sample which collide either elastically off the sample (backscattered electrons), or inelastically to produce secondary electrons and X-rays. The backscattered or secondary electrons are collected and used to image the sample up to over 100 000 times magnification. Both the electrons and the X-rays that are generated can be utilized to determine particular characteristics of a sample.

What can it do?
The secondary electrons are low-energy electrons emitted from within a few nanometers of the sample surface. These can be collected by a secondary electron detector to obtain topographical information. The backscattered electrons provide information from just below the surface and provide greater elemental contrast. These can be used, for example, to map particles in a substrate. The energy of the X-rays depends on the material. By looking at the energy spectrum at each point in the image the elements that make up the sample can be determined and mapped.



Coccoliths, produced by single-celled algae, form the natural chalk from Møns Klint.

What makes it special?
The Inspect ‘S’ is the simplest microscope at DTU Cen and has a similar interface to the other SEMs. It is therefore the first microscope to which new SEM users are introduced. Its short pump and vent times allows quick preliminary checks of sample quality for other instruments, such as the Helios. Most often, however, it is used as an excellent SEM in its own right with good imaging capabilities and X-ray detection possibilities.

Quanta 200 F

What is it?
The Quanta 200 F is a scanning electron microscope (SEM) with a field emission gun (FEG) which gives a high spatial resolution and high beam stability. The microscope can operate in high and low vacuum as well as in environmental mode, giving the possibility to examine many different types of samples under vacuum, in gas, or water vapor.

How are the samples imaged?
Electrons are accelerated from the FEG source in a small volume with a small angular spread and selectable energy – between 200V and 30 kV.
The secondary- and back scattered electrons and X-rays can be detected and analysed by the different detectors described earlier.

What can it do?
The FEG SEM can be used to obtain physical and chemical information about the surface of almost any sample – large or small – often without any preparation. The magnification ranges from 50x up to over 1 million times with a best resolution of less than 2 nm. The 3 vacuum modes provide possibilities for examining a wide range of materials.
Besides imaging, areas and distances or particle sizes can be measured. By using the backscattered detector, the elemental composition transformed to gray scale values in the image can be obtained. The backscattered signal can be collected along with the X-ray signal to get a total chemical analysis or the position of any single element.

What makes it special?
A Quorum Polar Prep 2000 Cryo Transfer System is attached, providing the possibility of freezing liquids, particles in liquids and beam sensitive samples. The frozen samples can be fractured, cut and/or coated and directly transferred to a cold stage in the microscope. The SEM is an extremely flexible tool capable of high resolution imaging.
To support the surface information obtained by the imaging detectors it is equipped with an Oxford Instruments INCA EDS spectrometer that allows analysis of the chemistry of a sample. This can be achieved either by position on the sample surface in single spots or over a selected area. The element distribution can be displayed as a mapped overlay on the surface image or the analysis of a single line displayed on the image. To extend the quantitative analysis further an Oxford Instruments Wavelength Dispersive Spectrometer (WDS) analyzing system is also attached to the microscope.

Micrograph of a frozen diatom taken in the Quanta FEG
Image by Anne Marie Rasmussen.

Quanta 200 3D

Micromachining a feature using the FIB

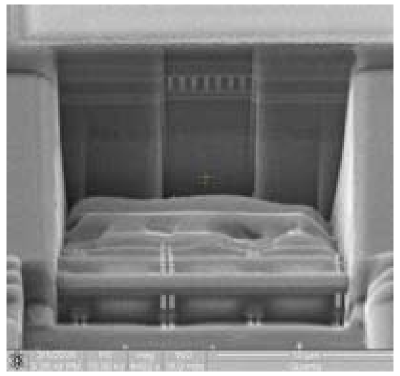
What is it?
The Quanta 200 3D is a versatile scanning electron microscope (SEM) combined with a focused ion beam (FIB) work station, i.e. it is a dual-beam instrument. Gallium (Ga+) ions are heavier than electrons, and their high momentum at a particular accelerating voltage can be used to remove material from a bulk sample. A long, fine tungsten needle, the Omniprobe, allows for in-chamber manipulation of samples, with the capability to remove sections from the bulk that have been cut out by the FIB.

How are the samples imaged?
The Quanta 200 3D has a tungsten filament electron source, and the imaging capabilities (secondary and backscattered electrons) are similar to the Inspect 'S'. When the ion beam probe is swept across the sample it also produces secondary electrons and backscattered ions. These can also be used to image the sample. The higher momentum of the Ga+ ions means that, even at low operating currents, the sample is damaged during every sweep.

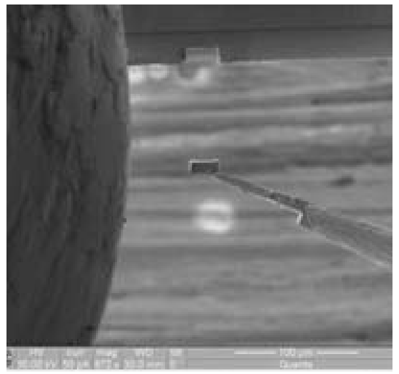
What can it do?
The FIB uses gallium (Ga+) ions rastered in defined patterns for fast and precise milling and deposition. FIB milling can also be used to reveal structure under top layers, cut cross-sections for SEM viewing, prepare site-specific specimens for transmission electron microscopy (TEM), or to modify microstructures. Tungsten and platinum can be deposited to provide extra strength to a TEM sample (typically of the order of a few hundred nm thick for electron transparency), to create a milling mask, or to weld two materials together (e.g. to weld the omniprobe to a TEM specimen for lift out, or a TEM specimen to a grid).

What makes it special?
With the dual-beam system it is possible to switch between the ion and electron beam to navigate for accurate milling and thereby reduce sample erosion and ion implantation. The electron beam can be used in conjunction with the ion beam on a non-conducting sample during milling to reduce charging, and therefore allow for more accurate milling by preventing beam shift.

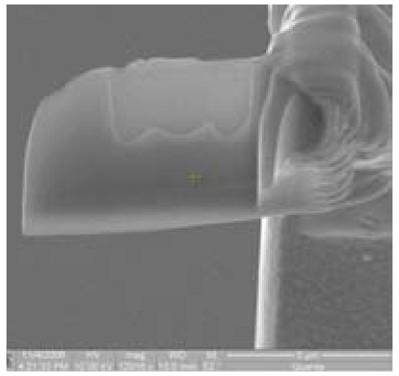
It is unnecessary to remove the sample from the vacuum chamber for SEM viewing. Therefore real-time cross-section images and videos can be taken with the electron beam during milling, and thus exposure to atmospheric contaminants is prevented.



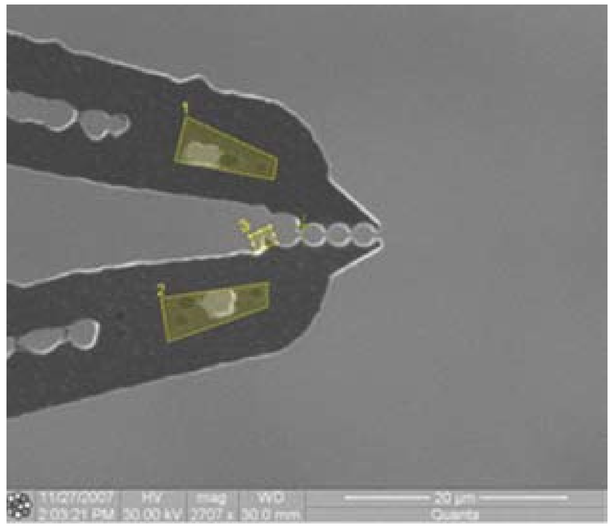
Secondary electron SEM image of a FIB-milled cross-section of an integrated circuit. By imaging with the SEM to choose an area to be cut, and removing material with the FIB, we can see a cross-section of the chip under a specific device.



Secondary electron FIB image of a lift-out process. On the left is the needle for platinum gas used in depositions. The centre top is the gap in the bulk material from which it was cut, and in the centre the cut-out sample is attached to the Omniprobe.



Secondary electron SEM image of a FIB-prepared TEM sample.



Secondary electron FIB image of a micromachined feature. The yellow cross-hatched areas are milling patterns - the ion beam will raster over these areas to remove the material

Helios NanoLab600

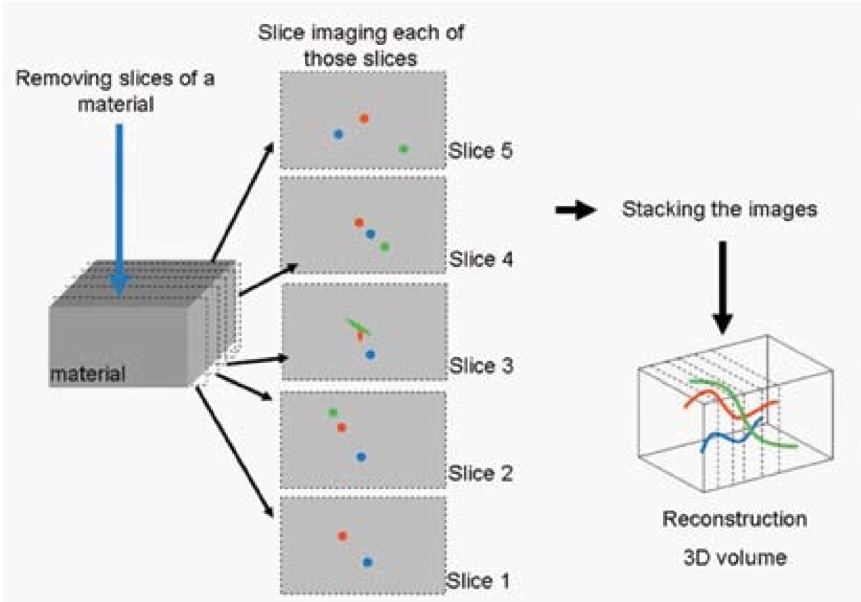


Figure 1: Schematic representation of 3D tomography by serial sectioning

The Helios Nanolab is a combination of a high resolution scanning electron microscope (SEM) and a focused ion beam (FIB) microscope in one single machine. This so called dual-beam scanning microscope allows one to use the higher energy of the gallium (Ga) ions to cut (mill) slices of the material being investigated and to use the electron beam and different signal detectors to perform high resolution imaging of the newly prepared surface. Compared to standard scanning electron microscopes, a dual beam permits exploration of deeper areas within the bulk of a sample. The Helios NanoLab also has ultra-high-resolution optics allowing SEM resolution in the sub-nanometer range.

The system is also equipped with five gas injection systems (GIS), two of which allow the deposition of tungsten (W) and platinum (Pt) films from organic precursor gases to mark or protect the area of interest. The other three use reactive gases such as XeF_2 to facilitate milling of particular materials. Furthermore the system is equipped with an electron backscatter detector (HKL EBSD system) for crystallographic characterization of crystalline materials and an EDS detector for chemical microanalysis of samples.

What can it do?

Some of the applications of the Helios NanoLab600 are:

· High resolution SEM imaging (sub-nanometer at 15 kV and better than 1.5 nm at 1 kV) without beam deceleration.
· Cross section preparation
· Ion induced secondary electron imaging
· Advanced integrated solutions for nanoprototyping.
· Prototype nano-writing and machining
· Crystallographic characterization by electron backscatter diffraction (EBSD) in two and three-dimensions
· Chemical characterization by energy-dispersive X-ray spectroscopy (EDX) in two and three dimensions
· Three dimensional material characterization using high precision FIB milling and high resolution SEM imaging

Why perform 3D characterization?
Most microscopy methods are based on imaging and characterizing 2-dimensional plane cuts through a sample. In reality, however, samples are three dimensional and in many cases volume information is required to get a complete understanding of their properties. The description of some microstructure characteristics, such as real grain size, grain shape and distribution in a sample volume are examples of interesting information that can be obtained by three dimensional analysis techniques.

EBS3 (3D Orientation microscopy)
EBS3 is based on 3D tomography (see Figure 1) in a dual beam system, whereby an EBSD map is acquired from every slice of the study. The FIB is applied for preparation of smooth surfaces by milling the material at grazing incidence (see Figure 2). This sectioning process allows a controlled removal of thin layers of materials with a minimum slice thickness of approximately 20-50 nm. The resulting smooth surface is in most cases very well suited for the formation of EBSD patterns. After the milling process, the sample is positioned for the acquisition of these patterns and the sample is rotated 180° inside the SEM chamber (see Figure 2).

By successive sputtering and EBSD measurements, the 3-dimensional microstructure can be explored. Each of the sections obtained is then used to reconstruct the original microstructure in three dimensions. This process is controlled by software, and runs completely automatically. With this technique, the three dimensional crystallographic characteristics of a sample can be explored with a spatial resolution of about 50 x 50 x 50 nm^3. Figure 3 shows a 3D EBSD map of a Ni-based superalloy studied in the Helios at DTU Cen.

This map was acquired automatically over a period of 30 hours and contains 100 slices with a spatial resolution of 100 x 100 x 100 nm^3.

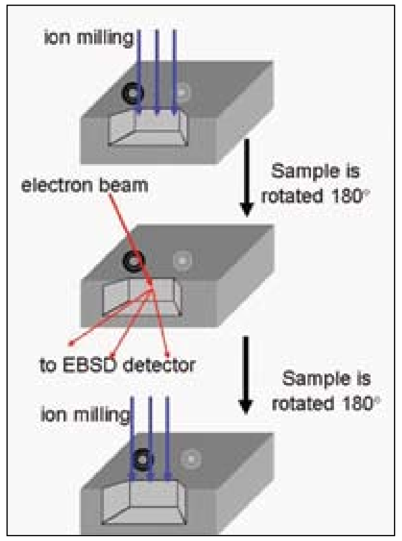


Figure 2: Ion milling at grazing incidence and rotation of the sample by 180° to collect the EBSD data

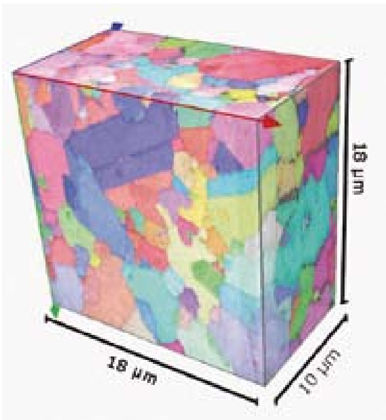


Figure 3: 3D EBSD map of a Ni-based superalloy studied at DTU Cen

Tecnai

Chris Boothroyd using the Tecnai for routine characterization

What is it?
The Tecnai is a transmission electron microscope (TEM) used for bright-field, dark-field and atomic-resolution imaging. Electron diffraction can also be performed to study the structure of crystalline materials and the microscope is fitted with detectors which can be used to collect chemical composition data at nanometer resolution.

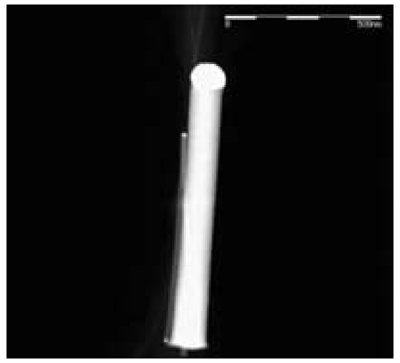
How are the samples imaged?
Electrons are accelerated from the LaB_6 electron source by an electric potential between 80 and 200 kV. These electrons pass through a thin sample (less than 100 nanometers), and are focused by a FEI Supertwin objective lens onto a phosphor screen or a CCD camera with a resolution of 2000 by 2000 pixels. The microscope has a point resolution of 0.24 nm, and a line resolution of 0.15 nm.

What can it do?
It can be used to obtain both physical and chemical information about a sample. It is suited for imaging all types of organic and inorganic materials, heterostructures or devices, whenever the sample is thin enough for the electron beam to pass through. Some examples of applications this microscope can be used for are:
· TEM images can be collected to measure sizes, shapes, and distances in a sample
· Electron diffraction studies to assess structures and orientations of crystalline areas
· Imaging of interfaces or surfaces at atomic-resolution, and studies of the presence of defects.
· Energy dispersive X-ray spectroscopy (EDS) and energy filtered TEM (EFTEM) studies to obtain the different chemical elements present, as well as their spatial distributions and relative amounts.

What makes it special?
The Tecnai is a robust microscope, and more user friendly than other microscopes at DTU Cen. It has an Oxford Instruments INCA EDS system and a GIF Tridiem for analytical electron microscopy. The GIF Tridiem is the 3rd generation of post-column energy filters, combining 3rd-order spectrometer aberration correction with a high-speed, high-resolution CCD sensor.

Titan Analytical

HAADF image of a nanowire (top) and high-resolution detail of it (bottom)



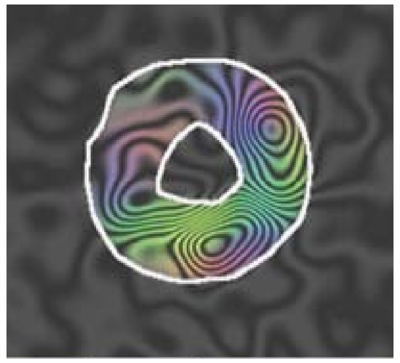
What is it?
The Titan Analytical (or A-Titan) is a 120-300kV transmission electron microscope (TEM) with a field-emission gun (FEG). It has a probe C_S corrector for atomic resolution scanning transmission imaging (STEM), a monochromator, an energy filter, a Lorentz lens, a biprism, an Energy dispersive X-ray spectroscopy (EDS) detector and tomography capabilities. It is especially suitable for studying the structures and chemistry of materials with the highest spatial resolution as well as electromagnetic properties.

Atomic-resolution studies
The A-Titan is special because it has a probe-corrector that enables it to perform analytical studies with sub-Ångstrom resolution. A small electron probe is formed and scanned across the sample and the electrons emanating from the sample can then be collected to form an image. The electrons scattered to high angles (HAADF) provide elemental contrast whereas lower scattering angles provide morphological and crystallographic information. The small electron probe can be used to elucidate local crystallographic information within a sample.

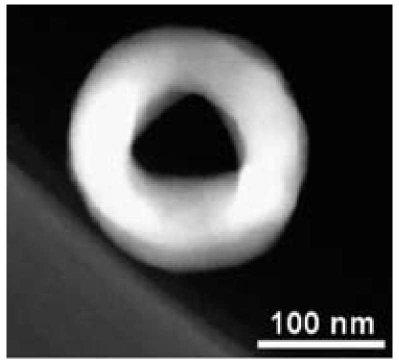
Tomography and holography
TEM images are two-dimensional projections of a three-dimensional structure. The A-Titan can be used for electron tomography, a technique which has been used in medicine for a long time, and which has now been applied into the field of nano research and in particular into electron microscopy. In short, it is a technique that involves retrieval of the three-dimensional spatial/chemical distributions in a given sample using dedicated sample holders, detectors and reconstruction algorithms.

The A-Titan is also equipped with a Lorentz lens and a biprism extending its capabilities to perform magnetic and electrostatic studies. Samples in a TEM

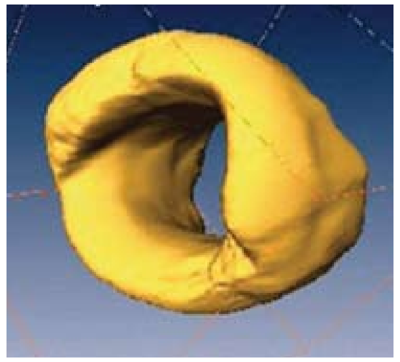
Magnetic field



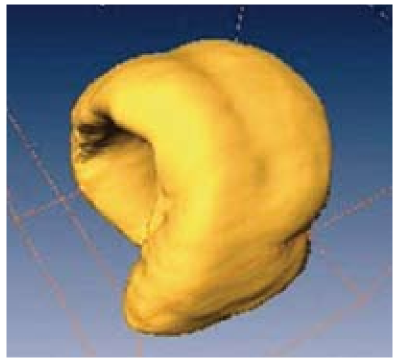
Density



3D shape



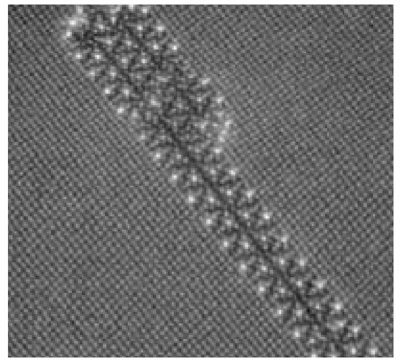
3D shape



Correlation between magnetic and three-dimensional shape of magnetite nanoring

Image of crystal containing silicon, magnesium, copper and silver in an Aluminum matrix.

Acquired by High Angle Annular Dark Field using the probe corrected Titan Analytical. Sample from Calin Marioara.

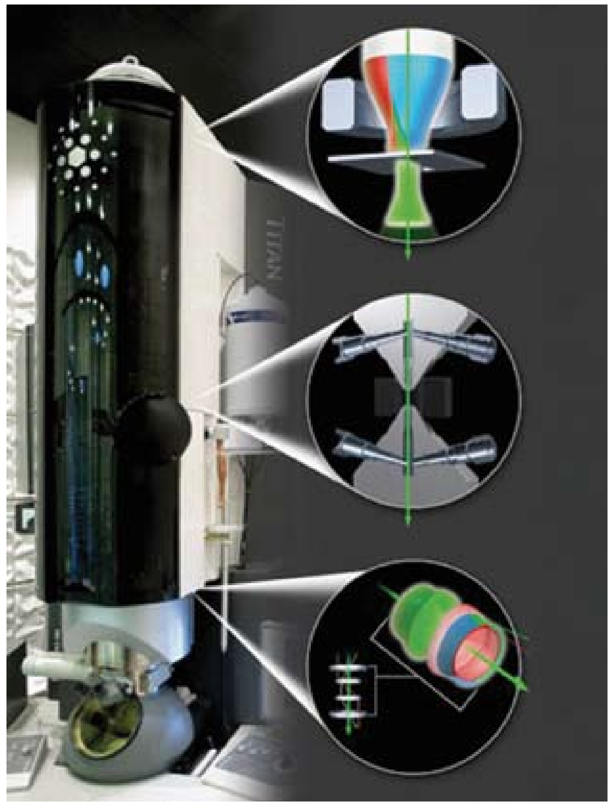


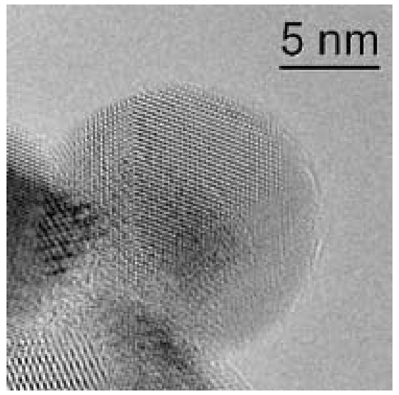
are usually subjected to the strong magnetic field of the objective lens which modifies the intrinsic magnetic field of the sample. Thus, magnetic properties of samples cannot be measured undisturbed. The Lorentz lens, in contrast to conventional magnetic lenses, is specifically designed so that TEM samples are in a field-free condition so that the intrinsic magnetism of the sample can be analysed. Furthermore, by using a Möllenstedt biprism in the focal plane of the objective lens it is possible to perform off-axis electron holography. This technique allows the phase shift of the electron wave that has passed through a sample to be determined quantitatively. As the phase shift is sensitive to the in-plane component of the magnetic induction and the electrostatic potential in the specimen, an electron hologram can be used to provide quantitative information about magnetic and electric fields. Examples of applications include the magnetic interaction in arrays of nanoparticles, dopant distributions in semiconductor devices and electrostatic fields around nanotubes and nanowires.

Monochromator and microanalysis
The A-Titan is equipped with a monochromator to limit the energy spread of the electrons used for imaging and spectroscopy. Electron energy-loss spectroscopy (EELS) and EDS yield compositional information about the sample and can be combined with linescans or maps to determine compositional variations across the sample. Using the monochromator the energy resolution of EELS spectra is improved down to 0.15 eV. Monochromated analysis provides increased energy resolution and further insight into valence states and band gap properties of, for example, semiconductor materials. In the low-loss range, the optical response of materials like dielectric constants and surface plasmons can be measured at the nanometer scale.

Titan E-Cell

Schematic view of the Titan E-Cell features. From top: Monochromator, Environmental Cell and C_S image corrector (Claus Lunau).





Ag particle supported on CeO_2. The sample is a catalyst for liquid phase oxidation reactions. (Sample provided by Matthias Josef Beier and Jan-Dierk Grunwaldt)

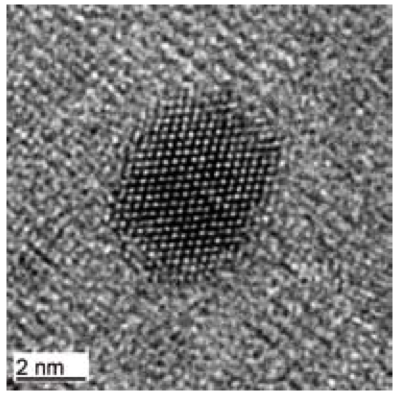


Image of Au particle supported on Al_2O_3 recorded at 0.5mbar of N_2. The sample is a catalyst for methanol synthesis.

What is it?
Studying gas-solid interactions on the atomic scale is important in several material problems. Examples include the fundamental understanding of the working state of catalysts, growth mechanisms, functionalized surface coatings and failure analysis, including deterioration of stainless steels and solid oxide fuel cells. An understanding of the materials on a microscopic level provides invaluable information for tailoring and tuning materials properties on the macroscopic level for optimized industrial performance.

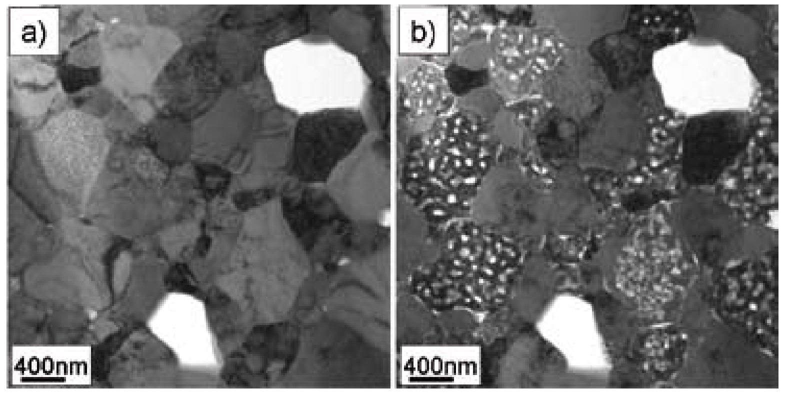
Only few facilities in the world provide capabilities for investigating gas-solid interactions on the sub-Ångström scale (1 Ångström= 0.1 nm.) The Titan E-cell or simply ETEM at DTU Cen, is a unique state-of-the-art monochromated and image C_S corrected transmission electron microscope equipped with an environmental cell, making it possible to locally study gas-solid interactions at the atomic level under controlled gaseous atmospheres at elevated temperatures.

By acquisition of high frame-rate movies, gas-solid interactions can be temporally investigated. This provides insight into reaction kinetics, for instance, by tracking particles over time or directly monitoring growth and morphology of nanostructures.

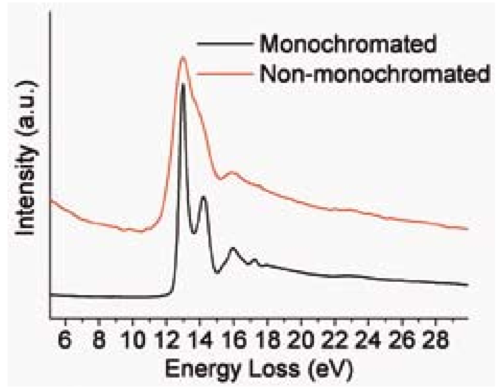
We are now able to follow the local atomic configuration of atoms at the surface of catalyst particles in various working states with high precision. This direct information, combined with interdisciplinary studies, gives a unique foundation for a scientific understanding of catalyst systems. These capabilities will be further exploited.

How are the samples imaged?
The Titan E-Cell provides two distinct ways of imaging (TEM and STEM) using electrons with a specific energy of 80kV, 200kV or 300kV. Having a range of energies available increases the flexibility of the instrument for optimal image conditions which vary with the materials studied. In TEM mode, electrons pass through the sample and are magnified

In situ reduction of a fuel cell anode. a) before reduction at room temperature. b) after in situ reduction in 1.3mbar H_2 at 500°C.



Electron energy-loss spectrum of nitrogen gas showing the improved energy resolution by using the monochromator.



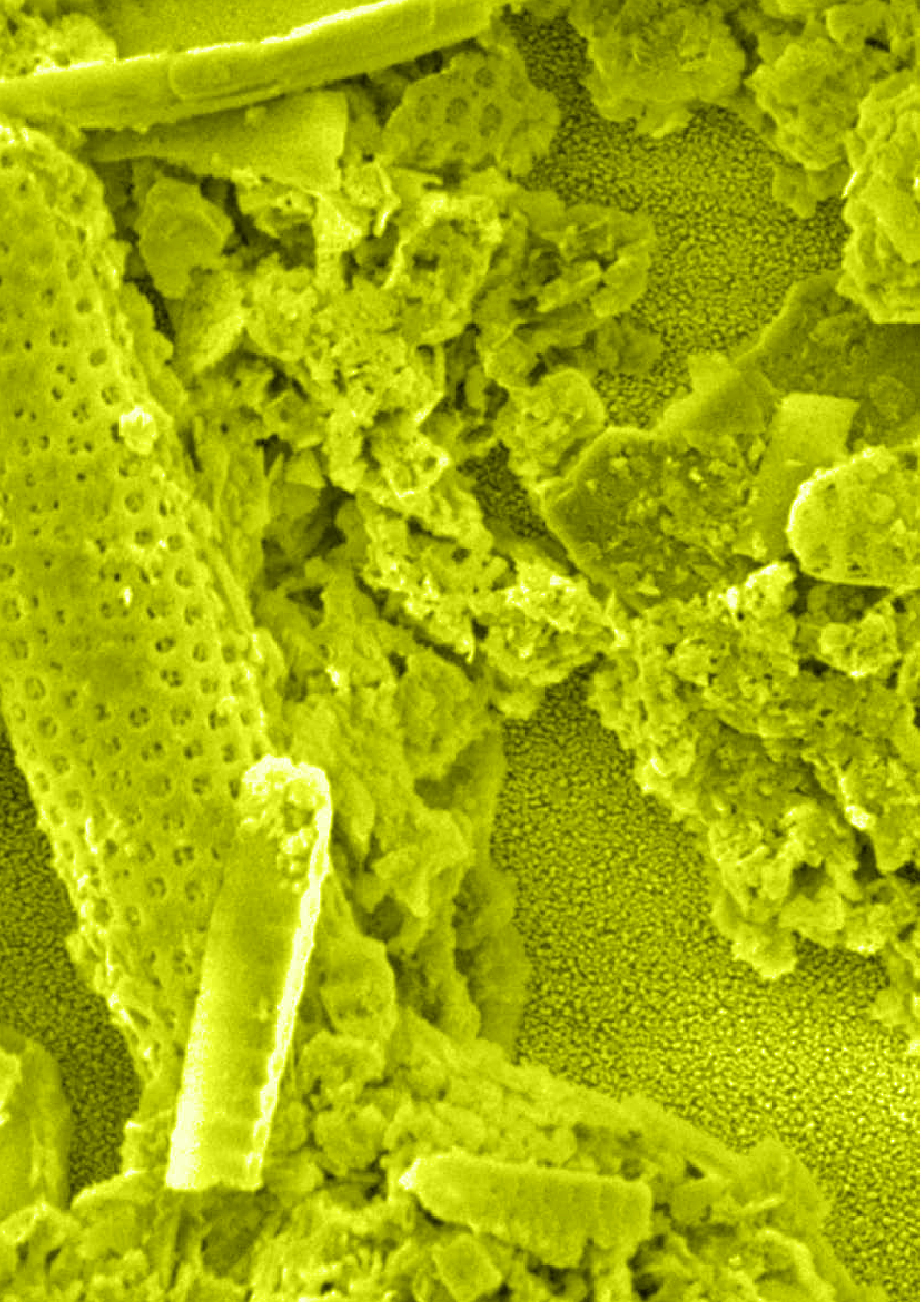
onto a screen as a projected image of the sample, providing morphological and crystallographic information. In STEM mode, the electrons are focused to a probe with a diameter of less than 0.2 nm. This probe is raster scanned across the sample and the electrons emanating from specific points of the sample are collected to form an image. Electrons scattered to high angles provide contrast varying with the atomic number of the atoms in the sample, whereas lower scattering angles provide morphological and crystallographic information. Aside from being used for imaging, the energy lost by electrons traversing the sample can be analyzed by electron energy-loss spectroscopy providing compositional as well as chemical state information of materials, both purely spectroscopically and spatially linked to the sample.

Image C_S Corrector
Traditionally, the spatial resolution of transmission electron microscopes is limited by aberrations in the electromagnetic lenses. These aberrations distort the formed image in such a way that it is hard to directly interpret features separated by less than 0.2 nm. The aberrations are corrected by additional electromagnetic lenses to a great extent so that features separated by less than 0.1 nm (comparable with projected interatomic distances) can be directly interpreted. A further benefit of the image corrector is the removal of delocalization effects in the images which complicates direct interpretation of surface and interface structure.

Environmental cell
The understanding of gas-solid interactions is of great importance in e.g. heterogeneous catalysis, where changes in the atomic structure and nanoparticle shape of the solid catalyst phase might change the catalytic performance significantly. In order to study these interactions in real time, the Titan E-Cell TEM at DTU Cen is equipped with an environmental cell allowing us to let gas into the microscope column without significantly affecting the spatial resolution. The basic idea of the environmental cell is to confine the gas to a small region around the sample. This is accomplished by limiting the gas diffusion through the column by inserting extra apertures and pumps. In this way the volume with high gas pressure is minimized along the electron beam path. A conventional electron microscope requires high vacuum around the specimen in order to maintain high resolution and proper operation.

Monochromator
The Titan E-Cell is equipped with a monochromator to decrease the energy spread of the electrons used for imaging and spectroscopy. Monochromated spectroscopic analysis provides improved resolution and further insight into valence states and band gap properties of e.g. (photo)catalytic and semiconductor materials.

Additional features
Taking advantage of the high resolution provided by the microscope, spatially resolved elemental analysis can be carried out by Energy Dispersive X-ray spectroscopy (EDS). As an example, the successful alloying of materials can be confirmed and the presence of contaminants determined. A common issue in electron microscopy is carbon contamination of the sample due to hydrocarbons initially present on the specimen surface decomposing in the electron beam. The Titan E-Cell is equipped with an in situ plasma cleaner allowing removal of these hydrocarbons from the specimen and the interior of the microscope thus reducing a major source of carbon contamination.



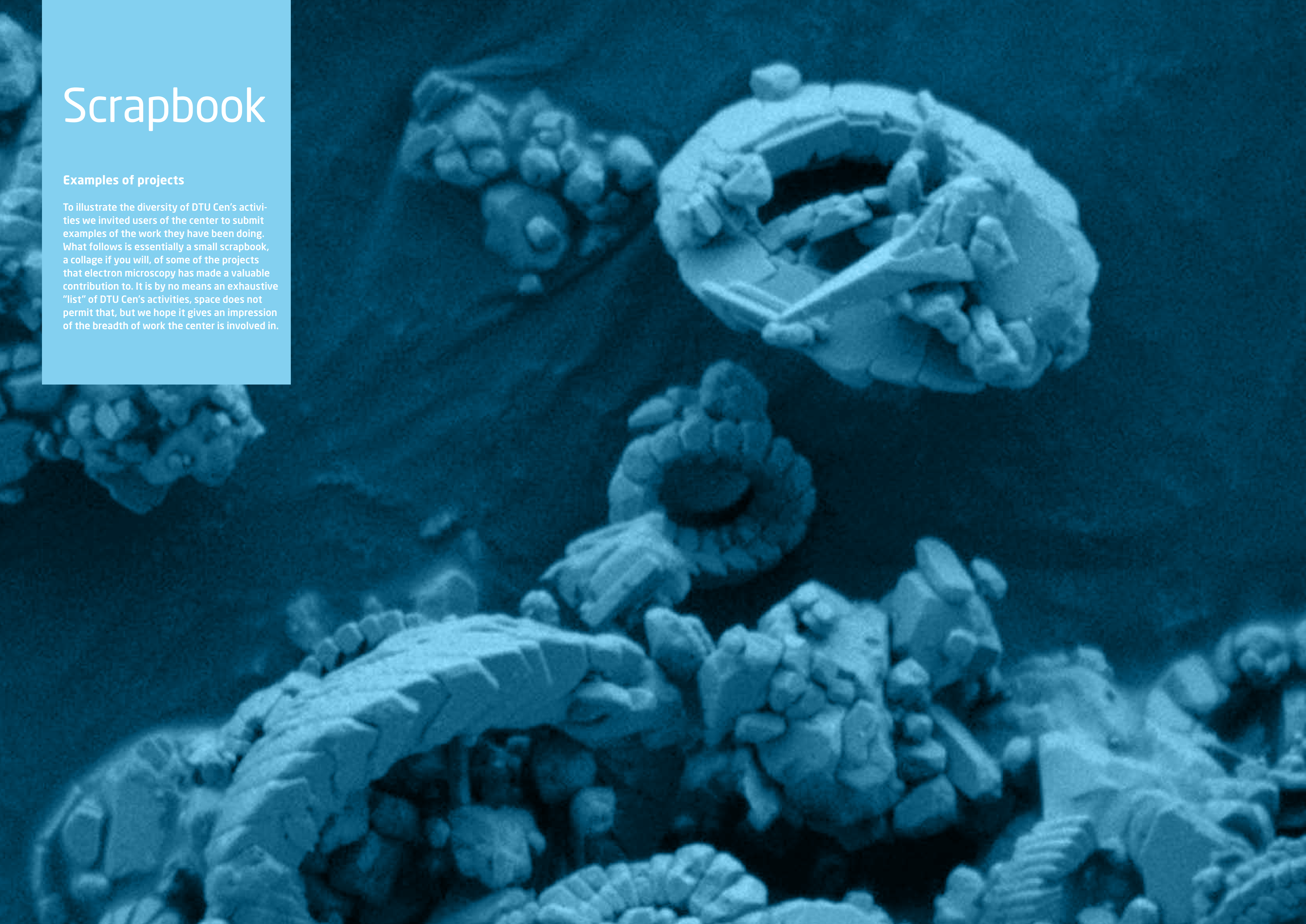
Funding

2009 - 2014 **UNIK grant** with Prof. J. Nørskov (PI), Prof. I. Chorkendorff, Prof. J.Grunwaldt, Prof. C. H. Christensen and Prof. M. Mogensen. Title: **"The Catalysis Discovery Initiative: Sustainable Energy Solutions".**	**120M Dkr (€16.1M)**
2009 - 2014 **ERC-2008-AdG grant** (proposal 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**
2009 **Otto Mønsted fellowship** to support a visiting guest professor in the Technical University of Denmark (M. R. McCartney from Arizona State University).	**186k Dkr (€25k)**
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**
2008 - 2011 **FTP grant** with Dr. P. Boggild (PI), Prof. A.-P. Jauho, Prof. T. Garm Pedersen and Dr. M. Brandbyge. Title: **"Nanoengineered graphene devices".**	**5.6M DKr (€750k)**
2008 - 2011 **Villum Kann Rasmussen Center of Excellence** headed by Prof. J. Mørk (PI). Title: **"NAnophotonics for TErabit Communications (NATEC)".**	**25M Dkr (€3.35M)**
2008 - 2011 **FTP grant** with Dr. K. Pantleon (PI) and Prof. M. Somers. Title: **"Grain boundary engineering of functional thin films".**	**4.1M Dkr (€550k)**

Scrapbook

Examples of projects

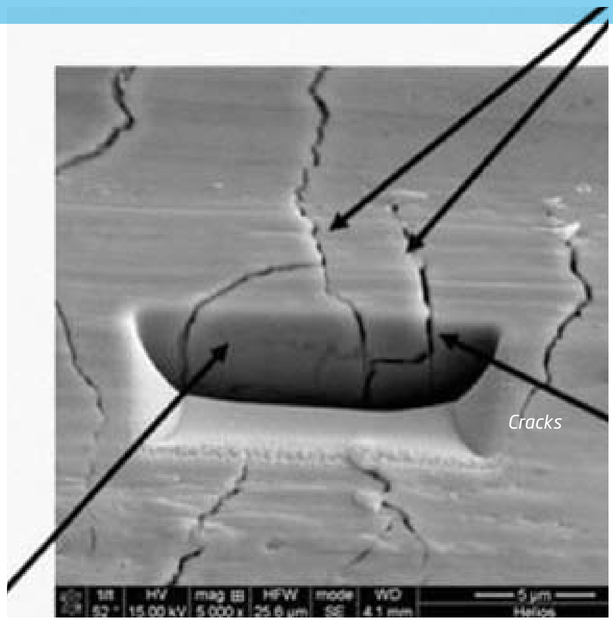
To illustrate the diversity of DTU Cen's activities we invited users of the center to submit examples of the work they have been doing. What follows is essentially a small scrapbook, a collage if you will, of some of the projects that electron microscopy has made a valuable contribution to. It is by no means an exhaustive "list" of DTU Cen's activities, space does not permit that, but we hope it gives an impression of the breadth of work the center is involved in.



Failure analysis of artificial hip implants

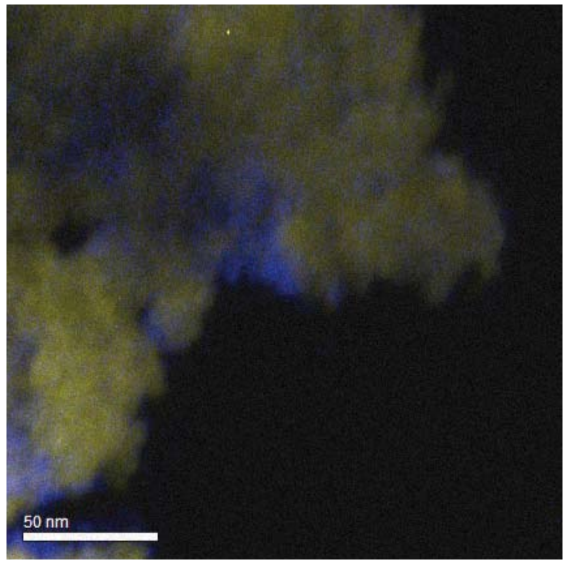
Trine Colding Lomholt, Karen Pantleon, Marcel A.J. Somers, Per Møller, DTU Mechanical Engineering
and Alice Bastos da Silva Fanta, DTU Cen

In this project FIB-SEM combination was applied to prepare cross sections and reveal the shapes and distributions of cracks in titanium based hip implants.



EFTEM, HRTEM, HAADF of NiO particles on hematite

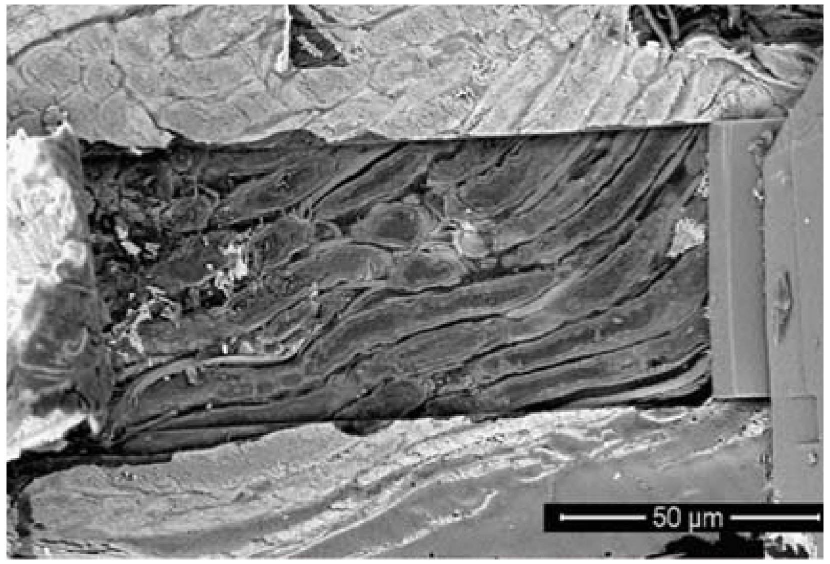
Cathrine Frandsen, DTU Physics



In-situ microtome with Smaract robot

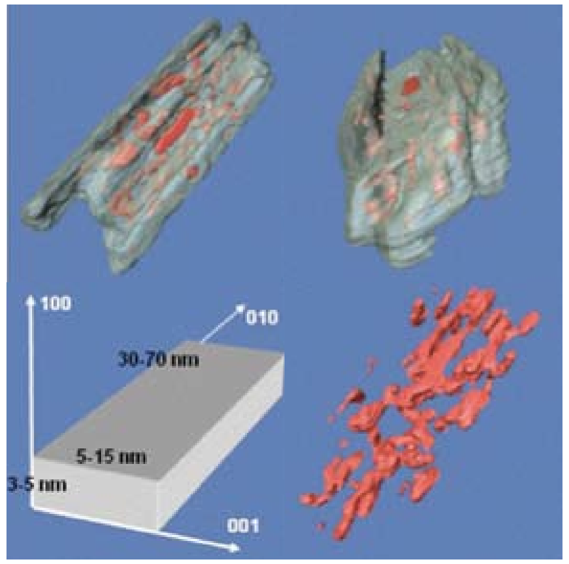
Kristian Mølhave, Lasse Høgstedt, Qi Hu and Søren Friis, DTU Nanotech

A resin embedded tissue sample was imaged through slice-and-view using an in-situ microtome. A FIB-SEM was used to cut a sharp knife from a silicon cantilever, which is then used as a knife mounted on a Smaract MCS-H3D actuator with position feedback. Repeated clean cuts can be made down through the sample (resin embedded and stained rat muscle).



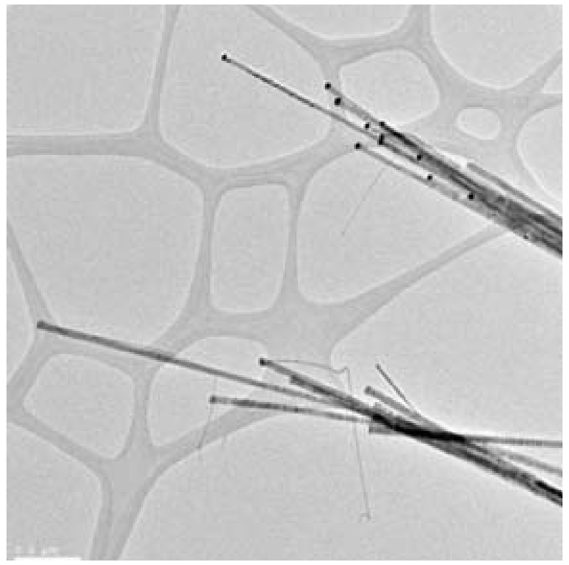
Studies on the structure of goethite crystals and its relation to its magnetic and chemical properties

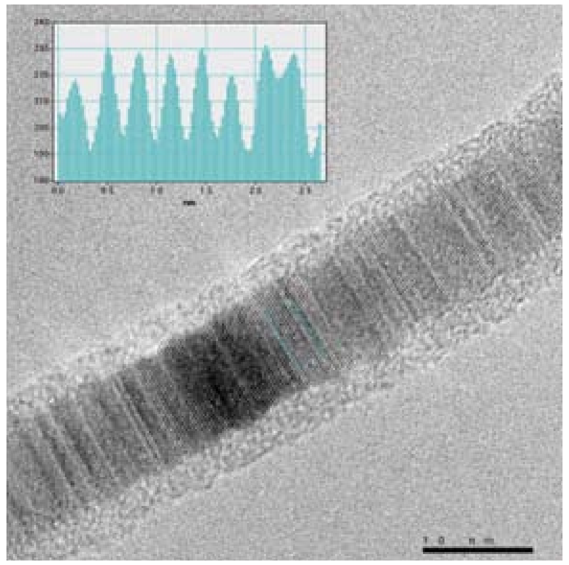
Steen Mørup, DTU Physics



HRTEM, DF and BF TEM of nanowires

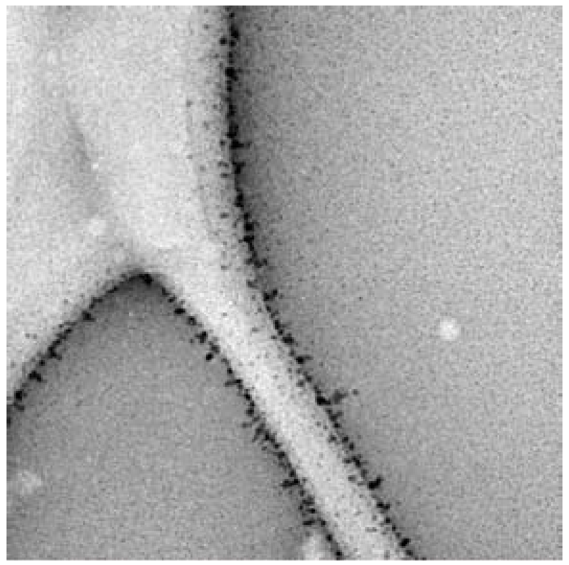
Christian Kallesøe, DTU Nanotech

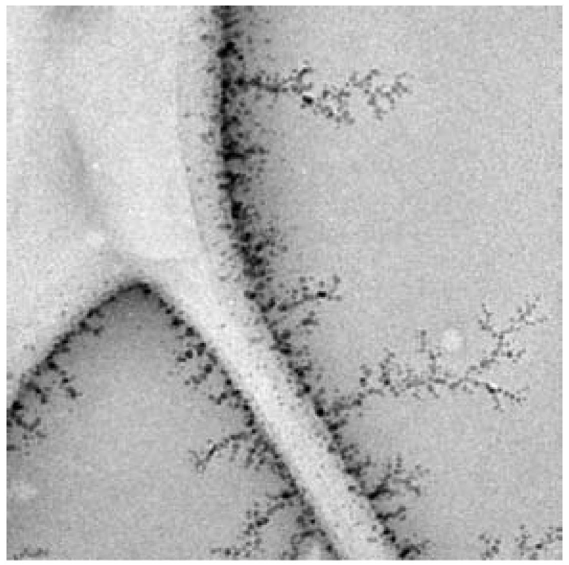




Characterization of dentritic growth of nanoparticles induced by the electron-beam

Christian Kallesøe, DTU Nanotech

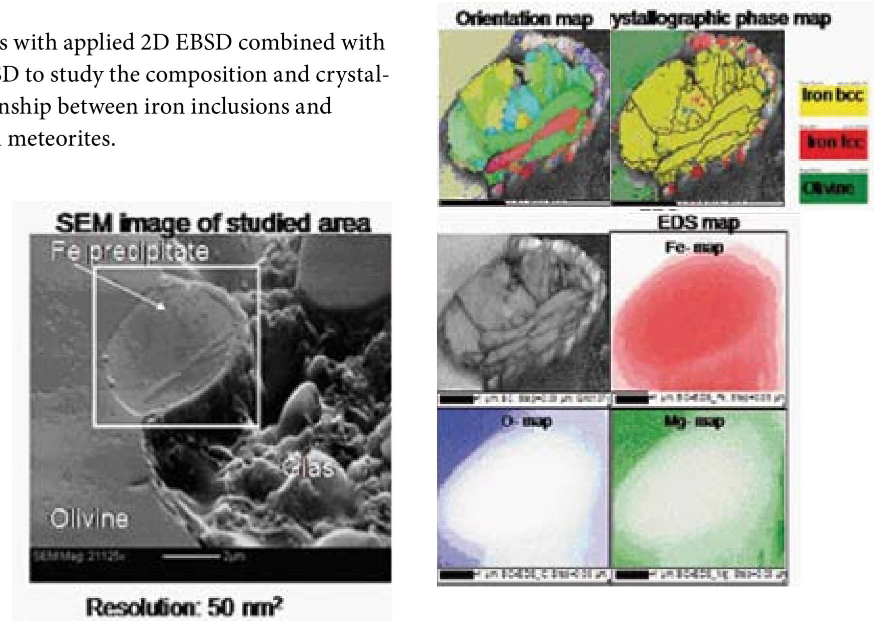




Characterization of iron inclusions in olivine $(Mg, Fe)_2SiO_4$

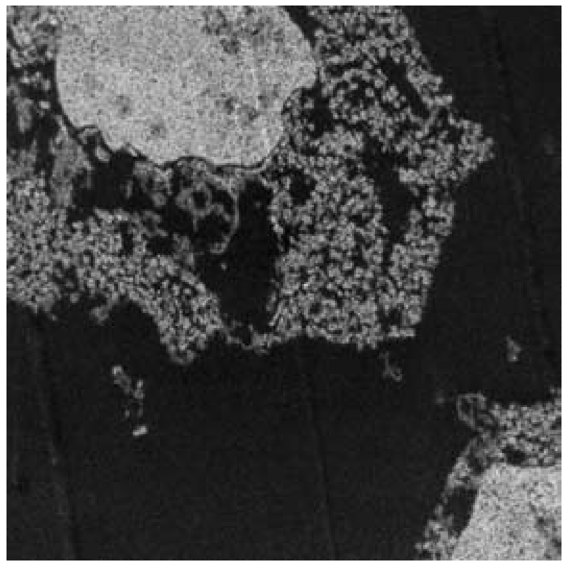
Alice Bastos da Silva Fanta, DTU Cen and Richard J. Harrison, University of Cambridge, UK

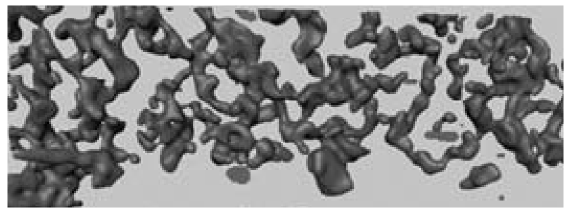
This project deals with applied 2D EBSD combined with EDS and 3D EBSD to study the composition and crystallographic relationship between iron inclusions and olivine matrix in meteorites.



Studies on structures of chromatin molecules in rat cells

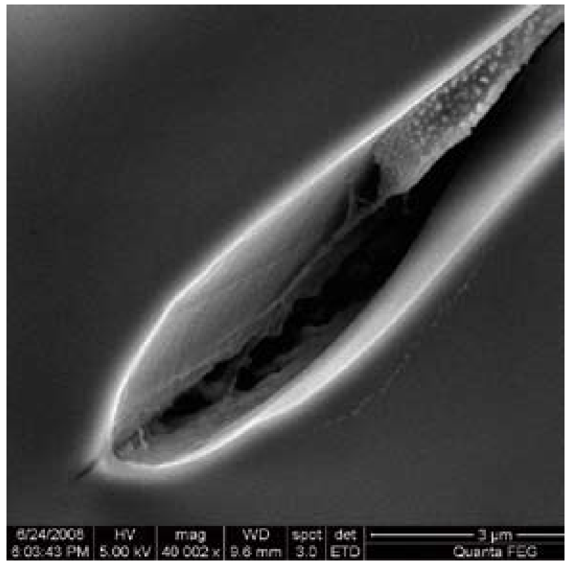
Mogens Engelhardt, University of Copenhagen

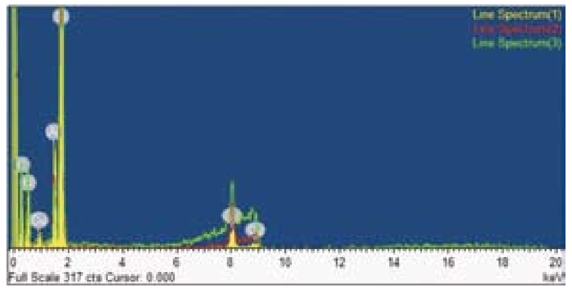




SEM study of novel wet cell for TEM in-situ experiments of liquids and solutions

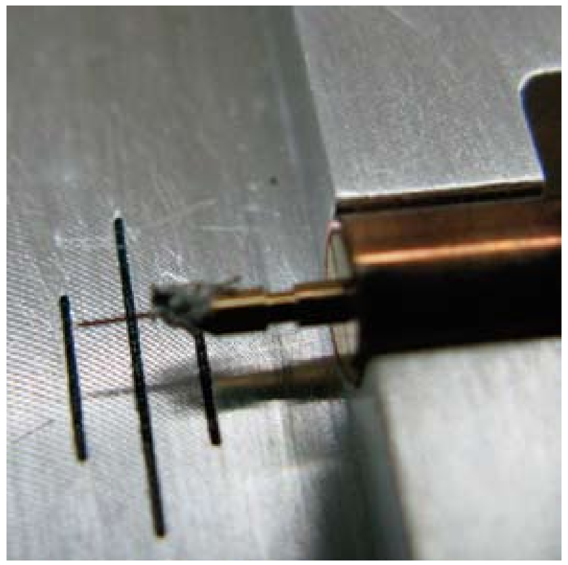
Christian Kisielowski, NCEM, Berkeley, USA





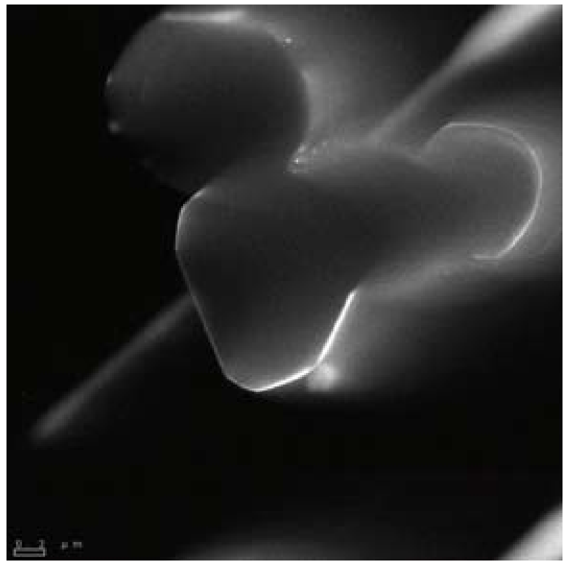
HAADF STEM tomography of small SiO_2 and Al_2O_3 nanoparticles mounted on a tungsten tip

Francesco Marinello, Universita' Degli Studi di Padova, Italy



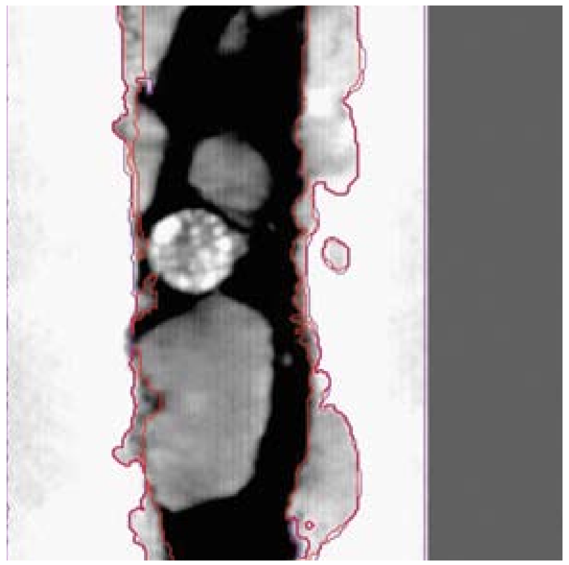
Studies on fluorescent materials (ZnO) for new TEM holder integrated with optical fiber

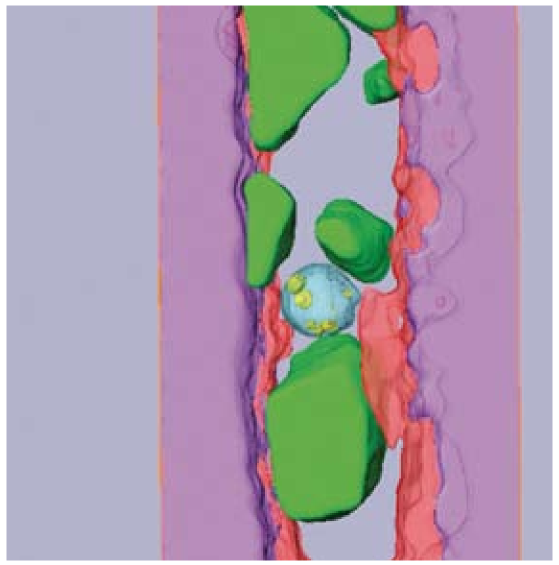
Kristian Mølhave, DTU nanotech



BF TEM and HAADF STEM tomography of Cr distribution in cracks in steel

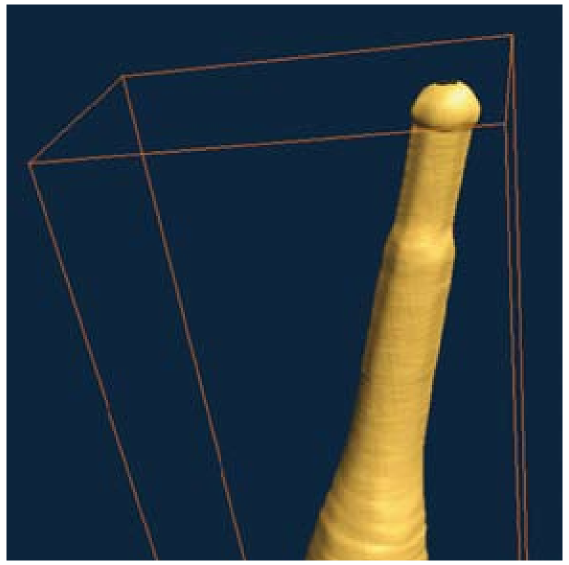
Sergio Lozano-Pérez, University of Oxford, UK





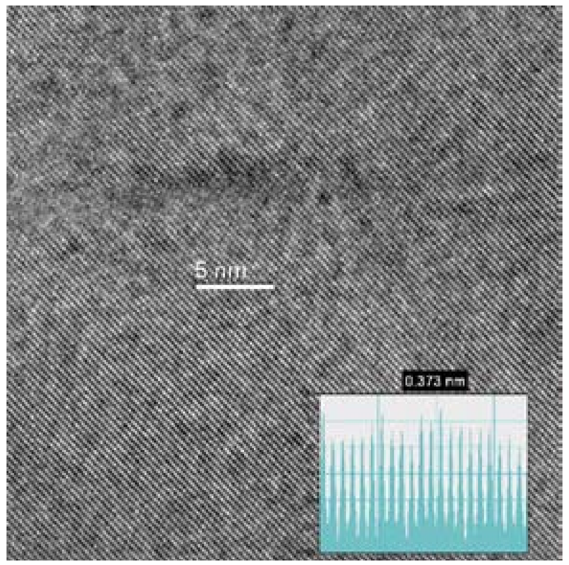
HAADF STEM tomography and HRSTEM imaging of semiconductor flakes and nanowires

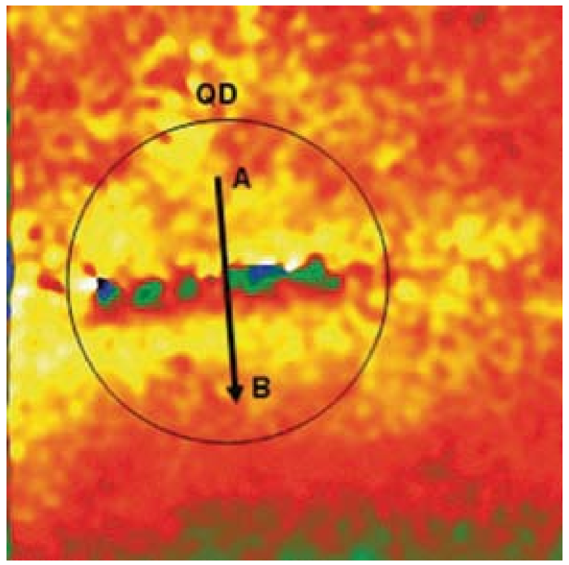
Peter Krogstrup, University of Copenhagen



Characterisation of embedded quantum dots using geometrical phase analysis, HAADF STEM and HRTEM

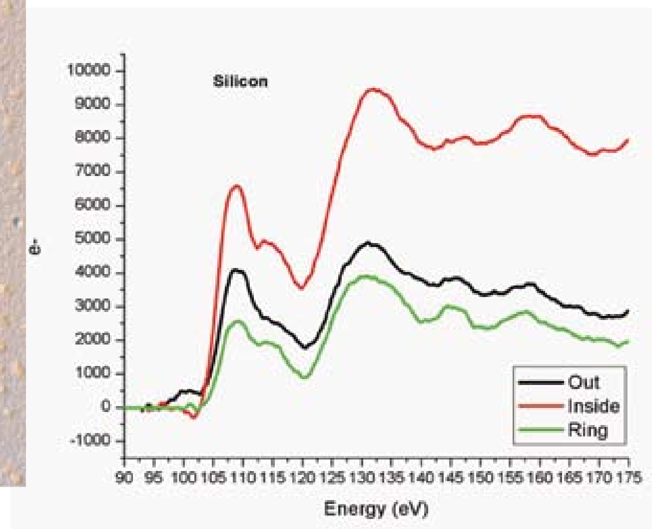
Kresten Yvind, DTU Fotonik





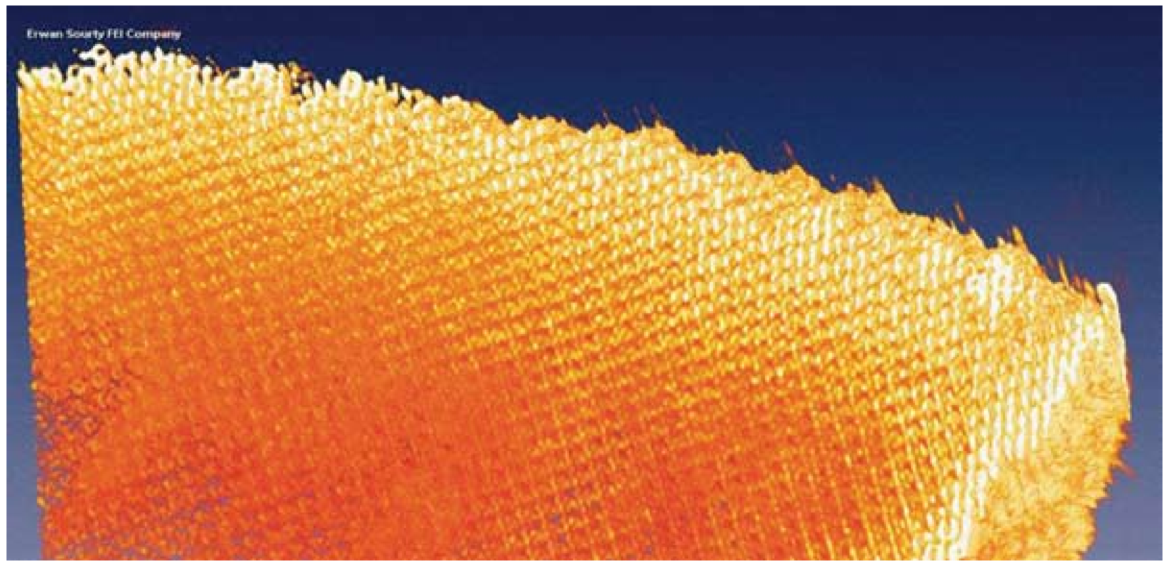
Study of modifications to Ge-doped silica glasses by high-energy electron probes

Haiyan Ou, DTU Fotonik



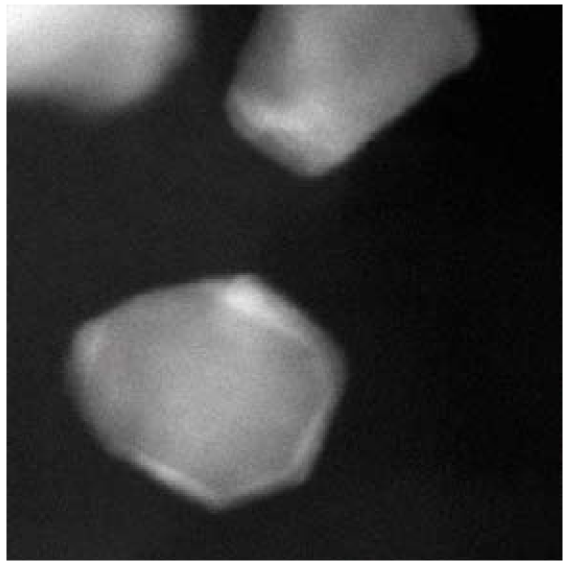
Study of microtomed sections of block copolymers

Andy Horsewell, DTU Mechanical Engineering



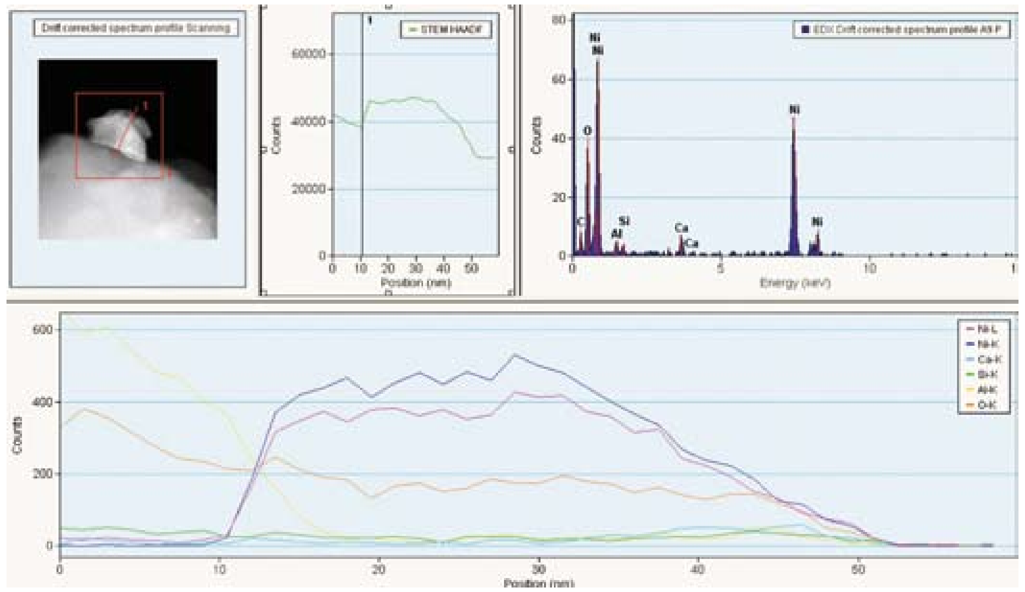
HRSTEM of core-shell particles

Johnson Matthey, UK



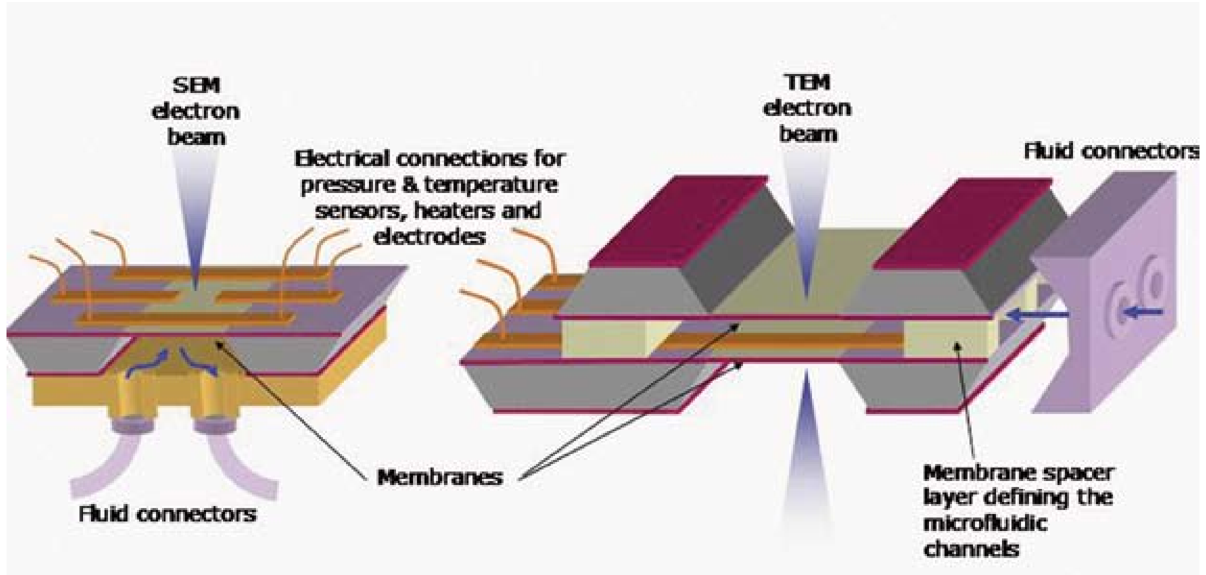
HRTEM and compositional mapping of Pt alloys on carbon

Johnson Matthey, UK



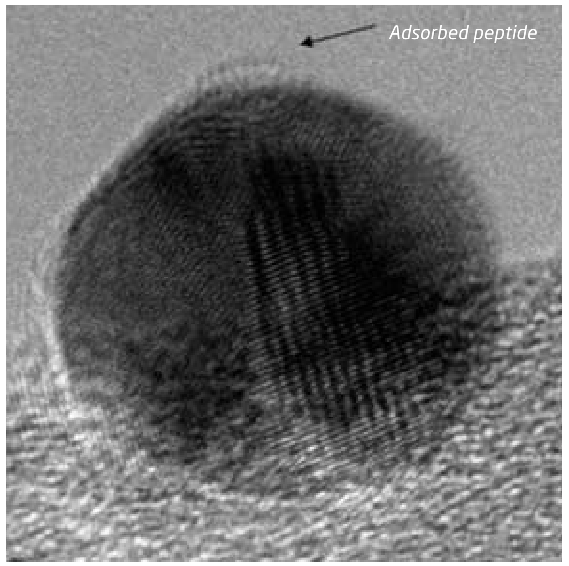
Fabricating microfluidic system with thin film membranes that enable imaging processes in liquids behind the membrane

Kristian Mølhave, DTU Nanotech and Søren Friis



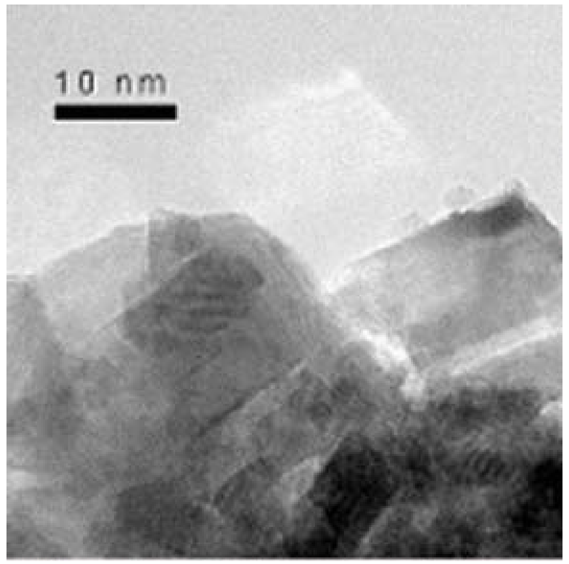
Study of the interaction of peptides with gold particles

Leticia Hosta, University of Barcelona, Spain



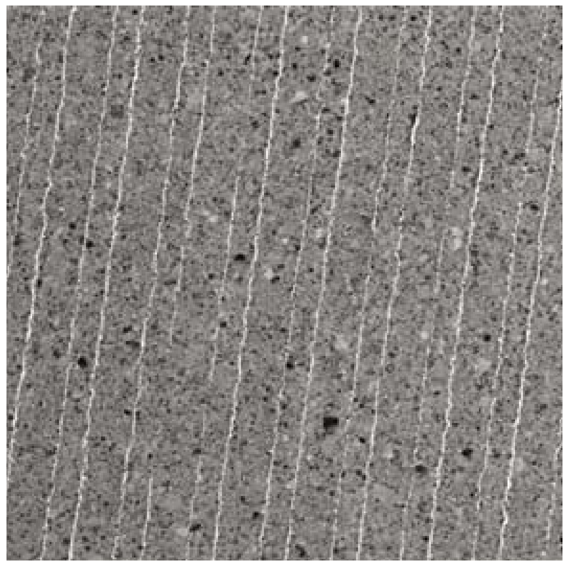
HRTEM studies of heterogeneous catalysts

Jan-Dierk Grunwaldt, DTU Chemical Engineering



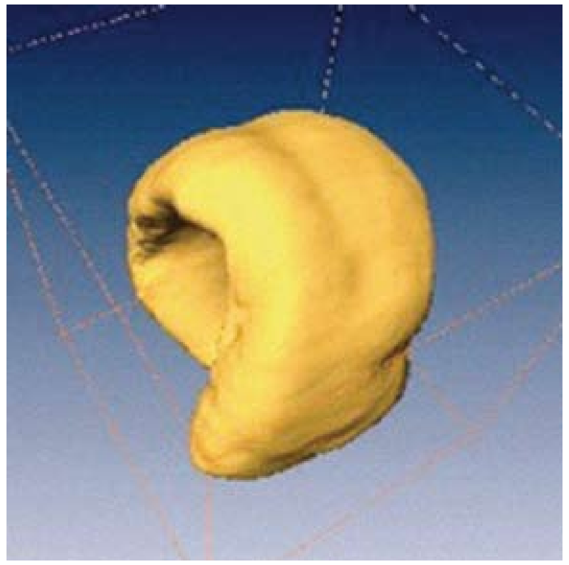
DF imaging and BF TEM tomography of gold coated patterned samples

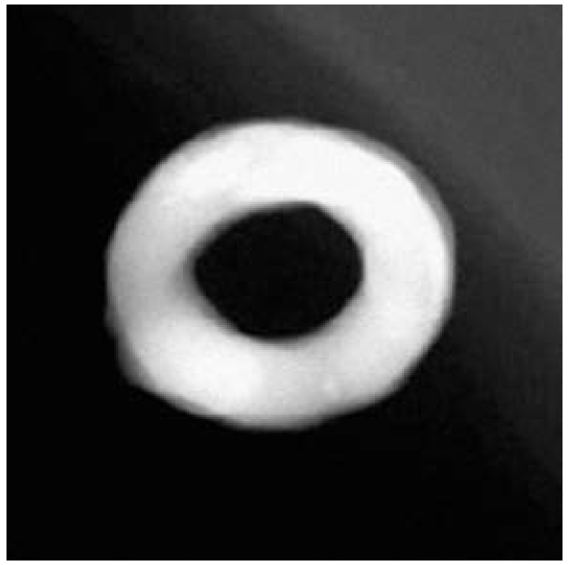
Kristian Mølhave, DTU Nanotech



HAADF STEM tomography of magnetite nanorings

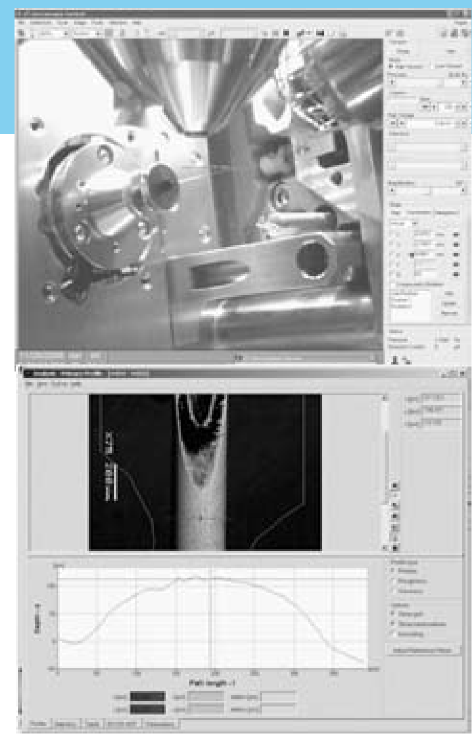
Matthias Eltschka, University of Konstanz, Germany





Metrology studies

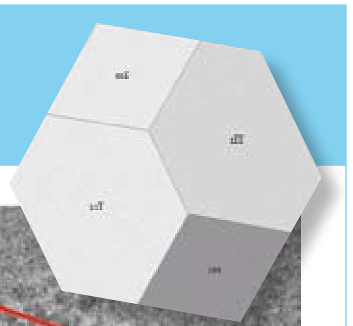
Lorenzo Carli, Daniele Santin, Mauro Caroli,
DTU Mechanical Engineering

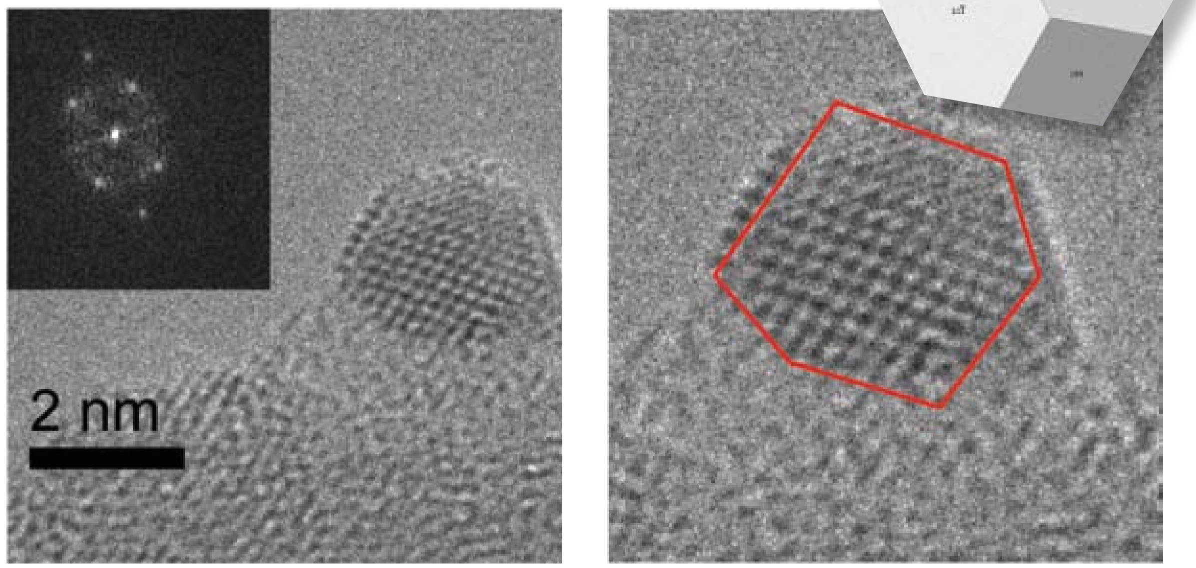


An experimental investigation of geometrical measurements on cylindrical items was carried out at DTU Cen using the FEI Inspect 'S' SEM. Two items were measured: a wire gauge which had a 0.25 mm nominal diameter and a hypodermic needle which had an external diameter of 0.26 mm. The wire gauge was used as a reference artefact to establish measurement traceability. A series of measurements were performed to determine the accuracy of 3D reconstructions obtained using stereo-photogrammetry methods, finding a procedure to determine the optimum number of rotations of the object for an acceptable measuring uncertainty.

HRTEM and HAADF STEM of Au nanoparticles supported on TiO_2, Al_2O_3 and ZnO

Guido Walther, DTU Center for Individual Nanoparticle Functionality





Grain boundary engineering of functional thin films

Hossein Alimadadi, Karen Pantleon, Marcel A.J. Somers, DTU Mechanical Engineering & Alice Bastos da Silva Fanta, DTU Cen

In August 2008, a PhD project on grain boundary engineering in functional thin films, started at DTU Mechanical Engineering in close collaboration with DTU Cen. Applying the Helios microscope the project aims to investigate the grain boundary characteristics and the crystallography of grain boundary planes in nanocrystalline films. Quantitative 2D EBSD on cross sections will be extended into the third dimension by successive serial sectioning using FIB milling. Based on the complete 3D microstructure characterization including local orientation relations between grains as well as the spatial distribution of the grain's size, shape, crystallographic orientation, and boundary types, functional properties of the films will be tailored.

Microstructure evolution during friction stir welding

Trine Colding Lomholt, Marcel A.J. Somers, Karen Pantleon, DTU Mechanical Engineering and Alice Bastos da Silva Fanta, DTU Cen

In October 2008, a PhD project has started on the characterisation of the microstructure evolution during friction stir spot welding of TRIP and TWIP steel. The material characterization involves investigation of the microstructure and associated properties and will be performed on the welds, the heat affected zones (HAZ) and their immediate surroundings. Reflected light microscopy as well as scanning electron microscopy (SEM) and transmission electron microscopy (TEM) will be applied for the determination of grain size and grain shape distributions and identification of the morphology. The equipment for reflected light microscopy and electron microscopy is available at DTU Mechanical Engineering, Risø DTU and DTU Centre for Electron Nanoscopy. In particular the 3D characterisation of welds with the newly acquired Helios Dual Beam FIB-SEM at DTU Cen is expected to yield unique results. X-ray diffraction and electron diffraction techniques will be applied for identification of the phases constituting the microstructure. Also texture development in and around the welds will be determined, primarily with Electron Backscatter Diffraction (EBSD) techniques, also on Helios Dual Beam FIB-SEM at DTU Cen. Residual stress distributions (both micro and macro stress) in and around the welds will be determined with X-ray diffraction. The microstructural details will be compared to micro-hardness distributions, which are a measure for the distribution of mechanical properties around the weld.

Orientation map of TWIP steel

Phase map of TRIP steel

Cleaning and in-situ lithography of graphene membranes in the Titan ETEM

Tim Booth, DTU Nanotech

Graphene is an exciting new material consisting of a monolayer of carbon atoms, analogous to an unrolled nanotube. Using the Environmental Titan we can take TEM images of graphene membranes with atomic resolution with small partial pressures of gases such as oxygen and hydrogen in the column, also at elevated temperatures. In contrast to the normal situation of imaging depositing amorphous carbon, we have observed regimes where the graphene membranes are cleaned by the beam, and even controllably etched. This work suggests that sub-nm scale lithography on individual graphene membranes is be possible, allowing the properties of graphene to be tailored and novel devices to be constructed and tested in the Titan ETEM in-situ.

Fuel cells

Signe Shim DTU Physics

In this PhD project, which involves the study of efficient catalysts for PEM fuel cells, the Tecnai 20T TEM at CEN is used to generate the particle size distribution of the catalyst. Furthermore, the TEM is used to study the sintering process of the catalyst particles.

Microstructures in impactites

Christian Bender-Koch, University of Copenhagen

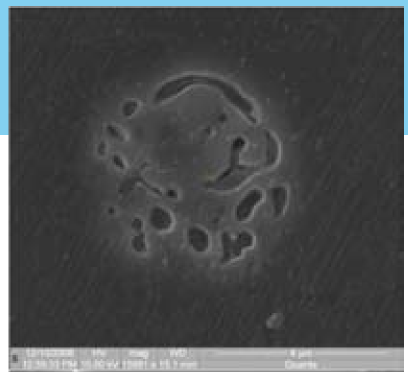
Impactites form during the focused energy release as meteoritic material interacts with the surface of the Earth. The temperature and pressure gradients during this interaction are huge and the time-span can be quite small.

Using microscopy, we attempt to establish facts of the late part of the interactions by studying, for example ”frozen-in” information captured by the material during the cooling phase. Several new types of morphological variations have been observed and stratigraphic correlations suggested.

We are particularly investigating the compositional and structural variations around the vesicles and metallic (FeNi) spherules.

Surface engineering of aluminium and its alloys

Manthana Jariyaboon and Rajan Ambat, DTU Mechanical Engineering

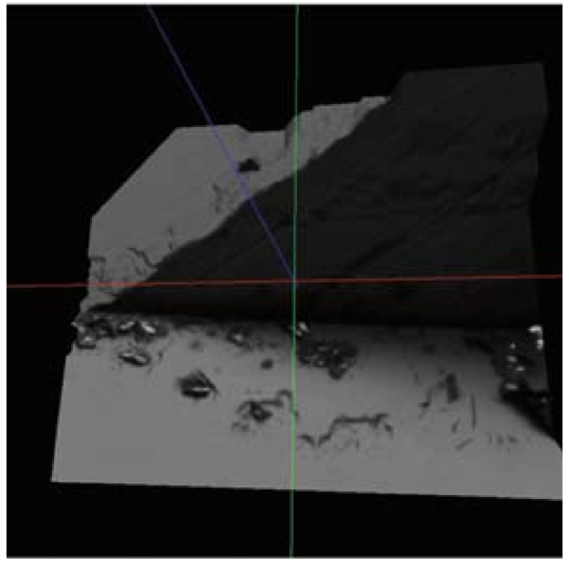


This project is in 2 parts:
1. FIB-SEM investigation of trapped intermetallic particles in anodic oxide films formed on AA1050 aluminium. The aim of this work is to understand the structure of intermetallics and localized composition changes in the oxide film using FIB-SEM, SEM and EDS.
2. Nanoscale surface modification of anodized aluminium. The aim of this work is to investigate the effect of incorporated TiO_2 nanoparticles in porous structure of anodized aluminium surface on non-wetting, self-cleaning, and anti-corrosion behaviour. The SEM images of nano-porous structure of andoized aluminium surface will be taken using FEG-SEM at CEN.

Metrology studies

Lorenzo Carli and Daniele Santin, DTU Mechanical Engineering

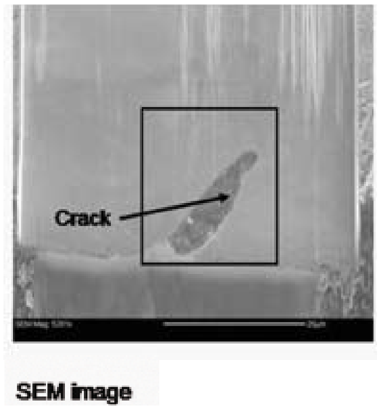
In order to better quantify the accuracy of the instrument in measuring the third dimension, an investigation has been carried on a two calibrated gauge blocks one tilted with respect to the other. The idea is to get 3D images of the system by means of the stereo photogrammetry technique and then, knowing the angle between the two items, comparing the calculated height with the measured one. This way it will be possible to evaluate the accuracy of the 3D reconstruction for different height values.

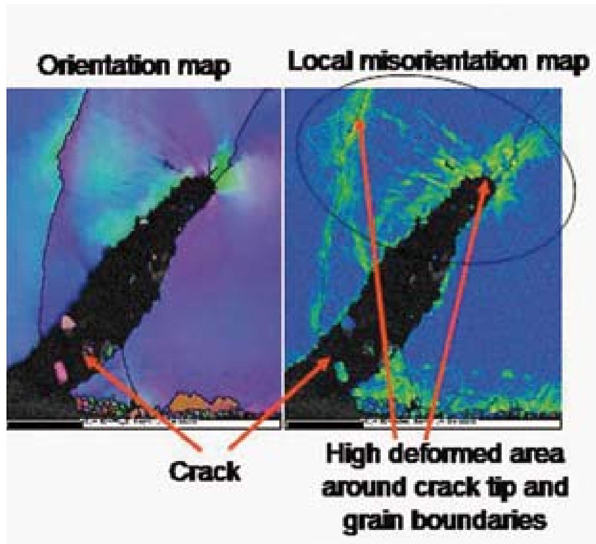


3D EBSD strain mapping of stress corrosion cracks

Alice Bastos da Silva Fanta, DTU Cen and Sergio Lozano-Perez, University of Oxford

In this project the 3D EBSD tomography is applied to understand how the alloy assumes deformation around corrosion cracks and how this deformation affects crack propagation.



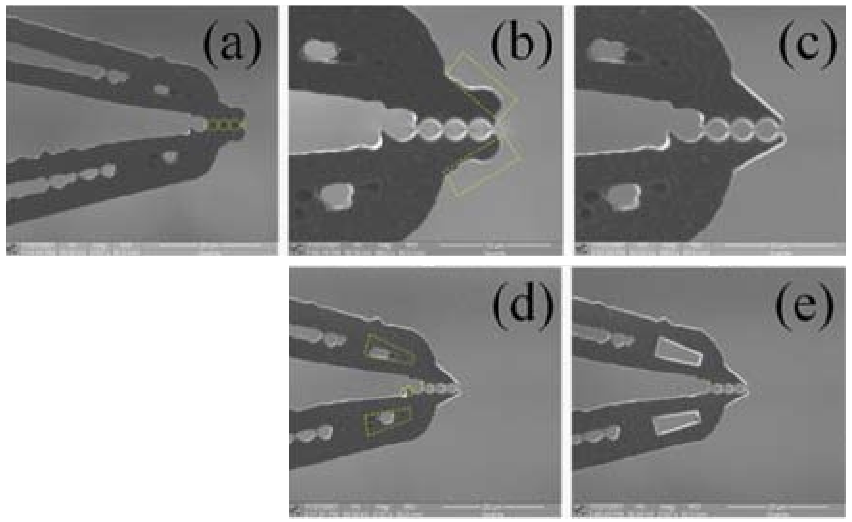


Focused ion-beam (FIB) modification of topology optimized polysilicon microgrippers

Ozlem Sardan, Peter Bøggild, DTU Nanotech

In this project, topology optimized polysilicon micro-grippers are modified using focused ion beam (FIB) milling. The main purpose is functionalizing faulty microgrippers by separating the merged end-effectors with a sub-micron gap. Furthermore, the end-effectors can be reshaped to achieve a smaller contact area with the manipulated object and the method can also be used for recovering dimensional accuracy or missing features during fabrication.
The microgrippers are designed at DTU Nanotech in collaboration with Ole Sigmund from DTU Mechanical Engineering. Fabrication of the microgrippers was performed at DTU Danchip. FIB experiments are performed at DTU Cen in collaboration with A. Nicole MacDonald.

The images demonstrate the modification of a topology optimized microgripper with fabricational defects via FIB micromachining: (a) Microgrippers before FIB modification, showing the region to be removed for separating the end-effectors. (b) Closer view after separation, showing the regions to be removed for further refinement. (c) Microgrippers with separated and functionalized end-effectors. (d) Overview before shape modification, showing the regions to be removed for recovery of features lost during fabrication. (e) Microgrippers after complete modification.



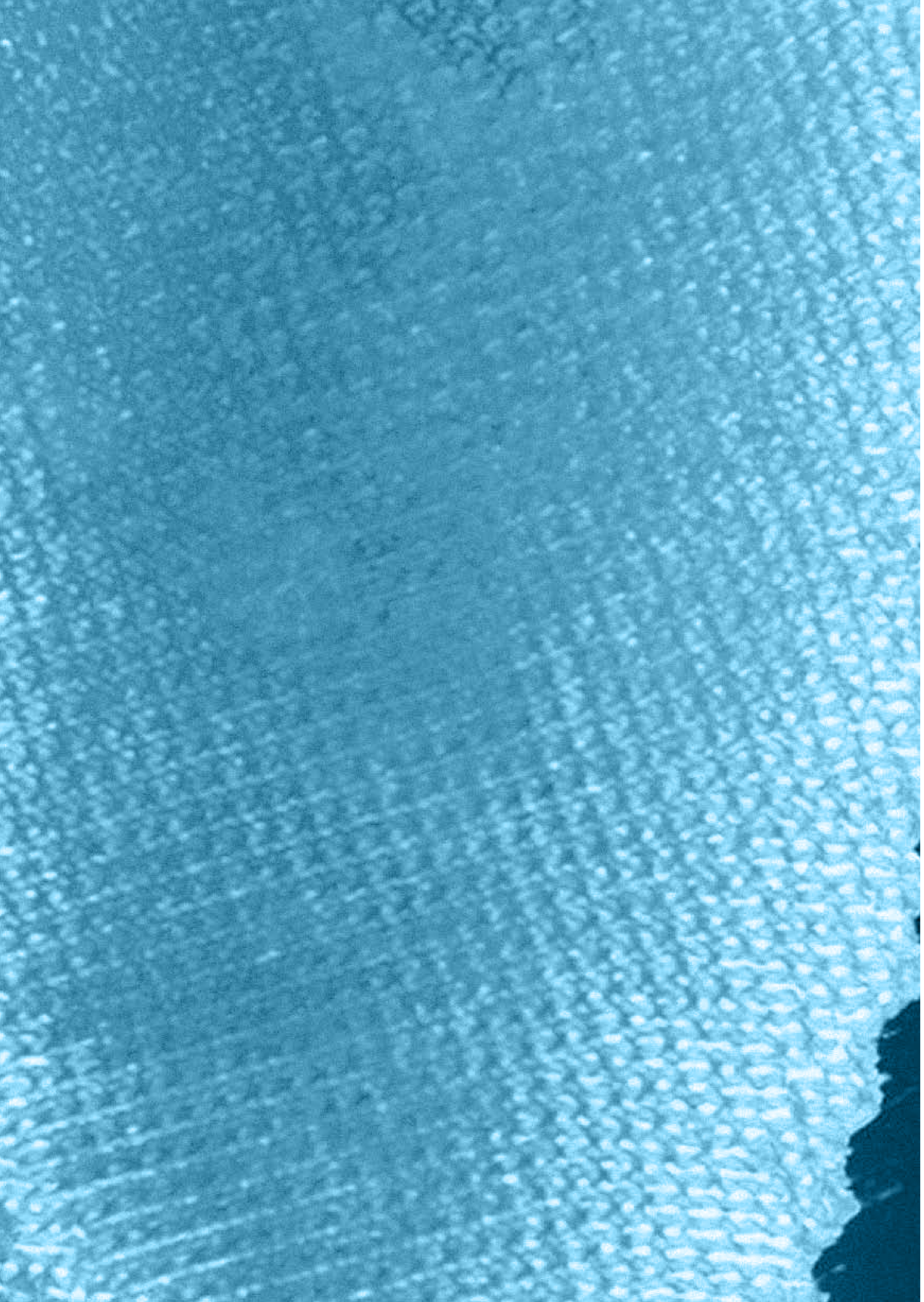
Ph.D. project

Robert Pennington, DTU Cen

The electron microscope is a versatile tool that can measure many different properties of the same sample using different characterization techniques. To pick a familiar example, a shiny metallic coin can be characterized using several senses, such as touch and sight. How the coin looks is influenced by the material composition, and how it feels is influenced by the texture. However, the texture also influences how it looks; a milled coin edge looks striped and feels rough, but both measurements are manifestations of the same property of the coin. To determine properties on the nanoscale, our senses are not good enough; we need an instrument such as an electron microscope that can make measurements on that level. My research focuses on using and combining different transmission electron microscopy techniques to make in-depth determinations of properties like structure and composition.

Electron tomography yields information about the form of the material by taking images while rotating the sample and reconstructing the structure from them, like a CAT scan. Electron holography yields information about the type of material and its electric or magnetic properties through interferometric images. By combining these two and several other techniques, a more complete picture can be drawn of the sample being studied, yielding more information than one technique alone. However, this requires in-depth knowledge of multiple techniques, because, like the milled coin edge, some properties, like the thickness of the material, affect both measurements and need to be taken into account.

My research focuses on using multiple transmission electron microscopy techniques to characterize nanostructures such as semiconductor nanowires. These structures have applications in fields like alternative energy and faster transistor design. The techniques I use, and analyze the results, from include combinations of electron holography, electron tomography, high-resolution electron microscopy, energy-dispersive x-ray spectroscopy, and atomic-resolution aberration-corrected scanning transmission electron microscopy, mostly on the Analytical Titan at CEN, and comparing the results with simulations.



Characterization of nanoporous polymers

Uffe Bihlet Supervisors: Sokol Ndoni, DTU Nanotech, Martin E. Vigild, Danish Polymer Centre, Andy Horsewell, DTU Mechanical Engineering

The nanoporous materials group, which is a collaboration between DTU Nanotech and the Danish Polymer Centre at DTU, is exploring a new process for producing nanoporous polymers. CEN has made SEM imaging of the polymer morphology on a previously unobtainable scale possible. Samples of Polybutadiene-Polydimethylsiloxane selectively etched block copolymers prepared by Lars Schulte and Kaushal Shashikant Sagar were imaged in the Quanta FEGSEM using a variety of very thin metal coatings. The deposition morphology of sputtered metal coatings has also been investigated using the Titan and the Tecnai.

1. Ru nanoparticles
2. Nanoparticle sintering study

Billie Abrams, DTU Physics

1. RuO_2 is known to be a promising material for the oxygen evolution reaction. As such we are making Ru nanoparticles synthesized using a cluster source (gas phase synthesis) and subsequently oxidized. These nanoparticles are then characterised in the TEM before activity measurements, analyzed for their activity and characterised again in the TEM to observe the effect of measurements on nanoparticle structure. Also, the change in the lattice structure between bulk metal Ru and RuO_2 can be studied in the E-TEM by creating either an oxidizing or reducing ambient.

2. Small Pt nanoparticles (~2nm) synthesized using an inverse micelle approach are being studied for their activity as potential electrocatalysts in the PEM fuel cell. In order to gain insight into the effect of structure on catalytic activity, the ETEM is being used to simulate the environment in the fuel cell. One of the main focuses is to understand the role of sintering.

Teaching Activities

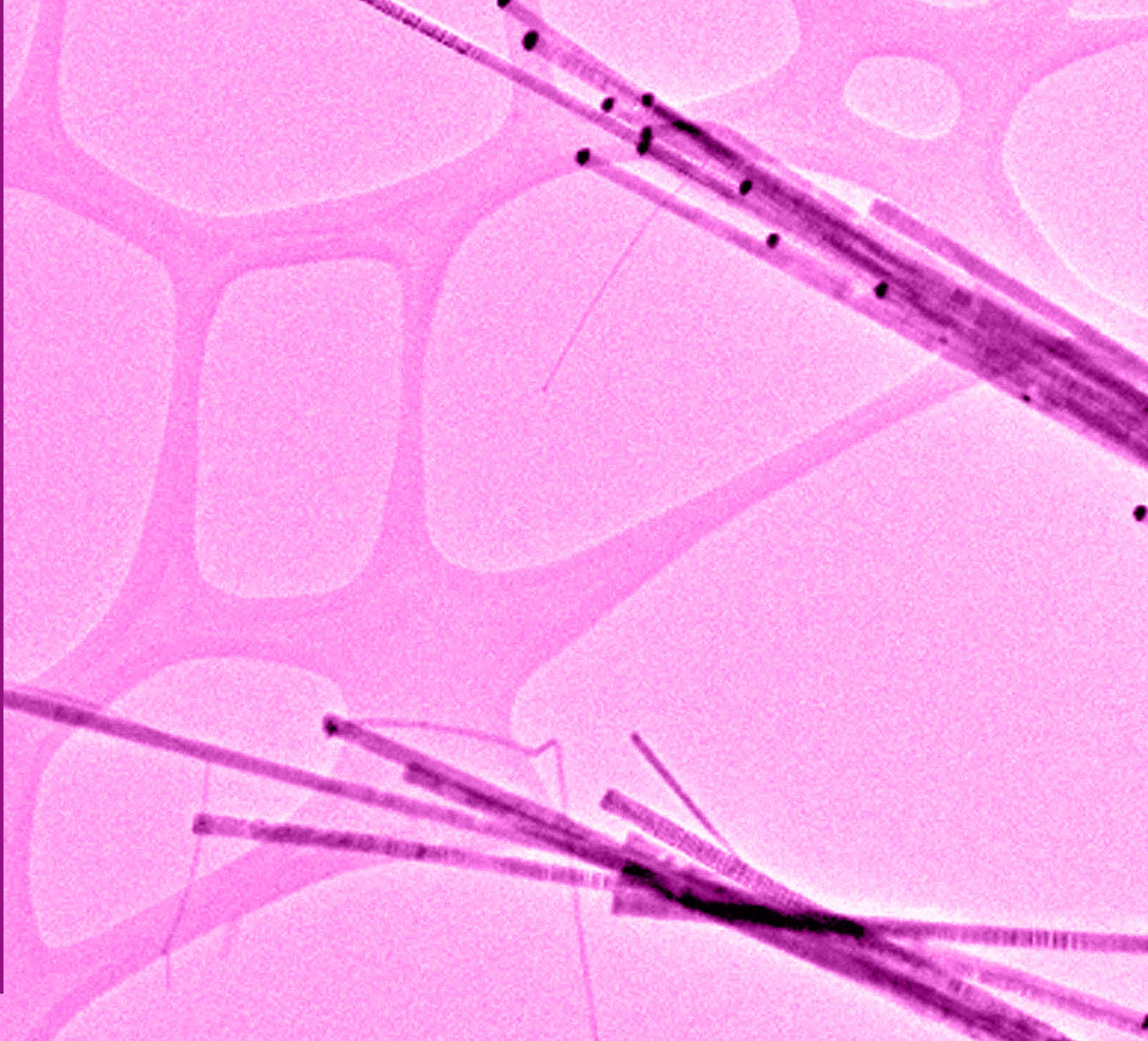
DTU Cen has been involved in several teaching activities during 2008. The teaching was carried out both as lectures, where the students were introduced to the basic principles and theory behind the different techniques available at DTU Cen and as practical teaching, where the students were taught to operate the microscopes. The balance between theory and practical work should give the students a strong background for performing efficient and optimized electron microscopy.

The teaching activities in detail

Electron Microscopy and Analysis for Materials Research: The course is aimed at PhD students and gives a theoretical and practical introduction to the different techniques present at DTU Cen. Each student has 2 days of supervised hands-on practical work at the microscopes.
The course involved all scientific and technical staff at DTU Cen, as the practical work was supervised by the experts within each technique. The course was initially thought to be run once a year, but due to the great success, we ran the course twice in 2008, with a total of approximately 20 Phd students participating.

Practical Training for Users of the DTU Cen facility: As part of making DTU Cen a multi-user facility, DTU Cen staff train users on a daily basis. This includes bachelor students, master students, Phd students and post docs, as well as scientific staff from DTU and other universities.

Visualization of micro and nanostructures: The planning of the course was initiated in 2008. The course is organized inter-departmentally within DTU, aiming at 2nd and 3rd year students. The course gives a theoretical introduction to different microscopy techniques, including electron microscopy. Furthermore, the students receive hands-on experience with the instruments. The course will be offered for the first time in the spring 2009.



Media

Supermikroskop til Danmark
DR 17, 12, 2007

Super Microscopy
Scenta 11, 12, 2007

DTU Inaugurates centre with the world's most powerful set of microscopes
Invest In Denmark 11, 12, 2007

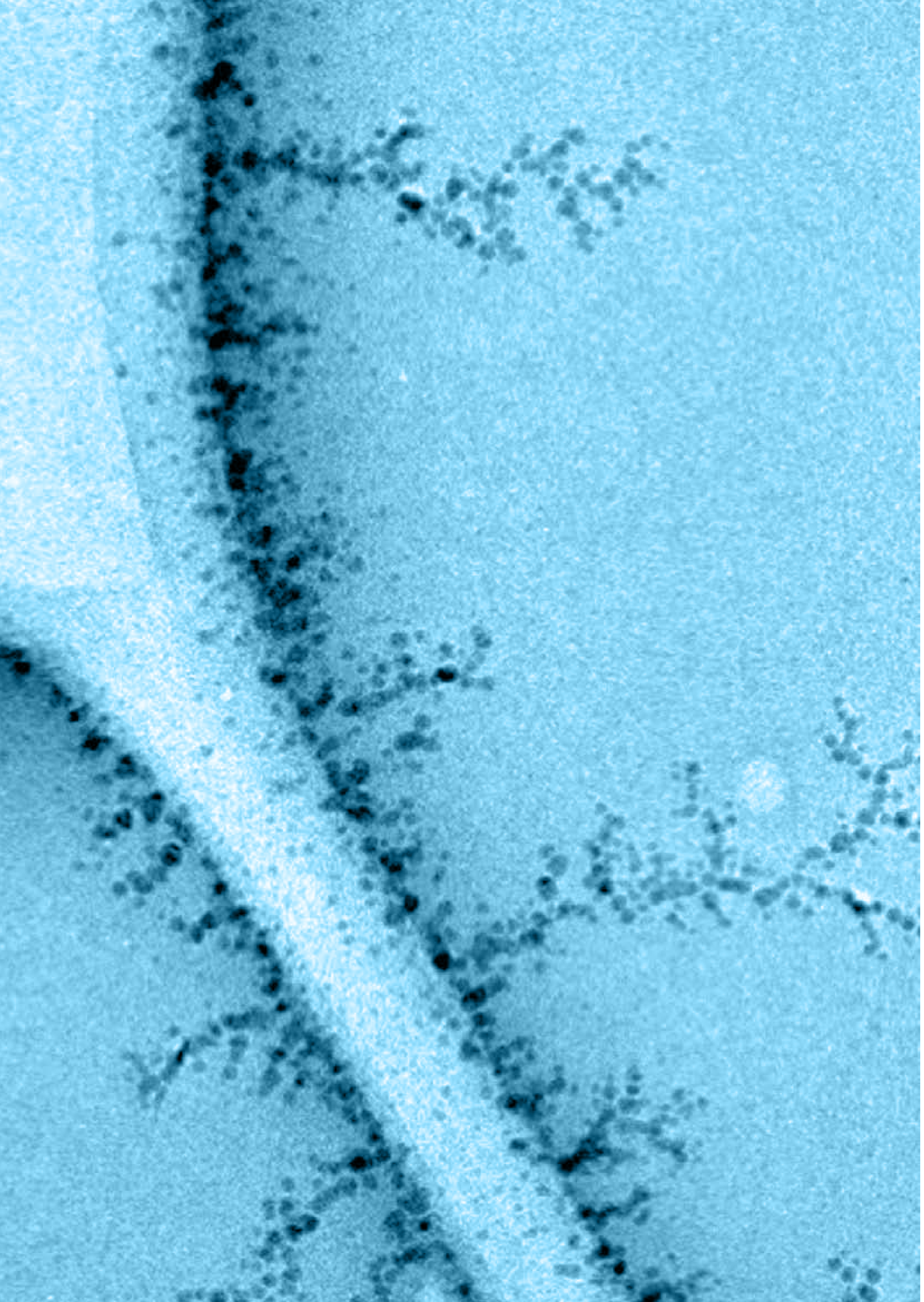
Most powerful group of microscopes in the world
Nanotechnology Now 10, 12, 2007

"Seven entirely new super microscopes in the same building means that scientists have a unique opportunities to see on the atomic level in 3D or observe what happens with the individual atoms when you change their structure. Ingeniøren was at the inauguration."
www.ing.dk
(Ingeniøren, Dec 7 2007)

Grundstenen til CEN er lagt
The DTU newspaper April 2007

"Dr Rafal Dunin-Borkowski, director of the new center said: "The seven electron microscopes from FEI will provide an outstanding suite of complimentary tools for characterizing new materials. DTU is very pleased to be working with FEI on the use and development of electron microscopy to advance scientific knowledge."
Electron Nanoscopy Center
(Microscopy and Analysis January 2007)

DTU indgår kontrakt om supermikroskop
News at DTU's intranet, Portalen,
January 1 2007



Events

Scandem 2008
The SCANDEM (Scandinavian Society for Electron Microscopy) conference is an international conference organized annually in Northern Europe on behalf of the Nordic Microscopy Society (http://www.scandem.org). In 2008 this event was hosted by the Technical University of Denmark, from Monday 2 June to Wednesday 4 June 2008.

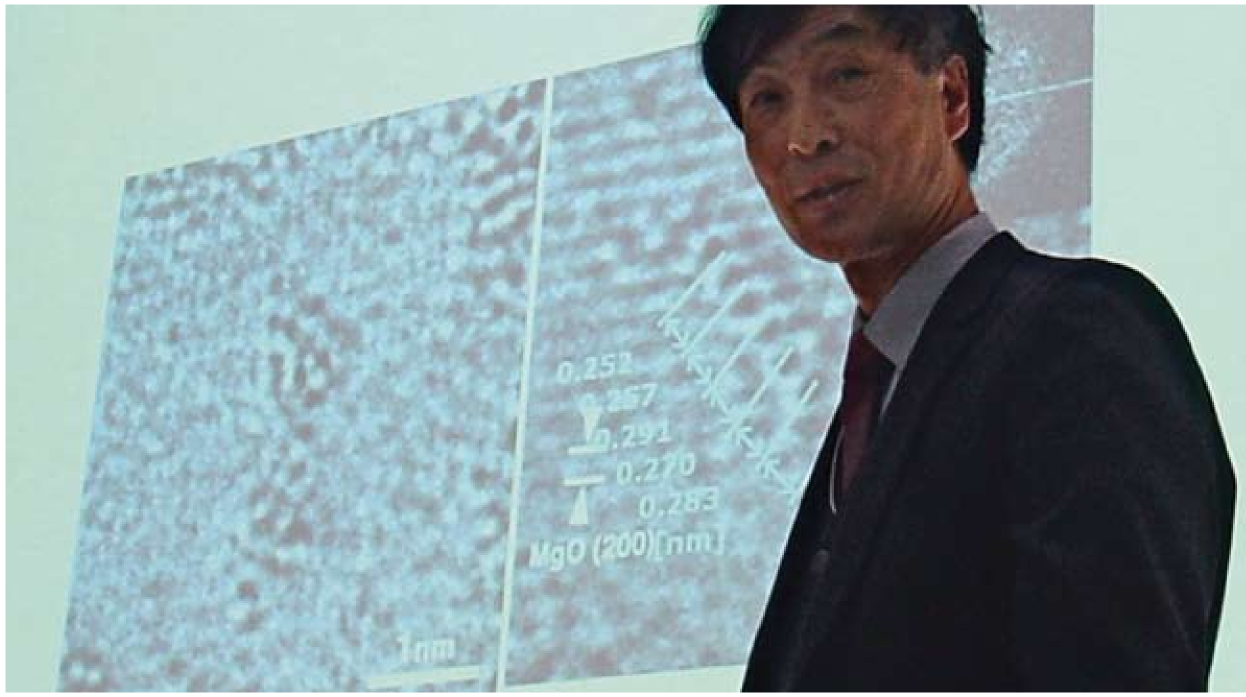
SCANDEM 2008 looked back over the history of electron microscopy in the Nordic countries as they celebrated the 60th Anniversary of SCANDEM, and also looked forward to exciting developments just beginning to take place in electron microscopy in Materials and in Life Sciences. SCANDEM 2008 also marked the first half year of operation of the Center for Electron Nanoscopy at DTU.

On the first evening attendees enjoyed a reception and buffet in the Danish Engineers' Headquarters (IDA-huset) on Copenhagen Harbour. On the second day they saw Copenhagen from the water on a harbour boat tour, which ended in Nyhavn. After a short walk to the Hotel D'Angleterre a galla dinner awaited them. The conference was very successful, with 25 invited speakers, almost 200 participants and 12 microscope manufactures displaying their latest instruments.

The conference is fully documented on the following site: http://www.cen.dtu.dk/English/SCANDEM2008_eng.aspx. The complete programme may be accessed on this site: http://www.cen.dtu.dk/upload/institutter/cen/billeder/SCANDEM2008/scandem_programmes.pdf. A printout of the complete programme is available on request. Abstracts of all 52 talks were distributed to all participants on a USB Memory stick, which is available on request.

The total expenditure for the conference was of the order of DKr 650.000,- The total revenues earned were DKr 470.000,- In addition, the following grants were received:
DKr 100.000,- from the Danish Agency for Science Technology and Innovation; DKr 55.000,- from the SCANDEM Organisation, Stockholm, DKr 5.000,- from the European Electron Microscopy Society. DKr 20.000,- from DTU

Seminars



Deformation of nano-laminated ceramics
Finn Giuliani, Linkoping, Sweden

In-situ growth of bridging silicon nanowires from locally heated cantilevers
Christian Kallesøe, DTU Nanotech, Denmark

Epitaxial metal GaAs contacts grown in water
Professor Karen L. Kavanagh, Dept. of Physics, 4D Labs
Simon Fraser University, Vancouver, Canada

Characterization of Precipitates in Al Alloys by three -dimensional electron tomography
Professor Kenji Kaneko, Department of Material Science and Engineering, Kyushu University, Japan

Modelling the electron phase:
a quantitative link to the physics of materials at the nanoscale
Seiji Takeda, Osaka University, Japan

Modelling the electron phase:
a quantitative link to the physics of materials at the nanoscale
Marco Beleggia, University of Leeds, UK.

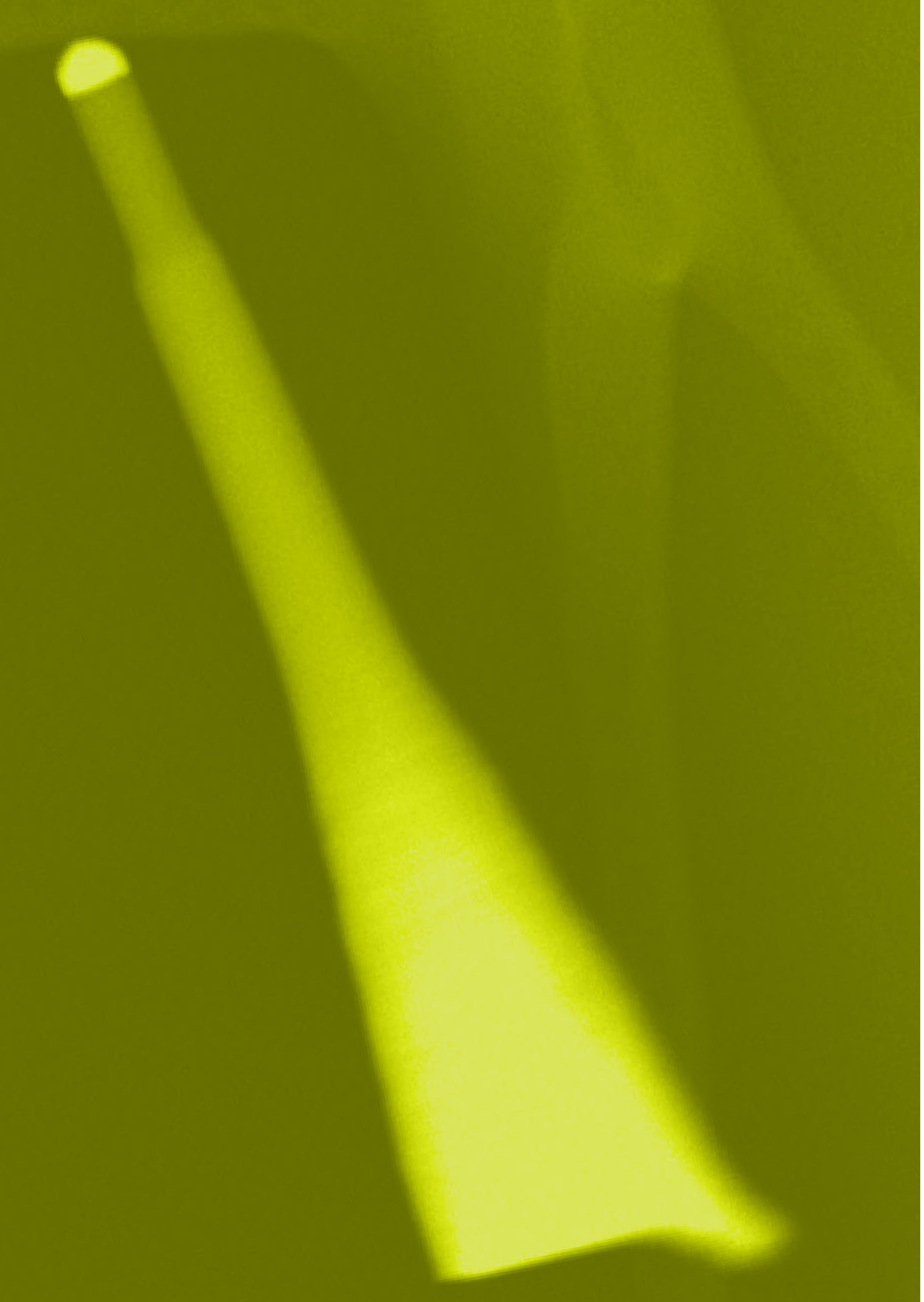
Spectrum imaging in an analytical TEM
Dr Bernhard Schaffer, Graz University of Technology, Austria

Prospects of a FIB as a sample modification tool and for 3D analysis
Dr Miroslava Schaffer, Graz University of Technology, Austria

Advanced electron microscopic characterization of nano-materials
Professor Nobuo Tanaka, EcoTopia Science Institute, Nagoya University, Nagoya, Japan

Interface dynamics of crystalline catalysts during Si nanowire and carbon nanotube CVD
Dr Stephan Hofmann, Center for Advanced Photonics and Electronics, University of Cambridge, U.K.

Microstructural characterisation at JFE Steel;
Nano-structure designing of advanced steel products using FE-TEM and ultra-low-voltage SEM.
Dr Kaoru Sato, JFE Steel, Kawasaki, Japan.



Publications & Presentations

Publications in 2008

1. Book chapters

Domain wall spin structures in 3d metal ferromagnetic nanostructures. M. Laufenberg, M. Kläui, D. Backes, W. Bührer, H. Ehrke, D. Bedau, U. Rüdiger, F. Nolting, L.J. Heyderman, S. Cherifi, A. Locatelli, R. Belkhou, S. Heun, C.A.F. Vaz, J.A.C. Bland, T. Kasama, R.E. Dunin-Borkowski, A. Pavlovska and E. Bauer, in: Advances in Solid State Physics 46 (R. Haug, ed.), Springer, 281-293 (2008).

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2. Refereed and invited journal papers

Large scale synthesis of single crystal iron oxide magnetic Nanorings. C.J. Jia, L.D. Sun, F. Luo, L.J. Heyderman, Z.G. Yan, C.H. Yan, K. Zheng, X.D. Han, Z. Zhang, M. Takano, N. Hayashi, M. Eltschka, M. Kläui, U. Rüdiger, T. Kasama, L. Cervera Gontard, R.E. Dunin-Borkowski, G. Tzvetkov and J. Raabe, J. Am. Chem. Soc. 130, 16968-16977 (2008).

Three-dimensional shapes and spatial distributions of Pt and PtCr catalyst nanoparticles on carbon black. L. Cervera Gontard, R.E. Dunin-Borkowski and D. Ozkaya, J. Microsc. 232, 248-259 (2008).

Mapping the electrical properties of semiconductor junctions – the electron holographic approach. A.C. Twitchett-Harrison, R.E. Dunin-Borkowski and P.A. Midgley, Scanning 30, 299-309 (2008).

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Correlation between magnetic spin structure and the three-dimensional geometry in chemically synthesized nanoscale magnetite rings. M. Eltschka, M. Kläui, U. Rüdiger, T. Kasama, L. Cervera Gontard, R.E. Dunin-Borkowski, F. Luo, L.J. Heyderman, C.J. Jia, L.D. Sun and C.H. Yan, Appl. Phys. Lett. 92, 222508 (2008).

Reversal of flux closure states in cobalt nanoparticle rings with coaxial magnetic pulses. T. Kasama, R.E. Dunin-Borkowski, M.R. Scheinfein, S.L. Tripp, J. Liu and A. Wei, Adv. Mat. 20, 4248-4252 (2008).

Electron holography for the study of nanomagnetic materials. J.M. Thomas, E.T. Simpson, T. Kasama and R.E. Dunin-Borkowski, Acc. Chem. Res. 41, 665-674 (2008).

Quantitative determination of vortex core dimensions in head to head domain walls using offaxis electron holography. F. Junginger, M. Kläui, D. Backes, S. Krzyk, U. Rüdiger, T. Kasama, R.E. Dunin-Borkowski, J.M. Feinberg, R.J. Harrison and L.J. Heyderman, Appl. Phys. Lett. 92, 112502 (2008).

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Imaging of radiation sensitive samples in transmission electron microscopes equipped with Zernike phase plate. M. Malac, M. Beleggia, R. Egerton and Y. Zhu, Ultramicroscopy 108, 126-140 (2008).

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Controlled chemical stabilization of self-assembled PS-P4VP nanostructures. Y.M. Lam, L. Song, Y.C. Moy, L. Xi and C.B. Boothroyd, J. Coll. Int. Sci. 317, 255-263 (2008).

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Site-specific growth of ZnO nanowires from patterned Zn via compatible semiconductor processing. J.B.K. Law, C.B. Boothroyd and J.T.L. Thong, J. Cryst. Grow. 310, 2485-2492 (2008).

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Off-axis electron holography of magnetic fields in biological Materials. R.E. Dunin-Borkowski, T. Kasama, M. Pósfai, R.K.K. Chong, E.T. Simpson, J. Dobson and J.F. Collingwood, Microsc. Microanal. 14 Suppl. 2, 54-55CD (2008).

Off-axis electron holography of coercive fields and magnetic states in cobalt nanoparticle rings. T. Kasama, A. Wei, S.L. Tripp and R.E. Dunin-Borkowski, AMTC Letters 1 (the 1st International Workshop on Advanced Microscopy and Theoretical Calculations), 56-57 (2008). (Invited paper)

Direct observation of the interaction between elastic and magnetic domain walls below the Verwey transition in magnetite using electron holography. T. Kasama, N. Church, J.M. Feinberg, R.E. Dunin-Borkowski and R.J. Harrison, Geophysical Research Abstracts 10 (European Geosciences Union General Assembly 2008), 06348 (2008). (Invited paper)

Quantitative transmission electron microscopy of iron oxide and sulfide nanocrystals in magnetotactic bacteria T. Kasama, M. Pósfai, R.K.K. Chong, P.R. Buseck, R.B. Frankel, R.J. Harrison and R.E. Dunin-Borkowski Geophysical Research Abstracts 10 (European Geosciences Union General Assembly 2008), 05676 (2008). (Invited paper)

Understanding stress corrosion cracking with electron. S. Lozano-Pérez and L. Cervera Gontard, Microsc. Microanal. 14 Suppl. 2, 642-643CD (2008).

4. Other conference papers or short conference abstracts

Electron holography of oxy-exsolution microstructures in synthetic titanomagnetites. N.S. Church, R.J. Harrison, T. Kasama and R.E. Dunin-Borkowski, Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract GP31A-0795. Paper presented at the American Geophysical Union Fall Meeting, San Francisco, 15-19 December 2008.

Simulations of electron holographic observations of magnetic microstructure in exsolved titanomagnetites. M. Beleggia, T. Kasama, R.J. Harrison, J.M. Feinberg and R.E. Dunin-Borkowski, Eos Trans. AGU 89 (53), Fall Meet. Suppl., Abstract GP31B-0799. Paper presented at the American Geophysical Union Fall Meeting, San Francisco, 15-19 December 2008.

Environmental electron microscopy study of the nucleation and growth of Si and Ge nanowires. S. Hofmann, R. Sharma, C.T. Wirth, C. Ducati, T. Kasama, R.E. Dunin-Borkowski, P. Bennett, J. Drucker and J. Robertson. Paper presented at the MRS Fall Meeting, Boston, 30 November - 4 December 2008.

Reversal of flux closure states in cobalt nanoparticle rings with coaxial magnetic pulses. J. Liu, T. Kasama, R.E. Dunin-Borkowski, M.R. Scheinfein, S.L. Tripp and A. Wei. Paper presented at the MRS Fall Meeting, Boston, 30 November - 4 December 2008.

In situ electrical biasing for electron holography of magnetic and electric fields in working devices. T. Kasama and R.E. Dunin-Borkowski. Paper presented at the 2008 European In Situ TEM Probing Workshop, Gothenburg, Sweden, 23-24 October 2008.

3D TEM nano-metrology. F. Marinello, A. Horsewell, L. Cervera Gontard, L. Carli, S. Carmignato, E. Savio and R.E. Dunin-Borkowski. Paper presented at the NanoScale 2008 Seminar on Quantitative Microscopy, Torino, Italy, 22-23 September 2008.

Calixarene-encapsulated cobalt nanoparticle rings. T. Kasama, R.E. Dunin-Borkowski, M.R. Scheinfein, S.L. Tripp, L. Liu and A. Wei. Paper presented at the Joint International Symposium on Macrocyclic and Supramolecular Chemistry, Las Vegas, 13-18 July 2008.

Switching phenomena in magnetic materials and devices studied using electron holography. R.E. DuninBorkowski and T. Kasama, Paper presented at a Conference on Innovative Dynamic Studies of Materials at the Nanoscale, Gyeongju, Korea, 2 July 2008.

Magnetosome biomineralization and chain arrangement in magnetotactic bacteria D Faivre, L Böttger, M Pósfai, T. Kasama, E.T. Simpson, B.F. Matzanke, R.E. Dunin-Borkowski and D. Schüler, Paper presented at the Biogenic Iron Minerals Meeting, Balaton, 9-11 June 2008.

Advanced electron microscopy techniques for studying magnetosomes in magnetotactic bacteria. R.E. Dunin-Borkowski, T. Kasama and M. Pósfai, Paper presented at the Biogenic Iron Minerals Meeting, Balaton, 9-11 June 2008.

The role of iron sulfide crystals in magnetotactic bacteria for magnetotaxis: A transmission electron microscopy study. T. Kasama, M. Pósfai, R.K.K. Chong, E.T. Simpson, P.R. Buseck, R.B. Frankel, R.J. Harrison and R.E. Dunin-Borkowski, Paper presented at the Biogenic Iron Minerals Meeting, Balaton, 9-11 June 2008.

Magnetic microstructures of chains and clusters of iron oxide and sulfide nanocrystals in bacteria. M. Pósfai, T. Kasama, E.T. Simpson, D. Faivre, D. Schüler and R.E. Dunin-Borkowski, Paper presented at a workshop on Functional Nanostructures and Particles, Portoroz, Slovenia, 26-29 May 2008.

Interface dynamics of crystalline catalysts during Si nanowire and carbon nanotube CVD. S. Hofmann, R. Sharma, C.T. Wirth, F. Cervantes-Sodi, C. Ducati, T. Kasama, R.E. Dunin-Borkowski, J. Drucker, P. Bennett and J. Robertson, Paper presented at the International Winter School on Electronic Properties of Novel Materials, Kirchberg, Austria, 18 March 2008.

Offaxis electron holography of multi-domain magnetite below the Verwey transition. T. Kasama, N. Church, J.M. Feinberg, R.E. DuninBorkowski and R.J. Harrison, Paper presented at the Magnetic Moments Meeting, Edinburgh, 8-9 January 2008.

Relationship between microstructure and texture evolution during cold deformation of TWIP-steels. A.B. da Silva Fanta,

S. Zaefferer, I. Thomas and D. Raabe, the 15th International Conference on the Texture of Materials (ICOTOM 15), Pittsburgh, 1-6 June 2008. (Invited talk)

3D Orientation microscopy. A.B. da Silva Fanta, S. Zaefferer and R.E. Dunin-Borkowski. Annual Meeting of the Nordic Microscopy Society (SCANDEM 2008), Lyngby, 2-4 June 2008. (Invited talk)

3D-Orientation microscopy in electrodeposited CoNi. A.B. da Silva Fanta, S Zaefferer, D Raabe.Poster, the 15th International Conference on the Texture of Materials (ICOTOM 15), Pittsburgh, 1-6 June 2008.

Investigations on the deformation mechanisms of TWIP steels using EBSD. A.B. da Silva Fanta, I. Thomas and S. Zaefferer, the 15th Conference and Workshop on Electron Backscatter Diffraction, Sheffield, March 31 March – 1 April 2008.

Electron microscopy characterization of Pd-Ce interaction on α–Al2O3 support. M.S. Moreno, F. Wang, M. Malac, T. Kasama, M.D. Sanchez, I. Costilla and C.E. Gigola, Microscopy and Microanalysis, Albuquerque, 3-7 August 2008

New possibilities with aberration corrected electron microscopy. C.B. Boothroyd, Royal Society, London, 24-25 November 2008.

Talks and presentations in 2008

1. Invited talks at international conferences and workshops

18-19 Nov 08
R.E. Dunin-Borkowski, Workshop on Advanced Electron Microscopy in Materials Science, Oak Ridge National Laboratory, U.S.A. Invited talk: "Electron holography and electron tomography of working devices".

10-11 Nov 08
R.E. Dunin-Borkowski, Molecular Foundry and NCEM Joint Users' Workshop, Berkeley, U.S.A. Plenary talk: "Catalyst nanoparticles imaged using aberration correction, electron tomography and environmental electron microscopy".

23-24 Oct 08
R.E. Dunin-Borkowski, 2008 European in-situ TEM probing workshop, Gothenburg, Sweden. Invited talk: "In situ electrical biasing for electron holography of magnetic and electric fields in working devices".

15-17 Oct 08
R.E. Dunin-Borkowski, Tsinghua-FEI Workshop on CS-corrected TEM, Beijing, China. Invited talk: "Catalyst nanoparticles imaged using aberration correction, focal series restoration and electron tomography".

14-17 Sept 08
R.E. Dunin-Borkowski, Advanced Workshop on Electron Tomography, Cadiz, Spain. Invited talk: "Magnetic vector field electron tomography – prospects and challenges".

15 Sept 08
R.E. Dunin-Borkowski, 14th European Microscopy Congress, Aachen, Germany.
Invited talk: "Off-axis electron holography and micro-magnetic simulations of magnetization reversal in cobalt nanoparticle rings".

25-29 Aug 08
R.E. Dunin-Borkowski, 22nd General Conference of the Condensed Matter Division of the European Physical Society (CMD-22), Rome. Plenary talk: "Magnetic nanoparticles in bacteria".

4-6 Aug 08
R.E. Dunin-Borkowski, Microscopy and Microanalysis 2008, Albuquerque, U.S.A. Invited talk: "Off-axis electron holography of magnetic fields in biological materials".

2 Jul 08
R.E. Dunin-Borkowski, Conference on Innovative Dynamic Studies of Materials at the Nanoscale, Gyeongju, Korea. Invited talk: "Switching phenomena in magnetic materials and devices studied using electron holography".

28-30 Jun 08
R.E. Dunin-Borkowski, 1st International Symposium on Advanced Microscopy and Theoretical Calculations (AMTC1), Nagoya, Japan. Invited talk: "Off-axis electron holography and micromagnetic simulations of magnetization reversal in cobalt nanoparticle rings".

9-11 Jun 08
R.E. Dunin-Borkowski, Workshop on Magnetotactic Bacteria, Balatonfüred, Hungary. Invited talk: "Advanced transmission electron microscopy techniques for studying magnetosomes in magnetotactic bacteria".

16 Apr 08
R.E. Dunin-Borkowski, Joint meeting of the Nano-Science Center, Nano•DTU and the Copenhagen Graduate School for Nanoscience and Nanotechnology, Nano-Science Center, Copenhagen University, Denmark. Invited talk: "Advanced electron microscopy for nanoscience and nanotechnology".

13-18 Apr 08
T. Kasama, M. Pósfai, R.K.K. Chong, P.R. Buseck, R.B. Frankel, R.J. Harrison and R.E. Dunin-Borkowski
European Geosciences Union General Assembly 2008, Vienna, Austria. Invited talk: "Quantitative transmission electron microscopy of iron oxide and sulfide nanocrystals in magnetotactic bacteria". European Geosciences Union General Assembly 2008, Vienna

17-19 Nov 08
A.B. da Silva Fanta, 1st Oxford Instruments Nordiska EBSD Users Meeting, Sweden. Invited talk: "An overview on 3D microstructure characterization by serial sectioning in a FIB-SEM". 1st Oxford Instruments Nordiska EBSD Users Meeting, (Sweden)

9-11 Jan 2008
C.B. Boothroyd, 25th Annual Conference of the Microscopy Society of Thailand

24-25 Nov 08
C.B. Boothroyd, New possibilities with aberration corrected electron microscopy, Royal Society, London

7 Jan 08
C.B. Boothroyd, 1/2 day lecture course on "TEM-EELS for analysis of Nanostructured Semiconductors", MTEC, Thailand

25 Sept 08
C.B. Boothroyd, ”Quantitative High Resolution Electron Microscopy”, IMRE, Singapore

19 Nov 08
C.B. Boothroyd, ”The Analytical Titan TEM at the Center for Electron Nanoscopy”, Oxford

2. Invited seminars

15 Dec 08
R.E. Dunin-Borkowski, University of Ulm, Germany. Seminar: “Advanced transmission electron microscopy of nanoscale materials and devices”.

27 Nov 08
R.E. Dunin-Borkowski, Departamento de Electrónica, Universidad de Barcelona, Spain. Seminar: “The Center for Electron Nanoscopy in Denmark and recent results obtained using advanced electron microscopy techniques”.

4 Nov 08
R.E. Dunin-Borkowski, Department of Materials Chemistry, University of Lund, Sweden. Seminar: “Center for Electron Nanoscopy, Technical University of Denmark”.

6 Oct 08
R.E. Dunin-Borkowski, Department of Mechanical Engineering, Technical University of Denmark. Seminar: “Center for Electron Nanoscopy at DTU”.

1 Jul 08
R.E. Dunin-Borkowski, JFE Steel, Kawasaki, Japan Seminar: “Advanced transmission electron microscopy of nanoscale materials and establishment of the Center for Electron Nanoscopy in Denmark”.

9 May 08
R.E. Dunin-Borkowski, Department of Micro and Nano Technology, Technical University of Denmark. Seminar: “Center for Electron Nanoscopy at DTU”.

3. Contributed talks and other presentations

13-15 May 08
R.E. Dunin-Borkowski, 4th European Electron Holography Workshop, Dresden, Germany. Talk: ”Medium resolution electron holography of magnetic and electrostatic fields”.

30 Apr 08
R.E. Dunin-Borkowski, Technical University of Denmark. Talk: ”Center for Electron Nanoscopy at DTU”.

13-18 Apr 08
T. Kasama, N. Church, J.M. Feinberg, R.E. Dunin-Borkowski and R.J. Harrison, European Geosciences Union General Assembly 2008, Vienna, Austria. Talk: “Direct observation of the interaction between elastic and magnetic domain walls below the Verwey transition in magnetite using electron holography”.

27-29 Feb 08
T.W. Hansen, Jahrestreffen Deutscher Katalytiker, Weimar, Germany

2-4 June 08
T.W. Hansen, Annual Meeting of the Nordic Microscopy Society (SCANDEM 2008), Lyngby, Denmark

3-6 Aug 08
O. Sardan, K.N. Andersen, A.N. MacDonald, O. Sigmund, P. Bøggild, A. Horsewell, Talk: “Focus Ion Beam (FIB) modification of topology optimized polysilicon micro-grippers”.

05 Sept 08
M. Beleggia, European Microscopy Conference 2008, Aachen, Germany. Talk: “The image intensity in Zernike mode with electrons”.

05 Sept 08
J.B. Wagner, T.W. Hansen, J. Jinschek and R.E. Dunin-Borkowski, 14th European Congress on Electron Microscopy, Aachen, Germany. Talk: “In situ HRTEM – Image corrected and monochromated Titan equipped with environmental cell”.

1-6 June 08
A.B. da Silva Fanta, S. Zaefferer, I. Thomas and D. Raabe. 15th International Conference on the Texture of Materials (ICOTOM 15), Pittsburgh (USA). Talk: “Relationship between microstructure and texture evolution during cold deformation of TWIP-steels”.

2-4 June 08
A.B. da Silva Fanta, S.Zaefferer and R.E. Dunin-Borkowski. Annual Meeting of the Nordic Microscopy Society (SCANDEM 2008), , Lyngby (Denmark). Talk: “3D Orientation microscopy”.

Posters

3-6 Aug 2008
O. Sardan, K.N. Andersen, A.N. MacDonald, O. Sigmund, P. Bøggild and A. Horsewell, Poster: “Focus Ion Beam (FIB) modification of topology optimized polysilicon micro-grippers, MNS

1-6 June 08
A.B. da Silva Fanta, S. Zaefferer and D. Raabe. 15th International Conference on the Texture of Materials (ICOTOM 15) Pittsburgh, USA. Poster: “3D-Orientation microscopy in electrodeposited CoNi”.

31 Mar -1 Apr 08
A.B. da Silva Fanta, I. Thomas and S. Zaefferer. 15th Conference and Workshop on Electron Backscatter Diffraction, Sheffield, U.K. Poster: “Investigations on the deformation mechanisms of TWIP steels using EBSD”.

27-29 Feb 08
T.W. Hansen, A. Celaya Sanfiz and A. Trunschke, D. S. Su, and R. Schlögl, 41st Jahrestreffen Deutscher Katalytiker, Weimar, Germany. Poster: “Microstructural characterization of Mo-V-Te-Nb oxides for selective oxidation of propane”.

27-29 Feb 08
J.-P. Tessonnier, T.W. Hansen, C. Hess, and D.S. Su, 41st Jahrestreffen Deutscher Katalytiker, Weimar, Germany. Poster: “MoxOy thin film supported on carbon nanotubes: benefits of non-oxidic supports for structure-activity correlations for selective oxidation reactions”.

27-29 Feb 08
A. Celaya Sanfiz, F. Girgsdies, T.W. Hansen, P. Schnörch, D. Teschner, A. Trunschke and R. Schlögl, 41st Jahrestreffen Deutscher Katalytiker, Weimar, Germany. Poster: “Selective oxidation of propane over MoVTe oxide catalysts prepared by hydrothermal synthesis”.

13 Nov 08
J. McGregor, Z. Huang, J.A. Zeitler, E.P.J. Parrott, L.F. Gladden, T.W. Hansen, D. Teschner, J.-P. Tessonnier, D.S. Su, E.M. Vass, A. Knop.Gericke, and R. Schlögl, DTU-Cen presentation, FN projektdag, Lyngby, Denmark. Poster: “Active coke: Carbonaceous materials as active sites for butane dehydrogenation Microstructural and surface properties of phase-pure MoVTeNb mixed oxide catalysts for selective oxidation of propane to acrylic acid”.

4. Other meetings and workshops attended

7-9 Apr 08
A.B. da Silva Fanta, FIB and DualBeam Workshop, Eindhoven, The Netherlands.

28-30 Jan 08
A.B. da Silva Fanta Titan Summit and Workshop, Eindhoven, The Netherlands.

Public understanding of science and outreach

Examples of events and activities include:

19 Sep 08
Evening activities for students participating in the European Union Contest for Young Scientists, including a talk entitled “Electron microscopy – exploring the nanoworld”, a tour and demonstrations.

26 Jun 08
Tour and demonstrations for visitors from the Ministry.

19 Jun 08
Tour and demonstrations for visting scientists from Berkeley.

22 May 08
Talk to members of the Danish Fundamental Metrology group, followed by a tour and demonstrations.

21 May 08
Talk, tour and demonstrations for guests from DTU’s Department of Chemistry.

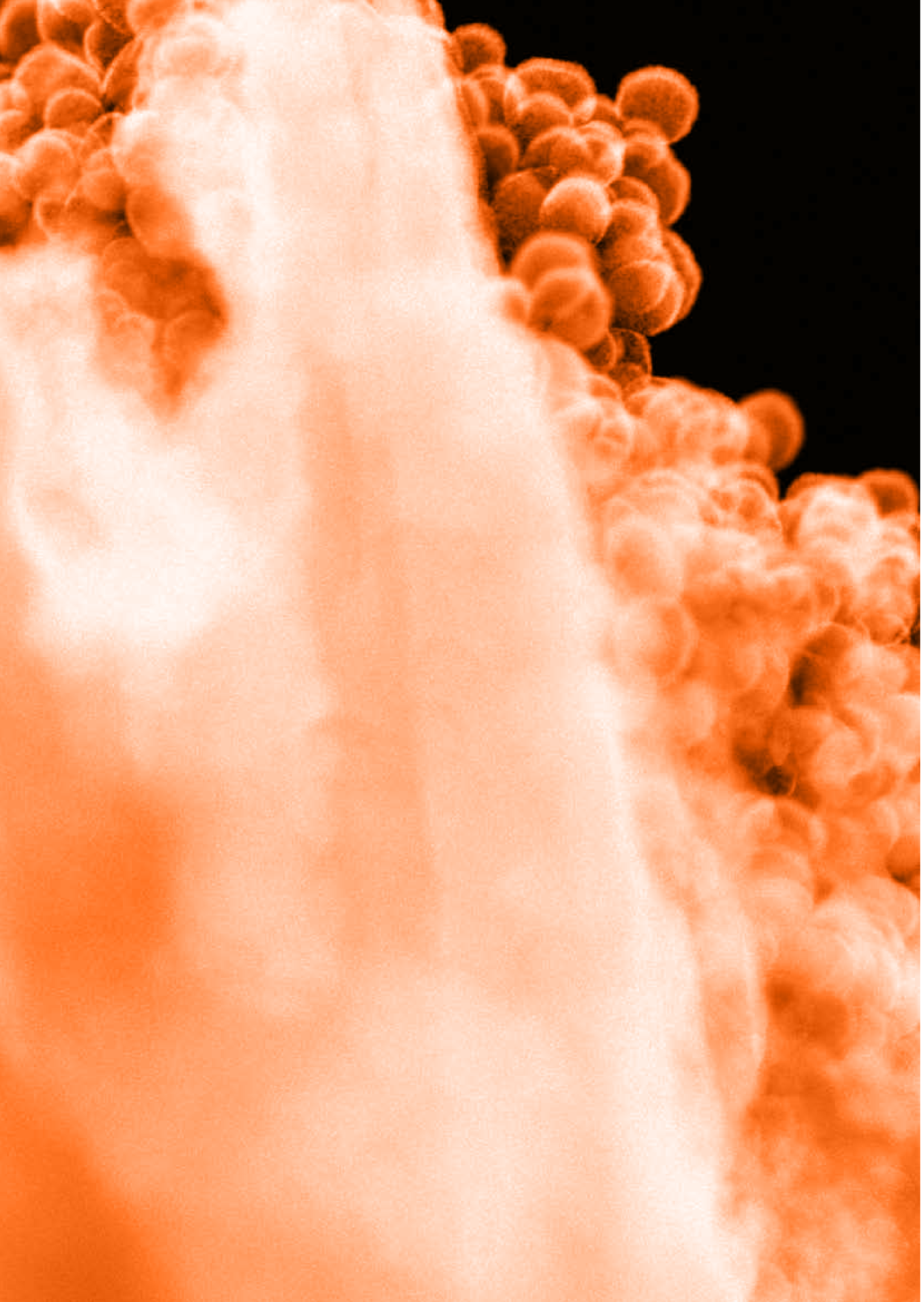
9 May 08
Talk, tour and demonstrations for the Department of Micro- and Nano-technology at DTU.

23 Apr 08
Tour and demonstrations for members of the Strategic Research Council.

4 Apr 08
Talk, tour and demonstrations for scientists from Lund University.

13 Mar 08
Evening event for UNF (a voluntary NGO association promoting science to young people), including a talk entitled “Electron microscopy – exploring the nanoworld”, a tour and demonstrations.

21 Feb 08
Scientific evening for DTU’s physics students, including a talk entitled “Exploring the nanoworld using electron micr scopes”, a tour and demonstrations.



Advisory Board

Advisory Board

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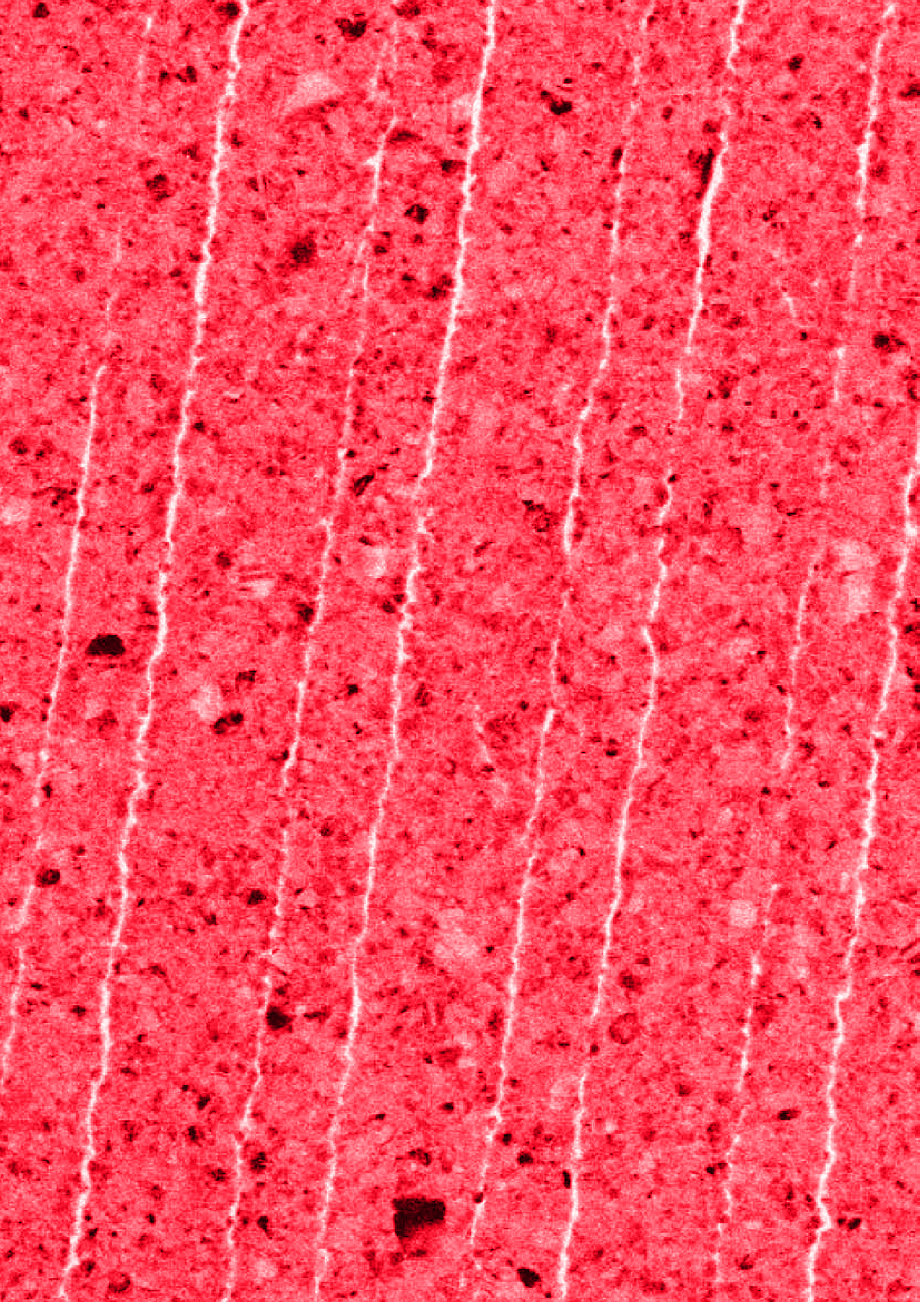

People

Rafal E. Dunin-Borkowski
Director

Rafal Dunin-Borkowski is responsible for directing DTU Cen's operation and activities. His research interests include off-axis holography, electron tomography, quantitative high-resolution electron microscopy, aberration-corrected imaging, image simulation, image processing, instrumentation development and 'in situ' electron microscopy.

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Anna Rink Baagøe
Center administrator

Anna Rink is responsible for DTU Cen's employees concerning HR, communications and the center's overall administration.

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Marco Beleggia
Associate Professor

Marco Beleggia is responsible for DTU Cen's teaching activities. His research interests include electron phase contrast and retrieval techniques, image simulation and processing, microscopy of magnetic materials and physics of condensed matter at the nanoscale.

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Chris Boothroyd
Senior scientist

Chris Boothroyd is responsible for the operation of DTU Cen's Analytical Titan TEM as well as the computing facilities in the center. In addition to developing highly sophisticated microscopy techniques in pursuit of his research, particularly in the area of quantitative microanalysis, his role at DTU Cen includes teaching at undergraduate and graduate level; both theoretical and practical in conventional and advanced electron microscopy techniques.

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Andy Burrows
Technical manager

Andy Burrows is responsible for ensuring that DTU Cen's instruments are maintained and serviced. His role is to co-ordinate technical support, access to instruments and training, to manage incoming projects and to maintain contact with DTU Cen's equipment manufacturers and other suppliers. He also has primary responsibility for the booking and billing systems of DTU Cen.

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Alice Bastos da Silva Fanta
Post doctoral fellow

Alice Bastos is responsible for DTU Cen's Helios dual-beam FIB, for the development and application of techniques based on electron backscatter diffraction, for training new users, and providing assistance in the FIB preparation of TEM specimens. Her research interests include the characterization of electrodeposited materials and steels.

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Lionel Cervera-Gontard
Post doctoral fellow

Lionel Cervera-Gontard has overall responsibility for the Tecnai TEM at DTU Cen and in this capacity he ensures all potential users are adequately trained through practical training sessions. When he is engaged in his research activities, Lionel pursues studies to advance the electron tomography technique and to understand electron beam modifications induced by high-energy electrons.

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Thomas Willum Hansen
Post doctoral fellow

Among Thomas W. Hansen's main tasks and research interests are the characterization of catalyst materials using the aberration corrected environmental Titan TEM (ETEM) at DTU Cen. Other tasks include keeping the ETEM running, training new users on the DTU Cen electron microscopes and investigations of other nanostructured materials.

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Takeshi Kasama
Senior scientist

Takeshi Kasama's research interests are in off-axis electron holography of magnetic and electrostatic fields in nanostructured materials. At DTU Cen he is responsible for the development and optimization of advanced specimen preparation techniques and specimen holder technologies for the examination of working devices using this technique. He also provides hands-on training, advice and assistance to users of DTU's transmission electron microscopes in conventional and advanced electron microscopy.

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A. Nicole MacDonald
Academic laboratory technician

Nicole MacDonald is the primary user of the Quanta3D FIB SEM, using it to prepare SEM and TEM cross-sections. She also works on the Inspect 'S', Quanta 200 FEG and Helios SEM, collaborating with and training users on all four instruments.

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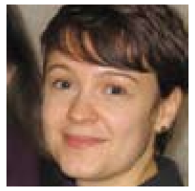

Ramona Valentina Mateiu
Academic laboratory technician

Ramona Mateiu is the primary user of the Inspect SEM. She also works on the Quanta 200 FEG, Quanta3D FIB SEM and Helios SEM, collaborating with and training users on all four instruments.

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Robert S. Pennington
PhD student

Robert Pennington is a PhD student at DTU Cen. His doctoral research is focusing on TEM characterization of nanowires and other nanostructures using a variety of electron microscopy techniques. He uses primarily the Tecnai and the Analytical Titan TEM.

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Amuthan Ramar
Ørsted post doctoral fellow

Amuthan Ramar arrived from the Swiss Federal Institute of Technology (EPFL). His research interests are mainly on diffraction contrast imaging, weak beam imaging, high resolution TEM imaging, X-ray microanalysis and scanning electron microscopy of ODS materials. His recent interest is on developing new 'in-situ' techniques in TEM, holography and tomography of dislocations.

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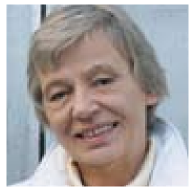

Anne Marie Rasmussen
Laboratory manager

Anne Marie Rasmussen is the primary user of the Quanta 200 FEG SEM. Along with imaging and analyzing samples she works with the cryostage, to image samples at very low temperatures. She also works on the Inspect 'S', Helios FIB SEM, and Quanta3D FIB SEM, collaborating with and training users on all four instruments.

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Jakob Birkedal Wagner
Senior scientist

Jakob B. Wagner is responsible for DTU Cen's Environmental Titan TEM and X-ray difractometer. His research interests include high-resolution electron microscopy, energy-filtered imaging and 'in situ' electron microscopy, with a primary emphasis on the characterization and in situ study of semiconductor nanowires and nanoparticle catalysts. He is also involved in DTU Cen's teaching activities.

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Berit Wenzell
Laboratory technician

Berit Wenzell is primarily responsible for X-ray analysis on the three SEMs: energy dispersive spectroscopy (EDS) on the Inspect 'S', the Helios FIB SEM and the Quanta 200 FEG, and wavelength-dispersive spectroscopy on the Inspect 'S'.

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Fuel Cells and Solid State Chemistry, Risø DTU

Kristian Mølhave
Department of Micro- and Nanotechnology

Kresten Yvind
Department of Fotonik

Former Staff

DTU Cen gratefully acknowledges the contribution of the former center administrator

Anita Kildebæk Nielsen

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Molly McCartney
Arizona State University, USA

Karen Kavanagh
Simon Fraser University, Canada

Yeng Ming Lam
Nan Yang Technological University, Singapore

Dave Cooper
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Sergio Lozano-Perez
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HREM Research, Japan

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