Project work / Master / Diploma topics in the TEM Gemini Centre, 2016

TEM Gemini Centre

The TEM activity in Trondheim is centered around the TEM Gemini Centre, which consists of professors, engineers, postdocs and students at IFY and IMT (NTNU) and TEM researchers at SINTEF.

We have in total 5 TEM instruments, three of which were installed in 2013 and one which is the most advanced currently available.

In 2016, we have 3.4 (ass./assoc.) professors, 3 engineers, 4 SINTEF researchers, 2 Postdocs, 7 PhDs and several Master students with TEM as a main activity.

Our research extends through various fields of solid state physics and materials technology, from cooperation with industry on Aluminum to 3rd generation solar cells and nanomaterials.

TEM Gemini Centre

http://www.ntnu.edu/geminicentre/tem

Last year the transmission electron microscopy (TEM) Gemini Centre started the regular use of three brand new microscopes. These TEMs include the most sophisticated technology available and give new possibilities for advanced materials characterization, novel experimental solid state physics and nanotechnology on an atomic scale. As a student in the TEM group, you will have a unique opportunity to use some of the world's most advanced scientific instrumentation, studying materials with atomic resolution on a daily basis!

As a project or diploma student in the TEM group you can take an active part in one of the exciting research projects which require nanoscale material characterization. You work together with a PhD student, a SINTEF research team or one of our external collaborators to achieve a common goal. The work can have an applied character and be very practical, or theoretical to support experimental activities within the group. Also a combination of practical and theoretical work is possible. In all projects the TEM or input from TEM is used to understand the structure of a material down to the atomic level and relate this to macroscopic properties of the materials.

Examples of student projects which are available and in which you can participate are:

- Studies of solar cell materials (Si, thin films, quantum dots & nanowires)
- Development and characterization of new aluminium alloys
- Analyses of catalyst materials for future applications
- Simulation, quantification and image processing of various TEM data
- Studies of thin film oxides for use in electronics
- These projects are described in more detail in the next pages.

Earlier, several student projects have led to publications [1-6]. Due to high demand on the research facilities and the intensive supervising we want to give, we can take in max 4 students the coming semester.

People working in the TEM group on microscopes, with sample preparation and simulations

We offer:

- Choice of a project that fits your interests and background.
- Training in operating advanced and modern scientific equipment or/and simulation and quantification software (theoretical/modelling).
- Weekly meetings with a supervisor during the project.
- Being part of a large and dynamic scientific consortium.
- Possibility in extending the project to a diploma or a PhD

WE WILL OFFER A SUMMER JOB FOR A STUDENT IN THE TEM GROUP THIS SUMMER – ASK US FOR DETAILS!

You are encouraged to contact one of us if you like to hear more details on a specific project, other available projects, options in academia or industry after a diploma in TEM or possibilities to incorporate own research ideas related to TEM. For more information on the current activities within the group, group members, equipment and recent publications, see the TEM Gemini Centre homepage: http://www.ntnu.edu/geminicentre/tem.

7th to 10th of June 2016 we will organize the Nordic microscopy conference SCANDEM 2016 (see https://www.ntnu.edu/physics/scandem2016). At this conference we need student assistance – and we hope that students who start project work in the group can participate and work as assistants at the conference. This will be an excellent opportunity for getting an overview of state-of-the-art research in the field of microscopy.

Contacts:




Photo: Ole Morten Melgård

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References:

[1] V. T. Fauske, M. B. Erlbeck, J. Huh, D. C. Kim, A. M. Munshi, D. L. Dheeraj, H. Weman, B. O. Fimland, and A. T. J. van Helvoort, “In-situ electronic probing of nanowires in an electron microscope”, Journal of Microscopy, in press, 2016. (DOI: 10.1111/jmi.12328)

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[3] E. Christiansen, M. Nord, I. Hallsteinsen, P.E. Vullum, T. Tybell, and R. Holmestad, "Structural investigation of epitaxial LaFeO3 thin films on (111) oriented $SrTiO_3$ by transmission electron microscopy", Journal of Physics: conference series, 644, 012002, 2015.

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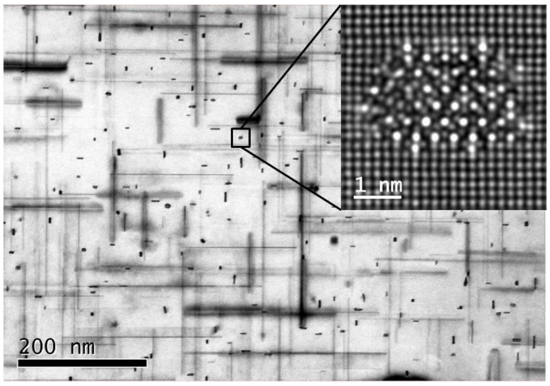
[6] F. A. Martinsen, F. J. H. Ehlers, M. Torsaeter and R. Holmestad, "Reversal of the negative natural aging effect in Al-Mg-Si alloys", Acta Materialia, 60, 6091-6101, 2012.

NANO-STRUCTURE CHARACTERIZATION FOR ALUMINIUM ALLOYS DEVELOPMENT



MOTIVATION:

In studies of light metal alloys there are challenges when it comes to establishing relations between the nano-structure and the mechanical properties, as for example strength and ductility. In Al-Mg-Si/Ge-(Cu) alloys, which are industrially relevant due to their superior mechanical properties (high strength /weight ratio and good corrosion properties), the hardness increase is due to precipitation of nanometre-sized metastable phases that form from solid solution during heat treatment.

WHAT THE STUDENT WILL DO IN THE PROJECT:

The student will do experimental testing of mechanical properties (such as hardness) with different heat treatments and alloy compositions, and complementary nanostructure studies on the TEM. The heat treatment and hardness measurements will be done at the Department of Materials Technology and Engineering.

REQUIRED FROM THE STUDENT:

Background in materials physics (solid state physics) and interest in materials science would be an advantage. We need a student interested in experimental work, and working independently in a larger group of scientists.

OTHER ASPECTS:

There are many people working on aluminium alloys in the TEM group, and we have several ongoing external projects where we work in close collaboration with SINTEF, Hydro Aluminium and other smaller companies producing aluminum products, and the students will participate in project meetings in these consortiums at Sunndalsøra and Trondheim. Students get their own problem which fits well into the rest of the work done. Within this field there are possibilities for continuation as a PhD student and summer job. We have collaboration with Hydro Bonn and two universities in Japan (Toyama and Tokyo Tech.) and stays abroad will also be a possibility.

CONTACT PERSONS:

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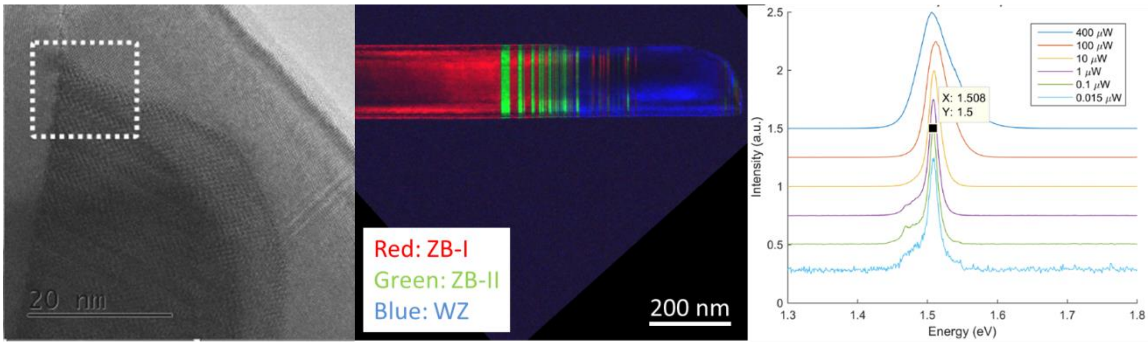
Structural characterization of heterostructured semiconducting nanowires

Motivation:

III-V semiconductor nanowires with high quality are grown Department of Electronics and Telecommunications (IET) for future application in optical devices (EDs, lasers) and solar cells. Because of their small size, nanowires have to be studied by characterization techniques with a high resolution as for example TEM.



What the student will do in the project:

You will study a specific batch of nanowires with interesting optoelectric properties. Your task is to help with optimizing the growth condition (to be specific GaN grown on a new MBE) or understanding the relation between optical & electric properties to the crystal structure / lattice defects/composition as determined by TEM. You will learn to use basic TEM techniques as electron diffraction and high resolution imaging techniques. SEM, STEM or FIB work within NTNU Nanolab could be part of the project. Your own characterization results are relevant to optimize growth and nanowire-based devices. An alternative project is making nanowire-based circuitry using FIB.

Required from the student:

Interest in experimental work using the TEM. Join weekly project meetings with academics and other project students that grow the nanowires. You should be able to clearly communicate and relate your results to others in the project and understand what feedback they expect from your TEM work.

Other aspects:

The field of semiconductor nanowires, fundamental understanding and application of them in devices had an enormous growth in the last years. We had already 10 project/diploma students working on TEM of semiconducting nanowires. Results of students' work are published afterwards. The research is interdisciplinary and a key example of fundamental & applied nanotechnology at NTNU. The obtained practical skills can be applied in the study of other nanostructures.

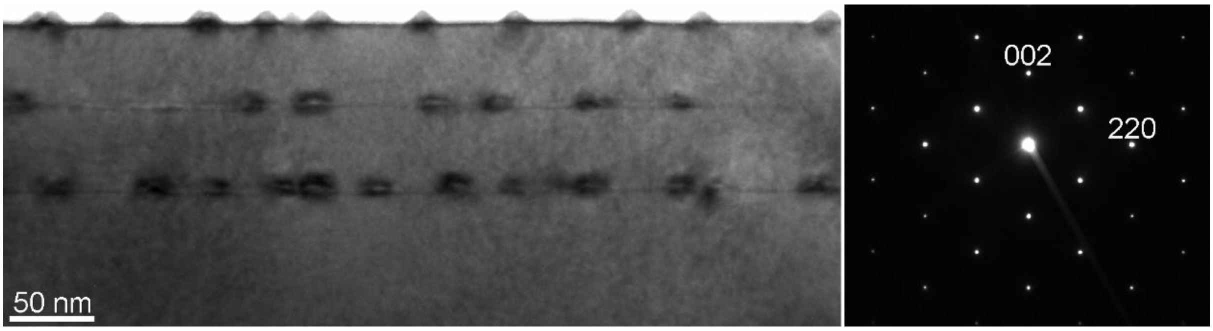
Contact persons:

Ton van Helvoort (IFY, a.helvoort@ntnu.no). Other key people in the project: Julie Stene Nilsen (IFY), Aleksander Mosberg (IFY), Helge Weman (IET) and Bjørn-Ove Fimland (IET).

TEM CHARACTERIZATION OF SOLAR CELL MATERIALS

MOTIVATION:

At NTNU there are several ongoing projects on developing new, mostly non-Si, materials for solar cells. The new materials consist of single- or multi-layer thin films on a crystalline substrate or nanoparticles/quantum dots (QDs) embedded in a matrix. TEM studies are important in many of these studies as defects, interfaces, size/shape and composition variations at the nm-scale can determine the overall efficiency of the solar cell.



InAs quantum dots in GaAs intermediate band solar cell material.

WHAT THE STUDENT WILL DO IN THE PROJECT:

The student will study the crystal structure and different phases in the thin films using TEM, and correlate this to process parameters and other material properties and/or device performance. The actual work will depend on the type of material and the interest of the student. Possible projects include studies of defects, grain structure, QD-density, strain characterization of quantum dot intermediate band solar cells, development of a specimen preparation routine that allows efficient characterization of thin films with respect to grain size, crystallinity and defects and studies of the effect of doping in relation to the electro-optical properties.

REQUIRED FROM THE STUDENT:

We seek students with background from physics or nanotechnology. Interest in solid state physics and nanoscience or solar cell physics is needed. We need a student interested in experimental work, working independently and being able to collaborate with the research groups synthesizing the materials/devices.

OTHER ASPECTS:

There is a large activity at Gløshaugen on characterization and on solar cell materials, and the student will get the possibility to join these activities, with participation in weekly lunch meetings etc. It is expected that the student projects will lead to important findings and thus be included in scientific publications. SEM and STEM work within NTNU Nanolab could be part of some of the suggested projects.

CONTACT PERSONS:

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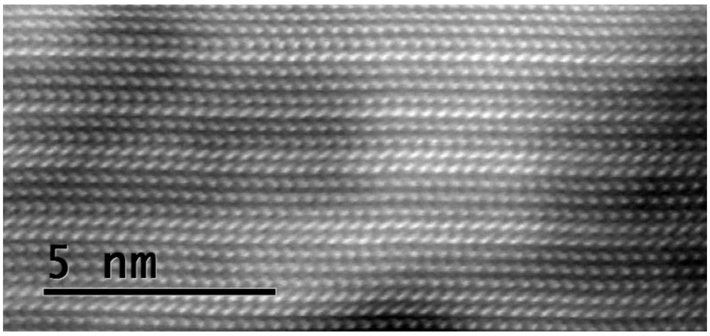
TEM CHARACTERIZATION OF NOVEL OPTOELECTRONIC MATERIALS

MOTIVATION:

At NTNU there are several ongoing projects on developing new materials for mid-infrared medical lasers, for solar cells and for all-optical switching for telecommunications. The optical response of these materials depends on the local structure of the materials; dopant placement, crystalline order and grain boundaries are all important in controlling the optical response. TEM investigation allows the determination of the detailed structure for comparison with first principles calculations and optical measurements made by our group and our collaborators.



This image shows stacking faults in Fe:ZnS; repeated departures from the ideal ABCABC... stacking of (111) crystal planes

WHAT THE STUDENT WILL DO IN THE PROJECT:

The student will prepare samples using the FIB in Nanolab and examine them in the TEM, to support and complement the other analyses being performed, and will work with the supervisors on the interpretation of the data. The material studied will depend on the interest of the student; possible projects include studies of semiconductor nano/microwires and thin films being developed for medical lasers and solar cells.

REQUIRED FROM THE STUDENT:

We seek students with background from physics, materials science or nanotechnology, interested in solid state physics and/or nanoscience. If you are interested in experimental work, working independently and collaborating with the research groups synthesizing the materials/devices, please contact the advisors listed below.

OTHER ASPECTS:

There is a large activity at Gløshaugen on characterization of optical materials, and the student will be included in these activities, with participation in weekly lunch meetings etc. It is expected that the student project will lead to scientific publications.

CONTACT PERSONS:

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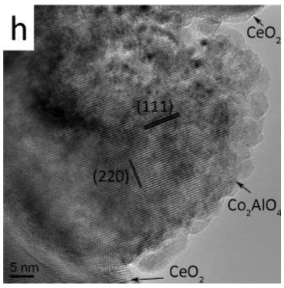
NANOSCALE TEM STUDIES OF CATALYST SYSTEMS

MOTIVATION:



LATTICE RESOLUTION IMAGE SHOWING MICROSTRUCTURE OF N_2O ABATEMENT CATALYST. BERNTSEN 2014. MASTER THESIS

Supported metal nanoparticles are used in in a range of catalytic processes in industry. They are also important in the growth of nanostructures and developing technologies such as fuel cells. We have a strong cooperation with the Department of Chemical Engineering who work with a wide range of catalyst systems and industry, through various ongoing projects. In order to understand, design and develop these systems it is increasingly important to have a detailed understanding of their microstructure. TEM is an important tool for studying morphology, crystallography and chemistry at the nanometre-scale. Two interesting projects are available that would be conducted in cooperation with Dr David Waller at Yara. Further details are given below.

WHAT THE STUDENT WILL DO IN THE PROJECT:

The student will learn the basics of TEM sample preparation and analysis. The analysis and data processing will be developed to increase the understanding of the microstructure and how this relates to catalytic properties.

1) Study of oxide-based ammonia combustion catalysts. Catalysts based on LaCoO3 with the perovskite structure, are produced in the form of porous tablets and as fully dense polished discs. The porous catalysts are representative of real catalysts. The fully dense discs are model systems with a geometry that is more amenable for analysis (we know exactly where the interface of the dense disc). Model catalysts are in three conditions; fresh polished disc (bulk lattice exposed at surface); air annealed (representative of a sintered catalyst); pilot plant exposed (exposed to ammonia combustion conditions for varying periods of timer – minutes to days). XPS and grazing incidence XRD, of the model catalyst discs, indicate some significant structural and compositional changes after pilot plant. The student project would involve TEM and or SEM analysis of the interface. For TEM, we envisage analysis of thin sections at the interface region. Analysis of the model catalysts would be compared to porous catalysts which had the same reactor exposure.

2) Study of sulphur diffusion into Zinc Oxide Adsorbents. In commercial production of hydrogen by steam reforming of hydrocarbons, sulphur compounds are removed by first converting them to hydrogen sulphide, and then trapping the sulphide in a zinc oxide bed (H_2S + ZnO = ZnS + H_2O) This process is limited by three factors. Firstly, by external mass transport (diffusion of H2S from the gas phase to the surface of the ZnO absorbent), Secondly by internal gas transport (diffusion of H2S in the ZnO pore structure). Finally, a solid state diffusion process where S diffuses into the ZnO and oxygen diffuses out of the ZnO. The project would involve TEM analysis of both single crystal model absorbents (ZnO/ZnS diffusion couples) and polycrystalline ZnO systems.

REQUIRED FROM THE STUDENT:

The student should be interested in learning new practical skills and developing methodology and technique to address the requirements of the project. The student should take an active role with respect to putting the observations on the context of the relevant industrial process.

OTHER DETAILS:

There is a large activity in catalysis research at Gløshaugen. This includes the national FME project "Innovation for a competitive and sustainable process industry (iCSI)" and the project will be part of this environment. Several possible projects are available and it will be an objective to include results in journal publications.

CONTACT PERSONS:

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TEM STUDIES RELEVANT TO THE PROPERTIES OF ALUMINIUM ALLOYS IN EXTRUSIONS AND HEAT EXCHANGERS

MOTIVATION:

Sapa AS is a leading international company in the area of aluminium alloy extrusion, building systems and precision tubing. Developing these products and optimising their properties needs a high level of material knowledge and this presents many interesting challenges. Projects are available where a need has been identified to use Transmission Electron Microscopy to obtain detailed, fundamental, information about the microstructure of aluminium alloys in industrial products to add to existing knowledge. The work will be conducted in close collaboration with Dr Jan Halvor Nordlien at Sapa, who has a Professor II position at the NTNU Materials Technology Department.

WHAT THE STUDENT WILL DO IN THE PROJECT:

The student will learn the basics of TEM sample preparation and analysis, developing procedures to address the chosen topic and interpreting the results in the context of the component properties. Materials for study will be provided by Sapa. Potential projects including the study of extruded alloys used in heat-exchanger units, how they are influenced by brazing and deformation and understanding corrosion properties.

REQUIRED FROM THE STUDENT:

The student should be interested in experimental work and learning new practical skills. It will also be important to develop the project and interpret results in the context of their technological relevance.

OTHER ASPECTS:

The project would be carried out in an environment where there is a broad activity in aluminium alloy studies and good interaction with industry. Opportunities to pursue PhD studies often arise in the group.

CONTACT DETAILS

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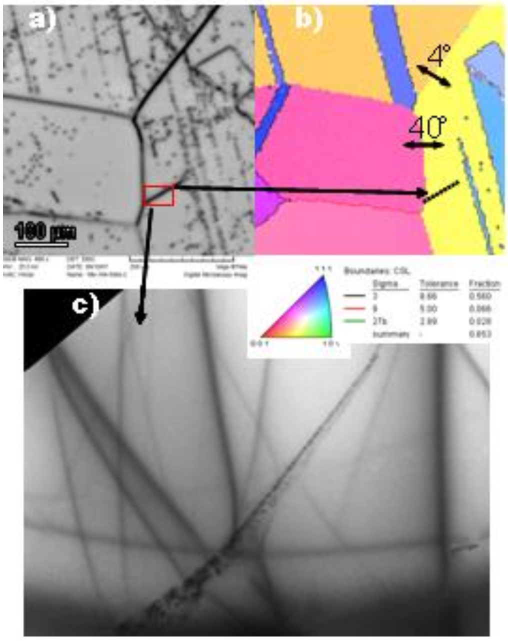
TEM INVESTIGATIONS OF MICROSTRUCTURE IN SILICON SOLAR CELL MATERIALS



a) EBIC, b) SEM, c) TEM

MOTIVATION:

Crystalline silicon still remains the dominant commercial material of solar cells and accounts for about 92 % of the total production in 2014. The record lab efficiencies for monocrystalline and multicrystalline solar cells are 25.6 % and 20.8 %, respectively. In order to close this gap, it is important to understand the role of impurities and defects, which typically have higher densities in multicrystalline silicon. It is, therefore, important to understand how defects are formed and grow during multicrystalline silicon solidification and cooling, and how this affects the silicon wafers lifetime. Another aspect is the interfaces and contacts in the produced cells. The structure at nanoscale of these contacts has to be studied in detail down to nanoscale to understand the properties and efficiency of Si solar cells. This is an important aspect for both multicrystalline and monocrystalline solar Si.

WHAT THE STUDENT WILL DO IN THE PROJECT:

Light microscopy and scanning electron microscopy techniques will be combined with TEM to study grain boundaries, dislocations and particles in the same material, Interfaces and contacts will be studied in TEM. The student will learn to use basic TEM techniques, and collaborate with other students at IMT who will do/have done most of the other experiments.

REQUIRED FROM THE STUDENT:

Interest in materials physics and experimental work and a background in solid state physics or functional materials is an advantage.

OTHER ASPECTS:

There is a large activity at Gløshaugen on silicon solar cell materials, this includes participation in a nationally Centre for Environmental-friendly Energy Research (FME) and the student will have the possibility to join this activity, with participation in regular meetings, etc.

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Data processing of electron microscopy experimental results

Motivation:

Electron microscopes are able to collect multiple and large data sets simultaneously. We have recently invested ~35 million NOK in TEM infrastructure in Trondheim. Because of better microscopes, detectors, more complex data sets and the availability of more advanced computing capabilities, post-acquisition processing beyond what standard TEM software packages can provide, becomes more demanding, but also more beneficial. We want to develop in this area and there are opportunities for Master-level projects that can contribute and be integrated into ongoing research projects. Example projects include:

- Quantitative compositional mapping by EDX: NORTEM has one of the most efficient detection systems on the market, however analytical software for mining these is not yet well developed. We consider here building our own routines using Python and contribute to open-source analytical packages.
- Electron energy loss spectroscopy fine structure (ELNES): Can be used to probe electronic fine-structure down to the atomic scale. Detailed analysis using for example FEFF9 (http://www.feffproject.org/index-feffproject.html) will allow simulation for comparison with experimental spectra.
- Electron tomography: 3D tomographic data collects electrons when a sample volume has been imaged over a range of orientations (typically +/- 70^{o}). Reconstruction of the raw data and quantification of the reconstruction in terms of dimensions, porosity and particle sizes in complex nanostructures such as catalyst systems need to be established and developed.
- Statistical analysis of EDX and EELS spectra: Principle components analysis (PCA) is becoming routine data processing for (noisy) spectra, however not yet implemented in acquisition software. Here existing routines in programs such as Hyperspy (based on Python) or Matlab would be used and developed.
- Strain analysis: Image processing to extract strain variation is important in different fields we work on as for example semiconductors and alloy design.
- Atomic resolved HAADF STEM image simulations and quantifications: Acquiring atomic resolved HAADF STEM where the intensity of an atomic column can reflect the average atomic number, allow mapping composition on the atomic scale. Quantification was successfully used for precipitates in Al-alloys and heterostructured nanowires. We want to extend the routines to other materials systems.

What the student will do in the project:

The student will work with new and existing data sets related to one of the techniques listed above. He/she will develop data analysis/routines that harvest more from a given data set. Data will come from ongoing or recent projects and understanding of the relevance of the data and interaction with the data-owner will be important. Such routines should also be made available and accessible so that other users of the facility will be able to apply it relatively easily. This means that the whole process of development, implementation and documentation will be addressed.

Required from the student:

An interest in using and developing software tools is required. Experience with Matlab, C++ or Python is essential. The student will learn how different datasets are build-up based on how the microscopes or detector acquire signals. Further he/she has to understand and address to the requirements an average TEM user has regarding data processing software. Good communication and interaction with scientific and academic staff and PhD students.

Other aspects:

The intention is that final results will form a part of ongoing research programs and contribute to a publishable result or contribute to open-access software. Related to this there might be a summer job offered. “Big data” and mining useful information from ever growing data set sizes are hot topic in today’s and future research.

Contact persons:

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TEM CHARACTERIZATION OF OXIDE THIN FILMS

MOTIVATION:

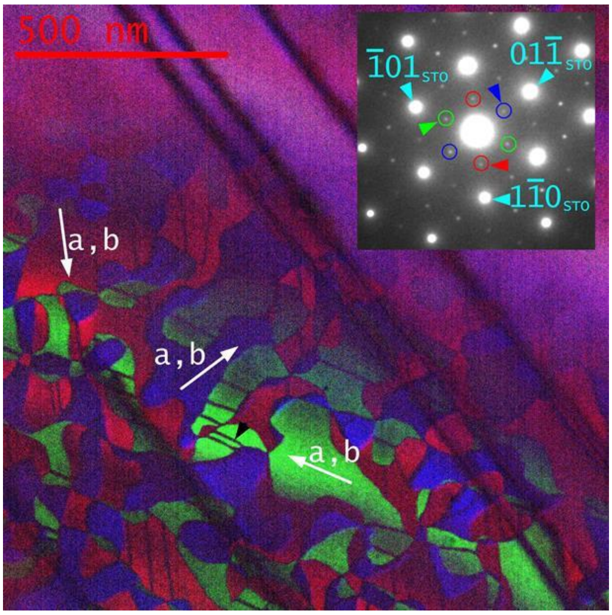
Oxide materials show superior optical, magnetic, dielectric, piezoelectric, and electric conduction (superconductivity, ionic conductivity, semi-conductivity) properties, as well as excellent mechanical performance, which make them an important and promising class of functional materials. In the oxide electronics group at Department of Electronics and Telecommunications they have currently large focus on the effect of interfaces on (anti-) ferroelectric and piezoelectric materials. The goal is to understand how interfaces can be used to control properties for applications within sensor technologies. System include (La,Sr)MnO_3, $LaFeO_3$ and $BiTiO_3$. The thin films are grown by the Pulsed Laser Deposition (PLD) technique.

WHAT THE STUDENT WILL DO IN THE PROJECT:

Study the crystal structure, domains and interfaces in the thin films using TEM and correlate this with properties. An important aspect here is to make good cross section samples, and TEM sample preparation will be a considerable part of the work.

REQUIRED FROM THE STUDENT:

We seek students with background from physics or nanotechnology. Interest in solid state physics and electronics is needed. We need a student interested in experimental work, and working independently. Accuracy and patience are needed for the sample preparation work.



TEM dark field mosaic image of domains in $LaFeO_3$.

CONTACT PERSONS:

Randi Holmestad (randi.holmestad@ntnu.no), Per Erik Vullum (per.erik.vullum@sintef.no) and Thomas Tybell (thomas.tybell@iet.ntnu.no).

TEM investigations of natural Quartz for technological solutions

Motivation:

High purity quartz (a crystalline form of SiO_2) is a remarkable material, widely used in industry today. Due to combination of specific conditions it is found only in a few locations in nature. Quartz has high chemical purity and resistance, high softening temperature and thermal resistance, low thermal expansion, high transparency and high irradiation resistance.

The Quartz Corp (TQC) is a major supplier of high purity quartz sand from the source of the worlds purest quartz in Spruce Pine (USA). The mineral is mined in the US and shipped to Drag in Norway for further purification processing. The processed quartz is sold to a wide range of customers all over the World. Quartz sand produced by TQC can for example be found in

- Crucibles for Si Solar PV production
- Semiconductor crucibles, glass windows, rods, tubes
- Optical fibers
- Optical lenses

The quartz sand is very pure after the processing, however, ~10 ppm of other elements than Si and O is still present in the material. These elements come from small inclusions of other minerals or other types of elemental inclusions, lattice bound or interstitial placed atoms. In order to be even better in processing the sand to top quality and extreme purity, detailed knowledge of the material down to atomic scale is needed. The topic of the student project will be investigations of quartz material by transmission electron microscopy (TEM) techniques, to understand more of the remaining impurity elements in the material.

What the student will do in the project:

The student will learn the basics of TEM specimen preparation and analysis, developing procedures to address the task and interpreting the results. The student will also be introduced to the world of quartz by TQC as a background for the experimental work to be executed. Quartz materials for study will be provided by TQC.

Required from the student:

Background in materials physics (solid state physics) and interest in materials science would be an advantage. The student should be interested in experimental laboratory work using the TEM, and learning new practical skills. The student should take an active role with respect to putting the observations in to quartz material context, and need to obtain knowledge about quartz and quartz sand processing through this project.

Other aspects:

There are possibilities for a summer job with The Quartz Corp in relation to the project.

Contact persons:

Ton van Helvoort (IFY, 73593637, a.helvoort@ntnu.no),
Astrid Marie F. Muggerud (The Quartz Corp, 91117754, Astrid.Muggerud@thequartzcorp.com)

Hybride-based smart windows

Motivation:

Smart windows that adapt to the amount of incoming light and thereby help to control the indoor temperature are one element in the design of zero emission buildings. At IFE (Kjeller) they develop several candidate transparent thin hybride films for smart window applications. To understand the transmission properties, local analysis of the crystal structure and compositional variations within these coatings are required.

What the student will do in the project:

Study the crystal structure of the thin films deposited on glass using TEM and correlate this with transmission properties measured done by IFE. A challenge will be to obtain suitable plane-view and cross section TEM specimens that allow detail characterization of the crystal structure and the composition. The student will make the specimens her/himself, do the TEM and the TEM related data analysis.

Required from the student:

We seek students with background from physics or nanotechnology, interested in practical experimental work. The student should be able to work independently and to communicate her/his results to the coworkers at IFE.

Contact persons:

Ton van Helvoort (IFY, 73593637, a.helvoort@ntnu.no) and Fredrik A. Martinsen (Fredrik.Martinsen@ife.no)