Project work / Master / Diploma topics in the TEM Gemini Centre, 2020/21

TEM Gemini Centre

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

We have in total three TEM instruments and are part of the national infrastructure NORTEM. One of these is one of the most advanced available.

In 2020, we have at IFY 3.4 (assoc.) professors, 2 engineers, 5 SINTEF researchers, 1 Postdoc, ~10 PhD students and several Master students with TEM as their main activity.

Our research extends through various fields of solid state physics and materials technology, from cooperation with industry on aluminum, solar cells, nano-materials and data analysis.

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

The transmission electron microscopy (TEM) Gemini Centre has three state-of-the art microscopes. These TEMs include the most sophisticated technology available and give new possibilities for advanced materials characterization, novel experimental solid-state physics and nanotechnology down to the 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 yourself or work with data from them!

As a project or diploma student in the TEM group you can take an active part in one of the exciting research projects which requires nanoscale material characterization. You work together with a PhD student, SINTEF researchers 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 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.

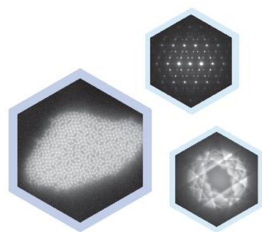
Examples of student projects which are available:

- Development and characterization of new aluminium alloys
- Study of nanoparticles and nanowires to optimize synthesis
- Simulations, atomistic modelling and advanced data processing
- Studies of thin film oxides for use in electronics
- Studies of multi-materials and joints
- Contribute to open-source code for data analysis

These projects are described in more detail in the next pages. Earlier, several student projects have led to publications [1-7]. Due to high demand on the research facilities and the intensive supervising we give, we can take in max 8 students (5 experimental) in the group in the coming semester.

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



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.
- Possibilities in extending the project to a Master or a PhD.

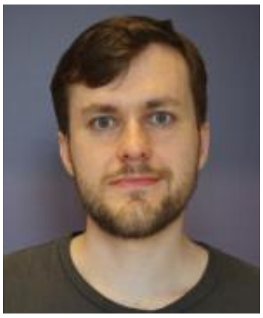
WITHIN THE ALUMINIUM PROJECTS WE THIS YEAR OFFER A SUMMER JOB AND THE POSSIBILITY TO STAY ONE MONTH IN JAPAN IN AN ALUMINIUM COMPANY AS A PART OF THE PROJECT/MASTER!

All topics can be adjusted to 15,30 or 60 ECTS. 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.

Also, take a look at our video! https://www.youtube.com/watch?v=BuLqv4_cIMU

Contacts





Prof. Randi Holmestad
Room D4-153
+4748170066
randi.holmestad@ntnu.no

Prof. Ton van Helvoort
Room D4-149
+4773593637
a.helvoort@ntnu.no

Assoc. Prof.
Magnus Nord
magnus.nord@ntnu.no

Assoc. Prof. II
Per Erik Vullum
Room D4-118
+4793820647
per.erik.vullum@sintef.no

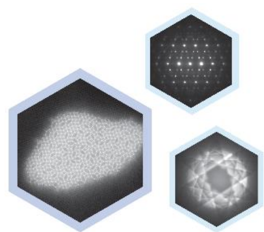
Assoc. Prof. II
Sigurd Wenner
Room D4-118
+4793016522
sigurd.wenner@sintef.no

References:

[1] T. Bergh, D. N. Johnstone, P. Crout, S**. Høgås**, P. A. Midgley, R. Holmestad, P. E. Vullum, and A. T. J. van Helvoort, “Nanocrystal segmentation in scanning precession electron diffraction data”, Journal of Microscopy, doi.org/10.1111/jmi.12850, 2020.
[2] N. H. Gaukås, S. M. Dale, T. M. Ræder, A. **Toresen**, R. Holmestad, J. Glaum, M.-A. Einarsrud, and T. Grande, “Controlling Phase Purity and Texture of $K_{0.5}Na_{0.5}NbO_3$ Thin Films by Aqueous Chemical Solution Deposition”, Materials 12, 2042, 2019.
[3] J. **Busam**, S. Wenner, A.M. Muggerud and A.T.J. van Helvoort, Structural Characterization of Natural Quartz by Scanning TEM, Microscopy and Microanalysis 24(S1), 2044-2045, 2018.
[4] H.W. Ånes, I.M. **Andersen** and A.T.J. van Helvoort, Crystal Phase Mapping by Scanning Precession Electron Diffraction and Machine Learning Decomposition, Microscopy and Microanalysis 24(S1), pp. 586-587, 2018.
[5] J.K. Sunde, **Ø. Paulsen**, S. Wenner and R. Holmestad, “Precipitate statistics in an Al-Mg-Si-Cu alloy from scanning precession electron diffraction data”, Journal of Physics: Conf. Ser., 2017, 902, 012022. doi :10.1088/1742-6596/902/1/012022
[6] A. Mosberg, S. **Myklebost**, D. Ren, H. Weman, B. Fimland and van A.T.J. Helvoort, “Evaluating focused ion beam patterning for position-controlled nanowire growth using computer vision”, Journal of Physics: Conf. Ser., 2017, 902, 012020. doi :10.1088/1742-6596/902/1/012020
[7] F de la Peña et al, Hyperspy 1.3 Zenodo. https://zenodo.org/record/1469364#.XHuZzTNKg2w and D. Johnstone et al, pyXem 0.10, Zenodo, https://zenodo.org/record/3667613#.XmPMHkdKg2w [Open source software]

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



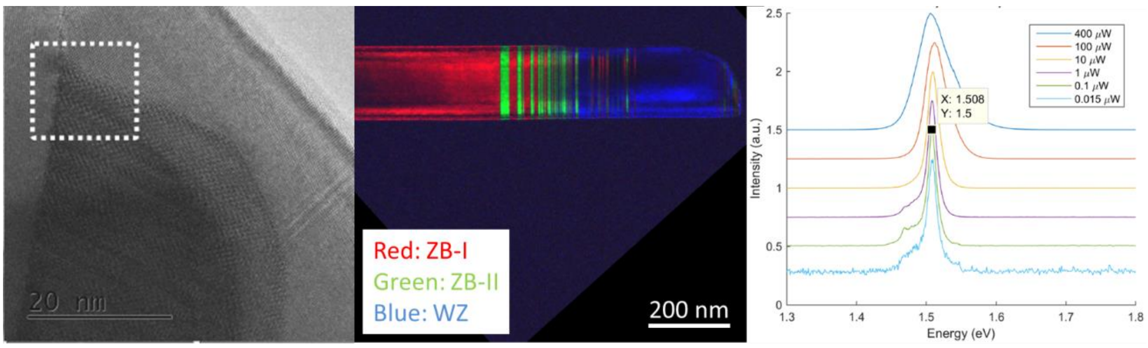
TEM Gemini Centre

NTNU
SINTEF

Structural characterization of heterostructured semiconducting nanowires

Motivation

III-V semiconductor nanowires with high quality are grown at Department of Electronic Systems (IES) for future applications in optical devices (LEDs, 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 optoelectrical 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 & electrical 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. The project can be adjusted to 15, 30, 45 or 60 ECTS.

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

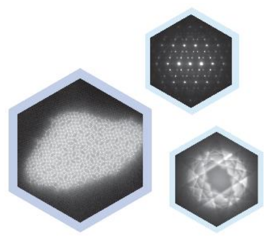
The field of semiconductor nanowires, fundamental understanding and application of them in devices had an enormous growth in the last years. We had already 14 project/master students working on TEM of semiconducting nanowires. Results of students' work are published afterwards. The research is interdisciplinary 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: Helge Weman (IES) and Bjørn-Ove Fimland (IES).

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



Joining for a Multi-Material Future

Motivation

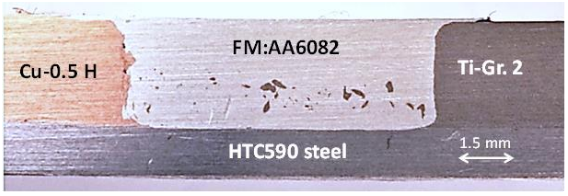


Figure 1: Image of a novel joint where the aluminium (alloy AA6082) filler material (FM) has been joined to copper (Cu), titanium (Ti) and steel (alloy HTC590).

The development of lightweight multi-materials in vehicles is inevitable to reduce the environmental impact and to increase fuel efficiency. Two examples here are 1) vehicle bodies, where aluminium-steel joints combine the low weight and formability of aluminium with the strength and low cost of steel and 2) battery power packs, where replacement of Cu with Al cables has enormous weight saving potential. To join or bond metals is challenging, since they often have large differences in thermo-physical properties, different solid solubility and new phases are formed on the interface. Hybrid metal extrusion and bonding (HyB) is a novel, patented solid-state joining technique developed by HyBond, where dissimilar metallic materials can be joined at low temperatures using a filler wire. Recently, multi-material joints of aluminium-steel-titanium-copper (Figure 1) were demonstrated for the first time. Structural characterization on the nano-scale of the multi-material joints and of the filler wire before and after joining is important to understand both the technique and the mechanical properties of the resulting joints.

Your project

The student will characterize multi-material joints with transmission electron microscopy (TEM). Thorough training will be given, and the student will learn how to use the TEM, and to analyze and understand the results of different electron microscopy techniques, such as energy dispersive X-ray spectroscopy, electron diffraction and scanning TEM (STEM). The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

The student should be interested in materials physics, electron microscopy and electron diffraction, as motivation for the project work is the most important requirement. Experience with electron microscopy or with programming, preferentially Python, is an advantage. The most relevant courses are Solid State Physics and Materials Physics. It is important to be willing to work both independently and in cooperation with other researchers in the project.

The student will collaborate closely with PhD candidates and SINTEF. The results from the project work will complement research done by others and will likely be part of scientific publications. The student will be a part of the TEM group and connected to the SFI Manufacturing centre that has 15 industrial partners, and the new NANO2021 project In-Sane.

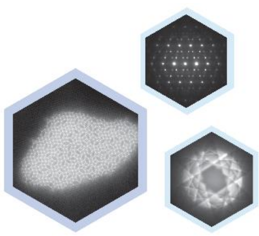
Contact persons

Per Erik Vullum, Associate Professor II, Department of Physics, NTNU / Research Scientist, SINTEF. Office: Realfagbygget D4-118. E-mail: per.erik.vullum@sintef.no
Randi Holmestad, Professor, Department of Physics, NTNU.
Office: Realfagbygget D4-153. E-mail: randi.holmestad@ntnu.no

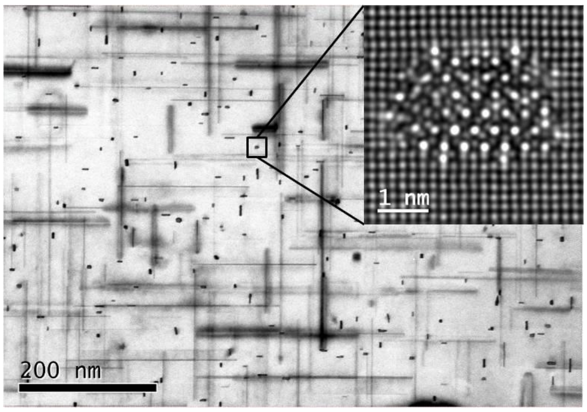
The project is a collaboration with Department of Mechanical and Industrial Engineering and professors Filippo Berto, Jan Torgersen and Øystein Grong.

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



TEM investigations of aluminium alloys in collaboration with industry



Motivation

In the 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-Cu alloys, the strength increase is due to precipitation of nanometer-sized metastable phases (see TEM image) that form from solid solution during heat treatment. These so-called precipitates are studied by transmission electron microscopy (TEM).

NTNU (Departments of Physics and Materials Science and Engineering) and SINTEF have several ongoing collaboration projects with Norwegian (and international) aluminium industry. Within this collaboration, we offer specialization projects/masters within characterization of microstructure in aluminium alloys. The work will contribute in the development and design of new aluminium alloys, mainly for the automotive industry. This work will be connected to the SumAl project, where we work in close collaboration with SINTEF, Hydro, Benteler Automotive and Neuman Aluminium. The students will invited to internal aluminium meetings as well as to project meetings in the SumAl consortium in Trondheim or/and at industry sites. Within this field there are possibilities for internships in Japan, summer job and continuation as a PhD student.

Your project

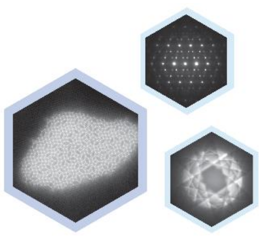
Currently we have started up a new collaboration with Benteler Automotive in Raufoss where two industrial alloys are produced for testing different thermomechanical parameters. The student(s) will here do experimental testing of properties (such as hardness, strength, conductivity..) with different heat treatments, and study the corresponding nanostructure (precipitates) in the TEM, supervised and in collaboration with PhD students and SINTEF researchers (who can help with more advanced microstructure characterization if needed). The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

Background in materials physics (solid state physics) and an interest in material science would be an advantage. We want students interested in doing experimental work and working independently in a larger group of scientists.

Contact persons

Randi Holmestad, Professor, Department of Physics, NTNU. Office: Realfagbygget D4-153.
e-mail: randi.holmestad@ntnu.no
Other key people in the project: Calin D. Marioara (SINTEF, calin.d.marioara@sintef.no), Christoph Hell (PhD student, Physics, NTNU, christoph.hell@ntnu.no)



Transmission electron microscopy of deformed aluminium alloys

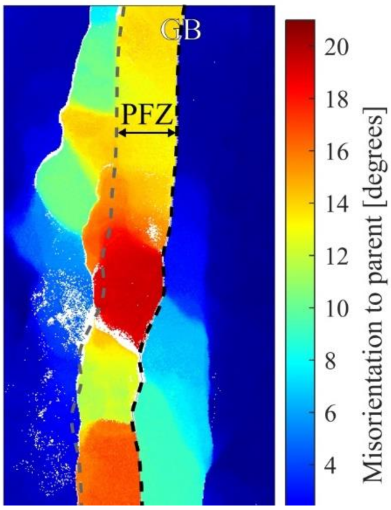
Motivation

Aluminium alloys are often used as lightweight alternatives for important structural components in e.g. the automotive industry. Design of safe and efficient vehicles requires experimental knowledge of microscale and nanoscale features that form in these alloys during deformation. The goal of this project is to learn more about the physics of deformation in aluminium alloys. The project is part of ongoing multidisciplinary research at the [Centre for Advanced Structural Analysis (CASA)], a centre for research-based innovation (SFI) at NTNU that focuses on understanding deformation of materials.

Your project

You will study deformed aluminium alloys in the TEM using a wide range of techniques. Different research problems are possible, depending on the skills and interest of the student. For example, you may investigate soft precipitate free zones along grain boundaries and the nanoscale features which develop within these during rapid deformation. Alternatively, you can study the nano-belts in a patented high-creep resistant Al-Hf cast alloy and how they resist creep deformation. The last will be in direct collaboration with Hydro.

The research involves many TEM techniques and can be tailored to your own interests and skills. Novel techniques using recent investments at the TEM Gemini Centre will be used and you can participate in developing techniques and data analysis code. The project can be adjusted to 15, 30, 45 or 60 ECTS.



Subgrains in a precipitate free zone along a grain boundary in an Al-Mg-Si alloy after slow compression by 20%. Will these structures also form during rapid deformation?

Requirements

The student must be interested in applied physics, electron microscopy, and materials physics. The student must also be motivated in the fields of Physics, Metallurgy, and Mechanics. Relevant courses are Solid State Physics, and Materials Physics. Prior knowledge and hands-on experience with TEM are beneficial. The student should also have skills and interests in data analysis and programming.

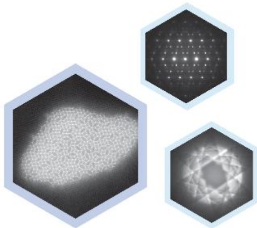
Contact persons

Randi Holmestad, Professor, Department of Physics, NTNU.
Office: Realfagbygget D4-153. Email: randi.holmestad@ntnu.no.

Emil Christiansen, Postdoc, Department of Structural Engineering, NTNU.
Office: Materialteknisk 2-52A. Email: emil.christiansen@ntnu.no.

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



TEM Gemini Centre

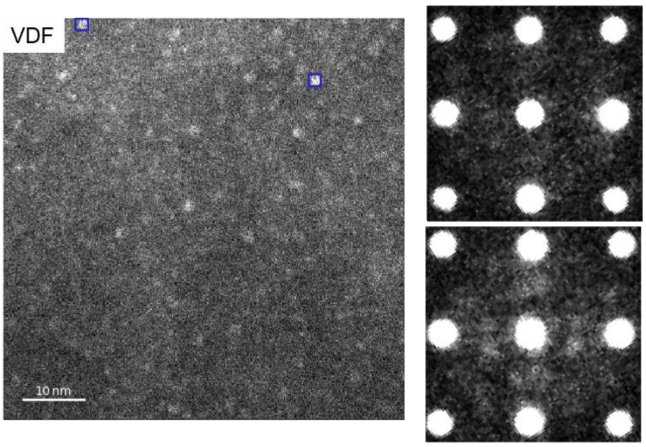
NTNU
SINTEF

Developing data processing routines for diffraction datasets from novel electron detectors

Motivation

Electron diffraction is a crucial tool in characterizing different materials. At NTNU, the so-called scanning precession electron diffraction (SPED) technique has been extensively used for characterizing different Aluminium (Al) alloys to explain their macroscopic properties. The goal is to understand the physics behind the strengthening mechanisms in Al alloys, by studying the early stages of industrial thermomechanical heat treatments at the nm scale. With the SPED technique, we obtain a 4D dataset comprised of a 2D real-space position and a 2D signal in reciprocal space (one electron diffraction pattern from each scanned position). Our facility has recently got one of the first new generation electron detectors, the so-called direct electron detectors. To fully use the potential of the new technology, there is a need to explore the detector settings and optimize the post-acquisition data analysis.

Your project



Some 4D datasets have already been acquired abroad, and an example dataset is shown in the figure. In the image denoted VDF (virtual dark field). The bright spots correspond to pixels where the diffraction patterns contain extra information compared to the Al surroundings. By adding the diffraction patterns inside the blue rectangles in the VDF, we obtain diffraction patterns like the ones shown to the left in the figure. Here, the large bright spots are signal from Al, while we are interested in everything between the Al spots (clusters which is responsible for the materials strengthening). Your initial task will be to try various denoising techniques on the dataset to extract structural information of the small cluster regions. In addition development of data processing routines for new datasets are planned. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

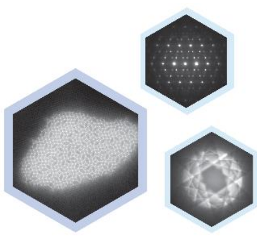
The student will need programming experience (eg Python) and interest as well as knowledge within condensed matter physics.

Contact persons

Elisabeth Thronsen, PhD candidate, Department of Physics, NTNU.
Office: Realfagbygget B4-115. E-mail: elisabeth.thronsen@ntnu.no
Randi Holmestad, Professor, Department of Physics, NTNU
Office: Realfagbygget D4-153. E-mail: randi.holmestad@ntnu.no
Others involved: Ton van Helvoort

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

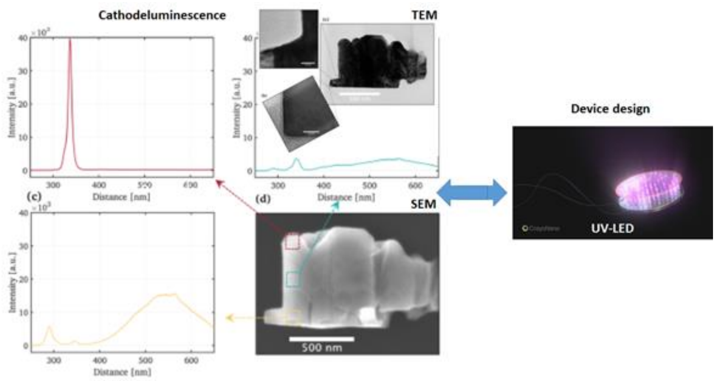
https://www.ntnu.edu/physics/temgemini



Structural characterization of nanowire-based devices

Motivation

Start-up CrayoNano has developed a method where heterostructured III-nitride semiconductor nanowires with high quality are grown on graphene. From them light emitting diodes (LEDs) emitting light in the UV-range are constructed. At Sluppen-Trondheim CrayoNano has recently established a brand new Metal-Organic Chemical Vapor Deposition (MOCVD) lab. They are now continuously producing nanowire samples which need further processing and characterization. Because of their small size, the heterostructured nanowires and device elements have to be studied by characterization techniques with a high spatial resolution as for example Transmission Electron Microscopy (TEM).



Your project

You will study a specific batch of nanowires with interesting optoelectronic properties. Your feedback helps to further optimize the growth conditions of the semiconductors (to be specific GaN and AlGaN segments grown with the new MOCVD). It is important to understand the relation between the optical properties as measured by cathodoluminescence (CL) and the crystal structure/lattice defects/composition as determined by you using TEM. You will learn to use basic TEM techniques as well as scanning electron microscopy (SEM) and CL. FIB work within NTNU Nanolab could be part of a following-up master project.

Requirements

- Interest in experimental work using SEM/CL and TEM.
- Have regular meetings with researchers at CrayoNano. You should be able to clearly communicate and relate your results to others in the project and understand what feedback they expect from your work.
- An interest in programming (Python/Hyperspy) is an advantage as these are valuable tools in the processing of the acquired data.

This is a unique opportunity to be part of applied nanotechnology and the dynamic practice in a high-tech start-up company. The obtained practical skills can be applied to study other nanostructures in academia and industry.

Contact persons

Ton van Helvoort (IFY, a.helvoort@ntnu.no) and Helge Weman (Crayonano, helge.weman@crayonano.com).

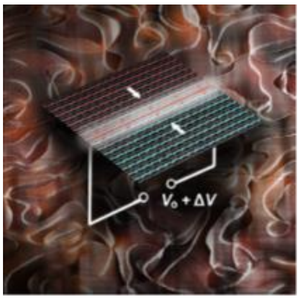
TEM Gemini Centre

NTNU
SINTEF

Domain imaging in ferroelectric oxides

Motivation

Ferroelectric materials exhibiting a spontaneous electric order that can be switch. This class of materials is now in the spotlights because of interesting solid-state physics phenomena, which already find application in state-of-the-art data storage and which hold great potential for next-generation nanoelectronics based on novel principles. The unique electric properties are related to the structure at the atomic scale and, hence, controlling structure means controlling electronic functionalities. At NTNU, there are several research groups working on the forefront in ferroelectrics research. This student project is part of a collaboration between the departments of physics and materials, where the ferroelectrics are studied in order to enable conceptually new applications. Transmission Electron Microscopy (TEM) is an indispensable technique to understand the electric order across all relevant length scales down to the atomic scale.



Your project

Your task will be to image the electric domain and domain-wall structure in functional ferroelectrics by TEM at different scales. The atomic-scale properties of the candidate materials fall into largely uncharted territory, offering an ideal playground for high-resolution TEM studies. You will learn to prepare TEM specimens starting from millimeter-sized single-crystals, study the microstructure at different length scales, including lattice defects and how these interact with the domain structure. The same materials will be studied by PhD students using complementary techniques such a scanning probe and scanning electron microscopy techniques. You can have a vivid exchange and scientific discussion with your colleagues. In the project you will learn basic TEM, including lattice imaging and diffraction techniques. In a follow-up master, the work might be extended with scanning electron microscopy (SEM) and electron spectroscopy techniques (EELS fine structure data analysis). The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

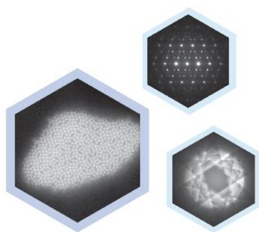
- Interest in experimental work, which here includes specimen preparation and operation of larger microscope units. Some data processing could be included.
- Have regular meetings with supervisors to link your TEM work to other activities on the same material. You should be able to clearly communicate and relate your own work to that of others in the group.
- Interest in doing research to understand how properties are related to the materials structure.

Contact persons

Ton van Helvoort (IFY, a.helvoort@ntnu.no) and Dennis Meier (IMA, dennis.meier@ntnu.no).

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



Extracting meaningful data from BIG electron diffraction data sets

Motivation

The advances made in data technology have made the terms *big data* and *machine learning* more than just buzzwords. In daily life, big data and machine learning are steering us in the background (e.g. with search engines) and will be even more used in the future (e.g. Google car). In nearly all research fields a disruptive transformation is ongoing due to these advances.

In the TEM group we have been working on new ways to analyze scanning electron diffraction data (ie acquiring 2D diffraction pattern at each pixel). Group members on all levels, including project students, have contributed to recent progress. We will get a state-of-the-art, special detector for electron diffraction. The new detector will enable acquisition of datasets 10 to 100 times as big as what is commonly acquired today. New ways are needed to handle the growing amount of data and to extract the added information in it. Work on analyses of such data is part of ongoing research and international collaboration focused on achieving smart data acquisition and data handling.

Your project

You will get TEM data sets, primarily scanning electron diffraction data, and develop and test new routines and algorithms for the analysis of the given data. The aim is to do crystal phase or orientation analysis over larger areas preserving nm-scale spatial resolution. The data could be from semiconductor material, nanoparticles, or aluminium-alloys. In addition, there is special interest in establishing routines for analysis of beam-sensitive non-crystalline materials, e.g. biomaterials and plastics. Collaboration with the data-owner, taking part of new experimental sessions, and understanding the physics behind the crystallography data can be important. The created digital tools should be made available and accessible to other people in the research community via open-source platforms, primarily by including developed code via Git into the repositories pyXem. This means that the whole process of development also must address implementation, version control, testing and documentation. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Required from the student

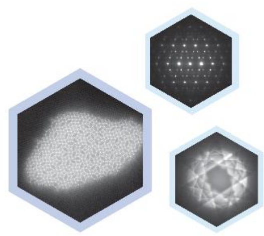
You should have an interest in using and further developing software tools. Experience with Matlab, C++ or preferably Python is essential. Good communication and interaction with scientific and academic staff and PhD students involved, as well as the skill to work independently, are also important. The intention is that results will contribute to scientific publications. The expertise you will gain during this project should be attractive for jobs outside the field of material physics, as the tools and skills can be applied to challenges in several fields.

Contact person:

Ton van Helvoort (a.helvoort@ntnu.no) Others involved: Magnus Nord (Magnus.nord@ntnu.no), Duncan Johnstone (University of Cambridge) and Randi Holmestad (randi.holmestad@ntnu.no)

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



Transmission electron microscopy investigations of catalysts, membranes and process materials

Motivation

Specialization projects are available within a collaboration between the TEM and KinCat NTNU Gemini Centres with link to iCSI – industrial Catalysis Science and Innovation – a Centre for research based innovation appointed by the Research Council of Norway and hosted by Department of Chemical Engineering, NTNU. Development of state-of-the-art research methodology is at the core of iCSI's generic activities and includes investigating catalysts and process materials at the nanoscale. The projects involve collaboration with ongoing research. Additional investigations by spectroscopy (e.g. Raman, IR, XPS, Auger) or theoretical modelling (DFT) can be included to the projects depending on the relevance and interests of the candidate.

Your Project

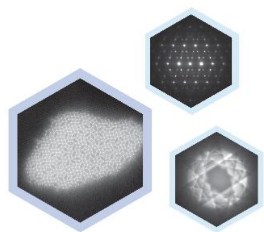
The project concerns TEM-based investigations on one of the two following systems of high industrial and environmental relevance, dependent on the candidate's interests:

1. Silver (Ag) catalysts for partial oxidation of methanol to formaldehyde (MTF) - characterization of Ag restructuring and O dissolution in Ag. Formaldehyde is the essential component of wood adhesives for a wide range of applications and an important intermediate in the production of many fine chemicals. We collaborate with the formalin technology operator and licensor Dynea and the catalyst producer KA Rasmussen AS. The Ag catalyst restructures heavily under process gas at 650°C and the restructuring is coupled to the interaction with and dissolution of oxygen. These phenomena again affect the selectivity to the desired product, CH_2O. Better understanding of the crystalline structure and chemical interactions before, during and after reaction may facilitate increased productivity in the MTF process.
2. Pd alloy thin films for hydrogen separation membrane technology – structural phenomena related to hydrogen transport and membrane stability. PdAg membrane technology is currently being commercialized by Hydrogen Mem-tech based on a sputtering fabrication process developed by SINTEF Industry. The idea is to enable Blue Hydrogen, i.e. hydrogen from natural gas with capture and storage of CO_2. Investigating the structural properties and changes occurring during separation could yield information critical to performance and stability improvements.

Both projects involve use of *state-of-the-art* instruments at the Norwegian national infrastructures NORTEM (TEM) and NorFab (SEM and FIB). The project can be adjusted to 15, 30, 45 or 60 ECTS.

Supervisors: Adjunct Professor (Prof. II) Per Erik Vullum (pererik.vullum@sintef.no) and Prof. Randi Holmestad (randi.holmestad@ntnu.no)

Co-advisors: Prof. Hilde J. Venvik (Hilde.Venvik@chemeng.ntnu.no), Dept. of Chemical Engineering (IKP), Dr. Ingeborg-Helene Svenum, Research Scientist at SINTEF Materials and Chemistry and Adjunct Associate Professor, IKP-NTNU

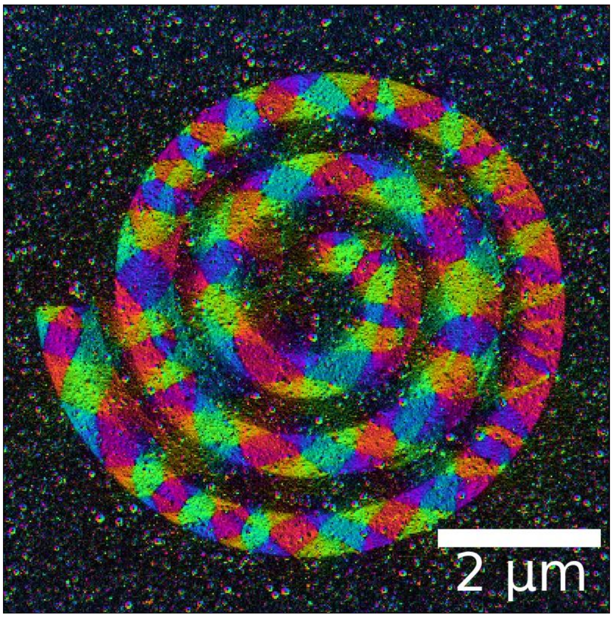


Nanoscale imaging of magnetic structures using Transmission Electron Microscopy

Motivation

Ferromagnetic materials are an important class of functional materials, with applications within data storage and sensing devices. A fairly recent development is nanostructuring of these materials, allowing for tailoring of the magnetic structure and properties, such as the spiral structure seen in the figure. These magnetic nanostructures not only allow for new types of device concepts, but they are also ideal as nanoscale physics "model systems" as potentially any shape can be made, essentially acting as an experimental "nano lab" for studying magnetic theory.

To properly understand the magnetic properties of these materials, it is of vital importance to not only be able to image magnetic fields at nanometre length scales, but also to visualize the crystal structure in the same area simultaneously. Thanks to advances in fast cameras used in transmission electron microscopes (TEM), this is now possible. However, as this is a very recent development, much work is need in both developing better experimental techniques and data processing routines. The latter requires the implementation of "big data" data analysis, as the datasets can range from 8 gigabytes for small sets, up to hundreds of gigabytes for larger ones.



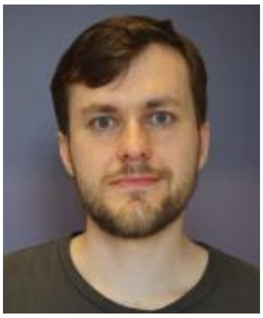
TEM image of ferromagnetic domains in a spiral shaped nanostructured thin film. The colours showing the magnitude and direction of the magnetic domains.

Your project

You will study both the crystal and ferromagnetic domain structure in permalloy thin films using the TEM. Here, you will learn how to do basic TEM, followed by state of the art magnetic imaging. Initially this will be done with the Fresnel imaging technique, which is faster, easier to use and well-suited for studying how the ferromagnetic domain structures respond to external magnetic fields. This will be followed by the more advanced differential phase contrast technique, which yields much more information, but is more difficult from an experimental and data processing point of view. The latter will involve learning "big data" processing using the Python library HyperSpy, pixStem and dask, and best practices within software development. You will also learn how to use the state of the art Merlin fast electron detector. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

The student should be interested in experimental work using the TEM, and programming using Python. The most relevant courses are Solid State Physics and Material Physics.

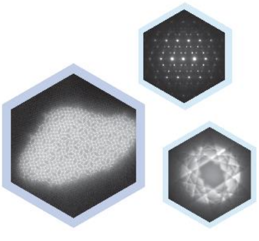


Contact persons

Magnus Nord, Associate Professor, Department of Physics, NTNU, magnus.nord@ntnu.no

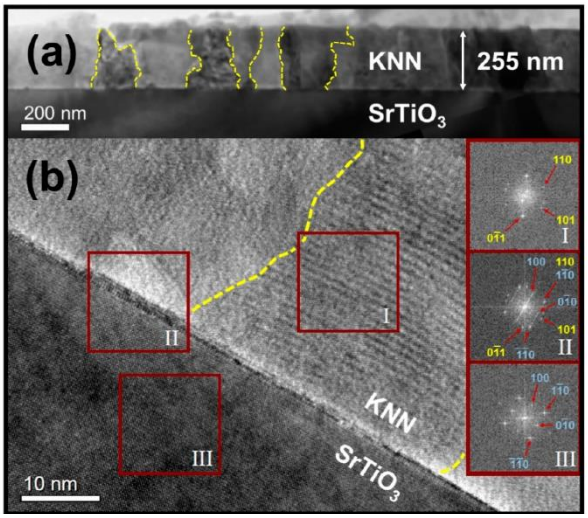
The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini



TEM characterization of oxide thin films made by chemical methods

Motivation



TEM figure made by Andreas Toresen, MSc student in TEM group in 2018 [1].

Ferroic materials constitute a unique class of materials possessing either ferromagnetism, ferroelectricity or ferroelasticity. Two or more of these properties are found in so-called multiferroics. These materials have many applications in information and communication technology as well as in energy and in medical technology. Applications include sensors, transducers, actuators, etc. Lead-free materials such as $K_{0.5}Na_{0.5}NbO_3$ (KNN) and $Bi_{0.5}Na_{0.5}TiO_3$ (BNT), ferroelectric tungsten bronzes such as $Sr_{1-x}Ba_xNb_2O_6$ and multiferroic materials such as $BiFeO_3$ and $YMnO_3$ have been central to the research in the last decade. At Department of Materials Science and Engineering, NTNU they have many years of experience in developing these materials and the characterization of their structural and functional properties. TEM investigation allows the determination of the detailed structure which can be related and compared to first principles calculations and functional properties.

Your project

The student will prepare samples (using Nanolab FIB or other routes) and examine them in the TEM, to support and complement other analyses being performed, and will work in close collaboration with others synthesizing the materials or studying the same materials with other techniques. There is a large activity at Gløshaugen on characterization of functional materials, and the student will be included in these activities, with participation in weekly lunch meetings etc. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

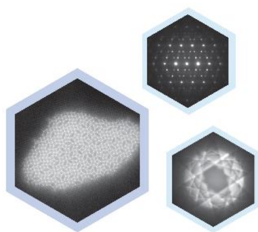
We seek students with background from physics, materials science or nanotechnology, interested in solid state physics/chemistry and/or nanoscience. If you are interested in experimental work, working independently and collaborating with the research groups synthesizing the materials/devices, please contact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

Contact persons

Randi Holmestad, Professor, Department of Physics, NTNU. Office: Realfagbygget D4-153.
e-mail: randi.holmestad@ntnu.no and Per Erik Vullum (per.erik.vullum@sintef.no).

This project is in collaboration with Mari-Ann Einarsrud and Tor Grande from Department of Materials Science and Engineering.

[1] N. H. Gaukås, S. M. Dale, T. M. Ræder, A. **Toresen**, R. Holmestad, J. Glaum, M.-A. Einarsrud, and T. Grande, "Controlling Phase Purity and Texture of $K_{0.5}Na_{0.5}NbO_3$ Thin Films by Aqueous Chemical Solution Deposition", Materials 12, 2042, 2019.



Electron microscopy of thin films for spintronics applications

Motivation

Spintronics is an emerging field which connects theoretical physics, nanotechnology, materials science and computer science. It is a method for computation with low energy dissipation, where information is transmitted by spins rather than electric charge. Certain materials such as antiferromagnets are ideal for the transmission of spin waves at low temperatures. The Center for Quantum Spintronics (QuSpin) at NTNU has established a lab for growth of the antiferromagnetic thin film materials FeSn and $CuFeS_2$. To assess whether growth conditions are ideal for creating a single phase, monocrystalline, defect free thin film, transmission electron microscopy characterization is essential.

Your project

Your work will be focused on the atomistic structure of thin films and their connection with the growth substrate. High-resolution TEM imaging of the atomic lattice will be used to observe defects, compositional changes, and lattice misfits between the substrate and the thin film. Samples will be prepared by mechanical polishing, Ar ion milling or focused Ga ion beam milling. There is a large activity at Gløshaugen on characterization of functional materials, and the student will be included in these activities, with participation in weekly lunch meetings etc. The project can be adjusted to 15, 30, 45 or 60 ECTS.

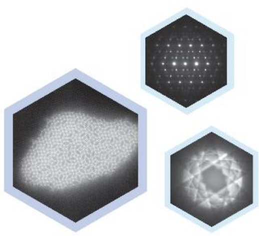
Requirements

The student should have a background within physics or nanotechnology and have an interest in condensed matter physics and crystallography. You will work independently with a range of experimental methods and provide feedback to the thin film growers on film quality and growth parameters. Any experience with SEM/FIB will be useful for sample preparation.

Contact persons

Sigurd Wenner, Associate Professor II, Department of Physics, NTNU. Office: Realfagbygget D4-118. E-mail: sigurd.wenner@sintef.no.

This project is in collaboration with Christoph Brüne from Center for Quantum Spintronics (QuSpin) - NTNU.



Advanced processing of electron spectroscopy data

Motivation

Determining the composition with high spatial resolution is important for many technological and academic projects. Of the two main spectroscopy techniques available in TEM, energy dispersive and electron energy loss spectroscopy (EDX and EELS respectively), EDX is the most used as it is relatively easy to acquire data and as there are less restrictions on specimen thickness. However, accurate quantification is in general challenging. The most used method for quantification of EDX data is based on a dated empirical method with drawbacks and presumptions that often are not met. Crystal orientation, particle shape and statistics can affect quantification.

People in the TEM Centre have been working on an alternative method, termed the zeta method, that is not yet available in commercial EDX packages. The zeta method can give more accurate compositional analysis than the currently default approach. Group members have also developed a factor-less approach and have worked on calibration routines. These methodologies should be developed further before it can be used by all TEM users. Developing the quantification code base ourselves allows linking EDX to other data types such as diffraction patterns and EELS. In addition, implementation of new technologies such as machine learning to reduce data set sizes or noise levels has proven valuable.

Your project

Your main focus will be on the data analysis, and you will get data acquired in other projects. There will also be possibilities for you to collect your own EDX data. You have to become familiar with the characteristics of the EDX technique and the data structure as well as code already developed by previous students. Depending on the chosen material system at the start of the project, the focus will lie on extending the zeta approach or automating the detector calibration so it can be implemented in the analysis to improve the overall accuracy in the final compositional analysis. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Required of the student

Interest and skill in applying and further developing Python-based software tools are required. You will have to balance fundamental aspects, implementation of code and working on real material systems and problems, i.e. to work on practical and theoretical aspects in parallel. Good communication and interaction with collaborating scientific and academic staff and PhD students, also based abroad, is essential. The project will use and contribute to the open-source platform HyperSpy. This project offers the opportunity to do code development and could be extended in a master to other techniques and material systems.

Contact persons

Ton van Helvoort (a.helvoort@ntnu.no)

Others involved: Postdoc Dipanwita Chatterjee, and senior engineer Bjørn Soleim

TEM Gemini Centre

NTNU

SINTEF

Mineralogy and TEM: nm-scale characterization of beautiful systems

Motivation

While mineral specimens are spectacular objects for rock collectors and wearers of gems, they also are invaluable recorders of rock-forming processes in the earth's crust and its deeper interior. Their detailed chemical composition (nominal constituents as well as impurities), their crystal structure (including polytypes), and fluid-driven reactions transforming pre-existing minerals into new that better suit changing pressure and temperature conditions, provide insights in rock formation and ore-forming processes. TEM is an essential tool to study the nature and transformations within and between minerals at the smallest scale.

What the student will do in the project

student will learn how to operate a TEM to characterize mineral crystallographic and compositional properties. The project aims to link observations at different size scales (eg. optical microscopy/petrography – SEM – TEM) and different techniques (eg. microscopy, EDS, XRD). Consequently, sample and specimen preparation will be an important part of the study. The project will look at illite, a phyllosilicate (clay) mineral closely related to muscovite and other micas. The illite is formed during brittle deformation (*viz.* 'earth quakes') and is particularly challenging to study because of fine grain size, as well as variations in chemistry (Al,Si-ordering, interlayer content/vacancies), polytypism and morphology. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Required from the student

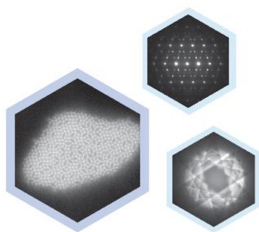
The perfect applicant has an interest in interdisciplinary experimental work, and is creative, inventive, self-reliant, independent, pro-active, and able to communicate cross-disciplinary with researchers from different disciplines.

Contact persons

Ton van Helvoort (a.helvoort@ntnu.no) and Maarten Broekmans (maarten.broekmans@ngu.no)

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

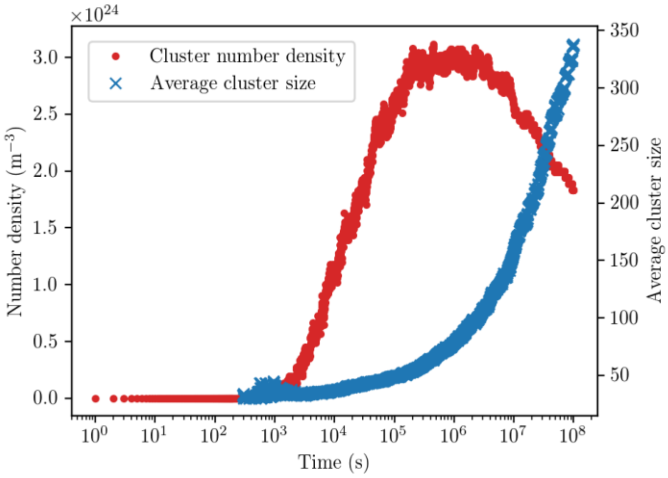
https://www.ntnu.edu/physics/temgemini

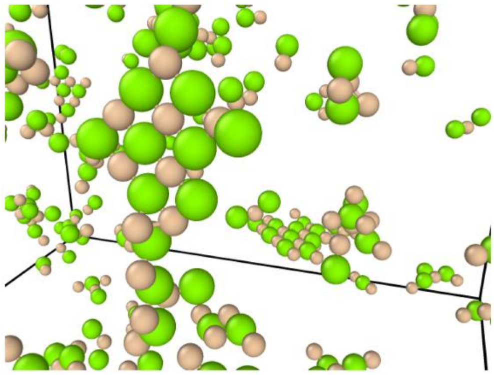


Atomistic modelling of clustering in aluminium alloys

Motivation

Precipitation hardening is the most important strategy for the aluminium industry to improve performance of both AA6xxx wrought alloys and foundry alloys. A key to control and manipulate nucleation and growth of hardening precipitates is to understand their formation, starting from clustering of solute atoms.





Simulated clustering of Mg and Si atoms in aluminium using kinetic Monte Carlo.

Your project

The student will study the clustering of solute atoms and the initial formation of metastable particles using kinetic Monte Carlo (KMC) and/or cluster dynamics. This will be done by using and extending an existing code. Input to the simulations will come from close collaboration with other researchers and students working experimentally with transmission electron microscopy (TEM) and theoretically with density functional theory (DFT) or cluster expansion. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

Background in materials physics (solid state physics), and interest in materials science would be an advantage. We need a student interested in modelling and programming, and working independently in a larger group of scientists. An interest in using and developing simulation tools is required. Experience with C or Python is essential.

Other aspects

There are many people working on aluminium alloys at NTNU, and we have several ongoing external projects. This work will be connected to the SumAl project, where we work in close collaboration with SINTEF, Hydro, Benteler Automotive and Neuman Aluminium. The students will invited to internal aluminium meetings as well as to project meetings in the SumAl consortium in Trondheim or/and at industry sites. 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. This topic is also coupled to the NTNU Digital Transformation project "AllDesign" by Professor Jaakko Akola which builds a multiscale modelling platform for these alloys.

Contact persons

Jesper Friis (jesper.friis@sintef.no), Jonas Frafjord (jonas.frafjord@ntnu.no) and Jaakko Akola (jaakko.akola@ntnu.no). Others involved in the project are Randi Holmestad, Inga Ringdalen and David Kleiven.

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics, materials science and metallurgy, and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/physics/temgemini