Specialization project and Master thesis topics in the TEM Gemini Centre, 2024/25

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 2024 we have at IFY 3.4 (assoc.) professors, 3 engineers, 5 SINTEF researchers, ~8 PhD students and several MSc 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 Master 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.

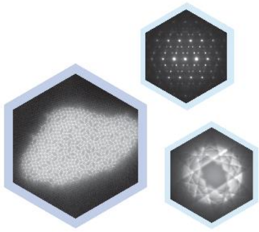
Examples of student projects which are available:

- 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 scientific publications [1-8]. Due to high demand on the research facilities and the intensive supervising we give, we can take in max 8 new 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 and materials science 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/temgemini



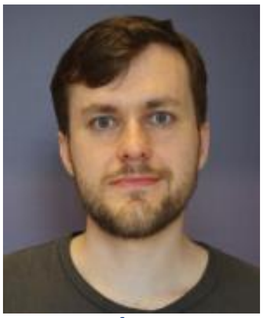
- Choice of a project that fits your interests and background.
- Training in operating advanced and modern scientific equipment or/ and simulation and quantification software (theoretical/modelling).
- Weekly meetings with a supervisor during the project.
- Being part of a large and dynamic scientific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

We offer several projects connected to industry where we also offer summer jobs!. See the different proposals.- Ask us about details!

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 the master 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





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
Room B4-113
magnus.nord@ntnu.no

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

Assoc. Prof. II
Ruben Bjørge
Room D4-118
+4793016522
ruben.bjorge@sintef.no

References: (master students in bold)

[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 279, 158-167, 2020. https://doi.org/10.1111/jmi.12850

[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. https://doi.org/10.3390/ma12132042

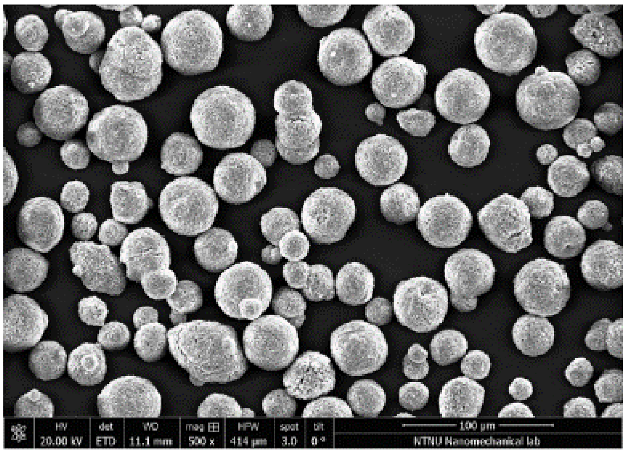
[3] F. de la Peña et al, Hyperspy 1.6 Zenodo. https://zenodo.org/record/4294676#.YD0tkuhKg2w and D. Johnstone et al, pyXem 0.13, Zenodo, https://zenodo.org/record/4436723#.YD0p2ehKg2w [Open-source software, >5 MSc listed as contributers]

[4] E. Thronsen, **H. Mørkeseth**, C.D. Marioara, K. Minakuchi, T. Katsumi, K. Marthinsen, K. Matsuda, and R. Holmestad The effect of small additions of Fe and heavy deformation on the precipitation in an Al-1.1Mg-0.5Cu-0.3Si at.% alloy, Metall Mater Trans. A 53, 3296–3310, 2022. https://doi.org/10.1007/s11661-022-06744-9

[5] K. Hunnestad, J. Schultheiß, **A. Mathisen**, I.N. Ushakov C. Hatzoglou, A. T. J. van Helvoort, D. Meier, Quantitative 3D mapping of chemical defects at charged grain boundaries in a ferroelectric oxide, Adv. Mat. 35, 2302543, 2023. https://doi.org/10.1002/adma.202302543

[6] T. Bergh, **H. Fyhn**, L. Sandnes, J. Blindheim, Ø. Grong, R. Holmestad, F. Berto P.E. Vullum Multi-material Joining of an Aluminum Alloy to Copper, Steel, and Titanium by Hybrid Metal Extrusion & Bonding, Metall Mater Trans. A 54, 2689–2702, 2023. https://doi.org/10.1007/s11661-023-07047-3

TEM characterization of ThermaSiC



Background

Silicon Carbide (SiC) is a synthetic mineral containing silicon and carbon. It is one of the world's hardest materials, and lightweight. Thermal spraying techniques are coating processes in which melted materials are sprayed onto a surface. ThermaSiC is Seram Coating's unique product which enables SiC to be applied as a coating by atmospheric thermal spraying. The coating can prevent wear, corrosion and withstand high temperatures – it is applied in many applications and surface properties can be engineered (see article in TU). The coating is produced through complex chemical thermal processes, including a layer of Al and Y (YAG) as a precursor which protects the SiC particles during the thermal spray process. Seram Coatings has contacted us to get more insight into the nanostructure of this powder. This project will study the coated particles at the nanoscale using transmission electron microscopy (TEM) to identify and understand where in the process segregation patterns and inhomogeneities which impact the final properties are generated.

Your project

You will work with ThermaSiC powder produced by Seram Coatings which has never been studied by TEM before. Samples will be produced by Focused Ion Beam (FIB). You will learn TEM, do chemical mapping at the micro- and nano-scale and investigate phase compositions and elemental segregations via energy-dispersive X-ray spectroscopy (EDS). You will look for pores and inhomogeneities and acquire diffraction patterns to recognize phases, determine orientation relationships and grain sizes – When data is acquired, you will analyze data obtained using data analysis software (like Hyperspy etc.). **Seram Coating will offer a summer job in Porsgrunn and Trondheim.**

Requirements

The student should be interested in materials physics, electron microscopy and electron diffraction. Experience with programming, preferentially python, is an advantage. Relevant courses are Solid State Physics, Nanotools, 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 Seram Coatings and others in the TEM group.

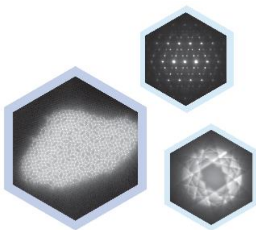
Contact persons

Randi Holmestad, Professor, Department of Physics, NTNU.
Office: Realfagbygget D4-153, randi.holmestad@ntnu.no
Ruben Bjørge (ruben.bjorge@sintef.no)

This project is in collaboration with Seram Coatings in Porsgrunn, Stian Sannes
stian.sannes@seramcoatings.com

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini



Structure determination via 3D electron diffraction
- *tomography in reciprocal space*

Motivation

Three-dimensional electron diffraction (3DED), or MicroED, is one of the hottest topics in electron beam analysis as it is relatively cheap, can be automated, leads to new discoveries in the field of minerals, and can be used for optimalisation in catalysis and pharmacology. Using an electron beam, very small volumes can be characterized beyond what is possible with any other technique. From a tilt series of electron diffraction patterns, i.e. electron diffraction tomography, the crystal structure of a nanoparticle can be determined, including the position of the atoms within the unit cell. This requires careful data processing and analysis and considering deviations from the ideal structure and dynamic diffraction effects. With assistance of a world leading group at Stockholm University, we establish Norway's first 3DED set-up. Data collection is fast, but the data processing workflow is under development and demanding.

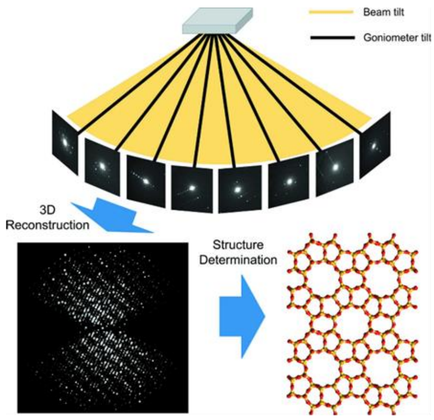


Illustration of the rotation electron diffraction (RED) method from Wan, Wei, et al. J Appl Cryst 46.6 (2013): 1863-1873.

Your project

You will help to establish a more robust and smooth data processing workflow and apply 3DED for the structural analysis of beam sensitive materials. This will require using crystallography and data analysis using different platforms to find the crystal structure. The data could be from zeolites and minerals of which the structure is questioned. You will collaborate with PhDs and postdocs collecting the data or develop the structure development routines. It is expected that you improve the digital tools and that these made available via open-source repositories. 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 and expanded to a Master.

Required from the student

You should have an interest in using and further developing software tools, applying and extending knowledge on basic crystallography and diffraction physics. 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 expertise you will gain during this project should be attractive for jobs outside the field of material physics, as the 3DED processing tools and skills can be applied to various fields.

Contact persons:

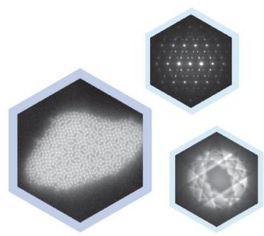
Ton van Helvoort (a.helvoort@ntnu.no))

Others involved: Tina Bergh (tina.bergh@ntnu.no) and

Oskar Ryggetangen (oskar.ryggetangen@ntnu.no)

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini



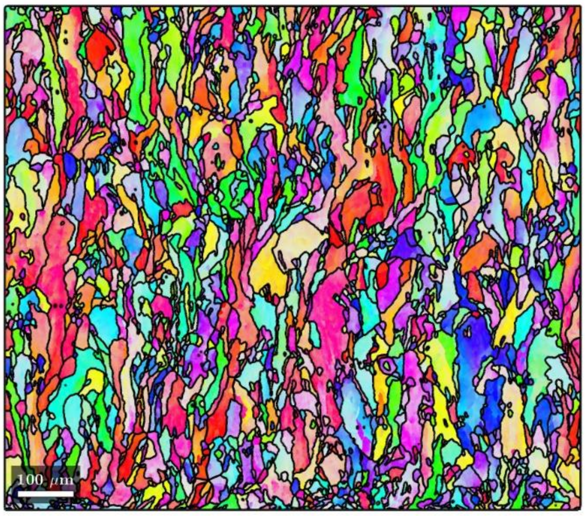
TEM Gemini Centre

NTNU

SINTEF

Microstructure of high strength aluminium alloys produced by powder bed fusion

Background



Grain orientation map of laser PBF aluminium alloy.

Powder bed fusion (PBF) is an additive manufacturing (AM) technology that prints components layer by layer, fusing powder particles together to form a continuous solid. Like other AM techniques, it has the advantage of flexible, on-demand production and very little material waste in processing. It can also produce component geometries which are difficult to achieve with traditional casting and forming methods. In [SFI PhysMet] – the Centre for research-based innovation in physical metallurgy - a process for laser PBF of aluminium alloys is being developed. Since the thermal and mechanical history of the material will be very different from a conventionally produced aluminium alloy, the chemical composition and heat treatment must be tailored such that this innovative manufacturing method can produce components with good performance.

Your project

The student will work with Al-Mg-Si-based alloys produced by laser PBF, using a combination of scanning and transmission electron microscopy (SEM and TEM). From images, the morphology of grains and phases will be obtained. From chemical mapping at the micro- and nano-scales, the student will investigate phase compositions and elemental segregation via energy-dispersive X-ray spectroscopy (EDS). The size, type and density of nano-sized hardening precipitates will be related to hardness and other properties. Lastly, the student will compare the microstructure and properties to conventionally produced alloys from literature. Activities the student will do;

- Heat treatment trials and measurement of properties such as hardness.
- Sample preparation via mechanical polishing and ion milling.
- Acquisition of SEM/TEM images, EDS spectra/maps and diffraction information.
- Analysis of obtained data, using and developing data analysis software (like Hyperspy etc.)

Requirements

The student should be interested in materials physics, electron microscopy and electron diffraction. Experience with programming, preferentially python, is an advantage. The most relevant courses are Nanotools, 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 as part of the TEM group and SFI PhysMet. The results will complement other work and will likely be part of scientific publications.

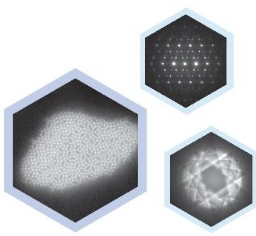
Contact persons

Randi Holmestad, Professor, IFY, NTNU.
Office: Realfagbygget D4-153, randi.holmestad@ntnu.no
Ruben Bjørge (ruben.bjorge@sintef.no),
Sigurd Wenner (Sigurd.wenner@sintef.no)

PhysMet

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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.

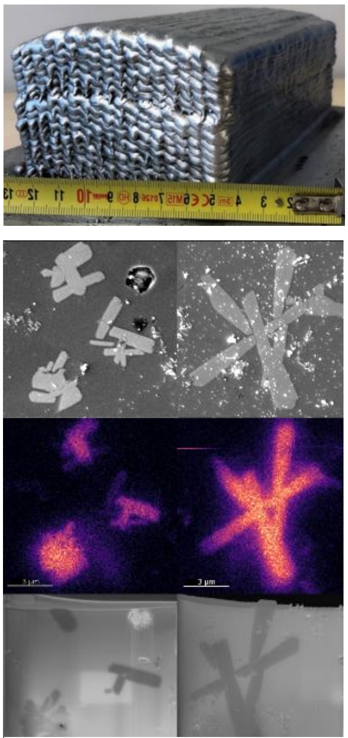
https://www.ntnu.edu/temgemini



Characterisation of aluminium alloy welding wires with nanoparticles using electron microscopy techniques

Motivation

Welding is one of the backbones of both traditional manufacturing and advanced additive manufacturing (AM) technologies. For aluminium alloys, welding is particularly challenging since the generated heat results in soft heat-affected zones that limit the mechanical properties of the component. The strength reduction can be limited by using specially designed welding wires, which is one of the focus areas of the research centre SFI PhysMet at NTNU. For example, one project (see figures to the right) looks at the use of aluminium alloy wires containing TiC nanoparticles for wire arc additive manufacturing (WAAM). The added TiC nanoparticles induce formation of $TiAl_3$ particles that act as nucleation sites for aluminium during the subsequent cooling after welding, which can result in smaller aluminium grains and stronger components. To develop such special aluminium alloy welding wires, it is crucial to understand how the nano- and microstructure affect the properties after welding.



Electron microscopy characterisation of aluminium alloy wires with TiC nanoparticles used for WAAM by previous PhD candidate Tor Inge Thorsen.

Your project

You will study selected aluminium alloy welding wires before and after welding. The project starts with metallographic sample preparation, before you get training to become an independent user of a dual-beam focused ion beam - scanning electron microscopy (FIB-SEM) instrument. You will use this instrument to image the particles in 3D and to make thin lamellae suitable for TEM studies. Depending on your preferences, you can also focus on image processing and data analysis or expand your characterization toolbox to include TEM. The project is connected to SFI PhysMet (RA1), where the results will complement other work and likely be a part of scientific publication. We will discuss your work during our weekly supervisor meetings, and we will invite you to the weekly TEM lunch meetings.

PhysMet

Requirements

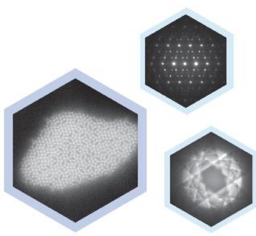
The student should be interested in materials science and materials physics, electron microscopy and diffraction. Experience with programming, preferentially python, is an advantage. You should enjoy both independent lab work and collaboration. The most relevant courses are Solid State Physics, Nanotools, and Materials Physics.

Contact persons

Randi Holmestad, Professor, IFY, randi.holmestad@ntnu.no
Tina Bergh, Postdoc, IKP, tina.bergh@ntnu.no
The project is a collaboration with Geir Kvam-Langelandsvik, Researcher, SINTEF Industry, Geir.langelandsvik@sintef.no, and
Jens Werenskiold, Associate Professor, IMA jens.c.werenskiold@ntnu.no.

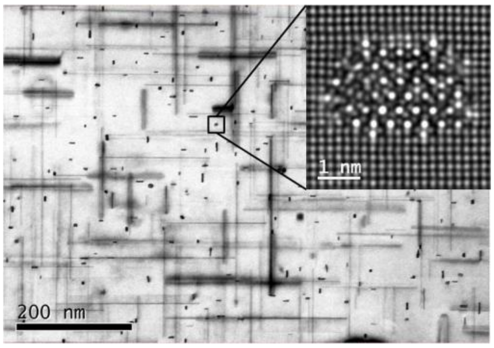
The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science and study a broad range of materials down to the atomic level. Our lab hosts some of the most advanced transmission electron microscopes (TEM) in the world.

https://www.ntnu.edu/temgemini



TEM investigations of aluminium alloys

Motivation



Pure aluminium is a relatively soft metal, but with small additions of other elements it is possible to create alloys with significantly increased strength. Al-Mg-Si-alloys are often extruded into their final shapes and are subsequently heat treated to gain their high strength. The strength increase is achieved by small additions of Si and Mg which form nanosized particles called precipitates. These strengthening phases are so small that a transmission electron microscope (TEM) is required to study them. When documenting the hardness evolution during heat treatment, one usually finds a maximum hardness after a certain ageing time (peak-aged condition). The TEM Gemini Centre has for many years worked with industry on studies of aluminium alloys and precipitates. The work will contribute to the development and design of new aluminium alloys, mainly for the automotive industry. This year we have several interesting challenges: working with alloys from Hydro, Raufoss Technology and SINTEF Manufacturing. Please come and talk to us to get more details! The student will be invited to internal aluminium meetings as well as to project meetings in Trondheim or/and at industry sites.

Your project

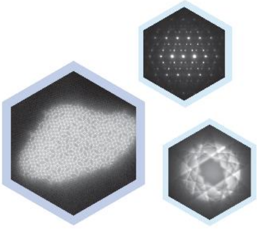
The student(s) will here run different heat treatments and measure/get results from properties (such as hardness, strength, ductility, and conductivity). Afterwards the student will study the corresponding nanostructure (precipitates) in the TEM, supervised and in collaboration with PhD students and SINTEF researchers (who can help with more advanced microstructure characterization if needed). Different research problems are possible, depending on the interest of the student, also on data analysis of already acquired images - you can participate in developing techniques and data analysis codes. One current MSc project is to utilize artificial intelligence (AI) to count and quantify precipitates to get out statistics for physically based methods, and this could be used and further developed. Summer job connected to SFI PhysMet is a possibility here.

Requirements

Background in materials physics, nanotechnology or chemistry is an advantage. We seek students interested in industrial problems and motivated to do experiments and interested in connecting large scale material properties to materials micro- and nanostructure.

Contact persons

Randi Holmestad, Professor, Department of Physics, NTNU.
Office: Realfagbygget D4-153. randi.holmestad@ntnu.no
People involved from SINTEF; Calin Marioara (calin.d.marioara@sintef.no), Ruben Bjørge (ruben.bjorge@sintef.no), Sigurd Wenner (sigurd.wenner@sintef.no), Jon Holmestad (jon.holmestad@sintef.no) Hydro (R&D centre at Sunndalsøra): Jostein Røyset (Jostein.royset@hydro.com)



TEM Gemini Centre

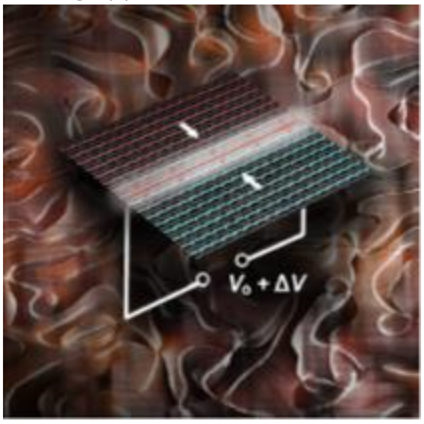
NTNU

SINTEF

Domain imaging in ferroelectric oxides

Motivation

Ferroelectric materials exhibit a spontaneous electric polarization that can be switch. This class of materials is now in the spotlights because of interesting solid-state physics phenomena, already finding application in state-of-the-art non-volatile data storage. In addition, these materials hold great potential for the realization of conceptually new nanoelectronics devices. The unique electric properties of ferroelectric materials 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 science, where the ferroelectrics are studied in order to enable next-generation nanotechnology. Central in this sub-project are novel and exotic ferroelectric crystals. 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

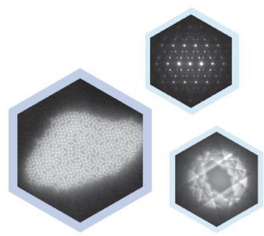
Your task will be to image the electric domain and domain-wall structure in functional ferroelectrics by TEM at different scales. The atomic-scale properties of the candidate materials fall into a largely uncharted territory, offering an ideal playground for high-resolution TEM studies. You will learn 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), scanning electron diffraction 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).



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 have a state-of-the-art, special detector for electron diffraction. The new detector enables 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. Projects can be focused on coding, other times implementing crystallographic analysis is central.

Your project9

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 obtain crystal phase or orientation analysis over larger areas preserving nm-scale spatial resolution or addressing fundamental challenges in this type of data. 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 in new experimental sessions, and understanding the physics behind the crystallography data can be important.

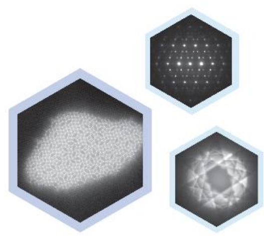
The created digital tools should be made available and accessible to other people in the research community via open-source platforms, primarily by including developed code via Git into the repositories pyXem. This means that the whole process of development also must address implementation, version 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) and Tina Bergh (Tina.bergh@ntnu.no)



TEM Gemini Centre

NTNU SINTEF

Orientation mapping of silver nanocrystals by vector analysis
- *use programming skills to see crystals in three dimensions*

Motivation

The TEM community has recently started to take more and more advantage of computational power and fast new detector technology to record bigger datasets which holds more information. By scanning a fine electron probe (nanometre- to sub-Ångström-sized) and recording a diffraction pattern for each probe position (4D-STEM), a 4D dataset is obtained. Each diffraction pattern can be analysed to get maps giving information on the local crystal structure in the material. At NTNU we have a state-of-the-art setup for one such method which is called scanning precession electron diffraction (SPED). The conventional way of analysing SPED data is based on comparing experiment and simulated patterns and has its limitations. We have worked on a novel alternative method which is based on the underlying physics, referred to as vector analysis. We now aim to generalize the method to handle orientation mapping, starting with a case study on polycrystalline silver. Examples of orientation maps from silver are shown in the figure below. Silver is used as a catalyst in industrial production of formaldehyde from methanol, which is one of the focus areas of the centre [iCSI – industrial Catalysis Science and Innovation] at IKP.

Your project

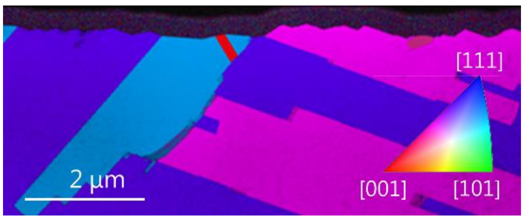
We will give you a python code and a relevant dataset from silver to start playing with. You will expand the vector analysis code to handle a range of crystal orientations, and we will compare your results to the conventional method of template matching. There are many ways that the vector analysis routine can be made more sophisticated. In the project you will work towards finding the best solution to a hot topic, challenging both your analytical skills and creativity. Your findings will be put into a bigger context and improvements will likely be part of a publication, presentation at an international conference and/or open-source packages. You can join sessions on the transmission electron microscope to better understand the sample and the data collection. We will organise weekly supervision meetings, and you will be invited and encouraged to join the weekly TEM lunch and the monthly SPED discussion meetings. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Required from the student

We look for a student who enjoys programming and data analysis, at the same time as you happily collaborate and discuss scientific work with others. You should have some basic background with programming in python and value community-based open-source software developments. In this project we will aim to find new and better ways of solving the 3D analytical task, and we will encourage you to share your own thoughts and think outside of the box. While being strong in mathematics, you should also be able to add a touch of creativity. Some familiarity with crystallography and diffraction will be a great advantage. Relevant courses include Numerical Physics, Solid State Physics, and Materials Physics.

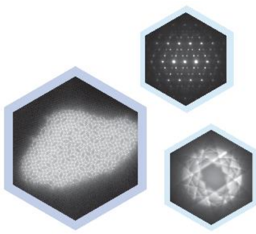
Contact persons

Ton van Helvoort, IFY,
a.helvoort@ntnu.no
Tina Bergh, IKP,
tina.bergh@ntnu.no



The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini



TEM studies of Pt- and Rh-TiO_2 catalysts for hydrodeoxygenation of bio-oil

Motivation

Biofuels are an alternative to fossil fuels. They are already being blended with traditional fuels, which makes them a convenient replacement to secure the carbon-neutral scenario for the transport sector. Hydrodeoxygenation (HDO) of biomass pyrolysis oil is considered a viable solution for obtaining fuel-like products. HDO requires bifunctional catalysts such as Pt- and Rh-TiO_2. The Pt or Rh nanoparticles provide sites for hydrogen adsorption, while the titania (TiO_2) provide acidic sites for adsorbing the C-O bonds in oxygenated compounds in order to cleave them. To assess the relation between catalyst function and structure, it is crucial to characterise the nanoparticle size and understand the interaction between the nanoparticles and the support. (Scanning) transmission electron microscopy (S)TEM is an invaluable tool in the characterisation of catalysts and allows us to study the morphology and particle size, the chemical composition, and the oxidation state of a catalyst at the nanometre scale.

Your Project

In the beginning of your project, you will synthesise Pt- and Rh- TiO_2 catalysts by incipient wetness impregnation. You will get TEM training and become an independent user. You will image your catalysts and measure the Pt and Rh particle size distributions. Depending on your interests, artificial intelligence (AI) tools can be used for advanced image analysis. If time permits, you can compare the titania with silica supports to evaluate the effect of the support on hydrogenation. In addition to TEM, you can characterise your catalysts using complimentary techniques. We will discuss your work during our weekly supervisor meetings, and we will invite you to the weekly TEM lunch meetings and the weekly KinCat meetings. The project can be adjusted to 15, 30, 45 or 60 ECTS and will be expanded to a Master thesis. In the Master thesis work, you can learn to operate an environmental cell TEM holder that allows sending a controlled hydrogen gas flow through the holder while heating the sample. This would allow us to study the effect of hydrogenation and encapsulation effects. Alternatively, this setup can be used to study Fe-based catalysts for Fischer-Tropsch synthesis in their reduced state, which is impossible using conventional sample preparation methods. The project will be a part of the centre iCSI – industrial Catalysis Science and Innovation, and both the TEM and the KinCat Gemini Centres. The studies will be done in collaboration with larger research groups, and your work is likely to be a part of a publication.

Required from the student

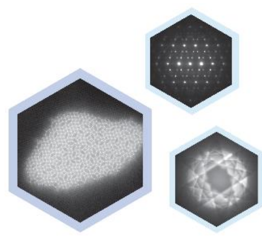
We look for a student who enjoys lab work and would like to combine nanomaterial synthesis with TEM characterisation. You should be happy to collaborate and discuss scientific work with others. Background within nanomaterials, catalysis and/or electron microscopy is an advantage. Relevant courses include Fabrication and Application of Nanomaterials, Nanotools, Materials Physics, and Reaction Kinetics and Catalysis.

Contact persons

Tina Bergh, Postdoc, IKP, tina.bergh@ntnu.no
Albert Miró i Rovira, PhD candidate, IKP,
albert.m.i.rovira@ntnu.no
Hilde J. Venvik, Professor, IKP,
Hilde.Venvik@chemeng.ntnu.no

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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.

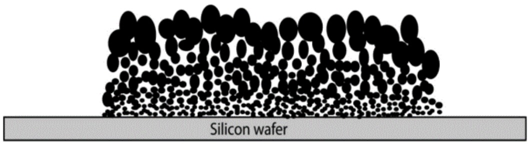
https://www.ntnu.edu/temgemini



Electron microscopy studies of Pd alloy membranes for hydrogen separation

Motivation

Hydrogen separation and recovery is possible using ultra-thin palladium (Pd) alloy membranes. The membrane technology is currently being commercialized by Hydrogen Mem-tech based on a sputtering fabrication process developed by SINTEF Industry. Up to 99% of the hydrogen can be recovered and used in for instance ammonia or methanol synthesis or fuel cells. Further, blue hydrogen can be separated from natural gas followed by capture and storage of CO_2. At IKP, Pd-Ag alloy membranes that are of high industrial and environmental relevance are tested on the lab scale. To understand and improve the performance and stability of the membranes, it is crucial to investigate the structural properties of the films and the changes that have occurred after use. In particular, pore formation, grain growth and element segregation are highly interesting phenomena.



Schematic illustration of the grain distribution of thin Pd–Ag films grown on silicon as resulting from the magnetron sputtering, from Vicinanza et al. 2015 J. Membr. Sci. 602-608

Your Project

You will get TEM training to become an independent user, and you will employ a combination of imaging, spectroscopy, and diffraction techniques to characterise your Pd alloy thin film/membrane samples before and after use. The project goals and experimental methodology will be tailored according to your interests. You can work with advanced dual-beam focused ion beam - scanning electron microscope (FIB-SEM) instruments to image the membranes in three dimensions and make thin samples suitable for TEM. You will have the opportunity to both work on collection of big electron microscopy data, and on data analysis and development. Additional investigations by spectroscopy (e.g. Raman, IR, XPS, Auger) or theoretical modelling (DFT) can be included depending on the relevance and interest. The project can be adjusted to 15, 30, 45 or 60 ECTS and will be expanded to a Master thesis. The project will be done in collaboration between the TEM and KinCat NTNU Gemini Centres with links to the centres iCSI – industrial Catalysis Science and Innovation and HYDROGENi. The projects involve collaboration with several research groups and industry, and it is likely that your work will be a part of a publication. We will discuss your work during our weekly supervisor meetings, and we will invite you to the weekly TEM lunch meetings and the weekly KinCat meetings.

Required from the student

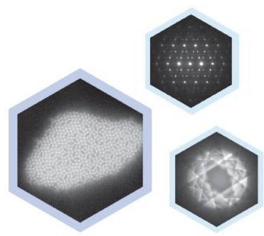
We look for a student who would like to specialise in characterising nanomaterials using advanced microscopy tools. You should both enjoy independent lab work and collaborating and discussing with others. Background within nanomaterials, catalysis and/or electron microscopy is an advantage. Relevant courses include Fabrication and Application of Nanomaterials, Nanotools, Materials Physics, and Reaction Kinetics and Catalysis.

Contact persons

Hilde J. Venvik, Professor, IKP,
Hilde.Venvik@chemeng.ntnu.no
Tina Bergh, Postdoc, IKP, tina.bergh@ntnu.no
Ingeborg-Helene Svenum, Research Scientist at SINTEF and Adjunct Associate Professor, IKP,
ingeborg-helene.svenum@sintef.no

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini



TEM Gemini Centre

NTNU

SINTEF

Strain engineering and characterization of nanomagnets using Focused Ion Beam implantation and Transmission Electron Microscopy

Motivation

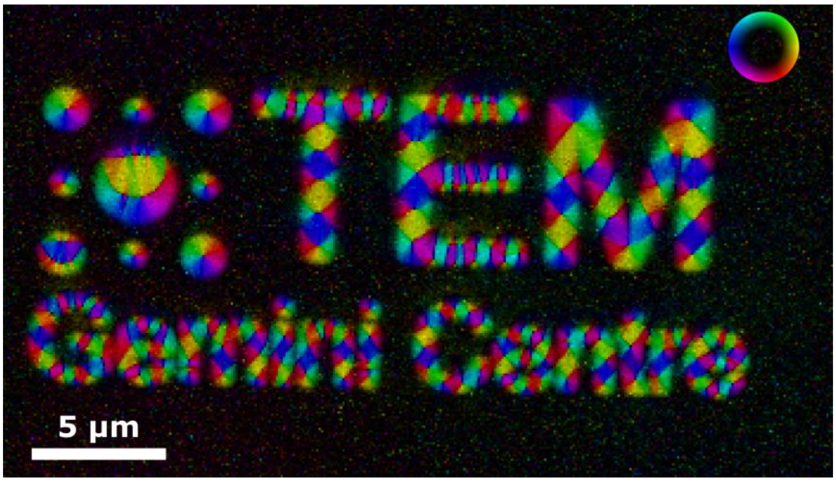


Figure 1: Ferromagnetic domains in ion implanted FeAl, imaged using STEM-DPC

With the increasing demand for more powerful and energy efficient computing devices, there is a need to move away from silicon based semiconductors. A potential concept is in-materio computational devices, which can be made by creating arrays of coupled nanomagnets. One way of creating these nanomagnets, is by implanting ions in FeAl thin films using a Focused Ion Beam (FIB). During the ion implantation, the non-magnetic FeAl becomes ferromagnetic, allowing us to create different magnetic structures in the film (see the figure for an example of this). One open question is the effect of using different ions: preliminary data indicates that the ferromagnetic properties are different when using Ne ions versus the heavier Xe ions. One possible explanation of this is induced strain in the FeAl from the heavier Xe ions. Another easily accessible FIB ion is Gallium, which is lighter than Xe, but heavier than Ne. Being able control the strain through the use of different ions is of great interest, as it allows us to tailor-make the magnetic properties.

Your project

You will study both the crystal structure and ferromagnetic domain structure of ion implanted FeAl thin films using the Transmission Electron Microscope (TEM). This will include the Scanning Transmission Electron Microscopy – Differential Phase Contrast (STEM-DPC) technique for magnetic characterization, and diffraction for structural analysis. The main aim will be to compare Gallium implanted FeAl, with Xenon or Neon implanted FeAl, to study the differences in crystal structure and magnetic domain structure.

You will both learn and use the NTNU NanoLab FIB to create Gallium implanted nanomagnets in FeAl thin films. This will be followed by learning and using the NORTEM JEOL 2100 TEM, to characterize the materials. You will also learn how to do advanced data processing utilizing Python libraries such as HyperSpy and pyXem. The project can also include micromagnetic simulations using the mumax software on NTNU's Idun cluster. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

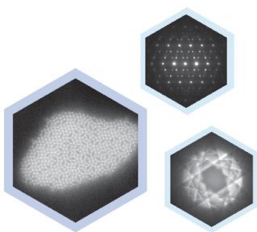
The student should be interested in experimental work using the FIB and TEM, and programming using Python. The most relevant courses are Solid State Physics, Material Physics and Nanotools.

Contact person

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 and materials science 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/temgemini

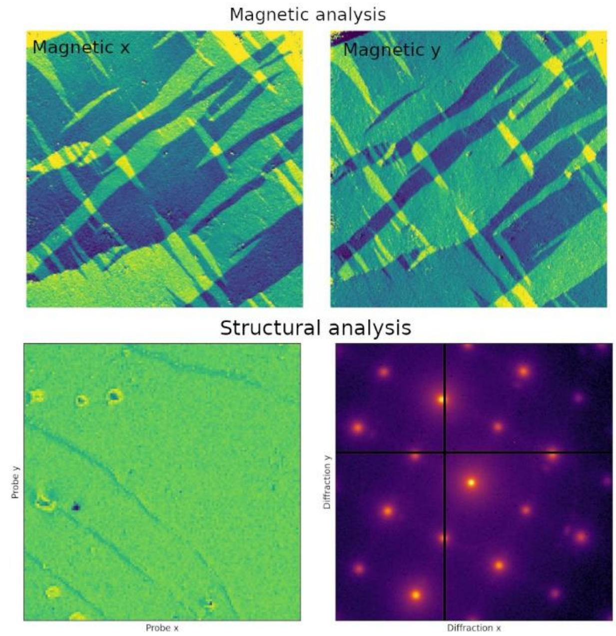


Nanoscale magnetic and structural imaging of freestanding perovskite oxide films using transmission electron microscopy

Motivation

The perovskite oxide material family exhibit a wide range of functional properties, from ferromagnetism and ferroelectricity, to multiferroicity and colossal magnetoresistance. This range of properties is enabled by a strong structure-function coupling, where small changes in the structure can result in large changes in the functional properties. Through careful tuning of growth parameters, different types of perovskite oxides can be grown epitaxially, down to nanometer length scales.

A recent development is freestanding perovskite oxide thin films. Here, a water soluble sacrificial layer is grown on the substrate, followed by growth of the magnetic film. This sacrificial layer is then dissolved in water, enabling the freestanding film to be “scooped” onto any substrate: for example a transmission electron microscopy membrane.



Magnetic and structural analysis of $La_{0.7}Sr_{0.3}MnO_3$ using Scanning Transmission Electron Microscopy

Your project

You will learn and use the Transmission Electron Microscope (TEM) to study freestanding magnetic perovskite oxide thin films ($La_{0.7}Sr_{0.3}MnO_3$). The aim will be to characterize both the magnetic properties, the crystal structure and chemical composition of the films, to better understand the coupling between the structure and magnetic properties. This will include studying how the magnetic domains are affected by external magnetic fields. Here, the magnetic domains will be imaged while an external magnetic field is applied. This will also be coupled with advanced data processing using Python, utilizing libraries such as HyperSpy and pyXem. The thin films will be made by Associate Professor Felix Trier’s group at the Danish Technical University, and Associate Professor Ingrid Hallsteinsen at NTNU will be co-supervising the project together with Associate Professor Magnus Nord. The project can be adjusted to 15, 30, 45 or 60 ECTS.

Requirements

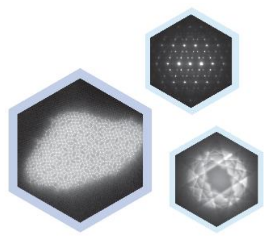
The student should be interested in experimental work using the TEM, and programming using Python. The most relevant courses are Solid State Physics, Material Physics and Nanotools.

Contact person

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 and materials science 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.

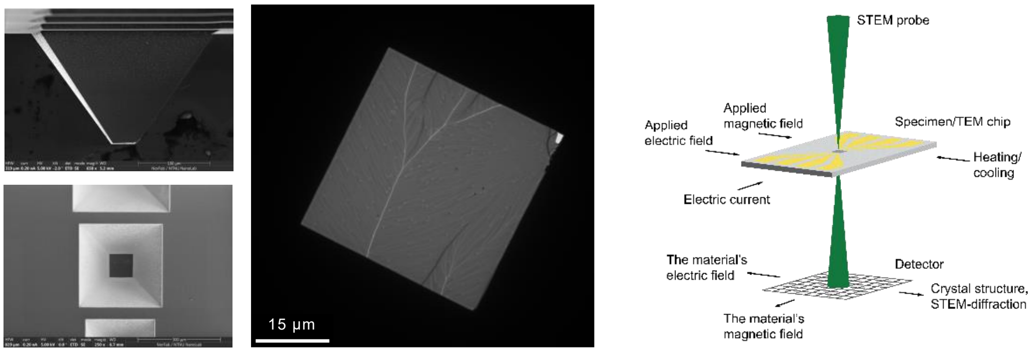
https://www.ntnu.edu/temgemini



Fabricating *in situ* TEM chips for characterization of ferroic materials

Motivation

Transmission electron microscopy (TEM) offers a wide range of materials characterization, from atomic resolution and crystallographic imaging to measurements of chemical and functional properties. With specialized TEM chips, it is possible to investigate the material *in situ* while applying external stimuli, such as heat, electric currents, or strain fields. We seek to fabricate customized TEM chips directly from the substrate of the material of interest. Starting with a sample that has been fabricated on a substrate, the process first involves the deposition of electrodes for the chip. Next, the front side is protected, and electron transparent windows are etched from the back side of the substrate. So far, the front side protection and etching has been optimized for silicon substrates. The next steps will focus on the fabrication of the actual chip for a variety of applications.



Your project

In the project you will be part of a project developing the process for fabricating customizable TEM chips for *in situ* applications working closely with PhD student Marthe Linnerud. The ultimate goal is to fabricate a TEM chip for *in situ* biasing of ferroic thin films. You will become an independent user of NTNU NanoLab. Techniques include lithography, wet and dry etching, and general characterization tools like electron microscopy. In the project, you will fabricate your own TEM chips and evaluate the feasibility and reproducibility of two approaches. If the student is interested, there is a possibility for extending the project to include TEM work in the master's thesis semester. There will be room for tailoring the project towards the student's interest if she/he wishes to.

Requirements

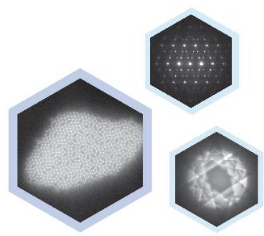
Since the majority of this work will be carried out at NTNU NanoLab, the student should be interested in nanofabrication and process development. The student should have knowledge about nanofabrication and/or semiconductor technologies. Laboratory experience from courses similar to TFE4167 and/or TFY4330 are desirable, but not a prerequisite. The project can be adjusted to 15, 30, 45 or 60 ECTS.


Contact persons

- Magnus Nord, Associate Professor, Department of Physics, NTNU, magnus.nord@ntnu.no
- Marthe Linnerud, PhD candidate, Department of Physics, NTNU, marthe.linnerud@ntnu.no

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini



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

The 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. Alternatively, the project can focus on finding crystal structure of debated minerals using (3D) electron diffraction. Such a project will be a combination of computational and practical work. Both project suggestions can be adjusted to 15, 30, 45 or 60 ECTS.

Required from the student

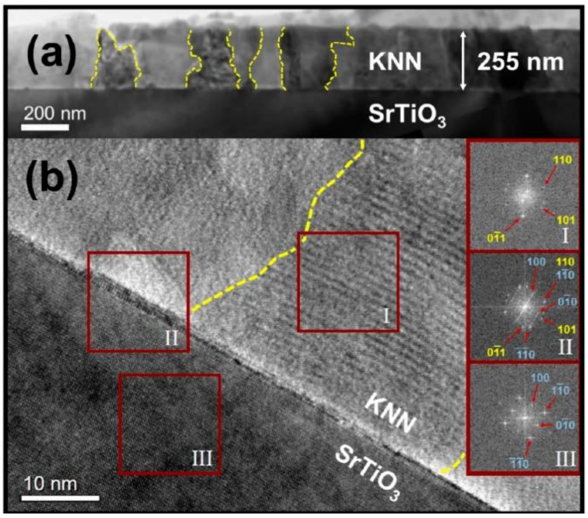
The perfect applicant has an interest in interdisciplinary experimental work, and is creative, inventive, self-reliant, independent, pro-active, and able to communicate cross-disciplinary with researchers from different disciplines.

Contact persons

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

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 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.

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

Per Erik Vullum (per.erik.vullum@sintef.no) and Randi Holmestad, randi.holmestad@ntnu.no

This project is in collaboration with Mari-Ann Einarsrud 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.

Characterization of inoculants in cast iron/ steels

Motivation

Cast iron and steel are two popular metal materials used in metal part productions. Cast iron contains over 2% carbon, while steel contains less than 2% carbon. Grain refinement is a critical process in production of cast iron and steels as a reduced grain size can significantly improve mechanical properties. For that purpose, inoculants (small amounts of other elements) are added to control the process of solidification and provide the desired microstructure and mechanical properties in the iron casting and their performance has an enormous effect on metallurgical quality. Elkem offers an unbeaten range of premium inoculants supplied globally and has pioneered the development of inoculant specifications for the worldwide iron foundry industry for decades. Due to geopolitical reasons, supply of some elements may become critical, and we aim to get a fundamental understanding of inoculants at atomic level of different types of inoculants. One example is cerium - as a highly reactive rare-earth element, cerium forms stable inclusions when added to the steel melt. These inclusions, including, cerium oxides, sulfides, aluminates and oxysulphides are supposed to act as nucleation sites for melted steel to solidify new grains. The nature of these microparticles is still debatable and not yet understood. A potential Ce-oxide phase is shown in Fig. 1.

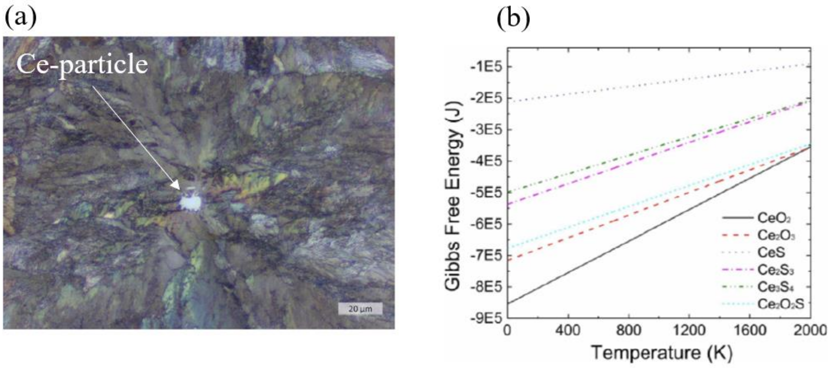


Fig. 2: (a) Ce-particles in the middle of an iron crystal. (b) Types of different Ce phases and their free energy of formation as a function of temperature [F. Pan et al. Sci. Rep. 6 (2016), doi: 10.1038/srep35843.].

Your project

The student will characterize microparticles in cast iron/steels made by Elkem Silicon Products, learn to use transmission electron microscopy (TEM) and to determine the chemical composition and crystal structure of the formed phases and their orientation relationships to the iron/steel. Also, a pure data analysis exercise is possible here – to analyze a 4D dataset acquired with scanning precession electron diffraction (SPED) to determine phase and orientation maps using pyxem. For this project there is a possibility for a summer job, and travel to Kristiansand to prepare materials.

Requirements

Background in materials physics, nanotechnology or chemistry is an advantage. We seek students motivated to do experiments and interested in connecting large scale material properties to materials micro- and nanostructure. For the data analysis, knowledge of Python is a big advantage.

Contact persons

This topic is a collaboration with Elkem Silicon Products and will dependent on material be connected to SFI PhysMet or the SIDI project and also different supervisors – contact us to get more details!

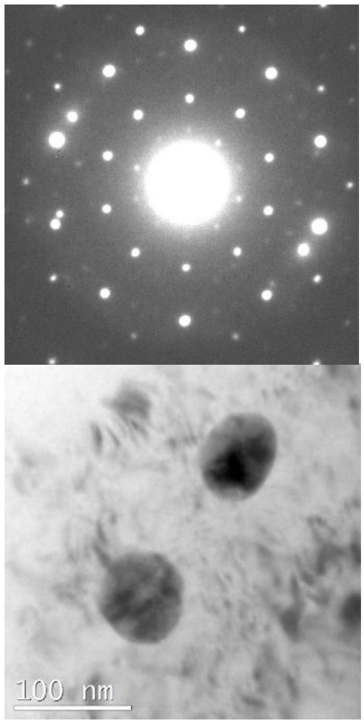
Randi Holmestad (NTNU) randi.holmestad@ntnu.no, Ruben Bjørge, ruben.bjorge@sintef.no, Ursula Ludacka ursula.ludacka@ntnu.no, Sigurd Wenner, sigurd.wenner@sintef.no, Yanjun Li, yanjun.li@ntnu.no
Co-supervisors from Elkem:
Leander Michels leander.michels@elkem.com, Håkon Mauset hakon.mauset@elkem.com

TEM investigations of quasicrystals

Motivation

Quasicrystals were discovered in 1982 in an aluminium alloy using transmission electron microscopy (TEM). Dan Shechtman received the Nobel Prize in Chemsitry for this discovery in 2011. While crystals have long-range translational order, quasicrystals have no translational order but do have long-range orientational order and display crystallographically forbidden orientation symmetry (for example, 5-fold rotation symmetry). Despite four decades of reasearch, how quasicrystals form and grow is not yet understood.

In the researcher project "QUATRIX", funded by the Research Council of Norway, we study quasicrystals that are found as particles (precipitates) in an aluminium matrix. The goal is to contribute to the knowledge of quasicrystal atomic structure and fundamental understanding of how quasicrystals form and grow by combining advanced characterizaton techniques with atomistic modelling.



Top: Electron diffraction pattern of a quasicrystal in aluminium showing 10-fold symmetry. Bottom: TEM image of quasicrystals in aluminium.

Your project

The student will work with particles formed in rapidly solidified aluminium alloys. The student will prepare TEM samples and investigate quasicrystalline particles in the aluminium matrix using TEM imaging and diffraction. From diffraction patterns taken in different orientations the orientational order will be investigated. If possible, three-dimensional electron diffraction techniques will be used to determine the three-dimensional structure of the quasicrystals. The student will take part in regular QUATRIX project meetings.

Requirements

The student should be interested in materials science and materials physics, electron microscopy and diffraction. We seek students interested in combining experimental work and data analysis.

Contact persons



Randi Holmestad, Professor, Department of Physics, NTNU.
Office: Realfagbygget D4-153. (randi.holmestad@ntnu.no)
Oskar Ryggetangen, Ph.D. student, Department of Physics, NTNU (oskar.ryggetangen@ntnu.no).
Ruben Bjørge, Research Scientist in SINTEF and Adjunct Associate Professor, Department of Physics, NTNU (ruben.bjorge@sintef.no).

The TEM Gemini Centre is a strategic collaboration between NTNU and SINTEF. We work within the fields of solid state physics and materials science 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/temgemini