Student Projects - Fall 2016

Materials Physics

Responsible: Dag W. Breiby

All these projects can be continued as master projects for spring 2018, and they can also be extended and suitably modified for 2-year Master programs.

Topics of particular interest:

- Functional materials. What are they, how are they built up, how do they function, and how can we describe them mathematically?
- Imaging of ocean-related structures is important for the climate. We have projects ranging from plankton, via hyperspectral imaging of the seabed, to cement structures in abandoned oil-wells for CO_2 storage.
- Organic electronics, for example OLED TV screens and organic solar cells. How can the molecular structure be optimized, measured and understood? How does it relate to the device performance?
- Coherent diffraction imaging and computational microscopy. Modern microscopy techniques rely heavily on computations, with keywords being compressed sensing, tomography, and sub-diffraction-limit imaging.
- X-ray imaging and scattering. Clearly, there is a trade-off between radiation dose and high-resolution imaging. How can we design our experiments to stretch the limits?
- Computed tomography (CT) applied to biological and medical samples. We can offer a project in collaboration with the Section for biophysics where CT imaging will be used together with Raman microscopy to study *cartilage* to better understand *osteochondrosis*.
- Soft materials like polymers and micelles exhibit complicated mesoscale 3D structures of high fundamental *and* industrial interest, for example for paints, cosmetics, foams, gels and cements. We work actively on refining microscopy techniques for understanding these structures.

If you are interested in one or more of these projects, please contact Dag.Breiby@ntnu.no

Student projects

Dag W. Breiby, Fall 2017

Fall 2017: 1-3 project students welcome!

A suitable background is Physics or Nanotechnology

We expect that you –

- *enjoy experimental work*
- *enjoy computer programming*
- *can work independently (yet under regular supervision)*

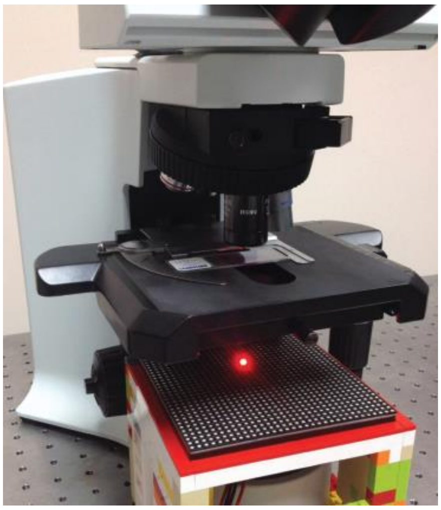
PhD in physics at NTNU, 2003.
Permanent staff at Dept. of Physics NTNU since 2007, professor since 2013.
Adjoint Prof. in micro technology at University College of Southeast Norway.

Teaching: Solid State Physics, Materials Physics, Measurements, General Physics, Optics.

Specialist on: Soft, biological and functional materials, self-organized nano- and mesoscale structures, X-ray diffraction and microscopy techniques.

Fourier-ptychographic microscopy with your smart phone

Considering that the fundamental design of standard light microscopes has not changed much since the first one was constructed about 400 years ago, it is quite refreshing that many research groups these days work actively on both miniaturization and how the performance can be radically improved when computers are employed as active elements in the imaging process. The last few years a *computational* revolution relating to the imaging process itself, i.e. not simply post-processing, has been taking place. This technology is promising for example for point-of-care healthcare diagnostics and wide field-of-view high-resolution screening.



Fourier ptychography [Zheng 2013, Tian 2014] is a microscopy technique based on a standard microscope where the traditional sample illumination has been replaced by a 2D array of partially coherent LED lamps, see figure. From each single LED, used one at a time, the light enters the sample with a unique direction. By taking one moderate-resolution exposure for each LED sequentially, one gets a set of images that can be used to reconstructed both the amplitude and the phase of the imaged object. In other words, one single high-resolution wide field-of-view (gigapixel) image is obtained after the numerical manipulations.

In this project you will

- Review & understand the physics of Fourier ptychography
- Implement Fourier ptychography on a standard light microscope (this includes construction, LED controller programming, and writing code for image synthesis).
- Optionally: Construct a microscopy extension including an *app* for your smartphone
- Optionally: Monitor the curing of paint or epoxy in collaboration with industry.

This project requires outstanding programming skills and an interest in photonics.

Co-supervision:

The project will be carried out in close collaboration with the University College of Southeast Norway, Prof. Muhammad Nadeem Akram Muhammad.N.Akram@usn.no

Zheng et al, Nature Photonics, 2013:
http://www.nature.com/nphoton/journal/v7/n9/full/nphoton.2013.187.html
Tian et al, Biomedical Optics Express, 2014:
https://www.osapublishing.org/boe/abstract.cfm?uri=boe-5-7-2376
See also this link, http://cellscope.berkeley.edu/technology/

RADESOL[1] (instrumentation)*

Organic photovoltaics is an emerging technology with the prospects of cheap, flexible and easy mass-production of solar cells. However, there are several challenging before reaching that goal, perhaps most fundamentally related to the chemical and morphological stability of the organic materials involved. It is a fact that different heat treatment of the polymer ("plastic") materials gives solar cells with widely different performances. While the fundamental reasons for this behavior are gradually becoming clear, much remains to be done also in the microscopic studies of such materials.

In this project, you will be modifying our modular optical microscopy setup, and work on implementing *flash heating* and fast scanning calorimetry (FSC) for *in situ* studies of the morphology changes triggered by thermal annealing. Flash heating allows heating/cooling rates of $>10^4$ K s^{-1} (!) for sufficiently small sample volumes.

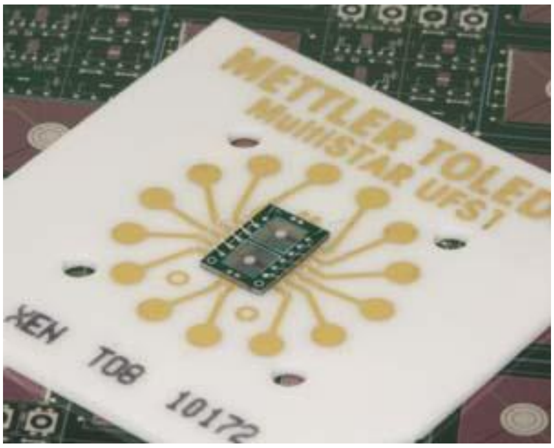


Figure 1. Example of electronic chip used for fast scanning calorimetry.

Project tasks:

1. Optimize microscopy setup for video-rate imaging. Possible extensions: computational imaging by using structured illumination and scattering contrast.
2. Design and build a *flash heating* setup, including PID-control, compatible with future synchrotron experiments
3. Understand quantitatively the measured crystal growth of different polymer mixtures under different thermal annealing schemes.

Co-supervision:

Post doc Leander Michels, email leander.michels@ntnu.no

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[*] RAtional DEsign of blends for bulk heterojunction SOLar cells. Funding: European M-ERA.NET programme.

Numerical simulations of X-ray optics

The scattering of electromagnetic radiation by spherical objects plays an important role in the development of physics, with highlights including Descartes' understanding of the rainbow 400 years ago, Rayleigh scattering by small particles, and Mié's exact solution to the scattering of a plane wave by a sphere. In this project, we will study X-ray scattering from densely (hexagonal) packed monolayers of absorbing spherical particles deposited on a multilayer thin film. The particles are of diameter $D >> \lambda$. X-rays typically have an index of refraction $n = 1 - \delta + i\beta$, with $\delta \sim 10^{-5} - 10^{-6}$ and $\beta \sim 10^{-6} - 10^{-8}$ for condensed matter, emphasizing the common knowledge that X-rays are highly penetrating.

We have already developed numerical software for solving the related problem of scattering from a single absorbing sphere. For the case of 2D layers of non-absorbing spheres, analytical solutions exist. It is a challenge to modify the software to deal with the 2D dense layer of absorbing spheres. Ultimately, the project aims at modeling experimental synchrotron data, and is thus of high applied interest.

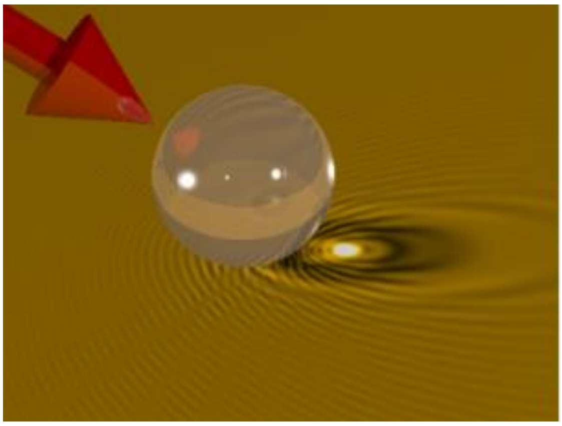


Figure 1. Modeling the light scattering from a single spherical object.

Project tasks:

1. Do a literature survey, study the relevant existing models for light scattering.
2. Implement an efficient computer program for calculating reflection-geometry reflectance for densely packed spheres.
3. Verification towards existing analytical solutions for limiting cases.
4. Participate in synchrotron experiment and apply computer model to experimental data.

Co-supervision:

The project will be carried out in close collaboration with Dr. Oleg Konovalov at the European Synchrotron Radiation Facility (ESRF) in France.

Understanding Emiliania Huxleyi

Emiliania Huxleyi (EHUX) is the somewhat whimsical name of an abundant photosynthetic micron-sized plankton. EHUX and other phytoplankton can serve as sinks of CO_2. The links between the global climate, the atmospheric level of CO_2, and the abundance of phytoplankton is poorly understood yet frequently discussed in the general media. This single-cell organism constantly creates new calcium carbonate-based *coccoliths*, i.e. regular thin disks with an intricate structure covering the alga surface. The exact role of the coccoliths is not clear, but it is known that EHUX exists in such quantities that it significantly alters the albedo of the oceans. Some studies suggest that the coccoliths act as photonic crystals, and this is the topic of this project proposal.

Using X-ray computed micro-tomography, we have obtained 3D models of EHUX of unprecedented resolution (< 50 nm). These structural models will be fed into finite-element software to study the photonic properties. Specifically, you will study the transmittance, reflectance and polarization properties in an attempt to better understand primarily the photonic properties of EHUX and secondarily her role in the climate system.

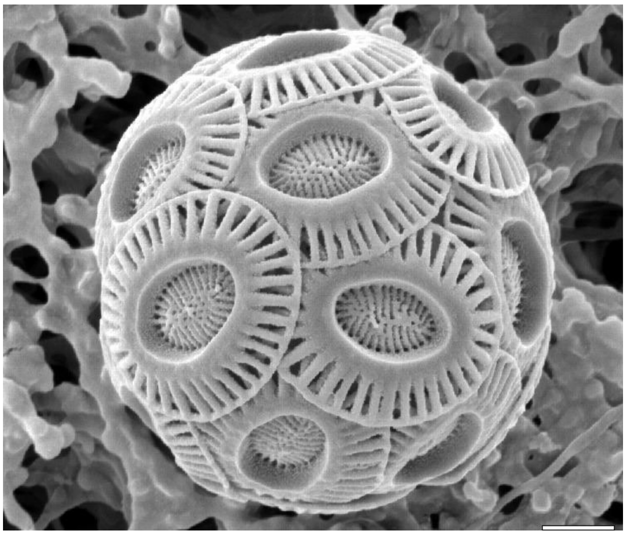


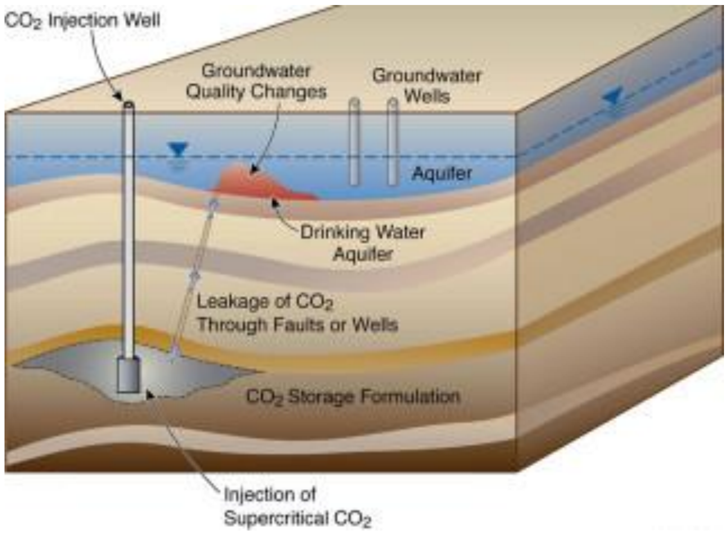
Figure 1. Electron micrograph of an EHUX phytoplankton covered with coccoliths.

Co-supervision:

The project will be carried out in close collaboration with Prof. Alain Gibaud at the Université du Maine in Le Mans, France.

External Projects

CO_2PLUG[*]



Motivated by the prospects of storing CO_2 in abandoned oil wells, structures in *cement* and how they respond to supercritical CO_2 at high p and T are a topic of high current interest world-wide. Are you keen on saving the environment and want to better understand CO_2 storage while learning the physics of X-ray imaging? Our approach is to do *in situ* studies of cement samples using tomography to get 3D images for better understanding the complex chemical reaction pathways.

For successful CO_2 storage in underground reservoirs, long-lasting cement plugging of wells is crucial. This requires a profoundly improved understanding of the behavior of fractured cement under realistic subsurface conditions including elevated temperatures (50 – 100 °C), high pressure (up to 200 bar) and anaerobic conditions. An important recent finding is that fractures in cement gradually heal when exposed to CO2. The healing process has not yet been fully understood. We thus propose to use X-ray tomography to study the healing process of fractured cement. The aim of the master project will be to learn about image treatment with MATLAB using micro-CT images obtained from cement samples under different condition and finally try to understand the phenomena involved.

[*] Project funded by the Norwegian Research Council.

Project tasks:

1. Do a literature survey about cement chemistry, hydration, CO_2 alteration, X-ray tomography.
2. Learn to use the CT machine, collect data.
3. Reconstruct the 2D projections using filtered back projection and, optionally, iterative methods.
4. Perform image segmentation of volumetric data using MATLAB
5. Learn to use advanced 3D visualization software (VG-studio, AVIZO).
6. Find out which phases that are present in the sample, and try to quantify volume ratios.
7. Study the effects of CO_2 exposure on fractured cement

Special remark:

Excellent opportunity to write an environment-oriented project in close collaboration with Norwegian industry!

Co-supervision:

Dr. Malin Torsæter (SINTEF)

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