



10th Workshop on NEUtron WAVElength Dependent Imaging

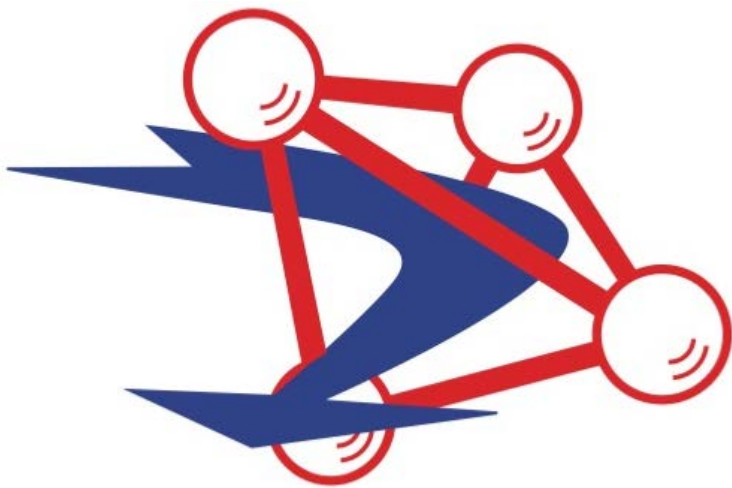
Sunday, 26 May 2019 - Wednesday, 29 May 2019

**Paul Scherrer Institut
Programme
and
Book of Abstracts**

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Laboratory for Neutron
Scattering and Imaging -
Paul Scherrer Institut

Monday 27 May 2019

Welcome to NeuWave 10 - OSGA/EG06 (08:45-09:00)

Facilities: Facilities I - OSGA/EG06 (09:00-10:15)

Reporting latest facility development

-Conveners: Burkhard Schillinger

time	[id] title	presenter
09:00	[32] Status and application studies of the energy-resolved neutron imaging at RADEN	SHINOHARA, Takenao
09:25	[30] Evaluation of the energy-resolved neutron imaging options on IMAT	KOCKELMANN, Winfried
09:50	[29] Progress and Applications of Wavelength Resolved Imaging at PSI NIAG	STROBL, Markus

Coffee break - OSGA/EG06 (10:15-10:45)

Facilities: Facilities II - OSGA/EG06 (10:45-12:30)

Reporting latest facility development

-Conveners: Winfried Kockelmann

time	[id] title	presenter
10:45	[15] Neutron Imaging at LANSCE – from cold to ultrafast	VOGEL, Sven
11:10	[28] The VENUS project at the Oak Ridge National Laboratory Spallation Neutron Source	BILHEUX, Hassina
11:25	[39] The ODIN instrument at ESS: current status	MORGANO, Manuel
11:40	[13] Project of energy-resolved neutron imaging instrument at CSNS	CHEN, Jie

Lunch - OSGA/EG06 (12:30-14:00)

Facilities: Facilities III - OSGA/EG06 (14:00-15:45)

Reporting latest facility development

-Conveners: Daniel Hussey

time	[id] title	presenter
14:00	[36] Energy-selective neutron imaging applications at continuous sources	KARDJILOV, Nikolay
14:25	[17] Foreseen energy-selective options at NeXT-Grenoble	TENGATTINI, Alessandro
14:40	[25] A simulation study of the photoneutron source for the bragg-edge analysis	YANG, Yigang
14:55	[51] Optimal design of a uniform resolution time-of-flight systems for wavelength resolved neutron imaging	STROBL, Markus

Poster session and Coffee break - OSGA/EG06 (15:45-16:15)**Poster list:**

ID	Title	Presenter
20	MULTI-GRAIN INDEXING WITH LAUE 3D NEUTRON DIFFRACTION	Stavros Samothrakitis
22	Progress and Updates on Energy Resolved Neutron Imaging Capabilities at LANSCE	Alexander Long
33	Neutron Diffraction at the SENJU diffractometer of J-PARC: The transmission data	Nancy Elewa
41	A study on possibility of grating interferometer with optical blocker	Daeseung Kim
43	Using a chopper and a 100 mm XS MCP detector to measure the spectrum of the NIST Cold Neutron Imaging Instrument	Daniel Hussey
45	NIMRA: the upgraded neutron imaging set-up at the JEEP-II reactor	Stefano Deledda
47	DataScripting: A flexible data acquisition tool for neutron imaging at NIST	David Jacobson
48	ReconstructCT: A complete graphical user interface analysis tool to process tomography data sets	David Jacobson

Applied Bragg edge imaging: Applied Bragg edge imaging I - OSGA/EG06 (16:15-17:30)**-Conveners: Filomena Salvemini**

time	[id] title	presenter
16:15	[38] Bragg Edge imaging for the visualization of engineered residual stress in additive manufacturing obtained through Laser Shock Peening	MORGANO, Manuel
16:30	[16] Study of Laser Shock Peening with Bragg Edge Imaging on Diffraction Beamlines	RAMADHAN, Ranggi Sahmura
16:45	[10] Optimization of crystal growth and material parameters through in-energy-resolved neutron imaging	TREMSIN, Anton
17:00	[46] Energy-resolved in-operando neutron imaging of lithiation and delithiation mechanism in graphite electrodes in rechargeable Li-ion batteries	LACATUSU, Monica-Elisabeta

Status and application studies of energy-resolved neutron imaging at RADEN

T. Shinohara¹, T. Kai¹, K. Oikawa¹, K. Hiroi¹, Y Su¹, Y. Seki¹, M. Segawa¹, T. Nakatani¹, H. Hayashida², Y. Matsumoto², J. D. Parker², Y. Kiyonagi³

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The Energy-Resolved Neutron Imaging System, RADEN, in the Materials and Life Science Experimental Facility (MLF) of J-PARC has been open for user programs from 2015 [1]. Owing to both J-PARC's short pulsed neutron beam with a narrow pulse structure and the specialized beam line design for pulsed neutron imaging, RADEN possesses the capabilities to perform precise measurements of wavelength dependent neutron imaging and wide energy-range imaging from keV (epithermal neutron) to meV (cold neutron) efficiently. Besides the user programs, the RADEN group is continuing technical developments on energy-resolved neutron imaging and their application studies. For example, Bragg-edge imaging and pulsed polarized neutron imaging were applied to industrial objects to study the inhomogeneous degradation of commercial Li-ion batteries under the charge/discharge process and to visualize the magnetic field distributions of driving electric motors and transformers. Very recently we have started a pulsed-neutron imaging project to contribute to the CLADS (Collaborative Laboratories for Advanced Decommissioning Science) activity for fuel debris characterization of the Fukushima-Daiichi nuclear power plant. The main purpose of this project lies in visualization and quantification of boron distributed in melted model fuels to obtain fundamental and indispensable knowledge for the safe removal of debris from the plants.

In this presentation, we will report activities conducted at RADEN and recent results for application studies regarding energy-resolved neutron imaging techniques.

This work was partially supported by Photon and Quantum Basic Research Coordinated Development Program from the MEXT, Japan and by the Momose Quantum Beam Phase Imaging Project, ERATO, JST (Grant No. JPMJER1403).

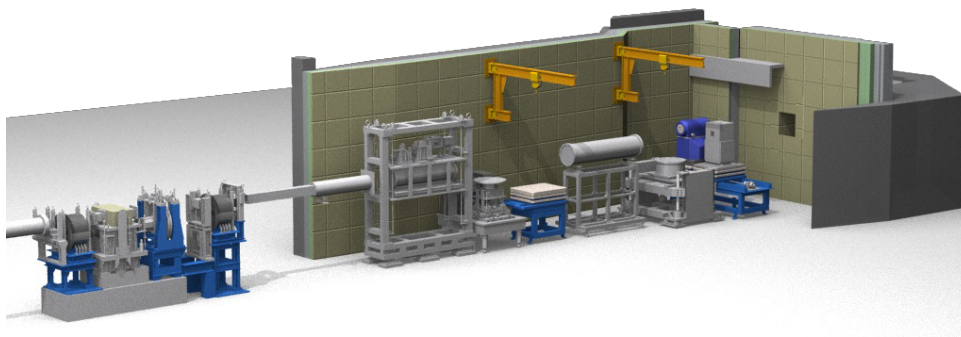


Figure 1. Illustration of RADEN instrument.

Evaluation of the energy-resolved neutron imaging options on IMAT

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IMAT is well into its commissioning phase, and has started a limited user programme. Here we report on results of the evaluation of the wavelength-resolving imaging modes, including energy-selection using disk choppers and energy-dispersive Bragg edge imaging using time-resolving detectors. A characterisation of beamline parameters is necessary, to identify problems with data collection and data analysis, and to provide potential users with the essential information for planning their experiments.

In addition to the basic instrument parameters for white-beam tomography, like flux and L/D [1] some of the performance parameters for energy-resolved neutron imaging have been determined. Beamline parameters like spectral resolution, spectral homogeneity of the beam and spatial resolution for Bragg edge imaging were evaluated, as well as the camera response and its uncertainties [2]. For strain mapping, one of the most important methods, the strain resolution and strain accuracy were evaluated [3]. The reproducibility, precision and accuracy of Bragg edge shifts were evaluated using metal sheets and powders of standard reference materials. In the absence of international standards, simple systems were studied and results were compared to parameters obtained by complementary methods, e.g. neutron diffraction (Figure 1). Due to the wide range of materials parameters to be calibrated, instrument variables to be considered, and different available methods, the evaluation of the energy-resolving imaging modes on IMAT is considered to be an ongoing task.

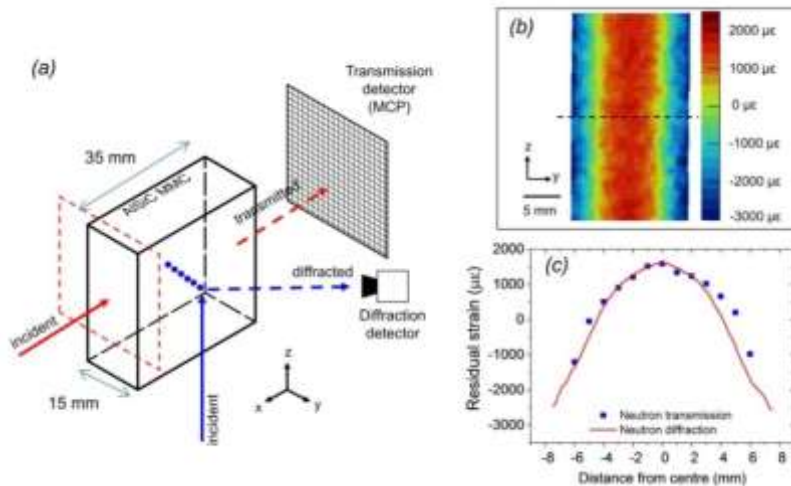


Figure 1. (a) Setup: neutron transmission (red lines/arrows) and neutron diffraction (blue dots/arrows) on an AlSiC_p metal matrix composite; (b) residual strain map; (c) comparison between neutron transmission (red line) and neutron diffraction (blue symbols) (from [3]).

[1] T. Minniti et al., Nucl. Instr. Methods (2018) A888 p. 184.

[2] K. Watanabe et al. Nucl Instr Meth (2017) A861.p55

[3] R. Ramadhan et al., J. Appl. Cryst (2019) in print.

Progress and Applications of Wavelength Resolved Imaging at PSI NIAG

M. Strobl¹, J. Valsecchi¹, M. Morgano¹, E. Polatidis¹, C. Gruenzweig¹, R. Harti, M. Raventos¹, S. Samothrakitis², M. Siegwart¹, P. Boillat¹, A. Kaestner¹, C. Carminati¹

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The engagement of NIAG in wavelength resolved imaging is growing steadily from the initial monochromatic and wavelength selective techniques towards wavelength dispersive measurements including a focus on applications at the future imaging instrument ODIN at ESS. The work is driven by methodical development and improvements as well as by applications [1-3]. Most work is embedded in the framework of collaborations with research groups and imaging specialists at other institutions. After providing an overview of NIAG activities and collaborations, this presentation shall focus on progress and application results in neutron dark-field contrast imaging. Results will be provided with respect to applications of dark field contrast and in particular quantitative dark-field contrast imaging conveying examples of observations of domain wall kinetics, quasi crystallization of micro-particles and observations of the structural breakdown of cohesive powder under pressure. Further the combination of DFI with polarized neutrons shall be introduced and discussed, before novel approaches beyond grating interferometry and towards achromatic solutions for wavelength dispersive ToF DFI shall be discussed.

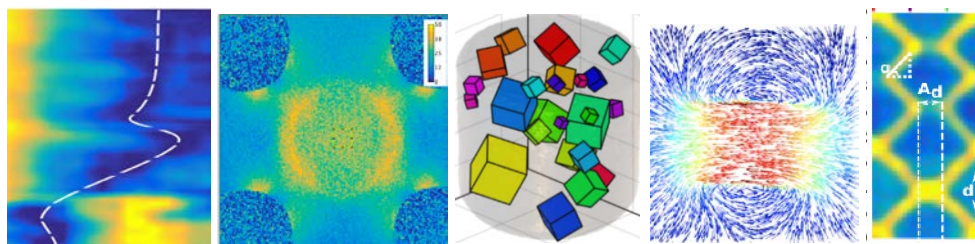


Figure 1. Collection of recent results in wavelength resolved imaging from PSI NIAG and in collaboration with partners: correlation of micro-particles in suspension via DFI, phase map in TRIP steel after controlled bi-axial loading, crystal grain map from diffraction imaging (with DTU), magnetic vector field from polarized neutron imaging (with DTU, JPARC) and magnetic domain wall kinetics in AC field (with HZB)

[1] M. Strobl, H. Heimonen, S. Schmidt, M. Sales, N. Kardjilov, A. Hilger, I. Manke, T. Shinohara, J. Valsecchi, Topical review: Polarisation measurements in neutron imaging, J. Physics D, DOI: 10.1088/1361-6463/aafa5e

[2] M. Strobl, R. P. Harti, C. Grünzweig, R. Woracek, J. Plomp, Small Angle Scattering in Neutron Imaging—A Review, J. Imaging 3 (2017) 64

[3] R. Woracek, J. Santisteban, A. Fedrigo, M. Strobl, Diffraction in neutron imaging—A review, Nucl. Inst. Meth. A 878 (2018) 141–158

Neutron Imaging at LANSCE – from cold to ultrafast

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LANSCE offers pulsed neutron radiography and tomography for neutron energies ranging from cold (ASTERIX beamline) to thermal and epithermal (ERNI-FP5 beamline) to 1-100 MeV ultra-fast neutrons (60R beamline). Furthermore, microtron generated hard X-rays (1-10 MeV) as well as proton radiography allow for complementing characterization capabilities. This presentation provides updates on developments of this program at LANSCE as well as highlights since the previous NEUWAVE meeting at NIST, Gaithersburg. On the ASTERIX beamline, pulsed neutron phase contrast imaging is under development. On the ERNI beamline, quantitative analysis of neutron absorption resonance data has enabled non-destructive 3D isotope densitometry on cm-sized sample. Data on a dU-20Pu-10Zr-3Np-2Am was in excellent agreement with conventional isotopic analysis, but provided 3D distribution of isotopes to characterize e.g. inclusions prior to destructive examination. A highlight of the past run cycle was the characterization of a unique gold-silver alloy specimen which was characterized by neutron resonance absorption imaging to provide elemental distribution, hard X-ray CT (blocking the neutron beam on the same beamline as well as with a microtron source) to characterize density variations, as well as neutron diffraction to obtain microstructural characterization. This example will be discussed in more detail.

The VENUS project at the Oak Ridge National Laboratory Spallation Neutron Source

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The VENUS project has officially started, and detailed engineering design is on its way to purchase the optical and beam delivery components of the beamline, such as the core vessel insert and the shutter insert. Located at the Spallation Neutron Source's First Target Station (beamline 10), the beamline is designed to utilize epithermal, thermal and cold neutrons from a 10 cm x 12 cm decoupled H₂ moderator. VENUS is optimized for both Bragg edge and epithermal imaging. Equipped with a T0 and four bandwidth choppers, it is optimized for two detector positions: (1) high flux, limited field-of-view (FOV) at 20 m; (2) lower flux, higher FOV and wavelength resolution at 25 m. Although not available at first at VENUS, the 20 m sample position is also designed to allow future magnification (using optical components) of an object onto the detector positioned at 25 m. The beamline specifications are described in Table 1. The collimation can vary from L/D 400 (the minimum L/D ratio that offers a full illumination of 20 cm x 20 cm at 25 m) to 2000, where L is the distance between the aperture of diameter, D , and the detector. With a cave of about $\sim 90 \text{ m}^2$ (floor space), VENUS can accommodate large samples, sample environment, and equipment. This presentation gives the overall layout of the beamline, with the optimization of the optics and choppers.

VENUS (Beamline 10)	
Beam Spectrum	Epithermal, Thermal, Cold
Moderator	H2 decoupled poisoned
Wavelength bandwidth	$\sim 2.6 \text{ \AA}$ (at 25 m)
Spatial resolution	$\sim 50\text{-}100 \text{ }\mu\text{m}$
Resolution $\Delta\lambda/\lambda$	0.12 %
Source-to-detector distance	25 m
Detection system and resolution	Camera and Micro-Channel Plate (MCP) detector
Flux on sample (n/s/cm ²)	1 x 10 ⁷ in TOF mode 1 x 10 ⁸ in white beam mode
Field of View	20 cm x 20 cm (full illumination)

Table 1. Expected performance of the VENUS beamline.

Acknowledgments: This research was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U.S. DOE. This research used resources at the Spallation Neutron Source and the High Flux Isotope Reactor, U.S. Department of Energy (DOE) Office of Science User Facilities operated by the Oak Ridge National Laboratory.

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The ODIN instrument at ESS: current status

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²*Technical University of Munich, Germany*

The European Spallation Source under construction in Lund (Sweden), promises to be the world's most intense pulsed neutron source and the first beam on target is expected to be in 2022.

The Optical and Diffraction Imaging with Neutron (ODIN) instrument (Fig. 1), which is being designed as an in-kind collaboration between the Technical University of Munich and the Paul Scherrer Institut, is scheduled to be in the first suite of instrument to come online and begin hot commissioning as the facility produces the first neutrons.

Here we present the status and current timeline of the project along with the foreseen instrument parameters and a brief description of the scope of the beamline

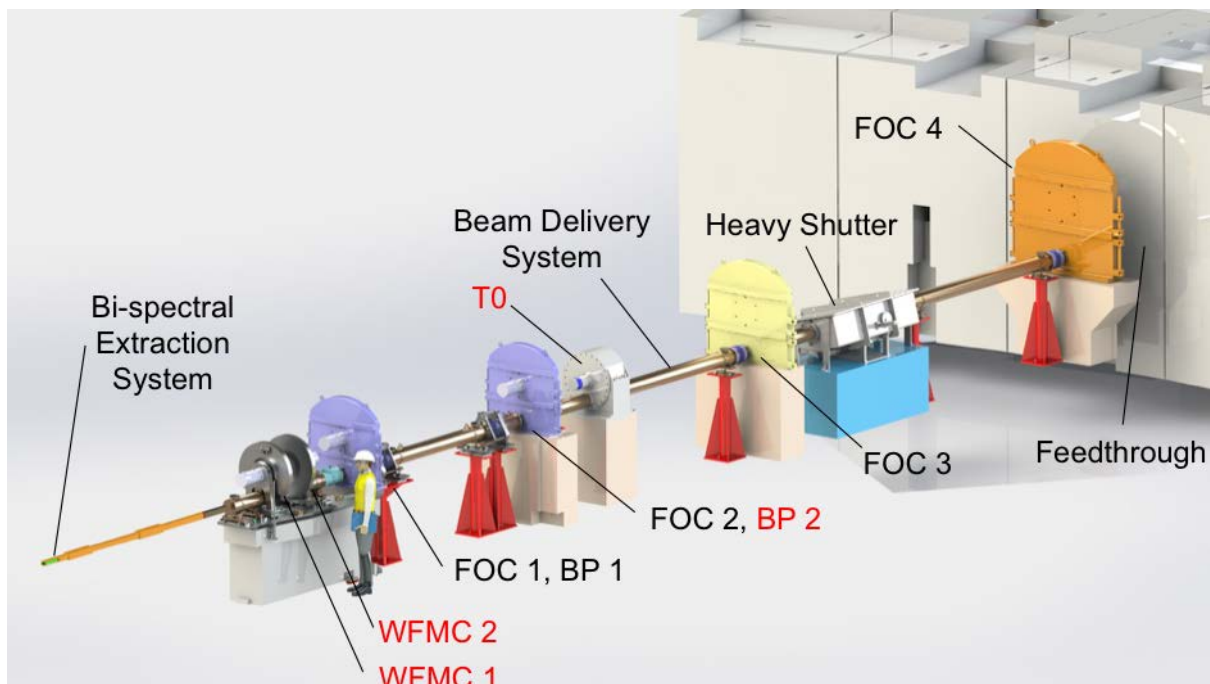


Figure 1. Rendering of the in-bunker components that will transport and shape the neutron beam of the ODIN instrument.

Project of energy-resolved neutron imaging instrument at CSNS

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In order to serve a growing multidisciplinary community beyond the traditional neutron scattering areas, an energy-resolved neutron imaging instrument (ERNI) has been proposed at the China Spallation Neutron Source (CSNS). The instrument is designed to provide state-of-the-art analytical techniques such as conventional neutron imaging, tomography, Bragg-edge imaging, grating imaging, and combined neutron diffraction. With a main emphasis on energy, engineering, and advanced materials studies, the instrument enables 2D/3D mapping of the microstructure, light element, strain, crystallographic structure information and so on. It also supports a wide range of researches in archaeology, biology, biomedicine, geosciences, building technology, forensic and homeland security applications.

Coupled hydrogen moderator (CHM) is used as its neutron source, which could provide good energy resolution while has highest neutron flux for cold neutron. Straight neutron guide ($m=3$) with a cross section of $8.5 \times 8.5 \text{ cm}^2$ is employed to transport neutron. One T0 chopper and four disk chopper will be used to define the wavelength needed. A collimation system (pinhole and slits) after the neutron guide and two sample positions will be used to provide a series of L/D ratios and imaging/diffraction modes to satisfy different user requirements. The distance between the sample and moderator is 32 m and 37 m, respectively. The wavelength resolution for Bragg edge imaging at 37 m will be better than 0.5%. The neutron flux at the sample position could reach the order of 10^7 n/s/cm^2 . For detectors, high spatial resolution CCD based detector will be needed for conventional neutron imaging. The best spatial resolution of the instrument will be around $50 \text{ }\mu\text{m}$, thinking about the state-of-the-art technique. A TOF detector with good spatial resolution, temporal resolution, and efficiency will be required to discriminate energy and collect data for Bragg edge imaging. Scintillator detectors or ^3He tubes will cover sufficient area at different scattering angles. The instrument should also provide sample environment such as load frames, low temperature, high temperature, battery chargers and so on. The project has already started and will be completed in the end of 2021.

Energy-selective neutron imaging applications at continuous sources

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Neutron imaging is a method of non-destructive investigation for objects of scientific and technological interest[1]. Within the last decade, neutron tomography and radiography have significantly gained importance among the neutron science community. One of the reasons is the fast development in digital image recording and processing technology, which has allowed overcoming of some previous limitations in spatial and time resolution. Another reason is that in addition to the attenuation contrast technique, new innovative methods for neutron imaging are being implemented. Using monochromatic neutrons for imaging, complementary contrast due to the coherent scattering in polycrystalline materials can be obtained, providing information about structural changes or composition inhomogeneity. In addition, neutrons possess a magnetic moment which makes them sensitive to magnetic fields. The magnetic interaction can be used for two- and three-dimensional visualization of magnetic field distributions both in free space and in bulk materials. Utilization of phase contrast and dark-field contrast techniques e.g. using grating interferometry allows for visualization of low-absorbing materials and microstructural heterogeneities, as well as magnetic structures (domain walls).

The energy-dependence of the mentioned neutron imaging methods can be used for localization of Bragg edges with high precision, for a reconstruction of vector magnetic fields and for a quantification of microstructural material properties. Examples of performed studies at the imaging instrument CONRAD-2 (HZB) at the steady state (reactor based) neutron source BER-2 will be presented and discussed. .

[1] N. Kardjilov, I. Manke, R. Woracek, A. Hilger, J. Banhart, Advances in neutron imaging, Materials Today, 21 (2018) 652-672.

Foreseen energy-selective options at NeXT-Grenoble

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NeXT-Grenoble is a Neutron and X-ray facility, which was built in 2016 in Grenoble [1], born initially from a collaboration between the Université Grenoble Alpes and the Institut Laue-Langevin. The team involved recently secured funds for an extensive upgrade (Fig. 1) within the Endurance phase II program, which will be carried out in partnership with the Helmholtz Centre Berlin, [2,3].

A key aspect of this upgrade involves the addition of the currently absent energy selective options, including a double crystal monochromator as well as a velocity selector, together with subsequent upgrades (polarised imaging and grating interferometry).

This contribution will focus on the current state of the instrument as well as on the conception and technical design of these components, and the foreseen applications.

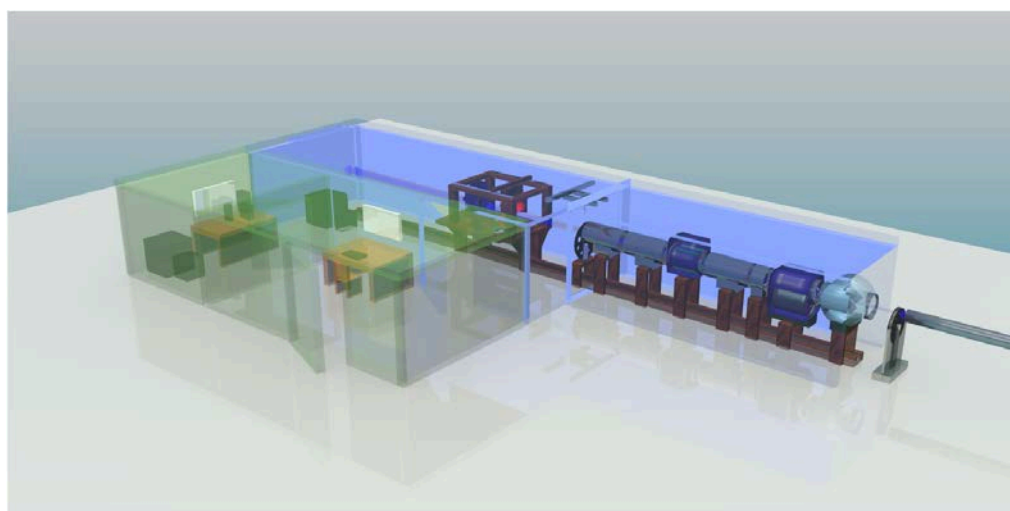


Figure 1 Conceptual design of the upgrade of the imaging instrument at ILL.

[1] A. Tengattini, D. Atkins, B. Giroud, E. Andò, J. Beaucour, G. Viggiani (2017). "NeXT-Grenoble, a novel facility for Neutron and X-ray Tomography in Grenoble". Proceedings ICTMS2017

[2] N. Kardjilov, A. Hilger, I. Manke, & J. Banhart (2014). CONRAD-2: The neutron imaging instrument at HZB. Neutron News, 25(2), 23-26.

[3] N. Kardjilov, A. Hilger, I. Manke, M. Strobl, M. Dawson, S. Williams, and J. Banhart. "Neutron tomography instrument CONRAD at HZB." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 651, no. 1 (2011): 47-52

A simulation study of the photoneutron source for the bragg-edge analysis

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² Ministry of Education, Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Beijing, P. R. China

The e-LINAC driven photoneutron source can deliver pulsed neutrons conveniently with the photo-to-neutron convertor made of different materials. As one of the candidates, D₂O has almost the lowest (gamma,n) threshold and can convert photons to photoneutrons efficiently. Meanwhile, its superb moderating capability enables the production of long wavelength neutrons with a good energy resolution, which is beneficial to the energy-resolving neutron imaging. A photoneutron source driven by a 10-MeV/20-kW pulsed e-LINAC, with D₂O as the photon-to-neutron convertor, PE as pre-moderator and solid CH₄ as main moderator was designed by simulation. The results show that the cold neutron flux is $3.4 \times 10^4 \text{ n/cm}^2/\text{s}$ at a position of 6 m from the source with a wavelength resolution better than 3% and $1.4 \times 10^3 \text{ n/cm}^2/\text{s}$ at a position of 30 m from the source with a wavelength resolution better than 0.5%. The simulation results indicate that this source is a promising neutron source for use in the Bragg edge transmission imaging, which could meet the requirements for the residual stress analysis in industrial applications.

Optimal design of a uniform resolution time-of-flight systems for wavelength resolved neutron imaging

Salvador Ortiz, Javier Santiesteban and Markus Strobl

Wavelength resolved imaging has gained significant importance with a number of applications enabled only through well-defined wavelengths applied. So far a ToF approach in neutron imaging appeared, apart from a few demonstration experiments, reserved to pulsed sources, whereas for continuous sources, wavelength selective imaging was pursued, with one wavelength at a time. However, where wavelength dispersive information is required, a time-of-flight approach at a continuous source is as efficient as wavelength selective imaging. Moreover, time-of-flight provides the advantage to collect all information simultaneously, hence being better suited for e.g. kinetic measurements. Additionally, the continuous nature of a source, in contrast to a pulsed one, provides in principle the advantage of full flexibility in resolution and bandwidth, which allows to tailor conditions to the needs of an individual measurement and thus optimizing efficiency. In this communication, we show an efficient strategy for optimizing the design of a system of choppers for time-of-flight (ToF) neutron imaging. This strategy contemplates several different scenarios, consisting of multiple bandwidth / resolution requirements, as well as operational, geometrical and constructive restraints. Uniform resolution is guaranteed by using the double-blind mode for the first pair of choppers. Next, the main point is given by an “elementary optimization” whereby the ToF corresponding to the end of the penumbra for one pulse coincides with the beginning of the following pulse. Building on this idea, a diverse set of requirements can be achieved by increasing the number of choppers. Special care must be taken in considering frame overlap from one pulse to the next one(s). We present the general strategy, validate with a Monte Carlo ray-tracing tool (McStas), and apply it to a particular set of requirements, given by the ASTOR instrument, presently being constructed at Argentina’s RA10 multipurpose reactor.

Bragg Edge imaging for the visualization of engineered residual stresses in additive manufacturing obtained through Laser Shock Peening

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⁴Materials and Life Science Experimental Facility, Japan

Additive Manufacturing is a quickly developing set of technologies that is revolutionising the manufacturing industry worldwide. The reduction of the number of parts, the possibility to manufacture complex shapes and the limitation of weights and costs are only a few of the key advantages that 3D printing is delivering.

A number of open problems however still remains, and this has an impact on the quality of the finished products and ultimately limits the spreading of such technology past the prototyping phase to only fields with very high added value such as the aerospace industry.

One of such problem is the introduction of residual tensile stress in particular in the surface regions of Selective Laser Melting (SLM) produced parts. This is the most widely applied metal Additive Manufacturing technique, where a metallic powder bed is repeatedly subjected to cycles of heating and cooling. These leave a severe tensile stress field, which can lead to deformation, cracking and decrease fatigue and chemical resistance, all of which can lead to adverse consequences on the finished part and even failure during the manufacturing process. A post-process technique that has been shown to limit and even counteract this effect is Laser Shock Peening (LSP) which can introduce compressive stress in the surface region of metals through the application of repeated concussive shockwaves using a laser.

Here we demonstrate that the effects of LSP on 316L AM steel specimens (Fig. 1) can be successfully mapped with Bragg Edge imaging and that the obtained 2D stress field agrees with more conventional, but destructive and with a far lower resolution methods such as hole drilling.

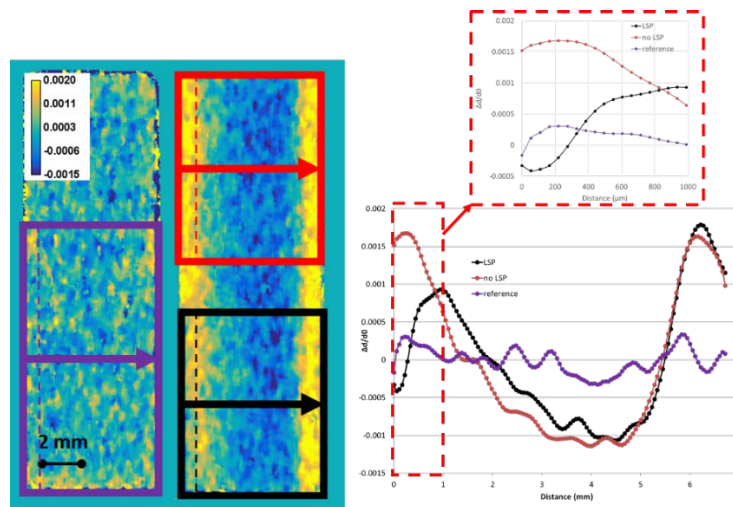


Figure 1. Visualisation of the residual stress field in two AM 316L steel samples. The left sample is the reference, while the right sample has undergone LSP treatment on the bottom half. On the right side of the figure, the corresponding line profiles.

Study of laser shock peening with Bragg edge imaging on different beamlines

R.S. Ramadhan^{1,2*}, W. Kockelmann², T. Shinohara³, T. Kai³, Y. Su³, H. Hayashida⁴, S. Kabra³, M. Fitzpatrick¹, D. Glaser⁵, and A. Tremsin⁶

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Laser-shock peening (LSP) has emerged as surface treatment process to improve fatigue performance of aerospace structures. The process includes shooting a high-energy, pulsed laser beam to the surface of a material, and introduces beneficial compressive residual stress near the surface of the component [1]. Under certain conditions, LSP can change the crystallographic texture [2]. Mapping a 2D strain profile due to LSP process using a diffraction based technique would require hundreds of measurement points. Meanwhile a complicated EBSD analysis is needed to study the changes in crystallographic texture. We have performed various Bragg edge imaging measurements on LSP sample on different imaging beamlines, i.e., IMAT at ISIS, UK and BL-22 RADEN at J-PARC, Japan. We have also performed a comparison on Bragg edge imaging capabilities of different instruments, including the two aforementioned instruments and ENGIN-X at ISIS. Changes in texture can be detected through energy selective radiography, while the reconstructed Bragg edge strain map shows the strain profile generated from the LSP process, Fig. 1(A). Fig. 1(B) shows the comparison between transmission spectra from IMAT & RADEN beamlines, showing different Bragg edge width.

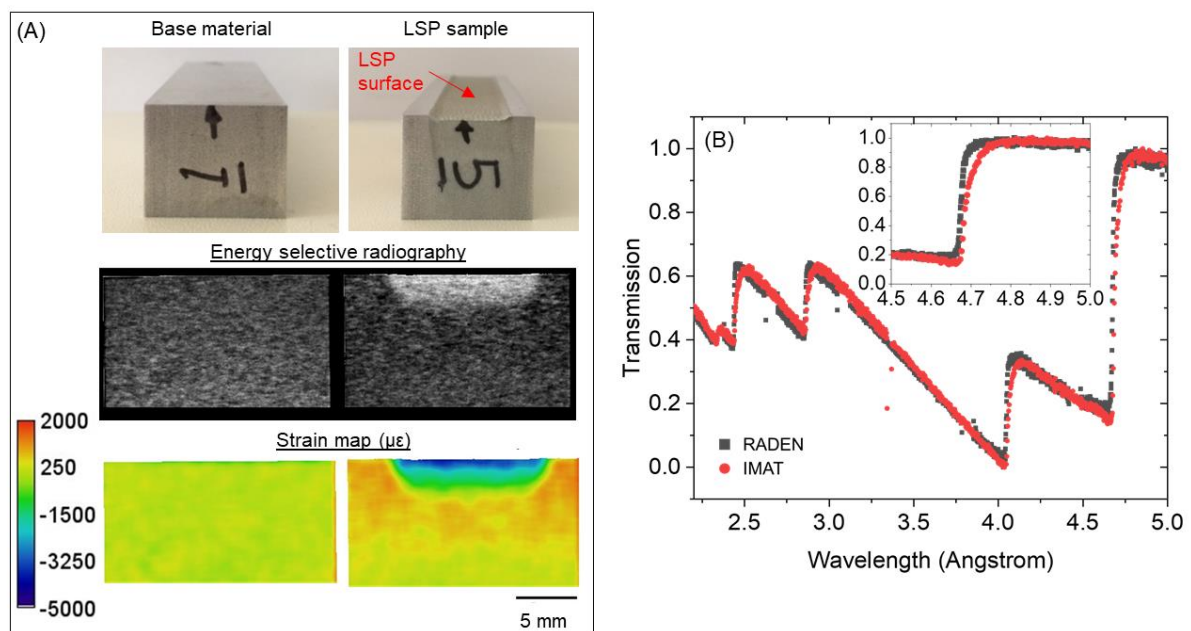


Figure 1. (A) Texture and residual strain information provided by Bragg edge imaging; (B) Comparison between transmission spectra (Al powder) from IMAT & RADEN

[1] M.B.Toparli, N. Smyth, M.E. Fitzpatrick, Metall. Mater. Trans. A (2017) 48 p.1519.

[2] Qiao, H., Zhao, J., Zhang, G., Gao, Y. Surface and Coatings Tech. (2015) 276, p.145.

Optimization of crystal growth and material parameters through in-situ energy-resolved neutron imaging

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Detection of gamma and neutron radiation in most devices relies on the conversion of incoming particles into either visible photons (e.g. by scintillators) or electrons (semiconductor devices). The efficiency of this conversion is determined by the characteristics of the converting material. Discovery of new materials for these applications, typically performed on powder or small crystal samples, needs to be followed by the growth of large single crystals. Uniformity of the crystals is critical as light scattering and charge trapping occurring at defects substantially degrade the performance of detection devices. It is the development of crystal growth recipes, which in many cases, becomes the most difficult, long and expensive part of novel material transition from the discovery phase into large scale production for detection devices. The trial and error approach frequently used in the past is very costly and time consuming as growth can take days to weeks.

Inherently many crystal growth techniques do not allow direct measurements during the growth, such as in case of hygroscopic or highly reactive materials, which are usually grown in a vacuum-sealed container by the Bridgman-Stockbarger technique. Energy-resolved neutron imaging provides the means for in-situ diagnostics during crystal growth due to high penetration capability of neutrons. In this paper we present the results of our latest experiments where the location and the shape of the interface between the solid and liquid phases is optimized in a multi-zone Bridgman furnace (Fig. 1). We also demonstrate how the speed of crystal growth can be optimized through neutron imaging, which also provides information on the elemental distribution in both liquid and solid phases and can even quantify the diffusion of some elements within and between these two phases.

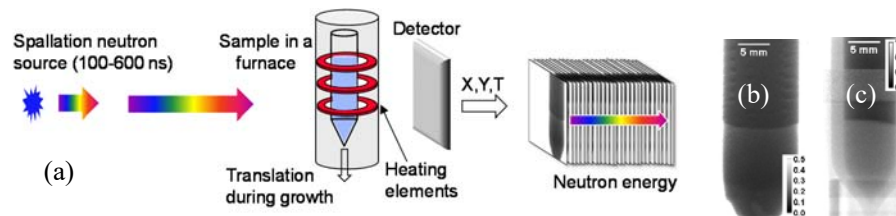


Figure 1. (a) Schematic diagram of energy resolved neutron imaging of crystal growth process in a Bridgman furnace. Neutron transmission spectra is measured in each pixel of the imaging data set, all energies simultaneously in one experiment. (b),(c) – concave and convex interface shape measured during crystal growth of BaBrCl:Eu (b) and CsI:Eu (c).

Energy-resolved in-operando neutron imaging of lithiation and delithiation mechanism in graphite electrodes in rechargeable Li-ion batteries

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One of the most present objects in daily life is the rechargeable lithium-ion (Li-ion) battery, either in our phones, laptops, electrical vehicles or other technologies. In order to improve Li-ion batteries, it is essential to be able to fully understand the mechanisms related to the present limitations of the technology, such as slow Li-ion transport in the electrode material and battery degradation. During battery operation, Li-ions are intercalated and de-intercalated in the structure of the electrode materials, creating crystallographic phase changes. These changes are mostly reversible. However, structural damage occurs upon extensive cycling.

The kinetic behavior of the Li intercalation and the spatially distribution of the lithiated phase during the transformation mechanisms are poorly understood. The large neutron cross-section of Li and the good neutron penetration of bulk samples make neutrons a well-suited probe for the investigation of Li-ion batteries [1]. Additionally, time-of-flight neutron imaging has the potential to provide information about the crystallographic phase, which for in-operando studies enables observation of crystallographic phase transformations.

The most common negative electrode material in commercial rechargeable Li-ion batteries is graphite, due to its mechanical stability and good electrical conductivity. In this project, we have focused on graphite, as the electrode material, in a half-cell, with metallic Li as the counter electrode. Here, we present the results of in-operando energy-resolved neutron imaging experiments performed at the RADEN and the SENJU beamlines at J-PARC, Japan, using custom-built Li-ion half-cells. In the experiment performed at RADEN, we have charged and discharged two cells at different current values normalized to the active material mass in the electrode. The results of conventional neutron transmission radiographies show changes in the lithium distribution in the electrode upon cycling. This observation can be correlated to the energy-resolved data. It indicates, from the changes in the Bragg-edges, phase changes in the graphite electrode with respect to the lithiated graphite phases. From the experiment at SENJU, we can obtain complementary information about the crystallographic changes from the diffraction detectors. This will add another piece to the puzzle by correlating the diffraction signal to the concomitant acquisition of images.

Tuesday 28 May 2019

Grating interferometry with neutrons - OSGA/EG06 (09:30-10:45)

-Conveners: Markus Strobl

time	[id] title	presenter
09:30	[27] Optimized neutron grating interferometer for the visualization of water in fuel cell materials	SIEGWART, Muriel
09:45	[24] Effects of stress on the performance of electrical steel sheets studied with the highly optimized neutron grating interferometer at ANTARES	SCHULZ, Michael
10:00	[21] Stressed Additive Manufactured Objects Studied with USANS, Talbot-Lau and Far-Field Interferometry	BUTLER, Les
10:15	[18] From omnidirectional to polarized dark-field image with neutron grating interferometry	VALSECCHI, Jacopo

Coffee break - OSGA/EG06 (10:45-11:05)

Methods - OSGA/EG06 (11:05-12:30)

-Conveners: Anton Tremsin

time	[id] title	presenter
11:05	[40] Multiprobe Imaging using Neutrons in conjunction with Gammas at the NECTAR Beam-Line	LOSKO, Adrian
11:20	[50] 3D Grain Mapping with Simultaneous Neutron Imaging and Time-of-Flight Neutron Scattering	TUNG, Patrick
11:35	[52] Broad pulse time-of-flight neutron imaging: current and future applications in electrochemistry	BOILLAT, Pierre
11:50	[44] Multi-scale, multi-mode neutron tomography at NIST	HUSSEY, Daniel

Lunch - OSGA/EG06 (12:30-14:00)

Technology and Software - OSGA/EG06 (14:00-15:45)

-Conveners: Anders Kaestner

time	[id] title	presenter
14:00	[42] Time of flight neutron imaging using pulse shaping and Monte Carlo simulations	WORACEK, Robin
14:15	[53] Technical aspects of the ESS test beam line	KADLETZ, Peter
14:30	[23] Development of neutron imaging detectors and analysis software environment at RADEN	PARKER, Joseph
14:45	[37] TOF neutron tomography of reference samples	CARMINATI, Chiara
15:00	[14] Python Libraries for Neutron Resonance Imaging	BILHEUX, Hassina

Poster session and Coffee break - OSGA/EG06 (15:45-16:15)**Poster list:**

ID	Title	Presenter
20	MULTI-GRAIN INDEXING WITH LAUE 3D NEUTRON DIFFRACTION	Stavros Samothrakitis
22	Progress and Updates on Energy Resolved Neutron Imaging Capabilities at LANSCE	Alexander Long
33	Neutron Diffraction at the SENJU diffractometer of J-PARC: The transmission data	Nancy Elewa
41	A study on possibility of grating interferometer with optical blocker	Daeseung Kim
43	Using a chopper and a 100 mm XS MCP detector to measure the spectrum of the NIST Cold Neutron Imaging Instrument	Daniel Hussey
45	NIMRA: the upgraded neutron imaging set-up at the JEEP-II reactor	Stefano Deledda
47	DataScripting: A flexible data acquisition tool for neutron imaging at NIST	David Jacobson
48	ReconstructCT: A complete graphical user interface analysis tool to process tomography data sets	David Jacobson

History and Texture - OSGA/EG06 (16:15-17:05)**-Conveners: Sven Vogel**

time	[id] title	presenter
16:15	[9] How the NEUWAVE workshop series has pushed neutron imaging developments	LEHMANN, Eberhard
16:25	[31] What can we learn about textured samples using Neutron Diffraction Contrast Imaging?	WORACEK, Robin

Arif - In Memoriam - OSGA/EG06 (17:05-17:30)**-Conveners: David Jacobson****Dinner - OSGA/EG06 (19:00-22:00)****-Conveners: Markus Strobl**

Optimized neutron grating interferometer for the visualization of water in fuel cell materials

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We present an optimized symmetric neutron grating interferometer (nGI) to obtain high quality dark-field contrast images with short acquisition times. The absorption and source grating lines were lasered into a 16 μm thick Gadolinium layer, which was sputtered onto Quartz wafers. With this setup, visibility values of up to 60 % are reached (Figure 1, blue bars). Visibility depends on spatial and temporal coherence and is therefore influenced by the source aperture size and the energy spectra. To obtain good image quality with short acquisition times, these parameters need to be optimized also with regard to neutron statistics. Most of the image noise is due to shot noise, which is related to the Poisson distribution of a particle beam hitting a detector. Therefore, the figure of merit for high quality of images acquired with an nGI setup can be estimated by multiplying visibility with the square root of the neutron intensity (Figure 1, black dots).

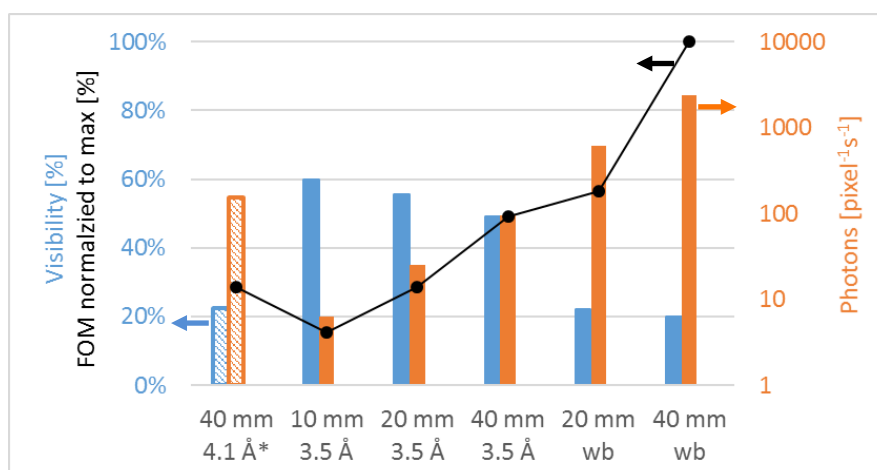


Figure 1. Mean visibility (blue), figure of merit (FOM) normalized to maximum (black) and photon counts per pixel and second (orange, logarithmic scale) for source aperture sizes 10, 20 and 40 mm, 3.5/4.1 Å and white beam (wb) (* = old nGI setup of PSI [1]).

In this presentation, we will discuss important setup parameters for achieving a high signal-to-noise ratio as well as the impact of method improvements on application cases. We demonstrated recently that dark-field imaging is able to visualize the water distribution in porous gas diffusion layers (GDLs) used for polymer electrolyte fuel cells. In these experiments, the GDLs were mounted in a capillary pressure setup [2]. It is more challenging to visualize the water distribution in GDLs during fuel cell operation. We will show that thanks to the use of the optimized setup it is possible to master this challenge.

[1] C. Grünzweig, F. Pfeiffer, O. Bunk, T. Donath, G. Kuhne, G. Frei, M. Dierolf and C. David, *Rev Sci Instrum* (2008) 79

[2] M. Siegart, V. Manzi-Orezzoli, R. Harti, J. Valsecchi, M. Strobl, C. Grünzweig, T. J. Schmidt and P. Boillat, *J Electrochem Soc* (2019) 166 p.1427-1427

Effects of stress on the performance of electrical steel sheets studied with the highly optimized neutron grating interferometer at ANTARES

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Electrical steel sheets are used in transformers as well as in electrical motors to guide the magnetic field. The efficiency of an electrical steel sheet strongly depends on the amount of energy lost during the reversal of magnetization, which is dependent on the mobility of the magnetic domains. The mobility of the magnetic domains is mainly influenced by internal stress caused during the manufacturing process [1, 2]. In contrast, intentionally induced stress may also provide a means to guide the magnetic field within electric steel sheets and to optimize the performance of electrical machines.

Neutron grating interferometry (nGI) is a valuable tool to probe the magnetic domain constellation in bulk samples of technically relevant dimensions based on the sensitivity of the dark field image (DFI) to scattering of neutrons on magnetic domain walls [3, 4]. A prerequisite for such measurements is a high signal-to-noise-ratio and consequently a high visibility of the setup.

We will present the upgraded nGI setup at the ANTARES beamline at FRM II, which has been equipped with optimized source and analyzer gratings and uses a more symmetric geometry. With these modifications, we have realized a visibility of 75% over the whole detector area (76mm x 76mm) at the design wavelength of 4 Å. The achieved visibility is close to the theoretical limit imposed by the spatial coherence generated by the G0 grating.

Moreover, we will show how this new setup has been used to study the effect of internal stress on the local hysteresis of an electrical steel sheet, causing a degradation of the magnetic domain mobility. Furthermore, studies on how an intended use of this effect by imprinting on the electrical steel sheets can increase the efficiency of an electrical engine.

[1] H. Weiss et al., pending (2018)

[2] A. Moses, IEEE Trans. Magn, Vol. 15, 1575-1579 (1979)

[3] C. Grünzweig, PhD thesis (2009)

[4] R. Harti et al., Review of Scientific Instruments 88, 103704 (2017)

Stressed Additive Manufactured Objects Studied with USANS, Talbot-Lau and Far-Field Interferometry

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⁴Buffalo Manufacturing Works, EWI, USA

⁵Louisiana State University, USA

Neutron grating interferometry of tensile stressed and bending fatigued additive manufacture objects appears to show a scattering image signature of early crack formation.[1] That is, a half-life sample imaged with Talbot-Lau [2] or far-field [3] at an appropriate interferometer autocorrelation length shows a feature that spatially corresponds to the site of eventual tensile or bending fatigue failure; the current success rate is three for three. The immediate questions are: What causes the scattering image signature? How early in the stress profile can early crack formation be detected? Which interferometry design is preferred?

Herein, in progress experiments will be presented. First, in a Talbot-Lau system, a tensile jig was used for in situ imaging. The jig disturbed the interferometer leading to imaging artifacts; a novel artifact removal algorithm will be applied to these data.[4,5]

Second, pristine, half-life, and fractured samples were studied with USANS. The 3 mm thick samples exhibit multiple scattering. Nevertheless, interfacial surface areas suggest a change in porosity structure at the potential crack.

Third, a head-head-to-head comparison of far-field and Talbot-Lau is planned. The far-field will use phase gratings with extremely small periods—1 μm to 1.7 μm —recently fabricated at KNMF.

[1] Brooks, A J., et al., Materials & Design 140 (2018): 420-430.

[2] Harti, R P, et al., Optics Express 25.2 (2017): 1019-1029.

[3] Pushin, Dmitry A., et al., Physical Review A 95.4 (2017): 043637.

[4] Vo, N T., , et al., Optics Express 26.22 (2018): 28396-28412.

[5] Github, Nghia Vo: <https://github.com/nghia-vo/sarepy>

From omnidirectional to polarized dark-field image with neutron grating interferometry

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²*School of Mechanical Engineering, Pusan National University*

³*Macromolecules and Bioimaging (LSB), PSI*

Neutron grating interferometry (nGI) is an established neutron imaging method that has found successful application in a wide range of scientific fields such as soft matter, magnetism and superconductors [1–5]. The directional sensitivity of the scattering signal of the existing methods is limited to a few directions on the imaging plane and it requires the scanning of the optical components, or the rotation of either the sample or the imaging setup, if the full range of possible scattering directions is desired. Here we present a new approach which allows the simultaneous acquisition of the scattering images in all possible directions at different autocorrelation length in a single shot. This is achieved by a specialized circular phase grating and a device for recording the generated interference fringe with sufficient spatial resolution. An arrangement of highly oriented carbon fiber has been investigated with the omnidirectional nGI setup.

The implementation of polarized neutron beams for imaging purposes has paved the way to investigate local magnetic phenomena in matter in an unprecedented manner[6]. Here we show a novel approach combining nGI with a polarized neutron beam and a spin state analyzer which enables us to retrieve quantitative information about the magnetic scattering signal. The potential for magnetic contrast variation is demonstrated by investigations a ferrofluid system and a sintered NdFeB sheet at different external magnetic field.

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- [1] Pfeiffer F. et al. Neutron phase imaging and tomography. DOI:10.1103/PhysRevLett.96.215505
 - [2] Strobl M. General solution for quantitative dark-field contrast imaging with grating interferometers. DOI:10.1038/srep07243
 - [3] Reimann T. et al. Visualizing the morphology of vortex lattice domains in a bulk type-II superconductor. DOI:10.1038/ncomms9813
 - [4] Betz B. et al. Magnetization Response of the Bulk and Supplementary Magnetic Domain Structure in High-Permeability Steel Laminations Visualized in Situ by Neutron Dark-Field Imaging. DOI:10.1103/PhysRevApplied.6.024023
 - [5] Harti R. P. et al. Sub-pixel correlation length neutron imaging: Spatially resolved scattering information of microstructures on a macroscopic scale. DOI:10.1038/srep44588
 - [6] Strobl M. et al. Topical review: Polarisation measurements in neutron imaging DOI:10.1088/1361-6463/aafa5e

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Multiprobe Imaging using Neutrons in conjunction with Gammas at the NECTAR Beam-Line

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NECTAR is a superior beam-line with access to fission neutrons for non-destructive inspection of large and dense objects, where thermal neutrons or X-rays face limitations due to their comparatively low penetration. With the production of fission neutrons at the instrument [1], as well as neutrons interacting with beamline geometry, such as the collimator, gamma rays are produced in the process. The production of these gamma rays is inevitable as they are inherent with the principles of collimating or stopping the neutrons. Furthermore, these gamma rays are highly directional due to their constraint to the same beam-line geometry and come with similar divergence as the neutrons. While difficult to shield, it is possible to utilize them by using gamma sensitive scintillator screens in place of the neutron scintillators, viewed by the same camera and swapped-out *in-situ*.

Here we present the advantages of combining the information gained from neutron imaging in conjunction with gamma imaging at the NECTAR beam-line, providing a unique probe with unparalleled isotope identification capabilities. Initial results were produced from data measured in the 2019 run-cycle, performed at and supported by the Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRMII). Furthermore, future improvements and advancements for the development of this technique will be discussed.

[1] T. Bücherl and S. Söllradl, “NECTAR: Radiography and tomography station using fission neutrons”, Journal of large-scale research facilities JLSRF (2015) 1 p.19.

3D Grain Mapping with Simultaneous Neutron Imaging and Time-of-Flight Neutron Scattering

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The mechanical and functional properties of polycrystalline materials are dictated heavily by the arrangement of the crystalline micro-structure. Furthermore, to gain a complete and realistic understanding of the interplay of all contributing components in the micro-structure, a sample of sufficient size, in the order of centimetres, is required to be tested. Here, combined neutron diffraction and imaging is employed to probe the micro-structure of Nitinol shape-memory single crystal.

The unique method utilises a simultaneous setup of neutron diffraction and neutron imaging; where a transmission detector is placed behind the sample in relation to the beam direction, with time-of-flight detectors that collect the back-scattering simultaneously. With such a setup, the crystalline domains, i.e. morphology and crystallographic phases, of the micro-structure can be obtained from the transmission imaging and their orientations can be correlated with the time-of-flight diffraction. Such reconstruction with neutron methods have proven successful previously [1] and is now being further developed.

Experiments will be performed at the BL18 SENJU single crystal diffractometer in late February 2019. A Nitinol single crystal will be subjected to in-situ compressive stresses to explore the micro-structural mechanisms responsible for its excellent shape-memory properties. Preliminary results and progression of the grain reconstruction algorithms will be presented.

[1] A. Cereser, M. Strobl, S.A. Hall, A. Steuwer, R. Kiyanagi, A.S. Tremsin, E.B. Knudsen, T. Shinohara, P.K. Willendrup, A.B. da Silva Fanta, S. Iyengar, P.M. Larsen, T. Hanashima, T. Moyoshi, P.M. Kadletz, P. Krooß, T. Niendorf, M. Sales, W.W. Schmahl & S. Schmidt, Scientific Reports (2017) 7 : 9561.

Broad pulse time-of-flight neutron imaging: current and future applications in electrochemistry

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Time-of-flight neutron imaging (TOF-NI) has been reportedly used for applications requiring energy selection, such as the imaging of different crystalline material phases based on the produced Bragg edges. The TOF approach allows reaching energy resolutions higher than velocity selectors or even double crystal monochromators, provided a beam with short pulses is used (either at a pulsed source or with the help of a chopper disk). However, this possibility should not overshadow the fact that TOF-NI is a highly versatile method which can be adapted for applications with minimal requirements on energy resolution, with the benefit of obtaining much larger neutron fluxes (when using a chopper) and, for a given neutron flux, better statistics due to the limited temporal resolution requirement for the detection.

In the recent years, we have investigated the use of energy selective neutron imaging for the distinction of liquid water and ice in operating fuel cells. The difference in total neutron cross section between these two aggregate states arise from the strong reduction of molecular diffusion in the solid state, and does not exhibit any sharp features such as Bragg edges. Thus, a comparison of images using two different energy spectra is sufficient. This dual spectrum approach was first demonstrated using the full white beam and a Beryllium filtered beam (1). Although promising, this approach yielded a low contrast due the limited flexibility of the approach. This was improved by the used of a broad pulse TOF imaging setup, where a chopper disk with a high duty cycle (30%) was used in order to keep the beam flux as high as possible. This optimized setup allowed to demonstrate the identification of freezing events during the sub-zero startup of a fuel cell.

The applications of broad pulse TOF-NI in electrochemistry are not limited to the distinction of liquid water and ice. The dependency of neutron cross section on the motion of hydrogen atoms by molecular diffusion can also be used for the measurement of water temperature in fuel cells and electrolyzers in a fully non-invasive way. Finally strong neutron absorbers such as Lithium have a stronger cross section dependency on energy than hydrogen. This allows to distinguish the transmission changes related to the motion of Li atom to those related to the displacement of the organic solvents in Li-ion batteries.

1. J. Biesdorf, P. Oberholzer, F. Bernauer, A. Kaestner, P. Vontobel, E. H. Lehmann, T. J. Schmidt and P. Boillat, *Physical Review Letters*, **112**, 248301 (2014).

Multi-scale, multi-mode neutron tomography at NIST

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Improvements in imaging detectors, neutron optics, and computation power enable the acquisition, reconstruction, and analysis of tomography data sets that span a fourth dimension, including time, mode (x-ray/neutron), wavelength, and autocorrelation length. Such data sets exploit the unique (or complementary) interaction of the neutron with matter and hold the promise to provide in depth structural information spanning length scales from the fm to cm! This talk will describe efforts on way at NIST to improve the data quality along the acquisition to analysis pipeline.

- H-Bearing Minerals
- Diogenite Pyroxene
- Impact Melt Clasts
- Eucrite Pyroxene and Plagioclase



Figure 1. Segmented Howardite meteorite using NeXT showing distributions of several phases of interest (center) and photograph of meteorite to show scale.

Time of flight neutron imaging using pulse shaping and Monte Carlo simulations

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The European Spallation Source (ESS) operates a time-of-flight testbeamline (V20) at Helmholtz Zentrum Berlin. The beamline serves two main purposes:

- Development and testing of key ESS technologies, such as centralized timing system, instrument control, data reduction, detectors, neutron optical devices.
- Development of cutting edge neutron methods in collaboration with in-kind and external partners.

We will report on developments and tests that are of significant importance in order to successfully commission and operate the first instruments when ESS starts operations in 2023, and we will focus on those that are relevant to the neutron imaging community.

The presentation (if timing will not allow, we will prepare two separate posters) will summarize tests of a range of neutron detector systems and comparisons between McStas simulations and experimental results obtained on V20 utilizing the complex chopper cascade, in particular Wavelength Frame Multiplication (WFM). The simulations are not only used for improved understanding of the instrumental parameters (such as spectral distributions due to guides and choppers), but also to e.g. model how temperature changes affect the transmission spectrum during a sample under in-situ heating. Specifically, the gradually decreasing height of the Bragg edges with increasing temperatures was evaluated and compared to theoretical calculations of the neutron cross sections that are influenced by the temperature dependent Debye Waller factor. It will be shown that the effects can be evaluated from the transmission spectra and that it can serve as a basis for corrections during in-situ studies and/or can be exploited for quantitative measurements.

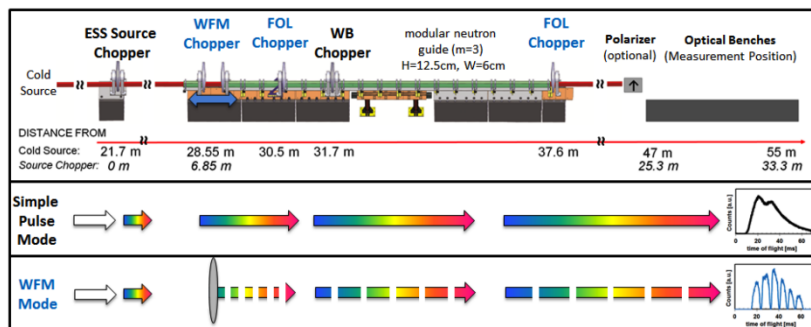


Figure 1. Operation modes of the ESS testbeamline V20

[1] M. Strobl, M. Bulat, K. Habicht (2013) Nucl. Instr. Meth. A 705

[2] R. Woracek, T. Hofmann, M. Bulat, M. Sales, K. Habicht, K. Andersen, M. Strobl (2016) Nucl. Instr. Meth. A 839

Development of neutron imaging detectors and analysis software environment at RADEN

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The Energy-Resolved Neutron Imaging System, RADEN [1], located at beam line BL22 of the J-PARC Materials and Life Science Experimental Facility (MLF), has been in user operation since 2015. RADEN is designed to take full advantage of the high-intensity pulsed neutron beam of the MLF to perform both conventional radiography/tomography and energy-resolved neutron imaging techniques. To meet the very different requirements for these imaging techniques, we employ various detector systems, from traditional CCD cameras [2] to cutting-edge, event-type micropattern detectors [3].

In this presentation, we will describe the current status of our detector systems, including our CCD/CMOS camera systems, the μ PIC-based Neutron Imaging Detector (μ NID), and the ^6Li Time Analyzer, model 2012 (LiTA12). The camera systems, with a spatial resolution from 30 μm and measurement area up to 30 cm \times 30 cm, are used to perform radiography, computed tomography, and stroboscopic imaging. The μ NID, a gaseous micropattern detector with a spatial resolution of 100 μm , an improved count rate of over 1 Mcps, and full integration into the RADEN experiment control system, is quickly becoming the main detector for energy-resolved neutron imaging. We are also exploring the LiTA12, a Li-glass scintillator detector, as a high-efficiency detector for neutron resonance absorption measurements.

We will also discuss ongoing development efforts, including new development for the μ NID system and improvement of the analysis software environment at RADEN. For the μ NID, we are developing a new 215- μm pitch readout element (down from 400 μm) in order to provide improved spatial resolution below 100 μm , as well as a μ NID with boron-based converter for increased count-rate capacity via a reduced event size. For the μ NID data analysis, we are planning to incorporate GPU processing to increase the speed and significantly improve the turn-around time for offline data processing. Additionally, to provide a more unified analysis software environment at RADEN, we will build on our recently-developed, web-based GUI for the μ NID data analysis by extending it to the other detector systems in use at RADEN and add some simple data analysis capabilities (image processing, normalization, rebinning, etc.), with more sophisticated analysis capabilities to follow later.

Finally, we will discuss upcoming development efforts, such as improvement of spatial resolution for our CCD camera system using event centroiding and a study combining energy-resolved neutron imaging with computed tomography for improved quantitativity.

The μ NID detector development was partially supported by the Momose Quantum Beam Phase Imaging Project, ERATO, JST (Grant No. JPMJER1403). Detector testing at RADEN was carried out under Instrument Group Proposal Nos. 2017I0022 and 2018I0022 and CROSS Development Proposal Nos. 2017C0004 and 2018C0002.

[1] T. Shinohara *et al.*, J. Phys.: Conf. Series (2016) 746 p.012007.

[2] Y. Matsumoto *et al.*, Phys. Proc. (2017) 88 p.162.

[3] J.D. Parker *et al.*, JPS Conf. Proc. (2018) 22 p.011022.

TOF neutron tomography of reference samples

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The ability to distinguish between different materials is an essential aspect of imaging. The IAEA contrast sample for neutron imaging (Conf. 2) [1] was developed to characterize the ability to represent the attenuation coefficients at different instruments. In this particular study, we evaluate if the sample is also suited as a reference for time of flight (TOF) neutron tomography, in the sense of enabling correct reconstruction of the material specific Bragg edge spectra on a voxel-wise basis in the volume. The specimen consists of an aluminium cylinder with cylindrical insets made of different materials (Al, Cu, Pb, Ti, Fe, Ni). High energy resolution TOF tomography was performed at the IMAT beamline at TS2 of the ISIS neutron source, UK [2]. We acquired 251 projections uniformly distributed over 360° using an MCP detector (55µm pixel size).

Our aim was furthermore to develop and present an image analysis pipeline and discuss specific software that needs to be developed to process energy resolved imaging datasets accordingly. We shall also discuss the need for standardized datasets for benchmarking TOF tomography capabilities and analysis software.

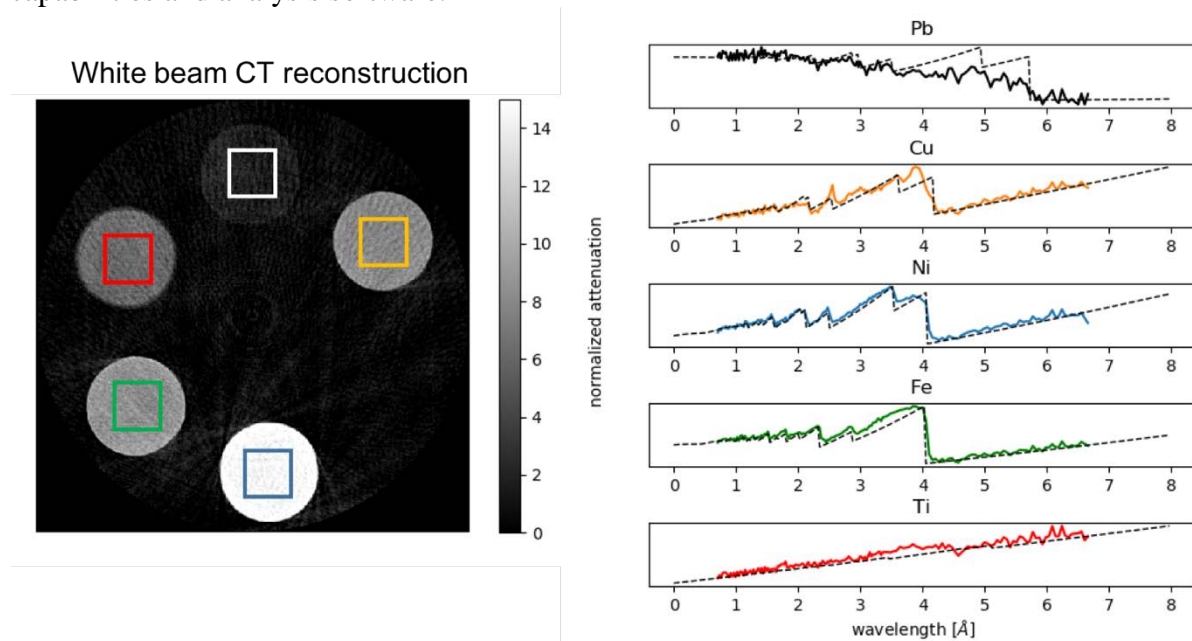


Figure 1. On the left panel: white beam CT reconstruction of a mid-slice of IAEA test sample, on the right panel: wavelength dependent normalized attenuation for each inset, coloured line for measured attenuation, dashed line for theoretical spectrum .

- [1] Kaestner, A. P., Lehmann, E. H., Hovind, J., Radebe, M. J., De Beer, F. C., & Sim, C. M. (2013). Verifying neutron tomography performance using test objects. *Physics Procedia*, 43, 128–137. <https://doi.org/10.1016/j.phpro.2013.03.016>
- [2] Minniti, T., Watanabe, K., Burca, G., Pooley, D. E., & Kockelmann, W. (2018). Characterization of the new neutron imaging and materials science facility IMAT. *Nucl. Instr. Meth. A* 888 (2017), 184–195. <https://doi.org/10.1016/j.nima.2018.01.037>

Python Libraries for Resonance Imaging

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We have built a couple of python libraries as well as an interactive web site to facilitate the life of users regarding the preparation of their sample and analysis of their resonance imaging data.

ImagingReso[1] and ResoFit are open-source python libraries that simulates the neutron resonance signal for neutron imaging measurements as well as fitting the neutron resonance signal for neutron imaging measurements.

By defining the sample information such as density, thickness in the neutron path, and isotopic ratios of the elemental composition of the material, ImagingReso plots the expected resonance peaks for a selected neutron energy range. Various sample types such as layers of single elements (Ag, Co, etc. in solid form), chemical compounds (UO₂, Gd₂O₃, etc.), or even multiple layers of both types can be plotted with this package. Major plotting features include display of the transmission/attenuation in wavelength, energy, and time scale, and show/hide elemental and isotopic contributions in the total resonance signal. On the other hand, ResoFit focuses on fitting the neutron resonance

The energy dependent cross-section data used in this library are from [National Nuclear Data Center](#), a published online database. [Evaluated Nuclear Data File \(ENDF/B-VII.1\)](#) [1] is currently supported and more evaluated databases will be added in future.



Figure 1. Screenshot of the Neutron Imaging Toolbox web site built on top of the ImagingReso and ResoFit libraries available to external users to prepare their resonance imaging experiment (<https://isc.sns.gov/>).

[1] Yuxuan Zhang and Jean Bilheux. DOI 10.21105/joss 00407

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How the NEUWAVE workshop series has pushed neutron imaging developments

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ABSTRACT

In 2008, a series of international workshops - named NEUtron WAVElength-dependent Imaging (NEUWAVE) - was initiated after several decisions were taken to build new neutron spallation sources in the world, namely target station two of ISIS in the UK, J-PARC in Japan, SNS in the US, and the future ESS, now being built in Sweden. The aim was to collect existing knowledge about energy-dependent effects in neutron imaging, but also to develop new energy-selective imaging methods for the upcoming spallation sources, and also for steady-state sources using energy selecting devices for neutrons. The special format was a workshop with plenty of discussions but without explicit publications, where participants discussed not their past work, but their ideas and future plans. This paper gives a résumé after nine such meetings and highlights the most important progress features. The series will continue in 2019 with NEUWAVE-10 to be organized by Paul Scherrer Institute.

What can we learn about textured samples using Neutron Diffraction Contrast Imaging?

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This presentation will first contextualize current capabilities of diffraction contrast imaging for quantitative analysis of phase transformations, including some new examples. The main focus will be on sample for which qualitative results have already been presented during Neuwave 5, held 2013 in Lund. While it was demonstrated that phase analysis in samples from TRIP steel can be performed in 3D by tomographic reconstruction, the main limitation concerns samples that possess preferred grain orientations (texture). In these cases, which are very common to alloys used in real world applications, the transmission depends not only on the phase specific attenuation cross section, but also on the grain orientations.

This aspect hence poses a major limitation to the method as whole and is probably one of the reasons yet hindering it to become a routine method that is of interest to the general material science community. We have employed texture measurements by neutron diffraction and EBSD and linked these findings to the contrast observed in neutron imaging. It is only the combination of these methods that enables a deeper understanding of the localized texture (evolution) within such samples.

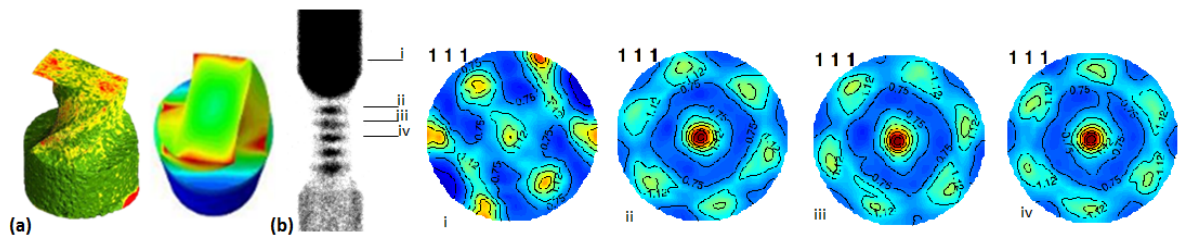


Figure 1. (a) Wavelength selective tomography successfully revealing localized phase transformation in a torsion sample with rectangular cross-section and comparison to FE modelling. (b) Radiographic projection obtained at a single wavelength for a torsion sample with circular cross-section showing localized texture. Pole figures (PF's) were measured along the sample height using a 2 mm slit enabling texture and phase evaluation. Four example PF's are shown for the gamma phase.

[1] Woracek, R., Santisteban, J., Fedrigo, A., & Strobl, M. (2018). Diffraction in neutron imaging—A review. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 878, 141-158.

Wednesday 29 May 2019

Applied Bragg edge imaging: Applied Bragg edge imaging II - OSGA/EG06 (09:30-10:30)

-Conveners: Manuel Morgano

time	[id] title	presenter
09:30	[34] Imaging investigation of Chinese bimetallic sword fragment from 2nd-1st century BCE	FEDRIGO, Anna
09:45	[11] Electrum plated coins. A novel approach for forensic analysis of numismatics materials	SALVEMINI, Filomena
10:00	[12] Energy-resolved analysis of neutron transmission of molten lead bismuth eutectic	OBA, Yojiro
10:15	[26] Analysis of a FeNi meteorite and Ni super alloy by energy-dispersive neutron transmission experiments	SANTISTEBAN, Javier

Coffee break - OSGA/EG06 (10:30-11:00)

Magnetism - OSGA/EG06 (11:00-11:40)

-Conveners: Takenao Shinohara

time	[id] title	presenter
11:00	[19] Influence of external AC magnetic fields on flux trap in Niobium during field cooling	TREIMER, Wolfgang
11:15	[49] Polarised Neutron Imaging	SALES, Morten

Closing session - OSGA/EG06 (11:40-12:00)

-Conveners: Markus Strobl

Lunch - OSGA/EG06 (12:00-13:30)

Tours - OSGA/EG06 (13:30-15:00)

Imaging investigation of Chinese bimetallic sword fragment from 2nd-1st century BCE

A. Fedrigo^{1*}, A. Scherillo¹, D. Raspino¹, W. Kockelmann¹, T. Minniti¹, and F. Grazzi²

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²IFAC-CNR, Country

Scientific investigations and archaeometric studies have played a major role in the field of archaeology, especially with regard to materials transformed through human activity, like metals. Metals are generally investigated through metallography and Scanning Electron Microscopy (SEM), which required sampling or surface preparation. Neutron techniques instead are able to provide the bulk properties of metals in a non-invasive way.

In this work we present a neutron imaging study of a Chinese bimetallic sword fragment from 2nd-1st century BCE. In particular, white beam Neutron Tomography (NT) and Neutron Resonance Transmission Analysis (NRTA) have been applied, using the IMAT and the INES beamlines of the ISIS pulsed neutron source in the UK, respectively.

The earliest example of bimetallic weapons in China dates as early as the Shang Dynasty (1600–1100 BCE), where meteoric iron and bronze were combined to forge weapons [1]. With the discovery of iron smelting technology during the Spring and Autumn Period (770–473 BCE), bimetallic swords with bloomery iron and bronze became more common [2]. They have been found in many parts of central China.

The sword fragment investigated has an iron blade mounted on a studded bronze grip (probably for a twine binding) and a ricasso with three long spikes protruding on each side. The object resembles two published examples with similar form of hilts [3, 4] listed as originating from burials investigated in the mountainous regions of Longpaozhai, in the Min River Valley (Central Sichuan), dating from the 2nd or 1st century BCE. Similar swords are also found further north and may have been introduced from further west.

NT allowed us to study the inner morphology of the sword, revealing details of its conservation status and the forging and/or casting of the different components. NRTA provided a 2D map of the elemental composition of the artefact, indicating the nature of the bronze alloy of the grip (whether tin bronze, leaded tin bronze, or arsenical tin bronze) and of the iron blade.

The study presented was complemented by Neutron Diffraction, Neutron Resonance Capture Analysis (NRCA), and by negative muons, providing a full characterisation of the object in terms of alloy composition, microstructural characterisation and elemental information, in a non-destructive way.

[1] http://en.cnki.com.cn/Article_en/CJFDTOTAL-WWBF2002S1027.htm

[2] IHTAN Derui, 2002. Study on bimetallic bronze swords in ancient China, *Sciences of Conservation and Archaeology*, The 69th WFC Paper

[3] M. Orioli, 1994. Pastoralism and nomadism in South-West China: a brief survey of the archaeological evidence, in *The Archaeology of the Steppes*, Methods and Strategies, papers from the International Symposium held in Naples 9-12 November 1992, 87–108

[4] *Kaogou Xuebao (Acta Archaeologica Sinica)* 1977.2. 51

Electrum plated coins. A novel approach for forensic analysis of numismatics materials.

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^b Space Sciences Laboratory, University of California at Berkeley, Berkeley California, USA

^c Australian Centre for Ancient Numismatic Studies, Macquarie University, Macquarie NSW 2109, Australia

In our study we have applied a multi-technique approach to explore two plated electrum coins, each 1/12 of a staters. These plated coins are usually described as forgeries (ancient or modern?) of the early coinage minted by Lydian kings at Sardis between 610 BC and 546 BC. The morphological, structural and compositional features of the coins were investigated at different levels, from the macro to the atomic scale, from the surface to the bulk, in a completely non-invasive way.

Coinage was invented in the Asia Minor kingdom of Lydia in modern Turkey perhaps around 630-620 BC. It was a precious metal coinage – but unexpected it was a coinage of electrum (contrast the later coinage of China, which was issued in base metals). The metal used by the Lydian mint was manipulated in sophisticated ways to obtain an artificial alloy (1). We now know that the royal mint at Sardis, the capital, employed a fixed ratio of gold and silver. It is also evident from unpublished recent research that other non-Lydian mints also struck electrum coins with a different ratio. Furthermore, we know that the Lydians were master metallurgists and there is some evidence that they were able to perform the surface enrichment or depletion gilding of debased gold artefacts, including coins.

In order to better understand the nature of our coins, neutron resonant transmission analysis (NRTA) was employed to quantify the overall content of Au and Ag, and to identify compositional variation throughout the sub-volume of the coin. The results obtained by NRTA were consistent and complementary with the data gathered from X-ray tomography, neutron texture measurements, and energy-dispersive X-ray detection (EDX) with a scanning electron microscope (SEM).

References

1. Ramage, Andrew and Craddock, Paul. *Archaeological exploration of Sardis: King Croesus's gold*. Cambridge, Massachusetts : The Harvard University Art Museums, 2000.

Energy-resolved analysis of neutron transmission of molten lead bismuth eutectic

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²Kyoto University, Japan

³Comprehensive Research Organization for Science and Society, Japan

With the progress of energy-resolved analysis techniques, neutron transmission imaging is growing as a powerful structural characterization tool. The analysis of Bragg edge transmission, which is the neutron attenuation generated by neutron diffraction, is vigorously used to visualize crystallographic information in crystalline materials.

However, little attention has been paid to the neutron attenuation by the neutron diffraction of liquid and amorphous structures. If these contributions in the neutron attenuation can be analyzed using the energy-resolved neutron imaging, it will be effective for the characterization of the atomic arrangements in the liquid and amorphous. Therefore, we performed the energy-resolved neutron imaging experiments of liquid and amorphous materials to extract and characterize the neutron diffraction contributions in the neutron attenuation spectra.

The experiment was carried out using the energy-resolved neutron imaging instrument BL22 RADEN [1] and the neutron beamline for observation and research use BL10 NOBORU at J-PARC [2]. Molten lead bismuth eutectic (LBE) was chosen as the model of liquid because of its low neutron absorption and incoherent scattering contributions. The LBE was melt using two cartridge heaters [3].

The neutron attenuation coefficient spectrum of the molten LBE shows a wavy behavior including several humps. This feature reflects the neutron diffraction profile of the molten LBE. According to a recent study [4], the neutron diffraction contribution in the neutron attenuation spectra can be related to integral of the corresponding diffraction pattern over all solid angles. This indicates that the broadened diffraction patterns of the liquid materials result in the wavy behavior in the neutron attenuation, while Bragg peaks of the crystalline materials provide sharp step-like Bragg edges. The observed features of the neutron attenuation coefficient spectrum of the molten LBE is well explained by that calculated from the neutron diffraction pattern of the molten LBE shown in a reference [5]. Based on this result, conventional analysis techniques for the neutron diffraction of the liquid materials will be able to be also applied to the neutron attenuation spectra.

[1] T. Shinohara, T. Kai, K. Oikawa, M. Segawa, M. Harada, T. Nakatani, M. Ooi, K. Aizawa, H. Sato, T. Kamiyama, H. Yokota, T. Sera, K. Mochiki, Y. Kiyanagi, J. Phys.: Conf. Ser. (2016) 746 p.012007.

[2] K. Oikawa, F. Maekawa, M. Harada, T. Kai, S. Meigo, Y. Kasugai, M. Ooi, K. Sakai, M. Teshigawara, M. Futakawa, Y. Ikeda, N. Watanabe, Nucl. Instrum. Met. Phys. Res. A (2008) 589 p.310.

[3] D. Ito, Y. Saito, H. Sato, T. Shinohara, Phys. Proc. (2017) 88 p.58.

[4] Y. Oba, S. Morooka, K. Ohishi, J. Suzuki, S. Takata, N. Sato, R. Inoue, T. Tsuchiyama, E. P. Gilbert, M. Sugiyama, J. Appl. Cryst. (2017) 50 p.334.

[5] Y. Waseda, The Structure of Non-Crystalline Materials, (McGraw-Hill, New York, 1980).

Analysis of a FeNi meteorite and Ni super alloy by energy-dispersive neutron transmission experiments

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²University of California at Berkeley, USA

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⁴Japan Atomic Energy Agency, Japan

We have studied two nearly monocrystalline metallic specimens, a FeNi meteorite and a piece of Ni super alloy, of irregular dimensions between ~1cm-3cm, by TOF neutron transmission experiments performed at SNS Snap beamline (meteorite) and J-PARC Noboru beamline (Ni sample), where an MCP/Timepix neutron counting detector was used for acquisition of energy-resolved imaging data set.

We have been able to quantify the spatial distribution of lattice parameters, crystal orientation and mosaicity by performing a Rietveld-type, least-squares refinement of the transmitted spectra, using physical based model of the wavelength dependent transmission. More precisely, the TOF neutron transmission spectrum of specimens formed by a small number of single crystals contains a series of dips in intensity at specific neutron wavelengths, due to neutrons removed from the beam as a result of Bragg reflections. The position, width and depth of those dips depend on the crystalline structure, the orientation and the imperfection of the crystals composing the sample.

We have found that the FeNi meteorite is composed by single crystals of Taenite (FCC) and Kamacite (BCC), with the number of crystals found across the thickness of the specimen (~1cm) varying between 3 and 6, whose lattice parameters vary respectively in the intervals 2.861-2.890 Å and 3.592-3.640 Å. The individual single crystals are composed by slightly misoriented mosaic blocks with average mosaicities of 0.7° for the Taenite and 1.1° for the Kamacite phase. On the other hand, misorientation between the different crystals can be as large as 30°.

The Ni super alloy is composed by two monocrystalline phases, γ and γ' , having FCC and cubic structures, respectively. Both phases present identical orientation, yet the relative orientation with the neutron beam changes up 1.5° across the specimen. The lattice parameters are in the range of 3.575-3.589 Å for the γ phase, and between 3.588-3.594 Å for the γ' phase. The difference in lattice parameter between the phases define the misfit, which for these alloys controls the coarsening behaviour under stress found at elevated temperatures. In all the analysed areas the obtained misfit (0.24-0.3 %), in agreement with the values reported in the literature.

Influence of external AC magnetic fields on flux trap in Niobium during field cooling

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Magnetic flux trapping is an unwanted effect for superconducting radio-frequency (SRF) cavities, as it increases their surface resistance and increases operational and investment costs for SRF based accelerators. It is therefore of great interest to understand the mechanisms leading to flux trapping and ultimately develop a procedure to mitigate its impact or avoid it altogether. Niobium is the most commonly used material in SRF cavities and therefore subject of this studies. Based on earlier studies [1- 4] we investigated a Niobium sample cut from a large-grain ingot of high purity RRR300 Niobium, prepared using buffered chemical polishing (HF 48%, HNO₃ 65%, H₃PO₄ 85%, ratio 1:1:2). The sample was investigated before and after vacuum-annealing at 1400°C. Samples were cooled down in different overlaid DC and AC magnetic fields of different amplitudes and frequencies. Magnetic flux trapping was measured by polarized neutron imaging (PNI), using PONTON II (already removed) at the BER II (Fig.1) compared with calculations. Detailed results will be given.

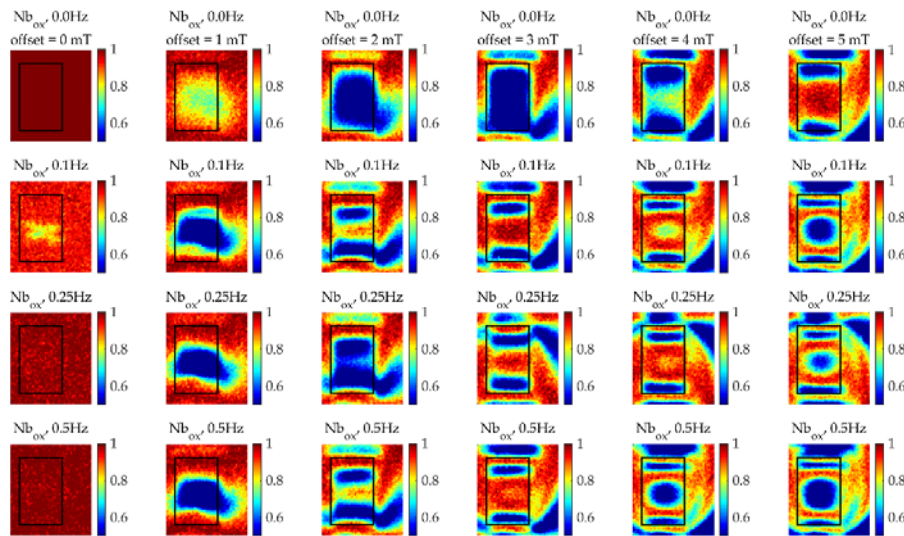


Figure 1. Magnetic flux trap in un-treated Nb for different AC and offset fields.

* Presenting author

- [1] S. Aull, O. Kugeler, J. Knobloch, Phys. Rev. STAB (2012) 15, 062001
- [2] S. Aull, O. Ebrahimi, N. Karakas, J. Knobloch, O. Kugeler, W. Treimer, Journal of Physics, Conf. Series (2012) 340, 012001, 1 – 7
- [3] O. Kugeler, M. Krzyzagorski, J. Köszegi, R. Ziesche, L. Riik, T. Junginger, J. Knobloch, W. Treimer, 18th Int. Conf. on RF Superconductivity, SRF2017, Lanzhou, China JACoW
- [4] J. Köszegi, O. Kugeler, D. Abou-Ras, J. Knobloch, and R. Schaefer, Journal of Applied Physics (2017) 122, 173901.

Polarised Neutron Imaging

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Within the last decade, the use of neutron polarisation has become more popular as it opens up new possibilities for the measurements of magnetic and electric material properties.

We present the results of applying polarised neutron imaging for:

- The measurement of 3D magnetic field strength and direction from a solenoid carrying an electric current [1], including the development of an algorithm for reconstructing the signal from magnetic fields strong enough to cause phase-wrapping of the neutron spin (see **Figure 1**, Left). This is achieved through an iterative forward model optimisation taking advantage of the time-of-flight information in a pulsed neutron beam [2].
- The measurement of a lithiated graphite battery electrode, in order to spatially resolve the electric current flow.
- The measurement of the trapped field in a LSCO superconductor for resolving the spatial distribution of the transition temperature as a non-destructive way of measuring the suspected variation in Strontium doping (see **Figure 1**, Right).
- The measurement of a multifilamentary YBCO superconductor.

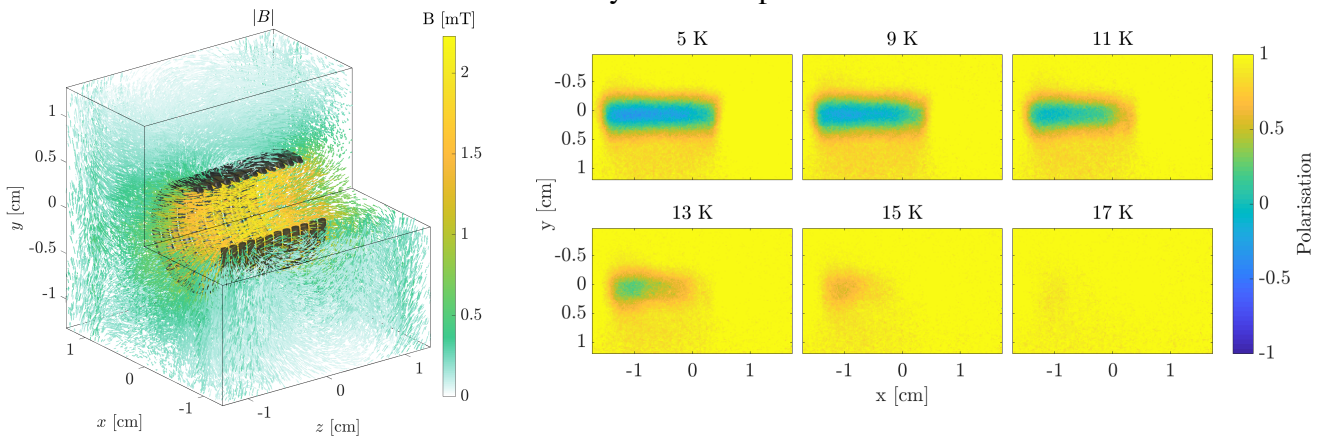


Figure 1. Left: result of iterative reconstruction of magnetic field strong enough to cause phase wrapping. Right: signal from trapped field in LSCO superconductor at different temperatures.

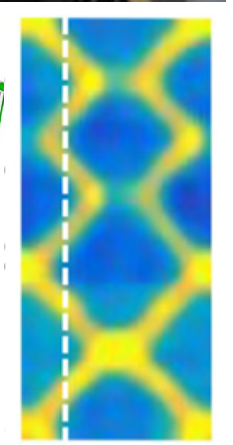
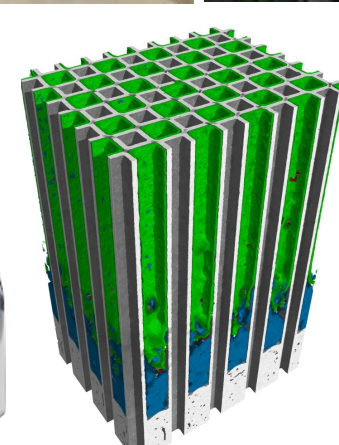
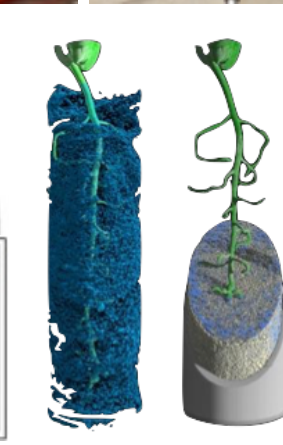
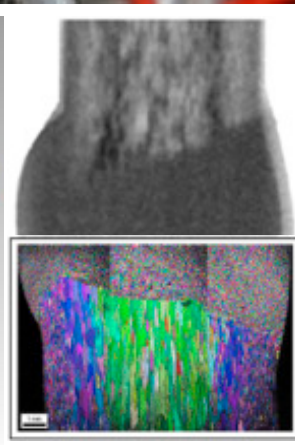
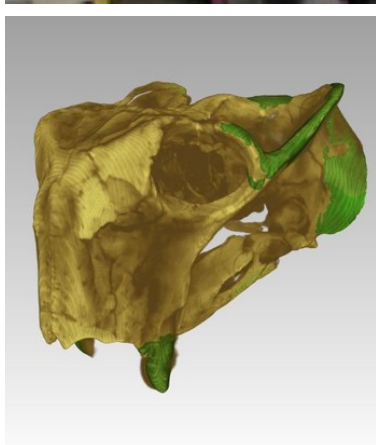
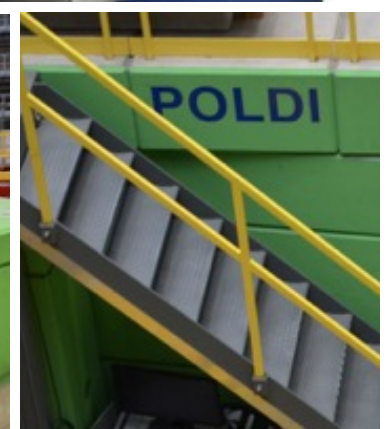
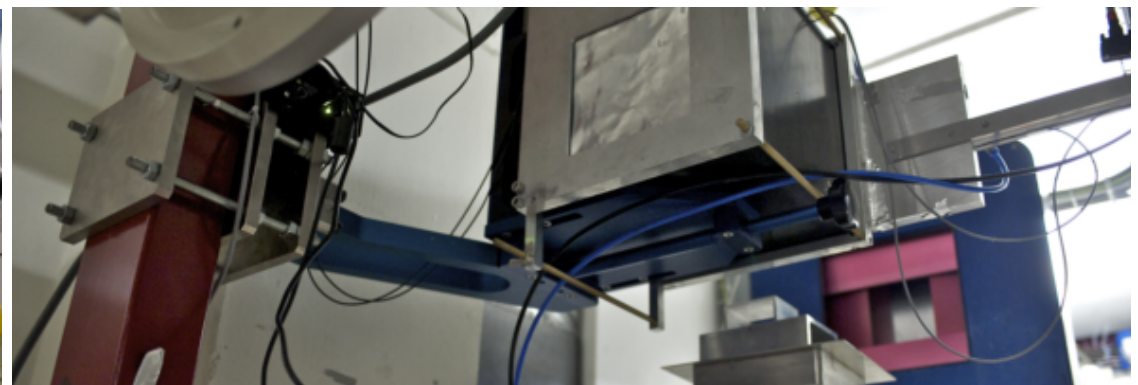
[1] M. Sales, et al. Scientific Reports, 8(1):2214, February 2018

[2] M. Sales, et al. J Phys D Appl Phys, 2019 (accepted)

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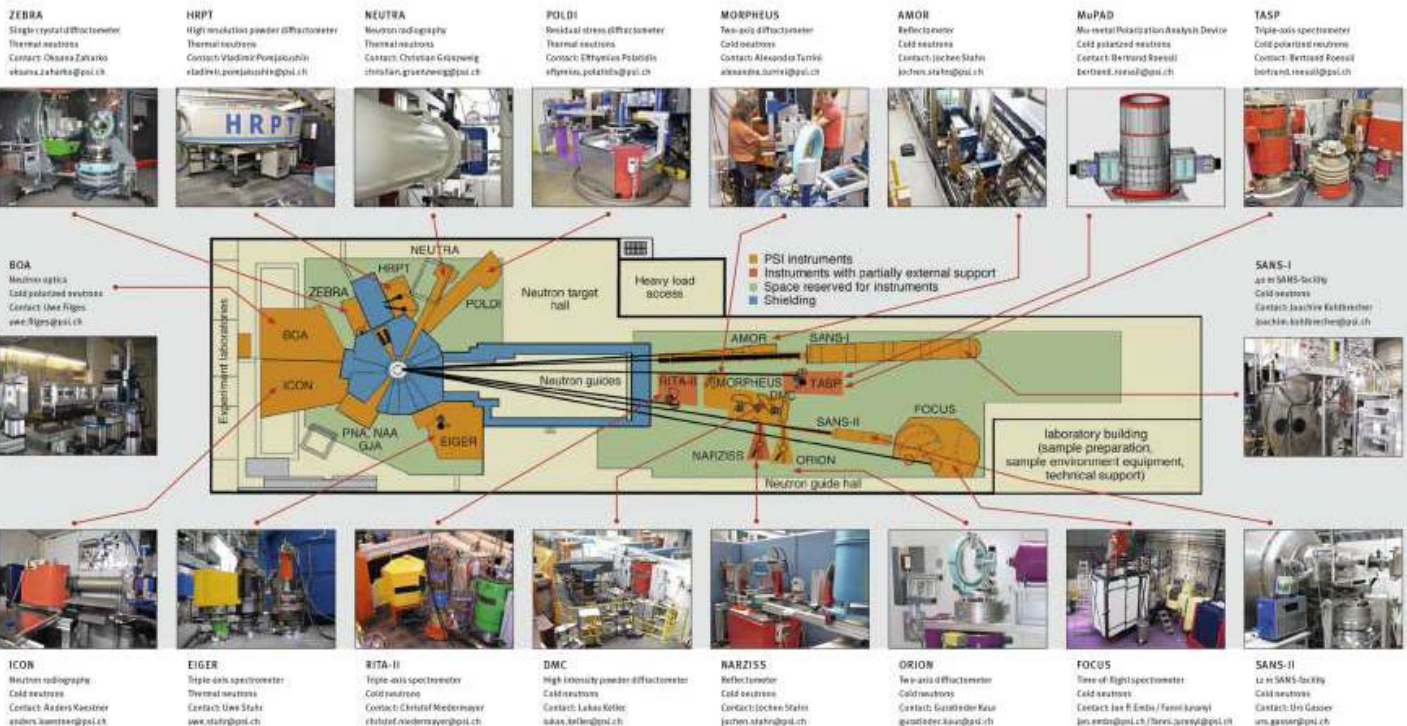


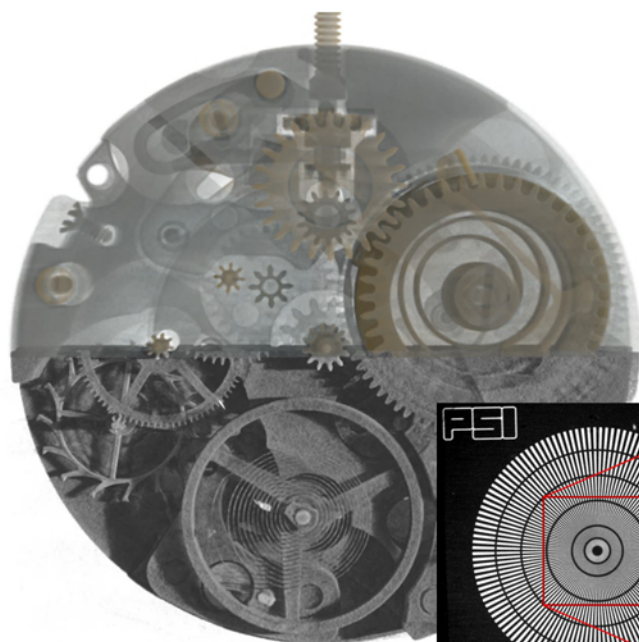
Contact: markus.strobl@psi.ch

LNS Laboratory for Neutron Scattering and Imaging

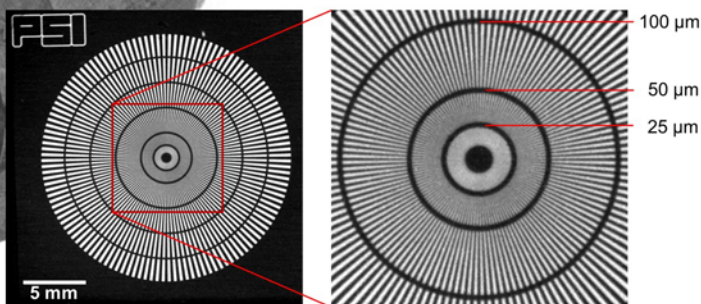


Neutron Scattering and Imaging Instruments at SINQ





Scintillation Screens for Neutron Imaging High Light Output High Resolution



Standard scintillation screens for neutron imaging with cold or thermal neutrons (0.12 – 100 meV):				
Base material	Emission	Dimension	Thickness	Comment
^6LiF / ZnS:Cu or Ag (ratio 1 / 2)	530 nm (green) 450 nm (blue)	up to 400 x 400 mm ²	50 up to 400 μm	High light output and high resolution
$\text{Gd}_2\text{O}_2\text{S:Tb}$ or $\text{Gd}_2\text{O}_2\text{S:Tb}$ / ^6LiF (20%)	447 / 549 nm (blue-green)	up to 400 x 400 mm ²	10 up to 50 μm	Very high resolution 6-LiF addition give enhanced intensity

Standard scintillation screens for neutron imaging with fast neutrons (> 0.8 MeV):				
Base material	Emission	Dimension	Thickness	Comment
PP / ZnS:Cu (30%)	530 nm (green)	up to 600 x 600 mm ² Stand. 310 x 310 mm ²	1.5 - 3 mm Stand. 2.4 mm	High light output and good resolution
PP / ZnS:Ag (30%)	450 nm (blue)	up to 600 x 600 mm ² Stand. 310 x 310 mm ²	1.5 - 3 mm Stand. 2.4 mm	High light output and good resolution

Special types				
Base material	Emission	Dimension	Thickness	Comment
$\text{Gd}_3\text{Al}_2\text{Ga}_3\text{O}_{12}:\text{Ce}$	535 nm (green)	up to 400 x 400 mm ²	10 up to 100 μm	Very high resolution and very short decay (<30 μs)
^6LiF / Zn(Cd)S:Ag	635 nm (red)	up to 400 x 400 mm ²	50 up to 400 μm	High radiation stability and high light output

We are open for extra specifications. Please contact us for a closer discussion.

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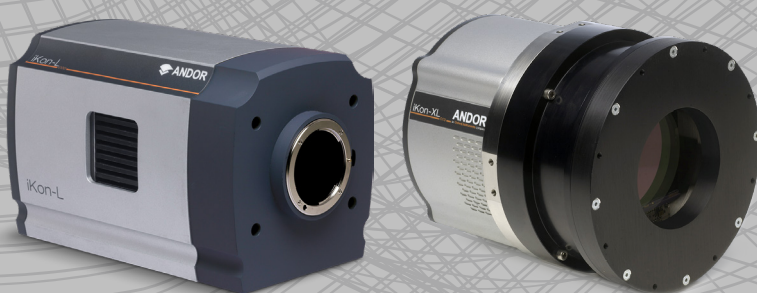
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Applications

- Archaeological, cultural heritage and geological artefacts
 - *In operando* Li-ion batteries and fuel cells behaviour
 - Water transport in biological and porous samples
 - Engineered materials structural integrity