NEUTRON IMAGING IN MATERIALS RESEARCH

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Summary: The material characterization by neutron imaging reached a new level after developing innovative techniques using different contrast mechanisms than the common beam attenuation. In this way properties of materials and complex systems can be resolved by position sensitive mapping of diffraction, small-angle scattering and refraction signals. The unique nature of neutron radiation allows for high sensitivity to light elements, distinctive penetration depth in metals and susceptibility to magnetic fields.

1. INTRODUCTION

In the last 10 years a rapid progress in the neutron imaging is observed. The development of digital detectors in combination with powerful computation systems allowed for improved spatial and temporal resolution as well as for implementation of tomographic option at many neutron imaging beam lines. The improvement of neutron instrumentation helped for better beam properties and for implementation of new methods like energy-selective, dark-field, phase-contrast and magnetic imaging. In summary these developments helped for attracting of larger number of scientists and industrial customers who discovered the neutron imaging and contributed to the increase of the neutron imaging community.

2. EXPERIMENTAL METHOD

The neutron imaging instrument CONRAD-2 at Helmholtz-Zentrum-Berlin has widely been recognized as a versatile and flexible instrument for innovative neutron imaging and has made decisive contributions to the development of new methods by exploiting different contrast mechanisms for imaging. The reason for the success in method development is the flexibility of the facility which permits very fast change of the instrument's configuration and allows for performing non-standard experiments.

CONRAD-2 is well suited for absorption contrast radiography and tomography used frequently in industrial applications but also for energy-selective measurements due to the double-crystal monochromator and velocity selector installed. Solid-state polarizers and polarized 3He filters are used for imaging with polarized neutrons. Phase grating setups can be used for grating interferometry experiments where phase contrast and dark-field imaging is used to obtain spatially resolved information about the microstructure of the materials in question or about their magnetic properties. The instrument has a prototype of a high resolution detector which can provide images of samples with a pixel size down to 6.5 µm at reasonable exposure times.

3. RESULTS

3.1 Absorption contrast imaging:

<u>Fuel cell research</u>: Investigations, especially in-situ, of the water distribution in operating low-temperature fuel cells are amongst the most important applications of neutron imaging. The ability of the neutron beam to easily transmit thick layers of metal on the one hand while, on the other hand, neutron absorption is very sensitive to hydrogenous substances, e.g. water, helps to visualize very small amounts (min. 10 µm thickness) of water. In image sequences with repetition rates of 6 to 30 frames per minute, the dynamics of water transfer has been visualized in single and multiple fuel cell stacks. Tomographic investigations of such stacks have been performed

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in which the water distribution was resolved three-dimensionally.

Plants: Water transport in plants is one of the most important factors for life, since it is a fundamental necessity for photosynthesis. Neutron radiography using D_2O as a tracer is an outstanding method to visualize water movement in small plants. In this way, parameters such as the speed of water uptake and the reaction to toxic atmosphere or soil conditions has been investigated.

Archeology, paleontology and geology: Neutron imaging has found use in the non-destructive investigations of fossil samples, and for the study of archeological artifacts. A broad range of samples were investigated, ranging from metal such as historical weapons or jewelry to fossils and geological samples.

Energy-selective imaging: The energy-selective method can be applied very successfully to material phase separation by choosing the neutron wavelength to be between the Bragg edges of the two material phases (e.g. γ- and α–ferrite). A combination of this technique with tomography allows for volumetric phase separation in heterogeneous materials.

High resolution imaging: Application areas are innovative microcellular materials such as metal and polyester foam structures, porous materials such as 'Membrane Electrode Assemblies' (MEA) or gas diffusion layers in fuel cells. The high penetration depth of a neutron beam in metals combined with high-resolution imaging will enable to trace crack initiation in welded materials or during fatigue testing.

3.2 Innovative neutron imaging

Imaging with polarized neutrons: Magnetic imaging has some very tantalizing prospects for future studies of magnetic phenomena throughout science and technology: the establishing and trapping of magnetic flux in superconductors below the critical temperature, the skin effect in conductors or magnetic domain distributions in bulk ferromagnets.

Grating interferometry can be used to characterize heterogeneities on the scale of 0.1 µm to 10 µm. Refraction at the magnetic domain walls can be used to visualize magnetic domains. Using tomographic reconstruction, the 3D domain network can be analyzed and studied under different external conditions, e.g. varying magnetic fields.

References

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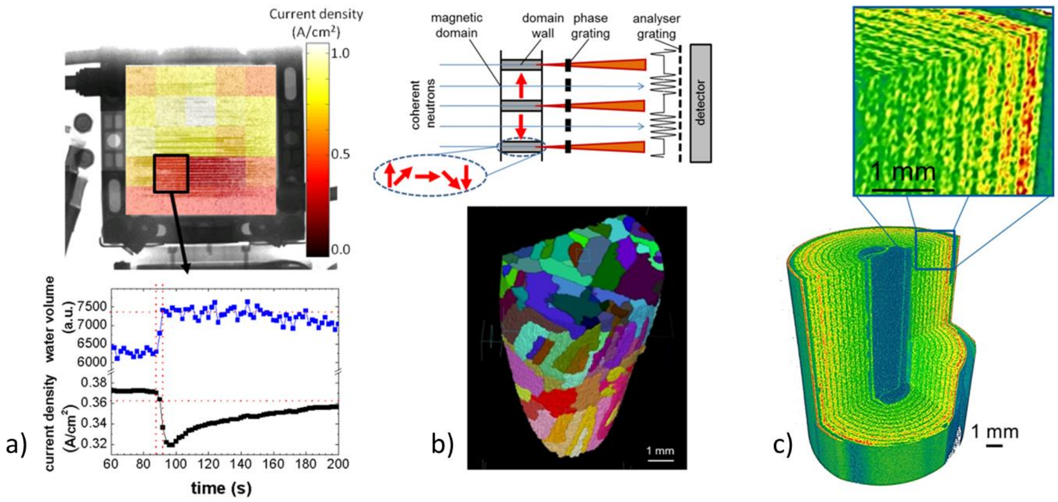

Figure 1: (a) Correlation between neutron radiography (top) and current density measurement (bottom) in operated PEM fuel cell; (b) Multiple refractions at the domain walls are detected by Talbot-Lau type grating interferometry (top). Magnetic domain structure in FeSi single crystal visualized in 3D (bottom); (c) Virtual cut through 3D data of a LiCoO2 battery. The high-resolution neutron tomography (pixel size 6.4 µm) provides information about the distribution of high absorbing Li in the battery.