High-resolution X-ray imaging in the laboratory – Status and perspectives

Ehrenfried Zschech
Brandenburg University of Technology Cottbus-Senftenberg, Germany

Abstract:

High-resolution X-ray imaging provides nondestructive characterization capabilities on opaque objects, observing features with sizes across a range of length scales, down to several 10 nanometers using lens-based transmission X-ray microscopy (TXM). Multi-scale X-ray computed tomography (XCT), characterized by a sample thickness / resolution value of ~ 10^3, and subsequent 3D data reconstruction is an efficient approach to study the 3D morphology of natural and engineered hierarchically structured systems and materials. Because of the ability of micro-XCT and nano-XCT to reveal structural characteristics, materials' microstructure and flaws, such as microcracks and micropores, or local composition and density differences, they are potential techniques for imaging of micro- und nano-structured objects (e.g. microelectronics products), advanced multi-component materials (e.g. composites and porous or skeleton materials) as well as biological objects (e.g. pollens and diatoms). In this talk, the huge potential, today's limits and the perspectives of laboratory XCT for high-resolution nondestructive 3D imaging of materials and biological objects will be described. Applications for nondestructive evaluation of geometrical features, materials' microstructure and flaws will be presented. Examples will be selected from natural objects (biomimetics), materials for energy storage and conversion as well as microelectronics. It will be shown that the combination of high-resolution X-ray imaging with set-ups for *in-situ/operando* studies opens the way for the development of design concepts for novel engineered materials systems as well as for the study of materials ageing and degradation processes.

Lens-based TXM and nano-XCT have been demonstrated at synchrotron radiation (SR) beamlines but also in the laboratory, with 24/7 tool access. Since the brightness of laboratory X-ray sources is several orders of magnitude less compared to that at SR sources and because of the limited efficiency of X-ray optics, signal-to-noise ratio is a challenge for laboratory X-ray imaging. Denoising algorithms are applied to get high-quality 3D information of the object and to reduce the image acquisition time. While XCT is pushed further into the micro- and nanoscale, the mitigation of artefacts caused by thermomechanical instability of the positioning systems for tool components and object motion, by center of rotation misalignment and by inaccuracy in the detector position require computational efforts, e.g. the application of deep convolutional neural network architectures and deep learning algorithms.