High-resolution 3D Imaging of crack propagation in materials using X-ray microscopy

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X-ray imaging and X-ray computed tomography (XCT) provide nondestructive characterization capabilities on opaque objects across a range of length scales, observing features with sizes down to several 10 nanometers. Because of the ability of X-ray microscopy (TXM) 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, diatoms or mollusk shells). In this talk, the huge potential and today‘s limits of laboratory X-ray microscopy and nano-XCT for nondestructive 3D imaging of materials and biological objects will be described. Applications for nondestructive evaluation of geometrical features, materials' microstructure and flaws will be shown. Examples will be selected from natural objects (biomimetics), engineered materials for lightweight construction and microelectronics.

Fracture mechanical properties of materials in micro- and nanoscale dimensions have become an important area of fundamental research, including the development and introduction of new techniques for micro- and nanomechanical testing. At the same time, there is an increasing need of industry to evaluate the risk of microcrack evolution at small length scales that can cause catastrophic failure in 3D nanostructured systems and functional materials such as composites, battery electrodes and integrated circuits. The combination of miniaturized mechanical tests with high-resolution imaging enables a precise control and monitoring of force and displacements in materials at the micro- and nanoscale. *In-situ* mechanical tests of 3D-structured systems and materials, e.g. applying a micro double cantilever beam (micro-DCB) test in a laboratory X-ray microscope, provide a unique capability for high-resolution 3D imaging of microcrack evolution while a force is applied. Nano-XCT is used to image microcracks in integrated circuits with sub-100nm resolution and to draw conclusions for the robustness of microchips. A novel methodology for the determination of the local critical energy release rate G_c in 3D-patterned systems will be explained, and the ability of a controlled steering of microcracks into regions with high fracture toughness will be demonstrated.

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 based on their 3D microstructure or morphology and their local properties.