X-ray Nondestructive Characterization of Mesoscale (mm extent with μm features) Objects[1]

H. E. Martz, Jr., M. B. Aufderheide, A. Barty, B. J. Kozioziemski,
D. J. Schneberk and A. M. Waters
Lawrence Livermore National Laboratory, Livermore, CA 94551

At Lawarence Livermore National Laboratory particular emphasis is being placed on the nondestructive characterization (NDC) of 'mesoscale' objects.[Martz and Albrecht 2003] We define mesoscale objects as objects that have mm extent with μm features. These objects include materials that vary widely in composition (~3 < Z < ~82), density (~0.03 g/cm^3 to ~20 g/cm^3), geometry (planar to spherical), and embedded features (joints to subassemblies). To be successful our NDC efforts must realize one micrometer or better spatial resolution over a few millimeters field-of-view with very high contrast (>0.999), which represents a signal-to-noise ratio of 1000:1. In the scientific literature there exists an extensive body of work that describes a variety of characterization techniques that may be applicable to mesoscale object characterization. Here we confine our discussions to x-ray imaging methods.

The work on x-ray radiography and tomography at various synchrotron facilities is widely known and respected. In addition, there are two commercial systems, Xradia and XRT, and an LLNL-built system called KCAT that provide x-ray radiographic and tomographic capability that are also close to our characterization requirements. Xradia, Inc.[2], Concord, CA, produces two products of interest for nondestructive characterization of mesoscale objects. One is a point projection system called μXCT. The second Xradia product is a Fresnel, zone-plate lens based x-ray microscope called nXCT. XRT Limited, an Australian company[3], produces a point projection x-ray system upgrade to a scanning electron microscope (SEM). The synchrotron, commercial and LLNL x-ray systems have spatial resolutions and field of views (FOVs) that are applicable to the mesoscale NDC problem. The synchrotron and XRT x-ray systems have a limited x-ray energy range from ~ a few keV up to ~30 keV. LLNL's mesoscale objects require energies from ~5 to 60 keV [Logan, et al. 2001]. Xradia's μXCT and LLNL's KCAT x-ray systems meet this energy range requirement.

We have developed methods and phantoms (well known test objects, also known as reference standards) to benchmark these systems for mesoscale object characterization (Figure 1). We use both radiographic (2D) and tomographic (3D) phantoms. For 2D phantoms we use a Ta edge, large radius of curvature edges made of Au coated on Cu, high-density polyethylene (HDPE) rods and polystyrene spheres. For tomographic phantoms we are using HDPE rods, polystyrene spheres, low-density polyethylene, copper and gold tubes, and cylindrical, spherical and inertial confinement fusion (ICF) standards. These phantoms have none-to-many complex features. In addition to their use to benchmark x-ray systems, they also will be useful in the validation of x-ray simulation (the forward problem) and object recovery (the inverse problem) algorithms under research and development at LLNL.

Future work includes the development and validation of algorithms to model phase-contrast effects observed in these x-ray systems, and to use these algorithms for quantitative object recovery. This requires four tasks. First, we are determining whether multislice techniques [Hare and Morrison 1994] within the object are needed to fully capture the physics seen in phase-contrast data. If it is needed, we will build such a capability into our x-ray, neutron and proton radiographic simulation code HADES [Aufderheide, et al. 2000]. Secondly, we are modifying HADES to model phase contrast for point projection and possibly x-ray optics systems. Thirdly, we will develop several object recovery approaches using parameter-based [Chambers, et al. 2003] and voxel-based techniques [see, for example, Gureyev, 2003; Paganin, et al. 2002; Barty, et al. 2000; Tiller, et al. 2000 and Gerchberg and Saxton 1972] Finally, we will validate these simulations against x-ray systems, including ALS, Xradia and KCAT, using well-known objects. Thus at the end of this R&D, we will have a set of validated codes for modeling and reconstructing objects including the effects of phase-contrast in the x-ray image data.

[1] This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

[2] http://www.xradia.com/

[3] http://www.xrt.com.au/

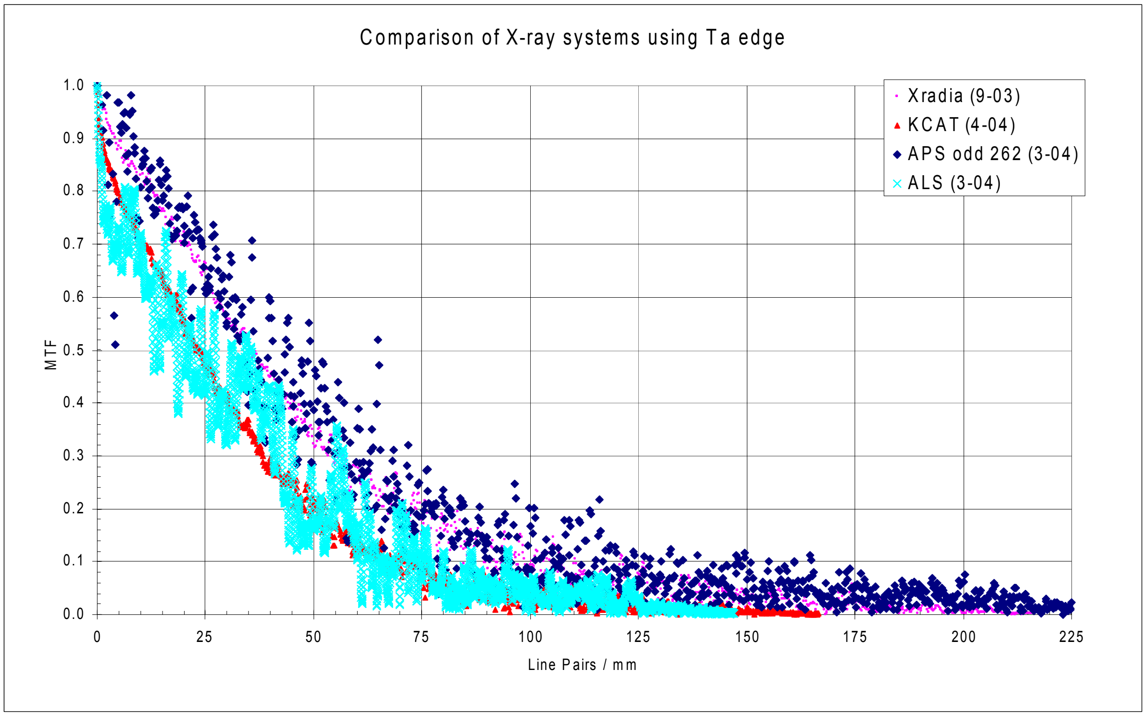

Figure 1 Modulation transfer functions (MTF) determined from digital radiographs of a 0.51-mm thick Ta edge for LLNL's KCAT, Xradia's µXCT, APS's 1-ID beamline and ALS's microtomography x-ray systems as labeled. The two camera-lens coupled to a CCD detector systems (KCAT and ALS) have similar MTFs while the two microscope-lens coupled to a CCD detector systems (Xradia and APS) have similar and better MTFs. The microfocus-source systems (KCAT and Xradia) have a less noisy MTF than the synchrotron-source systems.

References

Aufderheide, M. B., D. M. Slone, and A. E. Schach von Wittenau (2000), "HADES, A Radiographic Simulation Code," in *Review of Progress in Quantitative Nondestructive Evaluation*, **20A**, AIP Conference Proceedings 557, pp. 507-513.

Barty, A., K.A. Nugent, A. Roberts, and D. Paganin (2000), "Quantitative phase tomography," *Opts. Comm.* **175**, pp. 329-336.

Chambers, D. H., D. M. Goodman, and R. R. Leach (2003), "As-built model generation for a cylindrical test object," Lawrence Livermore National Laboratory, Livermore, CA, UCID-TR-200695.

Gerchberg, R.W., and W.O. Saxton (1972), "A practical algorithm for the determination of phase from image and diffraction plane pictures," *Optik* **35,** 237.

Gureyev, T.E. (2003), "Composite techniques for phase retrieval in the Fresnel region," *Opts. Comm.* **220,** 49-58.

Hare, A. R., and G. R. Morrison (1994), "Near-Field Soft-X-Ray Diffraction Modeled by the Multislice Method," *J. of Mod. Opts.* **41**, pp. 31-48.

Paganin, D., S. C. Mayo, T. E. Gureyev, P. R. Miller, and S. W. Wilkins (2002), "Simultaneous phase and amplitude extraction from a single defocused image of a homogeneous object," *J. Micros.* **206**, pp. 33-40.

Tiller, J.B., A. Barty, D. Paganin and K.A. Nugent (2000), "The holographic twin image problem: a deterministic phase solution" *Opts. Comm.* **183**, pp. 7-14.

Logan, C., Y. Wang, M. Aufderheide, and H. Martz (2001), "X-ray Energies for Imaging NIF High Energy Density Capsules," Lawrence Livermore National Laboratory, Livermore, CA, UCID-ID145954.

Martz Jr., H. E., and G. F. Albrecht, (2003), "Nondestructive Characterization Technologies for Metrology of Micro/Mesoscale Assemblies," *Proceedings of: Machines and Processes for Micro-scale and Meso-scale Fabrication, Metrology, and Assembly*, ASPE 2003 Winter Topical Meeting, Gainesville, FL, January 22-23, pp.131-141.