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Advancing the Technology R&D of Tabletop Mesoscale Nondestructive Characterization

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Tabletop Mesoscale Nondestructive Characterization[1]

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Project overview

This Strategic Initiative (SI) will advance nondestructive characterization of mesoscale (millimeter-sized) objects—allowing micrometer resolution over the objects' entire volume. X-ray imaging will be developed that allows object characterization with materials that vary widely in composition, density, and geometry.[Martz and Albrecht, 2004]

Project goals

The overall goal is to research the science and engineering needed to nondestructively characterize and model mesoscale objects. The spatial resolution goal for this microscopy is roughly one cubic micrometer or better, while the contrast goal represents a signal-to-noise ratio of 1000:1.

Relevance to the lab Mission

This SI will enable the science and technology of phase- and amplitude-contrast modeling and object recovery. Specific LLNL programs that would benefit include development of novel sensors for NAI applications, study of explosive samples for DOD and DOE, high energy density physics, and inertial confinement fusion (ICF) experiments for the National Ignition Facility (NIF).

FY04 Accomplishments and Results

We performed several types of modeling to better understand x-ray imaging of mesoscale objects. Characterization of the solid deuterium-tritium (D-T) fuel layer in an ICF capsule using a beryllium ablator requires phase-contrast imaging. We chose this as one example for our modeling work. We modeled projection imaging systems with a coherent parallel-beam and a point source, and a large-size source with a Wolter x-ray imaging optic (Figure 1). These studies showed that imaging was possible with either approach [Barty, et al. 2004]

Objects with geometric and x-ray properties comparable to an ICF capsule were used in initial experimental tests of the modeling results. These objects were successfully imaged using LLNL's KCAT system, Xradia's uXCT, and ANL's Advanced Photon Source [Kozioziemski, et al. 2004]. Due to the stopping of the SI proegrammatic funds and KCAT were used to successfully image both a D-T liquid/gas and solid/gas layer inside a beryllium capsule.

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We examined whether it is necessary to use the multislice method to solve the paraxial wave equation to simulate x-ray microscopy of mesoscale objects or if ray tracing will suffice. Preliminary results reveal ray tracing was adequate for modeling the propagation of x-rays through mesoscale objects of interest.[Kallman, 2004]

Additional modeling probed the imaging capability and limitations of a Wolter x-ray microscope system. This system was designed to characterize mesoscale objects to sub-micrometer spatial resolutions.[Nederbragt, 2002] A code has been developed to model the 2D image formation in a Wolter x-ray microscope.[Jackson, 2004] A series of simulations using various objects were run to study the effects of the optics, neglecting scattering and reflection losses (Figure 2). These simulations were analyzed using both laminographic and tomosynthesis methods (Figure 3).[Schneberk, et al., 2004]

One Wolter 8-keV x-ray optic was fabricated for the microscope. Unfortunately, the mandrel did not meet the required specifications.[see Taylor LDRD report] However, two important achievements resulted from the fabrication effort. First, the team developed a framework and methodology for the construction of high precision optics for future efforts at LLNL (Figure 4). The second achievement was the demonstration of both a laterally- and depth-graded multilayer coating to maximize the throughput of the optic (Figure 5).

FY05 Proposed Work

The SI was terminated and has evolved into two LDRD ERs. One focuses on x-ray phase-effects characterization,[see Martz LDRD report] the other on x-ray optics fabrication [see Taylor LDRD report].

Related References

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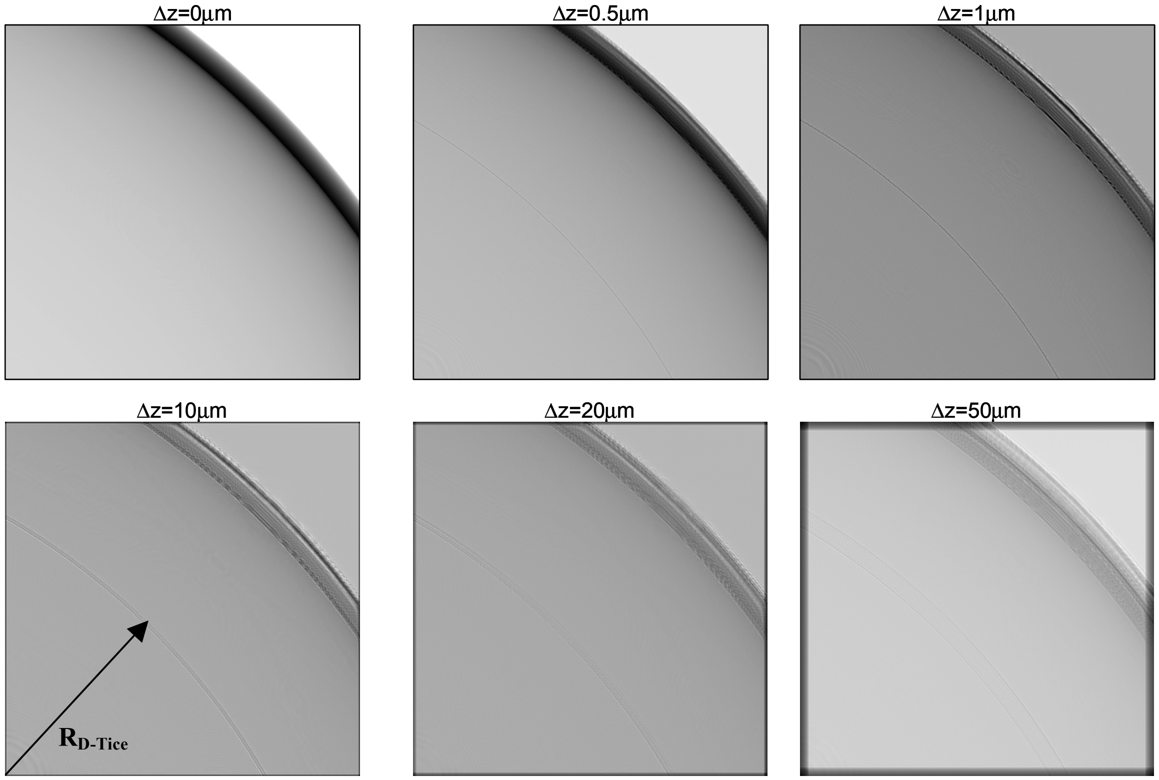


Perfect optic assumed at this stage
100 illumination points, annular fill of σ=0.8

Figure 1. A perfect Wolter optic microscope simulation of a D-T ice layer inside a Be capsule. Exit- to image-plane distances are labeled as Δz. The D-T ice gas layer is discernable for Δz of >= 0.5 um.

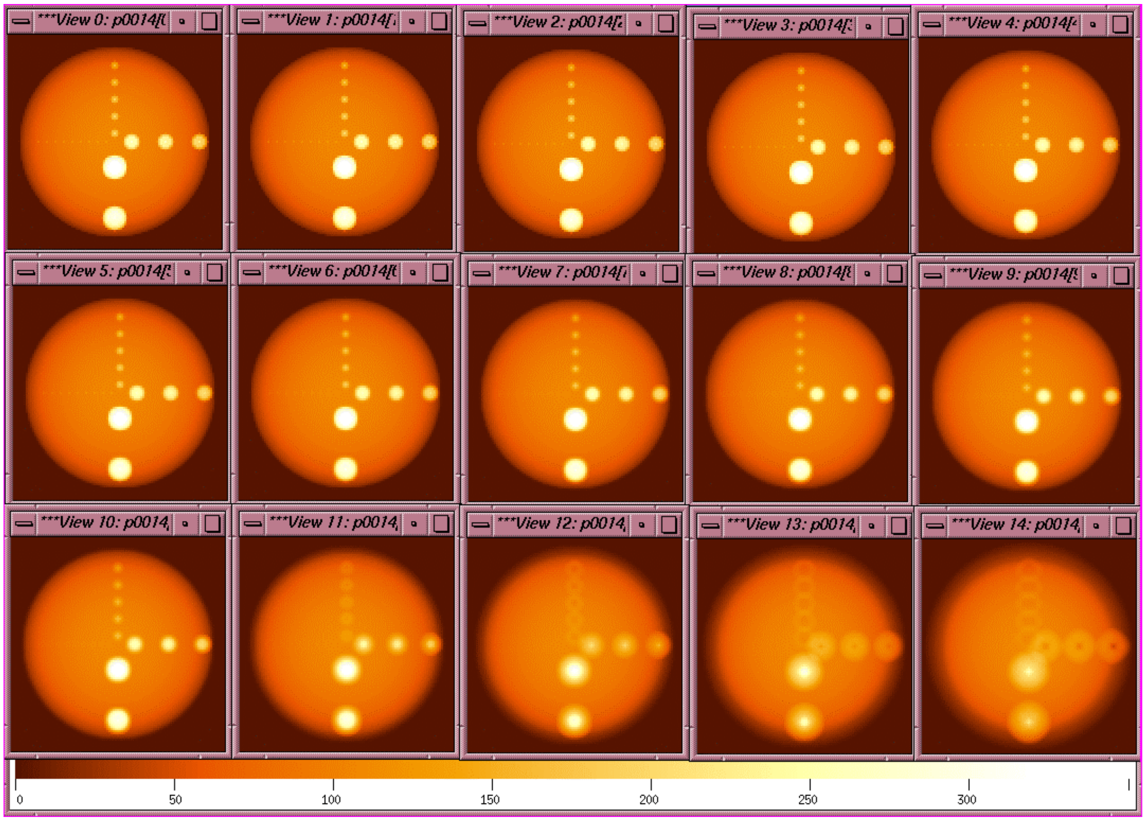
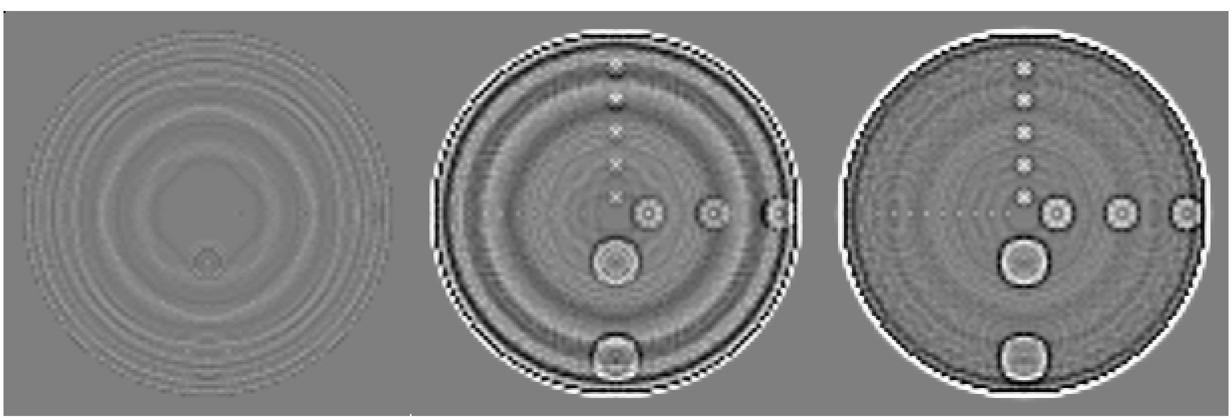


Figure 2 Simulated images of a 45-um diameter spherical object with a number of spherical (0.5-not observed, 2.5, 4.5, and 6.5-um diameter) inclusions on the center plane of the sphere. Each inclusion is 180 times more attenuating than the surrounding sphere. The first image has the center plane of the spherical object on the focal plane of the instrument. The succeeding images are the results of translations of the object toward the camera along the instrument axis. Images 2-9 are each 0.5 um steps further from the focal plane (0.5 um to 4.5 um). The last five images are at 5, 10, 15, 20, 25 um distance from the focal plane.



Difference of 0 & 0.5 um　　Difference of 0 & 2.5 um　　Difference of 0 & 5 um

Figure 3 Difference images of mid-plane focus, 0 um, to other translated views as labeled for the 45-um diameter simulated spherical object shown in Figure 2. Note that the 0.5 um inclusions are revealed in the 0 & 2.5 um and 0 & 5um difference images.

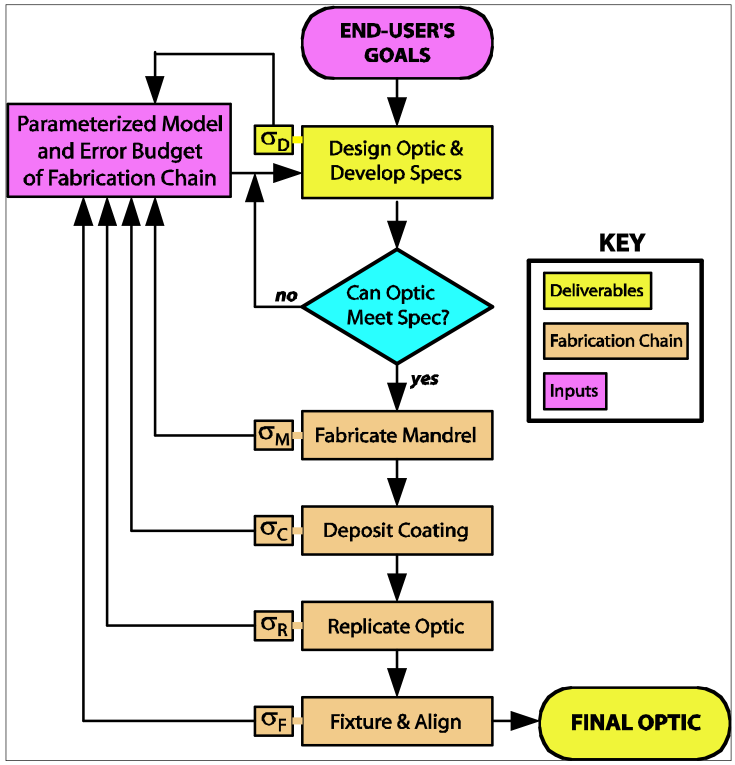


Figure 4: Replicated x-ray optic fabrication process flowchart

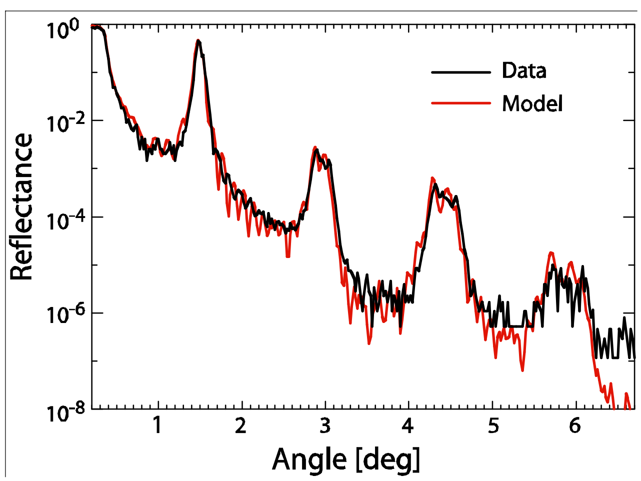


Figure 5: Measured reflectivity of the multilayer coating as a function of incident angle.