Near-Field Coherent Diffraction Imaging (NFCDI) of Electro-Deposited Lead Microparticles

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Introduction

When a fully coherent x-ray beam is used to illuminate a specimen, the resulting diffraction pattern can be interpreted using an iterative Gerchberg-Saxton phase-retrieval algorithm [1]. Coherent diffraction imaging (CDI) represents a major new imaging modality well-suited to use with fourth-generation x-ray sources. CDI is a wavelength-limited technique and can be performed without any resolution-limiting optical elements. Recent developments in CDI have demonstrated full-field reconstructions of several-micron samples with sub-10-nm resolution [2] and a reconstruction of the focal spot of an x-ray zone plate [3].

Unfortunately, iterative algorithms do not always converge uniquely or robustly and can be sensitive to image artifacts and missing information limitations. Xiao and Shen have recently proposed a near-field CDI (NFCDI) technique [4] that uses the inherent asymmetry of the near-field diffraction pattern to exclude ambiguities and thereby to improve the reconstruction convergence.

We report a recent NFCDI investigation of lead microparticles electro-deposited onto a silicon-nitride membrane. The measurements were made using a highly coherent beam of 8-keV x-rays at 32-ID of the APS.

Methods and Materials

CDI scattering intensities decrease in proportion to the fourth power of the scattering angle. High-resolution information is encoded in this high-angle data. Accordingly, it is necessary to use a clean x-ray beam with minimal high-angle intensity. We have investigated the production of a clean beam using multiple pinholes to select a highly coherent portion of the x-ray beam and to remove divergent beam components. The divergent components arise from the regular shape of the aperture—resulting in an Airy diffraction pattern, for instance—and from aperture imperfections, resulting in parasitic scattering.

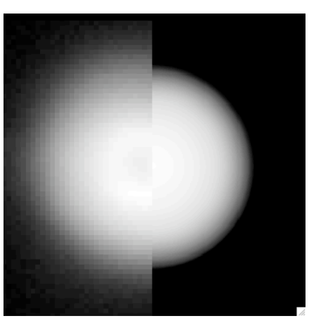

Figure 1. Comparison of our measurement (left) and simulation (right) of the intensity profile at the detector plane. The beam has been defined by a 10-μm pinhole and the higher-order Airy pattern removed by use of two further pinholes.

In order to determine the optimum location for the pinholes we have calculated near-field intensities along the beam axis. We have located a 25-μm pinhole so that its perimeter coincides with the second minimum of the Airy pattern. By choosing this location we are able to reduce the amount of scatter produced by this pinhole. A 45-μm pinhole was used to guard in the first minimum of the Airy pattern to produce a clean x-ray beam.

Results

Images were recorded in the near field, with a Fresnel number of around 1. Speckle patterns were recorded with and without a central stop using an optically-coupled liquid-nitrogen cooled CCD with an effective pixel size of 1.3μm.

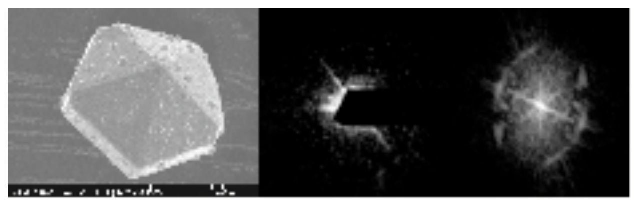

Figure 2. Representative lead micro-particle (~5 μm across) (left), measured speckle pattern (center), preliminary result: autocorrelation function determined from the FFT of the speckle pattern, indicating that the shape of the micro-particle is encoded in the the speckle pattern (right).

Discussion

Although still under development, CDI and NFCDI can be applied to solve a variety of otherwise inaccessible problems associated with imaging low-(absorption)-contrast biological materials and high-tech nano-materials. CDI measurements have demonstrated resolution below 10 nm over an object of several microns in size using available sources and should be exceeded using fourth-generation FEL sources.

The short-term implications of the work are manyfold. Many important experimental and theoretical details of the CDI imaging modality are under development. NFCDI can improve the robustness of reconstruction.

Acknowledgments

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