Full-field transmission x-ray microscopy at SSRL

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Abstract. A full-field hard-x-ray microscope at SSRL with 15 micron field of view and 40 nm resolution, as well as 3D tomographic capabilities, has successfully imaged samples of biological, environmental and astronomical origin. Spectroscopic imaging of a particle of comet dust from the NASA Stardust mission showed significantly more absorption contrast above the Fe K-edge, and tomography revealed the three-dimensional structure of the terminal particle and track through the aerogel.

1. Introduction

The imaging of biological, environmental and materials samples to capture structural detail and chemical composition has been attempted by many methods. X-ray microscopy in the soft x-ray region has been used extensively for biological imaging [1], and full-field hard x-ray microscopy has also been used successfully at several synchrotron sources [2]. The Xradia full-field hard x-ray microscope [3] was the first commercial instrument capable of sub-40 nm resolution. Using high resolution zone plates [4], it provides 3D tomographic capabilities [5], enabling spatial resolution in the 30-60 nm range. The transmission x-ray microscope (TXM) implemented at SSRL is capable of 2-dimensional imaging in phase and absorption contrast with 40 nm resolution, and 3D tomography and spectroscopic imaging from 4-14 keV [6]. Therefore, this instrument is an excellent tool for nondestructive high-resolution imaging as demonstrated across a wide range of samples, including mouse bone, plant roots, yeast cells [7]; and comet dust, as described below.

2. Microscope setup and capabilities

The x-ray microscope is located on beam line 6-2 at the Stanford Synchrotron Radiation Laboratory, with a 54-pole wiggler. The beam passes through vertical and horizontal slits, a vertically collimating mirror (M$_0$) followed by vertical slits, monochromator, and toroidal mirror (M$_1$) to focus the beam at the virtual source (S3) (figure 1a). A diffuser 3 meters before S3 and vertical stabilizer immediately after S3 (not shown) help to provide uniform illumination. A capillary condenser (C) provides hollow-cone illumination that is focused through a pinhole (P) onto the sample (figure 1b). A central stop (not shown) eliminates the direct beam and the remaining undeflected light is removed by the pinhole. The image is projected by a micro zone plate (MZP) onto the CCD (1024 x 1024). Zernike phase contrast can be provided by a gold phase ring (PR) that is centered prior to imaging by inserting a Bertran lens (BL).
The microscope is capable of 40 nm resolution in phase contrast at 8 keV (and soon at 5 keV), and absorption contrast from 4-14 keV over a 14 μm field of view. Because of the relatively large depth of focus (~20-40 μm), the samples can be imaged without sectioning as is routinely required for electron microscopy (EM). This depth of focus also provides full transmission imaging as opposed to surface only for EM. The sample stage allows for xyz and theta motion for 3D tomography. Spectroscopic imaging above and below the absorption edge facilitates studies of nanoscale trace element distribution. A modulation transfer function of an image of a Siemens star with 30 nm minimum feature size and analysis of the finer region confirmed 40 nm resolution (figure 2).

Figure 1: Setup of TXM on beamline 6-2 at SSRL (a) before and (b) after virtual source. (a) The beam passes through vertical and horizontal slits, a vertically collimating mirror (M₀) followed by vertical slits, monochromator, and toroidal mirror (M₁) to focus the beam at the virtual source (S₃). (b) Capillary condenser (C) provides hollow cone illumination and pinhole (P) removes undeflected light. Sample image is focused by micro zone plate (MZP) onto CCD detector, with optional phase ring (PR) for use at 8 keV and 5 keV. A Bertran lens (BL) is used to position the phase ring, and is removed from the beam for imaging. Drawings are not to scale.

Figure 2: Phase contrast image at 8 keV of Siemens star with 30 nm minimum feature size (a) and detail of region with smallest features (b). Modulation transfer function (not shown) confirms 40 nm resolution.

3. Spectroscopic and tomographic imaging of comet dust
In collaboration with NASA and the Institute for Geophysics and Planetary Physics at Lawrence Livermore National Laboratory, we obtained TXM images of dust gathered from comet 81-P/Wild2 by the Stardust spacecraft. Microprobe measurements (not shown) revealed the presence of Fe, Ni and Cu in the particle [8]. 3D tomography (not shown) portrayed the shape of the terminal particle with a portion of the trail through the aerogel. Spectroscopic imaging through the iron K-edge (figure 6 a-c) in absorption
contrast shows the location of iron within the particle, which grows darker above the iron K-edge (at 7112 eV).

Figure 6: Imaging of comet track T12 from Comet 81-P/Wild2 gathered in the Stardust mission. Absorption contrast images at (a) 7100 eV, (b) 7115 eV and (c) 7150 eV show darkening of the particle due to absorption above the Fe K-edge.

4. Conclusion
In summary, the TXM at beam line 6-2 at SSRL has successfully imaged samples with biological, environmental and materials applications. With this method we have been able to discern features not previously apparent with other methods. In the immediate future we will be upgrading the CCD to 2K x 2K pixels to increase the field of view, and adding a vortex detector for fluorescence detection of trace elements within a portion of the field of view. Plans are also being drawn up for a liquid nitrogen cryostat, and for a more sensitive sample stage which will improve tomographic resolution.

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