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Tomographic application of phase-contrast x-ray microscope with a zone plate

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Introduction

Hard x-ray microscopy offers an observation method of a relatively thick specimen with resolution around 0.1 μm. However, the image has low contrast especially for low-Z material. This problem is partially overcome by using a phase-contrast imaging method. We have been developing a Zernike-type phase-contrast microscope with a zone plate in the energy region from 5 keV to 10 keV.

Optical system

Figure 1 shows the optical system. An objective zone plate has the outermost zone width of 0.1 μm and the diameter of 155 μm. Monochromatic parallel x-rays were incident onto a specimen and enlarged by the zone plate at the magnification ratio of about 20. A phase plate was placed at the back focal plane of the zone plate. An aluminum foil (5 μm) with a pinhole (diameter: 5 μm) was mainly used as a quarter wavelength phase plate. In this case, negative phase-contrast could be obtained. Figure 2 shows the x-ray image of a tantalum line pattern (thickness: 0.5 μm) recorded on a nuclear emulsion plate (negative image). The vertical and horizontal line patterns as fine as 0.1 μm could be resolved with good contrast.

3D observation of biological specimens

In general, an image of a Zernike-type phase-contrast microscope does not represent quantitative phase-shift of a specimen. Then, it is not possible to reconstruct quantitative 3D phase image by tomography. However, tomographic reconstruction from phase-contrast images will give valuable information of microscopic 3D structure of an almost transparent specimen.

To evaluate the tomographic reconstruction, phase-contrast images of a pollen of a chrysanthemum were recorded on a CCD camera (Hamamatsu C4880, TC215) from 100 angles of view over 360 degrees. Figure 3 (a) is one of the images and Fig. 3 (b) is the reconstructed section image. The external form of the specimen was clearly reconstructed. In general, a dark phase-contrast image is surrounded by a bright band or halo. Then, a bright band is also reconstructed in the reconstructed section image as an artifact.

Using the CCD camera as a detector, the resolution was restricted to about 1 μm by the pixel size. Then, nuclear emulsion plates were tested for tomography with high resolution. Figure 4 shows diatom images from different angles of view. To reconstruct the 3D image, it is necessary to determine the center of the rotation axis in the all projection images. This is currently under way.

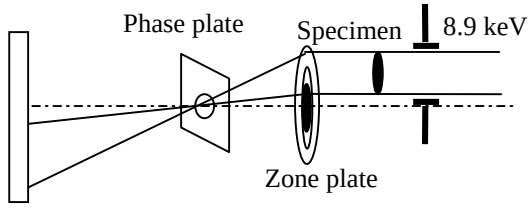

Fig. 1 Phase-contrast hard x-ray microscope.

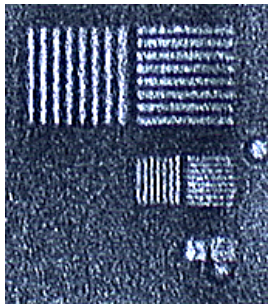

Fig. 2 X-ray image of a tantalum line pattern at 8.9 keV. Exposure time: 12 min.

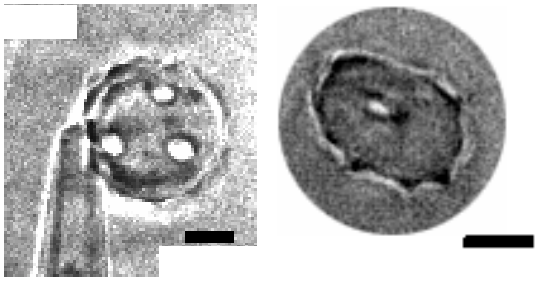

Fig. 3 (a) X-ray image of a pollen of a chrysanthemum at 8.9 keV, and (b) the tomographic reconstruction from 100 projections. The exposure time of each projection was 12 s.

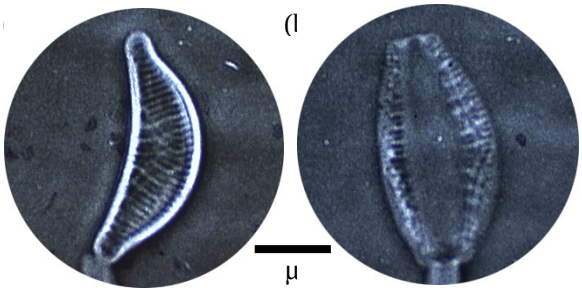

Fig. 4 X-ray images of a diatom from different angles of view at 8.9 keV. Exposure time: 9 min.

References

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