3-D Imaging Tomography with Sub-micrometer Resolution Using Fresnel Zone Plate Optics

X-ray microtomography has been developed for use in various fields such as biology, materials science, petrology, and medical diagnosis. This method's setup commonly consists of a simple projection geometry with a high-resolution imaging detector and a highly collimated beam, *e.g.*, a microfocussing X-ray tube or synchrotron radiation source, which can result in a spatial resolution of about 1 μm [1]. Achieving a higher resolution with this method, however, is difficult for two reasons: one is the image blurring caused by beam deflection (both refraction and diffraction), and the other is the limited spatial resolution of the imaging detector (~ 1 μm).

One promising way to overcome those problems is combining X-ray imaging microscope optics using an X-ray imaging device as an objective – so called "imaging microtomography." Various types of X-ray imaging devices whose theoretical spatial resolutions are in order of 10 - 100 nm have now been developed, and almost all of them have already attained the sub-micrometer resolution; even 100-nm-resolution has been achieved with some of them [2]. Since the imaging microscope setup enables magnification of the X-ray image, spatial resolution of the imaging detector is not a serious problem.

We have developed an imaging microtomography setup at beamline **BL47XU** using a Fresnel zone plate (FZP, fabricated at NTT-AT) which is one of the X-ray imaging devices utilizing X-ray diffraction. The experimental setup is shown in Fig. 1, and the X-ray energy was set to 8 keV. In this setup, a high coherent beam is not suitable for illumination because the images tend to be degraded by unwanted interference patterns such as speckle noise. Therefore, a "beam diffuser" made of graphite powder packed with Kapton films was installed in order to reduce the coherence. The measured spatial resolution of the microscope system, comprising the illumination system, a FZP objective, and a high-resolution imaging detector, was 0.6 μm [3]. The sample was mounted on the high precision rotating stage with a wobbling accuracy of 0.1 μm. One CT scan took approximately 4 - 8 hours with this system. More details about the system are described in refs. [3,4]. Spatial resolution and the time required for the CT scan are currently being improved.

Figures 2(a) - 2(d) show reconstructed images of a diatom fossil (*Achnanthidium lanceolata*).

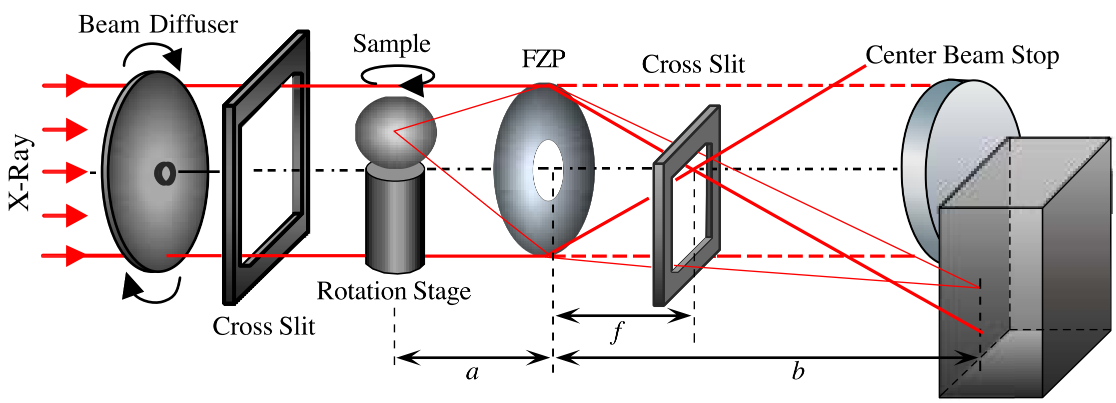

Fig. 1. Schematic diagram of the setup for X-ray imaging microtomography. $a = 176$ mm and $b = 1760$ mm (magnification is ×10), $f = 160$ mm.

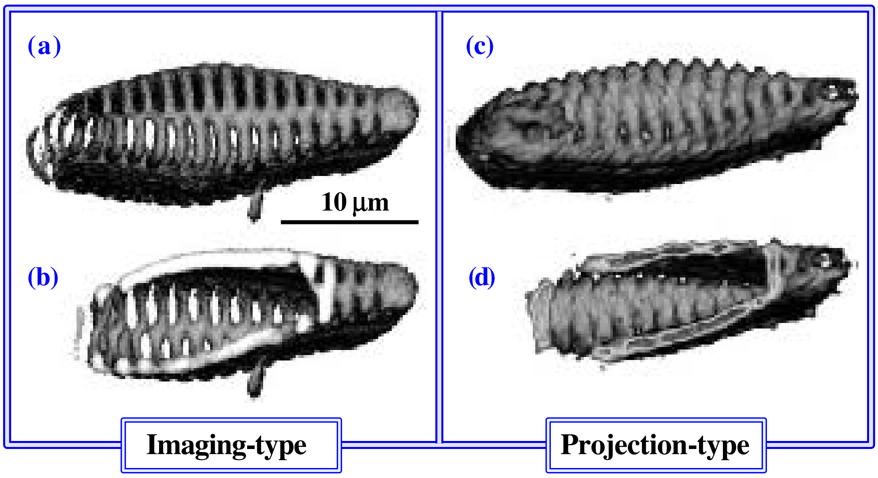

*Fig. 2. X-ray tomographic reconstructed images of diatom fossil (Achnanthidium lanceolata): **(a)** 3-D image of the outer structure, **(b)** inner structure revealed by cropping one part of the 3-D image, and **(c)** and **(d)** reconstructed images taken with projection-type microtomography [1].*

Figure 2(a) shows a whole three-dimensional image, while Fig. 2(b) shows a cropped one. For comparison, reconstructed images of the same sample taken with a projection-type microtomographic system with a spatial resolution of about 1 μm [1] are shown in Fig. 2(c) (whole image) and Fig. 2(d) (cropped image). The nesting fine structure (about 1.5 μm pitch) of the diatom was much cleaner in the imaging-type system (Figs. 2(a) and 2(b)) than in the projection-type one (Figs. 2(c) and 2(d)). Comparing both cropped images, the edge-enhancement effect due to X-ray refraction is clearly seen in the cropped section with the projection-type system (Fig. 2(d)) image, while it is not seen in the imaging-type image (Fig. 2(b)). These results demonstrate that imaging-type microtomography has a higher spatial resolution and a much smaller X-ray deflection effect than projection-type imaging.

Figure 3(a) shows the three-dimensional reconstructed image of a piece of stony meteorite (Allende), which has a complex texture made of silicates and metal-sulfides, and Fig. 3(b) shows its sliced image. Small cracks and holes are seen in the sliced image. The brighter area at the bottom of the sliced image is an iron-rich region that could be identified by comparing the images above and below the *K*-edge of iron.

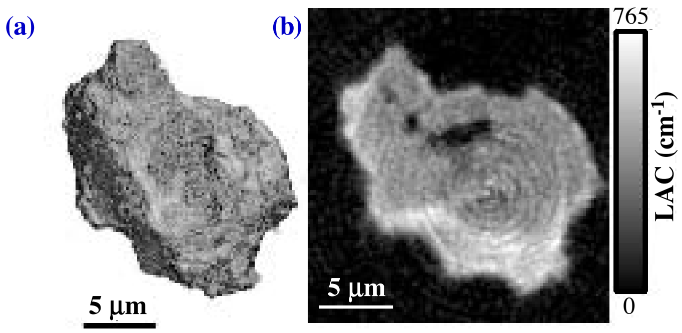

*Fig. 3. X-ray tomographic reconstructed images of a piece of Allende meteorite: **(a)** three-dimensional image and **(b)** sliced image (LAC: linear absorption coefficient).*

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References

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