Application of X-Ray Image Magnifier and Demagnifier to X-Ray Angle-Resolved Computed Tomography

X-ray angle-resolved computed tomography is sensitive to the X-ray phase gradients produced by a sample. Therefore, it has much higher sensitivity than conventional techniques based on absorption contrast. To improve the spatial resolution of this technique, we introduced an asymmetrically cut crystal for the analyzer, which functions as a magnifier. By using the magnifier at the wavelength of 0.0766 nm, we could improve the spatial resolution of reconstructed images. Further, by using the demagnifier, we could obtain reconstructed images for a sample which was larger than the viewing field of the X-ray area sensor. The X-ray magnifier will open up new ways, for example, to improve the spatial resolution of pixel array detectors (PADs) for high-sensitivity and high-resolution phase-contrast X-ray imaging.

When an X-ray beam propagates through an object, its direction is slightly refracted by the object. X-ray angle-resolved computed tomography (CT) detects this small refraction using an analyzer crystal for tomographic reconstruction of the sample image. Since the refraction contrast is mathematically equivalent to the differential phase contrast, X-ray angle-resolved CT has much higher sensitivity to low-Z elements than conventional techniques based on absorption contrast.

In X-ray angle-resolved CT, the spatial resolution is often limited by the X-ray detector. For example, in an X-ray imaging system using a fiber-coupled CCD camera or a pixel array detector (PAD), the overall resolution is often limited by the pixel size of the detector. Another problem is that the sample size is limited by the viewing field of the detector. In principle, it is impossible to perform CT measurements with a sample that is larger than the viewing field of the detector. To resolve these problems, we have introduced an asymmetrically cut analyzer crystal which functions as either a magnifier or demagnifier [1, 2].

Preliminary experiments were performed at BL-14B. The white X-rays produced by the vertical wiggler were monochromatized by a pair of Si(111) crystals at a wavelength of 0.0766 nm. The experimental setup is schematically shown in Fig. 1. The incident beam was expanded and collimated in the horizontal plane by an asymmetrically cut Si(220) crystal. The X-rays transmitted through a sample were analyzed by a Si(220) analyzer crystal. In order to magnify or demagnify the sample image in the horizontal direction, asymmetrically cut crystals were used for the analyzer. For observing the sample images, we used a fiber-coupled X-ray CCD camera consisting of a Gd_2O_2S:Tb scintillator, a 1 : 1 glass fiber plate and a CCD. The pixel size of the CCD was 6.4 μm (H) × 6.4 μm (V) and the number of pixels was 1384 (H) × 1032 (V). The viewing field was 8.8 mm (H) × 6.6 mm (V) in size.

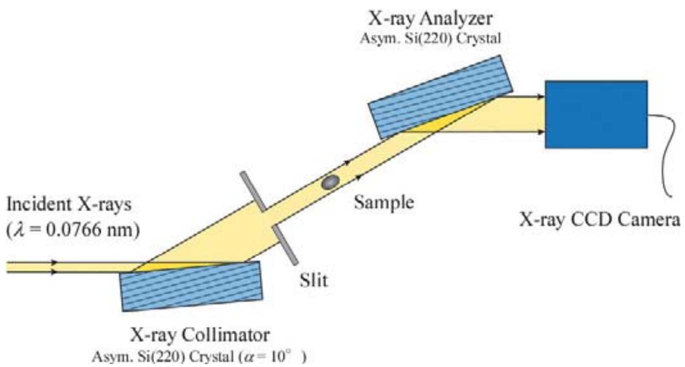

Figure 1
Experimental setup. The incident beam was expanded and collimated in the horizontal direction by an asymmetrically cut Si(220) crystal. The X-rays transmitted through a sample were analyzed by a Si(220) analyzer crystal. In order to magnify or demagnify the sample image in the horizontal direction, asymmetrically cut crystals were used for the analyzer. The sample images were observed with the fiber-coupled X-ray CCD camera.

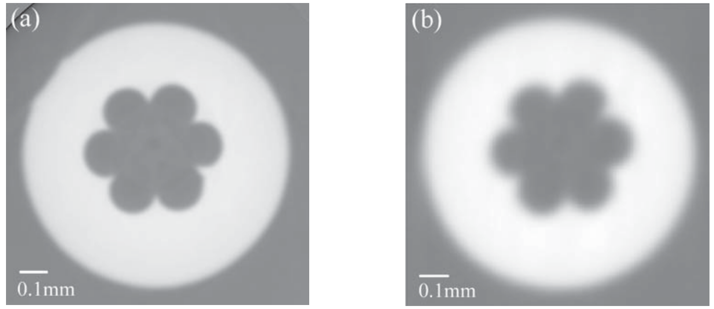

Figure 2
Reconstructed CT images of the plastic jacket of an electrical cable using the filtered back-projection method: (a) magnified image (m = 5.47) and (b) nonmagnified image (m = 1).

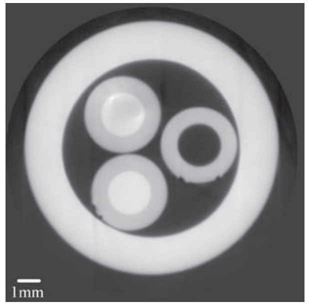

Figure 3
Reconstructed cross-sectional image of the sample using the demagnifier (m = 0.49). The sample consisted of an acrylic tube and three refills for a ballpoint pen. The size of the acrylic tube was 10 mm in diameter, and was larger than the viewing field of the X-ray CCD detector.

First, we carried out X-ray angle-resolved CT experiments using a magnifier. The calculated magnification ratio, *m*, was 5.47. The plastic sheath of an electrical cable was used as a sample. The sample was rotated around the vertical axis from 0 to 180° in 1° steps. At each angle, 21 images of the sample were recorded by the X-ray CCD camera, rocking the analyzer through the Bragg diffraction condition in 0.8-arcsec steps. The exposure time for each image was 4 s. The phase-contrast cross-sectional image of the sample was reconstructed using the filtered back-projection method, as shown in Fig. 2 (a). For comparison, a nonmagnified image was also obtained using a symmetric analyzer (*m* = 1), as shown in Fig. 2 (b). The spatial resolution was estimated to be 20 μm in the magnified image and 40 μm in the nonmagnified image. Although the magnification ratio was 5.47, the spatial resolution was improved only by a factor of 2. This was due to blurring of the image caused by the source size and by the X-ray penetration into the analyzer crystal.

Next, we carried out X-ray angle-resolved CT experiments using a demagnifier (*m* = 0.49). The sample consisted of an acrylic tube and three refills for a ball-point pen. The diameter of the acrylic tube was 10 mm. Note that it was impossible to perform tomographic reconstruction with the symmetric analyzer, because the sample was larger than the viewing field of the X-ray CCD camera. The procedure for the experiment was the same as that described above except that the exposure time for each image was set at 0.5 s. A cross-sectional image of the sample was successfully reconstructed, as shown in Fig. 3. The spatial resolution was estimated to be 112 μm.

REFERENCES

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[2] K. Hirano, *Jpn. J. Appl. Phys*. **50** (2011) 026402.

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K. Hirano (KEK-PF)