Quantitative Comparison of Imaging Performance of X-Ray Interferometric Imaging and Diffraction Enhanced Imaging

For detailed observations of biomedical and material samples by optimum phase-sensitive X-ray imaging, quantitative comparisons of two imaging methods—X-ray interferometric imaging (XII) and diffraction enhanced imaging (DEI)—were performed. The density sensitivity and spatial resolution of each imaging method were evaluated using phantom and biological sample tomograms obtained by each method under the same conditions. The results showed that XII has a higher density sensitivity (density resolution) than that of DEI and is thus suitable for observation of soft biological tissues. On the other hand, DEI has a wider dynamic range of density and is thus suitable for observation of samples with large differences in density.

Phase-contrast X-ray imaging, which uses the phase-shift caused by the sample as image contrast, is a powerful tool for biomedical and material imaging. The cross-section of phase-shift of light elements in the hard X-ray region is about 1000 times larger than that of absorption [1], therefore this method provides a way to perform detailed observations of samples consisting of light elements such as biological soft tissues and organic materials. To detect phase-shift, many phase-sensitive imaging methods have been developed (e.g. interferometry with an X-ray interferometer, diffractometry with a perfect crystal (expanded and called "diffraction-enhanced imaging"), a propagation-based method with a Fresnel pattern, and Talbot interferometry with a Talbot (grating) interferometer). However, the optimum imaging method for various samples is not known. To identify the optimum method, we quantitatively evaluated and compared imaging performance between two major methods: X-ray interferometric imaging (XII) and diffraction-enhanced imaging (DEI).

Figure 1 (a) shows a skew-symmetric two-crystal X-ray interferometer of the XII system used in this study [2]. The incident X-ray is separated by a wafer (indicated by "S" in Fig. 1(a)), reflected by M1 and M2 wafers, and recombined by another wafer ("A" in Fig. 1(a)) to produce interference beams. The sample is placed on the track of the object-beam of the interferometer, and the phase-shift caused by the sample is detected by the change of the interference beam intensities. Figure 1(b) shows a schematic view of the DEI system [3]. The X-ray that has passed through the sample is diffracted by a perfect crystal (analyzer crystal) and detected by an X-ray imager. By adjusting the crystal angle to satisfy the Bragg condition, the crystal functions as an analyzer of the X-ray diverged angle (*ds*) caused by the refraction of the sample. The *ds* is proportional to the spatial differential of the phase-shift, and therefore the phase map (spatial distribution of the phase-shift) of the sample can be obtained by calculating the integral of *ds*. The performance of each imaging method was evaluated using the same phantom consisting of polyethylene tubes (1-mm diameter) filled with saline solution. In addition, three-dimensional observations of formalin-fixed rat kidney were also performed. For precise comparison, the same measurement conditions, such as projection number and X-ray dose at the sample position, and the same X-ray imager were used. The observations were performed at BL-14C using 35 keV X-rays emitted from the vertical wiggler.

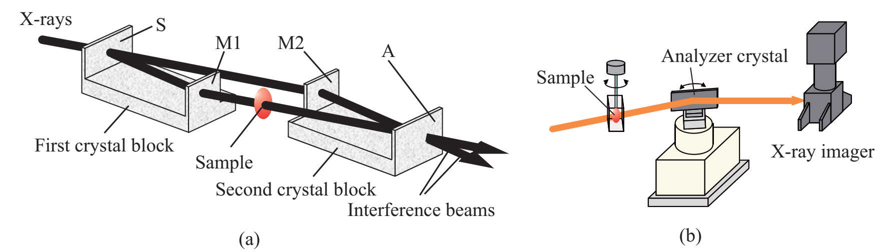

Figure 1
Schematic view of X-ray interferometer of XII system (a), and DEI system (b).

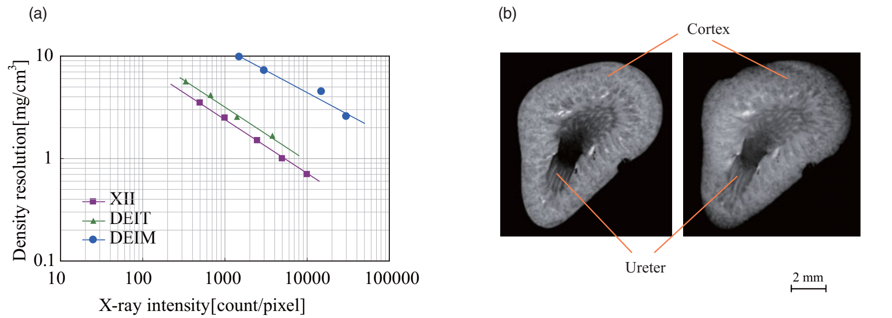

Figure 2
(a) Density resolution of XII, DEIT, and DEIM at each X-ray intensity, and (b) tomograms of rat kidney obtained using XII (left) and DEIT (right).

Figure 2(a) shows the obtained density resolutions of XII and DEI for X-ray intensities at the sample position. DEI measurements were performed in two different ways: the phase map was calculated by using either two diffraction images at the angle where the diffraction intensity was half the maximum (DEIT), or by using many images (9 images in this case) obtained by scanning the analyzer crystal throughout the rocking curve (DEIM). The density resolutions were calculated from the standard deviation of the background region in obtained tomograms. This result shows that the sensitivity of XII was the highest among these methods. In addition, the sensitivity of DEIM is about one fifth that of DEIT, because all the images (including those obtained at the angle far from the Bragg condition) were used to calculate the *ds* for a wider dynamic range of density. Figure 2(b) shows tomograms of a formalin-fixed rat kidney obtained using XII (left) and DEIT (right). The quality of the left image (XII) is better than that of the right image (DEIT), and cortex structures and ureters can be observed more clearly.

From these results, the following conclusions can be drawn. For XII, sensitivity (density resolution) is higher than that of DEI. It is therefore suitable for observations requiring high-density resolution such as visualization of β-amyloid plaques of Alzheimer's disease. For DEI, sensitivity is lower than that of XII, but the density dynamic range can be expanded by increasing the scanning angle. It is therefore suitable for observing samples including regions with large differences in density such as bone and soft tissues. By selecting the suitable imaging method according to the above findings, phase-contrast X-ray imaging can be used for detailed observation of biomedical samples.

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