X-ray Talbot Interferometry for Phase Imaging

Using phase information is a key in the modern X-ray image science. Biological soft tissues can be observed without using contrast media, and various phase-sensitive X-ray imaging methods have been reported so far. We have proposed and demonstrated X-ray Talbot interferometry (XTI) as a novel and simple phase-sensitive imaging method, three-dimensional imaging with which is also feasible [1,2].

XTI is based on the Talbot effect by a transmission grating. The Talbot effect is a self-imaging phenomenon observed at specific distances downstream from a grating illuminated coherently. For instance, although no contrast is detected just behind a phase grating, the pattern of the grating becomes visible at a distance determined by the wavelength of illumination and the period of the grating. The image is called the 'self-image'. It should be noted that the self-image is deformed when a sample is placed in front of the grating due to the refraction at the sample.

XTI employs another grating (G2) as shown in Fig. 1. The position of G2 is selected so that the self-image of G1 is formed on G2. A moiré pattern showing the self-image deformation is observed by the superposition of the self-image and G2. The contrast generated by XTI corresponds to the differential phase shift caused by a sample.

We prepared transmission gratings by forming gold stripes on thin glass plates by optical lithography. The height of stripes of G1 was 1.25 μm so that the π/2 phase shift was generated for 0.1 nm X-rays maximizing the contrast of the self-image. The height of stripes of G2 was 8 μm, which was a marginal value attained by optical lithography, so that the amplitude modulation power of G2 was as high as possible. Figure 2(a) shows an image obtained by XTI for a plastic sphere 1.2 mm in diameter. Structures seen in the sphere are air bubbles. Using a phase-shifting technique, the differential phase shift caused by a sample could be calculated from multiple images acquired by displacing G2 against G1 as indicated by an arrow in Fig. 1. A resultant image mapping the differential phase shift is shown in Fig. 2(b). Because the phase shift can be obtained by integrating Fig. 2(b) as shown in Fig. 2(c), a three-dimensional image mapping the refractive index (Fig. 2(d)) could be reconstructed from images such as Fig. 2(c) measured in multiple projection directions by rotating a sample (phase tomography). A phase tomogram maps the refractive index difference, and the noise level of the tomogram was 5×10^{-9} (standard deviation), which corresponds to the detection limit of the density deviation of 4 mg/cm^3.

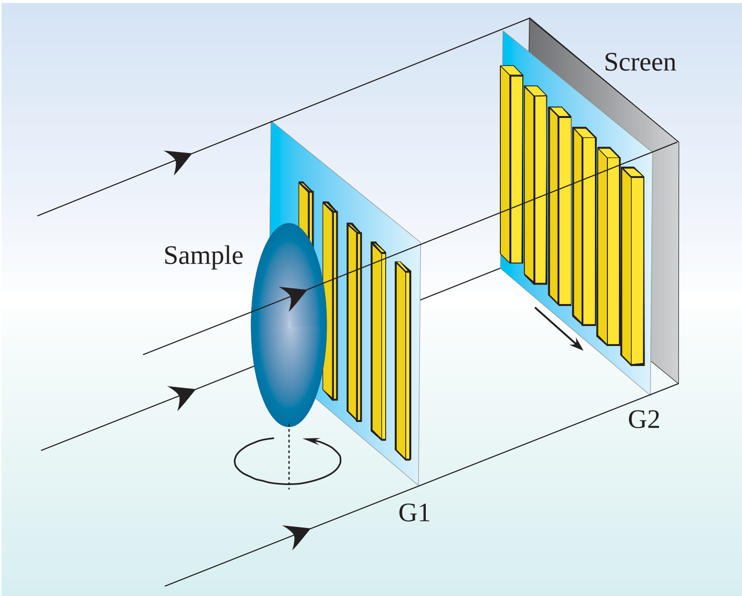

Fig. 1. Setup of an X-ray Talbot interferometer. Transmission gratings (G1 & G2) are aligned with a separation corresponding to the distance at which the Talbot effect by G1 occurs. A contrast corresponding to the differential phase caused by a sample placed in front of G1 is observed behind G2.

One advantage of XTI is that no crystal optics is used. This implies that a divergent X-ray beam with a broad energy band is available, provided that its partial spatial coherency is assured to some extent. Therefore, XTI would be practical with X-ray sources other than synchrotron radiation sources.

However, a technical problem to be solved for future applications is the fabrication of a better amplitude grating for G2. Because of high penetration power of hard X-rays, patterning with a high aspect ratio should be attained. The LIGA process would be a suitable technique for overcoming this difficulty, and a preliminary study for fabricating such a grating for XTI is in progress.

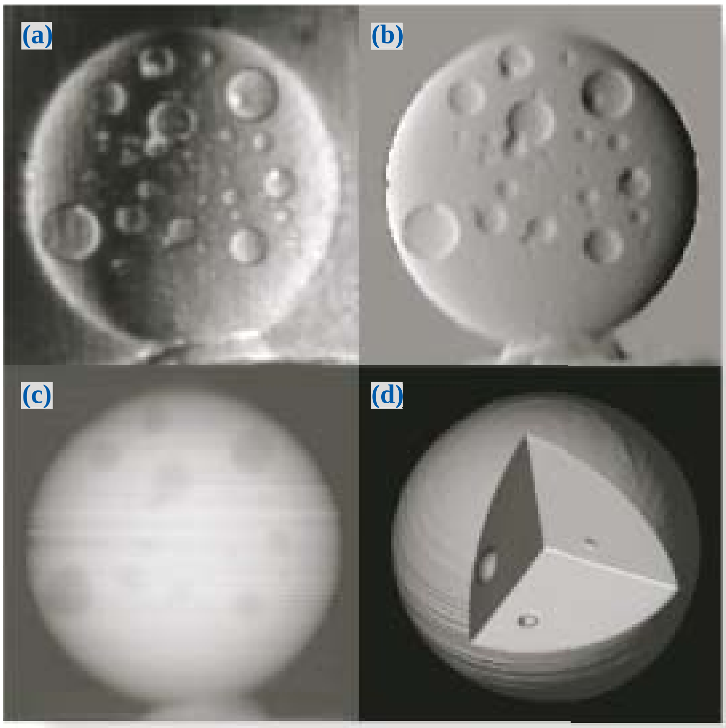

Fig. 2. Images obtained for a plastic sphere 1.2 mm in diameter: **(a)** a raw image generated by the X-ray Talbot interferometer, **(b)** an image mapping the differential phase shift measured by the phase-shifting technique, **(c)** a phase map obtained by integrating **(b)**, and **(d)** a three-dimensional rendering view of the data reconstructed by phase tomography. Structures seen in the sphere are air bubbles.

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References

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