Unique Recovery of Complex Transmissivity using X-ray In-line Holography and Two-beam Interferometry

In-line holography is most promising in the hard X-ray region because it requires only one propagation-based phase contrast image and no optical elements. Difficulty in the in-line holography is the overlapping of conjugate images, which is known as the twin image problem. The elimination of the conjugate image is usually achieved either by (i) using multi-holograms at different distances between samples and recording media [1] or by (ii) giving up the in-line scheme and employing two-beam off-axis holography [2]. Both of these are inapplicable to the objects having larger size than the field of view of the detector. The above problems, however, can be solved by a combined use of the in-line hologram and the shearing interferograms [3,4]. By recording them at the fixed sample and detector positions, the missing phase of the in-line hologram is determined. Deconvolution of the propagation from the sample to the detector, uniquely determines the exit-face wave field, in other words the complex transmissivity, of the sample without the overlap of conjugate images. The samples larger than the field of view of detector are measurable with a high precision.

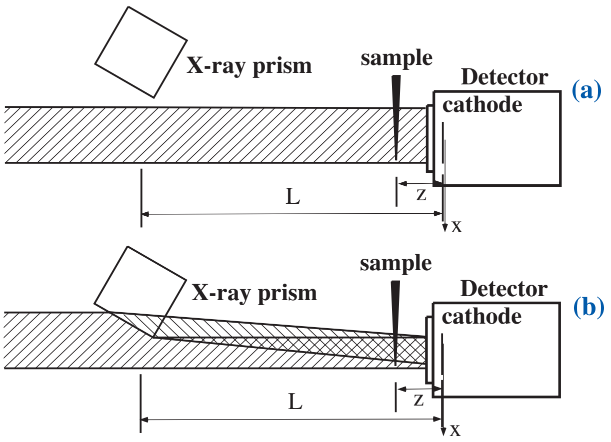

Fig. 1. Schematic experimental setup of **(a)** the X-ray in-line holography mode and **(b)** the X-ray shearing interferometry mode.

The experiments were performed at the undulator beamline **BL20XU**, using 12.4 keV X-rays. By placing the 20 µm-width cross slits about 200 m upstream of the experimental station, the coherence length of ~1 mm was achieved in two dimensions. The in-line holography mode and the shearing interferometry mode can be switched by insertion and retraction of an X-ray prism into the beam (Figs. 1(a) and 1(b)). In the X-ray shearing interferometry, the X-ray prism was inserted in the beam at $L = 6$ m and the sample was placed in the overlap of the two beams in the proximity of the detector at $z = 0.1$ m (Fig.1 (b)). The deflection angle of the X-rays was adjusted to $\Delta\theta = 23$ µrad for observing fringes with the spacing of 4.4 µm, which gives the width of the interference region of $L\Delta\theta = 140$ µm. The phase was determined by the fringe scanning method using the translational movement of the prism. The used detector was a modified version

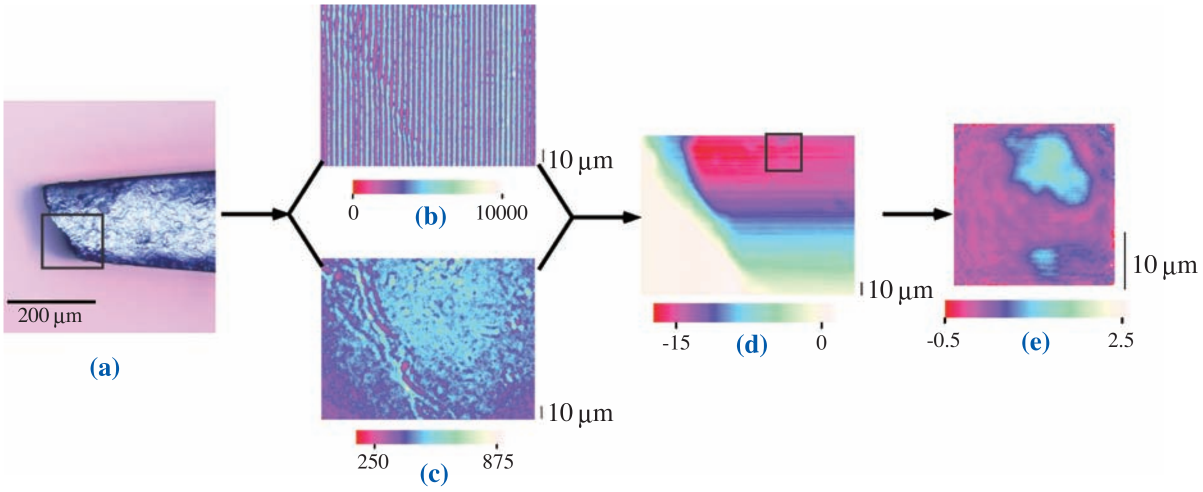

Fig. 2. Images of beryllium foil A. **(a)** Visible microscope image, **(b)** shearing interferogram, **(c)** in-line hologram, **(d)** phase image at the detector in wide field of view and **(e)** exit-face phase image for the box region in Fig. 2(**d**). The units of the phase images are radians. Bright spots in **(e)** correspond to defects with reduced thicknesses.

of Hamamatsu C5333 zooming tube having the spatial resolution higher than 1 μm. Samples were beryllium (Be) foils including defects, partly because the defects in them affect the coherence of the X-ray beam in the beamlines [5]. The size and the density of defects were quantitatively measured for (*A*) a hot-pressed powder Be foil (240 μmt) and (*B*) an ingot Be foil (180 μmt) from Brush Wellman Electrofusion Products, U.S.A.

Figures 2(b) and 2(c) show the X-ray shearing interferogram and the in-line hologram of the foil A. From the phase integrated from the differential phase (Fig. 2(b)), and the amplitude (derived from Fig. 2(c)), the complex amplitude at the detector plane is derived. By deconvoluting the propagation along distance *z*, the exit-face wave field (or the complex transmissivity) of the sample is uniquely determined (Fig. 2(e)). In Fig. 2(e), two defects with the size of around 4 and 7 μm (FWHM) are observed. The change of optical thickness at these two defects correspond to the reduced thickness of 6 and 12 μm assuming $\delta = 2.2 \times 10^{-6}$ for beryllium. Similar analysis was done for the foil *B*. Figure 3(d) shows the exit-face phase image where several defects are observed with reduced thickness. The size of typical defect is around 3 μm (FWHM). The change of optical thickness correspond to the reduced thickness of 3 ~ 7 μm at the defects assuming the same δ. The observed defects are generally smaller and thinner for the ingot foil than for the hot-pressed powder foil.

The simple experimental setup enabled us to uniquely determine the exit-face wavefield (or complex transmissivity) of samples larger than the field of view of detector. This method is applicable to samples with size variations, due to the tunable field of view of the zooming tube and the adjustable interference region size. The method is powerful for visualizing the phase objects such as the defects in low-Z material as in this research. We are planning to improve this technique for measuring more uniform foils such as the beryllium foils recently developed by the physical-vapor-deposition (PVD) method [5].

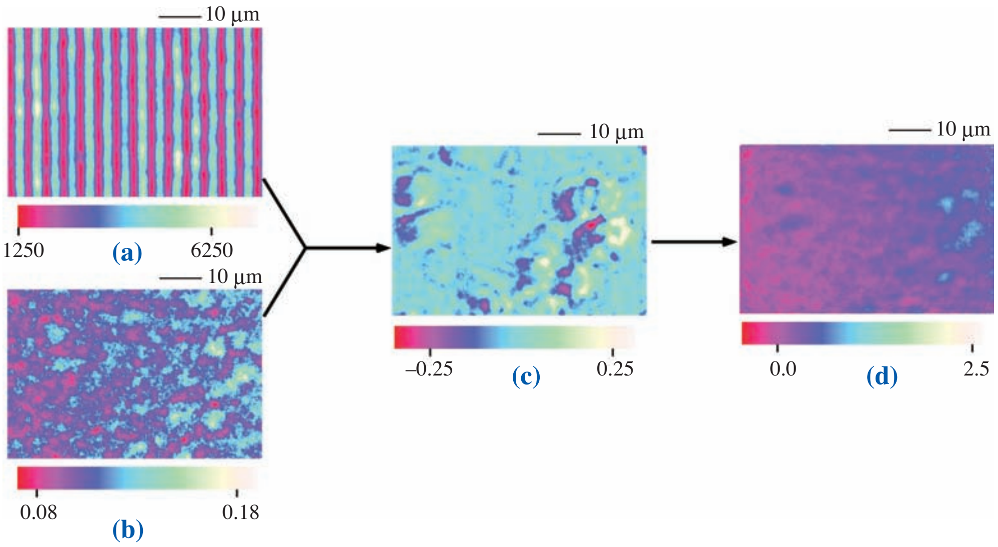

Fig. 3. Images of beryllium foil B. **(a)** Shearing interferogram, **(b)** in-line hologram, **(c)** differential phase image on detector plane and **(d)** exit-face phase image. The units of the phase images are radians. Bright spots in **(d)** correspond to defects with reduced thicknesses.

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References

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