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Sensitivity of X-ray Phase Imaging with X-ray Talbot Interferometer

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Introduction

We have been developing an X-ray Talbot interferometer for new-type phase-sensitive X-ray imaging and tomography [1,2]. An X-ray Talbot interferometer consists of two transmission gratings aligned in line along the optical axis, and differential phase imaging can be performed. Its sensitivity to soft materials is considered to be between those achieved by the conventional absorption-contrast method and by a two-beam interferometer, such as a Bonse-Hart X-ray interferometer. We report a comparison between the differential phase contrast and conventional absorption contrast both from theoretical and experimental points of view.

Theoretical description

In Talbot interferometry, one can obtain differential phase maps $\varphi(x, y)$ by fringe-scanning method. The error $\Delta\varphi(x, y)$ caused by photon statistics is given by $\Delta\varphi = d\sqrt{q_0}/\left(\sqrt{8}q_1 z_p N\right)$, where q_0 and q_1 are Fourier coefficients of moiré fringes generated by the Talbot interferometer. N, z_p and d is the number of photons per pixel of an image detector, the distance between two transmission gratings, and the pitch of the gratings, respectively. Consequently $\Delta\varphi$ is related to the detection limit of the difference in the refractive index $\Delta\delta$, which is given by $\Delta\delta = \lambda\sqrt{q_0 D}/\left(\sqrt{32}\pi q_1 d\sqrt{Nt}\right)$, where D and t are the pixel size and the typical structural size to be observed.

In the case of absorption-contrast imaging, the detection limit of the difference in the imaginary part of the complex refractive index $\Delta\beta$ is also determined by N, and given by $\Delta\beta = \lambda/\left(4\pi t\sqrt{N}\right)$. As a result, a proportional relation $\Delta\delta = \sqrt{q_0 Dt}\Delta\beta/\left(\sqrt{2}q_1 d\right)$ is found between $\Delta\delta$ and $\Delta\beta$. This equation gives a criterion of superiority of Talbot-type phase imaging as shown in Fig. 1. Although Talbot-type phase imaging is not as sensitive as with a Bonse-Hart interferometer, which is about a thousand times more sensitive than the absorption-contrast method, one can benefit the high sensitivity of the Talbot-type phase imaging when small structures are observed with small pixel size. In addition, it should be noted that the superiority of the differential phase contrast over the absorption contrast depends on the combination of matirials.

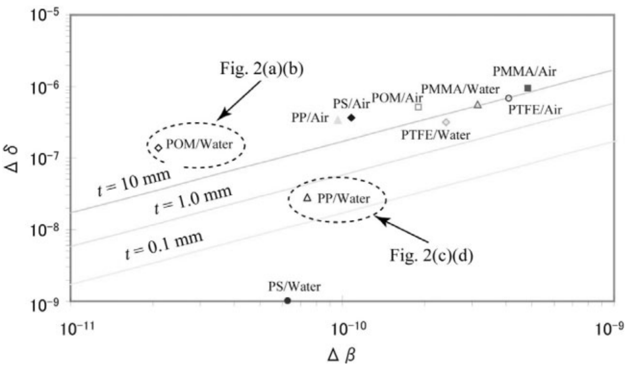

Fig. 1 Criterion lines in assumption of the coherence at BL-14C1 with some Δδ-Δβ values for some materials combinations. E = 25 keV, D = 50 µm, and d = 5.3 µm.

Phantom experiment

We performed an experiment to check the criterion using polymer spheres in air or water. A flat-panel sensor (Hamamatsu, C9728DK) whose pixel size was 50 µm was used.

Figures 2(a)(c) shows images of $\varphi(x, y)$ of POM (poly-oxymethylene) and PP (polypropylene) in water. Figures 2(b)(c) shows corresponding absorption-contrast images (strictly $-\log[I(x,y)/I_0(x,y)]$). Consistently with the chart (Fig. 1), fine structures (bubbles) were revealed clearly for the POM/water case by Talbot interferometry.

References

[1] A. Momose et al., Jpn. J. Appl. Phys. **42**, L866 (2003)
[2] A. Momose et al., Jpn. J. Appl. Phys. **45**, 5254 (2006)

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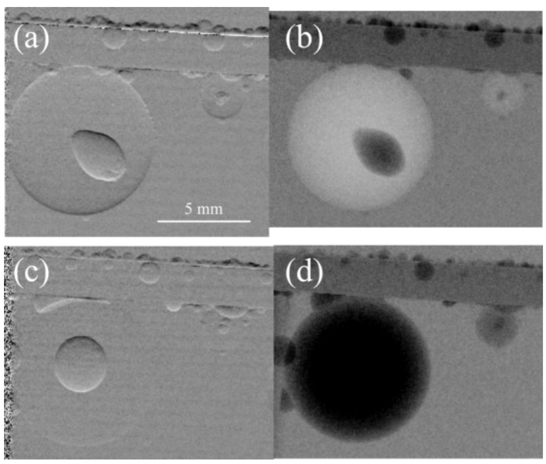

Fig. 2 POM sphere (a, b) and PP sphere (c, d) in water observed by Talbot interferometry (a, c) and conventional absorption-contrast method (b, d) at 25 keV.