X-ray Talbot-Lau Interferometer for Time-Resolved Imaging of Soft Materials

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Soft materials are composed of low-Z elements that weakly absorb x-rays, hence giving poor contrast in conventional x-ray imaging. For low-Z elements, the x-ray scattering cross sections responsible for x-ray phase shifts are a thousand times higher than absorption cross sections. For the past years, X-ray phase contrast imaging and tomography has therefore become a valuable tool in non-invasive visualization of soft materials [1]. In particular, the Talbot and Talbot-Lau interferometers which are composed of transmission gratings and measure the differential x-ray phase shifts have gained popularity because they operate with polychromatic beams [2, 3]. Taking advantage of the high-flux of white synchrotron radiation, the X-ray Talbot interferometer has been demonstrated for high-speed differential phase imaging at 2000 fps and x-ray phase tomography with 1 second time resolution [4, 5]. At the Photon Factory, the Talbot interferometer is located 37 m from the source and the spatial coherence of the synchrotron radiation is sufficient only for horizontally oriented gratings. Consequently in the previous experiments, the sample rotation axis during tomography had to be horizontal. In many cases, the observation of dynamic phenomena in materials necessitates a vertical axis of sample rotation. In this work, an X-ray Talbot-Lau interferometer was constructed so that the gratings and the sample rotation axis during tomography could be oriented vertically. An average of 20% moiré fringe visibility was obtained and the set-up was demonstrated for high-speed phase tomography of a polymer sample.

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2. A. Momose, S. Kawamoto, I. Koyama, Y. Hamaishi, K. Takai and Y. Suzuki, *Jpn. J. Appl. Phys.* **42**, L866-L868 (2003).
3. T. Weitkamp, A. Diaz, C. David, F. Pfeiffer, M. Stampanoni, P. Cloetens, and E. Ziegler, *Opt. Express* **13**, 6296-6304 (2005).
4. A. Momose, W. Yashiro, H. Maikusa, and Y. Takeda, *Opt. Express* **17**, 12540-12545 (2009).
5. A. Momose, W. Yashiro, S. Harasse, and H. Kuwabara, *Opt. Express* **19**, 8423-8432 (2011).

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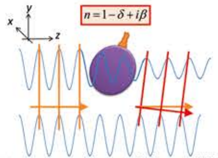
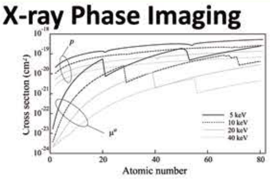
X-ray Absorption vs. X-ray Phase Imaging



X-ray absorption and phase shift due to an object

$$\log T(x,y) = -\int \mu(x,y,z)dz$$

$$\Phi = -\frac{2\pi}{\lambda}\int \delta(x,y,z)dz$$



X-ray Absorption Contrast

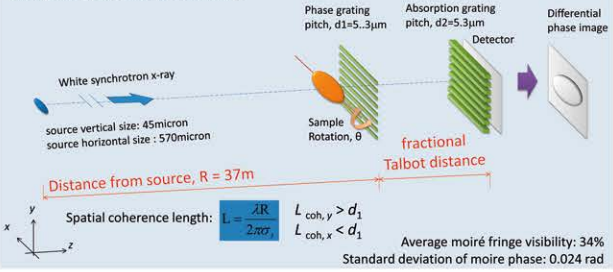
X-ray Differential Phase Contrast

For low-Z elements, the x-ray scattering cross sections responsible for x-ray phase shifts are a thousand times higher than absorption cross sections. In the past years, X-ray phase contrast imaging and tomography has become a valuable tool in non-invasive visualization of soft materials [1]. In particular, the X-ray Talbot and Talbot-Lau interferometers which are composed of transmission gratings and measure the differential x-ray phase shifts have gained popularity because they operate with polychromatic beams [2, 3].

Previously: X-ray Talbot Interferometer for High-speed Phase Imaging and Tomography

- ❖ The full brightness of white synchrotron radiation was utilized for high-speed and time-resolved phase imaging.
- ❖ Differential phase images with an exposure time of 1msec and 0.5sec tomography were obtained [4, 5].

ONLY the vertical spatial coherence requirement is satisfied.
The gratings has to be horizontal.



Spatial coherence length: $L = \frac{\lambda R}{2\pi\sigma_i}$ $L_{coh,y} > d_1$ $L_{coh,x} < d_1$

Average moiré fringe visibility: 34%
Standard deviation of moire phase: 0.024 rad

What is the problem?

◆ horizontal axis of rotation → unwanted motion in samples due to gravity →
→→resulting to blur in the tomographic reconstruction
◆ for the observation of phenomena in fluids, vertical axis of rotation is a must!

It is possible to orient the CT scan rotation axis perpendicular to the gratings. BUT, the integration of the differential phase images before the reconstruction of the tomograms proves to be cumbersome and sometimes impossible.

References

1. A. Momose, *Jpn. J. Appl. Phys.* **44** 6355- 6367 (2005).
2. A. Momose, S. Kawamoto, I. Koyama, Y. Hamaishi, K. Takai and Y. Suzuki, *Jpn. J. Appl. Phys.* **42**, L866-L868 (2003).
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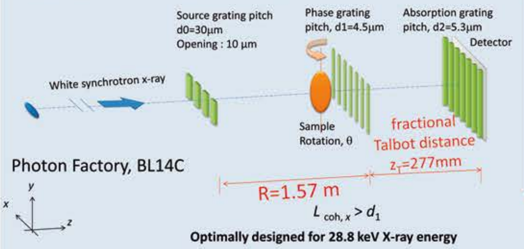
Experiment Design: X-ray Talbot-Lau Interferometer

- ❖ The absorption grating upstream the Talbot interferometer act as vertical line sources of horizontally spatially coherent white synchrotron radiation

The horizontal spatial coherence requirement is satisfied.
The gratings and the sample rotation axis can be vertical.



Photon Factory, BL14C

$L_{coh,x} > d_1$

Optimally designed for 28.8 keV X-ray energy

$$\frac{d_0}{d_2} = \frac{R}{z_T}$$

$$\frac{d_1}{d_2} = \frac{R}{R+z_T}$$

$$d_0 = \frac{d_1 d_2}{d_1 - d_2}$$

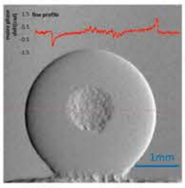
Source grating
Fabricated via X-ray lithography and electroplating of Au on Si substrate
Au thickness: 110μm, Grating area: 5 mm
Average transmission at the central part of the grating (measured using white synchrotron radiation): 44%

Detector: 20 μm-thick Y3Al5O12:Ce phosphor screen, a coupling lens system and a CMOS camera

Sample: 3.2 mm PE Sphere

Results

Moire fringes

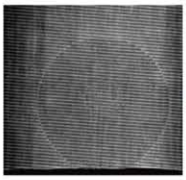


Differential Phase

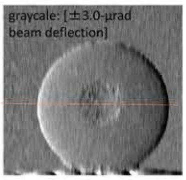
	Average visibility	Standard deviation of Moiré phase
Talbot interferometer	34%	0.02 rad
Talbot-Lau interferometer	20%	0.07 rad

High-speed Phase Imaging via Fourier Transform Method

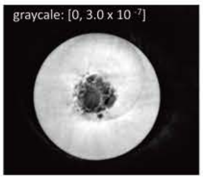
❖Carrier fringe period: 75 microns; Fringe visibility: 8.3%.
❖ Finer carrier fringes are desirable for better spatial resolution but it reduces the fringe visibility and the sensitivity to the detection of φ
❖ 500 projections/ 360° rotation; Exposure time per projection: 1.96 msec



Carrier Fringes



Differential Phase



δ(x, z) Tomogram Slice

◆ Ring artifacts in the tomogram are caused by the non-uniformities in the gratings.

Conclusion

The horizontal spatial coherence of white synchrotron radiation has been improved for the operation of the Talbot interferometer by adding an absorption grating upstream. The set-up which comprises the Talbot-Lau interferometer has allowed for a vertical orientation of the gratings and the CT sample rotation axis. An average moiré fringe visibility of 20% was observed. High speed tomography of a polymer sphere was demonstrated via the Fourier transform method at 500 projections/ sec. This result shows the feasibility of the set-up for future high-speed and time-resolved phase imaging of non-rigid and fluid samples.