Interferometer-based X-ray Phase-contrast Imaging
A Feasibility Test at Beamline 1BM

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Introduction

In a simple x-ray transmission imaging experiment, contrast arises from the differences in the refractive index between different object areas. Absorption (index imaginary part) and phase (index real part) contrast mechanisms are both present in the images. The contribution of the real part, compared to the imaginary part, becomes predominant at higher energy (1-100 keV) and lower sample electronic density, by several orders of magnitude, allowing consequently a lower radiation dose, which is crucial in life sciences for instance.

The availability of third-generation x-ray sources, by virtue of their high brilliance, made possible the development of such techniques.

To obtain contrast related to x-ray phase shift, several techniques can be used, including diffraction-enhanced imaging, free space propagation, and interferometer-based techniques [1].

Two interferometric x-ray phase-contrast imaging techniques are being developed at the XOR sector one. In the first one, the phase is measured via simple in-line Fresnel propagation [2], whereas, in the second one, a triple Laue (LLL) silicon interferometer is used to measure the sample phase projections. Both techniques lead eventually to a tomographic reconstruction of the 3-D electron density distribution of the sample.

We report here our first test of a new interferometer as a phase-imaging device. A first set of tomographic data of a simple phase test object has been successfully taken using a skew-symmetric LLL interferometer (Fig. 1), the phase retrieved and the 3-D refraction index reconstructed. Improvements of the imaging capability of this system are in progress.

Methods and Materials

The appeal of the LLL-based technique is its high sensitivity and ability to measure the phase directly. All other techniques are only sensitive to the first or second derivative of the phase. Its drawbacks include the size limitation for the sample, and the poor resolution (few microns) due to the Borrmann effect in the last blade of the interferometer. The beam being split and combined using three Laue transmission diffractions makes the high flux of the source a critical parameter for high-quality data; the stability of the beam is another very important criterion.

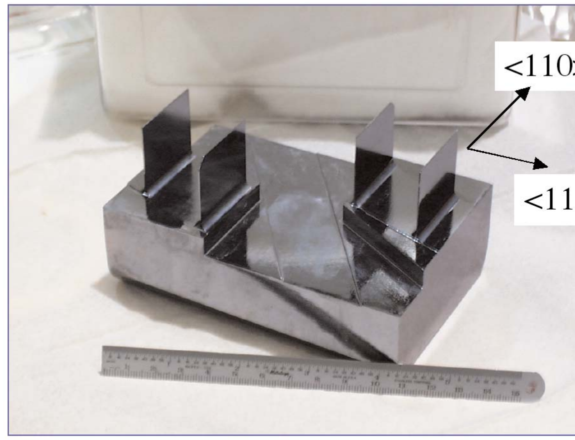

FIG. 1. Skew-symmetric LLL silicon interferometer

The skew-symmetric configuration was first used by Bonse and Hart [3]. It allows more room for the sample compared to the classic LLL. The general setup is shown in Fig. 2.

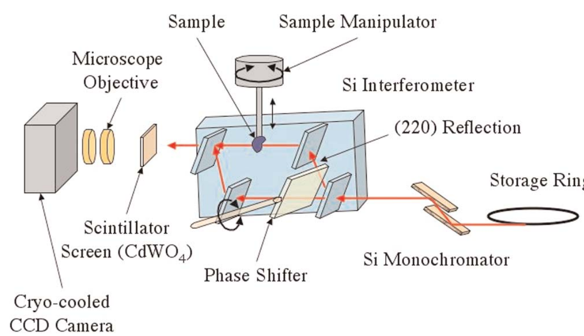

FIG. 2. Principal components of the phase-contrast tomography setup.

The role of the interferometer blades is to coherently split the incoming monochromatic beam (18 keV in our case) into two sub-beams, then superpose them again at the exit to form the interference pattern that carries phase-contrast encoded information about the sample. The pattern is recorded by an area detector consisting of a scintillator, the optical lens, and the CCD detector. The sample is placed in one of the two long parallel beams, the other beam is used as a reference. Typical interferograms are shown in Fig. 3. The sample was a plastic hollow tube, 3 mm in diameter. The field of view of the detector was only 1 mm by 1mm. Four samplings were necessary to map the entire specimen.

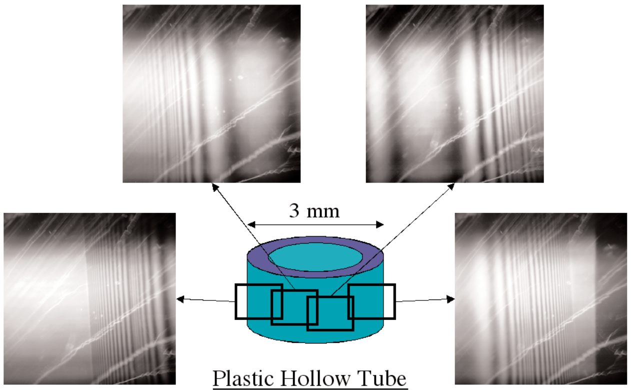

FIG. 3. Raw phase projections, as seen with the CCD camera.

Results and Discussion

One phase projection consists of four pairs of “associated” radiograms in the sense that one is taken with, and the other without, the specimen in the beam. Between pairs, a parallel-sided phase-shifter plate is rotated for changing the relative phase (a) of the two interfering beams by multiples of π/2 rad (Fig. 4).

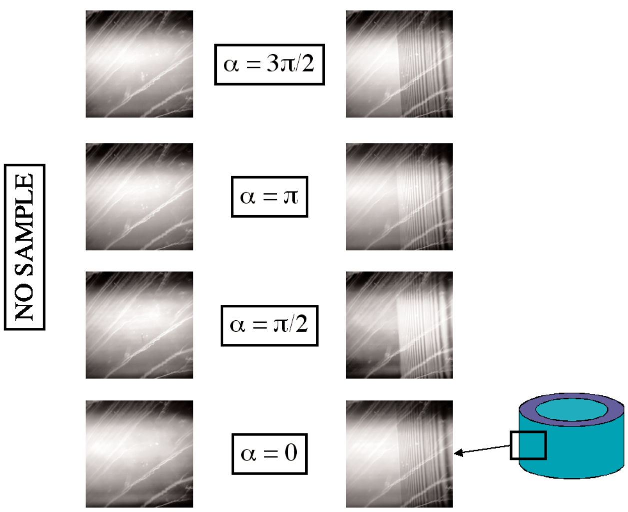

FIG. 4. The four associated pairs of interferograms, necessary for one phase projection (see text).

By calculating phase-weighted sums of all associated pairs of radiograms, true phase shift (modulo 2π)

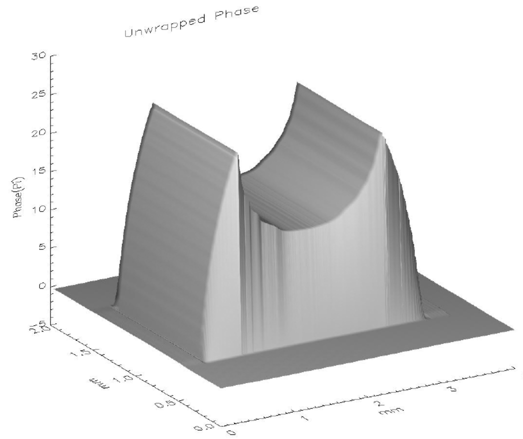

FIG. 5. Unwrapped (one) phase projection of the entire hollow tube, (x,y) in mm, (z) in π rad.

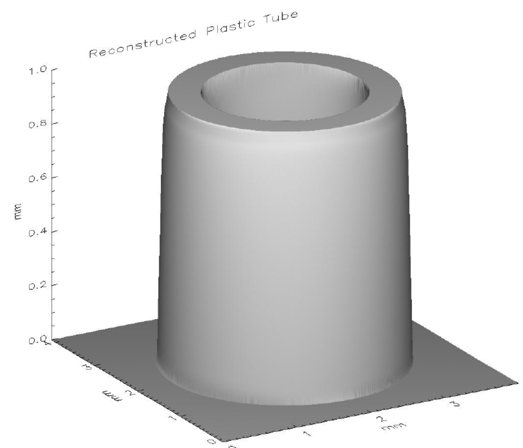

FIG. 6. 3D rendering of the reconstructed refractive index of the plastic hollow tube, 3 mm outer diameter, (x,y,z) in mm.

projections are obtained for all angular settings. Then an appropriate “phase unwrapping” algorithm is applied to remove the 2π ambiguities from the phase projections (Fig. 5), and then only, can tomographic reconstruction be done [4].

Figure 6 shows the reconstructed 3D hollow tube. The volume represents a constant value of the refractive index close to what we expected (~ 10^{-7}).

We showed with this example that an interferometer with a 30% contrast is sound and this phase-imaging technique is feasible at 1BM. Long-term stability of the beam needs yet to be addressed and improved to make this technique available for general users.

Acknowledgments

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References

[1] See for example A. Momose et al., *J. Syn. Rad*. **5**, 308-314 (1998) and references within.
[2] M.W. Weatneat et al. *Science* **299**, 558-560 (2003)
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