X-ray interferometry development at the Advanced Photon Source

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Introduction

The triple Laue (LLL) interferometer is one of the most used x-ray interferometers, be it in ultra-precision metrology [1] or in imaging techniques [2]. The advantage of the LLL interferometer is that it can be used within a wide range of energy and is easy to manufacture compared to other interferometer types. As a first attempt into x-ray interferometry, we have tested a triple Laue interferometer and measured contrasts better than about 90% when sliding a plastic wedge into one of the two interfering beam paths.

The LLL is interesting when a high spatial resolution is not needed. We were able to measure the angle-dependent phase of the forward Laue diffracted beam through a (220) oriented diamond crystal inserted in one of the arms of the interferometer. However, the Laue transmission geometry has two drawbacks: (1) absorption loss in each of the blades and (2) loss of spatial resolution due to the Borrman broadening in the last blade. These two disadvantages can be overcome by using all-Bragg reflection interferometers. One such design was proposed by Graeff and Bonse [3]. The main idea was to simultaneously excite two complementary [Si(440) and Si(404)] atomic planes in Bragg geometry to split the beam and gather them again after several Bragg reflections. The built-in spectral window of such a dispersive device is extremely narrow (compared to the LLL) and it only works at a particular wavelength. This makes it relatively difficult to operate and puts stringent requirements on the crystal. We fabricated a simplified version of this with no movable parts (see Figure 1).

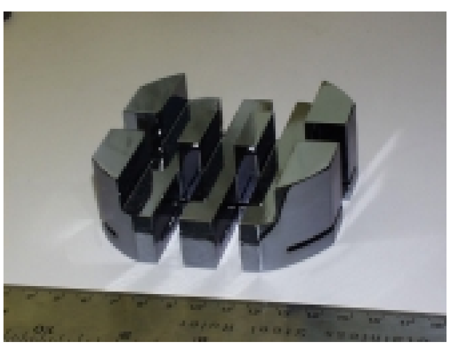


Figure 1: Four-Bragg-reflection silicon crystal.

In this paper, we report the initial test results of this interferometer at 7.46 keV, as well as (for the first time to our knowledge) at the higher energy of 14.91 keV [using the Si(880) and Si(808) reflections] where the spectral acceptance is about one order of magnitude smaller.

Methods and Materials

The interferometer was tested on the SRI-CAT 1-ID beamline at the Advanced Photon Source (APS). A double-crystal monochromator, which diffracts vertically with Si(111) crystals, was upstream of the interferometer. The interferometer itself diffracts in the horizontal (electron orbit) plane and was housed in a Plexiglas box to minimize air-flow-induced instabilities. For an incoming photon rate from the monochromator of about 10^{13} ph/s, the transmitted rate was about 10^{8}–10^{9} ph/s.

Results

<u>Contrast measurement at 7.46 keV</u>

Figure 2 shows the setup used to measure the contrast obtained through a 50 µm aperture in front of an ionization chamber detector while sliding a 4º plastic wedge in one arm of the interferometer. A thin piece of plastic attenuator in the other arm compensates for the absorption loss through the wedge.

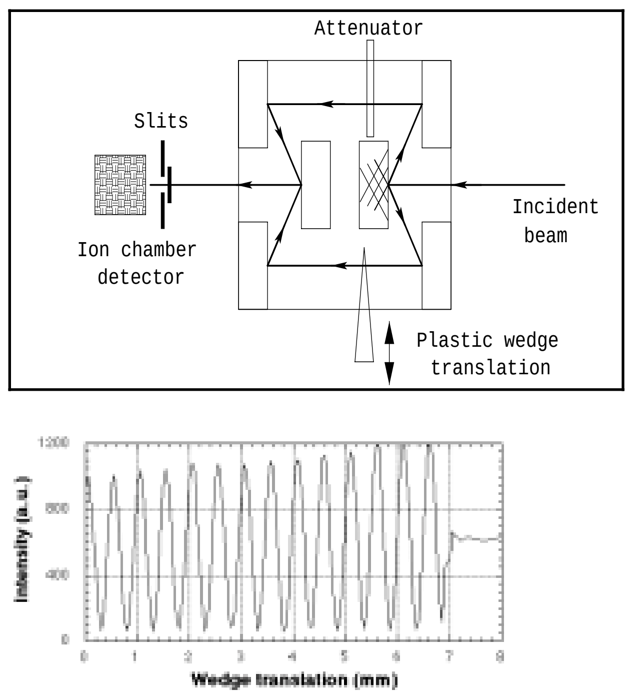


Figure 2: Wedge contrast setup top view (top) and the fringes obtained with the wedge (bottom).

The measured contrast was about 93%. The small increase in the contrast (Figure 2) at larger wedge translation (where the wedge becomes thinner) is an absorption effect. The contrast reaches its peak when the two interfering beams have equal amplitudes. The crystal contains residual strains, either from the fabrication process or slight imperfections in the silicon material itself. This was observed as Moiré fringes in the transmitted beam.

Phase contrast imaging

With minor changes in the setup, three methods of phase-contrast imaging techniques [2, 4, 5] were used. The sample was nonabsorbing animal cancer cells deposited on a thin plastic film. The first type of phase-contrast image is a Fresnel (or propagation) image [4], when the sample is downstream of the crystal with the CCD camera at 30 cm from the sample. Here the interferometer is irrelevant, and only the lateral coherence of the beam matters. Fresnel images are sensitive to sharp phase jumps, and the edges are well enhanced. These enhancements come from the interference between the distorted and undistorted wave fronts (assuming a plane wave) at the edge of a phase object.

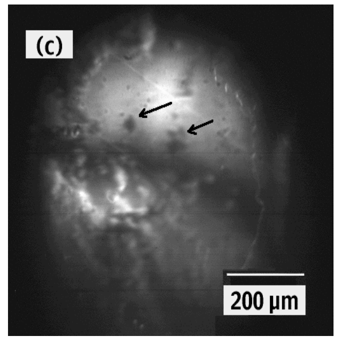
The second type of phase contrast image is an angle-resolved or differential phase image [5]. The sample is placed in one arm of the interferometer while the other arm is blocked. A phase gradient across a wave front is equivalent to a change in the local propagation direction of the wave [6]. Thus, using a crystal reflection as an angular analyzer, one can detect the small angular deviations of the beam and, thus, detect the edges of the phase object (or location of the phase jumps). In the interferometer, the reflections after the sample act as such angle analyzers. The contrast in the cells is in the horizontal plane, which is the diffraction plane of the setup.

The third type of phase contrast image (Figure 3) corresponds to a pure phase or a holographic image, where interference occurs between an object and a reference beam. When a point-to-point interference occurs between an object wave going through the sample and a reference wave, the contrast is due only to the local optical thickness of the sample. The dark horizontal strip in this image is a Moiré fringe. Unlike the previous two techniques, this method of phase contrast is sensitive to *all* phase changes and not just to sharp phase jumps (edge detection). Thus, smooth changes in phase can be detected. Although the quality of these first images is not great, they provide a qualitative comparison of the different methods of phase contrast imaging.

Measurement at 14.46 keV

Although this interferometer was originally designed to work at 7.46 keV using Si(440)/Si(404) reflections, it is sometimes useful to be able to work at a higher energy. The ratio between the sensitivity of phase contrast and absorption is proportional to the x-ray energy, and beam-path absorption (air) losses are smaller for higher energy. Thus, we proceeded to test the interferometer at 14.91 keV, using the Si(880)/Si(808) reflections.

At this higher order reflection, the interferometer spectral transmission is about $\Delta\lambda/\lambda \sim 2 \times 10^{-7}$. For an incoming photon count rate (14.91 keV) of about 10^{13} ph/s, the transmitted count rate was about 10^{7} ph/s. Figure 4 shows a Moiré pattern at 14.91 keV, from the Si(880)/Si(808) reflections using dental film. An 8º plastic wedge was inserted to cover half of one of the arms of the interferometer. The resulting effect of this linear phase gradient is a tilt of the fringes, which confirms that the Moiré pattern is indeed a two-beam interference effect. No fringes were seen with one arm of the interferometer blocked.



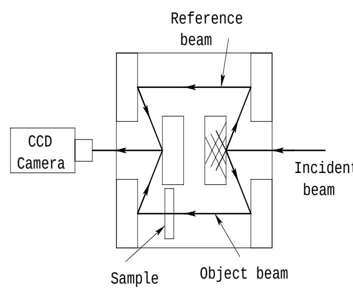
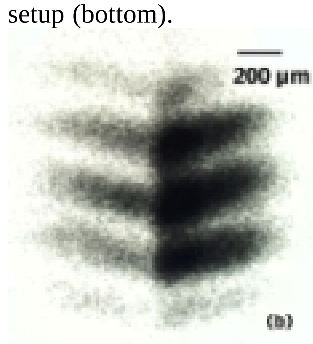


Figure 3: Holographic imaging. CCD picture (top) and setup (bottom).



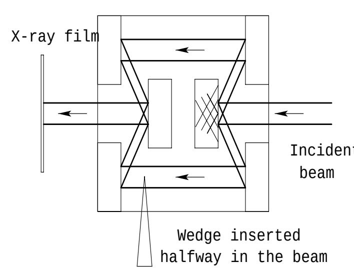


Figure 4: Crystal Moiré fringes with a plastic wedge halfway into one beam.

Discussion

The use of only external Bragg-reflected beams, like in the BBBB interferometer, allows for less absorption loss and higher spatial resolution than the transmission setups (useful for imaging). We have started using asymmetric crystals to enlarge the usable beam size over several millimeters (~ 10 mm) for large samples. High-contrast Moiré patterns over the whole expanded beam have been obtained. With new crystals and designs, we hope to reduce the residual strain of the interferometer so as to avoid the Moiré pattern and obtain a clean, flat field of view.

Acknowledgments

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