ESRF

Experiment title:

TOMOGRAPHY OF PHASE OBJECTS
WITH HARD SR X-RAYS

Experiment number:
M I 109

Beamline:
ID19/BL16

Date of Experiment:
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9

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Report:

Phase contrast using hard X-rays at ID19

The present report is concerned with our experimental results on the transverse (or spatial) coherence of the monochromated beam and the associated phase-contrast effects. Such experiments represent an intermediate and necessary step towards X-rays phase tomography.

A companion report deals with applications of phase contrast imaging in materials science.

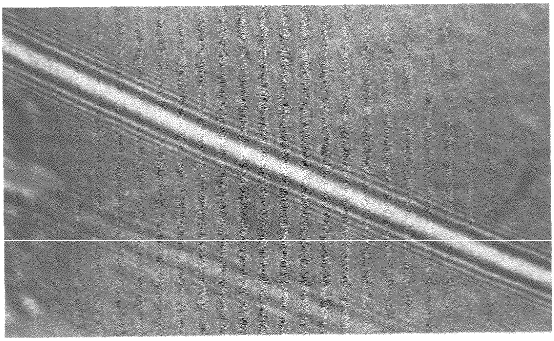
1) Phase contrast perturbation of diffraction topography images

We have observed the sensitivity of the monochromatic and highly parallel beam, now used in diffraction topography, to phase perturbations (due to the objects present in the beam, such as Be windows, filters, monochromator, investigated sample...) which produce Fresnel diffraction patterns on the topographic images. These undesirable effects should be partly eliminated by using polished Be windows. In order to reduce the transverse coherence of the X-ray beam, we have also used a “random-phase screen” (a rotating 60 µm thick plate of porous aluminium, for instance) , with the satisfactory result that spurious phase contrast could be eliminated, whereas the quality of the topographic images was well preserved.

An usual requirement in diffraction topography is that the surfaces of the investigated crystal and of the monochromator should be strain-free, but flatriess is not important. This is no more true when dealing with high quality crystals and a highly coherent beam. The figure presented hereafter shows a phase-contrast image of a scratch on a (111) Si crystal .

(Bragg symmetrical setting; sample-to-film distance ICO cm; $\lambda=0.7$ A)

100 µm



2) Determination of the coherence properties of the X-ray beam

ID 19 is a long beamline, with a wiggler source and a source-to-sample distance of 150 m, exhibiting unusually high coherence properties. It is of interest, for phase imaging applications, to have a measurement of the transverse coherence width d which is related to the beam angular size α and to the wavelength λ as $d= \lambda/2\alpha$. For this purpose, we have used the fact that a fringe pattern in a recording plane at distance D from the diffracting object should be washed out if the fringe spacing ε is smaller than αD. Since ε decreases steadily as we go to higher-order fringes, we obtain $\alpha=\varepsilon m/D$, where εm is the smallest fringe spacing which can be observed. We thus found that the horizontal angular size of the beam is 10^{-6} rd and that its vertical angular size is smaller than 3.310-7 rd (in this case, the measurement of εm was limited by the film resolution which is about 1µm). This corresponds, at the sample position, to a tranverse coherence width ranging from 50 µm in the horizontal direction direction to more than 150 µm in the vertical direction, when $\lambda=1$ A.

3) Phase contrast imaging and phase reconstruction

Valuable information on the internal structure of a transparent object is contained in the phase modulation of the coherent X-ray beam. The image formation is fully explained, in terms of classical optics, by the coherent wave propagation in free space from the object to the recording plane. The “images” are actually Fresnel diffraction patterns. From a qualitative point of view, the contrast is most directly related to phase edges (boundaries of the sample, or boundaries of regions of the sample corresponding to different thicknesses or to different values of the index of refraction).

In order to determine the phase distribution quantitatively, we must use several images recorded at different distances D from the object. This work is presently, in our group, under developments which include the digitalization of images recorded on a high-resolution film (the resolution of a CCD camera appears to be insufficient for this kind of work), with proper account of the film sensitivity curve and of the “flat-field correction”, and the adaptation of a numerical algorithm successfully used in electron microscopy by the group of Prof.Van Dyck (Antwerp, Belgium).