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Methods of angular scanning in X-ray imaging and topography

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Abstract

In an imaging experiment with the use of X-ray topography or phase contrast techniques, generally, the result is a single image, which represents the internal structure of the object. However, identification of the features of the observed structure is a challenge. In these methods, an important parameter is the scattering angle, and methods based on its variation are being actively developed, making possible to obtain a scattering characteristics for each local region of a sample. The present paper discusses the results of applying the methods of the angular scanning to some experiments on synchrotron topography and analyser based imaging.

Keywords: X-ray imaging, topography, analyzer based imaging

1. Introduction

The task of the X-ray visualization experiment is to identify some of the structural details of an object, whether it is an experiment on diffraction topography or transmission imaging. These details of the structure, generally speaking, are heterogeneities of the objects. Interaction of radiation with an object containing heterogeneities is always accompanied by scattering at angles determined by the properties and size of heterogeneity. In this regard, X-ray imaging techniques, comprising angular sensitivity, are recently actively developed both in topography, and in transmission imaging.

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In topography image of a crystal is formed due to the existence of long-range deformation field in the crystal associated with defects (dislocations, segregations etc.), as well as due to the bending of the whole crystal. Deformation fields, as a rule, lead to a local increase in the reflectivity of the crystal that forms a contrast in images. Changing in the rocking curve by the defect is determined by the deformation magnitude, type of the defect and other factors (Bowen and Tanner, 1998). Getting local rocking curves, called the method of quantitative topography was done previously (Lübbert et al. 2000, Kaloyan et al. 2016).

When forming a transmission image of the object in the analyzer based imaging (ABI) in the case of weak absorption the decisive role is played by the refraction of the beam and its small-angle scattering (Podurets et al., 1989, Chapman et al., 1997, Bravin et al., 2007). These two cases correspond to a shift of the scattering curve and its broadening, the last is determined by the average deviation of the beam at the single heterogeneity and their number (Podurets, 1995, Kaloyan et al. 2014).

Thus, to characterize the nature of the features revealed in X-ray imaging it is very useful to have information about X-ray scattering of the feature.

2. Experimental

A method which combines imaging and examination of scattering over a wide angular range is the double-crystal (+ -) diffraction in which the first crystal is monochromator. In the topographical survey the second crystal is the sample, and absence of dispersion is desirable, which is a condition of the minimum contribution of the monochromator to the width of the rocking curve. For ABI scheme the two identical perfect crystals is used, and the object under investigation is located between the crystals. As a result of the experiment the three-dimensional data set is obtained, which is the series of images taken at different angles of the second crystal.

Experiments were carried out at the "Mediana" station of the Kurchatov synchrotron radiation source. Images were recorded with two-coordinate detector based on CCD – matrix of 4008 x 2672 dimensions, GdOS:Tb-screen and pixel size of 8.9 microns. Flat silicon crystals were used as monochromators. The rotation of the crystal was controlled by a piezo actuator with feedback sensor. Image processing and construction of local scattering curves out of the series of images by averaging the intensity in a selected area and correlating it with the value of the scattering angle was carried out using the ImageJ software (Rasband, 1997).

3. Results

$ZnGeP_2$ crystals have non-linear behavior in the infrared region and are used for second harmonic generation (Nikogosyan, 2005), their properties depend on the quality of the crystal (Verozubova et al., 2010). For the experiment on quantitative topography at synchrotron radiation the silicon (511) asymmetric monochromator and close to the symmetric Laue reflection (336) of the sample were used, so the condition of almost zero dispersion was fulfilled. Radiation energy was E = 25 keV, the exposure time was 10 seconds. The total angular width of the reflection region was about 120 arcsec, because due to the macroscopic disorientation of different areas of the crystal they reflected non-simultaneously (Fig. 1). Series of topograms over a whole angular range of reflection was obtained, image of the crystal representing the distribution of the crystal integral reflectivity was got by summing up all that topograms, images of the crystal representing the local maximum intensity and the width of the rocking curve were also obtained. The width of the rocking curve was estimated as the ratio of the integrated intensity and the peak intensity for a given location in the crystal. The crystals exhibit subgrains, growth striation, dislocation bundles, individual dislocations and other defects. However, the width of rocking curves around 2 arcsec in some areas showed high crystalline perfection. Noteworthy is a big difference in peak intensity and almost the same width of the rocking curve in growth striations. The results will be useful for the improvement of the growth process.

As an object for which small-angle scattering determines formation of the ABI image, a sample of artificial opal matrix was taken (Bardyshev et al., 2006). Images of the opal matrix (plate 1 mm thick) were registered using the double crystal setup with flat silicon crystals in symmetrical (400) Bragg reflection at an energy E = 25.8 keV, with an exposure time of 5 seconds near the peak and 60 seconds at the tail to prevent detector overflow. Visually the sample looks inhomogeneous, with grains of about 1-2 mm in size. X-ray images obtained with the rotation of the analyzer crystal, also display flickering areas of a similar size. The sequence of images taken with an increase of the