ESRF	**Experiment title:** Phase sensitive x-ray imaging with asymmetric Bragg reflection as magnification optics	**Experiment number:** Mi-827
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Report:

The aim of experiment Mi-827 was to test and apply methods of X-ray phase contrast imaging based on the use of two asymmetrically cut crystal analyzers as X-ray optical elements behind the sample. To this end, a turnkey instrument ('the Bragg Magnifier box') developed at our home laboratory was brought to the ID19 beamline. Installation of the instrumental hardware, including a Bruker CCD camera and the corresponding readout electronics, worked without any problem. We have used two asymmetric Bragg reflections with perpendicular diffraction planes in order to obtain two-dimensional magnification and phase sensitive imaging. This technique is an extension of analyzer-based imaging (ABI) into two dimensions.
To start, the interplay of our external hardware and software with the beamline control system was successfully tested. The necessary energy changes for realizing magnification factors in a range between 20 and 200 proved to be feasible in rather short time. A set of magnification ratios was selected consecutively and calibrated precisely with the help of a reference object (square grid).
After adjustment, the instrument provides three main scan modes for experimental measurements: distance scans, analyzer rocking scans, and object rotation (tomographic) scans. All three were used in this experiment and all in all we acquired 110GB of data.
Distance scans with simple geometrical objects (metal edge, square grid) served to investigate X-ray optical effects occurring due to the combination of Fresnel propagation and Bragg reflection. They are to be compared with a theoretical model developed by us beforehand, in view of shape and strength of fringes at object edges. A preliminary result of the comparison showed good agreement. In the end, this will provide valuable hints on the accuracy of the model and the optical parameters.
Subsequently, analyzer rocking scans and tomographic scans were performed on a set of several different objects, including bone, horse-tail plant, a specimen of honey-bee brain and an antleg.
For a typical synchrotron source dispersion is known to be the main disadvantageous influence on contrast formation in ABI. As long as the angular width due to a finite bandwidth (typically $\frac{\Delta\lambda}{\lambda} \approx 10^{-4}$) is comparable or smaller than the angular acceptance (in our experiment typically $50 - 100\mu rad$) of the used reflection, influence of dispersion tends to smear out contrast, while the general contrast distribution is preserved. However, the use of two reflections with perpendicular diffraction planes yields the possibility of reducing the observable bandwidth in the experimental images by introducing

an intentional angular offset between the two reflections. In the experiment we successfully reduced the observable bandwidth by about a factor of two.
In the experimental images both absorption and phase contrast are visible thus a naive tomographic reconstruction does not reveal quantitative but only geometric information about the sample. The main purpose of the experiment was to overcome this limitation and develop an algorithm for two-dimensional diffraction enhanced imaging (2D-DEI), which allows to separate absorption and phase contrast contributions to the images.
Therefore, we used an antleg as a typical biological sample and determined the achieved resolution in the images as a first step. A new method, recently developed by our group, for determining the achieved resolution in experimental images revealed an effective resolution of $(0.5 \times 0.6)\mu m$. However, so far the images were not corrected in respect to the finite response width of the CCD-camera and the according deconvolution will improve the resolution significantly (down to the effective pixelsize of $(0.1 \times 0.16)\mu m$).
Secondly, the to-be developed algorithm has to be validated. For this purpose we used the known multi-image approach to analyzer-based imaging (MI-ABI) and demonstrated its applicability to magnifying imaging with asymmetric reflections for the first time. The pixelwise comparison of the rocking curves with and without sample yields the possibility to separate absorption and refraction (i.e. derivative of phase) contrast. Figure 1 shows the refraction image obtained by applying MI-ABI on the experimental images. However, due to the comparable large amount of projection images, which have to be acquired (41 were used here), this approach is not suitable for tomographic reconstruction.
Thirdly, we used the proposed 2D-DEI algorithm for separating absorption and refraction contrast. Instead of 41 projections only four projections were used to obtain the refraction image shown in Figure 2. A comparison of Figure 1 ('exact' values) and Figure 2 clearly shows that the 2D-DEI algorithm works well within the known limitations of standard DEI.

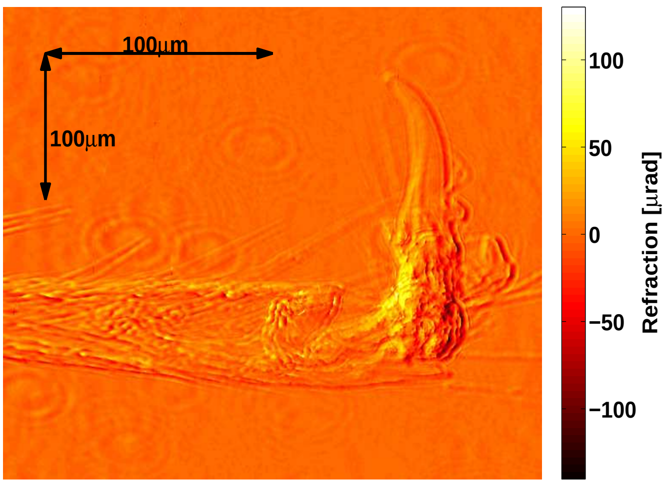

Fig.1: Refraction image from MI-ABI

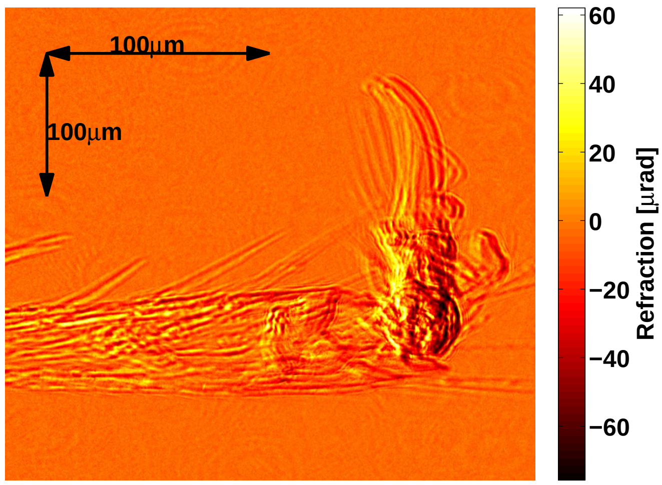

Fig.2: Refraction image from 2D-DEI

This proof of concept will allow us to realize quantitative three-dimensional reconstruction with high sensitivity to density variations present in the sample in future experiments.
Furthermore, the experiment also revealed that special attention to sample preparation of the brain of a honey-bee has to be made before three-dimensional reconstruction is possible.