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Application for beam time at ESRF – Experimental Method

This document should consist of a **maximum** of **two A4 pages** (including references) with a minimal font size of **12 pt**.

Investigation of Laue transmission case in diamond compound refractive lenses

Proposal Summary (should state the aims and scientific basis of the proposal) :

The current proposal is a continuation of the precedent study on diamond compound refractive lenses. With the advent of 4th generation synchrotron radiation and the X-ray Free Electron Laser (XFEL), deep insight into dynamical processes within small time scale has been provided. In the experimental set-up, compound refractive lenses (CRLs) are employed as an indispensable pre-focusing device. Compared with other X-ray focusing devices like Fresnel zone plates, KB mirrors and capillary lenses, CRLs have advantages of being compact, easy to align and being operated within a relatively wide energy range of X-rays. In particular, diamond could withstand extremely high heat and strong radiation loads while still providing effective focusing performance and is thus considered as an ideal material to focus X-ray radiation. The main purpose of the proposed experiment is to further investigate diffraction-induced effects on the transmitted (and refracted) intensity. In particular, as found in an ongoing theoretical development, the influence of sample orientation relative to the incoming beam plays an important role in describing the 'glitch spectrum'. In addition, the focal length and the intensity distribution on the focused plane can be readily obtained.

Scientific background :

The sample diamond parabolic X-ray refractive lenses [1-3] were manufactured in the laboratory with single-crystal diamond (HPHT grown, type IIa). Lenses were fabricated with laser cutting technique and lens profile of the paraboloid was polished by laser micro-machining technique to avoid spherical aberration. The Scanning Electron Microscope (SEM) images of the diamond lenses are shown in Fig. 1. Single lenses have various dimensions and parabola radii which are presented in Fig. 1. The average value of the web size between the parabola apexes is 60 ± 20 µm. Surface roughness at the apex of the parabola has been measured by the atomic force microscope (AFM) and it is in the order of ~ 1µm (peak-to-valley). For all lenses, the crystallographic planes are marked in Fig.1 and perpendicular to the diamond plate's side planes.

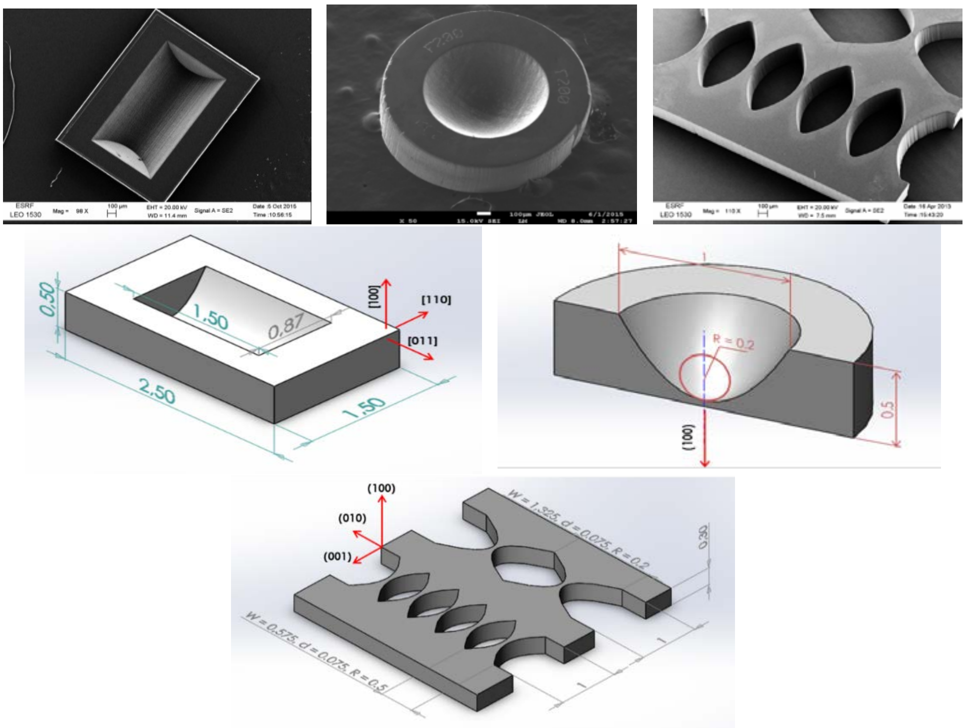

Fig. 1. SEM images and the sketches of the individual 1D *(left)*, individual 2D *(center)* and planar *(right)* diamond lenses. All dimensions are in mm. The crystallographic directions are marked by red. *R*, *d* and *W* correspond to the radius, web size and the thickness of the single double concave lens, respectively. R = 0.2 mm for the 1D and 2D lenses. [2]

There are many factors which account for the drop of transmitted intensity. The so-called ‘glitch effect’ [4] in the transmitted beam may thus have multiple causes. The obvious one being contributions owing to two-beam diffraction- but also multiple beam diffraction effects and divergence may play a role. As a first approach, we suppose that presence of X-ray glitches in the energy interval of 8-40 keV can be well explained by a simple ‘dynamical’ Ewald’s construction for the two-beam case. The method to approach the problem of the “transmission glitches” is simply by applying a matrix formalism of Bragg’s law, where we can follow the scattering contributions as a function of energy. However, we also allow for deviations of the sample orientation relative to the incoming beam direction. With the aid of a goniometer, we can quantify the deviation angles from the assumed ideal situation. Such a quantification is essential in order to be able to test the model tools under development. Therefore, it would be a good idea to revisit the measurements that Snigirev et al did on BM31 with the option of accurately orienting the CRL-sample.

Experimental technique(s), required set-up(s), measurement strategy, sample details (quantity...etc) :

We aim to investigate the loss of transmitted intensity primarily by Bragg diffraction and it is thus very important to precisely measure the orientation of the diamond lenses in advance. We propose to use 2-circle goniostat in addition to the φ-spinner available at BM31. After the sample stage, a two dimensional MAR detector may be used in order to determine more precise orientation of the sample lenses. Then we will perform energy scans with the monochromators in the optical hutch while recording both the transmitted through the CRL intensity and a diffracted signal. By using various slit systems available at the beamline, we should also be able to vary the collimation-thus assessing effects related to divergence. Before we utilize the polished lenses, we plan to use compact diamond (not ‘biased’ by any surface induced effects) as a sample to get some reference patterns. In this experiment, three different kinds of crystals are tested, they are 2D parabolic lenses, planar lenses on the same substrate and one half lens.

All the diamond CRLs will be put into a customized holder and can be easily mounted onto a goniometer head. No other material is present and there are no safety issues with all these samples.

Beamline(s) and beam time requested with justification :

BM31 (SNBL) with the MAR detector offers the optimum condition for the proposed experiment. With the goniometer, we may be able to obtain at least a crude orientation matrix of the samples. Allowing time for setup and calibration, 3 shifts should suffice for that part. To record the transmitted pattern of different diamond CRLs and at different energies and collimation conditions, several samples should be characterized, which calls for 6 shifts. We thus ask for **9 shifts**.

Results expected and their significance in the respective field of research :

We expect to scan the photon energy and get the glitch spectrum at some specific energy intervals. Our main goal is to investigate the influence of both the deviation angular parameters and beam divergence on the recorded pattern, which will then be compared with our computed spectrum. On one hand, the study of the presence of these effects and estimation of their relative influence will be useful for further improvement of the implement of refractive optics based on single crystals; On the other hand, the data sets from this experiment will be very useful as references for our current development of simulation tools for X-rays’ dynamical effects in interacting with single crystal-based CRLs.

References

1. Snigirev, Anatoly, et al., *A compound refractive lens for focusing high-energy X-rays.* Nature 384.6604 1996: p. 49-51.
2. Polikarpov, M., et al., *Large-acceptance diamond planar refractive lenses manufactured by laser cutting.* J Synchrotron Radiat, 2015. **22**(Pt 1): p. 23-8.
3. Terentyev, S., Blank, V., Polyakov, S., Zholudev, S., Snigirev, A., Polikarpov, M., Kolodziej, T., Qian, J., Zhou, H. & Shvyd'ko, Y. Parabolic single-crystal diamond lenses for coherent x-ray imaging// *Applied Physics Letters.* - 2015. – Vol. 107. – P. 111108.
4. Terentyev, S., Polikarpov, M., Snigireva, I., Di Michiel, M., Zholudev, S., Yunkin, V., Kuznetsov, S., Blank, V. and Snigirev, A., *2017. Linear parabolic single-crystal diamond refractive lenses for synchrotron X-ray sources.* Journal of Synchrotron Radiation, 2017. 24(1):p. 103-109.