EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office using the **Electronic Report Submission Application:**

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Reports supporting requests for additional beam time

Reports can now be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

Report:

As a continuation of previous experiments on sagittal focusing of synchrotron radiation (SR) by a diffractive-refractive x-ray lens (DRXL) the focusing of a broad beam on long distance using asymmetrically cut crystals is demonstrated. DRXL with sagittal acceptance of 200 µrad is presented. It is demonstrated both by the ray tracing simulations and by the experiment that a reasonably good sagittal concentration of 8 keV synchrotron radiation by the diffraction on the walls of the cylindrical groves drilled into Si crystals may be achieved. The groves were machined asymmetrically to (111) planes with the asymmetry angle $\alpha = 12.5$ degrees and their diameter, 22.79 mm, was chosen such that the focusing distance fits the geometrical arrangement of the optical hutches of BM5 beamline in ESRF. In our case the maximal focusing distance was about 21 m. We have used two such crystals in the dispersive arrangement. FWHM of the focus in sagittal direction is about 1.1 mm, which is twice as large as the ray-tracing simulations predicted. The focal spot size is about 6 times smaller than non-focused radiation spot. The intensity in the center of the focus is not considerably increased with respect to non-focused radiation.

1. Introduction

The utilization of refraction phenomenon for focusing of x-ray SR is now well established. Compound Refractive Lens (CRL) (Snigirev et al., 1996) is an analogue to the classical refractive lens in visible optics. It is relatively simple device, which works well for hard radiation. For longer wavelengths, however, the absorption in the material of the lens may deteriorate the intensity gain due to the focusing. To avoid this drawback rather sophisticated schemes were suggested (Lengler et al., 1999; Piestrup et al., 2000), which substantially reduce the absorption but the manufacturing of such lenses is arduous. The alternative way of SR focusing based on the refraction was proposed by Hrdý (Hrdý J., 1998). In his idea the refraction phenomenon occurring during Bragg diffraction is utilized. It was shown that radiation diffracted on longitudinal groove with parabolic profile machined into a single crystal monochromator is sagittaly concentrated (focused). Here the grooved crystal plays the roles of both x-ray monochromator and sagittaly focusing lens. There are no losses due to the absorption as in the case of CRL. At the same time it was shown that the best results are achieved when using the dispersive arrangement of such grooved crystals.

The sagittal focusing based on this idea was first experimentally demonstrated in National Synchrotron Light Source (NSLS) in the Brookhaven National Laboratory (Hrdý & Siddons, 1999) where 15 keV radiation was successfully focused at the focal distance 5 m after successive diffraction on four grooved crystal surfaces arranged in (-,+,+,-) position.

A grooved single crystal is relatively simple device but the production of the parabolic groove of given parameters needs to order a specially profiled tool (as we did) which is expensive and this tool could be used probably only once (or several times at the best case). In our recent work we show that in some cases a relatively good sagittal concentration of SR may be achieved by using the cylindrical shape of the groove instead of the parabolic one and that such a sagittaly focusing monochromator may be realized by a cylindrical hole drilled into a single crystal parallel with diffraction planes. In other words a hole plays a role of a channel with inclined walls. This work was done in ESRF in 2000 (the experiment MI-446). In this work we obtained very good coincidence between ray-tracing simulations and experimental results. The intensity in the focus was roughly 5 times higher than in the spot of non-focused radiation. (Artemiev N. et. al. 2001.)

Recently in (Korytar D. 2001) it was shown that in general case of Bragg diffraction, i.e. when working surface of a crystal is neither pure inclined nor pure asymmetrically cut with respect to the diffracting planes and the axis of incident radiation, the diffractive-refractive effect could be substantially enhanced.

In order to check the focusing ability of such optical elements, which utilize refraction phenomena occurring during Bragg diffraction, the special ray-tracing program was created.

2. Experiment description.

The draft of a crystal pair is shown in **Fig. 1.** The two working surfaces of the crystal are just parts of cylindrical holes, which were drilled into a Si single crystal. To decrease drastically linear sizes of the crystals the relative shift of the holes axes is 20.7 mm (see **Fig. 2**). Angle between axis of the groves and Si(111) planes is 12.8 degrees. To cancel large aberrations connected with the focusing surfaces profile, the crystals pairs were arranged into dispersive position shown in **Fig. 2**.
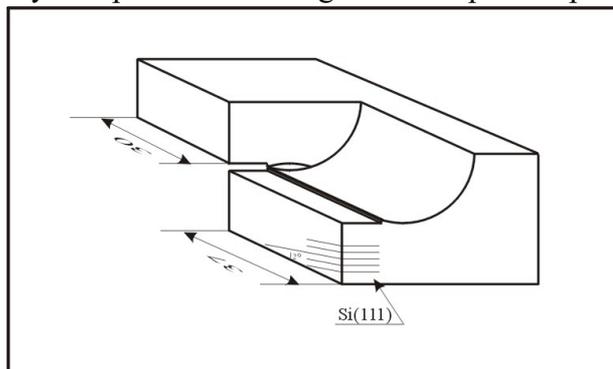
CRYSTALS ARRANGEMENT
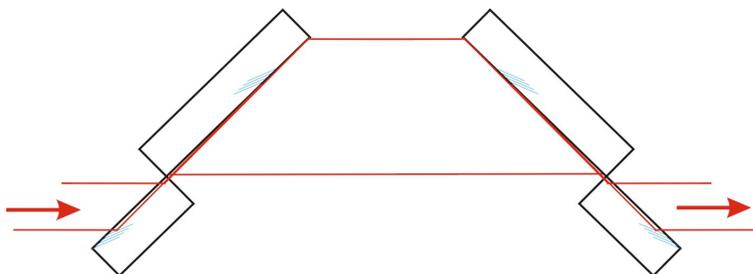
**Fig. 1**   **Fig. 2.**

Fine slits were installed on the same goniometer head 15 centimeters upstream the first pairs of crystals.

The first and the second pairs of crystals were mounted on the first and the second goniometer towers, forming DRXL. The distance between the pairs of crystals was about 0.5 m, which is roughly minimal distance between axes of the first and the second goniometer towers. The detector was positioned in two different points: first place was as close as possible after the lenses in the first optical hutch and the second place was at the focal distance of 20 m from the lenses in the second optical hutch of BM5. To decrease absorption of x-rays a long evacuated tube was installed between the lenses and the distant position of the detector.

3. Results and discussions.

The experimental snap shots of radiation, passed though DRXL are shown in **Fig. 3** and **Fig. 4. Fig. 3** presents a snap shot of radiation on close distance 15 cm after the DRXL, while **Fig. 4** shows an image of radiation, taken at the focal distance of about 20 m.
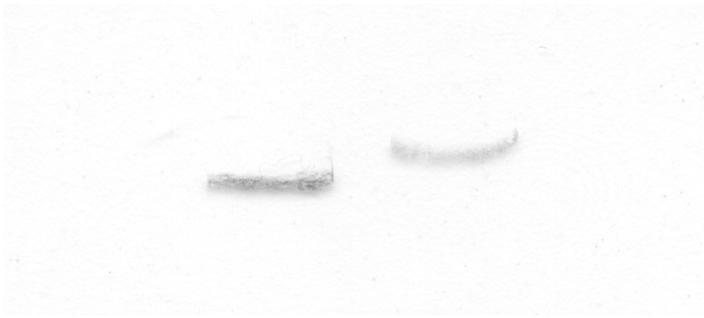
Fig. 3

Fig. 4.
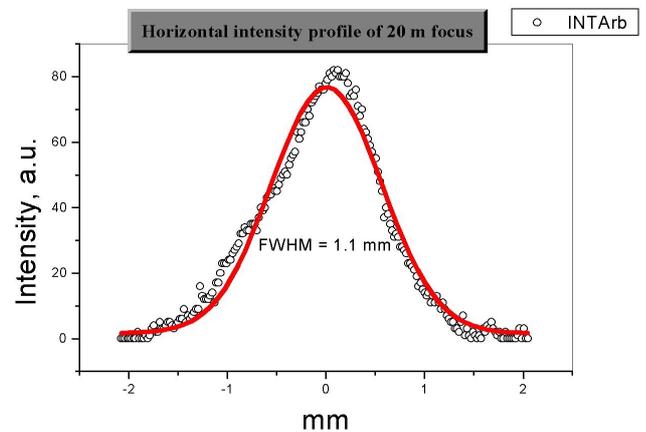
Fig. 3. Image of radiation, taken at 15 cm downstream the DRXL. Fig. 4. Image of radiation, taken at 20 m downstream the DRXL.

The horizontal strips on the left hand sides of these figures present the traces of radiation diffracted on flat, not-focusing parts of the crystals. These flat parts were made to help with alignment of the lens and to compare the intensities of focused and non-focused radiation. Right, slightly curved strip in **Fig. 3** is a trace of radiation, which was diffracted on focusing cylindrical groves. Unfortunately, it is seen that this lens is not free of aberration. It is because the distance between the pairs of crystals is not negligible and this lens could not be considered as a thin lens. The snap shot in **Fig. 3** was taken at so short distance after the DRXL, that focusing is practically negligible. The sagittal widths of both strips in this figure are roughly the same, which simplifies the comparison of focused and non-focused spots in **Fig. 4**. Due to natural divergence of the source sagittal width of the spot of non-focused radiation in **Fig. 4** is roughly 1.5 times larger, than that of in **Fig. 3**. The intensity profile and its Gaussian fit are shown in **Fig. 5**. FWHM of the focus in sagittal direction is about 1.1 mm, which is twice as large as the ray-tracing simulations predicted. The focal spot size is about 6 times smaller than non-focused radiation spot. The intensity in the center of the focus is not considerably increased with respect to non-focused radiation. Low gain in intensity could be explained by insufficient treatment of the working surfaces of the crystals. Quality of the working surfaces

Fig. 5. The intensity profile and its Gaussian fit of the focal spot

of such lenses could not be as high as in case of mirror optics. However, demands to surface quality increases in the case of high asymmetry. It can be explained as follows: under condition of high asymmetry in the case of Bragg diffraction, either incident or diffracted rays fall or leave the crystal under very grazing angle. If the crystal surface is not polished well and/or there are scratches introduced by machining process, then the rays, which run close to the surface under very small angles are spread and absorbed by these irregularities. Unfortunately, up to those experiment we didn't have an opportunity to treat the focusing crystal surfaces properly. The technology of mechanical-chemical polishing of Si single crystals and moreover their uneven surfaces is just under development in our group.

4. Conclusions.

The experimental results show that DRXL with large aperture appear to be feasible. The focused spot is 6 times smaller than that of non-focused. The intensity gain is hardly positive due to the crystals surfaces roughness. The experiment proved out assumption about low sensitiveness of such kind of focusing X-ray optics to the alignment in comparison with mirror x-ray optics. However, the demands to working surfaces unevenness appeared to be much higher, than we thought.

The advantage of this scheme is obvious: focusing and monochromotizing of synchrotron radiation is performed (during its monochromotizing) by the same optical elements.

So, we conclude that the experiment was rather successful and we intend to repeat this experiment on much higher level with the x-ray lenses of much better quality.

ACKNOWLEDGEMENTS.

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