Evaluation of Bragg-Fresnel Zone Plate for the Hard X-ray Focusing

Yoshiki KOHMURA, Tomoya URUGA, and Tetsuya ISHIKAWA

SPring-8 Project Team, The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-01, Japan

1. Introduction

Bragg Fresnel zone plates (BFZPs) are known to be a good tools for focusing hard X-ray in Synchrotron radiation [1,2]. They are particularly effective for 3rd generation low emittance rings. At SPring-8, BFZPs are planned to be used for producing a hard X-ray microbeams with high brilliance in the undulator beamlines[3]. For example, in the high pressure diffraction experiment, focus size of 1-80 μm is required at 20-40keV.

We collaborated with NTT-AT Co. to manufacture linear and circular BFZPs. These were characterised in terms of focusing capability. We designed a bender for 1-D X-ray focusing and the bent linear BFZP was evaluated.

2. Samples

Two types of the linear BFZPs and four types of the circular BFZPs were fabricated with the outermost zone width of 0.35 μm and 0.5 μm with an aspect ratio of ~5 and 8~10, respectively (see Table.1).

3. Experiments

3.1. Linear BFZP

As the first R&D of linear BFZPs, we tested the type 1 linear BFZP (Table.1) using a laboratory X-ray tube and a narrow slit (10 μm) as a virtual source. We tested the focusing characteristics in both sagittal and meridional geometries at the energy of 8 keV. In the sagittal geometry, we obtained the focus efficiency of ~20 %, which can presumably be raised to ~30 % by reducing the zone depth to the optimum depth of 1.3 μm. The obtained image size was ~8 μm (FWHM), in good agreement with the expected size of 8.9 μm (Fig.1).

In the meridional geometry, the focus efficiency was much worse and the profile manufested complicated interference patterns. We confirmed that this geometry is not suitable for the present focusing purposes.

3.2. Bent Linear BFZP

For two dimensional focusing, the type 2 linear BFZP (Table 1.) was bent. X-ray beam was focused in sagittal direction by the zone structure and in meridional direction by bending. A bender was designed, and the performance of the bent linear BFZP was evaluated using the laboratory X-ray generator and a narrow slit (10 μm × 20 μm) as a virtual source. A small spot with a size of 23 μm × 36 μm was obtained by focusing 17.4 keV X-rays with a radius of curvature of 6.6m (Fig.2). The curvature was well defined with good reproducibility of the focus size. The focus size in the sagittal direction was not largely affected by the change of curvature.

3.3 Circular BFZP

The four types of the circular BFZPs were evaluated in a back-reflection geometry at the BL 15C of the Photon Factory and at the laboratory X-ray source. In both experiments, the images obtained at focus showed a bright spot and the shadow area. However, an unexpected flat tail around the focus spot significantly degraded the focus efficiency. We are planning the second experiment at the Photon Factory coming spring.

4. Simulation for the Use in Undulator Beamline

We carried out ray-tracing simulations [4,5] for the following two cases to find out the best method of using BFZPs for focusing hard X-rays in a SPring-8 undulator beamline, (i) two linear BFZPs in a Kirkpatrick-Baez (K-B) configuration, and (ii) a bent linear BFZP. The obtained size and the efficiency are summarized in Table.2. By a single bent linear BFZP, we can obtain a point focus, two orders of magnitudes brighter than that of the unfocused beam, at the energy of 24 keV. We therefore conclude that a bent linear BFZP is one of the promising method for a point focusing in the energy range above 20 keV.

5. Summary

We evaluated a number of linear and bent linear BFZPs. We obtained a satisfactory imaging quality both with the linear and bent linear BFZPs. We are planning further investigations for the circular BFZPs.

We carried out ray-tracing simulation for the linear and bent linear BFZPs as the hard X-ray focusing element in a SPring-8 undulator beamline. We concluded that a bent linear BFZP is a promising method for a 2-dimensional focusing above 20 keV.

References

[1] A.Snigirev, Rev. Sci. Instrum. **66(2)**, 2053 (1995)

[2] A.Erko, Yu. Agafonov, L.A.Panchenko, A.Yakshin, P.Chevallier, P.Dhez, and F.Legrand, Optics Communications. **106**, 146 (1994)

[3] Y.Kohmura, T. Uruga, H.Kimura, K. Tamasaku, H.Yamazaki, and T.Ishikawa, Proc. SPIE, vol. 2856, 1996
[4] Y.Kohmura and T.Ishikawa, Proceeding of 145B Comittee Meeting, held by the Japanese Society for the Promotion of Sience (in Japanese), Nov., 1995
[5] Y.Furukawa, "RTW: Ray-Tracing program for Windows NT"

Table 1.

Sample parametersfor the preparedBragg Fresnel zone plates.

	Linear type1	Linear type2	Circular type1	Circular type2	Circular type3	Circular type4
x1,r1(μm)	7	5	10.31	10.31	7.02	7.02
xN,rN(μm)	69.6	35	105.6	105.6	49.1	49.1
Outermost Zone Width(μm)	0.35	0.35	0.5	0.5	0.5	0.5
No. of Zones	99	49	105	105	49	49
Depth of Zones(μm)	1.7	1.7	5.156	3.867	5.156	3.867
Crystal Plane	Si(111)	Si(111)	Si(444)	Si(333)	Si(444)	Si(333)
Optimum X-ray Energy(keV)	free	free	7.92(fix)	5.94(fix)	7.92(fix)	5.94(fix)
Focal Length(m)	0.318(8keV)	0.162(8keV)	0.68	0.51	0.31	0.24

Table 2.

Calculated focus size and efficiency in two cases using the Bragg Fresnel zone plates in the SPring-8 undulator beamline. A bent linear BFZP is used with zones for the vertical focusing and bending for the horizontal focusing. In both cases, Si(111) plane, a zone width of 200 μm, a zone length of 10 mm, and an X-ray energy of 24 keV are assumed.

	unfocused beam	Two Linear BFZPs in K-B Configuration	Bent Linear BFZP
Focus Position from undulator source(m)	(42m)	42.24	42.24
Horizontal Spot Size (FWHM, μm)	2100	4.75	16.4
Vertical Spot Size (FWHM, μm)	670	0.88	0.44
Throughput(%)	100	0.025	0.085
Relative Brilliance	1	84	166

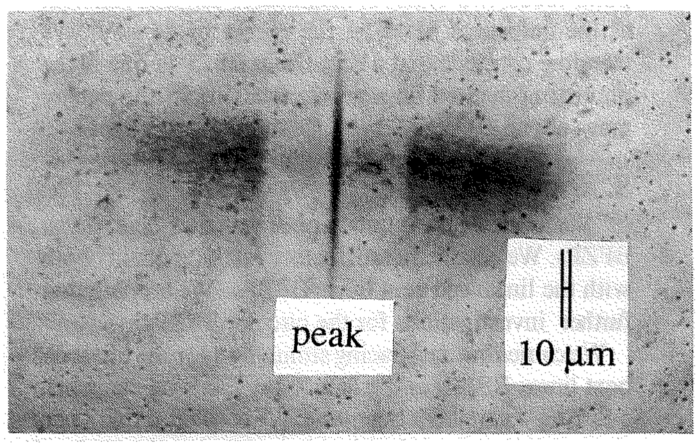

Fig.1.
At-focus X-ray image obtained with the type 1 linear Bragg Fresnel zone plate. An X-ray film of Fuji #80 was used.

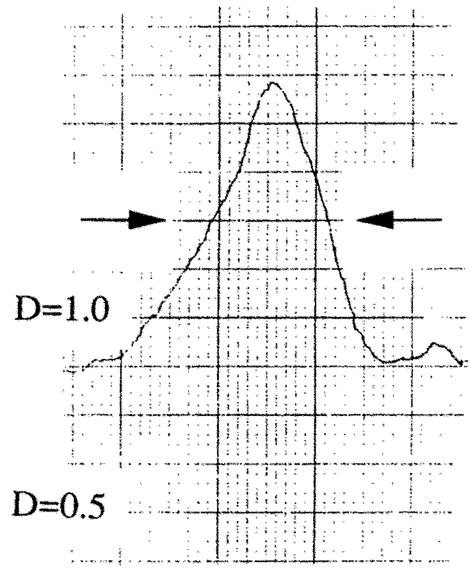

Fig.2.
One-dimentional densitometer profile observed for at-focus X-ray image with a bent linear Bragg Fresnel zone plate in sagittal configuration. The pairs of arrows show the full-width-half-maximum with a horizontal scale corresponding to 2 μm.