Hard X-ray Focusing by High-Reflectivity Non-Planar Supermirrors

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1. Introduction

For experiments that require high flux of hard X-rays with a fixed focal position, focusing device using non-planar supermirrors is one of the promising method. 1D focusing was achieved by bending a supermirror sample on a silicon wafer and X-rays from a laboratory X-ray tube was line-focused. The effect of the bending on the reflectivity was also measured.

We found that the obtained reflectivity doesn't fit well with the theoretical model unless a small surface roughness and high packing density (filling ratio) of the layered materials are assumed. We measured the surface roughness using atomic force microscope which indicated that the surface roughness of the sample is as small as 2 Å (rms) for the samples on silicon wafer and silicon blocks. Here we report our X-ray tests and the evaluation of the layer surfaces.

2. Samples

B_4C and W layers are deposited with the layer thickness parameters following the equation,
$d_i=a(b+i)^{-c}$,
where a and c are positive constants and i is the layer pair number counted from the top. The sample supermirror was deposited on a silicon wafer (190mm× 15mm×0.65mmt) and on silicon blocks (150mm× 20mm×10mmt) with the same layer design as shown as design A in Uruga et al.([2]) (summarized in Table.1 in this report). The former was bent by a bender of the four point bent type and the latter were evaluated as flat samples.

We measured the surface roughness of the bent and flat supermirrors using atomic force microscope, NanoScope III, manufactured by Digital Instruments Co., USA. The measured surface roughness for bent and flat supermirror were almost similar and were around 2 Å(rms). The measured two-dimensional surface profile is shown in Fig.1.

3. 1D Focusing with Bent Supermirror

The focusing capability of a bent supermirror was tested by monochromatic radiation of Molybdenum $K_{\alpha1}$ emission line (17.48 keV) through a channel-cut monochromator (as shown in Fig.2).

We fixed the glazing incident angle to 0.2 and 0.3 degree with the fixed focal length of 83 mm so that at-focus image could be obtained when the radii of curvature(R) of supermirror was adjusted to R=47m and 32 m, respectively. Fuji #80, X-ray film, was placed for taking 2D images, and the image of the incident beam and at-focus image are shown in Fig.3. Using a micro-densitometer, the vertical incident beam size,
170 μm(FWHM), was reduced to 17 μm(FWHM) by bending.

4. High and Smooth Reflectivity Profile with Bent Supermirror

The energy dependence of reflectivity for the bent supermirror was measured by obtaining the spectra of the incident and the reflected beam (at a fixed glancing angle of 0.2 degree) using Ge-SSD. Three slits were used and the vertical angular divergence for the incident X-rays was 2.6×10^{-4}rad. The measured reflectivity as a function of energy is plotted in Fig.4, together with those for flat supermirrors. The reflectivity for the bent sample is much smoother and higher above ~40keV.

We made model calculations taking account of the divergence of the beam and the variation of glancing angle by the curvature of the supermirror([3], with R=47m in our case). The measured reflectivity profile was close to the one expected from an a sample with the surface roughness (σ) of 2 Å and a large filling factor (**f**) (or packing density) of 100%.

5. Summary and Future Plans

By the use of a bent supermirror on a silicon wafer, X-rays from a laboratory X-ray tube was line-focused to the width of 17 μm. The smoothness of the reflectivity between 20 and 40 keV and the reflectivity above 40 keV was improved by bending.

In future, 2D focusing is planned using a supermirror formed on a sagittal cylinder. By bending the cylinder in meridional direction and changing the curvature, energy tunable 2D focusing can be achieved. However a substrate with a cylindrical grove with a very small radius of curvature, e.g. R~7 mm (for focusing of 40 keV X-rays with the focal length of 1 m), is needed. The deposition of the supermirror layers on the grove needs to be carefully controlled as well.

Acknowledgment

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References

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Table 1. Supermirror design parameter

parameter	a	b	c	Γ	N	bottom layer	last layer	cap layer
	100	1	0.27	0.5	19	B_4C 22.67Å	W 66.47Å	B_4C 20Å

Γ, N correspond to the ratio of the layer thickness of heavy element and the number of layer pairs and cap layer means the additional layer deposited on the last multilayer.

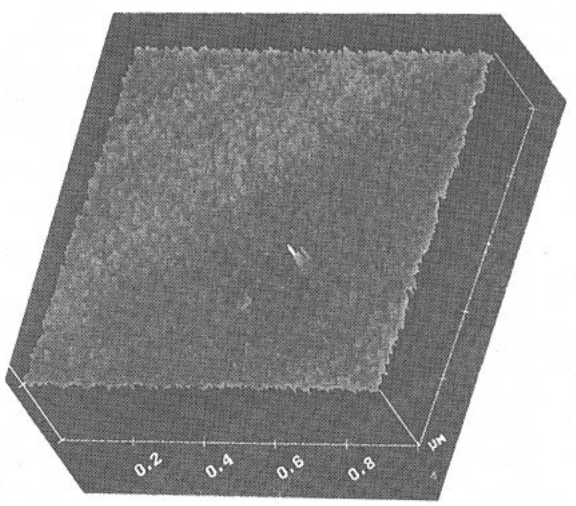


Fig.1.The two-dimensional surface profile measured with
an Atomic-force microscope (NanoScope III).

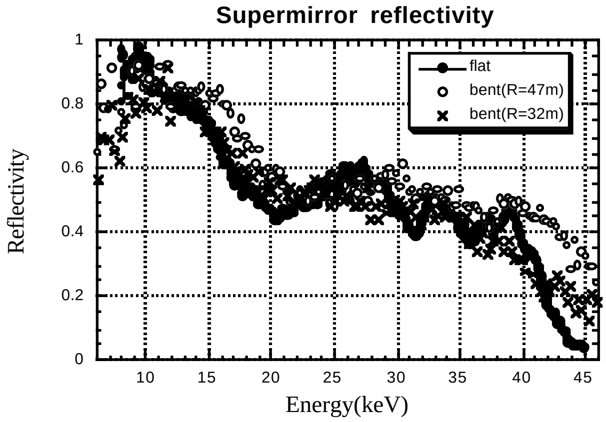


Fig.4.Energy dependence of reflectivity obtained by a flat and bent supermirror.

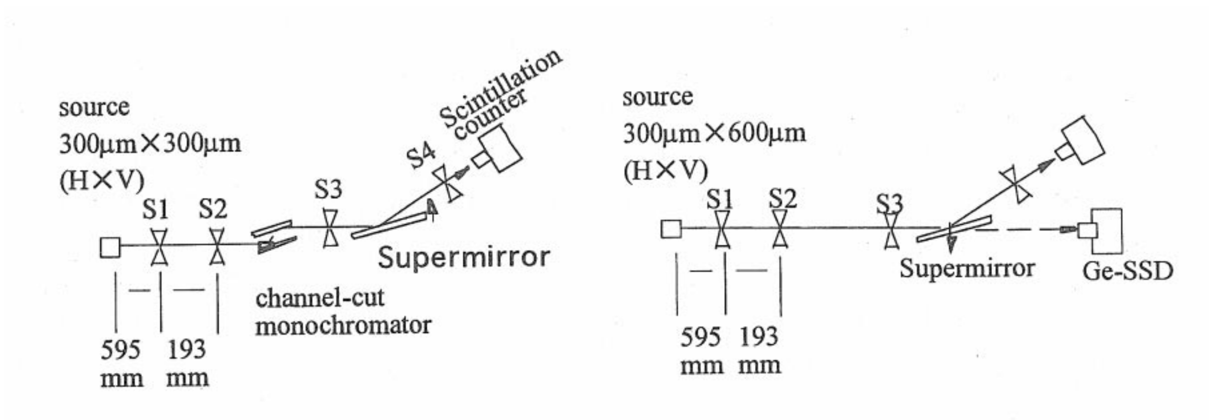
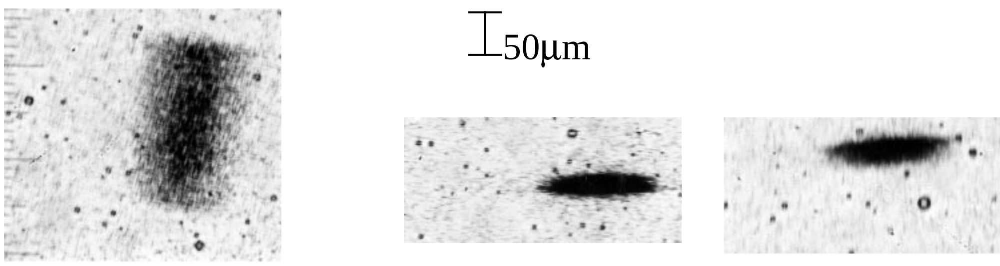


Fig.2.Setup for evaluating the flat and bent supermirrors using laboratory X-ray generator. The Molybdenum $K_{\alpha 1}$ emission line (17.48 keV, for focusing experiments) and white light (for measurement of energy dependence of reflectivity) were used.



Direct Beam

Focus Image (R=47m)

Focus Image (R=32m)

Fig.3.X-ray images of the incident beam and the at-focus image by a bent supermirror. The supermirror was bent to the radius of curvature of R=47m & 32m with the corresponding glancing angles of 0.2 & 0.3 degree. An X-ray film of Fuji #80 was used for recording these images.