Reflectivity Measurements of Supermirrors for 9 to 40 keV

Tomoya URUGA[1), Yoshiki KOHMURA[1), Hiroaki KIMURA[1), Tetsuya ISHIKAWA[1) and James L.WOOD[2)

[1)SPring-8, Kamigori, Ako-gun, Hyogo 678-12, Japan
[2)Osmic, Inc., 1788 Northwood Drive, Troy, Michigan 48084, USA

1. Introduction

In the third generation synchrotron radiation (SR) facilities, intense and high brilliant light is available in the high energy x-ray region (E>20 keV). It is desirable to have multi-wavelength x-ray optics which could be used for the beam collimation or focusing in the high energy region. One of candidates among those optics is an in-depth graded d-spacing multilayer, called supermirror. Supermirror could be designed to have a reflectivity with a wide band at a incident angle 2-3 times larger than the critical angle of total reflection mirrors [1], which makes the length of the optic and the bending radius for the beam collimation or focusing 1/2-1/3, that is, the inverse of the incident angle.

The protocol of the supermirror designs with required performance and its fabrication have not been completed. In this study, we designed the supermirrors to be used in the energy range from 9 to 40 keV, fabricated the prototype samples of the length of 150 mm and evaluated them by measuring the x-ray reflectivity.

2. Design and Fabrication of Samples

The goal of the supermirror design is to get highest reflectivity at a highest incident angle with a minimum reflectivity variation as a function of energy. In this study, we established the goal for the supermirror to have reflectivity greater than 30 % over the energy range from 9 to 40 keV. In the reflectivity calculation, the multilayer stack of supermirror was generated using the power function [1]: $d_i=a(b+i)^{-c}$, where a and c are positive constants and b is greater than -1, and i is the layer pair number counted from the top layer. The reflectivity calculations were done with the computer code ASA [2] and the numerical tables of anomalous scattering factor [3]. The optimization process of the design parameters was carried out by varying the following parameters: constant a, b and c, the ratio of the layer thickness of heavy element and the d-spacing, Γ, the number of layer pairs, N, the thickness of the last and cap layers and the depositing elements. Here, the cap (top) layer means the additional layer deposited on the last of multilayer. The W and B_4C were selected as the deposited materials because of the energy of their absorption edge and their layer smoothness.

From the reflectivity calculations, it seems to be difficult to design the suppermirror for 9 to 40 keV with an incident angle greater than 4 mrad. Therefore, we chose 3.5 mrad (=0.2°) as the incident angle. The model calculations show that about 20 layer pairs and Γ of about 0.5 gives high reflectivity between 20 to 40 keV with small reflectivity variation. It is also found that the last and cap layers significantly affect the reflectivity profiles. We obtained two characteristic designs, called A and B. The structural parameters are listed in Table I. The main difference in the design between A and B is the number of layer pairs and the thickness of the top and cap layers.

We manufactured the test samples. The substrates are blocks of CVD-SiC on sintered SiC (150×20×20 mm, about 4 Å rms surface roughness). The deposition was performed with RF-Sputtering process at Osmic, Inc. [4].

3. Experiments

The evaluation was performed by measuring the angular- and energy-dependent x-ray reflectivity of the supermirrors. The x-ray source was a rotating molybdenum target (Rigaku, RU-300). For the angular-dispersive measurement of the reflectivity, the MoKα_1 (E=17.48 keV) beam was collimated with a angular divergence of 1 mrad by two slits with a width of 100 μm, each separated 193 mm apart, and monochromatized with a channel-cut Si(111) crystal. The sample was mounted on the double-axis reflectometer and the reflective x-rays were detected using a scintillation counter.

For the energy-dispersive measurements, the bremsstrahlung from the molybdenum target was collimated with an angular divergence of 0.1 mrad by two slits 10 μm width, separated by 193 mm each other, and the reflected intensity is collected by the Ge-SSD. The energy resolution of the measurement system is estimated to be about 3 % fwhm. To eliminate the effect of the escape peak of GeKα, the measurements were performed at the tube voltages of x-ray generator of 20, 30, 40 and 50 kV, and the reflectivity data were combined with each other to reproduce the reflectivity profile from 9 to 50 keV.

4. Results

Figures 1 show the comparison between the calculated and measured angular-dependent reflectivity of the supermirrors of design A and B. The layer roughness was estimated about 4 Å for both samples, which corresponds to the surface roughness of the substrate. In both samples, the locations of maxima and minima show good agreements between the calculated and measured ones, especially in the design A sample, although the measured reflectivity over the incident angle from 0.2 to 0.3° were considerably high when compared with the calculated ones. It implies that minor errors might have been introduced in the layer thickness during the deposition process. Figure 1 (a) also shows the good agreement between the reflectivity measured at the central part and at 37 mm apart from the center of the surface of the design A sample. This indicates that the multilayer stack was fabricated with a good spatial uniformity of d-spacing over the 150 mm long.

Figures 2 show the comparison between the calculated and measured energy-dependent reflectivity at the incident angle of 0.2° . The present theoretical calculations took account of the effects of the incident beam divergence and the energy resolution of SSD system. It can be seen that both of manufactured supermirrors have a reflectivity greater than 30 % over the energy range from 9 to 40 keV. The measured profiles, however, were different from the theoretical ones. The former showed a greater reflectivity than the latter from 20 to 30 keV. These observations suggest that the design of the supermirror has not been optimized in this study. We will try to construct the theoretical model to analyze the measured reflectivity profiles and to find the way to the optimization of the supermirror design.

References

[1] K.D.Joensen et al., Proc. SPIE. **2011**, 360 (1994).
[2] H.Kimura, Supermirror reflectivity Calculation Program for PC, ASA.
[3] S.Sasaki, KEK Report 88-14 (1989).
[4] J.L.Wood, Proc. SPIE. **1738**, 22 (1992).

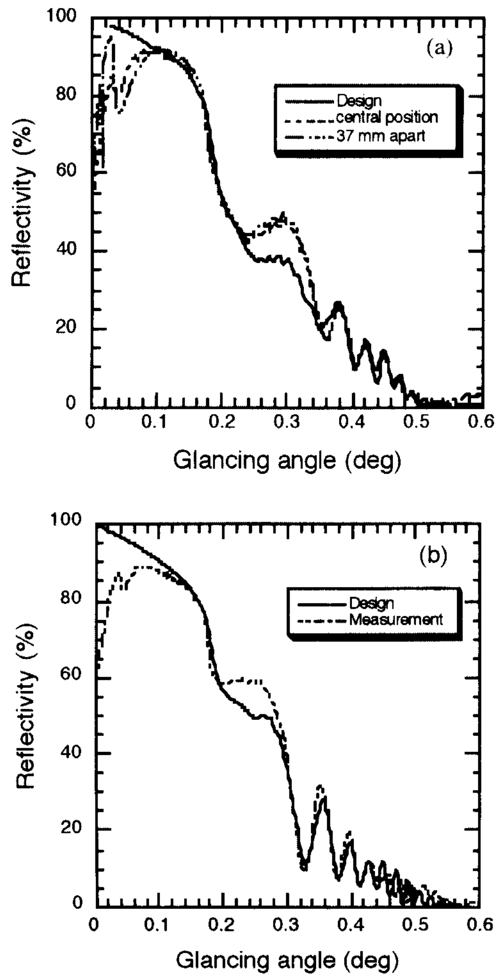

Fig. 1 Calculated and measured angular dependences of reflectivity of the test sample supermirrors of design A (a) and B (b).

Table I Supermirror design parameters

parameter	design A	design B
a	100	100
b	1	1
c	0.27	0.27
Γ	0.5	0.5
N	19	20
bottom layer	B_4C 22.27 A	B_4C 22.27 A
last layer	W 66.47 A	W 50 A
cap layer	B_4C 20 A	W 25 A

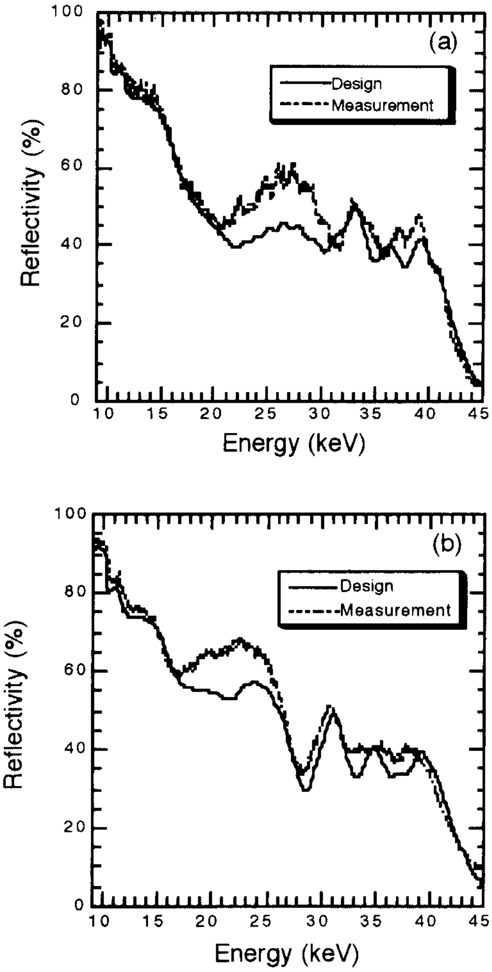

Fig.2 Calculated and measured energy dependences of reflectivity of the test sample supermirrors of design A (a) and B (b).