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Developments of the Supermirror Hard X-ray Telescope at Nagoya University

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1. Balloon borne hard X-ray telescope

We have developed a Pt/C supermirror hard X-ray telescope which can focus hard X-rays above 10 keV for the balloon-borne experiment in 2000 with NASA Goddard Space Flight Center. In this experiment, boundary conditions of the telescope have been set as 40 cm in diameter, focal length of 8 m and the energy range from 25 keV to 40 keV.

In the previous works, we selected a typical incident angle of 0.3 degrees and optimized the multilayer structure to maximize integrated reflectivity in the 25–40 keV energy band. Using the optimum parameters, we fabricated the supermirror on the gold replica thin-foil substrate developed for the *ASTRO-E* XRT. The reflectivity of about 30% in the energy range from 25 to 40 keV has been achieved. Furthermore, we made the demonstration model of the hard X-ray telescope which consisted of 20 foil supermirrors with the same multilayer parameters and succeeded in focusing the hard X-rays from 25 to 40 keV(Yamashita et al. 1998).

For the next step, we need to optimize the multilayer parameters for all mirrors of the full telescope, where incident angles range from 0.10 to 0.36 degrees. How to optimize the parameters and expected performance of the supermirror hard X-ray telescope are presented in the paper.

2. Supermirror design for the full telescope

In order to maximize the total effective area and to obtain flat response in the energy band of 25–40 keV, the parameters must be optimized at each incident angle of all mirrors. However, designing in each mirror, one by one, is not realistic, because the number of mirror shells is 256 for this telescope.

At first, monolayer mirrors are used as inner mirrors with incident angle less than 0.125 degrees, because the critical energy is above 40 keV at those incident angles. Then we optimized the multilayer for outer 227 mirrors.

Considering the Bragg equation that defines the relation between the periodic length d and the incident angle, we decided the parameters for all the mirrors by scaling the parameters at incident angle 0.3 degrees. For small incident angles, however, the peak width is too narrow, because the number of layer pairs was not optimized. Then we separated mirror shells into 12 groups so that the shift of the Bragg peak energy is within 10% in each group.

3. Fabrication and expected performance for the hard X-ray telescope

Based on the above method, we deposited one supermirror of each group on the replica thin-foil mirror shells. The reflectivity of about 20%–30% in the energy range from 25 to 40 keV has been achieved. Comparing to theoretical value of 40 %, the reduction of measured reflectivity is explained by the interfacial roughness σ=5–6Å(σ; Debye-Waller factor).

The simulated effective area of full telescope with optimized parameters is shown in Fig. 1. In an ideal case of $\sigma = 0.0$, the effective area has a flat response in the energy range of 25–40 keV, and achieves 170 cm^2. Effective area decreases with the increase of the interfacial roughness. In our previous experiment, the expected performance of hard X-ray telescope corresponded to a σ=5–6 Å. From our recent study, however, we can improve the roughness up to σ=4 Å.

It seems possible that the supermirror hard X-ray telescope for the balloon-borne experiment will have an effective area of 100 cm^2 at 25 keV and 70 cm^2 at 40 keV.

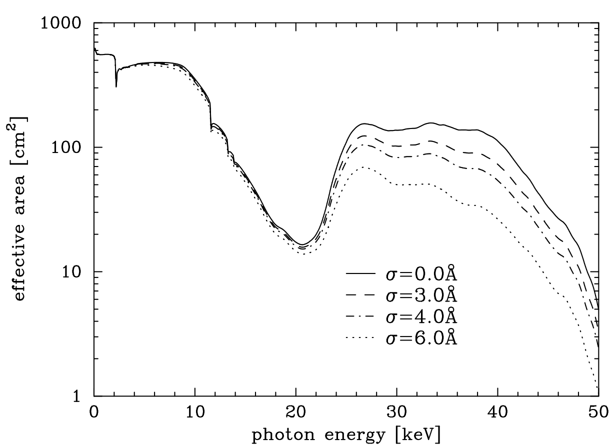

Fig. 1. — the simulated effective area of the supermirror hard X-ray telescope for the balloon-bone experiment with various Debye-Waller factors

References

Yamashita, K., et al., 1998, Applied Optics, Vol.**37**, 8067