別紙４

報告番号	※　　　　第　　　　号

主　論　文　の　要　旨

論文題目　Theoretical analysis, design and fabrication of supermirrors for hard X-ray telescopes
(硬Ｘ線望遠鏡に用いるスーパーミラーの理論的解析および設計とその製作)

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論　文　内　容　の　要　旨

Hard X-ray telescopes (10-80keV) can achieve high sensitivity in broad energy band with the supermirror coating on the surfaces of mirror shells. Supermirror is a layered structure which consists of up to 100 of layer pairs of two materials, and can reflect hard X-rays by means of the Bragg reflection. When the thickness of each layer varies gradually from the top to the bottom, the Bragg reflection can be satisfied in a broad energy band. Therefore, the thickness distribution of a supermirror determines the response of the hard X-ray telescopes (effective area and its energy/grazing angle dependence). Present paper describes the propagation of X-rays in the layered structure, design methods of improved supermirrors and fabrication of thus designed supermirrors.

In the first part of the thesis, the wave equation of X-ray propagation in the layered structure has been solved based on the understanding of the E-M wave theory. By examining the emerging amplitude from the top boundary, the X-ray reflectivity is successfully given for the block structure supermirror. It is also confirmed in these equations that the reflectivity profile against X-ray energy is optimized if the empirical design rules for InFOCμS and HXT of ASTRO-H are satisfied. Moreover, the theoretical work has been further developed to design a multilayer structure with response profile of suppressed side lobes, which is useful for various X-ray optics.

The second part of the thesis is the numerical design of supermirrors for specific purposes. In previous works, all the design methods were based on empirical rules to maximize integrate reflectivity within target energy bandwidth. However, the oscillation of reflectivity profile (ripple) was relatively large (~50%). Although the ripples were considered to be smoothed out by accumulating the reflection of many mirror shells with different grazing angles, the residual complex structures still could be found in the telescope response. Such ripples in the response reduce the detection limit of spectral structure, such as cyclotron absorption features from pulsars. In order to solve this problem, we consider to make reflectivity profile of each mirror shell as smooth as possible. Based on the understanding of supermirrors, a numerical design method has been developed. Starting from optimized layered structure by previous design methods, the thickness of each layer is tuned to get a target response profile. A merit function is introduced to evaluate the difference between the target and the designed response. After enough iteration, the optimization algorithm can reduce the ripples less than 2% or so. By adding random errors to individual layer thicknesses, it is possible to derive necessary thickness accuracy(~ 0.02nm) of the multilayer fabrication system.

The third part of the thesis is the fabrication and testing of designed supermirrors. In order to prove the feasibility of numerical design, two Pt/C supermirrors are designed for broad and flat angular (1.0-1.5deg, at 8.05keV) and energy (10-50keV, at 0.28deg) response. They are fabricated on float glass substrates by our DC sputtering system. X-ray reflectivity profiles of these samples are measured against grazing angles and X-ray energies. Obtained energy response demonstrates the ripple is as small as expected, which also confirms the fabrication accuracy of our system is high enough to achieve the target profile. Moreover the real thickness distribution of the fabricated supermirror is reconstructed by tuning designed structure with the obtained response as the target profile.

Present work provides new approach to design and fabricate designated supermirrors not only for X-ray telescopes but also ground-based experiments with smooth profile.