Study on Ni Mirror Chip for Space X-ray Telescopes Utilizing LIGA Process

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Abstract

This paper describes about the design and fabrication of a Ni mirror chips for using in space X-ray telescopes. Ni mirror chips are used for focusing and detecting X-rays, which are fabricated utilizing synchrotron radiation lithography and electroforming. In this time, to realize of the high accuracy microfabrication of Ni mirror chips, optimum experiment conditions are caused. Although collapse of the structure cased by the surface tension during dryness after development, it is possible to be improved by keeping liquid immersion from development process to electroforming process. And, fabrication of Ni structures with 20 μm pitch line & space and 200 μm high is succeeded. Based on this results utilizing improvement process, optical system mirror chip is designed. And fabrication of PMMA structure without collapses is succeeded. In the future, high aspect ratio Ni mirror structure will be fabricated utilizing liquid immersion, and makes a reflectance measurement of X-rays.

1. Introduction

Space X-ray telescopes are a telescope which focuses and detects the X-rays emitted from much galaxies, star cluster, gaseous nebula, etc. Since X-ray are absorbed and diffused by the atmosphere, X-rays are undetectable on the ground, and need to carry an optical system in an artificial satellite [1] [2]. Moreover, since X-rays have high transmissivity, they cannot use a lens optical system. Therefore, the mirror for reflecting and focusing X-rays is required. An-X-ray optics system can be manufactured by combining the grazing mirrors using total reflection phenomenon, as shown in figure1. This system is detected X-rays utilizing twice mirrors.

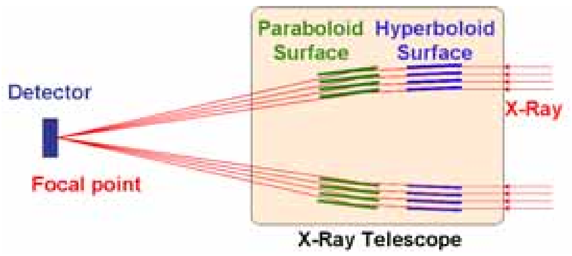

Fig.1 Schmatic of Wolter type-I X-ray optics: X-ray is reflected using twice mirrors. It is a system which can detect the reflected X-ray.

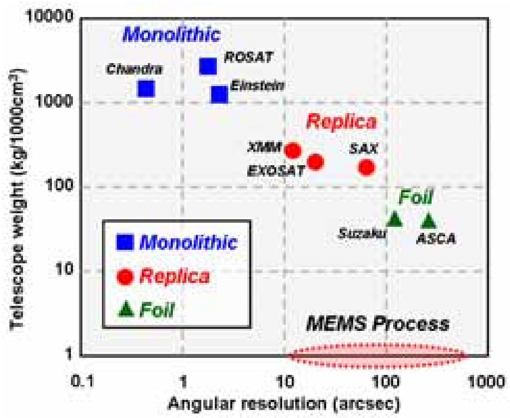

Fig.2 Relation of angular resolution and telescope weight: Monolithic, Replica, and Foil are traditional fabrication methods of miller for Space X-ray telescopes.

However, since X-ray mirror systems has heavy weight actually carried until now, recent years have required the reduction in cost, and a weight saving. Then, reducing the weight per unit area from $1/10^2$ to $1/10^3$ compared with traditional telescopes is expected utilizing MEMS (Micro Electro Mechanical Systems) process. The weight of mirror per same opening area is as shown in figure 2. This figure shows relationship between angular resolution and telescope weight. Monolithic, Replica, and Foil are traditional fabrication methods of miller for Space X-ray telescopes. The objective aims to reduce the weight, while maintaining degree angular resolution utilizing MEMS process.

As the requirements of the mirror chip, include surface roughness of several nm or less (smooth surface), made from heavy metal, alignment in a concentric pattern and Less than 1 ° incident angle. When using MEMS process, the technique of fabrication the mirror chip made from Si by DRIE (Deep Reactive Ion Etching) was in use [3] [4]. However, there is a problem that processing accuracy required for high resolution realization is not fulfilled. And when the viewpoint of reflective efficiency is considered, fabrication by Ni and Au other than Si is also important. Figure 3 shows relationships X-ray energy [eV] and reflectivity rate [%] of mirror surface in various materials. X-ray incidence angle is 1°, and mirror surface roughness is $\delta=0$. As shown in figure3, the X-ray reflectance of Si worsens rapidly near K absorption edge (1.85 keV), and after that reflection is almost lost. That is, when Si is made into mirror material, it cannot use for X-ray observation more than 1.85 keV. However, Au which is a metal heavier than Si is highly reflective over 2keV, and it has the reflectance of 30% or more to the X-rays of 4keV. The reflectance of Ni deserves attention. Although reflectance has fallen greatly in 852~870eV with L absorption edge, it has reflectance high to 1~3 keV after that, especially in the range of 2.2~3.4 keV Ni has exceeded the reflectance of Au. Therefore, in this research, mirror chips made from Ni which used LIGA (Lithographie, Galvanoformung, Abformung) process is fabricated.

Next, the influence of the reflectance by surface roughness effects is described. Figure 4 shows relationships X-ray energy [eV] and reflectivity rate [%] of mirror surface in Ni. In this figure, the reflectance when changing surface roughness is shown. In addition, an incidence angle is 1°. As shown in figure, when surface roughness becomes large, decline in reflectance is remarkable. In the high energy domain beyond 1keV, it is influenced especially greatly. If surface roughness goes into double figures, reflectance becomes less than 6% the domain beyond 1keV. From this, for measurement of a reflective ingredient, surface coarseness of 5nm or less is required.

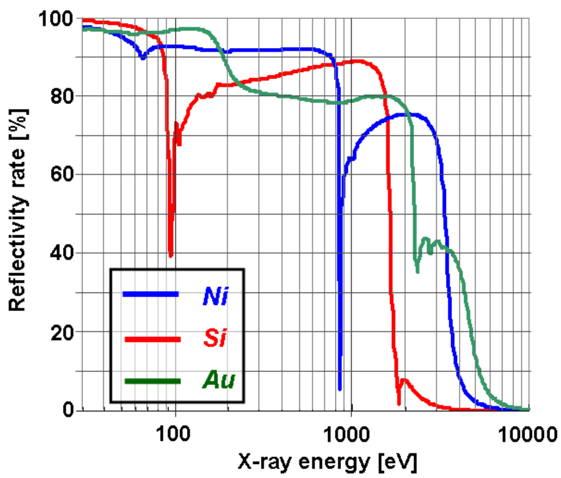

Fig.3 X-ray reflectivity of mirror surface in various materials (Ni, Si, Au): It shows relation of x-ray energy and reflectivity rate. X-ray incidence angle is 1°, and mirror surface roughness is $\delta=0$.

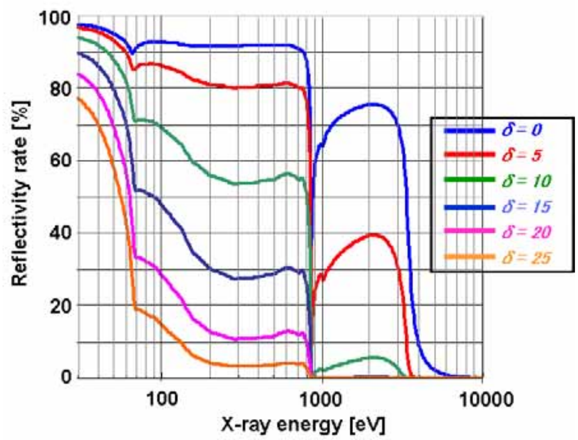

Fig.4 X-ray reflectivity of mirror surface in Ni when changing surface roughness: It shows relation of x-ray energy and reflectivity rate. X-ray incidence angle is 1°.

In this research, mirror chips made from Ni which used LIGA process is fabricated. LIGA process is a composition process having SR (Synchrotron Radiation) lithography technology and electroforming technology, and it has several characteristic. For example, high aspect ratio is possible, high accuracy fabrication is possible, and board material selection is possible. In this time, mirror chip is fabricated utilizing X-ray lithography, Ni electroforming.

2. Experimental Conditions

A number of experiments were carried out using beam line number 6 (BL-6) at the superconductivity compact SR source "AURORA", at the SR center, Ritsumeikan University, Japan. The properties of SR at AURORA are, wavelength of 0.15 nm range to visible light domain, applied orbital radius, electron energy and the maximum storage current in the experiment were 0.5m, 575 MeV and 300 mA, respectively.

The wavelength of between 0.2nm and 0.5nm is said to be the best for X-ray lithography also in this wavelength domain. This reason is for suppressing a spread by the secondary electron by the Fresnel diffraction in a long wavelength domain and the secondary electron generated within resist in a short wavelength domain, and making the fabrication line width narrow and raising resolution. The light from AURORA penetrates two 200μm Be windows, and uses within the chamber the light which has a 0.15 to 0.95nm wavelength domain. The exposure environment was covered with Helium gas at 1 atm in the chamber in order to prevent the attenuation of X-ray by N_2 or O_2 gases and to prevent damages of the mask or resist by heat generated [5].

The X-ray mask consisted of a polyimide membrane with a thickness of 50 μm and an Au absorber with a thickness of 3 μm. PMMA sheet provided by Nitto Jushi Kogyo Co., Ltd. was used as a resist. Since a resolution of PMMA is high, a reproducibility of fine structures for molding can be enhanced as the further fabrication process. The exposed PMMA structures gradually appeared during developing by GG developer (60 vol% 2-(2-butoxy-ethoxy) ethanol, 20% tetra-hydro-1, 4-oxazine, 5 vol% 2-amino-ethanol-1 and 15 vol% water) for 180 minutes. After that, stopper liquid (80 vol% 2-(2-butoxy-ethoxy) ethanol, and 20 vol% water) was used for 10 minutes then rinsing by water at for another 10 minutes. All the processes listed were done at the exact temperature of 37ºC.

In addition, optimization of exposure and development conditions was also performed. Since the water absorptivity of PMMA is high, if developing time is long, PMMA swells and becomes easy to come unglued from a substrate. In order to shorten development time, exposure amount must be more. However, if PMMA absorbed 80kJ/cm^3 or over, it will become easy to generate air bubbles inside Polymethylmethacrylate (PMMA). And, PMMA absorbed 1kJ/cm^3 or less, development stops [6] [7]. These things are taken into consideration, the dosage is set to 0.28 A·h. When PMMA exposed by this condition, it is possible to fabricate 250μm in the development of 2 hours.

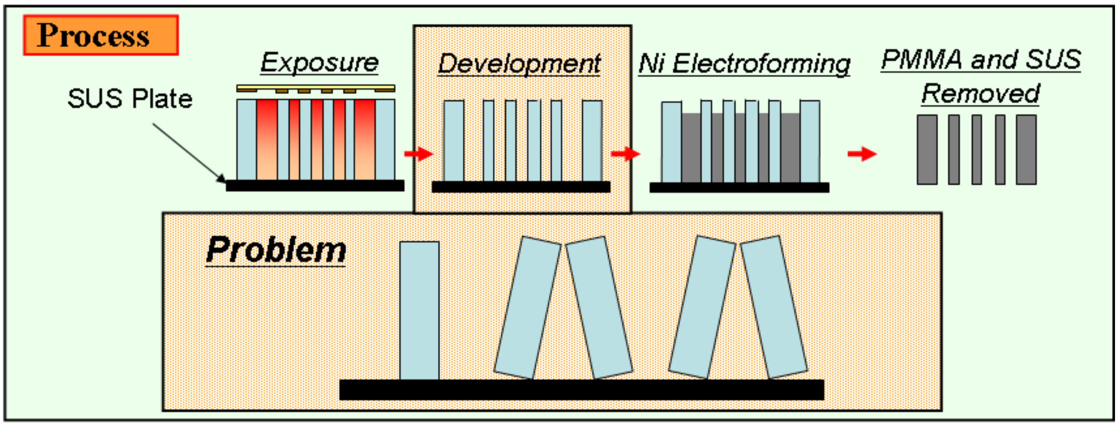

Fig.5 Fabrication process flow

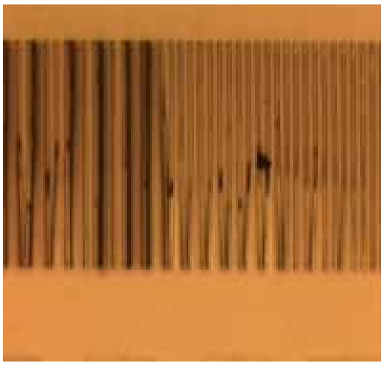

Fig.6 Microscope photo: Collapse of the structure (Line width 20μm, Space width 20μm) after development.

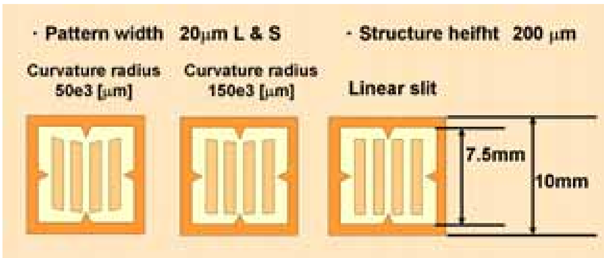

Fig.7 Target forms: One of them is a curvature radius of 50e^{3}μm, the second is a curvature radius of 150e^{3}μm, and the other is linear slit. All of them, line & space is 20μm pitch and target height is 200μm. Chip size is 7.5 x 7.5 mm^2.

3. Fabrication of Ni Structures

Figure 5 shows process flow. In this method, PMMA structure after development is easy to collapse. As this main factor, adjoining structure patterns are adsorbed by surface tension. Moreover, it is considered that PMMA structures come unglued from a substrate. In order to prevent collapse and come unglued, it is necessary to raise the adhesion of a substrate and PMMA, and make structure pattern interval large. When this process is used, fabrication of PMMA structures with 50 μm pitch line & space and 100 μm high is succeeded. On the other hand, in the case of PMMA structures with 20 μm pitch line & space and 200 μm high, the many patterns are collapsed. In order to improve the detection efficiency of X-rays, it is necessary to enlarge side wall area of the Ni structure used as usable area of mirrors. And, in order to enlarge usable area of mirrors, it is necessary to make the height of a structure high (miller area is made large), to make pitch width of a line & space narrow (the number of mirror per unit area is increased), and especially to make line width narrow (the interval of a mirror is narrowed). However in this method, there is a problem that the structure which can be fabricated will be limited.

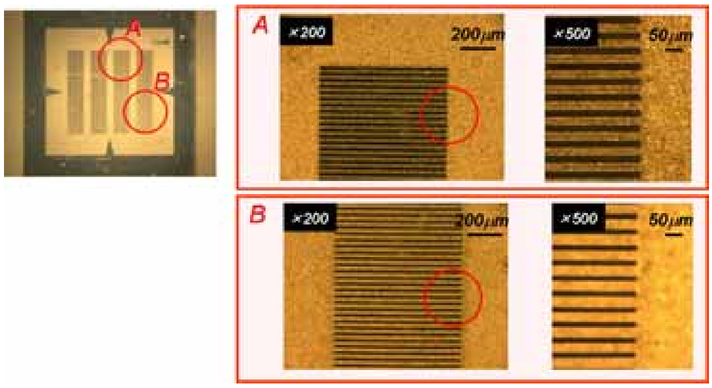

Fig.8 Mirror chip of linear slit after electroforming: Black color parts are PMMA, other areas are Ni. (A) is focuses to Ni surface, (B) is focuses to PMMA surface.

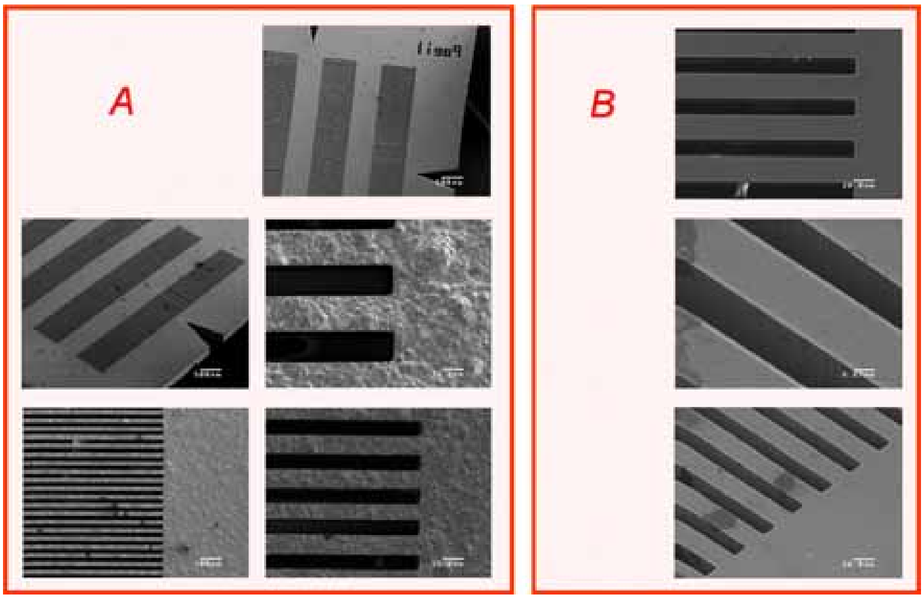

Fig.9 Mirror chip of linear slit after removing PMMA: (A) is top view, and (B) is bottom view.

Therefore, the improvement plan of the fabrication process is examined. This is because the adjoining structures are adsorbed by surface tension by the dryness after development. Therefore in this time, it keeps by liquid immersion from development process to electroforming process, collapse of the structure cased by the surface tension during dryness after development is prevented. In this time, realization of line & space 20μm pitch and 200μm in height is aimed at. Figure 7 shows target forms. One of them is a curvature radius of $50e^3$μm, the second is a curvature radius of $150e^3$μm, and the other is linear slit. Figure 8 shows mirror chip of linear slit after electroforming. As shown in figure, it succeeded at line & space 20μm pitch and 200μm in height utilizing improvement process without PMMA collapses. In the case of other target form, the same result was obtained. Therefore, it is possible to prevent that adjoining structure patterns are adsorbed by surface tension by keeping liquid immersion. As a result, pitch width of Ni structure could be made narrow, and it succeeded in making large usable area of mirrors required for improvement in condensing efficiency of X-rays. In addition, figure9 shows mirror chip after removing of PMMA.

4. Design of Optical System Mirror Chip

As already mentioned in chapter 3, fabrication of Ni structures with 20 μm pitch line & space and 200 μm high is succeeded utilizing improvement process. Consequently, based on these fabrication conditions, design of optical system mirror chip was decided as shown in figure 10. This mirror chip is a line & space 20 μm pitch structure (mirror slit width). Maxim slit length is 1.2 mm, and target thickness (structure height) is over 200 μm. PMMA structure of the designed mirror was succeeded fabricated without collapses as shown in figure 11.

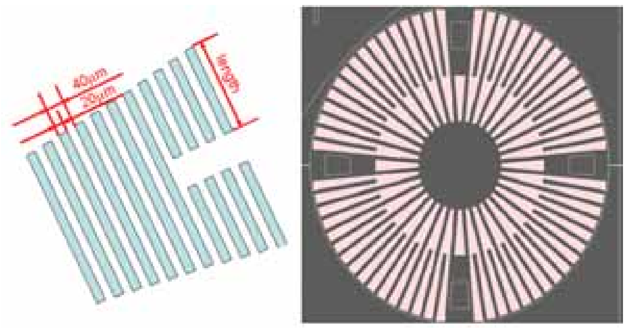

Fig.10 Mirror chip: Diameter is 3.5 mm, line & space (mirror slit width) is 20μm pitch width, and maxim slit length 1.2mm

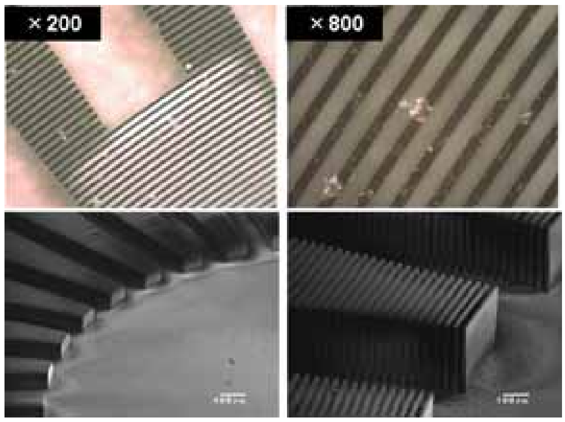

Fig.11 PMMA structure line & space 20μm

5. Conclusions

We are developing novel ultra light-weight and high-resolution X-ray micro pore optics for space X-ray telescopes. Ni mirror chip for focusing and detecting X-rays is fabricated utilizing LIGA process. In this time, in order to improve the detection efficiency of X-rays, fabrication process is improved. Especially, it keeps by liquid immersion from development process to electroforming process, collapse of the structure cased by the surface tension during dryness after development is prevented. Therefore, pitch width of Ni structure could be made narrow, and it succeeded in making large usable area of mirrors required for improvement in condensing efficiency of X-rays. In order to improve the detection efficiency of X-rays, it is necessary to enlarge side wall area of the Ni structure used as usable area of mirrors. In order to enlarge usable area of mirrors, it is necessary to make the height of a structure high, to make pitch width of a line & space narrow, and especially to make line width narrow. In this time, it succeeded at line & space 20μm pitch and 200μm in height. However, it is thought that still narrower pitch width and high structure height are realizable by using this liquid immersion process. In addition, based on these results, design of optical system mirror chip was decided. Since the improvement method is used, fabrication of PMMA structure without collapse is succeeded. In the future, high aspect ratio Ni mirror structure will be fabricated utilizing liquid immersion, and makes a reflectance measurement of X-rays.

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