Stacking mirror device using millimeter-thick elliptical supermirrors fabricated by numerically controlled local wet etching for focusing neutron beam

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Abstract

Stack of millimeter-thick aspherical supermirror enables us to focus neutron beams with wide divergence. We applied noncontact figuring by the numerically controlled local wet etching technique and fabricated elliptical mirror substrate with a thickness of 1 mm. Figure error of 0.29 μm p-v was obtained. In addition to the figure error, an alignment error of the mirrors is the main factor influencing focusing performance. An alignment device, which support 4 thin mirrors by independent three points respectively, was developed to satisfy the calculated alignment tolerance.

1 Introduction

Multiple aspherical supermirror devices using high-precision figured aspherical focusing supermirrors have received considerable attention with the aim of focusing neutron beams with high intensities, because multiple mirrors collect a very large beam divergence. Thin mirrors with a millimeter thickness are required to minimize the absorption loss of incident neutron beams since the thickness of a mirror shadows the reflective area of the other mirrors. Previously, we developed a fabrication process combined with numerically controlled local wet etching (NC-LWE) technique to figure the mirror substrate with high form accuracy and ion beam sputter deposition technique to deposit NiC/Ti multilayer [1].

In this paper, we report evaluation results of a figure error of the fabricated elliptical mirror substrate with a thickness of 1 mm and alignment accuracy of the stacking device for fabricated mirrors.

2 Optical design of multiple mirror system

We designed stacking mirror device using 1 millimeter-thick elliptical supermirrors. This focusing system consists of 4 mirrors with elliptical shapes represented by $(z/a)^2+(y/b)^2=1$ (unit:mm). The *a* and *b* values of the outmost mirror are 3750.279 and 45.758, respectively. The thickness of each mirror substrate is 1 mm and the clear aperture size is 100 x 20 mm^2. The magnification of the optical system and the focal length are 12:1 and 3750 mm, respectively.

3 Figuring of thin elliptical mirror substrate

We figured the mirror substrate by the NC-LWE technique. The material and outer size are synthesized quartz glass and 150 x 75 x 1 mm^3, respectively. In the NC-LWE technique, figuring is performed by controlling the dwelling time of the nozzle head for etchant supply. Because of its noncontact chemical removal mechanism, the NC-LWE technique enables us to fabricate a millimeter-thick mirror substrate without generating subsurface damage and deformation. As the processing parameters in NC-LWE figuring, we used 37 wt% HF acid with a temperature of 40 °C, a circular nozzle with a diameter of 15 mm and a feed pith of 0.5 mm.

Figure 1 shows the cross-sections of the fabricated elliptical mirror and the figure error after NC-LWE figuring. The residual figure error after NC-LWE was about 0.29 μm p-v. The shape of the mirror substrate was measured by a laser autofocus measuring machine (Mitaka Kohki NH-3SP, z resolution: 1 nm). This result indicates that the noncontact removal by controlling the dwelling time of the etchant nozzle deterministically figures the aspherical shape with a form accuracy of sub-micrometric level.

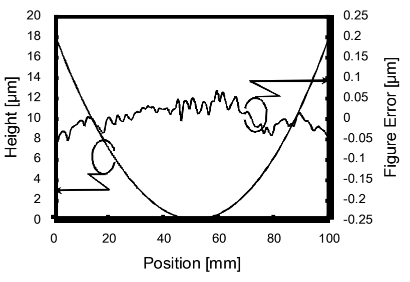

Figure 1: Figure errors of the fabricated mirror in meridional direction

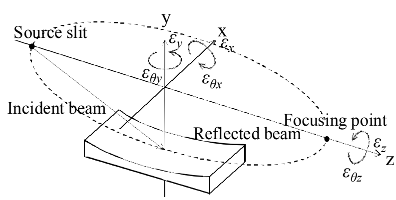

Figure 2: Schematic of coordination system for ray-tracing simulation

Table1: Aligment tolerance for designed focusing device

	ε_z	ε_y	$\varepsilon_{\theta z}$	$\varepsilon_{\theta y}$	$\varepsilon_{\theta x}$
Aligment tolerance	±50 mm	±1mm	±520mrad	±350 mrad	1.8 mrad

4 Development of stacking mirror device

In addition to the figure error, an alignment error of the mirrors is the main factor influencing focusing performance. We evaluated the relationship between the alignment error and the focusing spot size and calculated alignment tolerance for achieving sub-millimeter neutron focusing by the ray-tracing simulation. Figure 2 shows the schematic of coordination system for ray-tracing simulation. In this system, we evaluated the relationship between the alignment error and the focusing spot size. Calculated alignment tolerances are shown in Table 1. Simulation results indicate that the alignment errors of $\varepsilon_{\theta x}$ influence a lot to the spot size. We need to align $\varepsilon_{\theta x}$ within ±1.8 mrad to achieve the focusing spot size less than 105 % of an ideal FWHM.

To satisfy the calculated alignment tolerance, an alignment device for 4 neutron focusing mirrors was developed. The schematic of the alignment device is shown in Figure 3. In this device, 4 mirrors are supported by independent three points respectively and set same position in horizontal direction by three positioning pins. In the fabrication process of the focusing mirror, we measure the shape of mirror substrate on three support points with good reproducibility and calculate the residual figure error by subtracting the measured shape included gravitational sag from the ideal shape. In the NC-LWE technique, figuring is performed by controlling the dwell time of the nozzle head not controlling the depth of cut at arbitrary position such as a conventional machining. Because of its noncontact chemical removal mechanism, the NC-LWE technique enables us to fabricate a millimeter-thick mirror substrate without generating subsurface damage and deformation. Finally, we can focus neutron beam effectively using the figured mirror with an ideal shape because the gravitational sag is reproduced by supporting on the same three points.The heights of the support points are adjusted by applying a wedge mechanism. The displacement ratio of x and y direction in the wedge mechanism is 1/10.

We evaluated reproducibility of the measured shape of the mirror installed on the alignment device by continuous measurement and rearranged measurement. Temperature of the measurement room was kept within ±0.02°C.

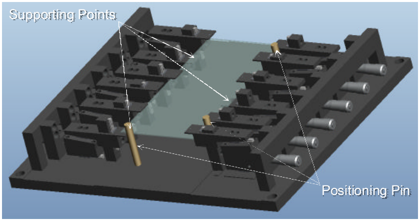

Figure 3: Neutron focusing device using stack of elliptically figured substrates

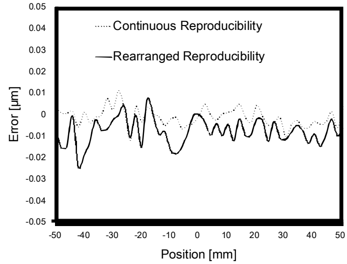

Figure 4: Measurement reproducibility of alignment device

At the beginning, we warmed up the measuring machine. After warm-up enough, we made a measurement of mirror substrate. After 5 h, we made a measurement again. Next we removed and reset the mirror substrate. And we measured after 5 h again.

In the result, reproducibility both in continuous measurement and in reset measurement are less than 0.05 µm p-v. This value is less than 0.5µrad in terms of $\varepsilon_{\theta x}$. These evaluation results indicate that the developed alignment device has an ability to focus neutron beam within a tolerance of defocusing.

Conclusions

We figured elliptical mirror substrate with a thickness of 1 mm by applying NC-LWE and obtained figure error of 0.29 µm p-v. An alignment device for precise stacking of 4 elliptical focusing mirrors was developed to satisfy the calculated alignment tolerance. The alignment device has a reproducibility which satisfies the alignment tolerance enough and enables us to focus neutron beam precisely.

Acknowledgements

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References:

[1] K. Yamamura, *et al.*, Opt. Express **17** (2009) 6414-6420.
[2] R. Maruyama, *et al*., Nucl. Instrum. Methods Phys. Res. A **600** (2009) 68-70.