Precision machining of diffractive lens made of synthetic silica

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Abstract

Micro diffractive optical components are required in the astronomical space telescope. In the space having so large temperature differences, it is very effective to install a diffractive optical lens to the conventional optical systems in order to reduce the astigmatism due to the thermal expansion. In this study, a new grinding process of the structured surface with a sharp diamond wheel and the uniform finishing process of the magnetic field assisted polishing were proposed and developed. In the machining experiments, a diffractive optical lens of synthetic silica was test to be ground by the resinoid bonded diamond wheel and the ground surface was finished with cerium oxide, and the changes of their form deviations and surface roughness were evaluated.

1. Precision grinding of structured shape of diffractive lens

A definition of structured diffractive lens is shown in Figure 1. The axis-symmetric shape of the diffractive lens is given by:

$$Z = f(Y) = \mathrm{mod}\left\{ \left[\frac{C_v \cdot Y^2}{1+\sqrt{1-(K+1)\cdot C_v^2 \cdot Y^2}} + \sum_{i=1}^{n} C_i \cdot Y_i \right],\ h \right\} \quad (1)$$

Where, Y is a radial position of the diffractive lens, K, C_v, C_i (i=1 - n) are aspheric constants, and h is a step height of the lens. In order to grind convex type of diffractive lens, a new grinding method was developed as shown in Figure 2. As a wheel, a disk shape of diamond grinding wheel, which edge is trued as a sharp knife-edge, is used and the wheel scans along the lens radial position vertically. The feature of this grinding method is that the wheel rotates in the parallel with the workpiece rotational direction at the grinding point. The axis-symmetric diffractive lens will be generated by the grinding wheel having sharp edge. Then the sharpness of the wheel is important to generate the structured surface precisely [2].

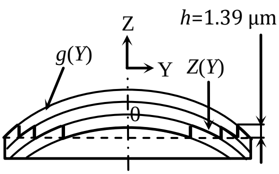


Figure 1: Definition of diffractive lens

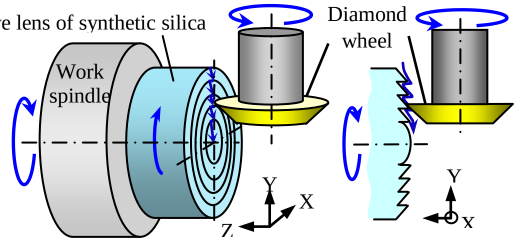


Figure 2: Two-axis controlled grinding method

2. Grinding experiments

The grinding wheel is attached to a 4-axis (X,Y,Z,C) controlled ultra-precision machine, as shown in Figure 3. The wheel spindle is an air bearing spindle. The positioning resolutions of X, Y and Z-axis are 1 nm. In the grinding test, the diffractive lens attached onto the jig is vacuum chucked onto the work air spindle (C-axis table). The diamond wheel is trued with tantalum (Ta) alloy. The grinding conditions are shown in Table 1. Figure 4 shows a measured profile of the

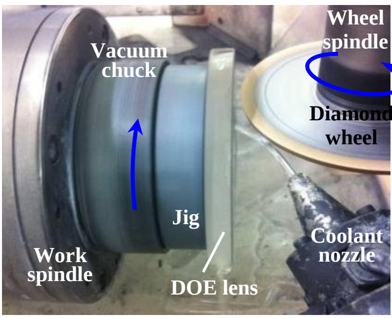


Figure 3: View of DOE grinding experiment

Table 1: Grinding conditions

Lens	Synthetic silica
Size	Φ110 mm x 20 mm t
Step height	1.39 µm
Rotation	100 min^{-1}
Wheel	Resinoid bonded diamond
Grain size	SD2000 (10µm)
Diameter	Φ100 mm
Side angle	80 degrees
Rotation	10,000 min^{-1}
Depth of cut	0.5 µm
Feed	0.2 mm/min
Coolant	Solution type

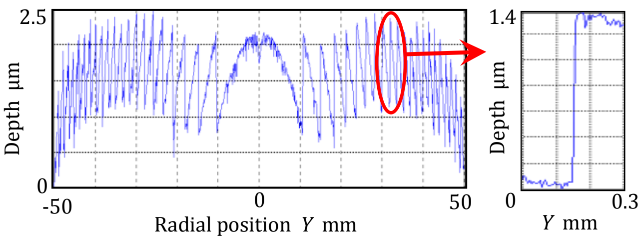
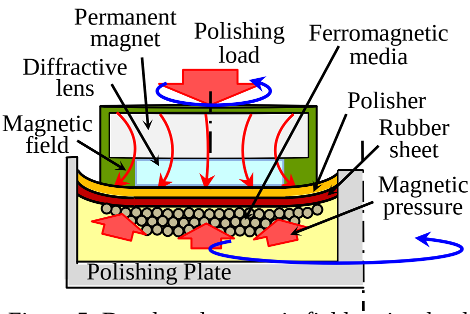


Figure 4: Measured profile of ground lens

ground lens, measured by the non-contact laser probe scanner. By the developed grinding method, very sharp steps height of the lens were generated because of the sharp wheel edge generated with the proposed truing method using Ta alloy.

3. Polishing of diffractive lens by magnetic field-assisted polishing

In order to finish the ground diffractive lens of synthetic silica, a new uniform polishing method applied with a magnetic force was developed. Figure 5 shows the developed magnetic field-assisted polishing system. A groove cut on a rotational stainless steel disk is sealed with a rubber sheet and polisher, and this groove is filled with ferromagnetic media. The permanent magnet is installed in the polishing jig and the lens is attached onto the jig. The lens contacts to the polisher and the polisher presses the lens surface by the magnetic pressure caused by the magnet and ferromagnetic media. The polishing plate and the lens also rotate in the same direction and the relative speed between the lens and polisher is uniform on the lens. This sun-and-planet motion makes the lens surface polish with polishing slurry. To keep the polishing pressure distribution uniform is important to keep the ground form. If the distribution of the polishing pressure is uniform, the removal distribution is also uniform [2, 3].



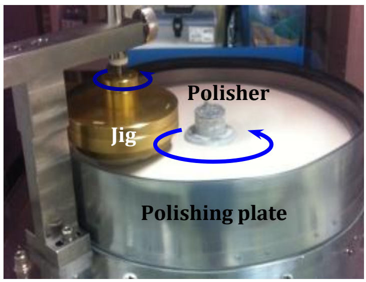


Figure 5: Developed magnetic field-assisted polishing set-up

4. Polishing experiments

Polishing conditions are shown in Table 2. Figure 6 shows surface roughness profiles of the polished surface in the centre region. Surface roughness of 7-10 nm Rz was obtained. Figure 7 shows a measured profile of the diffractive lens polished of 30 min. After polishing of 30 min, form accuracy was kept to be 1.09

μm P-V and polishing removal distribution was kept to be comparatively uniform, because the polishing pressure is uniform on the lens.

Table 2: Polishing conditions

Workpiece Diameter Step height of DOE Rotation	Synthetic silica glass Φ100 mm 1.39 μm ω=30 min^{-1}
Polisher Material Thickness	Blush type of pad Poly-ethylene terephthalate 1.0 mm t
Abrasive Density	CeO_2 10 wt%
Magnet Magnetic flux density Polishing pressure	Neodymium magnet (Φ100 mm) 0.221 T 4.97 kPa (50.7 gf/cm²)
Rotation Radius of polishing point Polishing speed	30 min^{-1} 118 mm 25.9 m/min

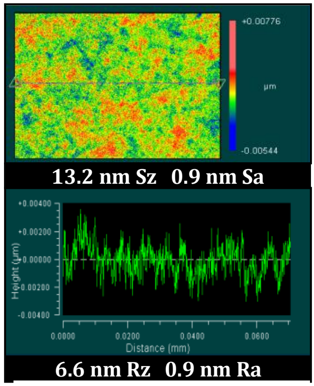


Figure 6: Surface roughness profiles after polishing

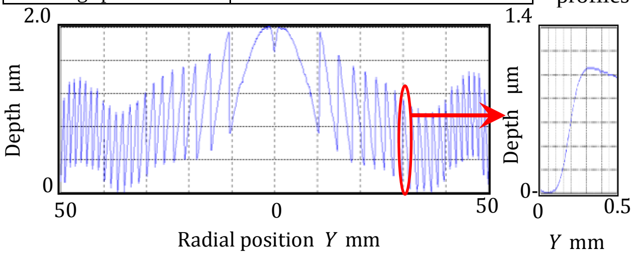


Figure 7: Measured profile of polished lens

5. Conclusions

In order to machine a diffractive lens of synthetic silica, a new grinding process with a sharp diamond wheel and the uniform finishing process with the magnetic field assisted polishing were developed. From the grinding and polishing experiments, the following results were obtained: (1) Convex type of diffractive lens was ground precisely. (2) The diffractive lens was finished uniform.

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