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Experimental investigation on non-contact polishing of microlens array mold

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Abstract

Microlens array elements have shown exhibited outstanding application values by leaps and bounds in the optical system towards high precision, lightweight and functional recombination. The mass manufacturing of microlens array elements mostly adopts compression molding. Therefore, the manufacturing level of the mold becomes the key factor restricting the optical performance of the components. Ultra-precision turning can directly obtain the microlens array structure with high surface quality and precision. However, tool markers formed by cutting also seriously affect the performances of the optical elements. It is necessary to polish the microlens array structure on the mold without changing the surface accuracy. In this work, the non-contact polishing method based on non-Newtonian fluid realizes the conformal polishing of tungsten steel microlens array mold. After polishing, the surface quality of the microlens array mold is significantly improved. The tool markers on the surface of the lens array unit are scattered, and the surface roughness was maintained at about 2.5 nm. the surface shape and depth of the array unit do not change significantly, and the form error due to non-contact polishing is less than 0.02 µm.

Keywords: Microlens array; Optical mold; non-contact polishing; tool mark removal; surface morphology

1. Introduction

The microlens array elements have shown exhibited outstanding application values with the development of the optical system towards high precision, lightweight and functional recombination. Because array units have a smaller structure than conventional optical elements, microlens array elements also have higher requirements for precision and surface quality [1].

The mass manufacturing of microlens array elements mostly adopts compression molding. The machining quality of the mold primarily determines the quality of the optical element. Therefore, the manufacturing level of the mold becomes the key factor restricting the optical performance of the microlens array elements. The microlens array structure with high surface quality and high surface precision can be directly obtained by ultra-precision turning and ultra-precision milling [2]. However, the tool markers formed by cutting also seriously affect the performances of the optical elements. Polishing can further remove the residual knife lines and damage on the mold surface, and improve the surface quality. It is necessary to polish the microlens array structure on the mold without changing the surface accuracy.

Due to the complexity of the shape of microlens array components, researchers have been looking for reliable and efficient ultra-precision polishing methods. However, traditional methods are difficult to improve surface quality while maintaining surface accuracy. Compared with contact polishing, non-contact polishing shows greater potential due to its difficulty in introducing damage. Currently, non-contact polishing methods include ion beam polishing, plasma polishing, magnetorheological polishing, and shear thickening polishing(STP) [3-4]. Zhu et al. realized micro-structure polishing using fast-tool-servo-controlled shear thickening micro-polishing methods [5]. At present, there are few reports on the non-contact polishing of microlens arrays.

In this study, a new type of STP fluid was prepared, and a non-contact polishing experimental device was developed. Finally, the non-contact polishing method based on non-Newtonian fluid realizes the conformal polishing of tungsten steel microlens array mold. Finally, based on the previous research, the non-contact polishing experiment based on non-Newtonian fluid was carried out for the tungsten steel microlens array mold.

2. Method and principle

In this work, the non-contact polishing method based on non-Newtonian fluid realizes the conformal polishing of tungsten steel microlens array mold. The principle of non-contact polishing is shown in Figure 1. The slurry was ejected by the nozzle and flowed into the removal interface and was induced by the polishing tool to form a hydrodynamic pressure-affected zone in the wedge gap. Surface material in the pressure-affected zone is removed by particle clusters formed by the Shear thickening effect [6].

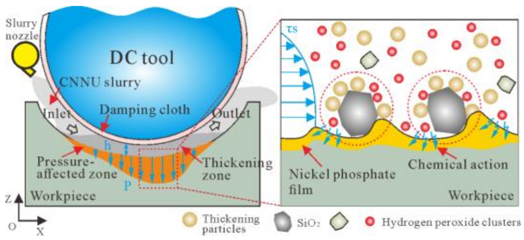

Figure 1. Diagram of the non-contact polishing method [6]

3. Experimental detail

3.1 Workpiece

The microlens array mold is shown in Figure 2. The lens array unit is evenly distributed on the spherical surface. The effective aperture of the array unit is 0.8 mm, and the curvature radius is 35 mm. The curvature radius of the spherical surface is 73.6 mm.

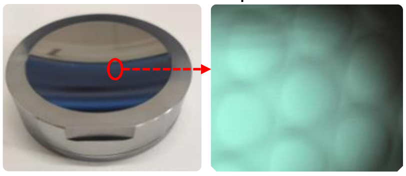

Figure 2. The microlens array mold

3.2 Experimental setup

The non-contact polishing experiments of the tungsten steel microlens array mold were conducted on a high-precision CNC grinding machine (ZCS-QGM3050) as shown in Figure 3. The tungsten steel microlens array mold was connected to the spindle I through a fixture. The polishing tool is installed on the displacement platform of the machine tool and can realize the movement in XYZ direction. The displacement platform can adjust the clearance between the polished workpiece and the mold surface. The polishing slurry is transported to the polishing interface through the supply pipeline. Spindle I speed can be adjusted between 0-3000 rpm. Spindle II with the polishing tool installed can be adjusted between 100-12000 revolutions. The XY axis positioning resolution is ±2 µm.

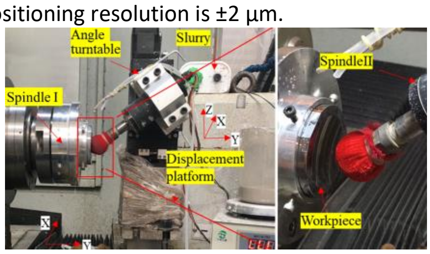

Figure 3. Experimental setup

3.3 Experimental parameters

The diameter of the polishing tool is 25 mm, and the polishing tool surface is covered with a fabric-clothed. The non-Newtonian ultrafine slurry for non-contact polishing was prepared by mixing the polyhydroxy polymer, 20 nm silica sol and deionized water, the proportion of polyhydroxy polymer is 58 wt%, and the concentration of SiO_2 abrasive particles in the system was 10 wt.%. The working gap interval used in the polishing experiments was 0.1 mm, the tool speed was 600 rpm, and the workpiece speed was 100 rpm. The polishing time is set to 6 h.

4. Results and discussion

4.1 Surface roughness

Figure 4 indicates that the non-contact polishing process used in the study has an excellent continuous removal capability. After polishing, the surface roughness is slightly reduced from 2.52 nm to 2.31 nm. Although the surface change roughness is not apparent, it can be observed that the tool marks are obviously dispersed and the surface homogeneity has been significantly improved.

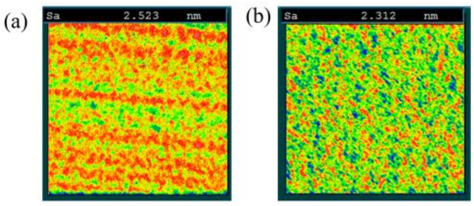

Figure 4. Surface roughness before and after polishing

4.2 Surface topography

Figure 5 exhibits a surface topography of the microlens array structure before and after the non-contact polishing. After polishing, the original surface defects of the array unit surface are effectively removed, and no new damage is introduced to the surface.

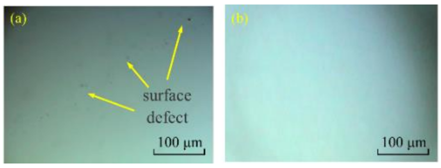

Figure 5. Surface topography of microlens array unit (a) before polishing and (b) after polishing

4.3 surface accuracy

The surface accuracy before and after polishing was measured by white light interferometer (NewView9000, Zygo, USA). The results are shown in Figure 6. the surface shape and depth of the array unit do not change significantly, and the form error due to non-contact polishing is less than 0.02 µm. The results show that the non-contact polishing method has excellent conformal polishing ability.

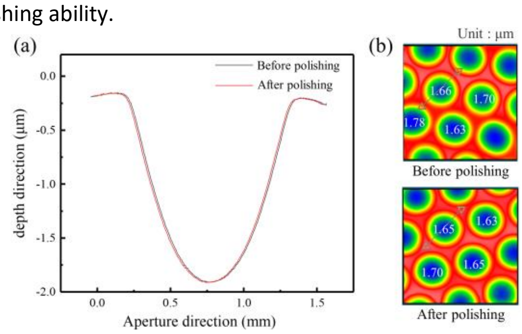

Figure 6. (a) Surface shape change and (b) depth change of array unit before and after polishing

5. Conclusion

In this work, the non-contact polishing method based on non-Newtonian fluid realizes the conformal polishing of tungsten steel microlens array mold. The main conclusions are as follows:

1. The non-contact polishing effect of the tungsten steel lens array mold is good under the parameters of the workpiece rotation speed of 100 rpm, the polishing tool rotation speed of 600 rpm and clearance of 0.1 mm.

2. After polishing, the surface quality of the microlens array mold is significantly improved. The tool markers on the surface of the lens array unit are scattered, and the surface roughness was maintained at about 2.5 nm.

3. The surface shape and depth of the array unit do not change significantly, and the form error due to non-contact polishing is less than 0.02 µm.

Acknowledgememt

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Reference

[1] Wang Z Z, Shi C C, Zhang P F, et al. Recent Progress of Advanced Optical Manufacturing Technology. *Journal of mechanical engineering*, 2021, **57** 23-56.

[2] Zhou T F, Zhou J, Wang T X, et al. Fabrication of high aspect-ratio aspheric microlens array based on local spiral diamond milling. J Manuf Process,2022,83 547-554.

[3] Li M, Lyu B H, Yuan J L, et al. Shear-thickening polishing method. *Int J Mach Tool Manu*, 2015, **94** 88-99.

[4]Zhu W-L, Beaucamp A. Non-Newtonian fluid based contactless sub-aperture polishing. *CIRP Ann-Manuf Tech*, 2020, **69** 293-296.

[5] Zhu Z H , Huang P, To S, et al. Fast-tool-servo-controlled shear-thickening micropolishing. *Int J Mach Tool Manu*, 2023, **184** 103968.

[6] Zhang P F, Li L G , Yang Z, et al. Achieving sub-nanometer roughness on aspheric optical mold by non-contact polishing using damping-clothed tool. *Opt Express*, 2022, **30(15)** 28190-28206.