Precision grinding of microarray lens molding die with 4-axes controlled microwheel

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Abstract

This paper deals with precision grinding of microarray lens (fly eye) molding die by using a resinoid bonded diamond wheel. An ultra-precision grinding system of microarray lens molding die and new truing method of resinoid bonded diamond wheel were developed. In this system, a grinding wheel was four-dimensionally controlled with 1 nm resolution by linear scale feedback system and scanned on the workpiece surface. New truing method by using a vanadium alloy tool was developed and its performance was obtained with high preciseness and low wheel wear. Finally, the microarray lens molding dies of fine grain tungsten carbide (WC) was tested with the resinoid bonded diamond wheel to evaluate grinding performance.

Keywords: Microlens array (fly eye) grinding system; Diamond wheel; Scanning direction; Form accuracy; Ceramics die; Microglass lens; Molding

1. Introduction

Recently, microlens arrays, consisting of many lenses are increasingly required for projection optical devices or optical transmission devices. In mass production process of optical devices, grinding and polishing process are conventionally used but they are not so efficient. Therefore, development of a low cost and high precision lens array machining method is required [1]. To meet this demand, the microglass lenses are mass produced by press molding of glasses with molding dies made of tungsten carbide (WC) or silicon carbide [2]. The molding dies are mostly ground with microdiamond wheels. The diamond wheel must be trued carefully on the machine before grinding. However, the grinding wheel wears soon and it is difficult to keep the original geometrical shape of the wheel.

This paper describes a newly developed precision grinding method of microarray lens surface with 4-axes controlled grinding wheel and new truing method of resinoid bonded diamond wheel. Therefore, new truing method of resinoid bonded diamond wheel by using a truing tool made of vanadium alloy [3] was developed to improve the form accuracy of the microarray lens. And ultra-precision grinding system of microarray lens surface was also developed. In this system, a disk type grinding wheel was used and was controlled four-dimensionally.

2. Principle of simultaneous 4-axes controlled microarray lens grinding

The principle of a microarray lens grinding is shown in Fig. 1. First, a workpiece is attached to a workpiece spindle (C-axis) and it is rotated at low speed, and the grinding wheel is contacted with the workpiece. The grinding wheel was synchronously moved in the same direction and speed as rotation of the workpiece, maintaining a constant distance from workpiece rotation center to machining point. The workpiece rotates by 180°: a precision ground concave spherical form will be obtained. Furthermore, a lens array shape will be obtained, if grinding wheel is moved to another lens position on the workpiece and these operations are repeated several times. By using this method, high accuracy of lens pitch could be obtained. The calculations of wheel path can be described as follows. The \((i, j)\)th ground spherical lens considered is shown in Fig. 2. If the coordinates of lens center is \((X_{ij}, Y_{ij})\), the...
turning radius $r_{ij}$ on the workpiece rotational axis and the rotation angle $C_{oij}$ are expressed as follows:

$$r_{ij} = \sqrt{X_{oij}^2 + Y_{oij}^2},$$  \hspace{1cm} (1)

$$C_{oij} = \tan^{-1}(Y_{oij}/X_{oij}).$$  \hspace{1cm} (2)

Moreover, the coordinates of an arbitrary lens center $(X_{oij}, Y_{oij})$, when the point of contacting the wheel tip on the workpiece rotates at the rotation angle $C_{oij}$, are
expressed as follows:

\[
X_{ij} = r_y \cos(C_{ij} - C_0),
\]
\[
Y_{ij} = r_y \sin(C_{ij} - C_0).
\]

Therefore, grinding wheel is controlled by simultaneous 4-axes \((X, Y, Z, C)\) with a cut in \(Z\) direction to meet Eqs. (1)–(3).

3. Experimental equipment

The simultaneous 4-axes \((X, Y, Z, C)\) controlled grinding machine, ULG-100D(SH3), Toshiba Machine Co. Ltd., was used in the experiments. The grinding wheel actuated in \(X\)-, \(Y\)- and \(Z\)-axes by the linear scale feedback system with 1 nm positioning resolution. In this research a vertical spindle having a disk type grinding wheel was used. The grinding spindle has an air bearing and the maximum rotational rate was 40,000 rpm. In the grinding test, workpiece was vacuum chucked to workpiece spindle \((C\)-axis). The diamond wheel was fixed to the grinding spindle with a collet chuck on the \(Y\)-axis table.

4. Truing experiments

4.1. Grinding experiments method

The performance of the trued wheel was evaluated by testing the quality of molding dies. Truing of the grinding wheel influences the form accuracy and the surface roughness of the workpiece. Conventionally, a diamond truer and green silicon carbide (GC) grinding stone or wheel is used for truing of the diamond wheel. However, both truing performance and grinding performance have not been satisfactory. In the lens array grinding which processes a large area at once, truing and dressing performance is important. Therefore, in this research a
new truer made of vanadium alloy was proposed. Then, the experiments were performed and the truing performance of new truer was evaluated. In this experiment, diamond truer and vanadium alloy were used for truer. Disk type resinoid bonded diamond wheels (#1200) with 10 mm diameter were trued by two kinds of the wheels explained before.

The microlens array which has 25 lenses ($5 \times 5$) was ground. Table 1 shows the grinding conditions. The tip end was trued to radius of 0.63 mm. Microlens array of 100 $\mu$m in depth was pre-ground on the workpiece. After that, each concave mold was finished by total depth of cut of 5 $\mu$m by the trued wheels. Finish grinding was performed about 5 times in each concave mold, finally 120 lenses were ground to examine grinding performance.

4.2. Grinding experiment results

Changes of the grinding wheel wear when grinding the lens array is shown in Fig. 3 and change of surface roughness is shown in Fig. 4. The wheel trued with the vanadium alloy truer had fewer wheel wear than the wheel trued with a diamond dresser. Moreover, the surface roughness was also improved to lesser value than using the wheel trued with the vanadium alloy truer. As a result, the grinding wheel trued by using vanadium alloy truer indicates lesser wear than the grinding wheels trued by using diamond dressers and GC grinding stones, when grinding WC.

5. Microarray lens grinding experiment

The microarray lens molding die shown in Fig. 5(a) was ground. It consists of 19 lenses with diameter of 2 mm each, and the pitch is arranged in a zigzag pattern by 1500 $\mu$m in the $X$ direction and 1732 $\mu$m in the $Y$ direction. Grinding condition is the same as in Table 1. The Nomarski micrograph of ground surface is shown in Fig. 5(b). Change of the form accuracy in the 19 concave molds is shown in Fig. 5(c). The form accuracy of 0.12 $\mu$mP-V or less was obtained. The form accuracy did not change so much while the number of ground lenses increased.

6. Conclusions

Ultra-precision grinding systems of microlens array and new truing method of resinoid bonded diamond wheel using a vanadium alloy truer were developed. Finally, the microlens array molding dies of a fine grain tungsten carbide were tested with a resinoid bonded diamond wheel to evaluate grinding performance, and the form accuracy of 0.12 $\mu$mP-V or less was obtained.

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