euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

# Shaping of lens array mold surfaces by electrical discharge machining

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**Abstract**
In the general fabrication process of a lens array mold, considerable time and labor are required for the shaping of optical surfaces; a numerical control machine tool is used in the shaping step, in which each element is shaped individually by feeding the tool precisely. To efficiently produce lens array molds, we have proposed a method for shaping the elements by electrical discharge machining (EDM). In this method, the tips of rods are machined individually to form a specific surface, and then a number of the machined rods are arranged to construct an electrode for EDM. By using such an electrode in the EDM process, a number of lens elements are simultaneously shaped on the mold surface. Moreover, we proposed an electrode for shaping spherical lens elements, which be constructed by fixing copper balls with a base plate. The ball type electrode is more easily manufactured than the rod type electrode. The reason for this is that a number of balls can be easily produced with high shape accuracy and smoothness by lapping and polishing with rotary discs. For the ball type electrode, the alignment accuracy of the balls on the baseplate affects the shape accuracy of the mold surface, the accurate alignment of which is required. In the present study, we propose a new ball type electrode, which enables the alignment of the balls with high accuracy. To fundamentally examine the applicability of the EDM using the new electrode to the fabrication process of the lens array mold, we manufacture a single ball electrode and process a lens array mold with 16 spherical elements using it.

Keywords: lens array, mold, electrical discharge machining, EDM, surface, optical fabrication

## 1. Introduction

To efficiently produce lens array molds, we have proposed a method for shaping the elements of a lens array mold by electrical discharge machining (EDM) [1]. Since EDM can remove hard materials more easily than precision grinding and cutting, molds can be efficiently produced. In the proposed method, the tips of rods are machined individually to form a specific surface, and then a number of the machined rods are arranged to construct an electrode for EDM. By using such an electrode in the EDM process, a number of lens elements are simultaneously shaped on the mold surface.

We also proposed an electrode for machining spherical lens elements, which is constructed by fixing spherical balls to a baseplate [2]. The ball type electrode is more easily manufactured than the rod type electrode. The reason for this is that a number of balls can be easily produced with high shape accuracy and smoothness by lapping and polishing with rotary discs. For the ball type electrode, the alignment accuracy of the balls on the baseplate affects the shape accuracy of the mold surface, the accurate alignment of which is required.

In the present study, we propose a new ball type electrode, which enables the alignment of the balls with high accuracy. To fundamentally examine the applicability of the EDM using the new electrode to the fabrication process of the lens array mold, we manufacture a single ball electrode and process a lens array mold with 16 spherical elements using it.

## 2. Principle of fabrication method of lens array mold by electrical discharge machining with spherical ball electrode

Figure 1 shows the principle of our proposed fabrication method. The electrode is constructed by arranging conductive spherical balls in an array. By using this electrode in the EDM process, a number of lens elements can be simultaneously shaped on a mold surface. In general, a lens element of the lens array is not a full hemisphere but part of a hemisphere. When the parts of hemispheres are shaped by the electrode shown in Fig. 1, the elements are necessarily generated at intervals; Fig. 1 schematically shows that the elements are produced with an interval of one element in each EDM process. Therefore, to produce a lens array mold whose elements are densely arranged, the repetition of the EDM process is required to fill the intervals with elements.

In the present work, we designed a spherical ball electrode, as shown in Fig. 2. The balls are fixed on the baseplate by force using plate springs. By using the baseplate with high flatness, the balls can be positioned along the Z direction with high accuracy. The balls are also accurately positioned along the X and Y directions by setting them into the holes.

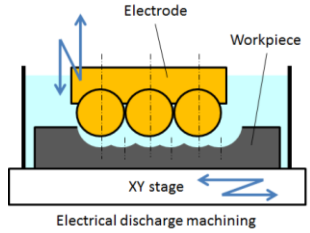


**Figure 1.** Fabrication of lens array mold by EDM.

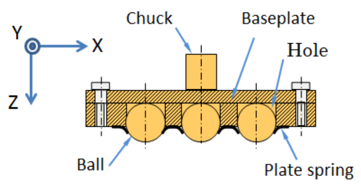


**Figure 2.** Spherical ball electrode designed in this study.

## 3. Experimental method

We manufactured an electrode and carried out removal experiments on lens array molds as follows. In this experiment, we machined a mold with 16 elements using a single ball electrode to fundamentally investigate the removal characteristics of the new electrode.

### *3.1. Electrode*

In the present study, we developed a single ball electrode on the basis of the design shown in Fig. 2 Figure 3 shows a photograph of the newly developed single-ball electrode. This electrode includes a ball finished by lapping and polishing using rotary discs. The ball is made of copper and its diameter is designed to be 4 mm. The baseplate and the plate with holes are made of stainless steel and copper, respectively.

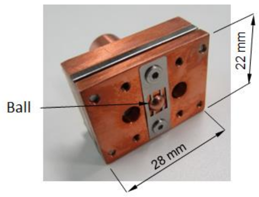


**Figure 3.** Photograph of electrode with a single ball used in the removal experiment.

### *3.2. Machining of lens array mold*

We shaped a lens array mold with 16 lens elements in this study. The distance between the elements is 1.5 mm. The depth of the elements is 350 µm. Stainless steel was used as the workpiece material. The curvature radius of the lens elements was set to 2.1 mm. To generate such a mold, the same EDM process was performed 16 times, in which the electrode was positioned at intervals of 1.5 mm. Since the ball of the electorde had a curvature radius of 2 mm, the clearance between the removed surface and the electrode surface during the EDM process was set to 0.1 mm to produce lens elements with a curvature radius of 2.1 mm. After the EDM processes, the surface profile of the workpiece was measured using the three-dimensional measuring instrument employing a laser probe.

A commercially available electrical discharge machine was used in this work. The EDM process conditions were determined through an expert system normally installed in the electrical discharge machine.

## 4. Results and Discussion

An example of a fabricated lens array mold is shown in Fig. 4. Figure 4(a) shows a photograph of the top view of the mold surface observed by an optical microscope and Fig. 4(b) shows the cross-sectional profile of the surface along line AA' in Fig. 4(a). As shown in Fig. 4, 16 elements were successfully generated on the surface.

The measurement of surface profiles was conducted for every element. On the basis of the measured surface profiles, the shape accuracy for each element was calculated; note that the shape accuracy includes the surface roughness in this study. The peak-to-valley (PV) values of the shape accuracies for every element are shown in Fig. 5. As shown in Fig. 5, the shape errors increase as the process proceeds. However, the 16 lens elements are machined with a PV shape accuracy of less than 25 µm.

Figure 6 shows the error profiles for the elements No. 1 and No. 16. As shown Fig. 6, for the element No. 1, the major component of the errors is surface roughness. For the element No.16, the error profile is concave, which proves that the lens element is machined to have a larger curvature radius than the designed one. The reason why the lens element No. 16 is shaped in such a manner is interpreted as follows. When the lens element is machined by EDM, the distribution of electrode erosion is the maximum at the top of the electrode. This is because the top of the electrode is used for the removal of the bottom of the lens element, which results in the long-term exposure of the electrode top to discharges. Therefore, the curvature radius of the electrode becomes large as the process progresses, leading to the curvature radius of the lens element to be large. In addition, the increase in the shape errors shown in Fig. 5 is due to the increase in the curvature radius.

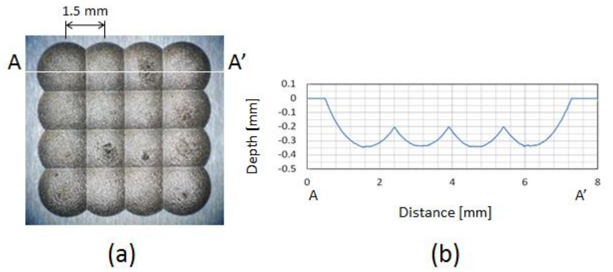


**Figure 4.** Example of fabrication results. Photograph of processed surface (a) and cross section of surface along line AA' (b).

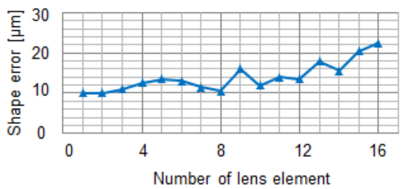


**Figure 5.** Shape error for each lens element.

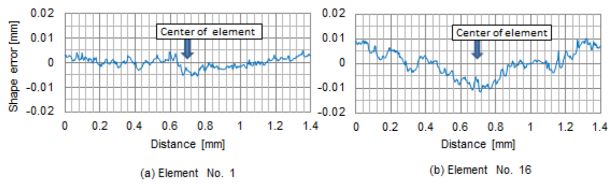


**Figure 6.** Measured surface profile of lens element. The shape error from the designed curvature radius of 2.1 mm is shown.

## 5. Conclusions

In the present study, we propose a new ball type electrode used in an EDM process for fabricating a lens array mold, which enables the alignment of the balls with high accuracy. To fundamentally examine the applicability of the EDM using the new electrode to the fabrication process of the lens array mold, we manufactured a single ball electrode and processed a lens array mold with 16 spherical elements using it. The curvature radius of the lens elements was 2.1 mm, and the depth of the elements was 350 µm. Stainless steel was used as the workpiece material. Consequently, the 16 lens elements were machined with a PV shape accuracy of less than 25 µm. Such shape errors possibly results from the erosion of the electrode by discharges.


**References**

[1] Takino H and Hosaka T 2014 Appl. Opt. 53, 33, 8002-8005

[2] Hosaka T and Takino H 2014 Proc. ICPE 696-699