Fabrication of Fresnel Lens by Glass Molding Technique

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In this paper, we describe the fabrication of a Fresnel lens with a diameter of 15 mm by a glass molding technique. Tungsten carbide and K-CSK120 were used as the materials of the mold and lens, respectively. The optimal parameters determined for the molding process included a molding temperature of 560 °C, a molding force of 300 N, a temperature holding time of 180 s, and a cooling rate of 18.5 °C/min.

Keywords: Fresnel lens, glass molding, diamond grinding, K-CSK120

1. Introduction

Compared with traditional lenses, Fresnel lenses are lighter, thinner, and have less volume. They require less material because traditional spherical lenses are divided into a set of concentric annular sections. In recent years, Fresnel lenses have been used in solar cells to collect and concentrate sunlight onto a chip. As a result, the chip area can be reduced, decreasing the cost of solar cell systems.[1)] Because solar cells must be designed for long-term outdoor use under sunlight, Fresnel lenses must be resistant to the effects of UV, heat, and humidity. Therefore, glass materials are more suitable than polymer materials.

The profile of Fresnel lenses is difficult to fabricate owing to the noncontinuous surface rings, which are usually small and steep. Therefore, it is difficult to use traditional lapping and polishing methods to manufacture such lenses. A precise diamond grinding process with a special wheel can be used to fabricate a Fresnel glass lens. Owing to the unacceptable wear of the wheel and processing time, it is not ideal to mass-produce the Fresnel glass lens. A precise glass molding (PGM) technique is an ideal processing method for fabricating high-precision glass elements because of its short cycle time, high accuracy, and high freedom.[2)] Therefore, the PGM technique is used for fabricating Fresnel lenses in this study.

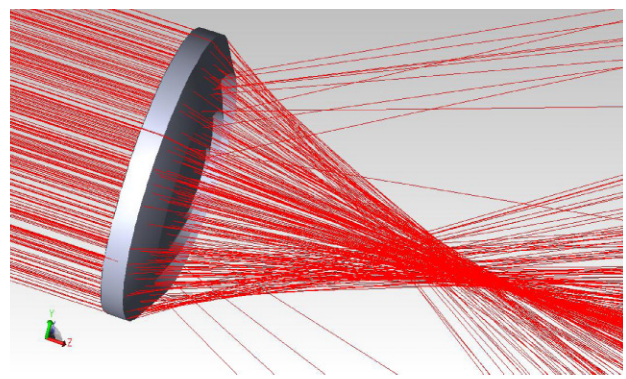

Fig. 1. (Color online) Optical design.

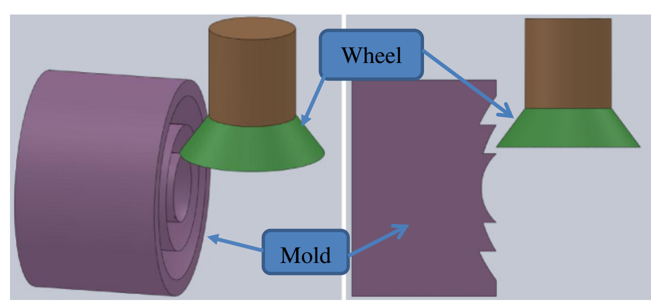

Fig. 2. (Color online) Schematic of diamond grinding process.

2. Mold Fabrication

First, the profile of a Fresnel lens was designed by optical software. Figure 1 shows the result of the design. The focal length is 32.6 mm, the diameter is 15 mm, the number of rings is 3, and the height of the structure is 50–220 µm. To obtain an accurate profile on a hard, brittle mold, a precise diamond grinding technique was used. The mold used in the PGM process usually consists of tungsten carbide (WC), silicon carbide, and glassy carbon materials. Owing to the special surface profile of the Fresnel mold, interference phenomena occur when a conventional wheel is used during diamond grinding. Therefore, a special wheel was developed to fabricate WC molds for Fresnel lenses.[3)] As shown in Fig. 2, the grinder was subjected to truing and dressing into an appropriate shape for a Fresnel lens surface. The grinding direction was set from the center to the periphery. The diameter of the mold was 15 mm. To avoid a chemical reaction between the glass and the mold, the WC mold was coated with a Pt–Ir film as a protective layer in this study. Figure 3 shows the Fresnel mold.

3. Glass Molding Process

To obtain the Fresnel lens, a glass molding system (Toshiba 207HV) was used. K-CSK120 glass with a glass transition temperature of 489 °C and a weight of 1.53 ±

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Fig. 3. (Color online) Fresnel mold.

Fig. 4. (Color online) Glass preform.

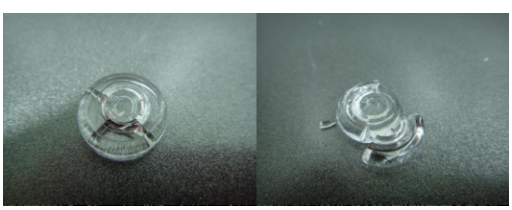

Fig. 5. (Color online) Cracked glass.

0.05 g was used as the preform for the Fresnel lens, as shown in Fig. 4. The fill rate is given as the depth of the structure on the lens divided by the height of the structure on the mold. At a fill rate of 100%, the profile of the mold is transferred completely to the glass. Optimal molding parameters, including molding temperature, molding force, temperature holding time, and cooling rate, are discussed in the following section.

During the PGM process, the primary parameter is the molding temperature. When the molding temperature is too low, the glass preform can break and the Pt–Ir film can be damaged. Figure 5 shows a glass that cracked when the molding temperature was 520 °C, which was too low. However, excessive heat causes an adhesive reaction between the glass and the Pt–Ir film. Figure 6 shows adhesion on the mold, when the molding temperature was 580 °C. Glass chips from the preform adhere to the mold.

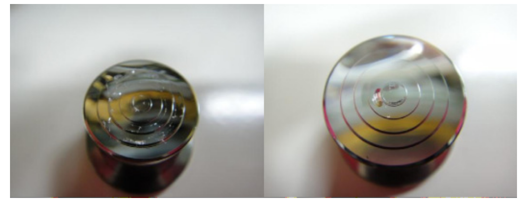

Fig. 6. (Color online) Adhesive phenomenon on mold.

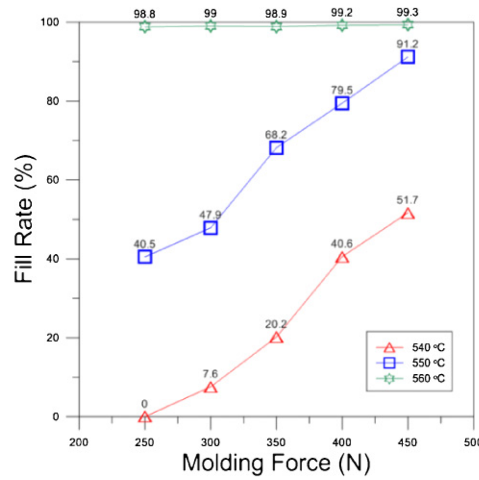

Fig. 7. (Color online) Relationships of fill rate with molding temperature and force.

Hence, the mold cannot be used. Figure 7 shows the relationships between the fill rate and the molding temperature and force. When the temperature is 540 or 550 °C, the fill rates are far less than 100%, indicating that the molding temperature is too low. The ideal molding temperature 560 °C yields a fill rate of more than 98% at a molding force of 250 N. The fill rate increases with increasing molding force. The glass preform breaks under excessive molding force at a low molding temperature, such as 500 N at 540 °C.

The set of molds includes the upside mold, the underside mold, and the STOP element. The underside mold used in this experiment is shown in Fig. 3, and the upside mold has a flat surface. The STOP element absorbs excessive molding force and controls the thickness of the lens. Therefore, the curve at 560 °C in Fig. 7 is nearly flat.

A longer temperature holding time produces a more uniform temperature in the glass preform but increases energy consumption and cost. Therefore, the ideal holding time is only that required to achieve a uniform temperature in the glass. In this experiment, the ideal time is 180 s. The Fresnel lens consists of many rings, and the top of the rings is sharp. When the cooling rate is high, e.g., 26.7 °C/min (30 L/min flow velocity of N_2), the rapid shrinkage of the Fresnel lens breaks the rings. Therefore, the appropriate cooling rate for the Fresnel lens in this study is 18.5 °C/min (15 L/min flow velocity of N_2). Figure 8 shows a Fresnel lens of 15 mm diameter made of K-CSK120 glass. Figure 9

Fig. 8. (Color online) Fresnel lens.

shows the central profile of the lens. The surface profile is smooth and symmetric. The top of the rings is sharp, indicating that the fill rate is close to 100% and the molding process is stable.

4. Conclusions

In this paper, we report the successful fabrication of a Fresnel lens with a diameter of 15 mm from K-CSK120 glass by a PGM process. The optimal molding parameters were a molding temperature of 560 °C, a molding force of 300 N, a temperature holding time of 180 s, and a cooling rate of 18.5 °C/min. The cycle time required to fabricate a Fresnel lens was 32 min. By using the parameters determined in this study, Fresnel lenses can be mass-produced rapidly and stably.

Acknowledgement

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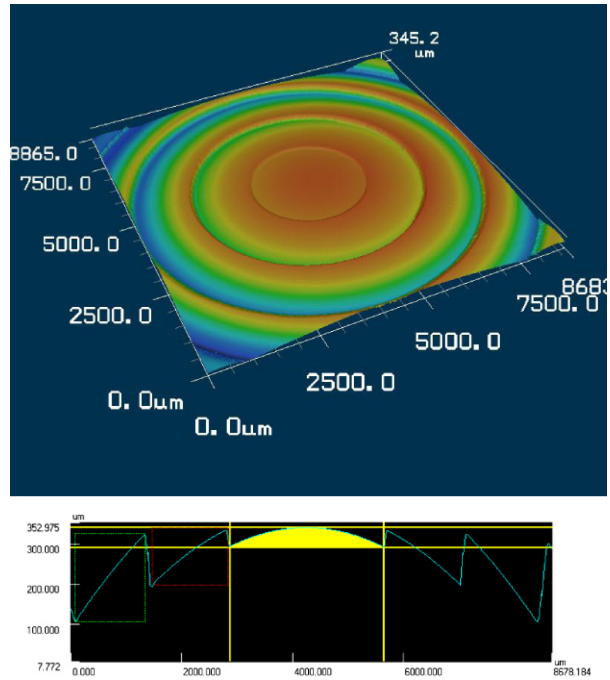

Profile1	Horz. dist.	Hght. diff.	Hght. ave.	Angle	C.S. length	C.S. area
All	8678.184um	151.430um	272.452um	1.000°	9018.007um	2298396.74...
Seg.1	2771.382um	48.926um	324.800um	1.011°	2773.584um	94943.309u...
Seg.2	1350.462um	141.343um	273.678um	5.975°	1358.943um	106378.551...
Seg.3	1244.773um	217.451um	219.485um	9.909°	1263.848um	142676.841...

Fig. 9. (Color online) Profile of Fresnel lens.

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