Molding of Diffractive Glass Lenses

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Abstract

The trend towards miniaturization and functional integration of optical systems and components is also reflected in the increased demand for structured glass optics. Precision glass molding, as a replication method for optical glasses, is a fast and reproducible manufacturing process for binary [1], blazed and kinoform [2] structures. Different application examples that were realized and the technological background are presented in this work.

Introduction

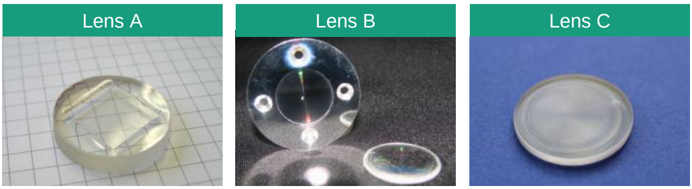
Diffractive optics, especially hybrid lenses such as asphero-diffractive lenses, which combine diffractive structures on an aspheric base surface, can be advantageously used in laser beam forming, new sensing devices, and for chromatic aberration correction in imaging optics. Current technologies for manufacturing diffractive optics comprise for example ruling, UV-curing, injection molding and embossing or lithography and etching. The use of glass as material for diffractive optics enables high UV-transmittance, high temperature and radiation resistance. However, for full-glass diffractive lenses made from optical glasses, none of the above processes can be reasonably applied. The fabrication technology of glass molding overcomes many of the obstacles mentioned before [3] and is well suited for linear, rotational symmetrical and elliptical geometries.

1 Technology

For a replication process, a suitable mold is needed. Depending on the temperature required to press a specific glass type into shape, molds can be made of metallic alloys, crystals or ceramic materials, each requiring specific manufacturing processes. For molds made of metals, for example Nickel alloys, and crystals, as silicon, diamond turning is applied. Using dedicated half-radius or sharp angle tools, rotary or linear structures with high accuracy, good roughness, sharp edge radii and narrow loss zones can be created. On these molds, protective thin-film coatings are applied to increase resistance to chemical attack of the hot glass. For ceramic molds made of silicon carbide or tungsten carbide, ultra-precision grinding is used. There are more restrictions on the geometry and edge radii are usually larger.

The precision glass molding process differs from fast glass molding processes by the fact that molding tool and glass part have a very similar temperature during most of the process. This enables the glass to adapt to the mold surface on a microscopic scale, while in molding processes involving heat transfer the surface solidifies first and does not replicate microscopic surface features.

Figure 1 shows three examples which demonstrate the feasibility of precision glass molding for producing diffractive optics. A linear blazed grating with a height of 3µm and a width of 50 µm is shown on the left, followed by a hybrid asphere which is used for chromatic aberration correction in the visible range, and a polynomial based kinoform structure on the right.



	Lens A	Lens B	Lens C
Glass Type	N-SF4	P-SK58	P-LASF47
Shape	Linear blazed grating	Convex Asphere with Kinoform	Kinoform
Molding Temperature	615 °C	410 °C	590 °C

Figure 1: Replication accuracy of mold and molded structure in glass

2 Application Examples

For Lens A, the ceramic molding tool was made of tungsten carbide and a blazed grating was machined by ultra-precision grinding on an area of 15 x 15 mm². The grating was then embossed in a dense flint glass.

Figure 2 shows a cross section of a white light interferometric measurement of the mold for Lens A made of tungsten carbide on the left. The structure height of 3 µm could be reached, but due to the processing by grinding, a rather high surface roughness is encountered. The roughness - found on both molding tool and molded glass part - and edge roundness are reasons that the grating does not exhibit optimum performance. As can be seen on the right, light is partly diffracted in diffraction orders adjacent to the desired 3rd order, reducing the diffraction efficiency.

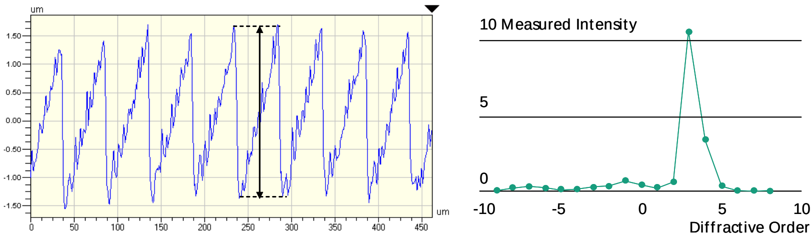


Figure 2: Measurement results of Lens A

As mentioned before, molds made of metallic alloys can be processed by diamond turning. The mold for Lens B was machined by diamond turning, using a half-radius monocrystalline diamond tool. On top of an asphere, a rotational symmetrical kinoform structure was created. From a disk-shaped preform made of a low-Tg crown glass, the plano-aspheric lens was molded. The shape deviation of the molded lens from the designed asphere is shown in Figure 3 left. The diffractive structure is not subtracted and still visible in the measurement. It can be observed that the structure was fully replicated over the entire aperture of the lens. There is still a residual shrinkage error in the base asphere with a magnitude of 1.5 µm, which could be further reduced with additional iterations on the shrinkage correction. The diffraction efficiency is shown in Figure 3 on the right. Under optimum conditions, the molded lenses get close to the theoretical efficiency maximum, as shown by lens 46 that was molded with a new molding tool. Wear on the tool surface caused by the contact with hot glass increases roughness and deteriorates the performance as in the case of lens 29 and 30.

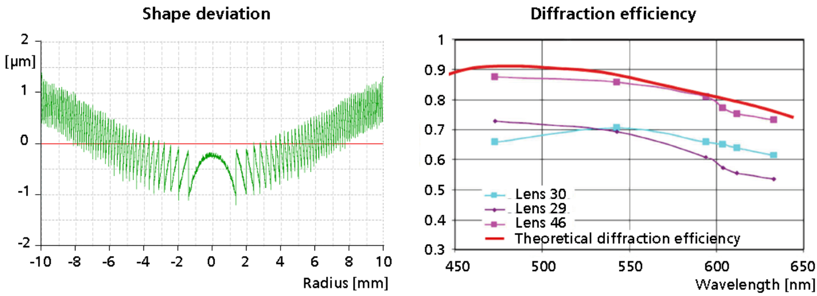


Figure 3: Measurement results of Lens B

Summary

Precision glass molding was applied to diffractive optics, presenting feasible solutions for molding hybrid or diffractive full-glass optics and their performance. Several application examples have been realized to illustrate this manufacturing method and critical points with need for optimization and further improvement have been shown.

References:

[1] Yi, A.; Chen, Y. et al.; "A high volume precision compression molding process of glass diffractive optics by use of a micromachined fused silica wafer mold and low Tg optical glass"; J. Micromech. Microeng. 16 (2006), pp. 2000–2005

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