„Aspheric Freedoms" of Glass

Precision glass moulding allows cost-effective fabrication of glass aspheres

Traditionally, the cost-conscious optical designer tended to avoid using aspheres, but today he finds himself deliberately incorporating them in products manufactured in medium to large numbers. This is thanks to the advent of precision glass moulding, which has allowed the cost-effective manufacture of aspheric glass lenses.

FIGURE 1: **Examples of preforms: balls and gobs.** (Source: FISBA OPTIK AG)

The typical method of correcting aberrations in optical systems is by splitting the optics into several spherical lenses and designing each individual element to compensate for the aberrations caused by the others. This leads inevitably to optics with many surfaces, increasing weight and space requirement. Using aspheres provides an additional method of correction, which allows aberrations to be reduced even at highly refractive components and results in smaller optical systems with fewer lenses and lower weight. The disadvantage of conventionally manufactured aspherical lenses in comparison with spherical lenses is the higher manufacturing costs. For optical components with low requirements, inexpensive lenses can be made from plastic by injection moulding. The disadvantages of plastic optical components however are their lower maximum power density, lower temperature resistance, greater dependency of their optical properties on temperature and less resistant coatings. Therefore precision moulding of glass is becoming increasingly predominant in the field of high-quality optical components. Considerable progress in the development of this process has been made in the EU project „Production4µ" [5].

Hot shaping

The starting point in the manufacture of a lens is always a preform in the shape of a ball, disc or gob (Fig. 1). Gobs are glass drops, coming directly out of the melt and are supplied by glass manufacturers for large scale production with the same volume as the moulded lens. The surface quality of the preform has to correspond to the surface quality of the optical component to be moulded, ensuring that the optical surface is created in a direct forming process without additional processing. The glass is heated in a nitrogen atmosphere (Fig. 2) and formed under a vacuum. The sequence of the steps involved in this process is shown schematically in Fig. 3.

Moulds of hard metal parts, manufactured to typical accuracies found in optical components, are suitable for most glasses to be manufactured [4]. The moulds have DLC (diamondlike carbon) or noble metal alloy coatings and are grouped together in a hard metal die holder. The number of separate moulds in this holder determines the number of lenses which can be manufactured per moulding cycle.

Effects

During the glass moulding process a number of effects occur that have to be taken into account:

The glass undergoes an „index drop" (Fig. 4), i.e. the refractive index drops slightly. The reason for this is that the refractive index of glass depends, among other things, on the speed of cooling. In glass moulding, the glass cools quicker than in conventional glass manufacturing processes. Therefore, the index drop must be determined for each glass, taking into account the intended cooling rate, and the appropriate measures taken.

During cooling, shrinkage of glass depends on its coefficient of thermal expansion. The mould also shrinks, albeit proportional to a different coefficient of thermal expansion. As the moulding takes place at mould temperature rather than room temperature, the mould cannot have the same shape as the final lens.

Not all effects can be fully simulated, it is usually necessary for mould development to go through at least one iteration stage. A process for moulding the lens is developed, using a mould based on calculations. Parameters such as the moulding temperature, pressing force, secondary pressing force and cooling rate must be determined.

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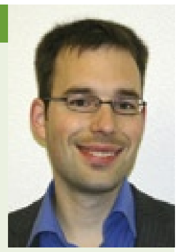

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The resulting lenses are then measured. The recorded measurements in turn are used to calculate the necessary correction data for the next iteration stage in the manufacture of the mould (Fig. 5) [1, 2].

That is one of the reasons why it takes a certain amount of time to supply even sample lenses in small production lots.

Suitable glasses

Not all glasses are suitable in the same way for precision glass moulding. Some glass manufacturers offer a special range of „low Tg glasses", which have been specifically developed for precision glass moulding and typically have lower transformation temperatures (Tg) than conventional optical glasses. Therefore they can be moulded at lower temperatures. This has a positive effect on the cycle time and the tool endurance.

Nevertheless there are striking differences in the mouldability of different glasses, even if they are from the „low Tg" range. Some glasses are optimised for particular applications, which can severely reduce their usability in other products.

Other glasses have transformation and moulding temperatures so low that they can also be moulded with diamond turned metal moulds. These moulds can be cheaper to manufacture. In addition, a considerably better surface roughness profile can be achieved without polishing than that obtained from ductile ground tungsten carbide moulds.

Metrology and quality assurance

Once the development of the process and the moulds is finished, precision glass moulding has one furhter decisive advantage over conventional manufacturing processes.

Most of the parameters of a lens are mould-related. In other words lenses that are moulded using the same mould and process exhibit a negligibly small amount of variance in these parameters. One of these parameters is the shape of the optical surface. Measuring this parameter on aspherical lenses is often very time-consuming. In addition if tactile methods are used, there is the danger that the optical surface may be scratched.

With precision glass moulded components, these measurements of the optical surface are merely necessary to check the tool and process against some specimen lenses [3]. Only the cleanliness of the optical surface has to be monitored. The centre thickness of the lenses can be determined from the measurable edge thickness. Alternatively a contactless measuring process can be used.

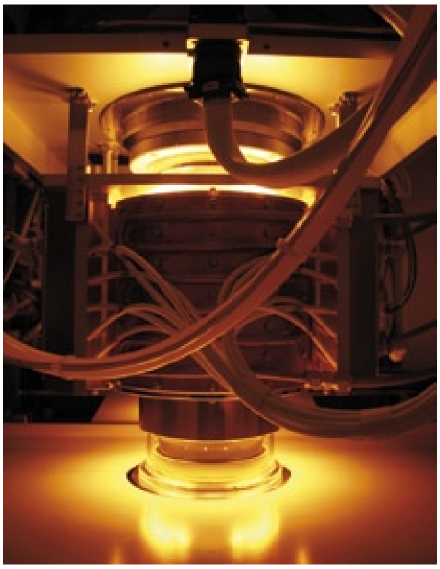

FIGURE 2: **Process chamber heated with an infra-red lamp.** (Source: FISBA OPTIK AG)

THE COMPANY

FISBA OPTIK AG

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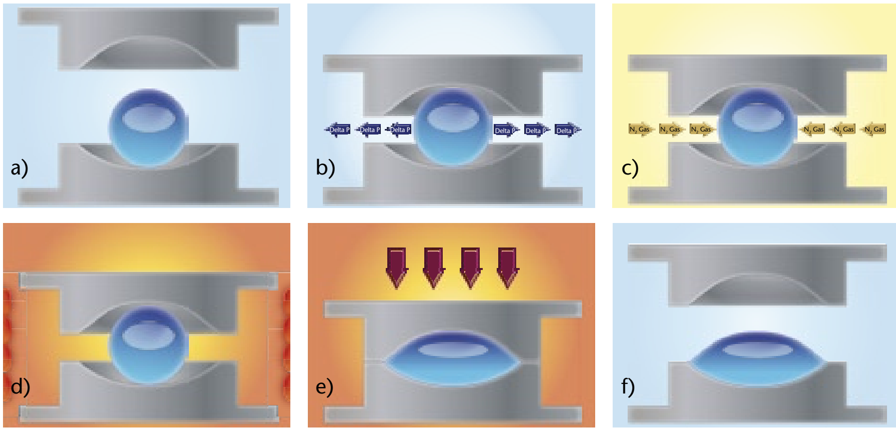

FIGURE 3: **Overview of production sequence for precision glass moulding a) Placing the preform b) Process chamber is evacuated c) Process chamber flooded with nitrogen d) Heat e) Moulding the lens f) Cooling the moulded lens.**

Special edge geometries

With conventionally manufactured lenses, there is much less freedom to design the edge geometry than with precision glass moulded lenses. In polishing processes the polishing movements must extend over the diameter of the clear aperture. Then the lens will be centered. Moulded lenses on the other hand can be moulded with the edge for the mechanical fitting if certain rules are observed. Therefore the method of manufacture of the lens must be considered at an early stage in the project when the optics and the mechanical fitting are being designed.

Instead of the usual protective chamfers, the lens edges are rounded to prevent chips occurring in the glass, as this can happen very easily with sharp-edged glasses. The rounding also acts as a volume buffer in the moulding process. In contrast to a primary shaping process such as injection moulding, this process starts with a preform, which has exactly the same volume as the moulded lens. Since the preforms are made according to specified manufacturing tolerances, the resulting deviation from the specified lens volume is taken up by a volume buffer. Alternatively there is a version of the moulding process in which an overrun is retained on the mould at the edge. In this case the lens must be conventionally centered, while ensuring that the orientation of the aspheric surfaces is correct. The selection of the most suitable moulding process (with moulded edge or conventionally centring of the edge) depends on the technical and economic restraints and desired end product.

Economies of scale

Aspheres in the precision glass moulding process can be produced more cost-effec-

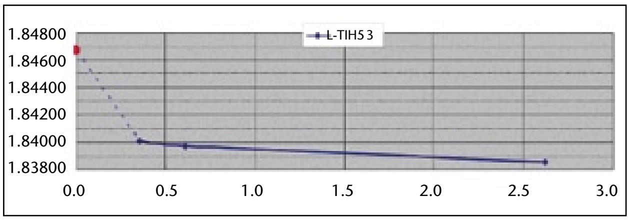

FIGURE 4: **In precision glass moulding, the glass is cooled so rapidly that the refractive index after the moulding process is marginally lower than it is in the glass catalogue (red dot).** (Source: Ohara)

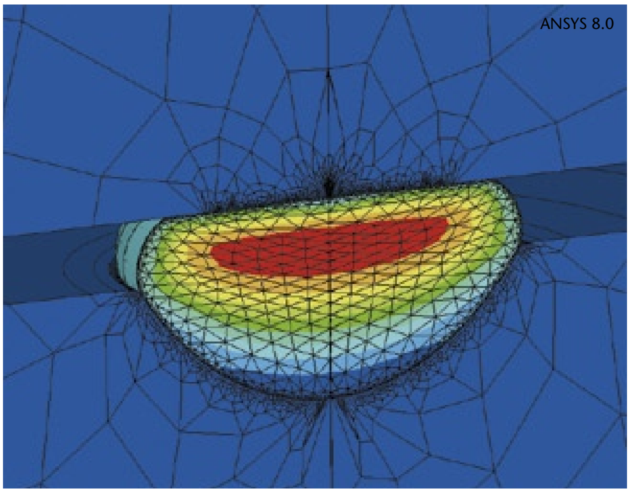

FIGURE 5: **The number of iteration stages can be minimised by using Finite Element Method (FEM) simulations.** (Source: Fraunhofer IPT)

tively than conventionally manufactured lenses for medium and high production volumes. However, relatively high one-off costs are incurred at the start from the need to develop the tooling and process and these initial costs would be unavoidable, even if only one lens was to be produced.

To allow the customer to obtain prototypes and medium production volume items, the first moulded lenses are produced using a single-cavity mould. If the customer then decides to place a large volume order, a multiple-cavity mould system can be developed. The moulds for this must then be manufactured and an automatic handling system installed, which again incurs one-off costs.

Maximum freedom by combination

The advantages of precision glass moulding are best exploited in combination with other technologies and skills. For OEMs it is advantageous to obtain complete optical systems from a single supplier. A precision moulded lens usually forms part of a larger, more complex optical system in which there are also spherical lenses (produced conventionally, depending on production volumes), filters or prisms. In arriving at the best precision moulded lens solution in technical and commercial terms, it is a considerable advantage to be aware of the limits and possibilities of the production process and the application.

Conclusion

Precision glass moulding is a process for manufacturing aspheric lenses in volumes of a few hundred upwards much more cheaply than conventionally produced aspheres. They can be effectively used in an optical system to correct aberrations, instead of attempting to do this using several spherical surfaces. Further advantages of optics with aspheric lenses include more compact dimensions and reduced weight. The numerous interfaces and interdependencies of the precision glass moulding process with the disciplines of optical design, mechanical design and assembly make it important to find an expert and experienced partner at an early phase in a project.

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