PRECISION GLASS MOLDING:
AN INTEGRATED APPROACH
APPLIED RESEARCH IN PRECISION GLASS MOLDING

Precision glass molding processes in which replicating optics are applied are capable of manufacturing large volumes of precision glass lenses. This technique was established many years ago and today is used, for example, to produce thousands of precision optics for consumer goods such as digital cameras. This replicative manufacturing approach can be used for more than simply the mass production of individual optical elements – it can also be applied to the efficient production of complex optics such as freeforms or lens arrays. There are a number of different processes that must be completed in order to successfully produce the optic; the optimization of each process in isolation will not necessarily lead to the desired results.

The Fraunhofer Institute for Production Technology IPT overcomes these challenges by applying an integrative approach that focuses on the entire sequence of processes, rather than dealing with each process on its own, and we optimize these sequences to meet our clients’ specific demands while reaching the highest levels of efficiency.

We have been carrying out applied research and development in the field of glass optics manufacturing via precision glass molding for nearly a decade. As the result of this extensive research work, we are now able to assist our clients with all aspects and processes linked to this replicative manufacturing technique. Specifically, we deal with the following topics:

- FEM process simulation to gain information about the molding results in advance
- Mold design to guarantee the successful implementation of the desired specifications
- Mold manufacture to enable the replication of complex optics
- Coatings to extend mold lifetime and assure an efficient molding process
- Molding to finally create the required glass optics
- Qualification of the optical elements to assure the quality of the process

Our expertise on the subject of all the processes involved in precision glass molding enables us to offer clients a wide range of services – from single process investigations to prototype manufacture and feasibility studies. We can also help our clients introduce the precision glass molding technique into their production portfolio – from a drawing of the specific optical lens to the final process capable of manufacturing that optical lens to the required specifications. Furthermore, with our spin-off company Aixtooling as well as a network of industrial partners we can provide the whole process chain for precision glass molding.
**FEM SIMULATION AND MOLD DESIGN**

In order to enhance process efficiency, we perform FEM process simulations of the molding process based on the optics’ design. This enables us to estimate – in advance – lens shrinkage and the final optical properties due to the effects of internal stresses or index gradients.

Another advantage of process simulation is that it enables us to optimize mold design. We can design molds that are best suited to the specific molding tasks, taking not only glass shrinkage but also flow behavior into consideration. The simulation process runs automatically for rotationally symmetrical geometries. After entering certain geometrical information and the molding process layout, our simulation software calculates the ideal mold and glass pre-form geometries. A graphical user interface allows for easy manipulation of all input parameters and the modular character of the simulation software makes special adaptations possible that meet the different molding needs of our clients.

This entire field of work is based on a sound understanding of the molding process and of adapted material models that characterize the glass during each phase of the molding process. On the basis of these results, we design a customized mold concept that is capable of replicating the optical element to the desired specifications. In the case of non-rotationally symmetrical optics, the potential alignment features need to be considered in order to avoid lateral or rotational displacement of the two optical surfaces.

**MOLD MANUFACTURING**

The major factor contributing to the success of nearly every replication processes is the mold. The molds applied in precision glass molding processes consist of adapted ceramic and tungsten materials that can only be ground to shape. When one also considers the accuracies required in the production of precision optics, the manufacture of the mold becomes the most challenging of all the processes to be accomplished.

Here, our process expertise enables us to manufacture molds with optical surfaces and accuracies in the sub-micrometer range. We can produce rotationally symmetrical spherical and aspherical geometries, cylindrical and non-cylindrical geometries and non-rotationally symmetrical surfaces such as freeforms or lens arrays. We use diamond cutting processes to produce diffractive molds for the precision glass molding process. In addition to conventional materials such as German silver or nickel-plated substrates, we are currently developing processes to machine diffractive molds from ceramics and tungsten materials. Our large machine park, consisting of five state-of-the-art ultra precision machines from various manufacturers, allows us to continuously add to our understanding of the process and design new manufacturing processes for future mold production.

Finally, the ground optical surfaces need to be coated to prolong mold lifetime. As the result of previous and on-going research, we can choose the right coating (PIr, TiAlN, Ir, etc.) for our clients’ molding processes and coat the molds using our specially adapted PVD coating machine.
The Fraunhofer Institute for Production Technology IPT has various commercially available glass molding machines on hand that are used when designing and evaluating the molding process for the replication of glass optics. We can therefore transfer the process we have developed directly to our clients’ production facilities. Prototypes and small series can also be manufactured by our machines so that our clients do not necessarily need to invest in the entire molding infrastructure.

The variety of machines allows us to mold a wide range of glasses – from the very low Tg glasses to fused silica, which is molded at about 1 400 °C. A specific process layout can be developed on the basis of the results of the process simulation. In order to ultimately successfully mold the optics, the process needs to be adapted for the specific glass required by the client.

As already mentioned, intelligent mold design also makes it possible to replicate double-sided, non-rotationally symmetrical elements. The efficient production of, for example, glass lens arrays becomes possible – elements that can currently be very expensive and complicated to manufacture.

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The final qualification of the molded optic is as important as the molding process itself. Here, the dimensional accuracy of the optic is crucial to its functionality. Tactile and optical metrology equipment is used to characterize the shape of the element. Further devices are used to investigate the surface quality and the performance of the molded glass optic. White light interferometric measurements characterize the optics surface, while wave front measurements are applied to test optical performance.

Metrology is, of course, used at every single process step in order to guarantee the highest possible quality throughout the entire process sequence. Feeding the gathered measurement data back into the processes allows us to perform our tasks with the greatest possible efficiency.
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