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SURVEY OF PRESENT LENS MOLDING TECHNIQUES

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This survey will provide an overview of glass molding technologies, with a concentration in the newest of the technologies - Precision Glass Molding (PGM). A brief description of various forms of glass molding, including an historical review of patents associated with precision molding, is given. A worldwide survey of known commercial availability and recent innovations in PGM at Kodak are presented as examples of the potential of the precision molding technology.

The various forms of glass molding techniques and their application can be described as follows:

1. Glass Lens Blank Molding - the near net shape molding of glass materials into a preform shape that minimizes removals during grinding and polishing to final form.

2. Molded Fire Polished Optics - the net shape molding of at least one, and in some cases both optical surfaces of a lens. This technique is capable of producing condenser lens type quality, but the process is limited by the glass materials that can be molded.

3. Thermal Replication - a thermal reshaping of a prepolished preform by heating the preform until it sags or conforms to the tool shape. Limits of the process for surface quality, figure and glass types appear to be in the ophthalmic optics range and are described in articles written by R. J. Tillen of American Optical.

4. Replication with Non-Glass Materials - a thin ultraviolet curing epoxy layer, that is shaped by a master asphere tool, is cured onto a prepolished best-fit spherical lens. N.V. Philips (The Netherlands) has used this technique to produce aspheric CD Audio lenses. Minolta Camera Company (Japan) has produced aspheric lenses for some of their 35mm lens systems.

5. Thermal Reforming - a prepolished lens, that closely approximates the final lens shape desired, is heated and then the surface is reformed by a heated tool of the required aspheric shape. This process is described in a Japanese Patent Application filed in 1983.

6. Precision Lens Molding of Specially Formulated Glasses - the precise molding of lenses to final shape using specially formulated glass materials. The optical surfaces can be very precisely figured but only a limited number of special glass formulations are available. Corning Glass Works (U.S.) and Matsushita Electric Industrial (Japan) have used the process to produce aspheric singlet lenses for CD systems.

7. Precision Glass Molding - the precise molding of optics to final shape using a wide variety of glasses and glass-based infrared materials. Kodak developed the process to produce spherical and aspheric lenses used in various photographic systems. Kodak also produces 0.05 wave rms lenses for CD Audio and optical data storage systems. Other recent innovations will be described later in this paper.

Lens Blank Molding has a very long history. Molded Fire Polished Optics are more recent, but as a frame of reference, Kodak developed a fire polished aspheric condenser lens for a projection illumination system in 1927. The first reference to Precision Glass Molding is a 1946 patent by Webb of Kodak. A list of patents that refer to precision molding are as follows:

1946	Webb	(Kodak)	1978	Wu	(Corning)
1974	Angle	(Kodak)	1984	Sato	(Ohara)
1975	Parsons	(Kodak)	1985	Hirota	(Hoya)
1979	Blair	(Kodak)	1986	Kuribayashi	(Matsushita)
1979	Blair	(Kodak)	1986	Kogure	(Olympus)

Worldwide, the companies that have an announced capability in some form of precision molding are Kodak, Corning, Matsushita, Canon, Olympus, Hoya, and Ohara. Some companies either have very limited capabililies or do not make the technology available on an OEM basis. Kodak uses its capabilities for both internal and OEM sales. It would be best to contact any company to discuss actual sales practices. It is hoped that no company has been overlooked and it is not claimed that this listing is complete.

It is easiest to describe the potential of precision molding using Kodak's PGM technology as an example. As a basic reference, the Technology Trends section of "Photonics Spectra" carried an article in September 1986, titled "Finished Lens Molding" by Aquilina, Richards, and Pollicove of Kodak.

To briefly describe the Kodak Precision Glass Molding (PGM) process:

* A wide variety of glasses and glass-based infrared materials are molded.
* Optical surfaces of the lenses are essentially a replica of the molding tool surface.
* PGM produces extremely precise surface figure and polish finish.
* Unusual geometry and tolerance controls are achievable.

One primary advantage of PGM optics is the fact that very precise aspheric lenses are possible, especially in large quantities. Mechanical dimensions and reference features can be molded with very precise alignment to the optical axis of the lens. Because the lens surface is essentially a replica of the tool surface, part to part variation is greatly reduced. In fact, lenses produced by the same tool package are within very small fractions of a wavelength of each other.

General aspherics are the most common application of the PGM technology. For instance, optical data storage lenses, with numerical aperatures of 0.50, 0.53, and 0.55, are produced with a single aspheric lens element using a high index glass material. Transmitted wavefronts of 0.04 wave rms are achieved with the single element lens system. These singlets are typically superior to a three-element lens system when manufacturing variations that reduce field performance, magnification, and numerical aperture control are considered. Aspheric singlet laser diode collimators with NA's of 0.3 and 0.38 have been produced to transmitted wavefronts of 0.05 wave rms with the same excellent results.

Non-symmetrical optics are a more unusual application of the PGM technology. An off-axis ellipsoidal mirror with reference features molded into the backside for quick mounting and alignment, has been produced. The process is very cost effective when compared to the grinding and polishing methods previously used and the alignment features are unique.

Alignment and mounting of aspheric optics are always a challenge. One aspheric lens, almost a hemispheric bump in the middle of a flat glass disc, provides built-in alignment of the aspheric axis to the outer plano reference disc. Alignment and mounting problems are significantly minimized, since it is relatively simple to align a plano as compared to determining the alignment of an aspheric surface in an optical system.

Another alignment method often used, is to create a spherical surface outside the aspheric surface - both axisymmetric surfaces are on the same optical surface. The sphere is used as the mounting reference for the asphere.

Over fifty optical glasses, including radiation hardened glasses and glass-based infrared materials have been molded. Both crowns and flints, ranging in index from 1.51 to 1.85 have been used. As indicated earlier, maintaining very precise surface figure accuracies and lens to lens consistency are a major benefit of the PGM process. Lens center thickness can be held very precisely. Surface quality, as defined by MIL-O-13830, can be maintained at the 20-10 level. Although production costs tend to increase as tighter tolerances are required, the cost penalty is usually not as severe as with conventional manufacturing methods.