Optical Short Course International

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What's "Inside The Box"?

Optics of Digital Projectors Weekly Newsletter

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Molded Glass Aspheric Lenses

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Over the last several issues we have been looking at illumination systems and their components and how they work in light engines. This week we will continue our look at illumination systems again but at a specific optical fabrication technique called glass molding. Glass molding is used to make many optical elements in illumination system such as light source mirror substrates, aspheric condenser lenses, fly's eye arrays, field lenses, and prism and mirror substrates. Molded glass element fabrication is much different from conventional glass fabrication processes. The high tooling costs require high volumes so that the tooling costs can be amortized over many optical elements so this technology can be cost effective.

How are Molded Glass Elements Made?

The glass is heated to a temperature at which it is soft and then is pressed into a mold with high pressure and then the mold and glass is cooled at a controlled rate. Some of the lens surfaces on molded glass elements are then fire polished to provide a smoother surface if the mold is too rough or the process does not provide a good finish. Simplified versions of this process and some general glass bottle molds can be seen at these websites:

http://www.optics.co.uk/rod.html
http://www.nikon.co.jp/main/eng/portfolio/technology_e/aspherical_lenses_e/
http://www.welcome-web.com/KATA/glass-mold.htm
http://www.skloform.cz/ge/vyrprog.htm

Precision molding of glass aspherics elements is a high tech process where thermodynamics of the process is very important to the accurate surface profile. The precision mold which is made from high temperature steel is heated to over 500 degrees C and the glass at about 1000 degrees C is placed into the mold. The mold has the precision finish of the aspheric or fly's eye surface machined into the mold. The plunger part of the mold is pressed onto the glass which forces it into the precision finish of the mould with about 500 kilograms or 2 tons of force. This high pressure and heat wear out the plunger and can affect the surface quality of the mold over time. The mold is then water and or air cooled at a controlled rate to control glass and metal shrinkage. The annealing process helps control the stress birefringence in the bulk glass.

There are many important process parameters that affect the finished quality of the aspheric glass element and this varies with each company. About 20% of the cost of glass aspheric elements is the bulk glass material cost. B270 is a popular molded glass material as is fused quartz and several other in-house optical glasses at various companies who make their own special glasses. About 80% of the cost of glass aspheric elements is amortizing the cost of the mold as well as grinding and polishing the second surface and coating the lens element. Molds can cost anywhere from about $10,000 to $50,000 or more for high volume molds. This high mold cost needs to be spread over many thousands of lenses in order to make economical optical elements and thus light engines for digital projectors.

Why Molded Glass Fabrication?

Molded glass fabrication is used as a fabrication method because it may be the only way to fabricate some optical elements or it is financially attractive compared to the alternatives. Take a fly's eye array used to spatially homogenize the light in a digital projector light engine. There is physically no possible way to form some of the convex fly's eye lens surfaces on a single substrate using conventional optical fabrication; it must be molded as a single element. Single element condenser lenses with one or both surfaces shaped as deep aspherics can be made conventionally but it is more economical to use glass molding fabrication.

Let's take a look at the single element condenser lenses that can be fabricated using conventional optical fabrication tooling and methods. http://www.universalphotonics.com/pod.htm A single element lens will start out as a disk or cylinder of glass and will have the spherical surface curves generated into the disk with diamond impregnated generating tools. Next these generated surfaces will leave tool marks in the glass which must be removed by the grinding process. The grinding process requires a cast iron tool with the spherical curvature of the required surface. The grinding starts with large diameter grinding particle in a wet slurry and removes the high points on the glass surface. The grinding process continues by using smaller and smaller diameter grinding particles until most of the generating tooling marks have disappeared and the grinding has progressed deeper than the subsurface damage. At this point the polishing process can begin.

The polishing process consists of another spherical curvature tool with pitch formed on the surface of the correct accurate radius of curvature. The polishing tool is run with polishing slurry of a certain size diameter polishing powder and progresses to smaller and smaller diameter particles until the surface is completed. The lens is then typically edged and sagged so that it can be properly mounted into an optical assembly. This fabrication procedure was for a spherical surface if the surface is aspheric or not spherical then there will be additional steps to form the aspheric surface.

There are some high speed optical fabrication machines that can perform the conventional steps to form a lens from a disk of glass in about a minute. These machines are certainly impressive and expensive and require high volumes to justify the fixed tooling costs. There are also some automated machines that will fabricate aspheric surfaces on spherical surfaces such as MRF or magnetorheological finishing. This technology makes a magnetic fluid stiff with a precisely applied magnetic field while the lens surface spins in front of the fluid. Another technology or process is deterministic micro grinding or DMG. These technologies and machines can be found at the websites below. http://www.opticsexcellence.org/InfoAboutCom/WhoWeAre/magfinishing.htm
http://qedmrf.com/
http://www.nanotechsys.com/index.html

Volume, Scale, and Standardization

The manufacturing volume drives many of the costs in modern day high tech manufacturing. Having a high enough volume of a particular part can enable a company to invest in an automated high precision machine that can produce accurate parts at a much lower cost. One way to increase the volume is to use the same part in multiple high volume models in a company's product line of digital projector light engine. This manufacturing scale would significantly reduce the cost of light engine parts such as lamp reflectors, aspheric condenser lenses, field lenses, and projection lenses. All industries progress towards the shakeout and have about seven or eight dominant players as they mature. When we reach this shakeout point it may be possible to get a few of the smarter companies together and standardize on some of these light engine components to achieve the volumes necessary to get significant cost benefits.

If you need to better understand digital projector costs take a look at ARS Labs and some of their display manufacturing costs analysis services.
http://www.ars1.com/displays.asp

Summary

We have looked at why and how some optical elements in digital projector light engines must be molded out of glass. In some cases it is the only fabrication method to produce these complicated surfaces in a single element. In other cases molded glass is a very cost effective method to produce certain optical elements. The glass molding process is a high precision process that must be thermally controlled during the complete process to maintain accurate surfaces. Glass molds are expensive and their costs must be amortized over many optical elements and thus are best for high volume applications.

Stay tuned and keep looking for your weekly dose of "In The Box" to understand the optics of digital projectors. If you enjoy increasing your knowledge about digital projector optics please tell a friend about this e-newletter, your referral is the kindest compliment we can get to show your appreciation.