# An Introduction to the Optics Manufacturing Process

Katie Schwertz
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## Abstract

Although technological advances are continually being made in machinery for optics manufacturing, the actual manufacturing process has, in many ways, remained unchanged. This paper serves as a basic overview of how a lens is manufactured from a blank. A lens is typically ordered from a glass company in a form called a glass blank. From there, the lens goes through generation where the rough shape is ground into the blank. A lens is then blocked and undergoes further grinding to improve the surface and shape. Polishing is the final fine grinding stage where the surface and shape of the optic is finished to specification. The optic is then centered and bevels are put on the edges. Typically the optic is then coated and it is ready to be used in a system. Diamond turning, injection molding, and precision glass molding are also discussed.

## The Beginnings of a Lens

The typical life of a lens begins as a glass blank. This is the basic material that the final lens will be made from and can be ordered in many shapes and sizes (Figure 1). These are usually ordered from an optical glass company. Major glass companies include Schott, Ohara, and Hoya.

**Figure 1: Glass blanks**

Glass choices are made during the design process and involve a variety of factors including the refractive index, Abbe number, and availability/cost. Chemical and thermal properties are also important depending on the application and manufacturing process. The actual properties of a particular glass blank will deviate from the ideal design. A data sheet (or melt sheet) is included when purchasing blanks so the actual properties of that particular batch are known as compared to catalog values.

**Generation**

The first step in the lens manufacturing process is generation. This process will 'generate' the shape of the lens into the blank, getting close to its final shape, size, and curvature. Although an outdated process, one generation technique that is still used today is loose abrasive grinding. This involves using various grit sizes mixed with water (this mixture is called a slurry) to remove glass. The larger the grit size, the more glass is removed, resulting in a faster removal rate. However, a rougher surface will be produced. Therefore, generating begins with large grit sizes of up to 100-200μm and moves to grits as small as 5-10μm.

A more modern method allows you to program a removal function into a computer controlled tool that has diamond cutting edges (Figure 2). This process has a much faster removal rate and once a template is programmed, it can be used for multiple runs. A limitation to this method is that the generating tool must have a larger diameter than the radius of the optic being generated.

**Figure 2: Generation tool**

Unfortunately, both methods result in surface damage to the optic. Further grinding and polishing is then needed to smooth the surface to its final form.

**Blocking and Grinding**

Before the lens undergoes further grinding, the lens must be blocked, or mounted, to begin the process. Blocking involves mounting lenses onto a convex or concave surface (inverse of the tool being used) with pitch or wax. A lens can be blocked individually (Figure 3a), but more often, many lenses with the same radii are mounted on one surface for high production (Figure 3b).

**Figure 3:**
**(a) Single optic and slurry** **(b) Multiple optics on one tool**

Loose abrasive grinding uses inverse spheres of the same radii ground together so that the hills and valleys on the optics will wear away to produce a true sphere. Slurry flows in between the blocked parts and the spherical tool to keep the parts cool and wash away debris created during the grinding process.

## Polishing

After the lens is generated and fine ground, it undergoes polishing. Depending on how precise the generation is, the lens may go through several stages of polishing. Whereas the grinding process mechanically removes material by breaking off small pieces of glass, the polishing process is both mechanical and chemical. In this stage, the final figure is put into the lens, including its radius of curvature and center thickness. There are a variety of methods and materials available for polishing, the most conventional of which is pitch polishing.

Pitch is a unique, and very useful, compound which can be found naturally or made synthetically. It is usually a dark color and is viscoelastic at room temperature. For polishing, a mixture of wood tar pitch and colophonium (a type of resin) is used. Pitch is adhered to a polishing tool which is the inverse of the radius of optic being polishing. The tool with the pitch will be placed on the optic and rubbed together, much like the grinding process. As the polishing process continues, the pitch will slowly conform to the shape of the optic so that the surface of the optic is smoothed out, but its overall radius is not changed. To aid in removing debris, grooves are cut along the pitch to allow slurry to flow more readily between the tool and the optic. A hole is also cut in the pitch at the center of the tool since pitch will flow toward the edges and center of the tool during polishing.

For higher production parts, high speed CNC (Computer Numerical Control) machines can also be used. This process involves using synthetic pads and a variety of cerium oxide based polishing compounds (Figure 4). The pads have relatively high hardness and will keep their shape for long periods of time.  Unlike pitch, however, the pads will not conform to the optic which is why this polishing tool must be precisely controlled.

**Figure 4: CNC Polishing Machine with synthetic pads**

A more recent polishing technology is Magneto Rheological Figuring (MRF).  This polishing process also has a removal function programmed into a computer, but the slurry used contains microscopic magnetic and diamond particles.  The slurry runs over a belt on a spinning wheel and the lens is lowered into the slurry from above (Figure 5).  The computer can control the hardness of the slurry by applying a magnet beneath the spinning belt.  This effectively allows you to combine many polishing processes into one since you can make your polishing compound harder and softer just by altering the strength of the magnet.  Although very precise, MRF is expensive for regular optics since the slurry must be changed every few weeks with regular use. However, it is very cost effective when optics must be polished to λ/10 or λ/20 surface finish.

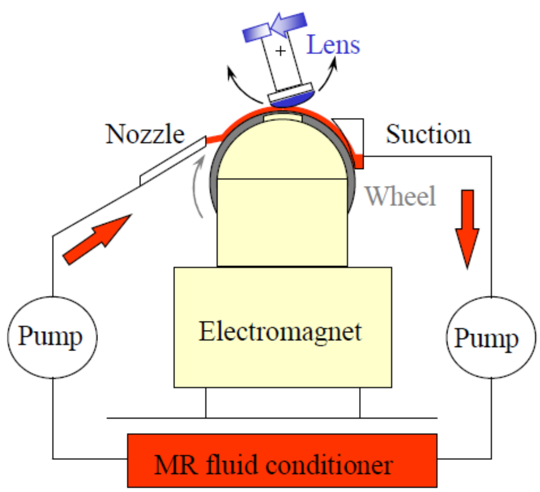


**Figure 5: Schematic of an MRF Machine**

## Centering and Edging

Before centering begins, the polished surfaces are first inspected. Surface accuracy is checked by using test plates or an interferometer and the optic is inspected for surface defects such as scratches, digs, and sleeks. If the optic does not meet its specifications, it is returned to polishing.

A lens has both a mechanical axis, defined by the outer edges of the lens, and an optical axis, defined by the center of curvatures of each surface of the lens. The process of centering attempts to make the optical axis co-linear with the mechanical axis. Plano surfaces do not need to be centered. Small centering errors can have large effects on an image since the optics will be assembled according to their mechanical axes and the errors will multiply.

Lenses can be centered both optically and mechanically. The mechanical method uses bell chucks and can be both a manual and/or automated process. The lens is placed between two precision aligned chucks and it will slide to the point where there is even edge thickness. This self centering process automatically lines up the mechanical and optical axes and the edges can be beveled and cut while spinning in the chucks. Figure 6 shows a lens that has been placed in aligned chucks and will slide to the left as it self centers.

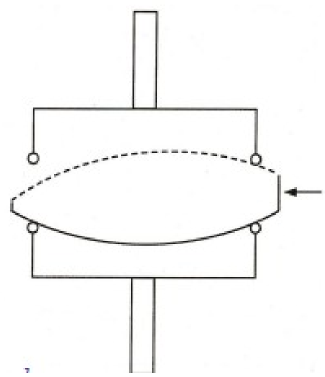

**Figure 6: Mechanical Centering**

Using the optical method, the lens is mounted on a mandrel, or spindle, and light is passed up through the optic to the operator's eye (a lit target can also be used). As the mandrel and optic rotate, the collimated beam will appear to move unless the optic is centered. The operator will move the optic while looking at the beam until there is no motion and then the optic is fastened in place and edged.

It is important to add bevels to any sharp glass edges to avoid chipping or cracking a lens. Typically, edging is done during the centering process. Figure 7 shows a centering and edging machine that can grind the outer diameter and put bevels on both sides in one run. Although less common, bevels can also be added after centration, either using a stone grinding wheel or convex or concave bevel tools.

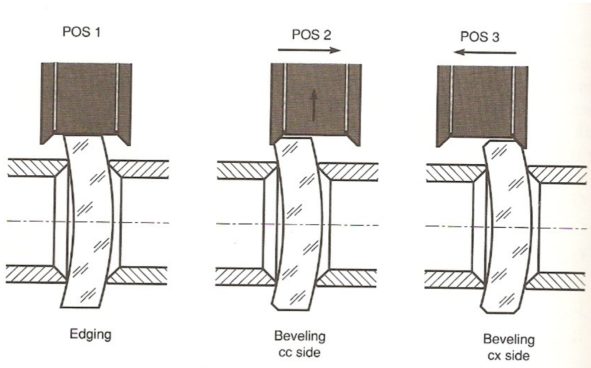


**Figure 7: Combination bevel and centering tool**

## Coating

Once the optic is centered and edged, it is cleaned and inspected a final time. Most often an optic will then be coated to enhance its performance at specified wavelengths. Both reflective and anti-reflective coatings can be applied using evaporation in a vacuum chamber. First, the optics are cleaned thoroughly since the coating will not adhere to a dirty surface. The optics are placed into holders which are loaded into the top of a vacuum coating chamber. The most common holder is a rotating planetary style device seen below (Figure 8).

**Figure 8: Vacuum chamber and planetary optic holder**

The coating material is then heated within the chamber and evaporates, coating the optics in the holder from below. The optics are held above the coating material so they are coated evenly at normal incidence. The thickness of the coating applied depends on how long the optics are exposed to the evaporated material. Coating thicknesses and evaporation times are well documented and are typically computer controlled.

## Other Lens Fabrication Methods

The process described above is the most general, and typical, manufacturing process that a small optic goes through. There are a variety of other manufacturing methods that are used for large optics, aspheres, plastics, and extreme surface shapes. Aspheres can utilize many of the same manufacturing techniques, but they are done by hand, or in very small areas of the optic at a time. A process often used is single point diamond turning in which a lathe with diamond tips of increasing precision is controlled by a CNC machine.

Molded optics are a common way to produce small lenses in high volume. A molded optic starts as a preform, which is a ball or disc that has already been polished to very high quality. It is then shaped in a mold at high temperatures. The overview of this process can be seen in Figure 9.

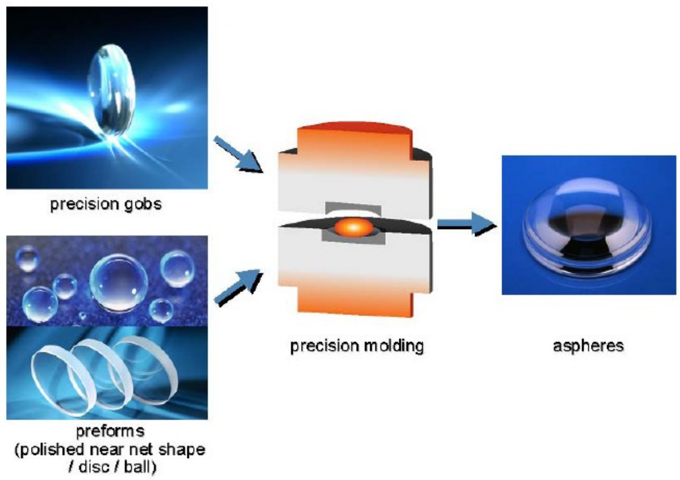


**Figure 9: Overview of the Molding Process (Schott)**

This process deals with glass and is called Precision Glass Molding (PGM). However, molding can also be used with plastics in a process called injection molding. In this process, melted plastic is pressed into a mold (spherical or aspheric), then cooled and ejected from the mold. The injection molding process must be carefully controlled, especially the flow of the plastic and cooling, since stress patterns can show up within the lens.

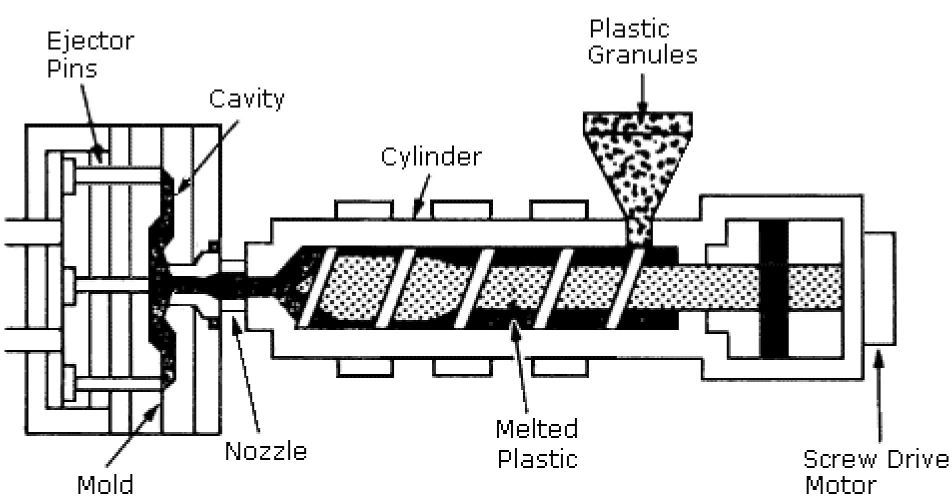


**Figure 10: Schematic of an injection molding tool**

## Conclusion

This paper has served as a basic introduction to the manufacturing process. However, there are many subtleties and a variety of other processes that are available for manufacturing lenses. Many optical engineers will only ever work with a finished product, or even software that models a finished product, but it is important to understand the process of how a lens is made. Knowledge of the manufacturing process will allow an engineer to understand the limitations of an optical design with regards to a timeline, budget and tolerances.

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