Molded Optics

Molded optics are conveniently categorized by the base material, plastic or glass. Subsequent classification can be further subdivided based on the manufacturing process.

Plastic molded optics can be injection molded, cast, or compressed/embossed.

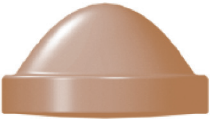
Injection molding is the process of injecting molten plastic into a mold under pressure and then allowing it to cool. Injection-compression molding is a subset of this process and adds a compression step within the molding process.

Cast plastic optics are primarily used for the ophthalmic industry. These are made simply by introducing liquid plastic resin into a mold and allowing it to solidify.

Molded plastic optics can also be formed using compression or embossing.

Glass molded optics are made using several processes: blank molding, traditional glass molding, and precision glass molding (PGM).

Blank molding is an old method of heating a glass blank in a furnace to a near-net shape for further processing.



Glass molding is a non-isothermal process in which a molten gob of glass is introduced into a mold and is allowed to cool.

PGM is typically an isothermal process in which a glass preform is formed by compression at a set temperature.

A further type of molded optics is **glass replication**, which consists of an ultraviolet (UV) monomer cured over a glass substrate.

Why Use Molded Optics?

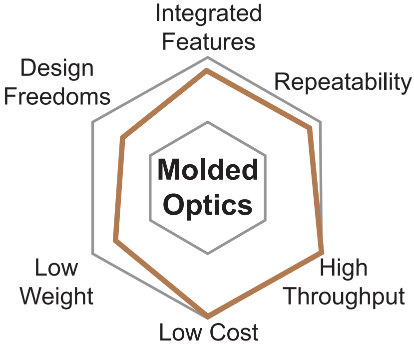
Molded optics first come to mind for high-volume applications. Why? Because molding is a process that can be replicated quickly with high throughput and low cost, two very desirable features for high-volume applications.

Molded optics provide many other potential advantages. **Injection-molded plastic optics** (IMPO) can incorporate a significant number of integrated features, thereby reducing part count and assembly complexity.

Optical molding processes lend themselves to high repeatability from component to component. This consistency can improve assembly and alignment, resulting in high performance and improved yields, which lead to cost savings.

Molding enables the replication of shapes that might not be achievable with conventional manufacturing techniques. Steeper slopes, advanced freeforms, and multisurface shapes can be achieved.

Molded plastic optics present a significant weight savings over their glass counterparts, while molded **chalcogenides** are lighter than their diamond-turned germanium substitutes.



Regardless of optical molding technology, the reasons for selecting a molding process are similar: high-volume manufacturing, lower cost, repeatability, integrated features, and design freedoms.

Applications of Molded Optics

Molded optics are everywhere.

Injection-molded plastic optics (IPMO) offer a combination of high performance and low cost. Their ability to be produced at extremely high volumes enabled the cellphone camera.

Precision-glass-molded (PGM) aspheres are used in the read head of every Blu-ray disc player.

Glass molding is enabling the next generation of automotive headlights.

State-of-the-art digital still cameras use a combination of IMPO and PGM lenses.

The development of cast plastics for eyeglasses revolutionized the eyewear industry due to their lower cost and lower weight with improved impact resistance.

PGM Infrared Imaging Lens

PGM **chalcogenide** lens assemblies are the driving technology used in the manufacture of low-cost thermal imaging systems. Traditional manufacturing methods cannot keep pace with the reduction of costs of uncooled infrared detectors (microbolometers).

Glass replication enabled the development of wafer-level optics and the mass production of very low-cost cellphone modules.

Endoscopes, laser pointers, gun sights, machine vision, thermal imaging, eyeglasses, automotive headlights, telecommunications, all of these use molded optics.

Comparison of Molded Optics

Each type of molded optics has its own set of advantages and disadvantages. A general comparison is shown below; each process can have individual materials or applications that can be better or worse.

	Precision Glass Molding	Glass Molding	Plastic Injection Molding	Cast Plastic	Glass Replication
Surface Quality	Excellent	Moderate	Good	Moderate	Good
Service Temperature	Excellent	Excellent	Moderate	Moderate	Moderate
Chemical Durability	Excellent	Good	Poor	Poor	Poor
Moisture Resistance	Excellent	Excellent	Poor	Poor	Excellent
Weight	Poor	Poor	Excellent	Excellent	Poor
Integrated Features	Moderate	Good	Excellent	Moderate	Poor
Material Selection	Excellent	Good	Poor	Poor	Poor

Excellent Good Moderate Poor

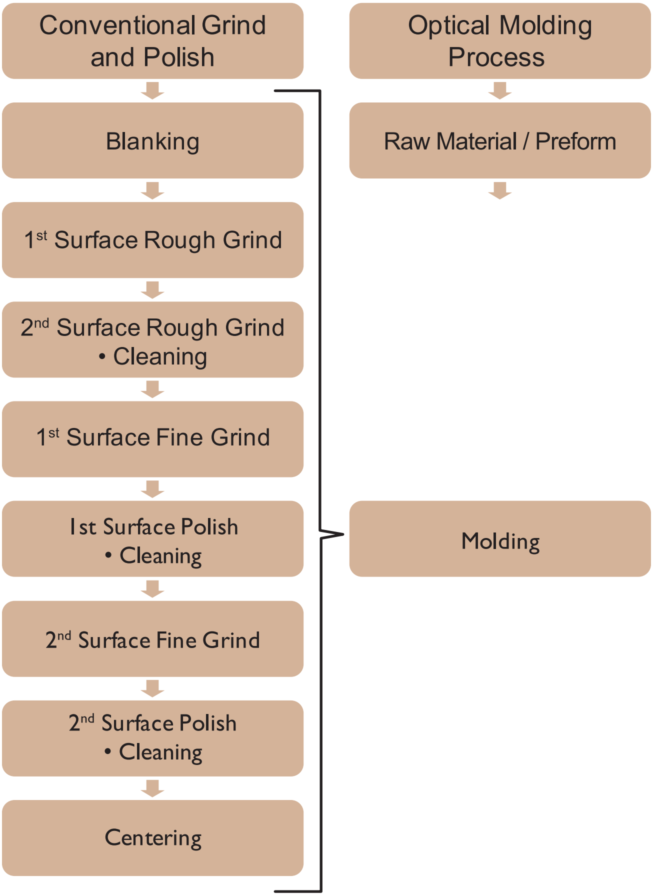
The costs of the different types of molded optics vary greatly based on many criteria but can be generalized.

	Precision Glass Molding	Glass Molding	Plastic Injection Molding	Cast Plastic	Glass Replication	Wafer Level Glass Replication
Prototype Tooling Costs	Low	High	Moderate	Low	Very Low	Very High
Prototype Part Cost	Moderate	Moderate	Moderate	Low	Moderate	High
Production Tooling	Moderate	Moderate	High	Low	Moderate	Very High
Production Part Cost <10k pcs.	Moderate	Moderate	Moderate	Low	Very Low	Low
Production Part Cost <50k pcs.	Low	High	Moderate	Low	Very Low	Low
Production Part Cost <500k pcs.	Low	Very Low	Very Low	Low	Very Low	Very Low
Production Part Cost >1M pcs.	Low	Very Low	Very Low	Low	Very Low	< Very Low

Very High High Moderate $ Low ¢ Very Low

Conventional Manufacturing versus Molded Optics

The traditional method of manufacturing optics is conventional **grind and polish**. The number of steps it takes to grind and polish a single bi-convex lens is extensive; molding presents a significant reduction in process steps.



Aspheric Advantage

One of the primary advantages of molded optics has always been the use of **aspheric surfaces**. Aspheric surfaces are simply surfaces that are not spherical. Historically, most optical surfaces have been spherical (or flat) due to ease of fabrication and testing with the exception of molded optics. Aspheric surfaces have long been the standard in molded optics, regardless of process, again due to ease of manufacture. The mold manufacturing process is well suited to aspheric manufacturing, and only having to cut a small number of molds to make a large quantity of optics made an increase in tooling cost trivial when amortized over a molding run.

The most common forms of **aspheres** are conics. A **conic surface** is described by

$$z(x) = \frac{\frac{1}{R}x^2}{1 + \sqrt{1 - (1+k)(\frac{x}{R})^2}}$$

$$c = \frac{1}{R}$$

- $k = 0$: sphere
- $-1 < k < 0$: ellipsoid with major axis on the optical axis
- $k = -1$: paraboloid
- $k < -1$: hyperboloid

where $z(x)$ is the **sag**, R is the **radius**, c is the **curvature**, and x is the **lateral coordinate**.

The addition of even polynomial terms to the **conic equation** results in the most common rotationally symmetric aspheric equation used for molded optics:

$$z(x) = \frac{\frac{1}{R}x^2}{1 + \sqrt{1 - (1+k)(\frac{x}{R})^2}} + Ax^4 + Bx^6 + Cx^8 + Dx^{10} + Ex^{12} + Fx^{14} + Gx^{16}$$

The polynomial terms are used to optimize the system and reduce **aberrations**, and typically reduce the number of elements in a system. Alternative equations, including the **Forbes polynomials**, can be used, but the above equation is the industry standard.

The cost difference between a spherical molded optic and an aspherical one is essentially negligible for most applications.