ALL ABOUT ASPHERIC LENSES

BY JEREMY GOVIER

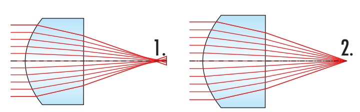
GETTING STARTED: BENEFITS OF AN ASPHERIC LENS

Spherical Aberration Correction

The most notable benefit of aspheric lenses is their ability to correct for spherical aberration. Spherical aberration results from using a spherical surface to focus or collimate light. In other words, all spherical surfaces suffer from spherical aberration independent of alignment or manufacturing errors; therefore, a non-spherical, or aspheric surface, is needed to correct for it. By adjusting the conic constant and aspheric coefficients, an aspheric lens can be optimized to minimize aberration. For example, consider ***Figure 1*** which shows a spherical lens with significant spherical aberration compared to an aspheric lens with practically no spherical aberration. In a spherical lens, spherical aberration causes incident light rays to focus at different points, creating a blur; in an aspheric lens, light focuses to a point, creating comparatively no blur and improving image quality.

To get a better idea of the difference in focusing performance between an aspheric lens and a spherical lens, consider a quantitative example of two comparable lenses with 25mm diameters and 25mm focal lengths (f/1 lenses). The following table compares the spot size, or blur size, of on-axis (0° object angle) and off-axis (0.5° and 1.0° object angles) collimated, monochromatic light rays of 587.6nm. The spot sizes from the asphere are several orders of magnitude less than those of a spherical lens.

Figure 1: Spherical Aberration (1.) in a Spherical Lens Compared to No Aberration in an Aspheric Lens (2.)



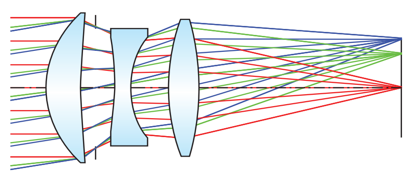
Object Angle (°)	0.0	0.5	1.0
Spherical Spot Size (µm)	710.01	710.96	713.84
Aspheric Spot Size (µm)	1.43	3.91	8.11

Additional Performance Benefits

Although various techniques exist to correct aberrations caused by spherical surfaces, none match the imaging performance and flexibility that aspheric lenses provide. Another technique used includes increasing the f/# by "stopping down" the lens. Although this approach can increase image quality, it also reduces the amount of light throughput in the system, thereby leading to a tradeoff between the two.

On the other hand, when using aspheric lenses, additional aberration correction makes it possible to design high throughput (low f/#, high numerical aperture) systems while simultaneously maintaining good image quality. Consider an 81.5mm focal length, f/2 triplet lens ***(Figure 2)*** consisting of all spherical surfaces versus the same triplet with an aspheric first surface where both designs use the same glass types, effective focal length, field of view, f/#, and total system length. The following table quantitatively compares modulation transfer function (MTF) @ 20% contrast of on-axis and off-axis collimated, polychromatic light rays at 486.1nm, 587.6nm, and 656.3nm. The triplet lens with the aspheric surface shows increased imaging performance at all field angles, indicated by high tangential and sagittal resolution values, by factors as high as four compared to the triplet with only spherical surfaces.

Figure 2: Polychromatic Light Through A Triplet Lens



Object Angle (°)	All Spherical Surfaces		Aspherical First Surface	
	Tangential (lp/mm)	Sagittal (lp/mm)	Tangential (lp/mm)	Sagittal (lp/mm)
0.0	13.3	13.3	61.9	61.9
7.0	14.9	13.1	31.1	40.9
10.0	17.3	14.8	36.3	41.5

System Advantages

Aspheric lenses allow optical designers to correct aberrations using fewer elements than conventional spherical optics because the former gives them more aberration correction than multiple surfaces of the latter. For example, in zoom lenses where ten or more lens elements are typically used, one or two aspheric lenses can be substituted for a handful of spherical lenses in order to achieve similar or better optical results, minimize the overall cost of production, as well as reduce system size.

An optical system with more elements can negatively affect both optical and mechanical parameters, contributing to tighter mechanical tolerances, additional alignment procedures, and increased anti-reflection coating requirements. All of these may ultimately decrease total system utility because of the necessity for increased support components. As a result, incorporating aspheric lenses (though higher priced than similar f/# singlet and doublet lenses) can actually reduce overall system design costs.

ANATOMY OF AN ASPHERIC LENS

The term asphere encompasses anything that is not a portion of a sphere, however when we use the term here we are specifically talking about the subset of aspheres that are rotationally symmetric optics with a radius of curvature that varies radially from the center of the lens. Aspheric lenses improve image quality, reduce the number of required elements, and lower costs in optical designs. From digital cameras and CD players to high-end microscope objectives and fluorescence microscopes, aspheric lenses are growing into every facet of the optics, imaging, and photonics industries due to the distinct advantages that they offer compared to traditional spherical optics.

Aspheric lenses have been traditionally defined with the surface profile (sag) given by ***Equation 1***:

(1)

$$Z(s)=\frac{Cs^2}{1+\sqrt{1-(1+k)C^2s^2}}+A_4s^4+A_6s^6+A_8s^8+\ldots$$

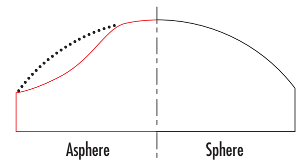
Where:
Z = sag of surface parallel to the optical axis
s = radial distance from the optical axis
C = curvature, inverse of radius
k = conic constant
A_4, A_6, A_8...= 4th, 6th, 8th… order aspheric terms

When the aspheric coefficients are equal to zero, the resulting aspheric surface is considered to be a conic. The following table shows how the actual conic surface generated depends on the magnitude and sign of the conic constant, k.

Conic Constant	Conic Surface
k = 0	Sphere
k > - 1	Ellipse
k = - 1	Parabola
k < - 1	Hyperbola

The most unique geometric feature of aspheric lenses is that the radius of curvature changes with distance from the optical axis, unlike a sphere, which has a constant radius ***(Figure 3)***. This distinctive shape allows aspheric lenses to deliver improved optical performance compared to standard spherical surfaces.

Figure 3: Comparison of Spherical and Aspheric Surface Profiles



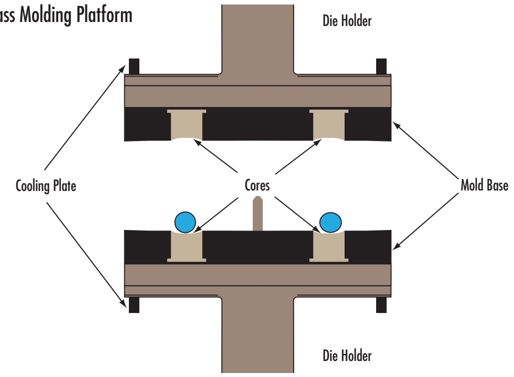
Over the past few years, two other definitions that use orthogonal terms have gained in popularity called Q-type aspheres. These Q-type aspheres, Q_{con} and Q_{bfs} allow designers more control over the optimization of the aspheres by using orthogonal coefficients and generally reduce the terms needed for manufacturing the asphere.

HOW ARE THEY MADE? TYPES OF ASPHERES

PRECISION GLASS MOLDING

Precision glass molding uses a manufacturing technique where optical glass cores are heated to high temperature until the surface becomes malleable enough to be pressed into an aspheric mold ***(Figure 4)***. After cooling the cores to room temperature, they maintain the shape of the mold. Creating the mold has high initial startup costs because it has to be precisely made from very durable material that can maintain a smooth surface and take into account any shrinkage of the glass cores in order to yield the desired aspheric shape. However, once the mold is finished, the incremental cost for each lens is lower than that of standard manufacturing techniques, making it a great option for high volume production.

Figure 4: Precision Glass Molding Platform



HOW ARE THEY MADE? TYPES OF ASPHERES (CONTINUED)

PRECISION POLISHING

For a number of years, machined aspheric lenses have been ground and polished one lens at a time. Although this process of individually producing machined aspheres hasn't changed dramatically, significant fabrication technology advancements have recently elevated the achievable level of accuracy possible from this production technique. Most notably, computer controlled precision polishing ***(Figure 5)*** automatically adjusts the tool dwell parameters to polish away high spots where more polishing is needed. If higher quality polishing is required, magneto-rheological finishing (MRF) is used to perfect the surface ***(Figure 6)***. MRF technology provides high performance finishing in less time than standard polishing techniques because of its precise control of the removal location and high removal rate. While other manufacturing techniques generally require a special mold, unique to each lens, polishing utilizes standard tooling which makes it the primary option for prototyping and low volume production.

Figure 5:
Computer Controlled Precision Polishing

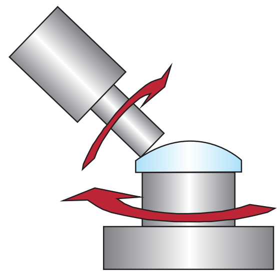
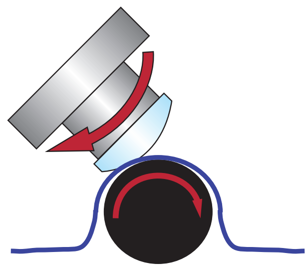


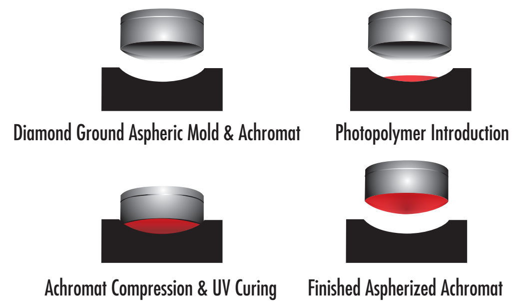
Figure 6:
Magneto-Rheological Finishing (MRF)



HYBRID MOLDING

Hybrid molding begins with a standard spherical surface, such as an achromatic lens, which is then pressed onto a thin layer of photopolymer in an aspheric mold to give the net result of an aspheric surface. The technique uses a diamond ground aspheric mold and a glass achromatic lens (though other types of singlet or doublet lenses can be used). A photopolymer is introduced into the aspheric mold, against which the achromatic lens is pressed. The two surfaces are compressed and UV cured at room temperature to yield an aspherized achromatic lens that combines the desired optical properties of the constituent parts: chromatic and spherical aberration correction. ***Figure 7*** illustrates the process of creating a hybrid lens. Hybrid molding is useful for high volume precision applications where additional performance is required and the quantity can justify the initial tooling costs.

Figure 7: Hybrid Molding Technique



PLASTIC MOLDING

In addition to the aforementioned manufacturing techniques for glass, there exists one unique technique for plastic. Plastic molding involves injecting molten plastic into an aspheric mold. Since plastic is not as thermally stable and resistant to pressure as glass, it has to be treated specially in order to create a usable aspheric lens.

Nevertheless, plastic is advantageous because it is light-weight, easily molded, and can be integrated with a mount to create a single element. While the selection of optical quality plastic is limited, the cost and weight benefits sometimes drive designs toward plastic aspheric lenses.

ADVANTAGES FOR EACH TYPE OF ASPHERE

Since all applications do not require identical lens performance, selecting the appropriate aspheric lenses is an important decision. Key factors to consider include your project timeline, overall performance requirements, budgetary constraints, and anticipated volumes.

Many applications may be completely satisfied with an off-the-shelf aspheric lens, taking advantage of the immediate availability and straightforward order fulfillment. Often, these standard aspheric lenses can also be quickly and easily modified with anti-reflection coatings or dimensional reduction to address requirements that are reasonably close to the standard offering. If off-the-shelf products are not sufficient, consider custom aspheric manufacturing for prototype, pre-production, or large volume applications.

Type	Benefit
Precision Glass Molded	Ideal for high volume production requirements because of rapid production of many lenses and low tooling upkeep costs.
Precision Polished	Ideal for prototype or low volume requirements because of short lead time, minimum special tooling setup
Hybrid Molded	Ideal for multi-spectral applications because of correction for both spherical and chromatic aberration.
Plastic Molded	Ideal for volume production as a weight-sensitive, low cost alternative to glass aspheric lenses.

CUSTOM ASPHERIC MANUFACTURING CAPABILITIES

	Commercial	Precision	High Precision
Diameter	10 - 150mm	10 - 150mm	10 - 150mm
Metrology	Profilometry	Profilometry	Interferometry
Asphere Figure Error (P - V)	±5μm	±1μm	±0.25μm
Vertex Radius (Asphere)	±1%	±0.1%	±0.05%
Radius (Spherical)	±0.5%	±0.1%	±0.025%
Power (Spherical)	2λ	$\frac{1}{2}\lambda$	$\frac{1}{10}\lambda$
Irregularity (Spherical)	$\frac{1}{2}\lambda$	$\frac{1}{4}\lambda$	$\frac{1}{20}\lambda$
Centering (Beam Deviation)	3 arcmin	1 arcmin	0.5 arcmin
Center Thickness Tolerance	±0.100mm	±0.050mm	±0.010mm
Diameter Tolerance	+0/-0.050mm	+0/-0.025mm	+0/-0.010mm
Surface Quality	80-50	60-40	20-10
Bevel	0.5mm Max Face Width @ 45°	0.2mm Max Face Width @ 45°	0.1mm Max Face Width @ 45°

ASPHERIC LENS SELECTION GUIDE

PRECISION POLISHED ASPHERIC LENSES

Precision polished aspheric lenses are ideal for the most demanding applications. Designed to offer high numerical apertures while creating diffraction-limited spot sizes.

- Available in UV, Visible, and IR Grade Materials
- Variety of Standard Coating Options Available
- Full Prescription Data for Easy Integration into OEM Applications

Stock Products:

- TECHSPEC® Calibration Grade Aspheric Lenses
- TECHSPEC® Precision Aspheric Lenses
- TECHSPEC® UV-Grade Fused Silica Precision Aspheric Lenses

PRECISION MOLDED ASPHERIC LENSES

Precision molded aspheric lenses are ideal for volume applications, including laser diode collimation, bar code scanners, and optical data storage.

- Micro-sized Aspheres (2-10mm Diameters)
- Variety of Standard Coating Options Available
- Available in Glass and Plastic Substrates

Stock Products:

- Precision Molded Aspheric Lenses
- Mid and Long Wave Infrared Aspheric Lenses
- TECHSPEC® Plastic Hybrid Aspheric Lenses
- TECHSPEC® Plastic Aspheric Lenses

COLOR-CORRECTED ASPHERIC LENSES

We offer several unique families of aspheric lenses, designed to provide both spherical and chromatic aberration correction. These families are ideal for applications requiring near-diffraction limited focusing performance over a range of wavelengths.

- Aspherized Achromats Combine Glass Achromat with Plastic Asphere
- Hybrid Aspheres Combine Refractive and Diffractive Properties

Stock Products:

- TECHSPEC® Aspherized Achromatic Lenses
- TECHSPEC® Plastic Hybrid Aspheric Lenses
- TECHSPEC® Hybrid Germanium Aspheric Lenses

INFRARED ASPHERIC LENSES

From small molded aspheres for use with MWIR quantum cascade lasers, to families of germanium and zinc selenide aspheres, we offer solutions for the entire infrared spectrum.

- Available in Diameters from 5.5 - 50.8mm
- Hybrid Designs Available for Improved Broadband Performance
- Variety of Coating Options Available

Stock Products:

- TECHSPEC® Germanium and Hybrid Germanium Aspheric Lenses
- Zinc Selenide Aspheric Lenses
- Mid and Long Wave Infrared Aspheric Lenses
- IG6 Aspheric Lenses

HOW CAN I DESIGN YOUR NEXT PROJECT TO MEET BUDGET, PERFORMANCE, AND SCHEDULE REQUIREMENTS?

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Aspheric Lens Guru

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