QUALITY MATTERS

Edmund Optics®
WHITE PAPER

CHARACTERISTICS TO SPECIFY A HIGH QUALITY OPTICAL COMPONENT

Introduction

Quality and precision is a fundamental part of optical component manufacturing and an appropriately specified optic is crucial to get the performance your system requires. The optical surfaces in a system are the main contributors to transmission loss, wavefront errors and aberrations. In addition mechanical specifications can also impact the alignment and stability of an element and consequently the overall system performance.

For example if you are trying to focus a laser down to a spot size of a few microns a poor quality optical surface will lead to scattered light or small areas of high concentration that could damage the lens. If you have loose mechanical specifications that could mean that your spot is off-centre, poorly focused or unstable.

If an image is being formed at any point precision becomes even more important. Surface quality and flatness can have a big effect on the resultant wavefront error and must be minimised to avoid aberrations and the associated loss of image quality.

As one would expect, higher quality and tighter tolerances have a much higher cost associated with them. This is due to the additional time and precision equipment involved in the manufacturing process. Mirrors with different surface flatness values can vary in price by a factor of 10, so when choosing optics is also important not to over-specify your components. Ideally the application should determine what level of quality is the most appropriate; in this way unnecessary expense can be avoided.

Manufacturing Specifications

Aside from the standard tolerances on the physical dimensions of an optic, such as diameter or edge thickness, there are a number of other more optics-specific parameters to consider.

Radius of Curvature

Radius of Curvature is the distance between the vertex of an optical surface and the center of curvature of that surface. Every curved surface in an optical component is defined by this parameter, this is inversely proportional to the optical power and any significant deviation from what is specified will lead to an error on the focal length. Some typical radius tolerance values are ±0.5% (standard), ±0.1% (precision), and ±0.01% (ultra-high precision). It is common to factor this into the overall focal length tolerance of a lens. It is worth pointing out here that the actual focal length of any lens is dependent on wavelength and will also be affected by the thickness and refractive index of the substrate as well as the radius of curvature. This is what makes it such a difficult parameter to specify and tolerance. This is why you may see a focal length tolerance as large as ±1% even on high quality components.

Center Thickness

Center Thickness is simply the thickness of the substrate at the centre of a lens. This, along with the radius of curvature, determines the optical path length for rays passing through the component. This will have a direct impact on optical performance and as such must be tightly controlled. Typical tolerances start at 0.1mm but can be as high as 0.01mm for high precision optics.

Figure 1

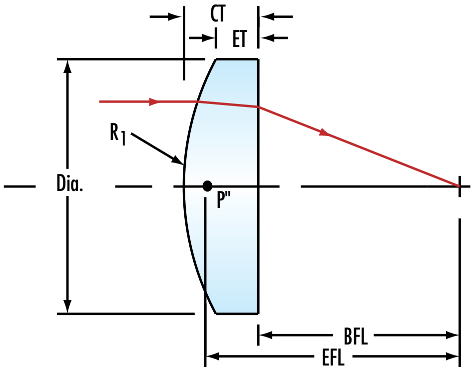

Figure 1: Basic structure of a plano-convex lens: Edge Thickness (ET), Center Thickness (CT), Effective Focal Length (EFL), Back Focal Length (BFL), Principal Point (P) and a curved surface with Radius of Curvature (R1).

Decenter

This is also known as centration or centering. The amount of decenter in a lens is the physical displacement of the mechanical axis from the optical axis. The mechanical axis of a lens is simply the geometric axis and is defined by its outer edges. The optical axis of a lens is defined as the line that passes through the center of curvature of any optical surface. This angular difference is referred to as the beam deviation and is usually on the order of arc minutes. As with other manufacturing errors a beam deviation leads to aberrations, however the effects have the most impact in imaging systems. Decenter causes a shift in the image location and can cause coma, particularly on-axis.

Figure 2

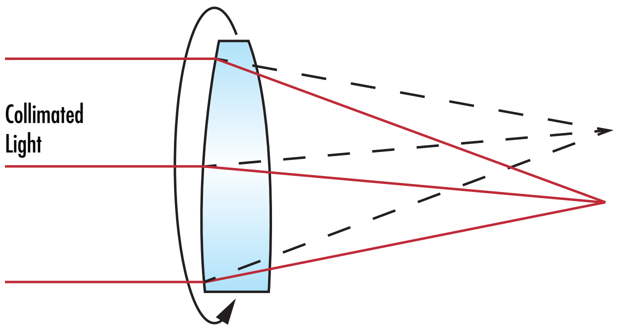

Figure 2: Decentering of Collimated Light.

Parallelism

This defines how parallel two surfaces are with respect to each other. It is most relevant when dealing with flat components like windows, filters or polarizers. Non-parallel surfaces in components like these can lead to an increase in the transmitted wavefront error. In a high precision system it is not uncommon to see values of a few arc seconds.

More information about Edmund Optics® manufacturing capabilities here: **www.edmundoptics.eu/Document/Download/396275**

CHARACTERISTICS TO SPECIFY A HIGH QUALITY OPTICAL COMPONENT

Surface Specifications

It is also necessary to properly specify the optical surface itself. You might have extremely tight tolerances on a number of the mechanical parameters listed above but if your surface is poorly defined your system performance will suffer regardless.

Figure 3

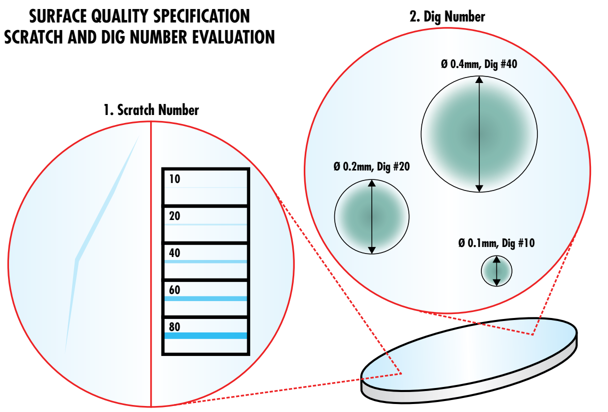

Figure 3: An illustration of scratch-dig evaluation.

Surface Quality

This parameter is related to the cosmetic appearance of the surface and is quoted as two numbers separated by a dash, for example 60-40. The first number represents the visibility of a scratch, the number is arbitrary and references a set of calibrated standards. The second number represents the width of the largest dig in 1/100ths of a millimetre.

This specification is actually based on the U.S Military document MIL-PRF-13830B released for the first time in the 1950´s, often referred to as MIL-SPEC for short. The arbitrary nature of the scratch standard is controversial and there have been recent efforts to improve it. While MIL-SPEC is still the US standard other methodologies are now available. Outside the USA the ISO 10110 standard developed in Germany is more commonly used.

In most optical systems, surface defects like these won't really have any noticeable impact on the system performance – nothing more than a small reduction in throughput or a small increase in scattered light. However for certain applications controlling these features becomes more critical. Defects can cause increased absorption at high energies potentially damaging the optic or if the optical surface is at the image plane defects will be in focus and could appear in the image.

Figure 4

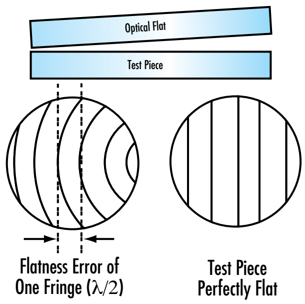

Figure 4: This is an illustration of how the surface accuracy of a flat component can be measured using a calibrated optical flat.

Surface Accuracy

Also referred to as surface irregularity, this is a measure of how much a surface deviates from the intended design shape. It is quoted as a number of waves (λ), typical values are λ/4 for standard quality and up to λ/20 for high precision grade. The deviation is measured by placing the component on a calibrated reference surface, the observed fringe pattern created describes the accuracy of the test surface relative to that of the reference.

This can be done for both flat and curved geometries, the interference pattern differs but the method is essentially the same. The separation between the fringes indicates a height difference between the reference and test surfaces. Each fringe represents half a wavelength of the light used to make the measurement, usually 632.8nm. It is easiest to visualise what this means when considering an optical flat. A surface with a λ/20 accuracy will have a maximum distance of 31.64nm (632.8nm/20) between the lowest and highest features on its surface.

Any deviation from the ideal shape will induce errors in the desired wavefront, increasing aberrations. More aberrations in a precision system means it will no longer be diffraction limited. When it is important to minimise the transmitted wavefront error a high surface accuracy is essential.

GUIDELINE TOLERANCES FOR SPHERICAL OPTICS

	Commercial	Precision	High Precision
Diameter Tolerance:	+0/-0.100mm	+0/-0.025mm	+0/-0.010mm
Thickness:	±0.100mm	±0.050mm	±0.010mm
Radius:	±0.3%	±0.1%	+/-1um
Power:	3.0λ	1.5λ	1/2λ
Irregularity (P-V):	1.0λ	1/2λ	1/10λ
Centering (Beam Deviation):	3 arcmin	1 arcmin	0.5 arcmin
Surface Quality:	60-40	40-20	10-5

Table 1: Guideline Tolerances for Spherical Optics.

Conclusions

This is just a broad overview of key parameters to consider when choosing an optical component, some guideline values for different grades of spherical optics are given in ***Table 1***. With high energy lasers, and deep UV applications pushing the boundaries of what's possible, high quality optical components are an important part of modern research and technology. Precision optical manufacturing and the metrology to support it is very costly but if you are serious about minimising aberrations and maximising throughput it is a necessary and worthwhile investment. In complex systems the optics often have a crucial role to play but represent a fraction of the total cost, in these situations the quality, precision and reliability of the components are absolutely critical. The right result is what's needed. Ignoring the quality of your optics in a situation like this and sacrificing precision and accuracy for price can have dire consequences. High quality optical specifications can also simplify assembly and remove the need to align each element. In this situation precision components could actually reduce the overall cost of the system and the time required to put it together. It must be said however that it is also important not to over-specify. Consulting with optical experts is always the best option if you are unsure.

More information about Edmund Optics® manufacturing capabilities here: www.edmundoptics.eu/Document/Download/396275