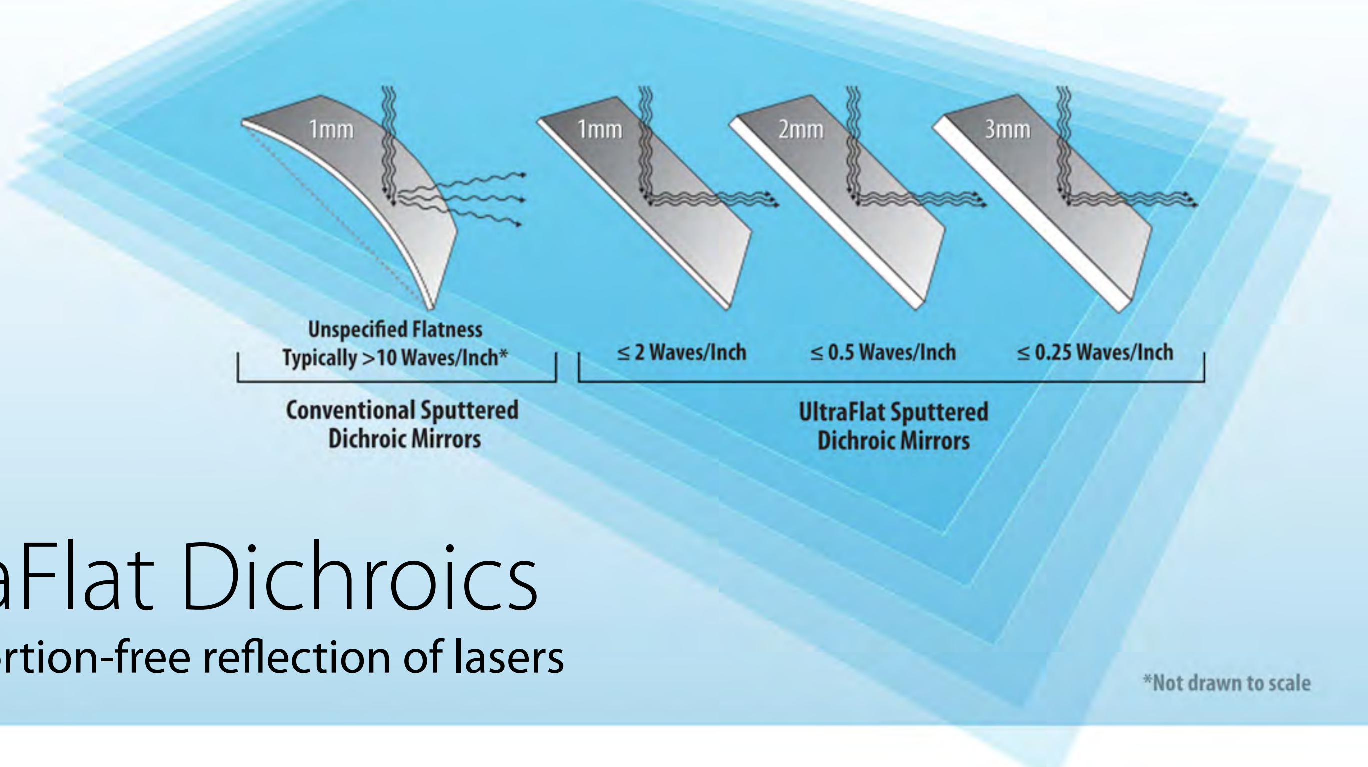

UltraFlat Dichroics

For distortion-free reflection of lasers

Chroma manufactures UltraFlat dichroics for applications demanding superior levels of surface flatness for laser applications such as TIRF and other super-resolution techniques. We offer UltraFlat dichroics either for use as individual parts or included in assembled filter sets.

However, the secret with flat dichroics is that they need to stay flat in your imaging system. Filter cubes that use clips, springs or screws to hold dichroics will torque them out of flatness. Chroma's TIRF & Super-resolution filter cubes keep your dichroics just as flat in your microscope as they were when we made them.

In this context, surface flatness typically relates to curvature, and describes how curved the dichroic surface is. Surface curvature causes convergence or divergence of reflected light waves, depending on whether the surface is concave or convex. This results in reflected wavefront distortion (RWD) of whatever is being reflected: lasers, both in basic imaging applications and in more advanced methods such as TIRF and STED; structured illumination patterns; and reflected images in image-splitting systems.

Sputtered thin-films exert stress on glass and fused silica substrates and warp them into varying degrees of curvature. Chroma has learned how to control this to a large extent by developing a proprietary manufacturing method which minimizes surface curvature. Another factor which reduces surface curvature is the use of thicker substrates which provide greater stiffness and therefore more resistance to the stress exerted by these coatings.

Combining these two elements allows Chroma to specify levels of dichroic surface flatness according to thickness. We offer Chroma's *UltraFlat* dichroics with the following specifications for final, post-coating surface flatness:

Thickness	Surface Flatness	Application
1mm thick:	=/< 2 waves/inch Peak-Valley (P-V)	Standard Laser Filter Sets
2mm thick:	=/< 0.5 waves/inch P-V	TIRF Filter Sets, PALM and STORM
3mm thick:	=/< 0.25 waves/inch P-V	STED and Structured Illumination
=/>5mm thick:	Contact us	Custom Applications

The surface flatness of each lot of our *UltraFlat* dichroics is measured using laser interferometry. Possibly even more important regarding flatness is how the dichroic is held or housed. Even the flattest optics are warped by varying degrees when held in place by mechanical means. See "Holding Dichroics" below.

Note: *Our catalog dichroics for basic epifluorescence widefield applications are not controlled for flatness because widefield illumination does not require it. Please specify when you require our UltraFlat dichroics.*

Holding Dichroics

The manner in which dichroics are held or housed in filter cubes dramatically affects their actual flatness in real world applications. Any mechanical means of holding a dichroic will introduce some degree of pinching or twisting which invariably results in warping of the surface of the dichroic, reducing it's flatness. In addition to any spherical curvature, this will contribute irregular deviations from surface flatness.

Major microscope manufacturers generally specify 1mm thick dichroics for their standard filter cubes, and these are often held in place mechanically, by springs or clips. Often, this is sufficient for holding 1mm-thick dichroics flat enough for routine laser applications such as confocal or epi-fluorescence using laser illumination, photo-activation and laser ablation. Our 1mm thick UltraFlat laser dichroics measure <2 waves/inch Peak-Valley surface flatness, providing the performance needed for routine laser use.

For more demanding laser applications such as TIRF and other super-resolution techniques, as well as applications where images are reflected to a camera or to other optics, our thicker UltraFlat dichroics can provide much better results. In order to optimally hold these dichroics, Chroma has designed and manufactured metal microscope cubes which fit most current microscope models and can accommodate dichroics up to 3mm thick. These cubes affix the dichroics without the use of springs, clips or screws and are aligned at Chroma using set screws to a precise 45 degree angle of incidence.

For workers with their own holders or mounts, we recommend that you hold by placing minimal pressure on the outside edges, rather than by pinching on the top/bottom surfaces to minimize warping. Call or email us to discuss the range of sizes and thicknesses we can provide.

How We Specify Surface Flatness

The surface flatness parameter we measure is referred to as "Peak-to-Valley" (P-V) deformation, and is expressed in "waves/inch" (or lambda/inch) as determined by laser interferometry. This measures the maximum deformation across the clear aperture of a dichroic, and includes the curvature (Power) plus any surface irregularities.

Industrial standards for surface flatness measurements of flat optics, such as dichroics, conform to ISO standards, and are expressed in terms of interferometric "fringe spacings" or fringes. These are interference patterns which appear as a result of differences in index of refraction between that of the dichroic substrate material and air as a laser is reflected off of the measured surface.

The number of fringes is used to calculate the deviation of the measured surface from that of a reference optical "flat". We measure this using a wavelength of 633nm, which is the laser most often used in an interferometer.

Occasionally, a filter manufacturer may express surface flatness in terms of radius of curvature (ROC), which in the context of flat optics is a more obscure and confusing metric. ROC is used mainly by lens manufacturers who deal with relatively large values for curvature. As an example of how our flatness specification relates to ROC, consider that a 0.5 wave/inch surface flatness is equivalent to a radius of curvature of 254 meters (or about 830 feet). ROC defines the actual radius of a sphere which surface curvature is identical to the curvature of a surface of an optic.

Others prefer the parameter of "RMS" (root mean square) which provides a measurement of the uniformity of the surface. Because any distortion to surface flatness as a result of the thin film coatings we use will be spherical distortion, this means that the RMS value will typically be approx. =/< ¼ of the of the P-V value. "RMS" will result in a smaller value than P-V to describe the surface of the same dichroic or mirror.

For the same surface curvature, the various measured values for these parameters will typically vary in the following way:
P-V > Power >> RMS.

Sometimes, P-V flatness is defined over a smaller area, such as a 10mm or 15mm clear aperture. The values listed above use the larger scale of 1 inch which results in a larger value for the same curvature.

The relationship between measurement length and flatness is non-linear. Assuming the deformation is primarily spherical curvature due to coating stress, this can be described by a simple quadratic formula. To calculate the equivalent flatness for a clear aperture of ½ the measured value, the flatness expressed as number of waves will be ¼ of the measured value. As the denominator in the expression (inches) varies by "x", the numerator (waves) varies by x^2. An optic which measures 2 waves/inch P-V will measure 0.5 waves/0.5 inch P-V.

If you prefer the surface flatness expressed as Surface Power or RMS, we will provide this upon request.

Finally, remember that the method of holding or housing the dichroic will greatly influence its actual flatness when used in an imaging system.