

OPTICAL FILTERS 101

A Practical Guide to
Leveraging the Right Optical
Filters for Your Needs



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Introduction

Semrock, part of IDEX Health & Science, specializes in optical interference filters for use in life sciences and industrial applications. The most widely used technique in life science is fluorescence, which typically involves adding photo-excitabile labels or fluorophores to the sample to highlight areas of interest.

Examples of Fluorescence Applications



FLUORESCENCE MICROSCOPY AND ITS VARIANTS

Confocal, Multiphoton, TIRF, PALM, STORM, etc.



FLUORESCENCE GUIDED SURGERY

Micro or Mesoscopic



FLOW CYTOMETRY

Counting, Sorting, and Imaging



NUCLEIC ACID AMPLIFICATION TECHNIQUES

qPCR, dPCR, LAMP, and Others



DNA SEQUENCING

Next Generation Sequencing, Capillary Electrophoresis



ENZYME LINKED IMMUNOSORBENT ASSAYS

A.K.A. ELISA



WESTERN BLOTTING

1D or 2D





The role of the filter is to physically and spectrally separate the excitation light from the emission light in the detection path.

Semrock also produces filters for label-free detection methods such as intrinsic fluorescence, second harmonic generation (SHG), Raman scattering and its variant, coherent anti-stokes Raman scattering (CARS). These methods detect intrinsic spectral signatures of molecules already present in the sample. Again, the role of the filter is to separate the detection channel from the illumination channel.

Choosing and specifying the correct optical filters is crucial to success in these types of biological experiments. This guide will help take the mystery out of modern interference filters and their use.

Essential Filter Concepts

Optics is the science concerning the production, manipulation, control, and detection of light. Optical filters are used in all of these areas. The basic functions of an optical filter are to provide spectral blocking, transmission, reflection, or a combination of these functions across specified spectral regions.

Concept of Interference

Modern optical filters use the wave nature of light and the phenomenon of optical interference to produce the desired spectral output. Optical interference occurs when light is incident on a layer of material with a thickness close to the wavelength of the incident light. The intensity of the incident light (I_o) is equal to the intensities of light that are absorbed, reflected, and transmitted ($I_o = I_A + I_R + I_T$) at an interface. Interference filters are typically made from materials that do not absorb light in the region of interest, so I_A can be assumed to be zero (or negligible), and $I_o = I_R + I_T$.

In order for reflection (and refraction) to occur at a surface, the two materials must have different refractive indices. The bigger the refractive index difference, the more light is reflected. Microscopists often use “index

matched” oils or immersion lenses to reduce or eliminate unwanted reflections (and refractions) that occur when the light travels through air, into the coverslip, through the aqueous media, into the sample and back. While a nuisance to microscopists, filter manufacturers use refractive index differences to design and build their filters.

An optical interference filter is constructed of a substrate (usually glass) to which alternating layers of low and high refractive index material are applied (Figure 1). By optimizing the layer structure (individual layer thickness and total numbers of layers), constructive and destructive interference within the multilayer coating results in the desired transmitted and reflected spectrum.



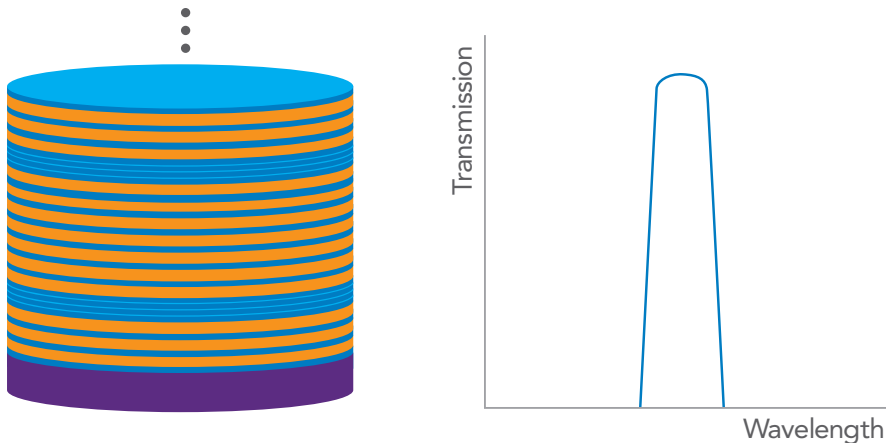


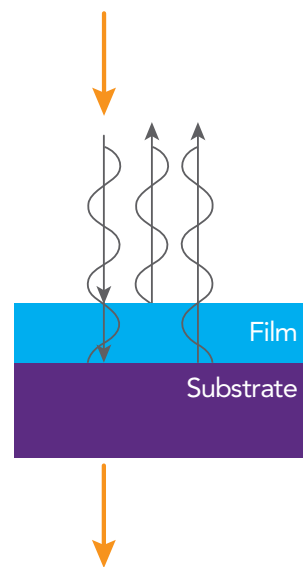
FIGURE 1. An interference filter is made of alternating layers of high and low refractive index materials to achieve the desired spectral output.

When the thickness of a thin film layer is an odd multiple of $\lambda/4$, (e.g. $\lambda/4$, $3\lambda/4$, $5\lambda/4$, etc.), reflected light exhibits destructive interference at that wavelength while transmission increases. Conversely, when the thickness is an even multiple of $\lambda/4$ (e.g. $2\lambda/4$, $4\lambda/4$, etc.) reflected light exhibits constructive interference and transmission decreases at that wavelength. These cases are illustrated in Figure 2.

To achieve the desired spectral performance, hundreds of individual layers can be required. These individual layers can be as thin as a few nanometers and as thick as a micron or so. During the design process, the constructive and destructive interference at each interface is calculated and the layer thicknesses are optimized using advanced algorithms.

DESTRUCTIVE INTERFERENCE

The waves reflected off the successive interfaces add up out of phase, thus causing the light to be transmitted.



CONSTRUCTIVE INTERFERENCE

The waves reflected off the successive interfaces add up in phase, thus yielding a large total reflection.

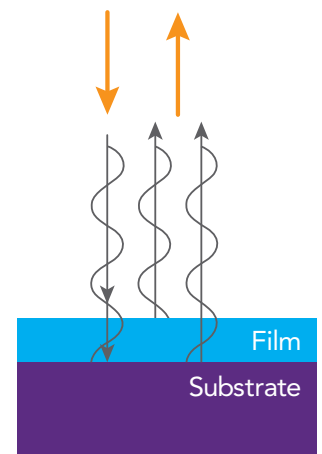
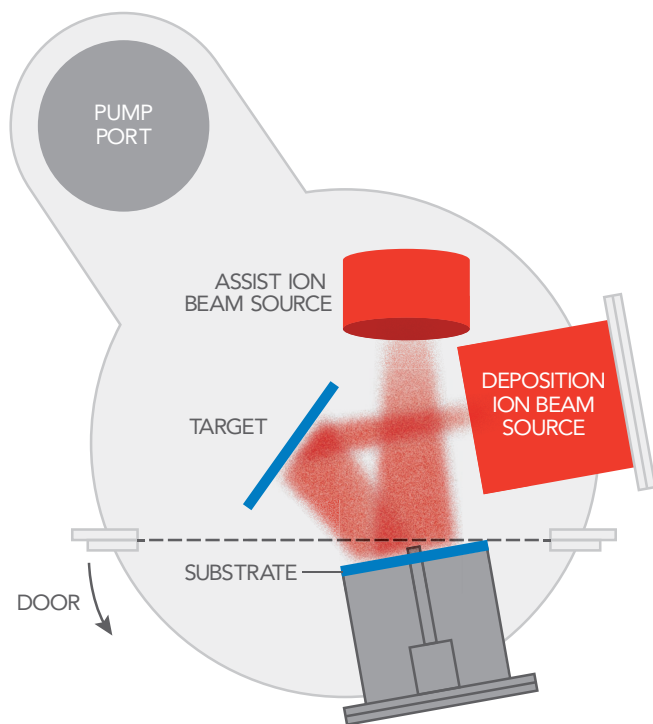


FIGURE 2.

Destructive interference (left) in reflection causes higher transmission. Constructive interference (right) of reflection causes lower transmission.

Filter Manufacture

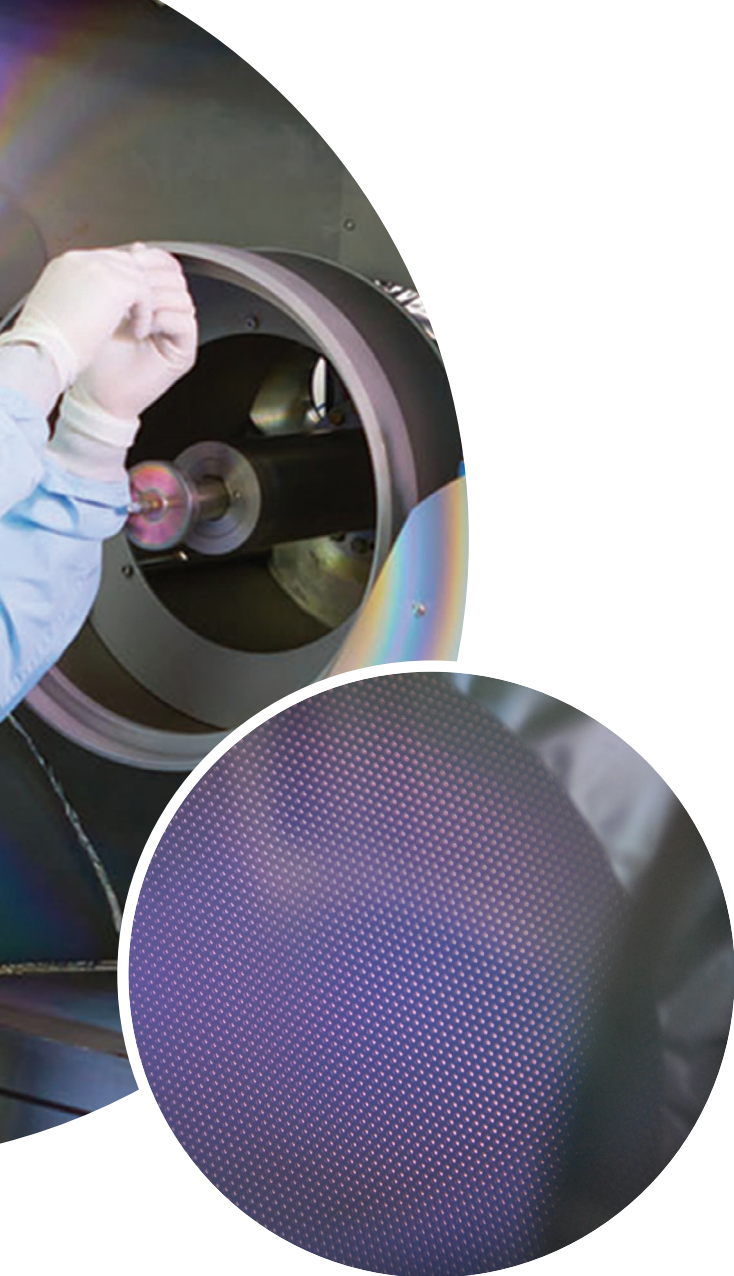
Reliably and reproducibly coating glass with a few nanometers of material is a complicated process. Most traditional filter manufacturers employ vacuum methods, such as sputtering, to achieve good results. The vacuum system keeps the glass substrates clean, and lowers the energy required to dislodge the materials from the sputtering target onto the substrate. In sputtering, target materials (what the filter layers will be made of) are bombarded by heavy atoms with high kinetic energy (Figure 3). This blasts off some of the target material which redeposits on the filter surface. Conceptually, it is similar to sandblasting a painted object, but the



“sand” is a heavy, nonreactive ionized gas (like Argon). The “paint chips” are the target material flying off in individual atoms, molecules and small clusters. They recondense, or deposit, on the substrate because it is cooler. The resulting film is then densified with another ion beam which knocks any voids out of the film, creating a very smooth, dense film.

FIGURE 3. Ion-assisted ion-beam sputtering.





FILTER SPECTRA MEASURED BEFORE AND AFTER AN AGGRESSIVE 10 14-HOUR CYCLES OF AGGRAVATED HUMIDITY TESTING ACCORDING TO MIL-STD-810F.

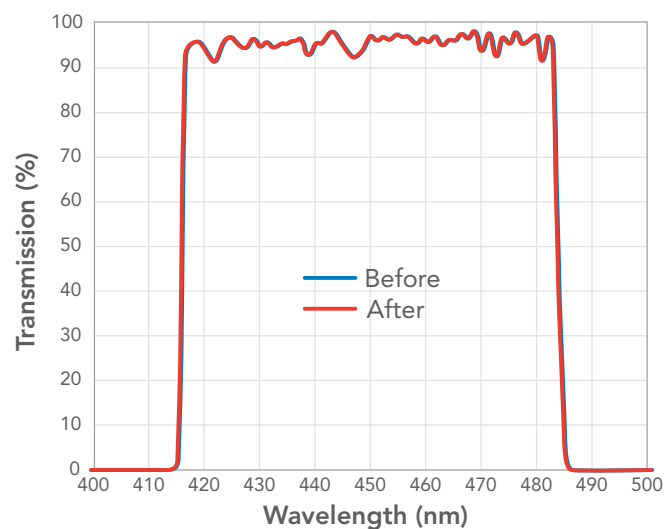


FIGURE 4. Semrock filters easily pass the 10-cycle MIL-STD-810F specification



**LEARN MORE ABOUT OUR
SPUTTERING PROCESS:
[IDEX-HS.COM/SPUTTERING](https://idex-hs.com/sputtering)**

Durability

The sputtering process enables manufacturers to deposit very high-melting oxides and refractory materials onto the surface of the filter. These oxide materials are very hard and durable- comparable to the durability of the glass substrate itself (Figure 4).

Specifications

Filters are Typically Characterized by What the Customer Wants it to Do

Figure 5 lists the six broad categories of filters. The y-axis represents the transmission of the filter, while the x-axis represents the wavelength range. Some of these curves look similar. For instance, Clean-up filters and Bandpass filters are very similar except the transmission range is much smaller for Clean-up filters. Also, Dichroic Beamsplitters and Steep Edge Filters have a similar shape. The difference between these is that Dichroic Beamsplitters are typically meant to work at an angle-of-incidence (AOI) other than zero degrees. Specifying filters is

complicated, but our Semrock applications team members and Searchlight spectral analysis tool make it easier.

Optical filters have two basic categories of specifications — (1) spectral specifications, (2) physical specifications which will be explained in more detail below. Note that all manufacturing processes contain intrinsic variations, so to properly specify filters, tolerances should also be considered for all specifications. In general, tighter tolerances command a higher level of inspection and higher costs.

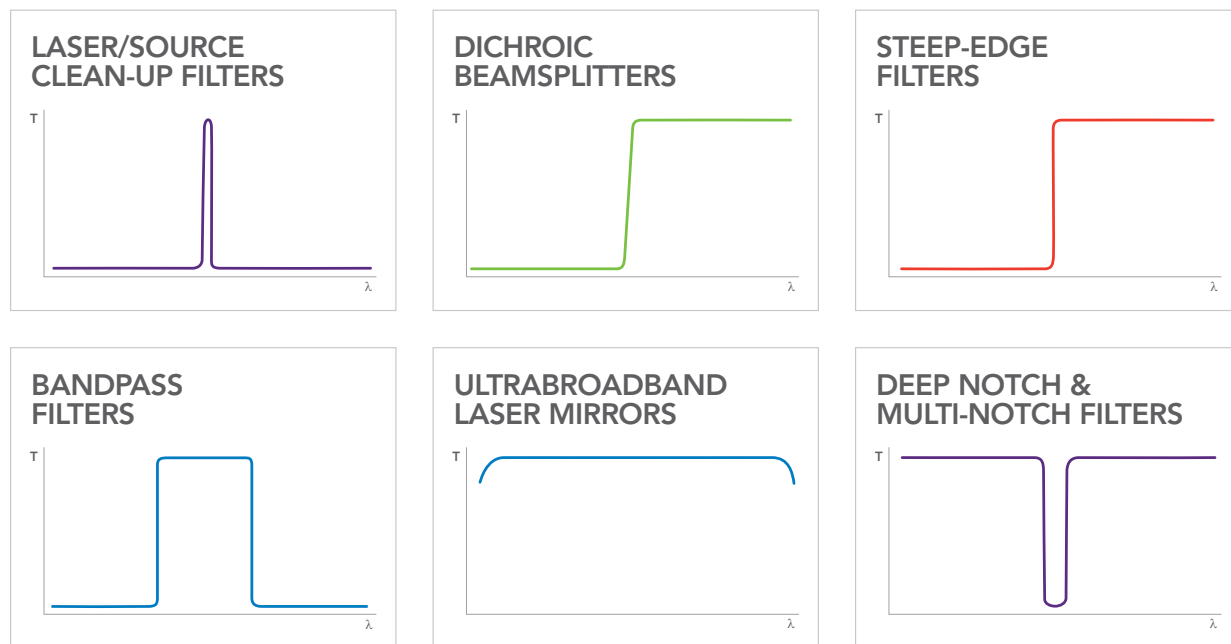


FIGURE 5. Types of optical filters.





CLICK TO LEARN MORE ABOUT
HOW SPECIFICATIONS AFFECT PRICE:
[IDEX-HS.COM/COST-DRIVERS](https://www.idex-hs.com/cost-drivers)

Spectral Specifications

These specifications describe which wavelengths of light pass through and are reflected by the filter. They also describe at what angles the filter will be used and polarization requirements.

Angle-of-Incidence (AOI) and Cone Half Angle (CHA)

Angle of Incidence, or AOI, is the angle at which a collimated beam of light is incident on the filter's first surface, measured relative to the surface normal. Collimated light does not converge or diverge, it follows a straight path, creating a beam of light with constant diameter. In Figure 6A, the collimated beam is normal to the filter surface and $\text{AOI} = 0^\circ$, while in Figure 6B, the collimated beam is at an arbitrary angle.

Cone Half Angle, or CHA, refers to the largest angle produced in a converging or diverging beam as measured from the AOI. Figure 7A shows a converging beam at an arbitrary CHA at $\text{AOI} = 0^\circ$. Figure 7B shows a converging beam at an arbitrary CHA at an $\text{AOI} > 0$. Collimated beams have a $\text{CHA} = 0^\circ$. In photography, CHA is related to the $F/\#$ of a system.

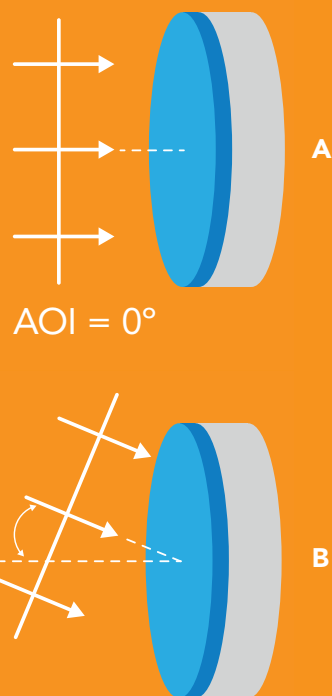


FIGURE 6. (A) At normal incidence $\text{AOI} = 0$; (B) At arbitrary angle, $\text{AOI} > 0$.

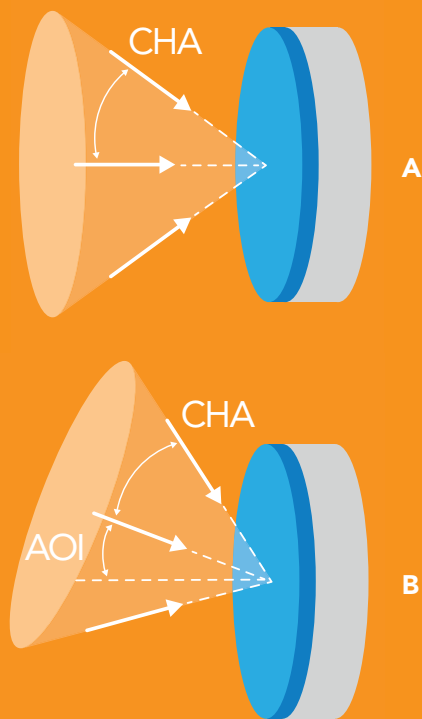


FIGURE 7. (A) CHA in a converging beam at $\text{AOI} = 0$; (B) CHA in a converging beam at $\text{AOI} > 0$.

When to Use

Most transmission filters (Bandpass, Laser Cleanup, and Edge filters) are used in a normal, collimated configuration where AOI and CHA both equal zero. If the filters will not be used in this configuration, the AOI and CHA must be specified.

Filters designed to be used in reflection (dichroic beamsplitters and ultrabroadband mirrors) require that the AOI is specified as well as the CHA if the beam is not collimated.

An $\text{AOI} > 0$ shifts the spectrum to lower wavelengths and causes polarization splitting of the spectrum (Figure 8). Using a filter in a beam with a large CHA also shifts the spectrum to lower wavelengths.

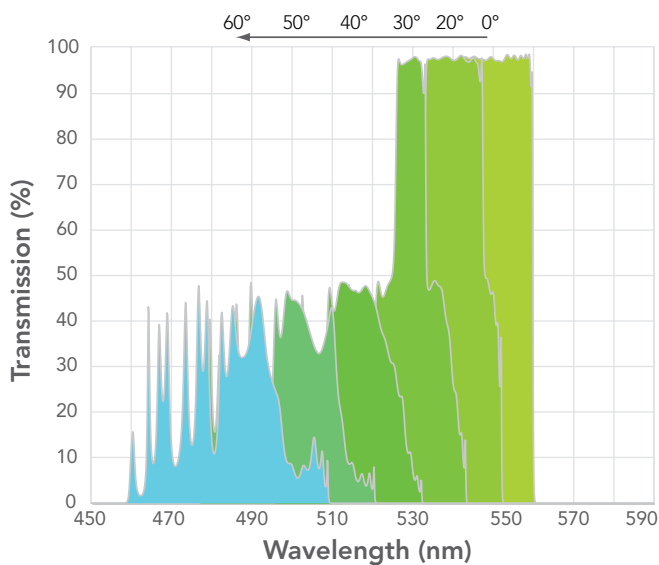


FIGURE 8. Spectral response of a typical bandpass filter designed for use at normal incidence at different AOIs. The response becomes distorted at non-zero AOI.

The resulting spectrum integrates the spectral response at all angles from the AOI to $\text{AOI} + \text{CHA}$ in proportion to the light intensity at each angle.

Filters are designed to be used at a particular angle (or range of angles), so specifying AOI and CHA early in the design process ensures better product performance.

SPECIFICATION INCLUDES

- › AOI in degrees
- › CHA in degrees



Angle-Tuning of Filters – VersaChrome

IDEX Health & Science | Semrock innovation has produced VersaChrome filters that are insensitive to s-, p-polarization splitting. Upon rotation, the wavelength of the filter shifts lower - up to approximately 10% at 60° – without losing edge steepness, % T, or high blocking. Learn more: idex-hs.com/versachrome-bandpass

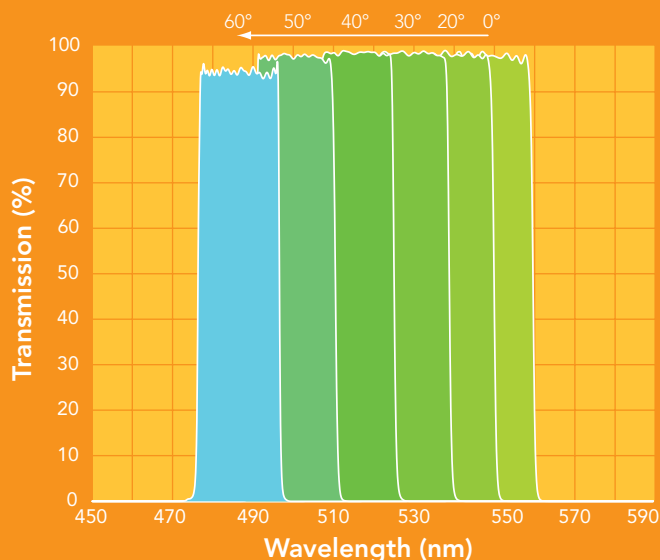


FIGURE 9. VersaChrome filters can be rotated up to 60° without a degradation of performance

VersaChrome bandpass filters allow for continuous spectral scanning by simply rotating the filter. They enable fine-tuning of both the excitation and emission channels in fluorescent high-content screening applications for the highest sensitivity measurements. VersaChrome longpass and shortpass filters increase the versatility even more by letting the customer control both center wavelength and bandwidth by tuning both edges independently. Learn more: idex-hs.com/spectral-imaging



MORE INFORMATION IS PROVIDED IN
SEMROCK'S VERSACHROME WHITE PAPER:
[IDEX-HS.COM/FILTERS-TUNABLE](https://idex-hs.com/filters-tunable)

Transmission

Transmission describes the percentage of incident light that passes through a filter according to the following equation where I_T is the light that passes through the filter and I_o is the incident light's intensity.

$$\%T = 100 * I_T / I_o$$

When to Use

%T must be specified in the case of Bandpass filters, Laser/Source cleanup filters, Edge filters and Dichroic Beamsplitters – any filter where the light of interest passes through the filter.

SPECIFICATION INCLUDES

- › Average percent transmission, peak transmission and/or minimum transmission
- › Range of wavelengths (or single wavelength) where the transmission must occur (sometimes called a Pass Band)

Blocking

Blocking is the percentage of incident light that is transmitted by the filter expressed in optical density (OD) according to the following equation:

$$OD = -\text{Log}_{10}(T)$$

(T expressed as a decimal)

The lower the %T, the higher the OD value. For example, 10% T = OD1 and 0.01% T = OD4. Learn more: [idex-hs.com/optical-density](https://www.idex-hs.com/optical-density)

High blocking levels (above about OD 6) are difficult to measure reliably because of the low number of photons transmitted by the filter. IDEX Health & Science has developed methods to measure up to OD 10 in certain wavelength ranges. Learn more: [idex-hs.com/measurement](https://www.idex-hs.com/measurement)

When to Use

Blocking must be specified in the case of Bandpass filters, Laser/Source cleanup filters, Edge filters and Notch filters.

SPECIFICATION INCLUDES

- › Average blocking, and/or minimum blocking – in OD
- › Range of wavelengths (or single wavelength) where blocking must occur
- › Different spectral ranges may have different blocking requirements



Reflection

Reflection is the percentage of incident light that doesn't go through the filter, but bounces backward. It is expressed as a percentage of incident light (I_o) where I_R is the reflected light intensity.

$$\%R = 100 * I_R / I_o$$

When to Use

Reflection must be specified in the case of Dichroic Beamsplitters, Ultrabroadband Laser mirrors or in any case where the reflected beam will be used in the experimental setup.

SPECIFICATION INCLUDES

- › Average reflection, peak reflection and/or minimum reflection
- › Range of wavelengths (or single wavelength) where reflection must occur

Polarization

Polarization describes the orientation of the oscillating electric field vector component of the electromagnetic wave. It runs perpendicular to the direction of travel. In linearly polarized light, these electric field vectors are oriented in a single direction, while in unpolarized light, they are at arbitrary angles perpendicular to the

direction of travel across all light rays. Referencing the filter's surface, in an incident beam that is s-polarized, its electric field vectors are parallel to the filter surface. The electric field vectors in p-polarized light are perpendicular to the filter's surface. In the diagram below, s-polarized light is parallel to the y-axis (E_s), while p-polarized light lies in the x-z plane (E_p). The blue horizontal line signifies the y-z plane and the s-polarized electric field vector (E_s) is going in and out of the page, while the p-polarized electric field vector (E_p) is in the x-z plane.

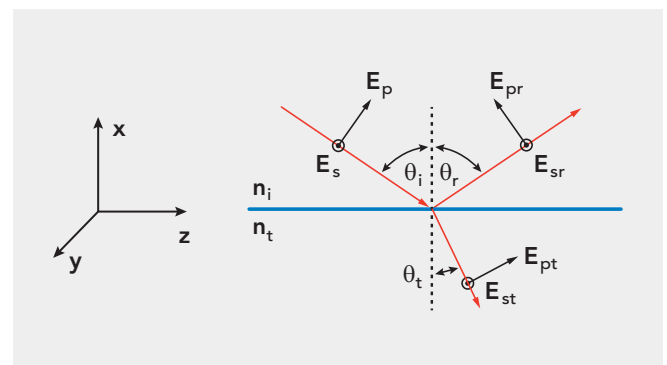


FIGURE 10. s- and p-polarization orientations with respect to a surface.

The interaction of s- and p-polarized light with filter surfaces is described by Fresnel equations. To learn more about them, visit: idex-hs.com/polarization. As a filter is tilted in the light beam, p-polarized light shifts to lower wavelengths faster than s-polarized light. In fact, this property can be exploited to create polarizing beamsplitters, as shown in Figure 11.

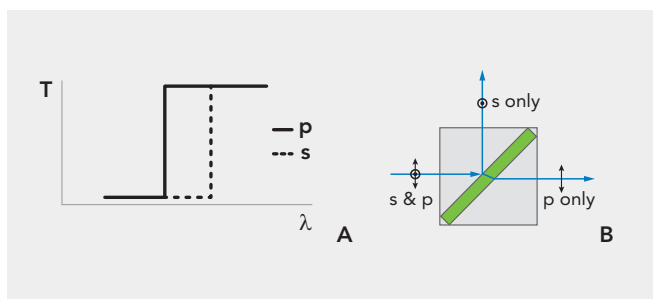


FIGURE 11. (A) For a longpass edge filter, p-polarized light shifts faster as a function of AOI. (B) this can be used to create a polarizing beamsplitter.

When measuring a dichroic beamsplitter with unpolarized light, the s-, p- splitting is observed as a “step” in the spectrum at about 50% transmission, as the p-polarized light is transmitted first, followed by the s-polarized light, as seen in Figure 12. At low angles (up to about AOI=10°), polarization splitting is small or non-existent and increases at higher angles. Our team has developed methods to both mitigate and exploit this splitting for various customer needs. Learn more about polarization at: idex-hs.com/polarization

RAZOREDGE® DESIGN SPECTRA VS. AOI

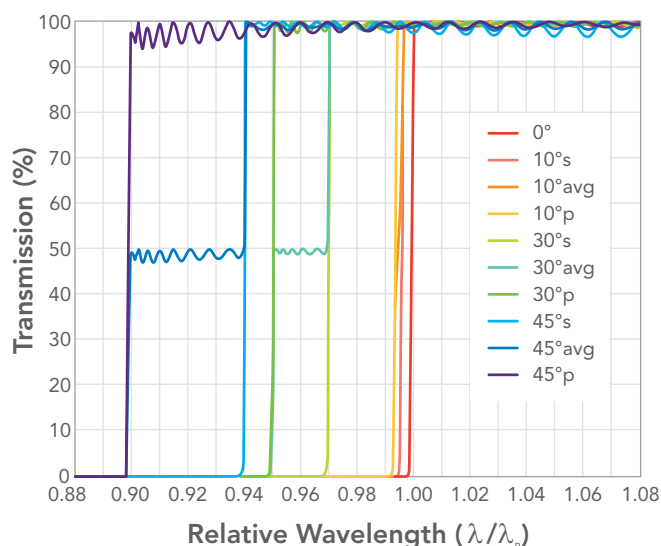


FIGURE 12. The s/p polarization splitting shows as a “step” in the transmission spectrum at large AOI.

When to Use

Specify polarization parameters when using a polarized light sources or if maintaining or controlling polarization is required.

SPECIFICATION MAY INCLUDE

- › Type (s/p) of transmitted and/or reflected light
- › Relative ratios of s + p polarized light
- › Wavelength ranges
- › Polarization source and orientation (e.g.: laser source, etc)



Transition Width and Edge Steepness

Transition width and edge steepness, while related, have different meanings. Edge steepness is a measured spectral response, while transition width is a performance specification describing the acceptable location of the filter's spectral curve. Transition width can be thought of as the "goal posts" – a filter's spectral edge should fall within the specified spectral width. These specifications are important in laser-based experiments, such as Raman, where the laser wavelength is very close to the signal wavelength.

In Figure 13, the transition width is the spectral distance between the 785 nm laser-line (where OD 6 blocking is required) and the maximum wavelength at which transmission = 50%. The edge steepness is the spectral distance between the longest wavelength at which the given filter exhibits OD 6 blocking and the wavelength at which the filter exhibits 50% transmission.

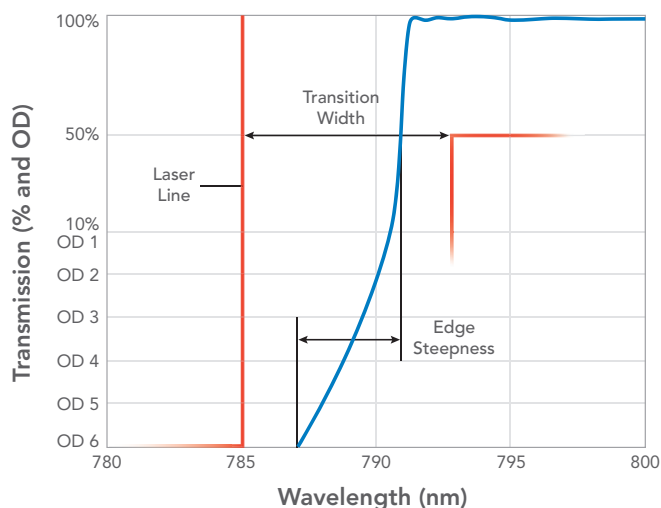


FIGURE 13. Specified transition width versus measured edge steepness of a longpass edge filter.

In Figure 13, the blue line shows the filter's actual spectral response (edge steepness) which falls within the specified transition width (the "goal posts"). The edge steepness is 4 nm (787 nm to 791 nm) and the transition width is 8 nm (785 nm to 793 nm).

Semrock specifies both transition width and edge steepness with respect to a blocking level of OD = 6 and a transmission level of 50%. Because they are often important for laser applications, instead of nm, these can also be specified as a percentage of the laser wavelength, so a 1% transition width for a 785 nm laser would mean that 50% transmission occurs at 785+7.8 nm, or ~793 nm.



**TO LEARN MORE ABOUT
TRANSMISSION WIDTH AND
EDGE STEEPNESS VISIT:
[IDEX-HS.COM/EDGE-STEEPNESS](https://www.idex-hs.com/edge-steepness)**

When to Use

Use this specification whenever the spectral difference between the laser (or other light source) and signal are very close together (<2%).

SPECIFICATION INCLUDES

- › Laser wavelength
- › Transition width as a % of laser wavelength (or in nm)
- › Blocking and transmission criterion if it is other than OD=6 to %T=50

Limitations of Spectral Measurements

Spectral measurements of filters using standard spectrometers suffer from a few limitations, especially when attempting to measure very steep edges and sharp transitions.

UNCOLLIMATED BEAM

1

Standard spectrometers generally have a sample compartment where the sample is positioned at a beam focus. The beam typically has a CHA in the 3-5°

range. This results in a spectrum that is /integrated over all subsumed angles, softening the edge steepness and corners in the spectrum.

LIMITED SENSITIVITY

2

Even with reference beam attenuation, it's difficult to achieve OD measurements above OD=7. As the measurements approach

this limit, the spectrum begins to deviate from the predicted performance in a standard spectrometer.

TRADE-OFFS BETWEEN SPECTRAL RESOLUTION AND SENSITIVITY

3

To measure high OD values, customers often open the slits of the spectrometer to increase incident light intensity. In so doing, spectral details are smoothed out

over a number of wavelengths and "measurement artifacts" are observed in the steep edges. Reducing the slit width will remove the artifacts and increase spectral resolution, but result in a reduction of OD measurement sensitivity.

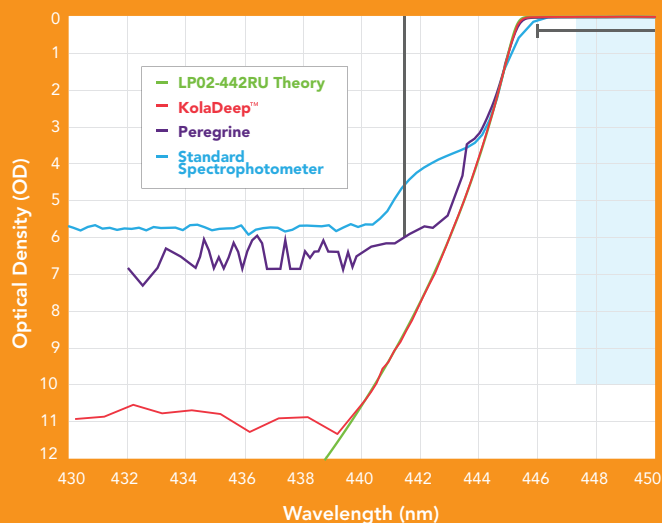


FIGURE 14. IDEX Health & Science custom-designed Peregrine and KolaDeep™ SMS systems enable measurement of the steepest edges and deepest blocking.

Semrock has addressed these issues by designing custom spectral measurement systems. These custom systems enable Semrock to accurately measure, test, and verify designs with deep blocking and/or steep spectral edges.

Semrock's workhorse is the Peregrine SMS. It was designed with a CHA <0.3° to eliminate one of the major sources of error described above. It has allowed Semrock to consistently lead the way in the development of extremely steep edges and multi-band designs.

KolaDeep SMS is Semrock's newest system- it combines the features of the Peregrine SMS sample configuration with a proprietary optical design to deliver best-in-class sensitivity without compromising spectral resolution. It can measure OD>8 from 275–800 nm and OD>7 from 800–1100 nm while simultaneously accurately measuring the entire edge slope and transmission region.



LEARN MORE ABOUT OUR UNIQUE SPECTRAL MEASUREMENT CAPABILITIES:
[IDEX-HS.COM/MEASUREMENT](https://www.idex-hs.com/measurement)



Physical Specifications

Size and Shape

Semrock filter substrates are glass with standard thicknesses of 2 mm and 1mm. Filters can be shaped to a minimum length/width dimension of 4 mm or a 5 mm diameter. The maximum length/width dimension and diameter is filter type dependent, but is on the order of 100 mm (length/width) and 200 mm (diameter). Rectangular and round shapes are available.

SPECIFICATION INCLUDES

- › Length, width, diameter as appropriate
- › Thickness
- › Drawings with tolerances are preferred

Clear Aperture (CA)

This specification describes the area of the filter over which spectral and cosmetic specifications apply. The CA is specified in either mm or as a % of the filters dimensions. The CA is centered on the filter unless otherwise specified. A 25 mm circular filter, with an 80% CA, equates to 20 mm CA centered on the filter's surface. The clear aperture is always smaller than the filter's dimensions to allow for edge defects in the manufacturing process.

SPECIFICATION INCLUDES

- › Length, width, diameter in mm, or % of total size
- › Drawings with tolerances are preferred
- › Standard CA is 1 mm smaller than the size of the part

Rings, Edge Blackening, and Mounting

Bandpass filters for fluorescence in standard sizes (25 or 12.5 mm diameter) are often mounted in anodized aluminum rings. Carets, edge markings, and part identification labels can be applied to the housing. Edges of unmounted filters can be blackened to reduce scatter within the optical system.

Filter Sets and Cubes

Filters for fluorescence microscopy are often sold in sets that are optimized for specific fluorophores. These sets are comprised of an excitation filter, a dichroic beamsplitter and an emission filter. The excitation light of the microscope passes through the excitation filter and is reflected by the dichroic beamsplitter to the sample. The fluorescence signal from the sample transmits through the dichroic beamsplitter and the emission filter and onto the camera.

Each fluorescence microscope manufacturer uses a unique filter cube. While the filters and dichroics can be changed by the user, Semrock can assemble the filter set in the appropriate filter cube for your microscope. The microscope cube securely holds all three filters in optimal alignment for the associated microscope. Learn more at: [idex-hs.com/filter-sets](https://www.semrock.com/index-hs.com/filter-sets)

SPECIFICATION INCLUDES

- › Mounting requirements (rings, blackening, etc)
- › Microscope type (for cube-mounting)

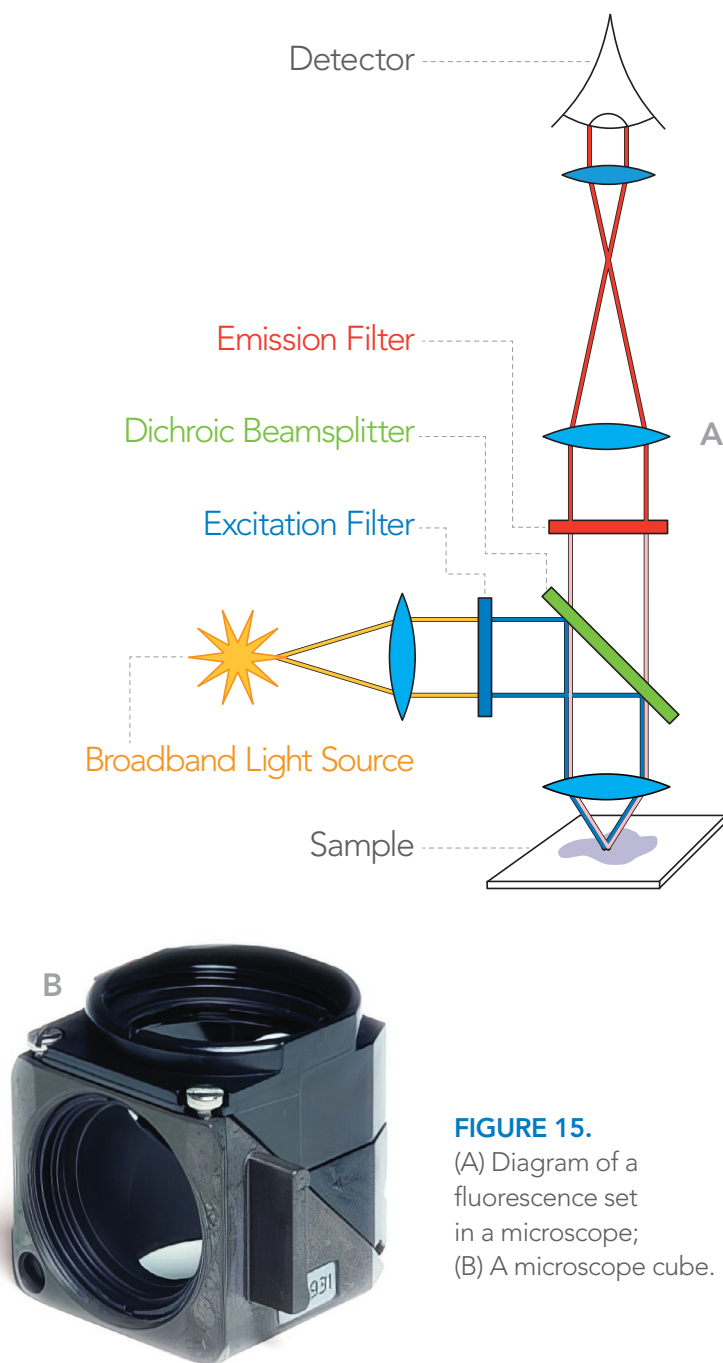


FIGURE 15.
(A) Diagram of a fluorescence set in a microscope;
(B) A microscope cube.



Scratch and Dig (S-D)

Scratches (S) and digs (D) are commonly specified together and noted as S/D. S specifies the maximum allowable scratch width in microns. D specifies the maximum allowable size of holes, bubbles, and other defects in the films. Digs are specified in units of 10 microns, so a dig spec of 40 = 400 microns in diameter. Note that scratch and dig specifications only apply within the CA of the filter.

SPECIFICATION INCLUDES

- › Acceptable scratch width in microns
- › Acceptable dig diameter in units of 10 microns

Transmitted Wavefront Error (TWE) and Wedge

An ideal wavefront of a collimated beam is a plane, perpendicular to the direction of travel. Transmitted Wavefront Error (TWE), expressed in waves, describes the deviation of the filter's transmitted wavefront from a perfect plane. TWE is caused by the filter's thickness deviations and material inhomogeneity.

TWE can be specified at any wavelength, but is usually normalized to 633 nm over some diameter (typically 25 mm).

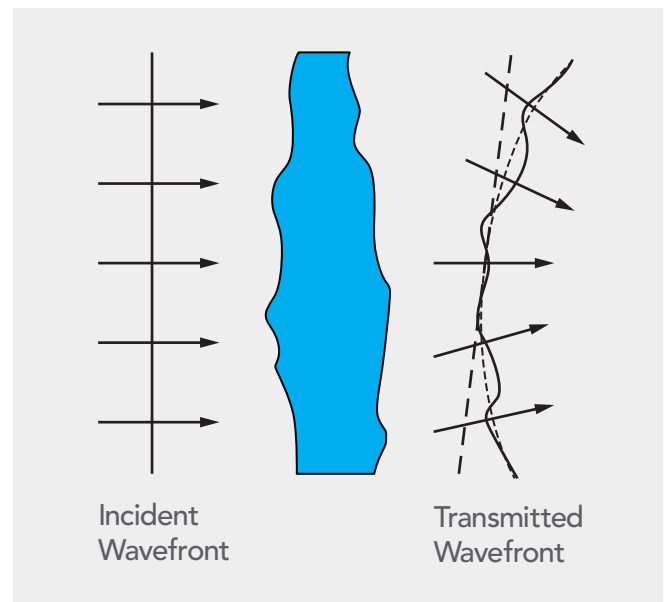


FIGURE 16. TWE (exaggerated surface deformation).

TWE can be specified as an absolute (peak-to-peak) error or as an RMS (root-mean-square) error, or both. Generally, it is not difficult to control TWE to meet the most common tolerances (typically $\lambda/4$ to 1λ , RMS). For most transmissive filters, only TWE matters as the wavefront transmitted through the filter is of interest and not the reflected light. TWE is illustrated in Figure 16. In this example, TWE has several components. (1) Wedge causes an overall deflection of the beam in one direction (dashed line). (2) Spherical error, due to the optic being thicker in the middle, causes the wavefront to globally bend and start to focus (dotted line). (3) Other surface and refractive index variations cause higher order bumps in the wavefront.

Semrock uses high quality substrates with very low wedge, thickness and refractive index variations. Small TWE can arise from stress and inhomogeneities in the coating process.

When to Use

Use TWE specifications in transmissive optics such as Bandpass filters, Edge filters and Laser Cleanup filters. Customers should not use flatness as a substitute for TWE.

SPECIFICATION INCLUDES

- › Waves of acceptable TWE over a specified diameter
- › Peak-to-peak and/or RMS
- › Wavelength (if not 633 nm)



Reflected Wavefront Error (RWE) and Flatness

Flatness is the physical deviation of the filter surface from a perfectly plane surface. Reflected Wavefront Error (RWE), expressed in waves, describes the deviation of a wavefront from a perfect plane after being reflected from the filter. It is caused by surface curving and irregularities. Similar to TWE, it is usually specified at 633 nm over some diameter or length (usually 25 mm). It can also be specified as peak-to-peak error, RMS error, or both.

The relationship between flatness and RWE depends on the AOI θ (see Figure 17). At normal incidence, $\cos \theta = 1$, so RWE is twice the flatness.

$$\text{RWE} = 2 \times \cos \theta \times \text{Flatness}$$

$$\text{Flatness} = \frac{1}{2 \times \cos \theta} \times \text{RWE}$$

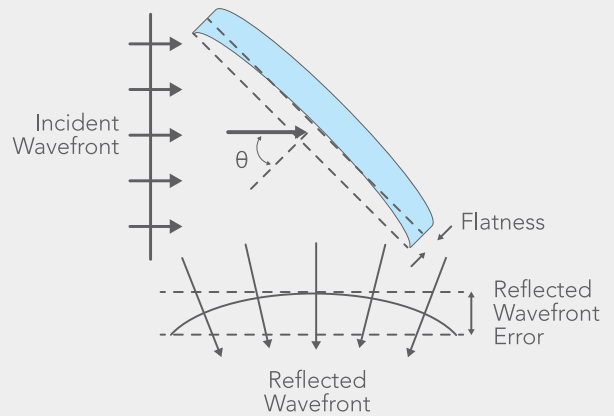


FIGURE 17. RWE is dependent on AOI (θ)

Because of the factor of 2, RWE is much more susceptible to slight bending of the filters due to intrinsic stress in the coatings than TWE. Stress typically causes a spherical RWE contribution, which cause small focus changes in the optical system. Sometimes, refocusing can solve this issue. Surface irregularity also contributes to the overall RWE, as illustrated in Figure 18.



LEARN MORE ABOUT HOW RWE AFFECTS THE RESOLUTION IN VARIOUS FLUORESCENCE MICROSCOPY METHODS:
IDEX-HS.COM/RWE

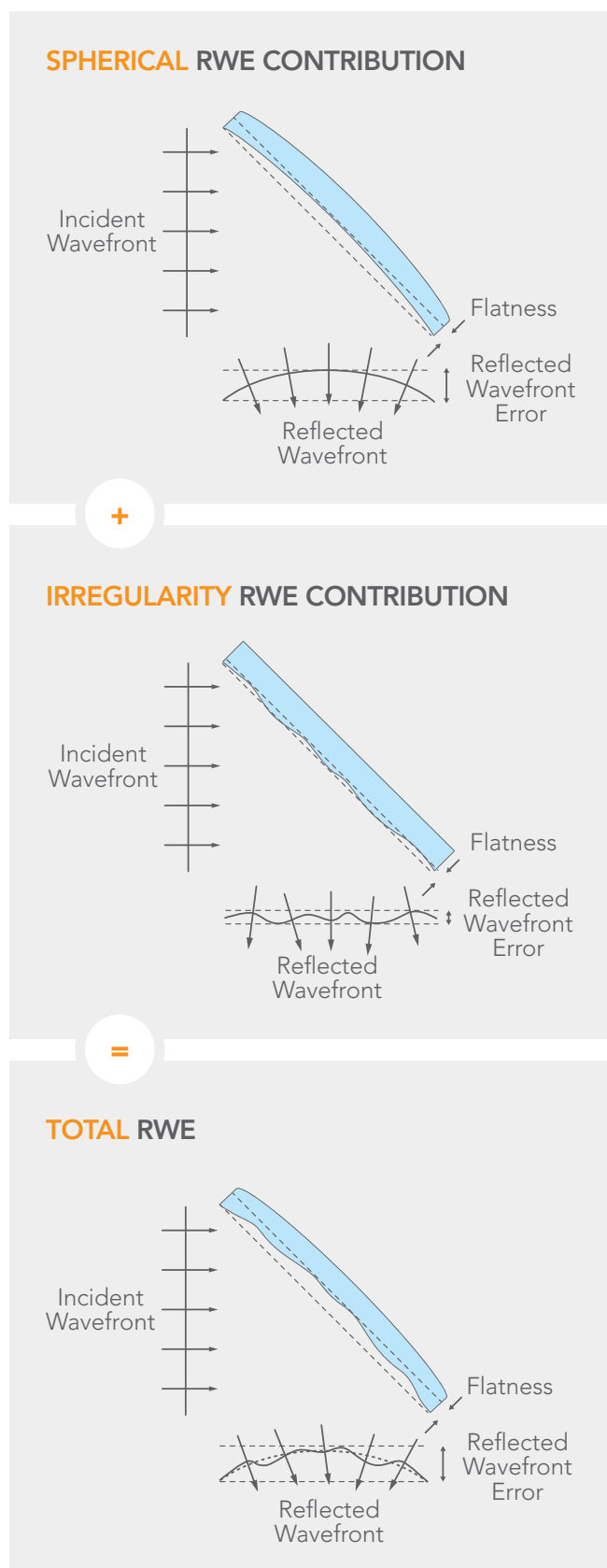
When to Use

RWE must be specified in imaging applications that are using the reflected beam to create the image. A high RWE can significantly blur and distort the image in these systems. A low RWE is also very important in laser-combining applications.

SPECIFICATION INCLUDES

- › Waves of acceptable RWE over what diameter
- › Peak-to-peak and/or RMS
- › Wavelength (if not 633 nm)

FIGURE 18. RWE contributing factors.



Laser Damage Threshold (LDT) of Filters

Laser damage to optical filters is strongly dependent on many factors, and thus it is difficult to guarantee the performance of a filter in all possible circumstances. LDT is typically specified in units of Joules/cm². Factors important to determining LDT include:

Material properties of the filter, such as:

- › Absorption coefficient
- › Specific heat
- › Melting temperature
- › Defects and impurities
- › Thickness
- › Surface morphology

Laser beam properties, such as:

- › Beam size
- › Wavelength
- › Pulse length
- › Repetition rate or duty cycle
- › Peak power



**LEARN MORE ABOUT LASER
DAMAGE THRESHOLD:
[IDEX-HS.COM/LDT](https://idex-hs.com/LDT)**

For continuous wave (cw) lasers, Semrock filters have a LDT_{cw} on the order of 10 J/cm² or higher. Damage by cw lasers is mostly thermal in nature. Very fast pulsed lasers (picosecond-femtosecond pulses) can be treated as

“quasi-cw lasers.” The pulse and repetition rates are so fast that the filter materials have no time to relax before the next pulse. The average power density can be used to estimate LDT.

For long-pulse (nanosecond-microsecond pulse length) lasers with repetition rates of 1–100 Hz, dielectric breakdown is the primary damage mechanism. Most Semrock filters have LDTLP values on the order of 1 J/cm², and are thus considered “high-power laser quality” components. An important exception is the narrowband laser-line filter in which the internal field strength is strongly concentrated in a few layers of the thin-film coating, resulting in an LDTLP that is about an order of magnitude smaller.

When to Use

We have developed an online tool for our customers to estimate the likelihood of laser damage: idex-hs.com/ldt-calculator

If it appears that laser damage may be a problem in your system, please specify LDT for your filters. Note that LDT measurements are not performed in house and will add time and cost to your order.

SPECIFICATION INCLUDES:

- › Laser properties mentioned above

Ordering Information



Semrock, Inc. manufactures optical filters that set the standard for the life science and analytical instrumentation industries, as well as optical filters and mirrors for laser and optical systems. OEM filters are manufactured in volume using thin-film sputtering and proprietary volume manufacturing technology. All Semrock products carry a ten-year warranty.

Founded in September 2000, Semrock is based in Rochester, New York, a well-known world center for optics, and has sales offices throughout the United States. In October 2008 Semrock became a unit of IDEX Corporation.

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Ordering

OEM customers in the USA and Canada may place orders on the IDEX Health & Science website using a credit card. An account is required to order — visit www.idex-hs.com for details on setting up your account. Please note that credit approval is subject to review.

North American Government, University, and National Laboratory customers may purchase Semrock Optical Filters through our domestic distribution partner, AVR Optics (account required, www.avr-optics.com).

International customers (outside the USA and Canada) may purchase Semrock Optical Filters through Semrock's distribution network. Please visit our website, www.idex-hs.com, to find your local distributor.

Online Quotes

OEM Customers in the USA and Canada can generate quotes online (account required, www.idex-hs.com).

North American Government, University, and National Laboratory customers can generate quotations through our domestic distribution partner, AVR Optics (account required, www.avr-optics.com).

International customers purchasing through Semrock's distribution network may send shopping cart contents to their local distributor (account required, www.idex-hs.com).

Pricing & Availability

All prices are domestic USD and subject to change without notice. Check our website for current pricing and availability.

Shipping

Orders received for catalog products will be reviewed for best possible delivery date within 48 hours. Domestic orders are shipped UPS Ground or 2-day, unless otherwise requested. We also accept customers' shipping account numbers for direct carrier billing.

10-Year Warranty

Be confident in your filter purchase with our comprehensive 10-year warranty. Built to preserve their high level of performance in test after test, year after year, our filters reduce your cost of ownership by eliminating the expense and uncertainty of replacement costs.

30-Day Return Policy

Semrock offers a 30-day return policy for unused, undamaged standard-sized catalog products in their original packaging. Returns must be made within 30 days of purchase with an RMA number to qualify for a full credit. OEM volumes returned after 30 days may incur a restocking fee, and custom-sized parts are not eligible for return. Products purchased through distributors must be returned via the distributor, and all returns are subject to inspection. Returns without an RMA number will not be accepted and will be returned at the sender's expense.

RoHS & REACH Compliant

Semrock complies with both RoHS and REACH regulations. You can find our full compliance statement at www.idex-hs.com/about/environmental-policy

ISO 9001:2015 Certified

Semrock's Quality management system is certified to ISO 9001:2015.



ISO 9001: 2015

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