

How to Select a Filter

Optical filters make it possible to precisely select a specific band of wavelengths or intensity within an optical system. Bandpass, edge, and notch filters are used to narrow, purify, or isolate light sources used for excitation or illumination, and to select specific portions of a signal for detection by PMT, CCD, or other single-element detector. Neutral density filters can attenuate a source, reduce the intensity of a light for viewing, or bring a signal within the optimum sensitivity range of a detector. Choosing a filter requires first identifying the spectral profile, transmission, and out-of-band blocking required, at which point more than one type of filter or coating may be offered. Each filter technology offers its own advantages and limitations as regards power handling, transmission, blocking depth and range, and cost.

Filter materials and coatings

Optical filters are designed to absorb or reflect radiation at certain wavelengths while transmitting others. This can occur via absorption in the filter material, reflection from an applied coating, or both. CVI Laser Optics' filter technologies include metallic films, colored glasses, and thin dielectric coatings, used alone or in combination to create a wide variety of filter shapes and properties.

The term "color glass" refers to optical filter glass, known for its selective absorption at UV, visible, and/or near-infrared wavelengths. These optical filter glasses appear colored when their absorption occurs at visible wavelengths. The absorption profiles of various color glasses are dependent upon the type and amount of colorant material and base glass composition. In some glass types a secondary heat treatment is used to activate the colorant optical properties. Since there can be variations between glass melts, actual thickness and glass material may vary in order to guarantee a specific optical density. Absorbed light is dissipated as heat, making color glass filters vulnerable to structural damage if used with high power lasers, though 25 W/cm² cw damage threshold is typical. Though low in cost, color glass filter transmission curves tend to have slow-transitioning, rounded edges, making them unsuitable for some applications.



Like their mirror counterparts, filters coated with metallic films offer broadband performance that is insensitive to angle and polarization. These films make excellent neutral density (ND) filters, transmitting a precisely controlled fraction of light while reflecting or absorbing the remainder. CVI Laser Optics' Inconel® ND filter coating is composed of metal alloys specially chosen to create a spectral curve that is more uniform over a wider range than the curves of most pure metals, making it ideal for use at 200 – 2500 nm (fused silica) or 350 – 2500 nm (N-BK7). This vacuum-deposited alloy film is corrosion resistant, and does not age at normal operating temperatures. Adhesion of Inconel® to the substrate is excellent, and is unaffected by moisture and most solvents from -73°C to +150°C. Exposure to higher temperatures should be avoided as it may cause film oxidation and increased transmittance. These filters are not suitable for use with high power pulsed lasers, but can be used at up to 25 W/cm² with cw lasers.

Dielectric coatings enable the greatest variety of filter spectral shapes, as well as the highest durability. They employ quarter-wave thicknesses of alternately high and low refractive index materials applied to a substrate to form a multilayer stack. By choosing the coating materials

and thicknesses carefully, the reflected wavefronts from each layer are made to interfere constructively to produce a highly reflective mirror. These coatings are remarkably hard, durable, and abrasion-resistant. Over a limited wavelength range, the reflectivity of a dielectric coating can easily be made to exceed the most efficient metallic coating. Furthermore, the coatings are effective for both *s*- and *p*-polarization components, and can be designed for a wide range of angles of incidence. As AOI moves significantly away from the design angle, however, reflectance can be markedly reduced.

CVI Laser Optics uses a variety of technologies for dielectric coatings. The interference filter product line, as well as the lower blocking long and short wavepass filters, are manufactured using hard, semi-hard, and soft coating technologies that balance price and performance for each filter type. Thermal evaporation is very low cost, but results in soft films suitable only for lower power use. Electron beam deposition utilizes an electron beam to vaporize the material to be deposited. When combined with careful control of the temperature and vacuum conditions, it creates uniform coatings with excellent optical characteristics, high laser damage threshold, and good reliability. Plasma ion-assisted bombardment deposits material at low temperatures. Ion assist during the coating process leads to a higher packing density in the thin-film layers, increasing the index of refraction, minimizing wavelength shift, and achieving the highest adhesion levels with very low absorption. Magnetron sputtering uses a magnet behind a cathode to trap free electrons near the target surface, where they collide with and ionize a plasma used to sputter the target material onto the substrate in the form of neutral particles. The confinement of free electrons in this process accelerates the deposition rate, and generates coatings with exceptional uniformity and durability.

Ion beam sputtering uses a very high kinetic energy ion beam to sputter target materials directly onto the substrate with a high level of accuracy and repeatability over numerous coating runs. It produces dense coating layers with almost no scatter or absorption, which minimizes spectral shift due to moisture absorption. In addition, the coating density and durability allows for high damage threshold, excellent environmental stability, and fewer pin-hole defects in the coated surface. When utilized by the best filter designers, IBS coating technology

can also achieve superior optical performance, including ultrahigh transmission, superior out of band blocking, steep edges, reduced AOI dependence, and broader bandwidths. All of our Semrock manufactured optical filters are manufactured using ion beam sputtering technology.

The coating technique alone does not determine performance. Control of the coating process is essential to achieving durable, high-reflectivity coatings. We use advanced production systems and methods to apply our coatings, and employ optical monitoring throughout the deposition process to check the intensity of reflected or transmitted light until a mirror coating is complete. All coating batches are rigorously tested and inspected to ensure consistent, high performance. Our state-of-the-art deposition facilities are able to coat large volumes of standard catalog and custom optics, and we can also develop and evaluate new coatings for customers' special requirements. In addition to our own range of N-BK7, crown glass, and fused silica substrates, CVI Laser Optics' coatings can be applied to customer-supplied substrates.

Filter types & nomenclature

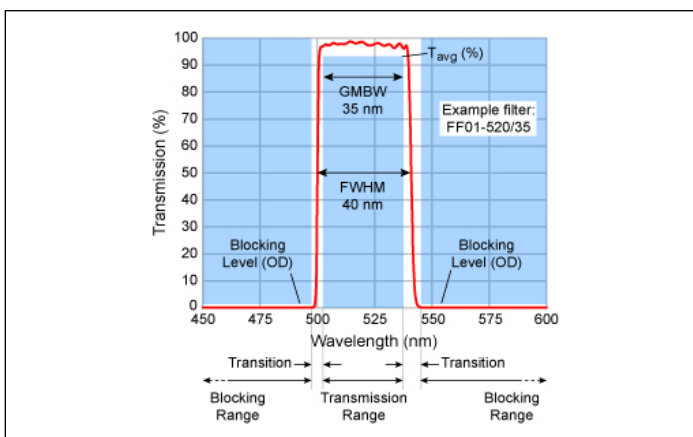
CVI Laser Optics offers optical filters with a wide variety of spectral profiles for use in laser systems and laser-based applications. This section will describe the primary filter types, as well as the terms and specifications used to describe their performance.

Bandpass filters transmit a band of wavelengths ranging from 1 nm to hundreds of nanometers in width while blocking adjacent wavelengths. Bandpass filters are used in fluorescence applications, for Raman and general spectroscopy, and as laser cleanup filters to eliminate optical noise from non-lasing (plasma) lines and spontaneous emission.

The passband range of a bandpass filter is often described using a center wavelength together with the full width at half maximum (FWHM), as shown in the figure below. Either minimum or average transmission over this range may be specified. The Semrock MaxDiode™ bandpass cleanup filters (LD), however, are specified using an approach which very accurately reflects the performance of the filter in an optical system. As shown in the figure below, the filter spectrum (red line) must lie within the unshaded regions. The average transmission must exceed

the specification T_{avg} (%) in the transmission region, which has a certain center wavelength (CWL) and a width called the Guaranteed Minimum Bandwidth (GMBW). The transmission must lie below the blocking level specifications (OD) in the blocking regions. The precise shape of the spectrum is unspecified in the transition regions. However, typically the filter passband has a FWHM that is about 1% of the CWL wider than the GMBW bandwidth:

$$\text{Eqn. 1} \quad \text{FWHM} \approx \text{GMBW} + 0.1 * \text{CWL}$$



So, for the example shown in the diagram, the filter has a GMBW of 35 nm and a FWHM of 35 nm + 1% of 520 nm, or 40 nm.

The ability of a filter to block light outside the passband range is described via optical density (OD). Higher OD values indicate a higher level of blocking. Optical density uses a logarithmic scale to describe the transmission of light through a highly blocking optical filter, particularly useful when the transmission is extremely small.

Eqns. 2a & b

$$\text{OD} = -\log_{10} T$$

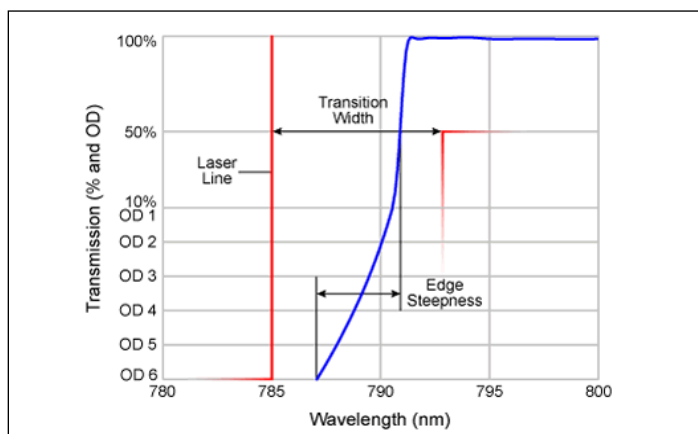
$$T = 10^{-\text{OD}}$$

The F series of bandpass interference filters are available from stock in a large variety of bandwidths and with center wavelengths from 193 to 1900 nm. These economical filters offer minimum peak transmission values ranging from 12 – 70%, depending on the center wavelength

(lowest at UV wavelengths). The center wavelength and FWHM on these filters carries a moderate tolerance, and out of band blocking is a modest OD 4 (average), OD ≥ 3 absolute. They are not recommended for use at high power, and do not have sufficient blocking for use in applications requiring high signal to noise or strongly scattered laser light. The Semrock MaxLine® laser clean-up filters (LL), in contrast, have been designed specifically to suppress sidebands and spontaneous emission in laser output. Narrow passbands with high transmission are combined with deep blocking (OD_{abs} > 6) directly adjacent to the passband and slightly reduced extended blocking (OD_{abs} > 5) to efficiently and precisely isolate a specific laser wavelength. High laser damage threshold and excellent environmental reliability enhance their suitability for laser applications. The Semrock 45° polarization bandpass filters (PBP) also have a moderate passband of 10 – 43 nm, but are designed to transmit only *p*-polarized light at 45° AOI, reflecting virtually all *s*-polarized light (1,000,000:1 contrast ratio). This allows them to be used as laser clean-up filters, polarizing beamsplitters, or for detection.

Edge filters transmit all light above a reference wavelength (longpass filter) or below it (shortpass filter). They are often used in fluorescence and Raman spectroscopy to block scattered laser light, or to separate two signal ranges. They also find use as heat-absorbing filters (hot mirrors), in which case the infrared wavelengths are reflected or absorbed while visible wavelengths are transmitted.

Their performance is often described in terms of a cut-on wavelength, λ_c , which denotes the wavelength at which the filter begins to transmit. The terms transition width and edge steepness are also used, typically in specifying the Semrock filters. Transition width is the maximum distance between the laser line (where OD > 6) and the 50% transmission point. Edge steepness is the actual distance between the point at which OD > 6 ends and the 50% transmission point. Transition width is the term most often used to specify sharp edge filters, as it allows the user to know exactly how far away from the laser line to expect transmitted light. Edge steepness is a more effective term to describe how fast the filter transitions from blocking to transmission. Note that transition width is always greater than edge steepness, as shown in the figure below.



Our LPF series of long wavepass filters are an economical option when a steep edge and deep blocking are not required. Though these filters are not suitable for high power use, they possess extremely broad blocking and transmission ranges, which when combined allow their use at wavelengths from x-ray through 2500 nm. The analogous SPF shortpass filters span a combined 415 – 1200 nm. Both offer average transmission of up to 80% and OD ≥ 3 blocking. Color glass can also be used for longpass applications, albeit with lower transmission and even less edge steepness. Longpass color glass includes the WG, GG, OG, and RG glass filter series.

For steeper edges, higher transmission, and deeper blocking, the Semrock EdgeBasic™ long pass edge filter series (LPEB) may be more suitable. They possess OD >6 blocking at the laser line, and OD >5 extended blocking transitioning within 1.5% of the blocking edge wavelength, followed by $>98\%$ average transmission over a broad passband. These filters are ideal for Raman spectroscopy, and for fluorescence imaging and measurements. The Semrock RazorEdge™ ultrasteep long pass edge filters (LPRE) possess an even steeper edge, transitioning from OD >6 blocking to guaranteed $>90\%$ average transmission in just 1% of the laser wavelength. Though higher in cost, they are ideal for applications with signal close in wavelength to the excitation laser such as Raman spectroscopy. Both the LPEB and LPRE edge filters are suitable for use at high laser damage threshold, and offer excellent environmental reliability.

Notch filters are opposite in profile to bandpass filters. They are designed with high blocking over a narrow range of wavelengths while transmitting a wide range of adjacent wavelengths. Notch filters are generally used for rejection of laser light, in applications including Raman

spectroscopy, laser-based fluorescence instruments, and biomedical laser systems. When used in Raman spectroscopy systems, they allow both the Stokes and anti-Stokes light to be collected with a single spectrometer. The Semrock StopLine® single notch filters (NF) are described using 50% and 90% notch bandwidths, together with high transmission passband ranges. These extend up to 1600 nm for the E-grade filters and are truncated in the visible for the 532 nm U-grade filter to allow blocking of the primary Nd:YAG wavelength at 1064 nm. An extended reduced transmission band is also specified for near-UV wavelengths. These filters are suitable for use at high laser damage threshold, and offer excellent environmental reliability.

Schott color glass filters (CG series) include longpass filters (WG, GG, OG, and RG glass), heat absorbing filters (KG glass), and bandpass filters (UG and BG glass). The spectral profiles of color glass tend to be more broadly varying, and may include different transmission bands of varying efficiency. Though not suitable for high power pulsed laser applications due to their absorbing nature, they are capable of withstanding up to 25 W/cm² of power. They are an economical option for many spectral-balancing applications, provided the right profile exists within the product line.

Neutral density filters are used to attenuate, split, or combine beams in a wide range of irradiance ratios with minimal dependence on wavelength. They are most often used to precisely attenuate light, allowing detectors to be used at the intensity at which they are most accurate and linear, thereby extending their useful range. They can be used in combination to increase attenuation or achieve different optical densities, though care must be taken to avoid reflections between ND filters used in tandem. Broadband neutral density filters are often described using the optical density at 546 nm, sometimes in combination with a density tolerance that is specified as a percentage of the value at 546 nm. High energy dielectric attenuators are often intended for use at a specific wavelength, for which a single OD value is given.

Our ANG series of absorptive neutral density filters are manufactured from NG optical (color) glass, offering broadband attenuation at visible and near-infrared wavelengths. Though economical, they tend to have the greatest variation in spectrum and optical density from

batch to batch, and are recommended for low power applications due to their light absorbing properties. These filters are available in sets of 5 (FSA series) or 8 (ANGS series) filters, varying in optical density from 0.1 to 4.0.

Our metallic neutral density filters utilize a unique Inconel® alloy coating to achieve spectral attenuation curves that are more uniform with wavelength than those of pure metals. They are coated on N-BK7 for visible and near-infrared use (ND series), and on fused silica for UV through near-infrared (NDQ series). These filters work through a combination of reflection and absorption, and are suitable for use at power up to 25 W/cm², though they are not recommended for use with pulsed lasers. Sets of filters varying in OD from 0.03 to 3.0 are available in N-BK7 (FSG, NDS series) and fused silica (FSQ, NDQS series).

If working at higher power, a non-absorbing neutral density filter like our high energy dielectric attenuators may be more appropriate. Designed for transmissive applications at 0° AOI, these filters introduce low transmitted wavefront error, and are manufactured using all-dielectric coatings. Unlike our absorptive or metallic coated ND filters, these filters are designed for use at a specific laser wavelength; attenuation at adjacent wavelengths will vary. The HPDA series on N-BK7 is offered for laser wavelengths from 532 – 1064 nm, while the UVDA series on fused silica addresses laser wavelengths from 248 – 355 nm.

Calibration filters are simply neutral density filters which have been carefully calibrated for transmittance at a series of wavelengths. Our spectrophotometer calibration filter sets (CFS) include several metallic neutral density filters and a holmium oxide filter, all mounted in cuvette-sized holders for protection and insertion into spectrophotometers. The UV-visible set contains filters calibrated from 250 – 635 nm, while the visible set covers 440 – 635 nm with OD values from 0.1 to 1.0. Calibration data is traceable to NIST, with uncertainty of ±1.0% and variation of less than ±1.0% over the period of 1 year. Power handling is not relevant for these filters, as they are intended for use at the low energies utilized by most spectrophotometer systems.

Measurement of Optical Filters

No discussion of optical filters would be complete without addressing the practicalities and limitations of their

measurement. Standard metrology techniques often cause the measured spectral characteristics of thin-film interference filters to be determined inaccurately, especially when there are steep and deep edges. The actual blocking provided by an optical filter is determined not only by its designed spectrum, but also by physical imperfections of the filter, such as pinholes generated during the coating process and surface defects like dirt or dust. Commercially available spectrophotometers are used to measure the spectral performance of optical filters, but these instruments can have significant limitations when the optical filters have narrow transition width and/or very deep blocking.

As a result of these limitations, there can be three main discrepancies between the actual filter spectrum and its measured representation (see figure below). The first discrepancy is the “rounding” of sharp spectral features. This is a result of the non-zero bandwidth of the spectrophotometer probe beam. The second measurement discrepancy, limited OD measurement range, is a result of the limited sensitivity of the spectrophotometer. The third discrepancy is unique to measurements of very steep transitions from high blocking to high transmission, and is referred to as a “sideband measurement artifact.” This artifact arises from the non-monochromatic probe beam that also has weak sidebands at wavelengths outside of its bandwidth.

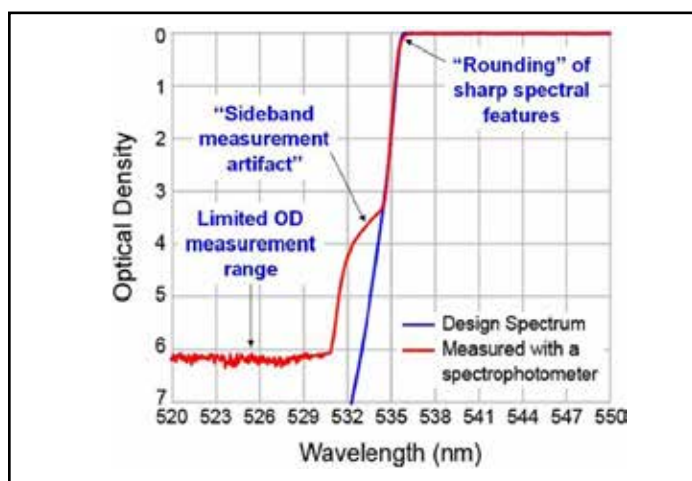


Figure: Measurement artifacts observed using a commercial spectrophotometer

Alternative methods do exist to evaluate filter spectra. The next figure shows five measured spectra of the steep edge of an “E-grade” RazorEdge® filter that is guaranteed to block a laser line at 532 nm with OD > 6 and transition to high transmission within 0.5% of the laser wavelength (by 534.7 nm). The measured spectra are overlaid on the design spectrum of the filter (blue line). As observed on the graph, the measurement instrument and technique greatly influences the measured spectrum of a filter. Measurement method A in this graph is from a custom-built spectrophotometer. This measurement uses instrument settings such as short detector integration time and low resolution, optimized for very rapid data collection from a large number of sample filters during thin-film filter manufacturing process. This method, however, has poor sensitivity and resolution. Measurement method B uses a standard commercial spectrophotometer (Perkin Elmer Lambda 900 series). All of the discrepancies between the actual filter spectrum and the measured spectrum as noted above are apparent in this measurement. Measurement methods C and D utilize the same custom-built spectrophotometer from method A. It uses a low-noise CMOS camera (i.e., detector array) capable of measuring a wide range of wavelengths simultaneously. Measurement method C uses instrument settings (primarily integration time and resolution) designed to provide enhanced

measurement of the steep and deep edge, but the “sideband measurement artifact” is still apparent. Measurement method D is a modification of method C that applies additional filtering to remove this artifact. Method E shows the results of a very precise measurement made with a carefully filtered 532 nm laser and angle tuning of the filter itself. Experimentally acquired transmission vs. angle data is converted into transmission vs. wavelength results using a theoretical model. This measurement method comes closest to the actual design curve, but since it is not as suitable for quality assurance of large volumes of filters, it is best applied as a verification step to validate new filter designs.

Measurement of very high OD or optical density is another challenge. Filters can be designed in theory to have $OD \gg 10$ of blocking, but in practice even the tiniest of physical defects in the optical coatings or mounting, as well as imperfections in the control of system-level stray light, limit the achievable blocking to values in the range of about OD 6 to, at most, OD 10. Given that standard spectrophotometers have a limited OD measurement range due to the instrument noise floor explained above, it can be very challenging to accurately determine higher blocking levels.

A straightforward, production-compatible technique for assuring higher OD values (up to OD 8 or even 9) is called the “complementary filter method.” An approximately collimated broadband beam of light is filtered using a widely blocking reference filter, a bandpass filter with its passband overlapping the region of spectrum of the test filter where high OD measurement is required. The transmitted light is focused onto a low-noise detector capable of measuring very small light levels, such as a large-area photodiode with a low-noise amplifier circuit or a photomultiplier tube (PMT).

First, the signal strength on the detector is recorded with only the reference filter and a calibrated neutral-density (ND) filter of OD ~ 3 in the light path to reduce the light level on the detector by a calibrated amount so that the limited dynamic range achievable by practical detectors can be adjusted to reach the signal level that will be seen by the detector when the test filter has OD 8 or 9 blocking. Next, the ND filter is removed from the light path and replaced by the test filter. The ratio of these two measurements gives the OD of the test filter over the

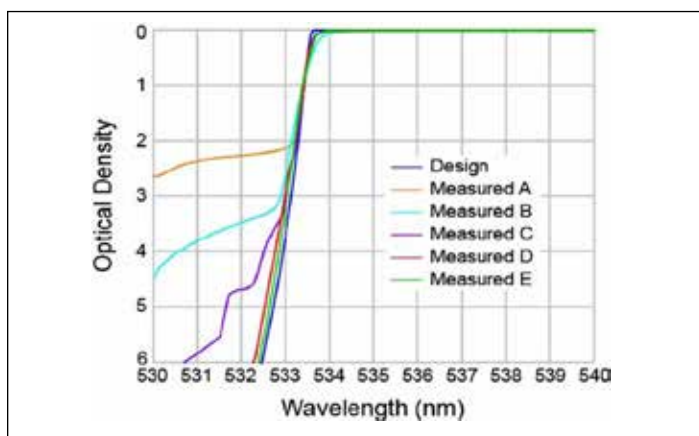


Figure: Design and measured spectra of the same filter (specified in the figure above) using different measurement approaches as explained in the text

spectral range of the reference filter (after adjusting for the calibrated ND value). To achieve OD levels as high as 8 or 9 and ensure accuracy of measurement, it is vital that the measurement setup be sufficiently shielded from ambient light and minimize scattered or other stray light from reaching the detector.

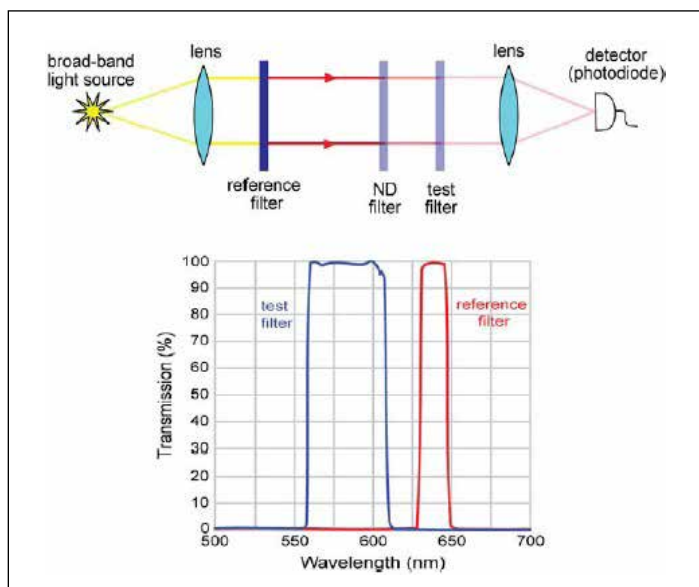


Figure: Measurement of very high OD values. The reference filter covers the range of wavelengths over which high OD must be verified in the test filter.

This method works well to evaluate physical defects which reduce the OD from the designed value, as they do so at every wavelength where a given coating blocks light. Thus, if it can be shown that there are no defects that reduce the blocking to below, say, OD 8 in one wavelength region, then the blocking will similarly not be reduced to below this value at other wavelengths blocked by that same coating. As a result, generally only one reference filter and measurement are required for each test filter.

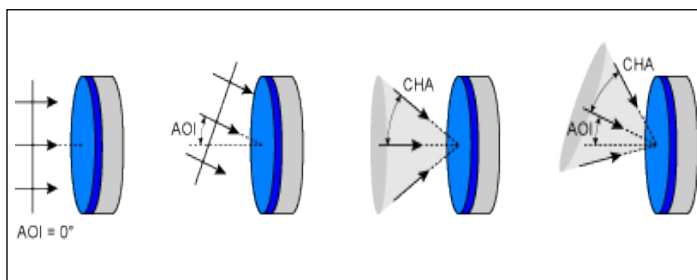
The measurement techniques described above are applied to many of the Semrock bandpass, edge, and notch filters. For these filters, the typical OD noise floor limitations are as follows:

- At 320 – 1120 nm, OD values > 6.5 are measurement noise limited
- At < 320 nm and 1120 – 1500 nm, OD values > 5.5 are measurement noise limited
- At > 1500 nm, OD values > 5.0 are measurement noise limited
- For some filters and/or blocking wavelength ranges, measurements with a noise floor of ~ OD 4 are shown

Angle of incidence

Metal coatings are, by nature, equally reflective at all angles of incidence. Dielectric coatings, however, owe their reflectivity to interference between the reflections from their many layers. As a dielectric coating is angled with respect to an incident beam, the effective thickness of the layers is altered and causes the spectrum of the coating to shift and change. As the angle of incidence (AOI) increases from 0°, the spectrum of a typical dielectric coating shifts toward shorter wavelengths. Two distinct spectra also emerge, one for s-polarized light and one for p-polarized light. At larger angles, the spectrum becomes highly distorted, and the shift can be significantly different for s- and p-polarized light, depending on the filter design. The spectral shift with angle can sometimes be used to tune a filter to shorter wavelength, provided that the design allows and the change in AOI is kept relatively small. Using a single polarization also tends to reduce the distortion of the shifted spectrum. Our Semrock StopLine® single notch filters are designed to allow up to 1% of angle tuning to shorter wavelengths (up to 14° AOI) without degradation of performance.

Cone half angle (CHA) of the incident beam should also be considered when working with dielectric filters. Spectral performance will vary over the range of incident angles contained within the CHA, so a filter may not meet specification when incident light exceeds the CHA for which the filter was designed. This tends to be a greater concern for optics with sharp spectral profiles. The figure below demonstrates the difference between AOI and CHA



for a beam incident on a filter.

The AOI and CHA ranges for which filter performance is guaranteed are included in many filter specifications tables. The AOI and CHA specifications given are exclusive; filters may not meet specification when incident light has non-zero values for CHA and AOI simultaneously. If your operating parameters lie outside the given AOI and CHA specifications, please contact technical support to discuss the potential effects on filter performance, as these can sometimes be modeled.

Filters with sharp spectral features are affected most by changes in AOI. The shift of almost any spectral feature can be approximated by a simple model of the wavelength of the feature vs. angle of incidence, given by the equation:

Eqn. 3

$$\lambda(\theta) = \lambda_0 \sqrt{1 - \left(\frac{\sin \theta}{n_{\text{eff}}} \right)^2}$$

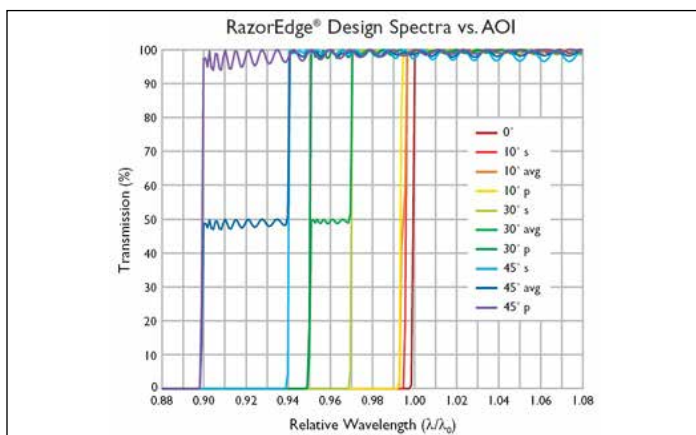


Figure: AOI effect on LPEB ultrasteep long pass edge filter spectrum

where n_{eff} is the effective index of refraction, which varies with AOI and polarization, and λ_0 is the wavelength of the spectral feature of interest at normal incidence.

As a Semrock RazorEdge® ultrasteep long pass edge filter (LPEB) is moved away from 0° AOI, the filter edge shifts toward shorter wavelengths and the edge associated with p -polarized light shifts more than s -polarized light (see figure below, left). Although this polarization splitting causes the unpolarized spectrum to show a "shelf" near the 50% transmission point, the edge steepness remains intact, even for polarized light. For the LPEB family of edge filters, the shift of the 90% transmission point on the edge is described by the equation above with $n_{\text{eff}} = 2.08$ and 1.62 for s - and p -polarized light, respectively. As a Semrock MaxLine® laser cleanup edge filter (LL) is moved away from 0° AOI, the center wavelength shifts toward shorter wavelengths and the bandwidth broadens slightly for p -polarized light while narrowing for s -polarized light, as shown below. The most striking feature is the decrease in transmission for s -polarized light, while the

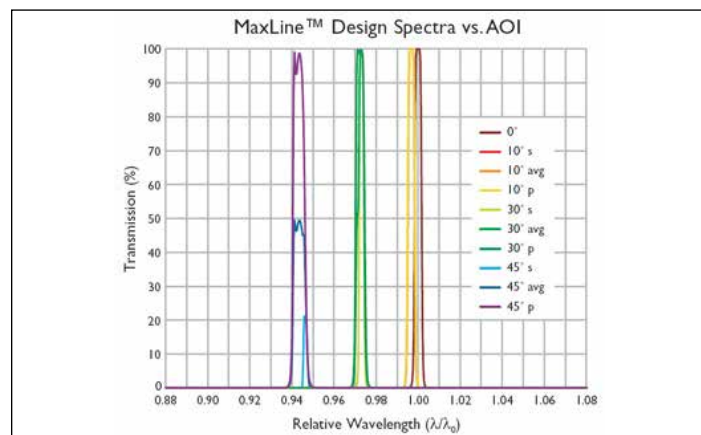


Figure: AOI effect on LL laser cleanup filter spectrum

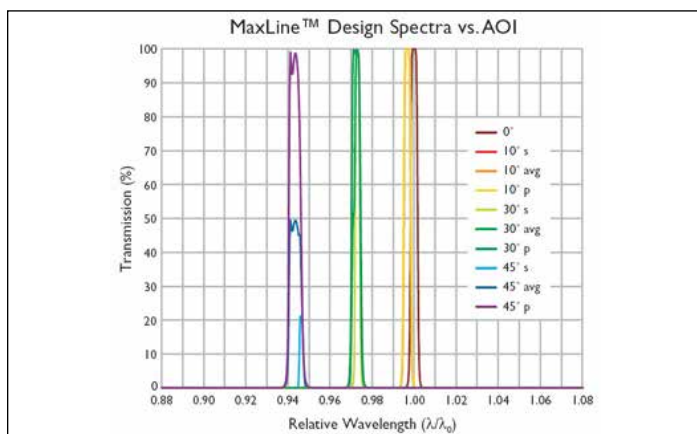


Figure: AOI effect on U- and S-grade StopLine filter spectra

p-polarized light maintains high transmission. The center wavelength shifts for many of these filters are described by the equation above with $n_{\text{eff}} = 2.19$ and 2.13 for *s*- and *p*-polarized light.

The response of a Semrock StopLine® single notch filter (NF) as it is moved away from 0° AOI is different for E- and U-grade filters due to differences in their design. As a U-grade filter is moved away from 0° AOI, the notch center wavelength shifts to shorter wavelengths, the notch depth decreases, and the notch bandwidth decreases (with a greater decrease for *p*-polarized light than for *s*-polarized light). The shift of the notch center wavelength is described by the above equation with $n_{\text{eff}} = 1.76$ for both *s*- and *p*-polarized light. As an E-grade filter is moved away from 0° AOI, a large increase in OD for *s*-polarized light is observed. As the angle is increased from normal incidence, the notch center wavelength shifts to shorter wavelengths; however, the shift is greater for *p*-polarized light than it is for *s*-polarized light. The shift is described by the above equation with $n_{\text{eff}} = 1.71$ for *p*-polarized light and $n_{\text{eff}} = 1.86$ for *s*-polarized light.

Laser damage threshold

Filtering mechanism and coating type are the primary factors to consider when choosing a filter based on laser damage threshold (LDT). Absorptive filters such as the color glass offered for bandpass, longpass, heat absorbing, and neutral density applications are not recommended for high power continuous laser use due to

the heat absorption that occurs in the substrate, though they are rated for up to 25 W/cm^2 in CW operation. Absorptive filters are able to handle low power pulsed lasers since they are capable of dissipating the heat quickly. Metallic coatings used for neutral density filters reject light through reflection and some absorption, and are also not recommended for high power pulsed lasers or intensities above 25 W/cm^2 . Metallic filters are not recommended for pulsed laser applications since the high peak powers can ablate the metal coating. Dielectric coatings are based on reflection of rejected light, reducing the thermal load on the substrate and improving power handling. The laser damage threshold for a specific filter is very dependent on the coating technique used: its density, purity, moisture content, defects, and uniformity. The substrate material is also a factor; higher damage thresholds can be achieved using fused silica instead of N-BK7. Ion beam sputtering creates dense, robust coatings with low scatter and absorption to achieve maximum LDT. Our IBS notch filters (NF) and polarization bandpass filters (PBP) are rated to 1 J/cm^2 at 532 nm when used with 10 ns , 20 Hz pulsed lasers.

If you are unsure if your laser will damage a CVI Laser Optics filter, please contact our technical support team for assistance. Please be sure to include the following information:

1. Type of laser (laser pulsed, continuous-wave, or quasi-cw)
2. Pulse width (if pulsed)
3. Average power
4. Beam diameter
5. Operating wavelength

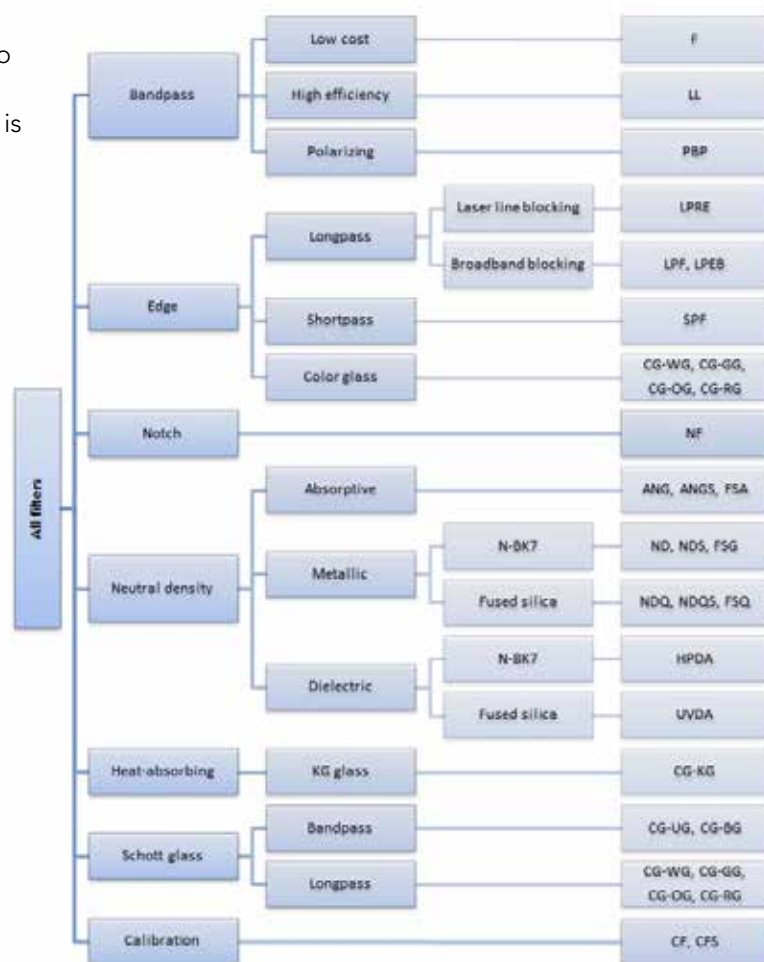
Making the final decision

Spectral profile, transmission, blocking depth, and laser damage threshold will largely determine the best filter for your application, but a few other factors may also influence the decision. Angle of incidence and cone half angle of the beam to be filtered must be considered, as non-zero values can significantly affect filter performance, particularly in combination. Surface figure or transmitted wavefront error of the filter will determine the distortion of your beam profile. This is not often specified or particularly relevant for bandpass, edge, or notch filters,

but becomes important for the 45° polarizing bandpass filters and high energy attenuators. Surface quality is also a consideration for scatter. Most of the IBS coated filters inspected to 60-40 or better scratch and dig, while 80-50 is more typical for other filter technologies.

Whatever your requirements may be, remember that our catalog and semi-custom product offerings are only the beginning. Our technical staff is on hand to assist you in selecting or creating the optimum filter for your application.

Selection Guide



Product Code	Description	Min. Trans.	Transmission Bandwidth	Blocking	LDT	Additional Features
ANG	Absorptive Neutral Density Filters	0.001 - 89.0%	400 - 650 nm	OD ~ 0.05 - 5.0	low power	▪ Schott NG color glass
ANGS	Absorptive Neutral Density Filter Sets	0.0001 - 80%	400 - 650 nm	OD 0.1 - 4.0	low power	▪ Schott NG color glass ▪ 8 ND filters in set, OD 0.1 - 4.0
CFS	Spectrophotometer Calibration Filter Sets	N/A	440 - 635 nm (UV-Vis) 250 - 635 nm (Visible)	OD 0.1 - 1.0	N/A	▪ NIST-traceable calibrated OD values
CG	Schott Color Glass Filters	> 80% (typical)	200 - 400 nm FWHM	Up to OD ~ 5	25 W/cm ²	▪ BG, GG, KG, OG, RG, WG, UG glass
F	Bandpass Interference Filters, UV (193 - 399 nm)	12 - 25% (peak), depending on CWL	10 - 25 nm FWHM, depending on CWL	OD ≥ 3 (absolute) OD ~ 4 (average)	1 W/cm ²	▪ Blocking from x-ray to 1200 nm
F	Bandpass Interference Filters, Visible (400 - 749 nm)	25 - 60% (peak), depending on CWL	1.5 - 70 nm FWHM, depending on CWL	OD ≥ 3 (absolute) OD ~ 4 (average)	1 W/cm ²	▪ Blocking from x-ray to 1200 nm
F	Bandpass Interference Filters, Near IR (750 - 1900 nm)	35 - 60% (peak), depending on CWL	1.5 - 70 nm FWHM, depending on CWL	OD ≥ 3 (absolute) OD ~ 4 (average)	1 W/cm ²	▪ Blocking from x-ray to >3500 nm
FCG	Heat Absorbing Filters	92 - 94 % @ 375 nm	350 - 650 nm	OD 0.01 - 5	25 W/cm ²	▪ Schott KG color glass

Product Code	Description	Min. Trans.	Transmission Bandwidth	Blocking	LDT	Additional Features
FSA	Absorptive Neutral Density Filter Sets	0.001 - 50.0%	400 - 650 nm	OD 0.3 - 3.0	low power	<ul style="list-style-type: none"> Schott NG color glass 5 ND filters in set, OD 0.3 - 3.0
FSG	Metallic Neutral Density Filter Sets	0.001 - 91%	350 - 2000 nm	OD 0.04 - 3.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve 7 ND filters in set, OD 0.03 - 3.0
FSQ	Metallic Neutral Density Filter Sets, Fused Silica	0.001 - 93%	250 - 2000 nm	OD 0.03 - 3.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve 7 ND filters in set, OD 0.03 - 3.0
HPDA	High Energy Dielectric Attenuators	0.003 - 80%	Single wavelength, 532 - 1064 nm	OD ~ 0.1 - 2.5	20 J/cm ² , 20 ns, 20 Hz @ 1064 nm	<ul style="list-style-type: none"> TWE < $\lambda/4$ @ 633 nm over 6 mm CA N-BK7 substrate
LD	Semrock MaxDiode® Bandpass Clean-up Filters	> 90% over GMBW	1.2 - 4.0 nm FWHM (typical)	OD > 5	not tested	<ul style="list-style-type: none"> OD_{avg} > 5 close to passband OD_{avg} > 3 over extended range
LL	Semrock MaxLine® Laser Clean-up Filters	> 90% (typical)	1.2 - 4.0 nm FWHM (typical)	OD > 6	0.1 J/cm ² @ 532 nm, 10 ns	<ul style="list-style-type: none"> OD_{abs} > 6 close to passband OD_{abs} > 5 over extended range
LPEB	Semrock EdgeBasic™ Long Pass Edge Filters	> 90% (average)	290 - 540 nm (depending on laser)	OD > 6	not tested	<ul style="list-style-type: none"> Transition width < 2.5% of λ_{long} Extended short-wavelength blocking
LPF	Long Wave Pass Filters	75 - 80 % (average)	λ_c to 2500 nm	OD \geq 3, x-ray to 85% of λ_c	1 W/cm ²	<ul style="list-style-type: none"> Cut-on wavelength tolerance is \pm 10 nm
LPRE	Semrock RazorEdge® Ultrasteep Long Pass Edge Filters	> 90% (average)	328 - 922 nm (depending on laser)	ODabs > 6 @ laser	0.5 J/cm ² @ 266 nm, 10 ns 1 J/cm ² @ 532 nm, 10 ns	<ul style="list-style-type: none"> Transition width < 0.5% of λ_{long} (E-grade) Transition width < 1.0% of λ_{long} (U-grade)
ND	Metallic Neutral Density Filters, N-BK7	0.01 - 79.43%	350 - 2000 nm	OD ~ 0.1 - 4.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve
NDS	Metallic Neutral Density Filter Sets	0.1 - 80%	350 - 2000 nm	OD 0.1 - 1.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve 10 ND filters in set, OD 0.1 - 1.0
NDQ	Metallic Neutral Density Filters, Fused Silica	0.01 - 79.43%	250 - 2000 nm	OD ~ 0.1 - 4.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve
NDQS	Metallic Neutral Density Filter Sets, Fused Silica	0.1 - 80%	250 - 2000 nm	OD 0.1 - 1.0	25 W/cm ²	<ul style="list-style-type: none"> Inconel® coating for flat spectral curve 10 ND filters in set, OD 0.1 - 1.0
NF	Semrock StopLine® Single Notch Filters	> 93% (average)	400 - 1600 nm (typical, excludes notch & transition)	OD > 6	1 J/cm ² , 10 ns, 20 Hz @ 532 nm	<ul style="list-style-type: none"> Notch width is 17 nm FWHM @ 532 nm Extended >80% average transmission to ~ 350 nm
PBP	Semrock Polarization Bandpass Filters, 45°	> 95% (absolute, p-polarization)	10 - 43 nm for p-polarization	1,000,000:1 contrast ratio	1 J/cm ² , 10 ns, 20 Hz @ 532 nm	<ul style="list-style-type: none"> Transmits p-polarization, reflects s-polarization at 45° AOI
SPF	Short Wave Pass Filters	75 - 80 % (average)	415 nm to λ_c (typical)	OD \geq 3, 120% of λ_c to 1200 nm	1 W/cm ²	<ul style="list-style-type: none"> Cut-off wavelength tolerance is \pm 10 nm
UVDA	High Energy Dielectric UV Attenuators	0.003 - 80%	Single wavelength, 248 - 355 nm	OD ~ 0.1 - 2.5	2 J/cm ² , 20 ns, 20 Hz @ 355 nm	<ul style="list-style-type: none"> TWE < $\lambda/4$ @ 633 nm over 6 mm CA Fused silica substrate