

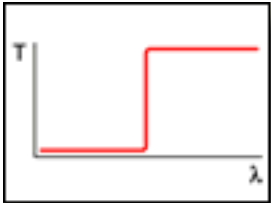
Optical Filters

Filters for Raman & Laser Applications

Turan Erdogan, PhD (CTO and Co-founder)
Semrock, A Unit of IDEX Corporation

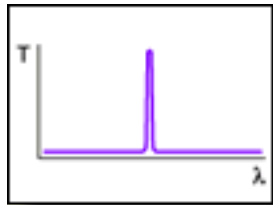
May 31, 2011

Semrock makes a variety of optical filter types



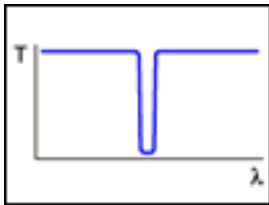
Steep Edge Filters

RazorEdge® & EdgeBasic™



Laser Clean-up Filters

MaxLine® & MaxDiode™



Deep Notch and Multi-notch Filters

StopLine®



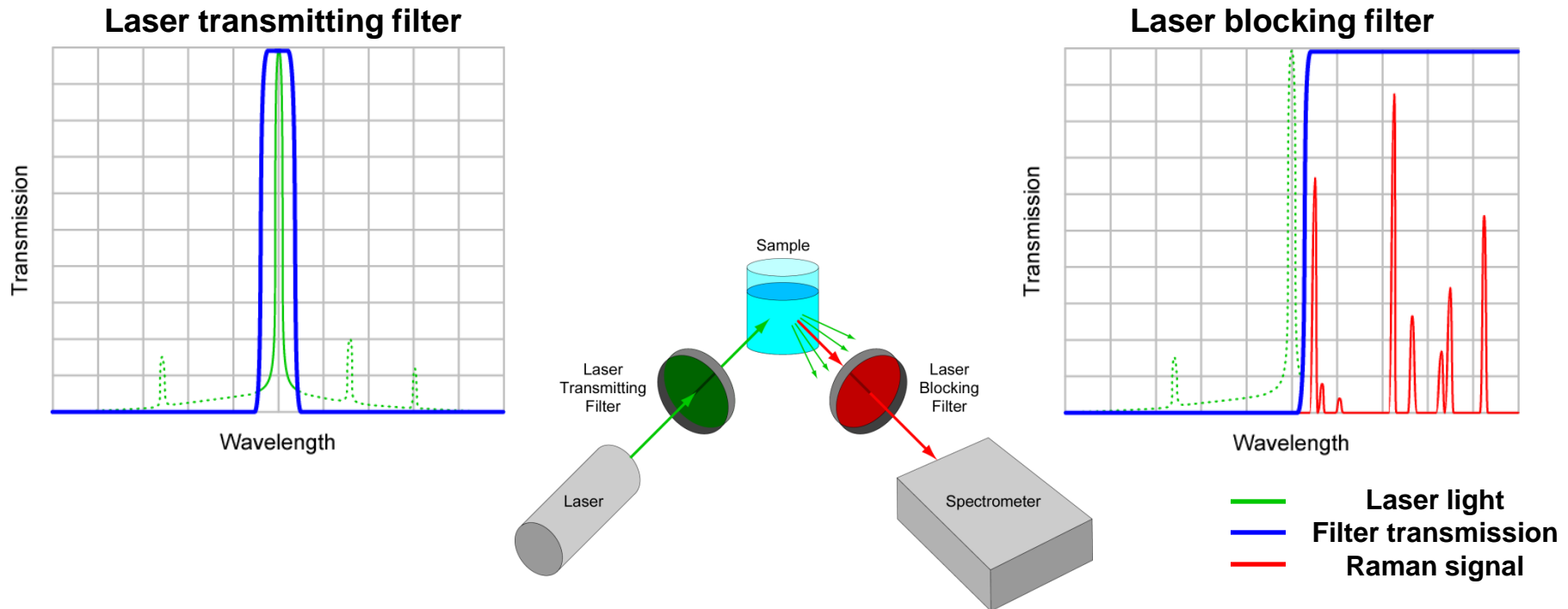
Ultrabroadband Mirrors

MaxMirror®



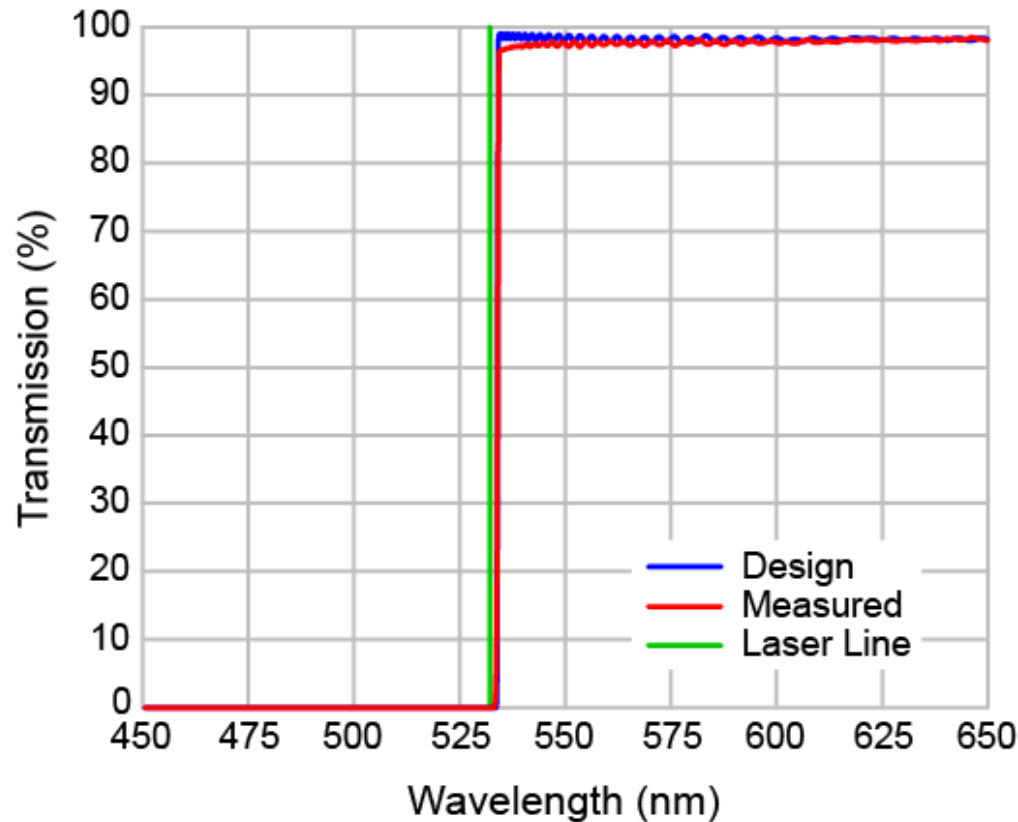
Raman spectroscopy

- The Raman “finger print” is measured by a spectrometer, but high-performance filters are needed to stop undesired source light from reaching the sample, and to prevent scattered laser light from overwhelming the measurement system



RazorEdge[®] long-wave-pass filters*

Typical 532 nm RazorEdge filter

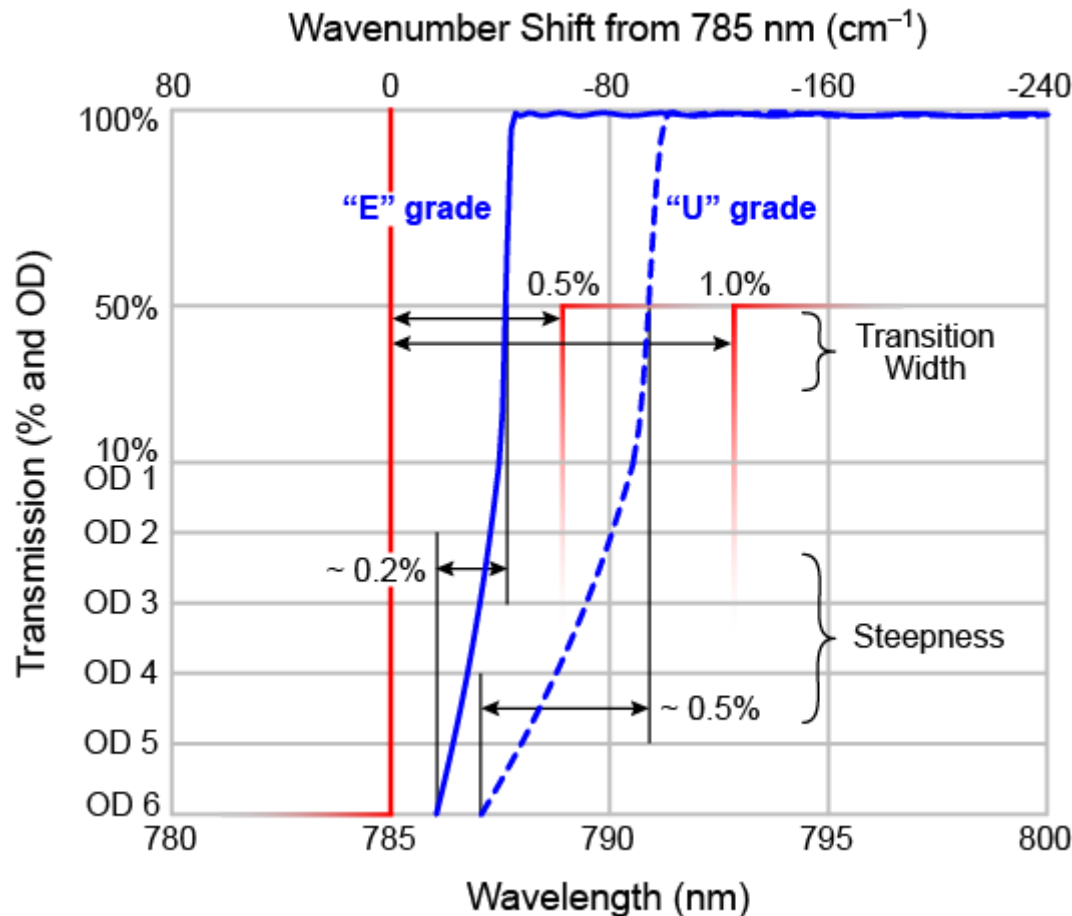


- Steepest edges
- OD 6 laser-line blocking
- Highest transmission
- High laser damage threshold (1 J/cm²)
- Low temp dependence (< 5 ppm / °C)

* U.S. patent 7,068,430

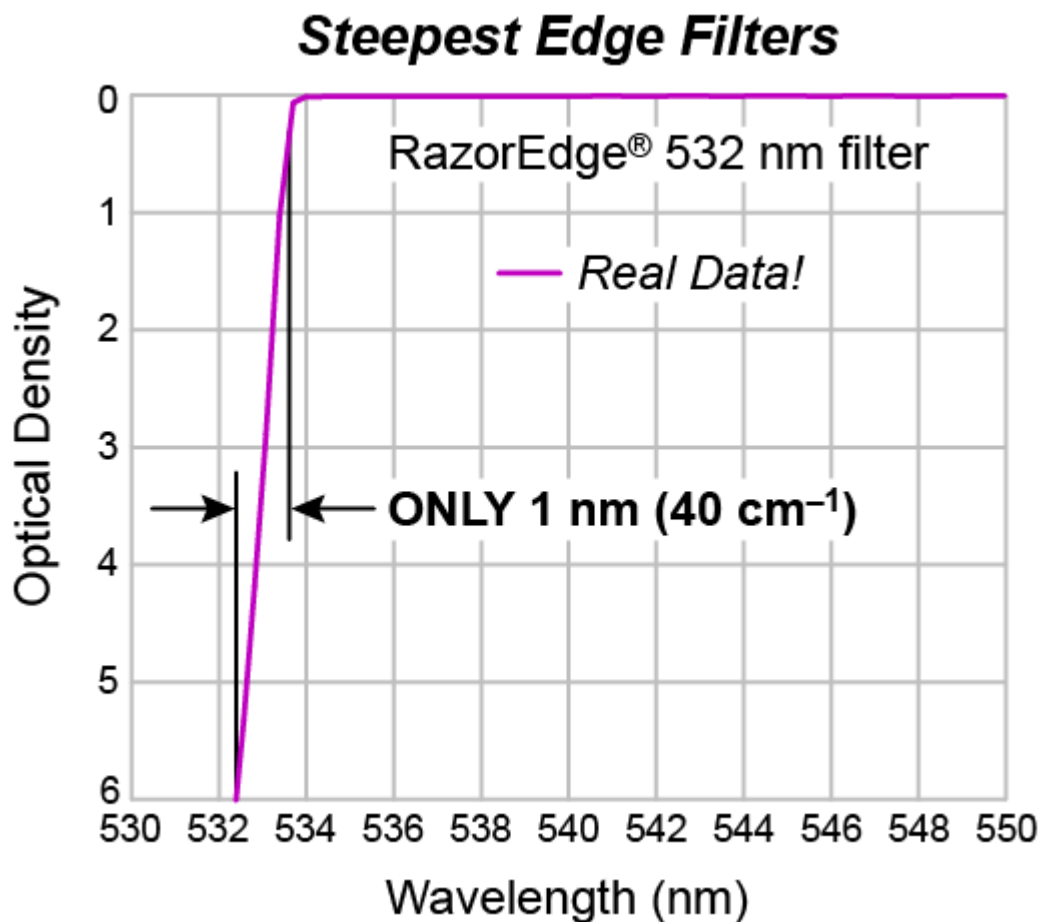
RazorEdge® “E-grade” Raman LWP filters

- Ultra-steep (2x steeper than current U-grade filters), since “closeness to laser line” is a critical Raman system specification

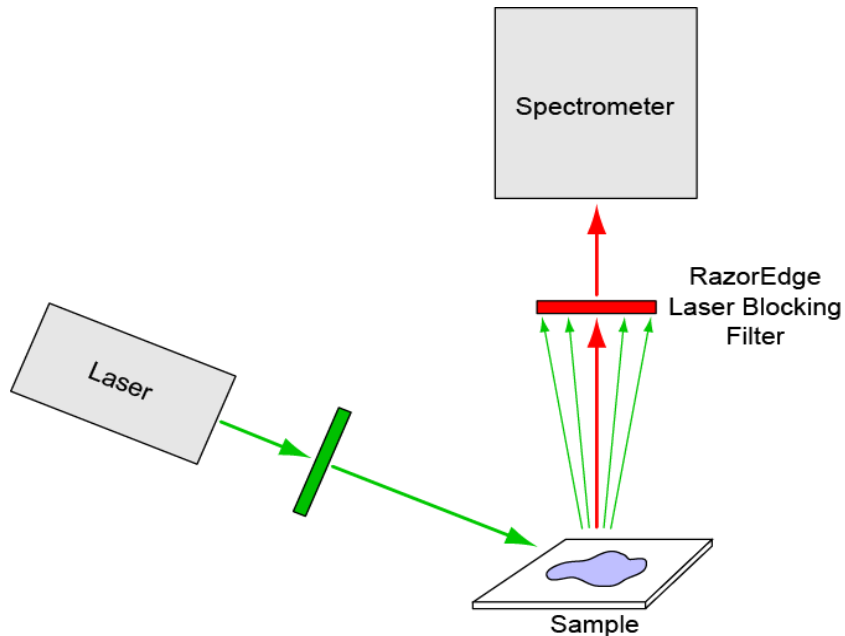


RazorEdge® “E-grade” Raman LWP filters

- Initially offer only the most popular wavelengths (532, 785, 633, 514, and 488 nm)

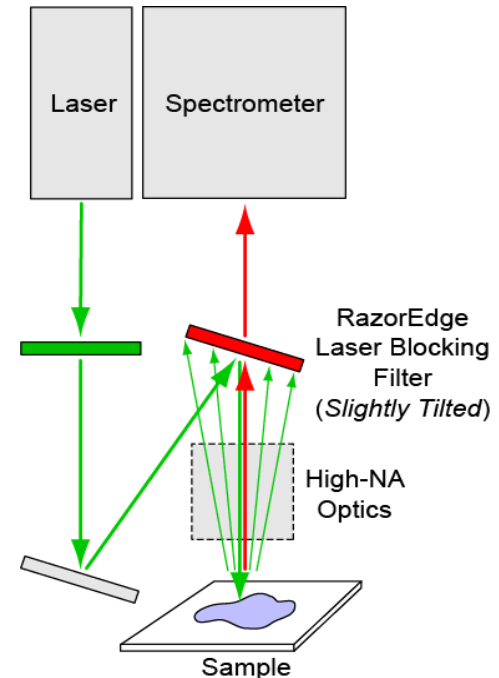


Common Raman system configurations



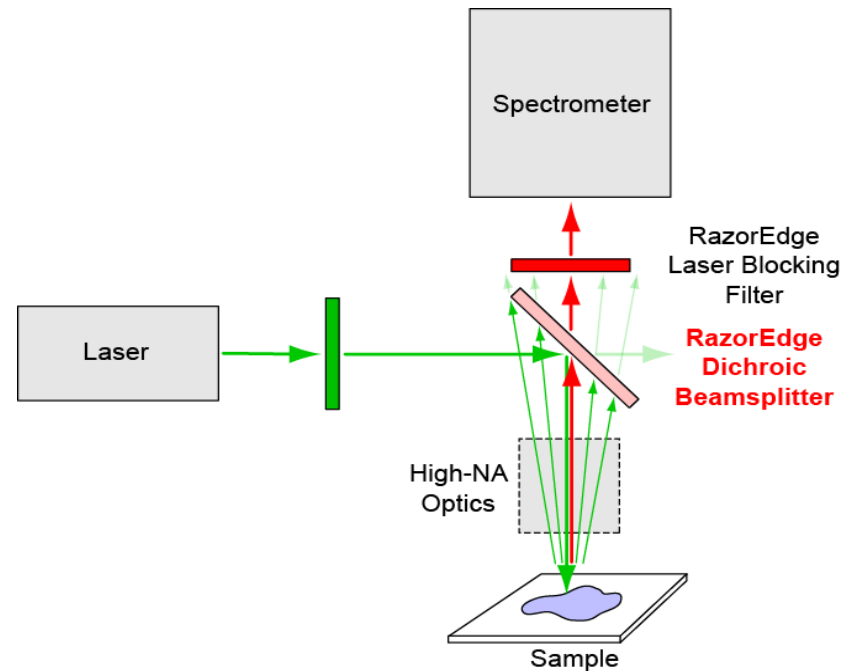
Normal-incidence RazorEdge Raman filter

blocks the scattered laser light and passes the Raman signal as close to the laser wavelength as possible (very steep spectral edge is advantageous).



When the laser and Raman light share a common path (e.g., with high-NA collection lenses) a **slightly tilted RazorEdge filter** can be used. *But the resulting system layout is awkward.*

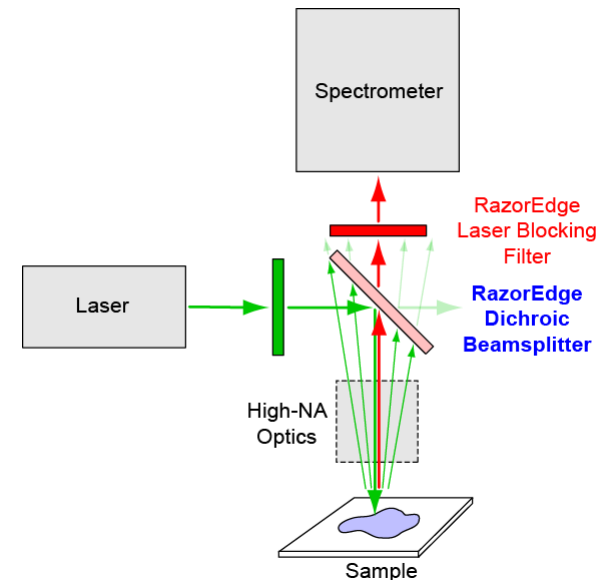
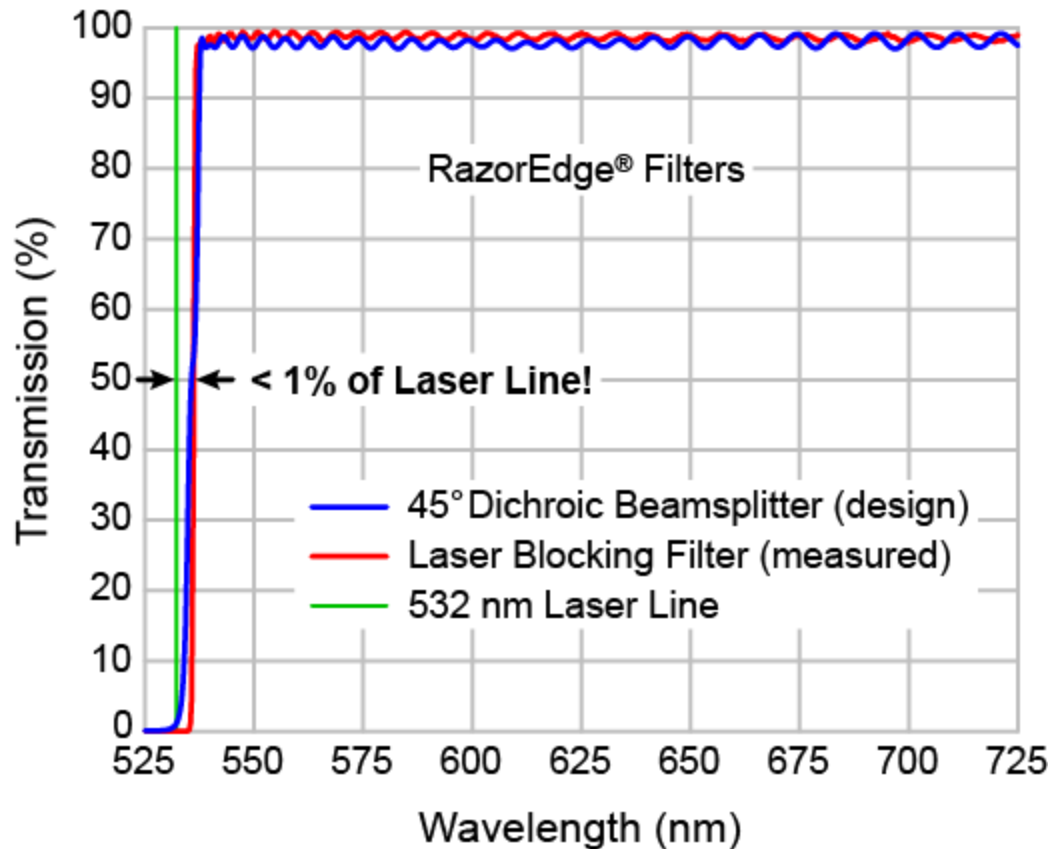
Raman configurations – 45° dichroic beamsplitter



- Compact geometry with uncompromised RazorEdge performance is now possible: ***novel 45° dichroic beamsplitter*** is matched to the ultrasteep laser-blocking filter
- Only Semrock has the advanced technology to enable this high performance RazorEdge dichroic beamsplitter!

RazorEdge Dichroic™ ultrasteep 45° beamsplitter

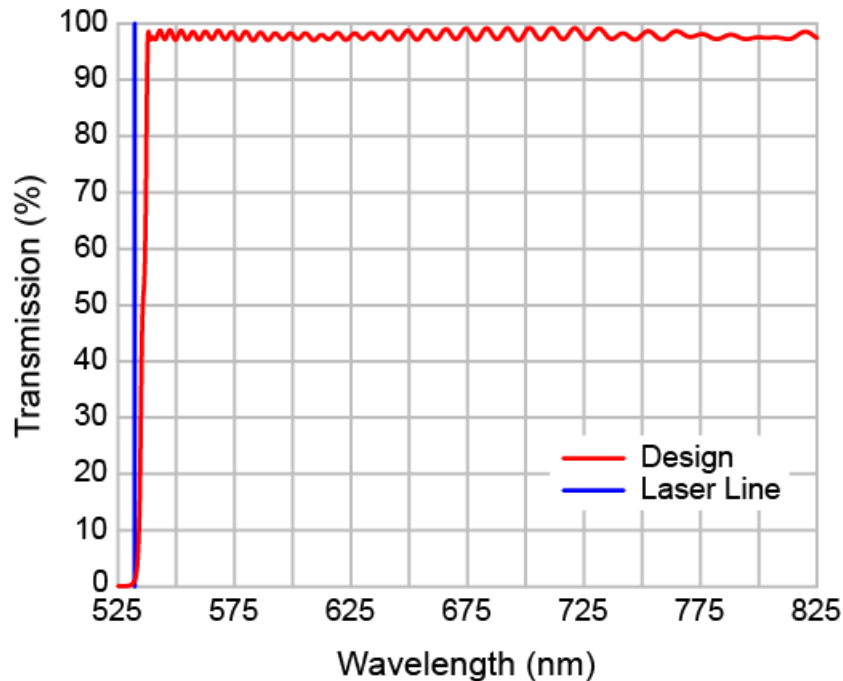
- Ultrasteep dichroic edge transition (< 1% of the laser wavelength) is uniquely matched to our normal-incidence RazorEdge blocking filter!



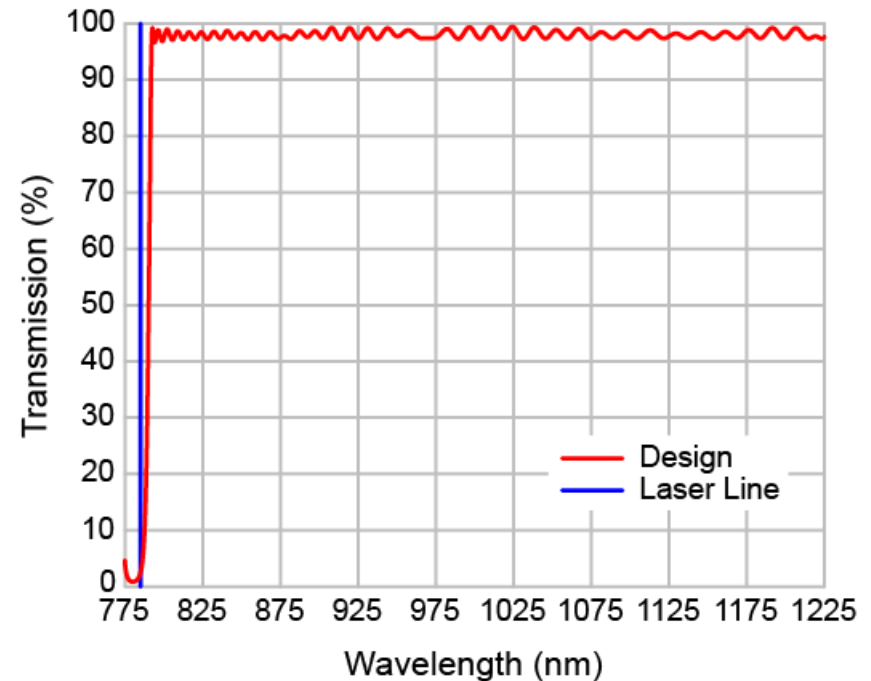
RazorEdge Dichroic™ ultrasteep 45° beamsplitter

- Excellent transmission over a very wide wavelength range
- Extreme edge steepness!

532 nm Laser

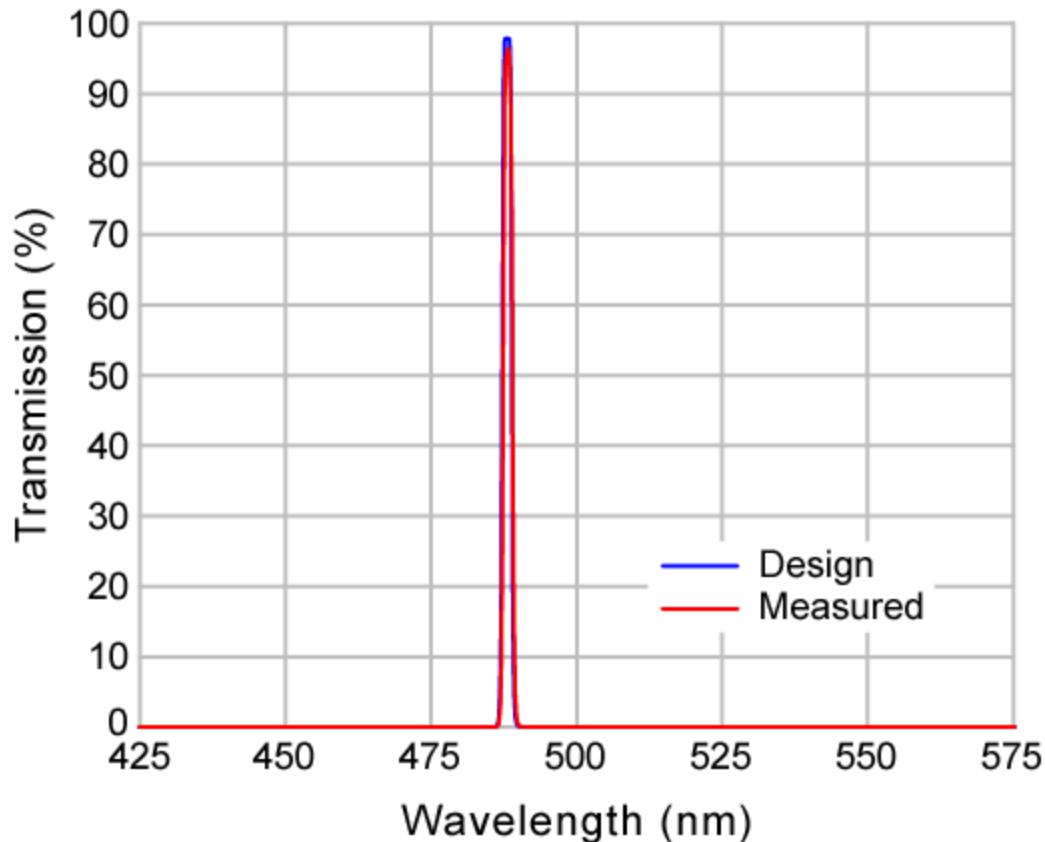


785 nm Laser



MaxLine[®] narrowband laser-line filters*

Typical 488 nm MaxLine laser-line filter

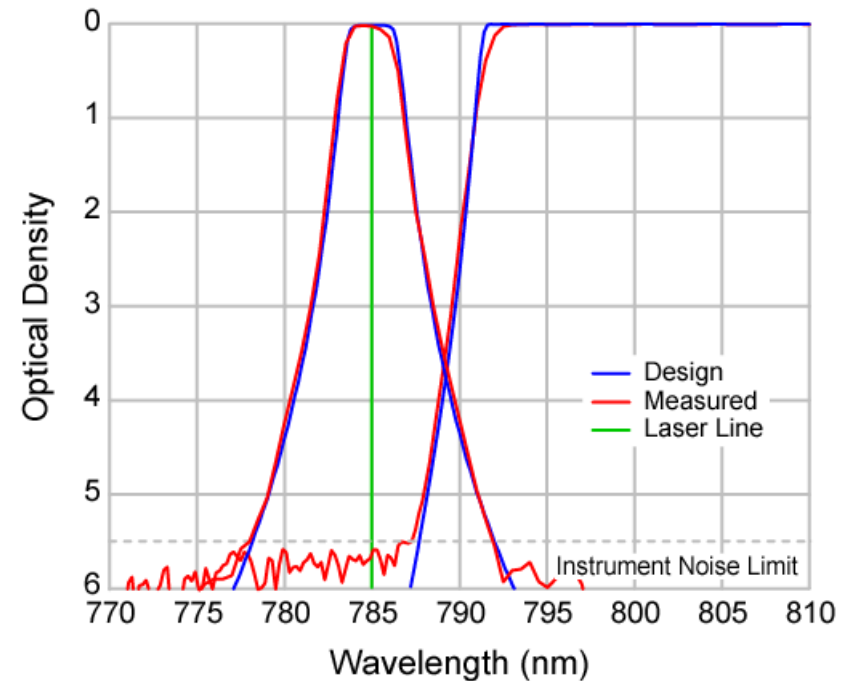
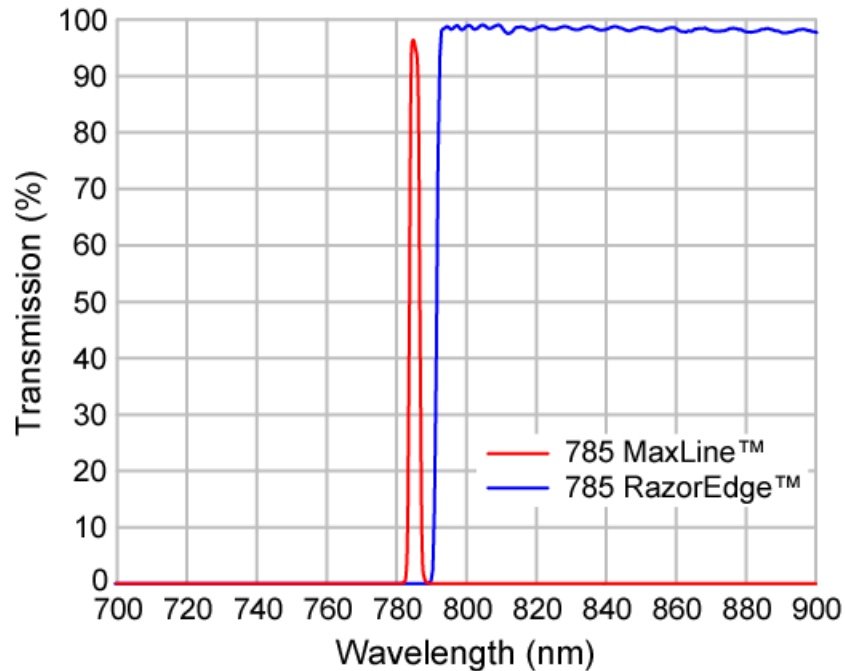


* U.S. patent 7,119,960



- Highest laser-line transmission
- Ultrafast roll-off (give your laser > 50 dB side mode suppression!)
- Hard dielectric coatings for proven reliability
- Low temp dependence (< 5 ppm / °C)

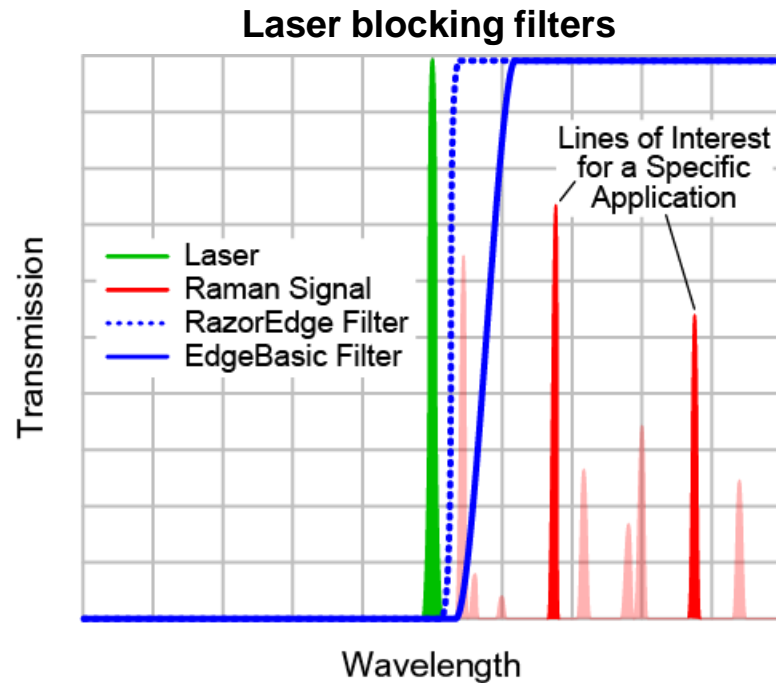
MaxLine & RazorEdge – perfect together!



Note the perfectly dovetailed spectra – *this is real data!*

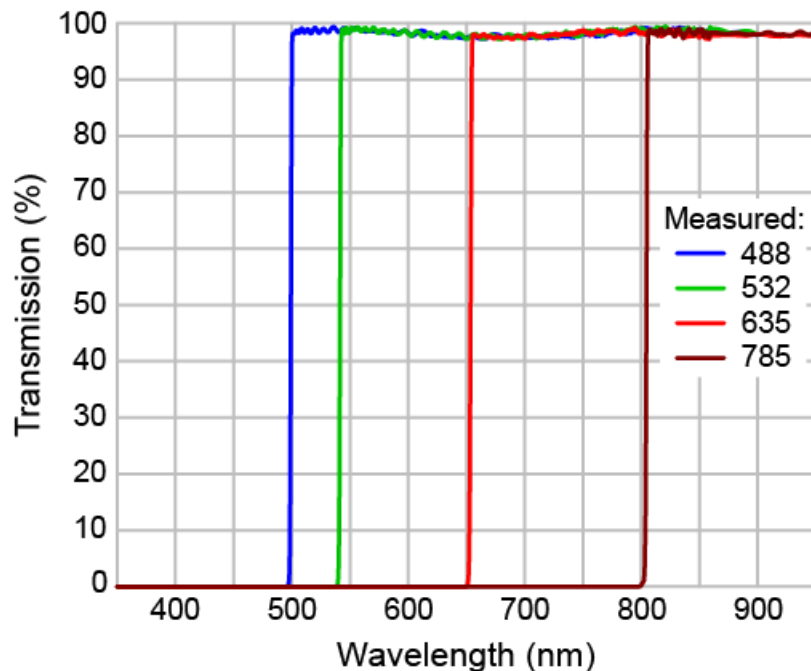
“Application-specific” Raman system

- Many (especially high-volume) Raman systems are designed to be used for a specific application in which only one or several Raman lines are important
- High blocking of the laser and high transmission of the Raman signal are still critical, but edge steepness is not as important
- Cost is also critical!



EdgeBasic™ “best-value” edge filters

- EdgeBasic long-wave-pass edge filters are value-priced, hard-coated optical filters for Raman spectroscopy **and** for fluorescence imaging and measurements – another push into the “middle market”
- Ideal for specific, cost-sensitive Raman applications that do not require measuring the smallest possible Raman shifts, but still demand high laser-line blocking and high transmission over a range of Raman lines



Initial offerings include:

488 nm (486 – 491)

532 nm

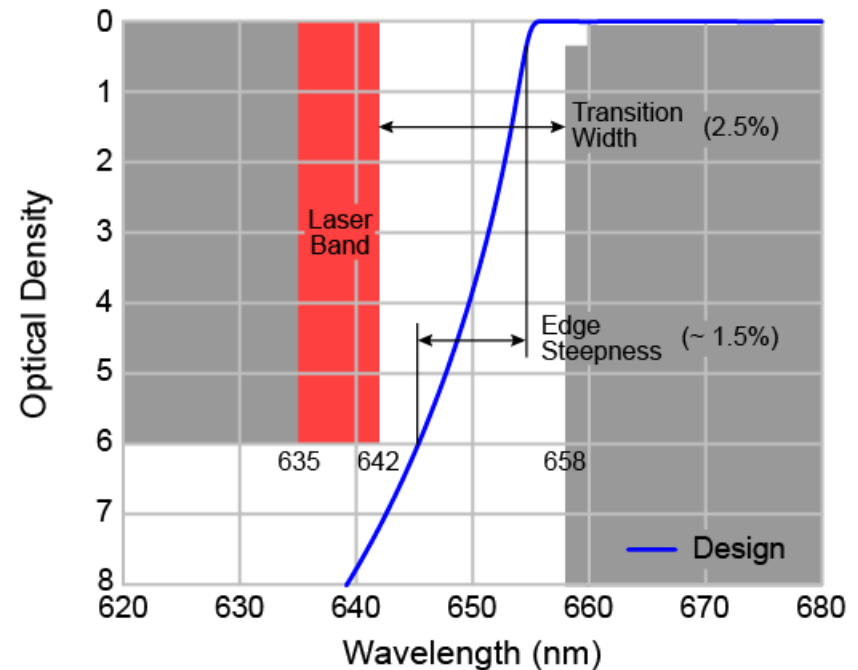
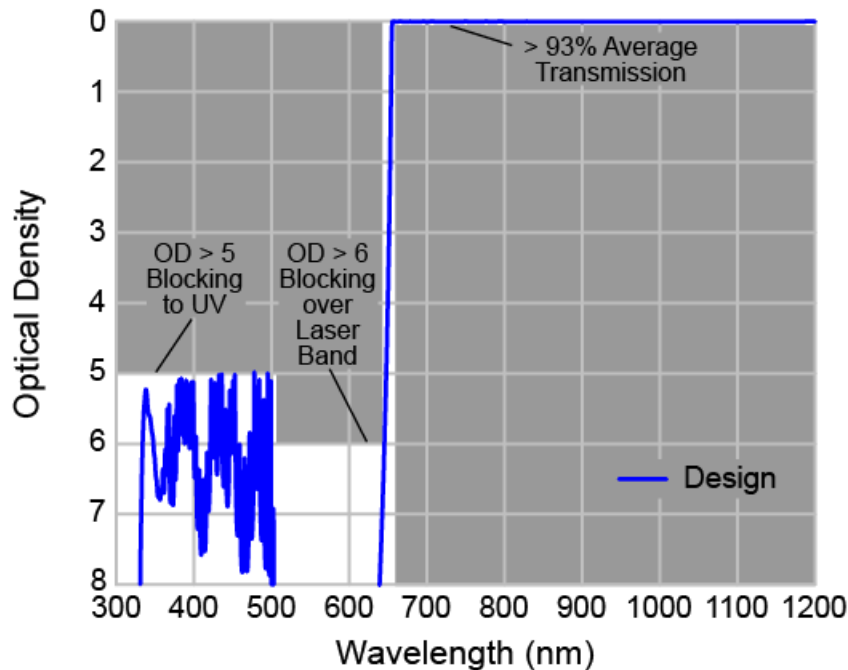
635 nm (633 – 642)

785 nm (780 – 790)



EdgeBasic™ “best-value” edge filters – specs

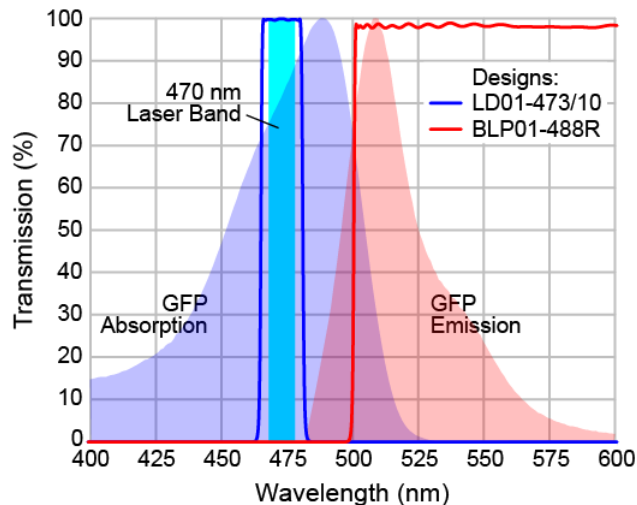
- Deep laser-line blocking – for maximum laser rejection (OD > 6)
- Extended wavelength blocking – to eliminate light to the UV
 - Short wavelength blocking important for fluorescence imaging
- High signal transmission – to detect the weakest signals (> 93% average)
- Hard-coating reliability and durability – for lasting performance



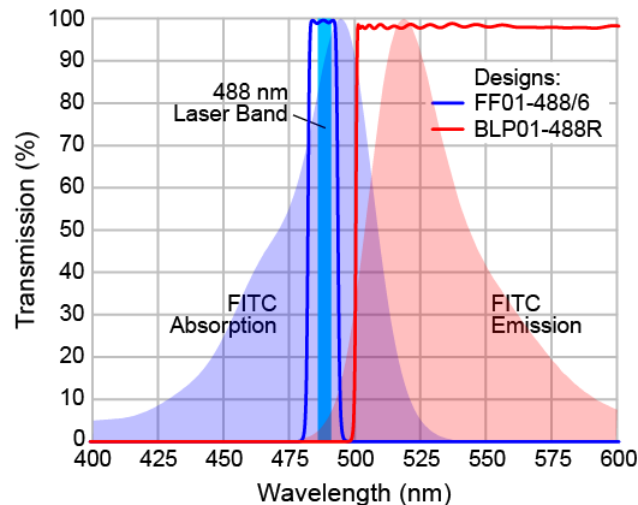
EdgeBasic™ filters – also for fluorescence!

- EdgeBasic filters are also ideal for laser-based fluorescence microscopes and instruments
- Edges are specified relative to the longest wavelengths of the bands of the most popular lasers for low-cost Raman and for fluorescence (e.g., 492 nm for “488” lasers, 642 nm for “635” lasers, etc.)

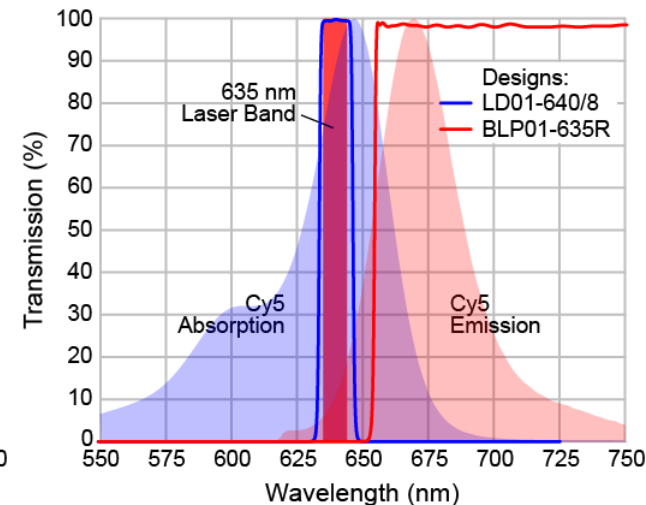
GFP (w/ “470” laser)



FITC (w/ “488” laser)



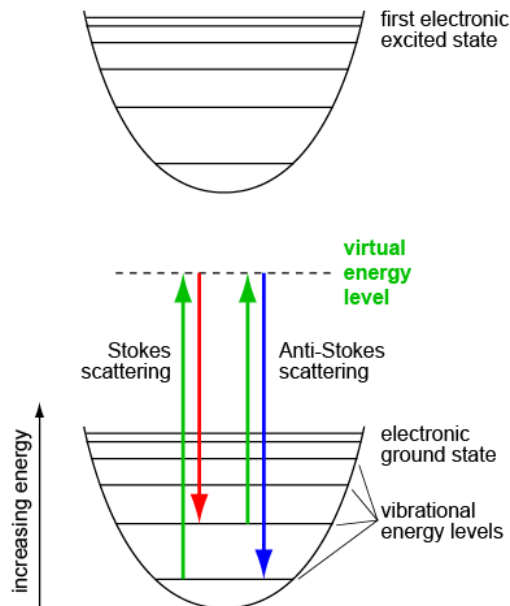
Cy5 (w/ “635” laser)



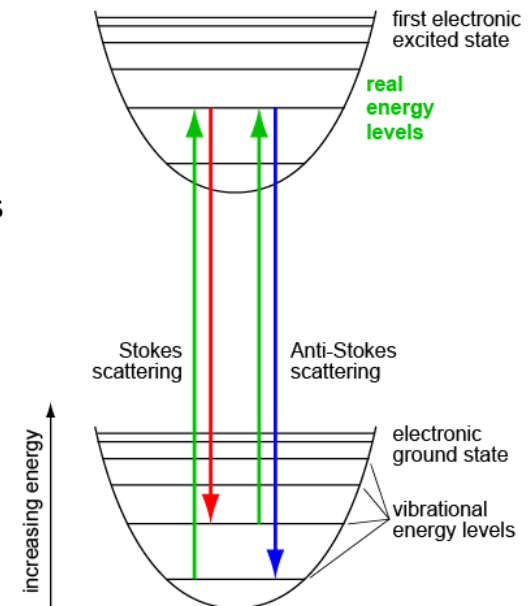
UV filters for Raman spectroscopy

- *Why do Raman in the UV?* **Resonance enhancement of an otherwise very weak signal:** visible and near-IR lasers have photon energies below the first electronic transitions of most molecules; however, when the photon energy of the laser lies within the electronic spectrum of a molecule, as is the case for UV lasers and most molecules, the intensity of Raman-active vibrations can increase by many orders of magnitude – this effect is called “resonance-enhanced Raman scattering”

Standard Raman Scattering: for visible and near-IR lasers and most molecules

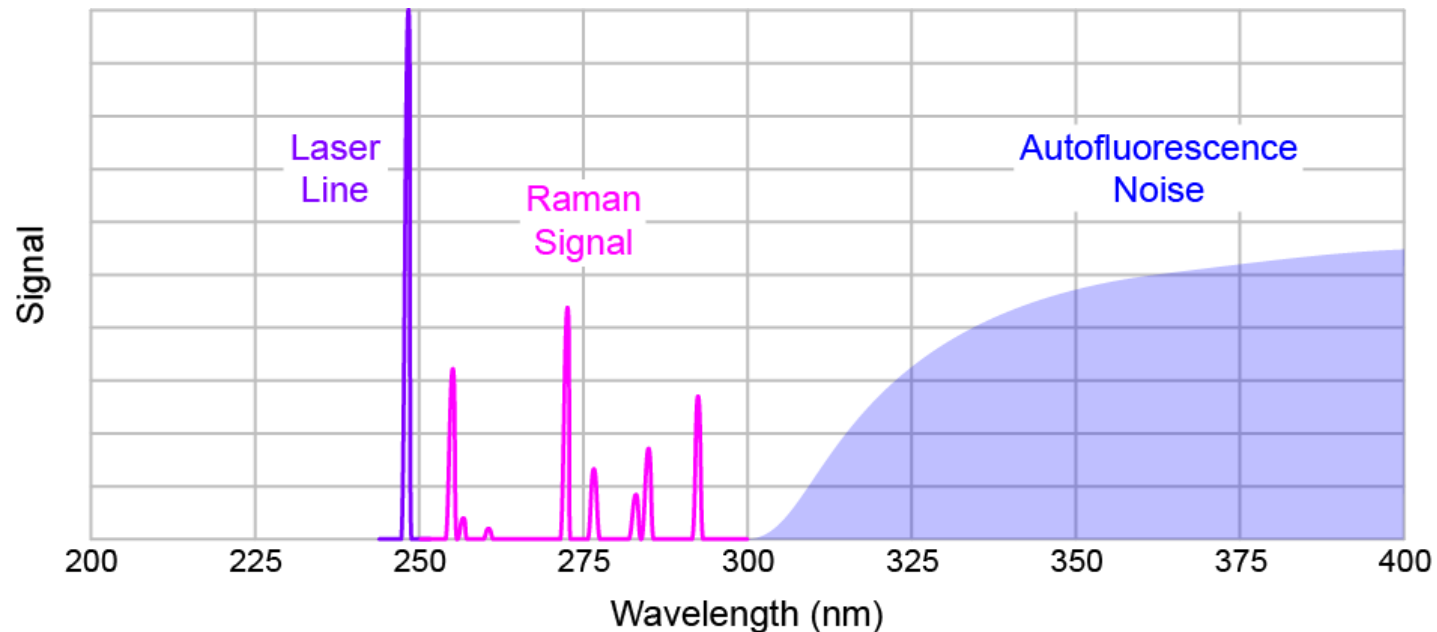


Resonance-enhanced Raman Scattering: for UV lasers and most molecules



UV filters for Raman spectroscopy

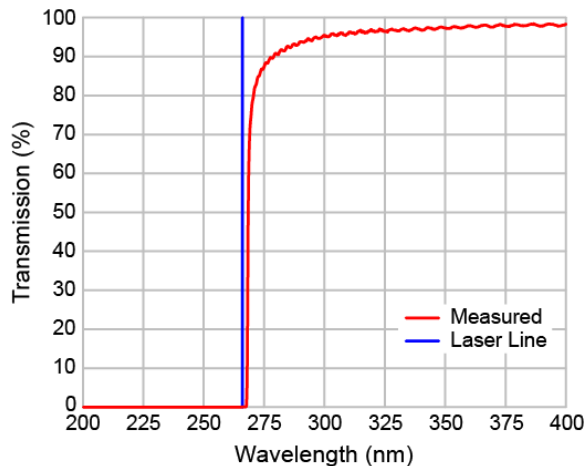
- *Why do Raman in the UV?* **Elimination of autofluorescence noise:** although UV lasers excite strong autofluorescence, it typically occurs only at wavelengths above about 300 nm, independent of the UV laser wavelength; since Raman emission remains below 300 nm even for a 4000 cm^{-1} (very large) Stokes shift when excited by a common 266 nm laser, autofluorescence simply does not interfere with the Raman signal making high signal-to-noise ratio measurements possible



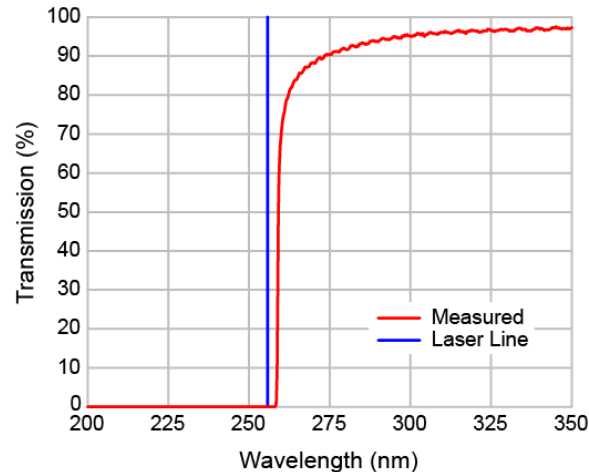
UV RazorEdge[®] laser blocking filters*

- Same ultrasteep edges (0.5%) and deep laser-line blocking (OD 6) of Semrock's renowned visible and near-IR RazorEdge filters
- Superb UV transmission for detecting the weakest Raman signals
- High laser damage threshold and proven reliability

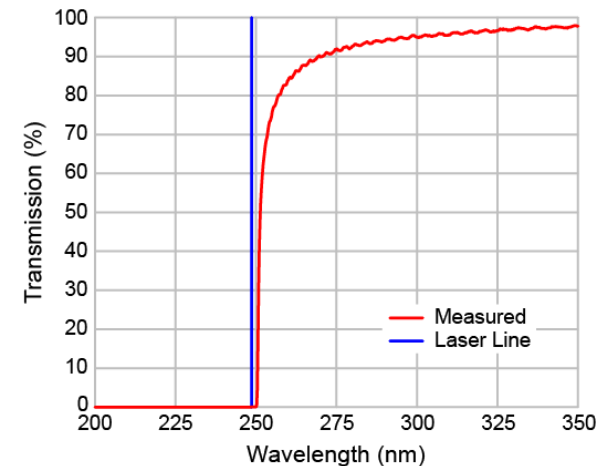
266.0 nm – ideal for
4th harmonic of Nd:YAG



257.3 nm – ideal for
2nd harmonic of Ar-ion



248.6 nm – ideal for
new compact NeCu lasers

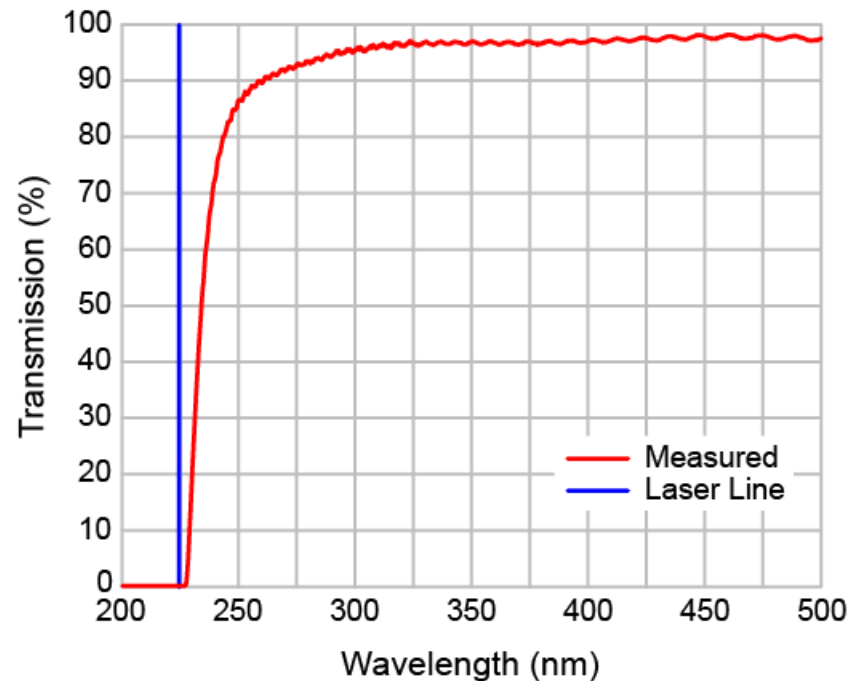


**Patent pending*

UV RazorEdge[®] laser blocking filters*

- Shortest wavelength filter: **224 nm** RazorEdge filter
- Still superb UV transmission for detecting the weakest Raman signals
- Still with high laser damage threshold and proven reliability

224.3 nm – ideal for new compact HeAg lasers

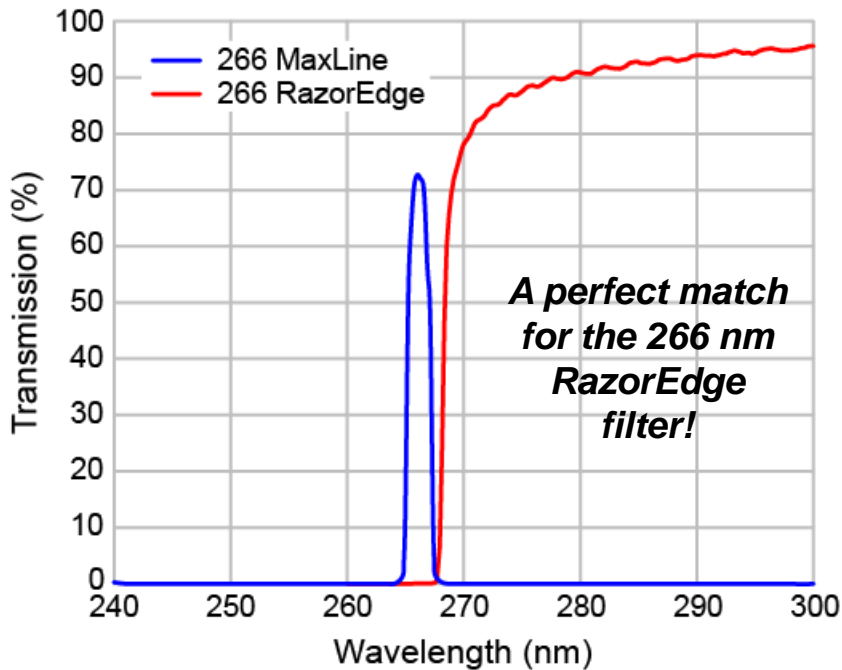


**Patent pending*

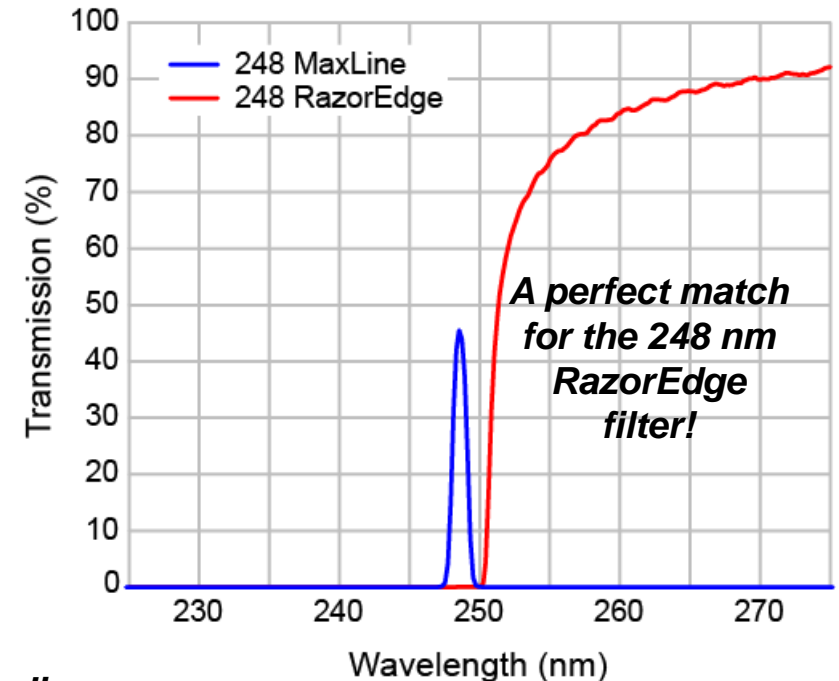
UV MaxLine[®] laser transmitting filter*

- Same rapid roll-off and deep blocking of Semrock's popular visible and near-IR MaxLine laser-line filters
- Excellent UV transmission: *don't waste expensive UV laser light*
- Proven MaxLine laser damage threshold and reliability

266 nm – ideal for 4th harmonic of Nd:YAG



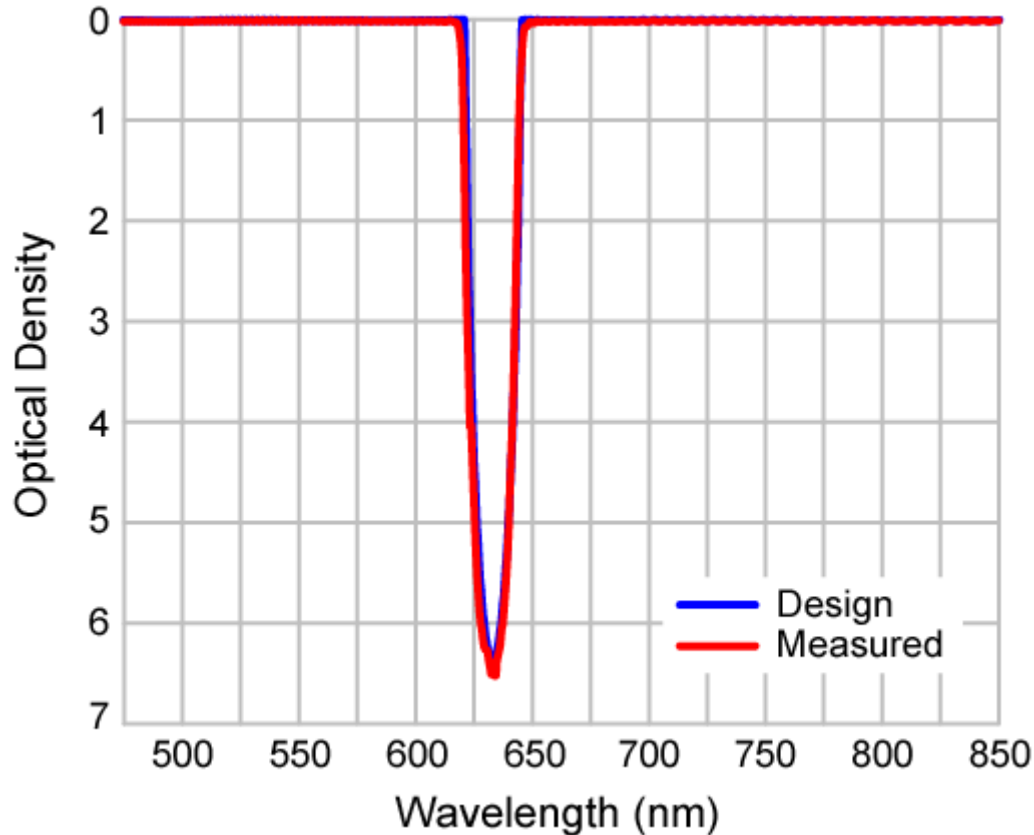
248.6 nm – ideal for new compact NeCu lasers



*Patent pending

StopLine[®] deep notch filters*

Typical 633 nm StopLine notch filter

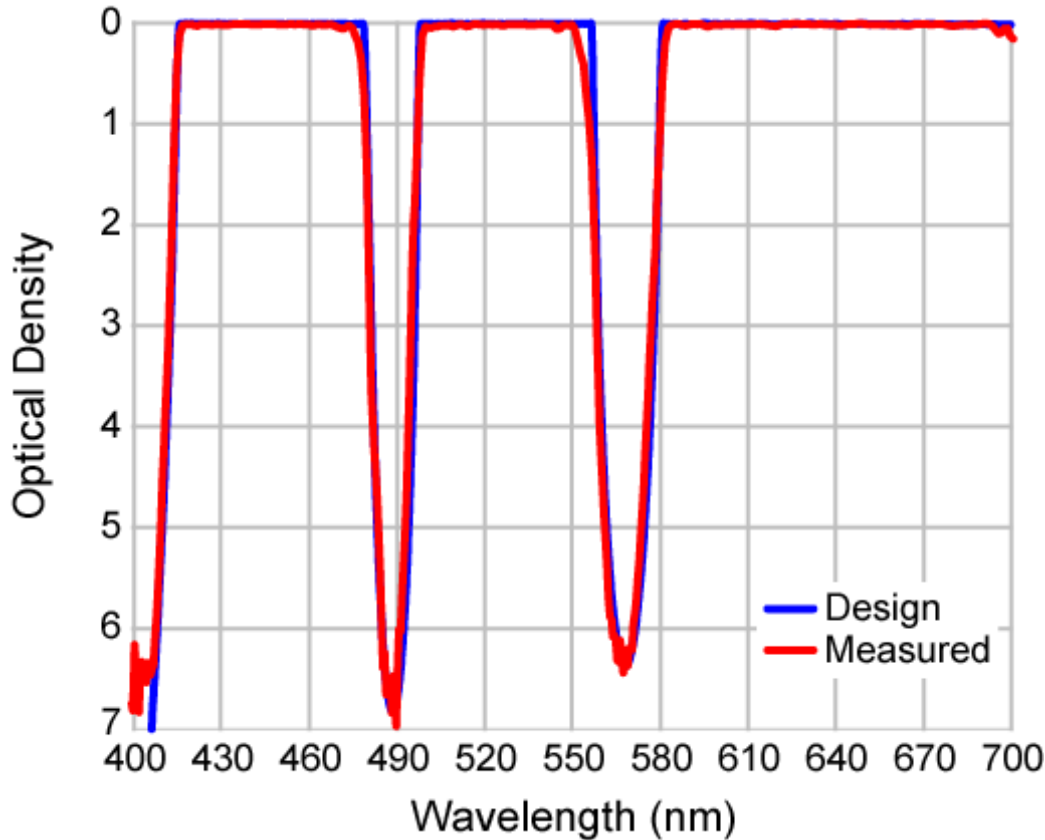


- OD 6 laser-line blocking
- Narrowest bandwidth thin-film notch filters
- Highest transmission
- High laser damage threshold (1 J/cm²)
- Low temp dependence (< 5 ppm / °C)

**U.S. patent 7,123,416*

StopLine[®] multi-notch filters*

405 / 488 / 561-568 nm triple-notch filter



- Deep blocking at multiple laser lines
- Single to quad-notch available
- Arbitrary notch wavelengths
- Popular for multi-laser fluorescence instruments

*U.S. patent 7,123,416

Notch filters with *ULTRAWIDE* passbands!

- E-grade StopLine notch filters* offer yet another Semrock breakthrough in optical filter technology...
 - All the advantages of Semrock's renowned StopLine® thin-film notch filters – including narrow notches **and** deep (OD > 6) laser line blocking

now combined with...

- **Ultrawide passbands that extend from the UV (< 350 nm) well into the near-IR (> 1600 nm)**



Five Year Warranty

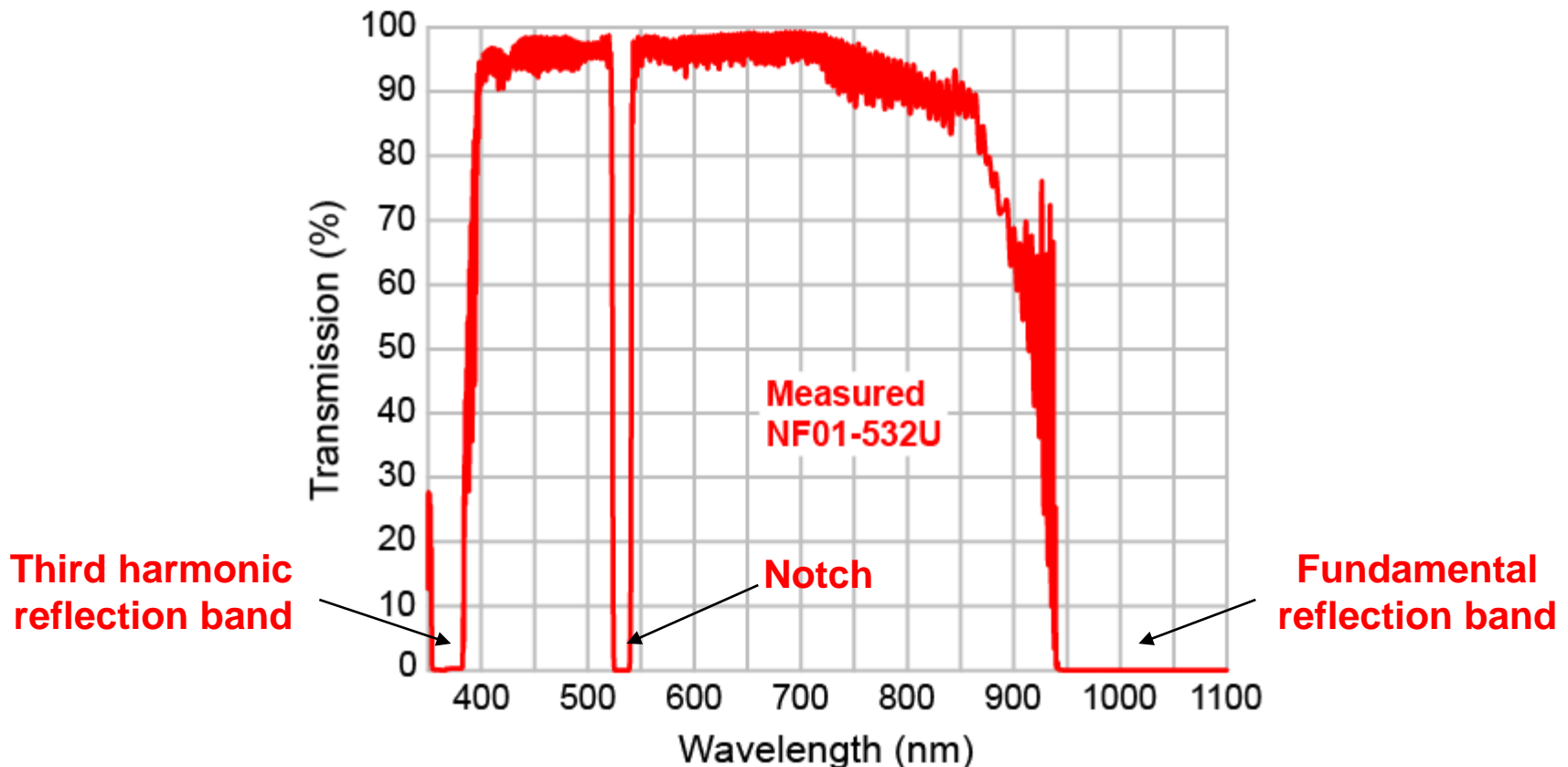
* Patent pending

Thin-film notch filters – advantages

- Notch filters are ideal for applications that require nearly complete rejection of a laser line while passing as much non-laser light as possible
- Hard-coated thin-film notch filters are the superior solution for
 - Highest transmission ($> 93\%$)
 - Deep laser line blocking ($OD > 6$)
 - Narrow notch bandwidths ($\sim 3\%$ of the laser wavelength)
 - Environmental reliability (even in hot, humid, and corrosive environments)
 - High laser damage thresholds ($> 1 \text{ J/cm}^2$)
 - Compact format and convenient back-reflection of the rejected laser light
- However, until now the main drawback of thin-film notch filters has been *limited passband range...*

Thin-film notch filters until now...

- Exhibit excellent spectral and physical properties, but with a limited passband range due to the fundamental reflection band and its higher harmonics

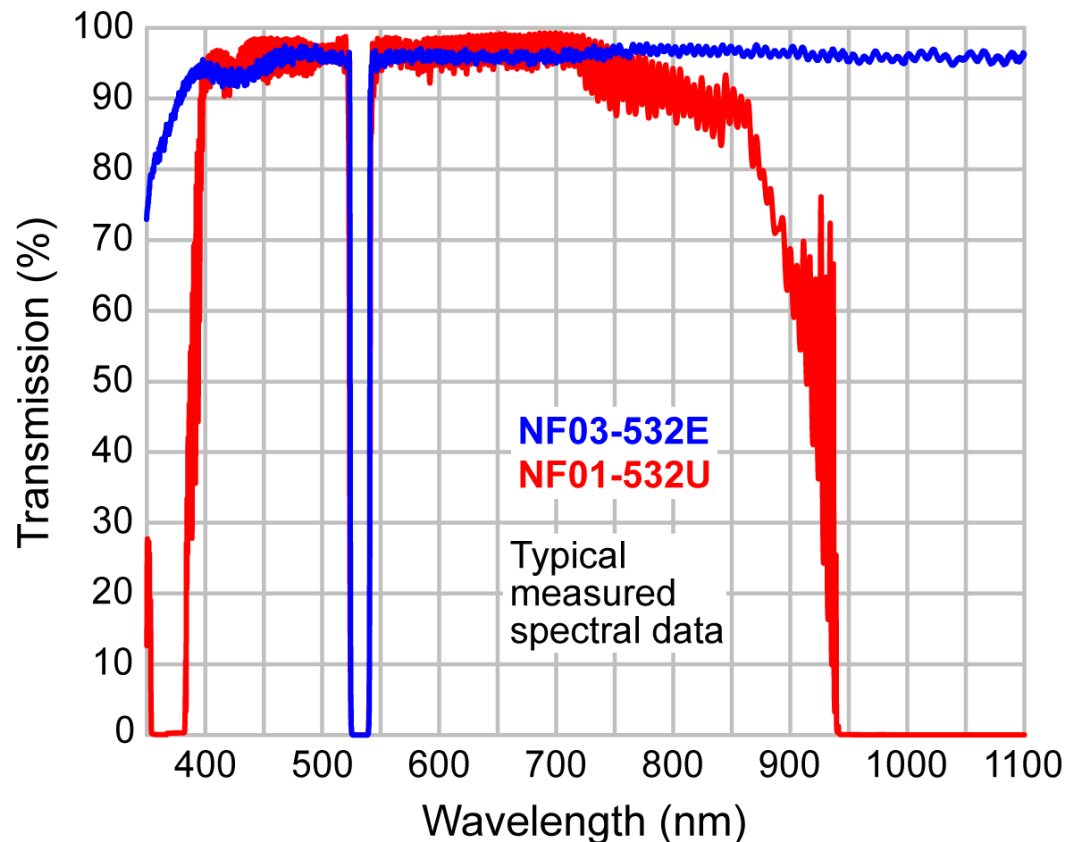


Thin-film notch filters – the superior solution

- To achieve a wider passband than thin-film notch filters could provide, optical engineers had to turn to “holographic notch filters” or “Rugate notch filters”
 - Unfortunately, **holographic notch filters** suffer from lower reliability and transmission (due to gelatin-based, laminated structure), higher cost (due to serial production process), and poorer system noise performance and/or higher system complexity (since rejected light is diffracted at an acute angle)
 - And, unfortunately, **Rugate notch filters** suffer from lower transmission, especially at shorter wavelengths, and less deep notches (due to limited materials and/or fabrication processes and complexity of the process)
- **Fortunately, now Semrock’s new “E-grade” StopLine® notch filters bring together all the advantages of hard-coated thin-film notch filters with the ultrawide passbands previously possible with only holographic and Rugate notch filters!**

New StopLine® “E-grade” notch filters

- The spectral performance of the notch is virtually identical to that of Semrock’s renowned “U-grade” StopLine filters, but the passband extends from < 350 nm to > 1600 nm!



532 nm
filter
example
shown

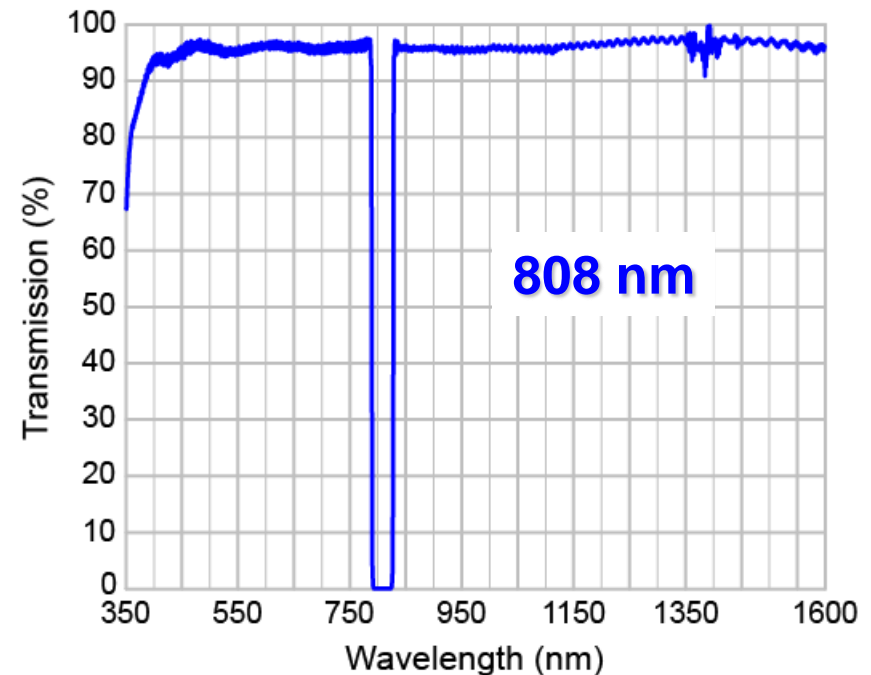
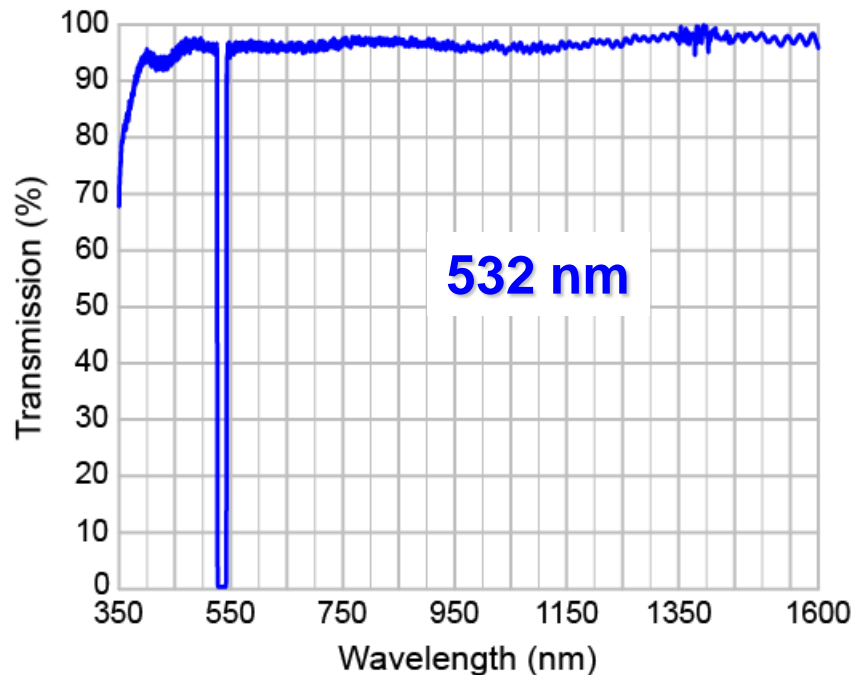
Typical
measured
data for
both filters

Applications for wide-passband notch filters

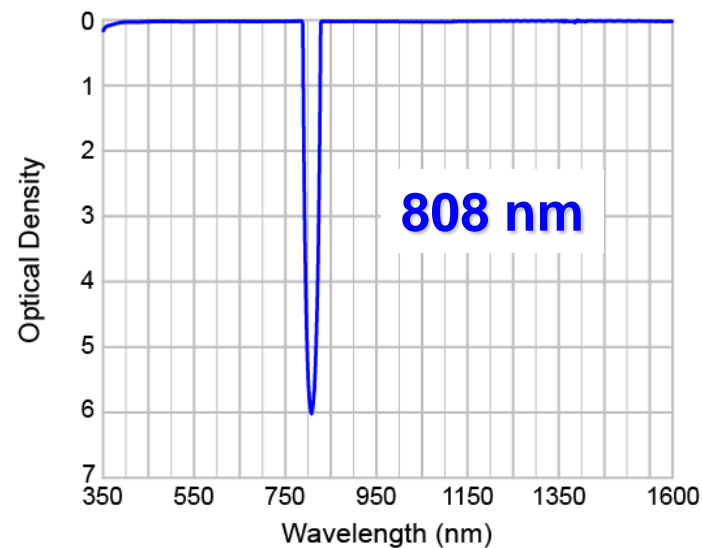
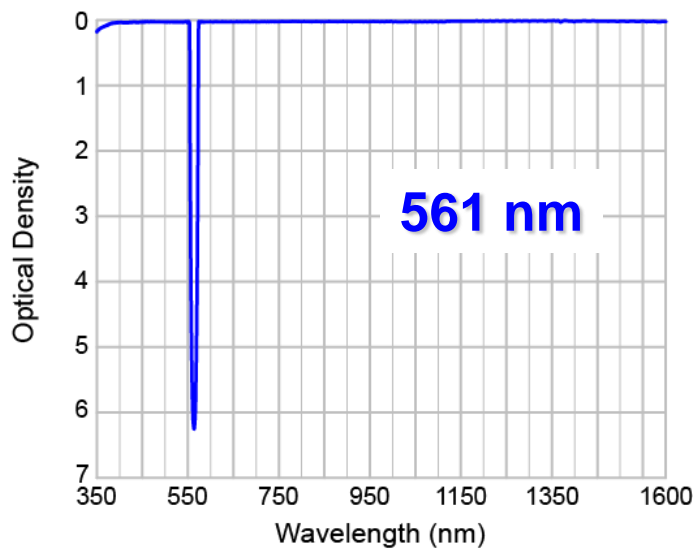
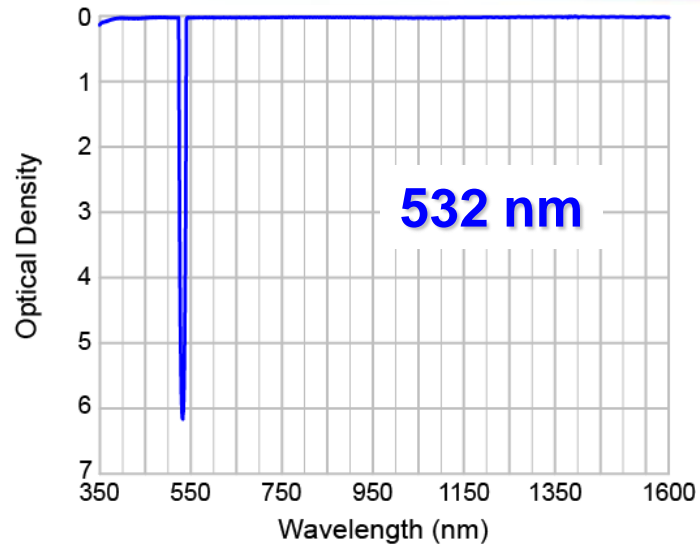
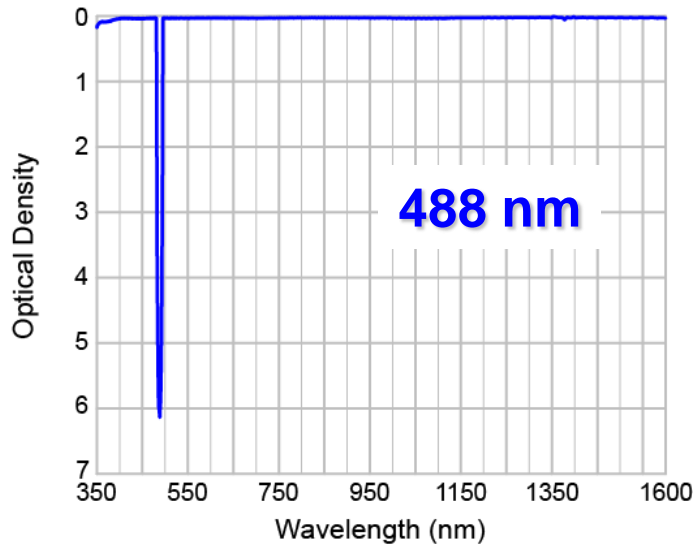
- Any application that requires high rejection of one or more laser line, while transmitting signal light over a wide range of wavelengths on either side of the laser wavelength
- Especially suited for systems that employ multiple excitation and associated detection wavelength ranges in different, widely separated regions of the optical spectrum (from the UV to the near-IR)
- Also ideal for systems that employ multiple detection modes simultaneously (including fluorescence, Raman spectroscopy, laser-induced breakdown spectroscopy, etc.)

Examples of typical notch filter spectra

- Examples of *measured* filter spectra are shown for 532 nm and 808 nm laser lines
- Ultrawide passbands from 350 to 1600 nm!

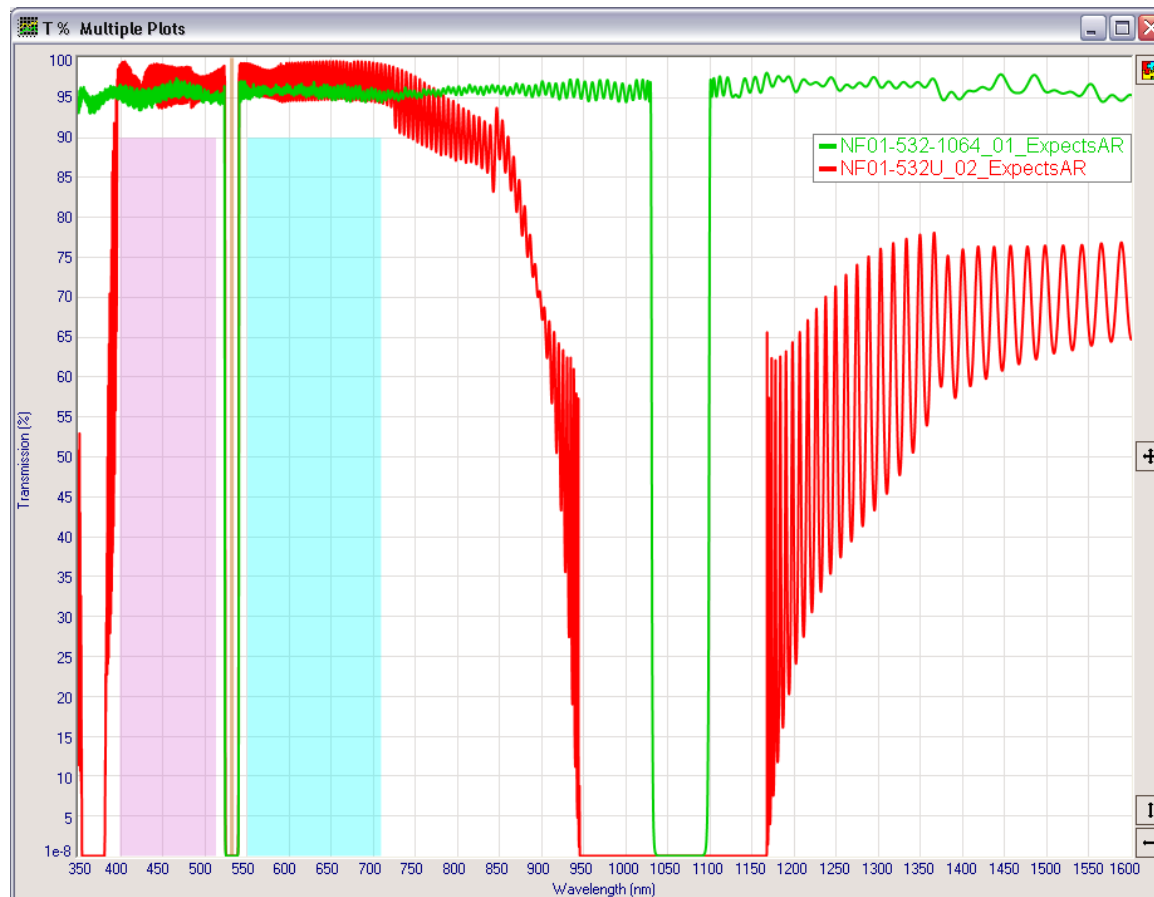


More examples – *measured* data, log scale



StopLine[®] 532/1064 dual notch filter

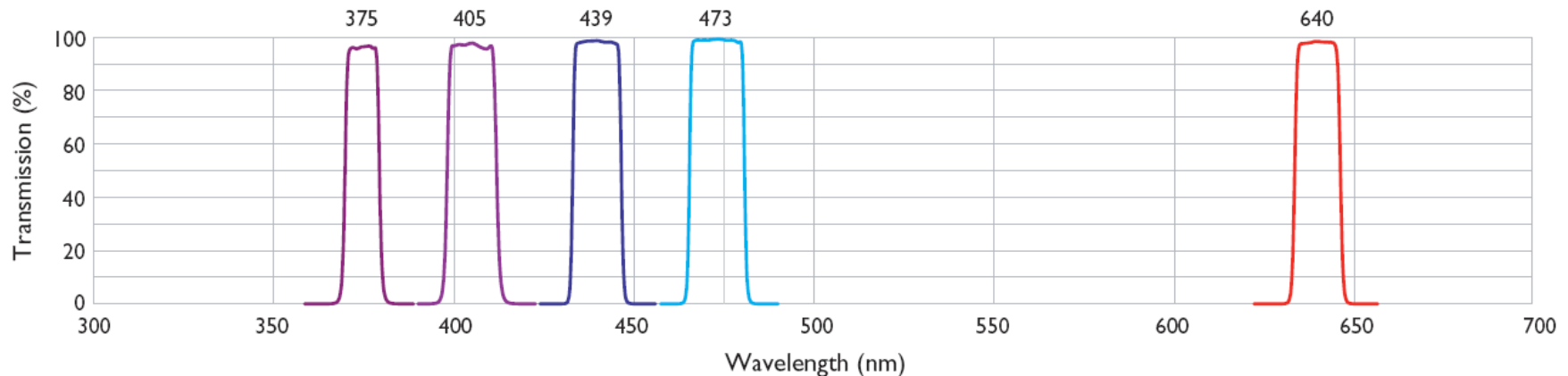
- The new wide-passband E-grade 532 single-notch doesn't have any blocking at 1064nm (like the old U-grade filter did) – so in addition we will offer wide-passband filter with notches at both 532 & 1064 nm



MaxDiode™ laser diode clean-up filters

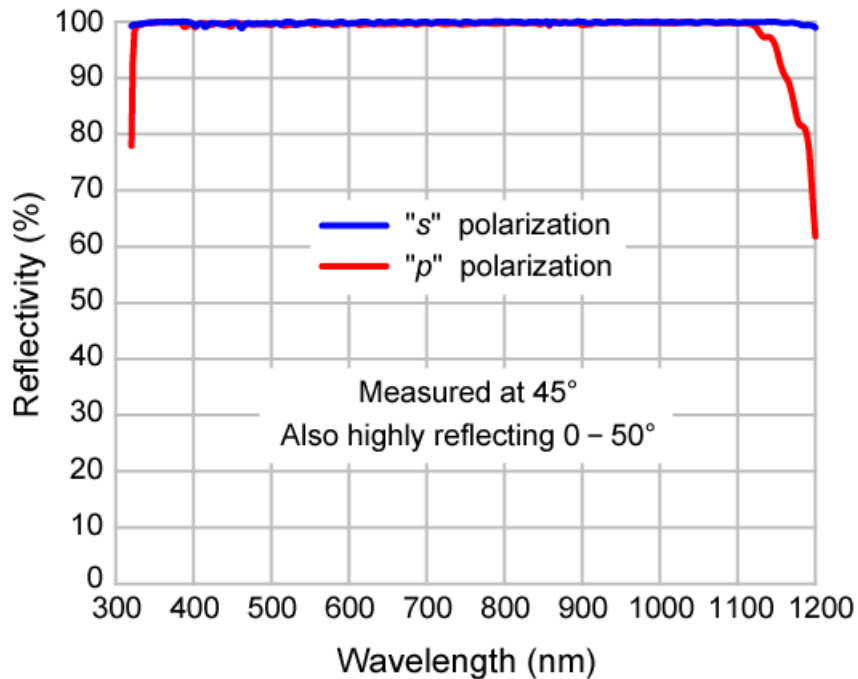
- **Square ultra-low-ripple passband** for total consistency as the diode laser ages, over temperature, or when replacing a laser
- **Highest transmission** exceeding 90%, over a carefully tailored range of each diode's possible laser wavelengths
- **Extremely steep edges** transitioning to very high blocking to filter out the undesired out-of-band noise

Available for many popular diode laser wavelengths (*note this is typical measured data!*)



MaxMirror[®] – ultra-broadband laser mirror

To steer all those colors, only one mirror* does it all...



> 99% reflection for ...

- 350 – 1100 nm (*inclusive*)
- **All** polarization states
- 0° – 50° angle of incidence
- **> 1 J/cm²** laser damage threshold



*** US Patent 6,894,838**

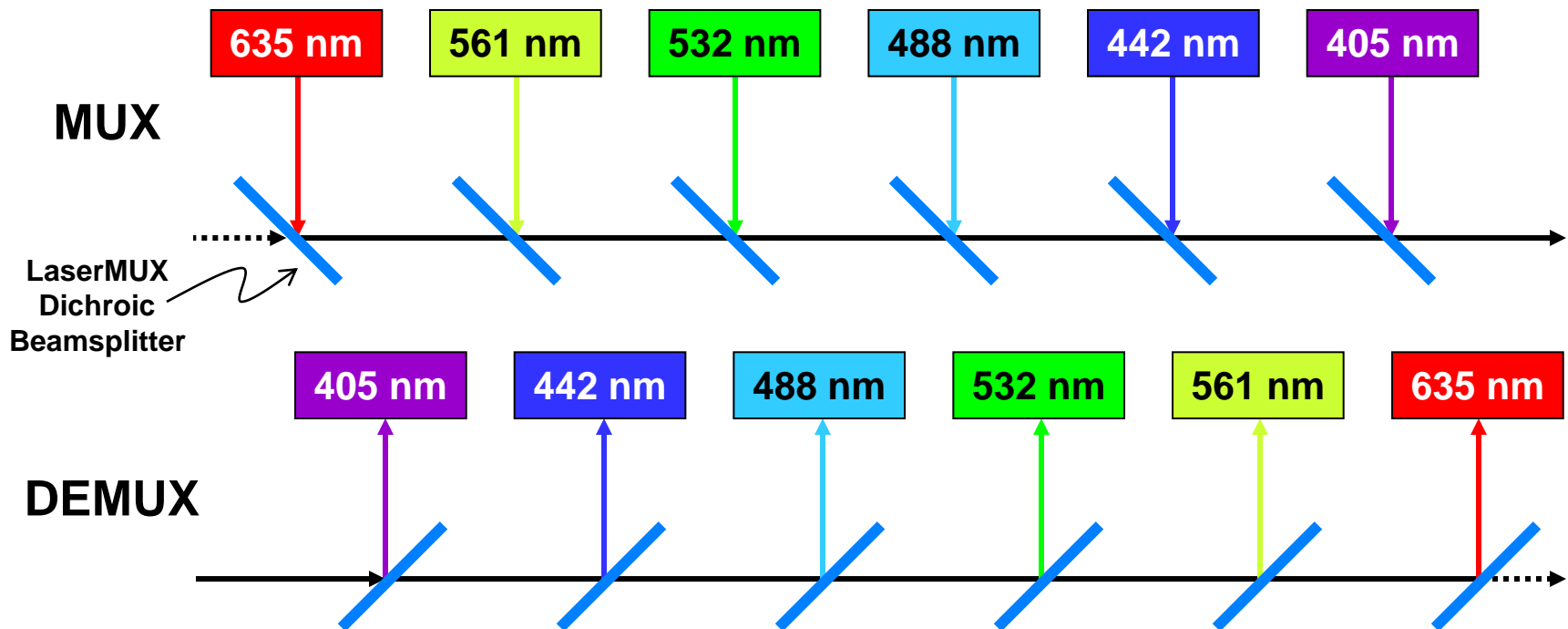
LaserMUX™

Laser Combiner/Beamsplitter Filters



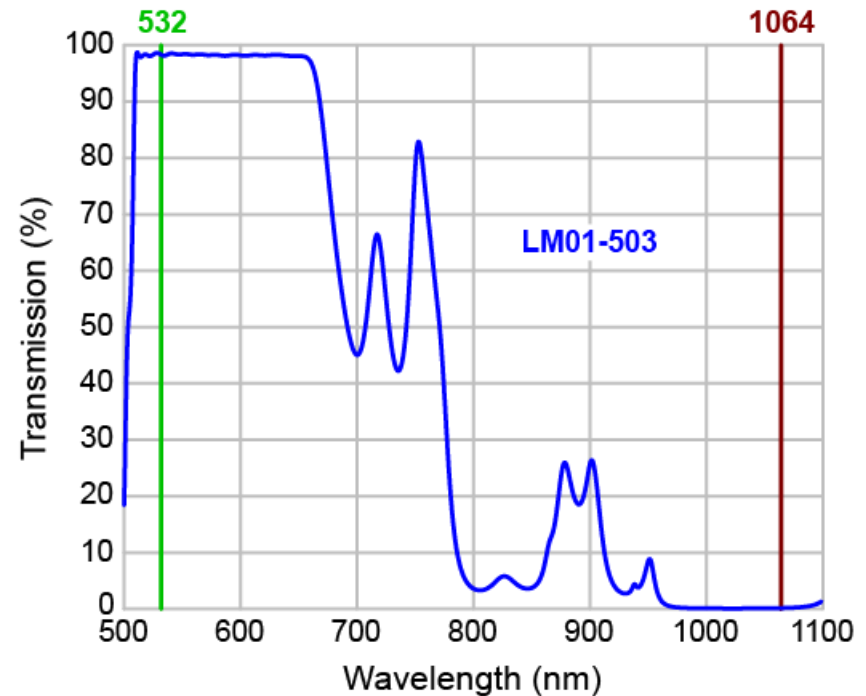
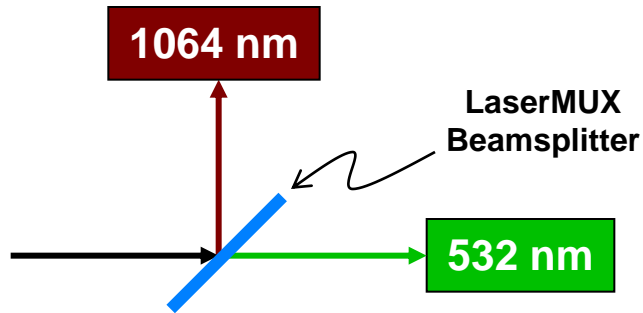
LaserMUX™ laser combiner/splitter filters

- The “LaserMUX” family is a set of laser multiplexing dichroic beam combiners, which allows for the combination of multiple laser wavelengths into a single beam (MUX), and when used in reverse, also allows for DEMUX.
- Filters are arranged depending on the desire to MUX or DEMUX, with the longer-wavelengths transmitted and shorter wavelengths reflected (see below)



532/1064 splitting

- The LaserMUX LM01-503 filter also provides a convenient way to separate a 532 nm second-harmonic laser beam from a 1064 nm fundamental beam in a Nd:YAG laser



Thank you!