

Optical Filters: Tunable Filters

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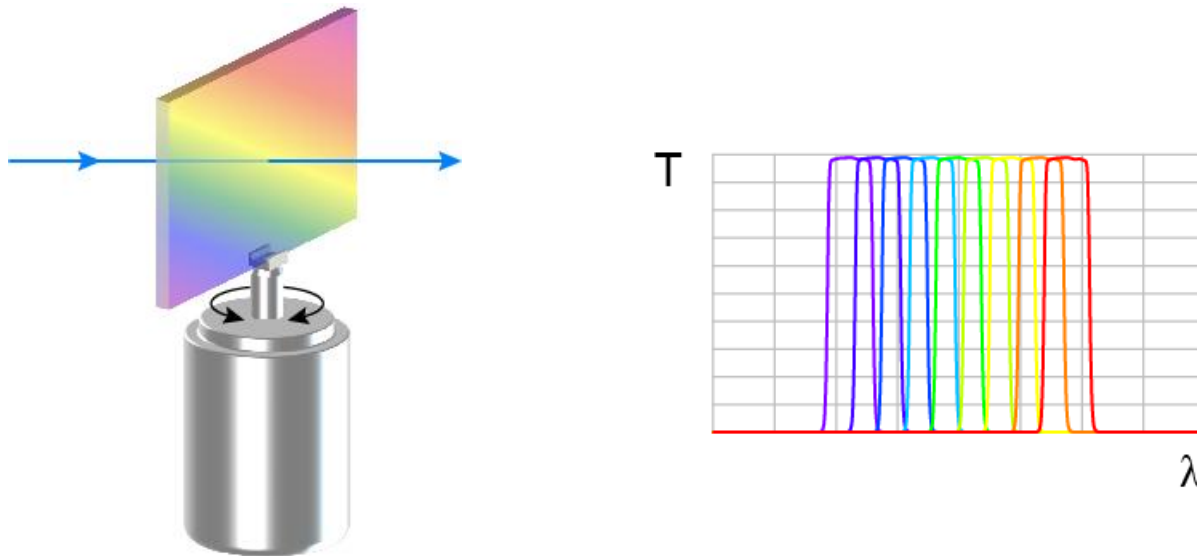
Semrock, A Unit of IDEX Corporation

May 31, 2011

Introducing VersaChrome®

- Semrock has now developed a revolutionary new optical filter technology

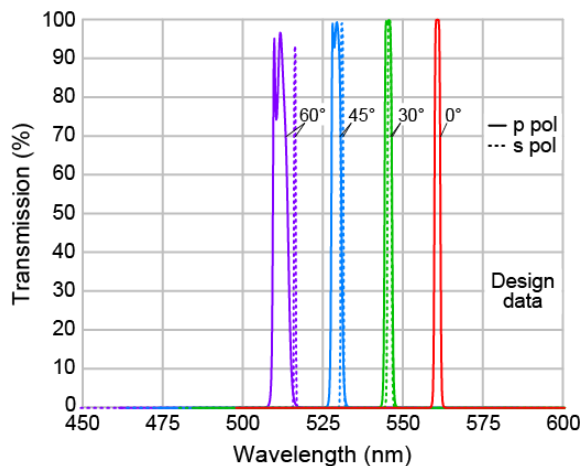
Thin-film filters tunable over a wide range of wavelengths by adjusting the angle of incidence with essentially no change in spectral performance*



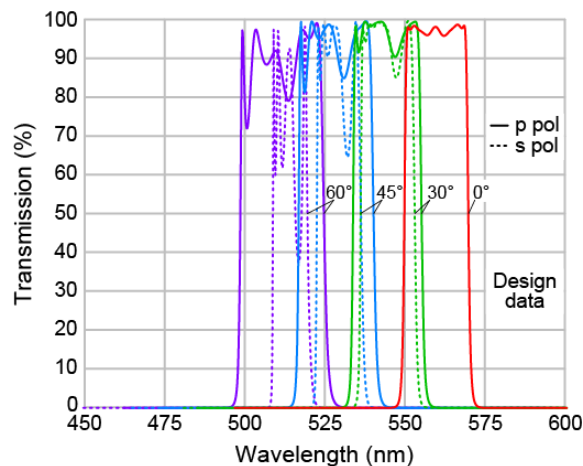
* Patent pending

Tuning range for bandpass filters is very limited

- Polarization splitting of the edges causes the spectrum for unpolarized light to “fall apart” at higher angle of incidence (AOI) values

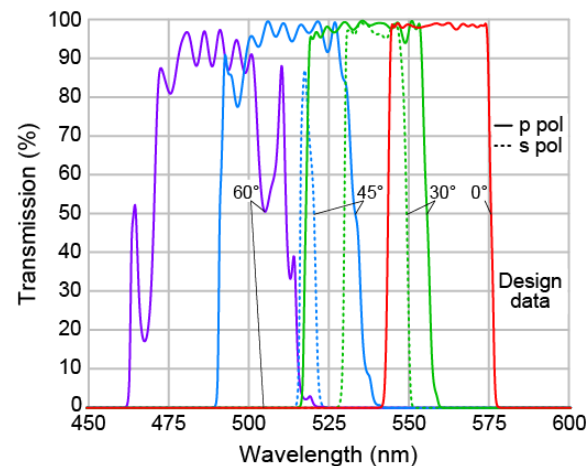


Narrowband multi-cavity
Fabry-Perot filter (~ 2 nm)



Wider passband multi-cavity
Fabry-Perot filter (~ 20 nm)

Tuning range ~ 2 to 3%
(10 to 15 nm in visible)

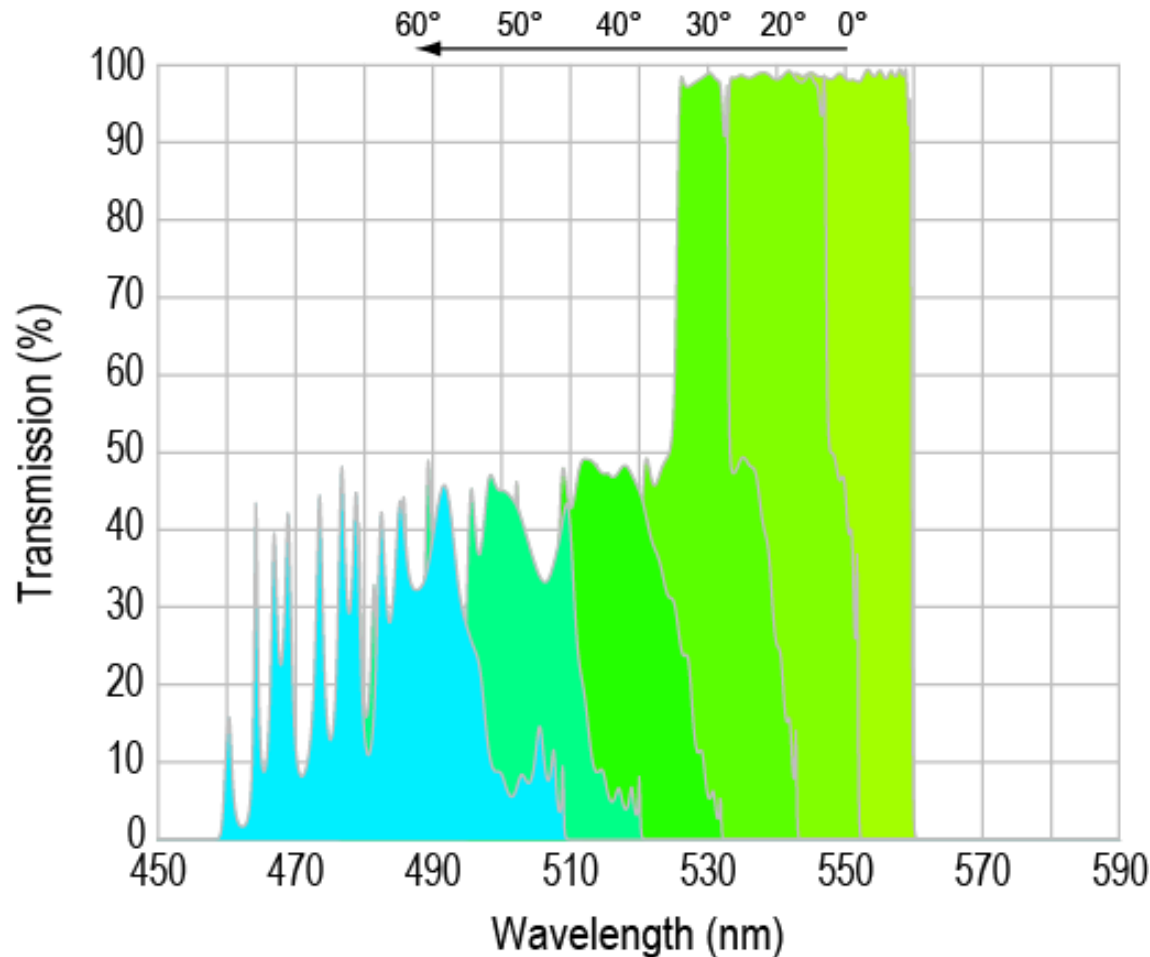


Typical fluorescence filter
(long-pass/short-pass type)

Tuning range ~ 0.5 to 1%
(3 to 5 nm in visible)

Tuning range for bandpass filters is very limited

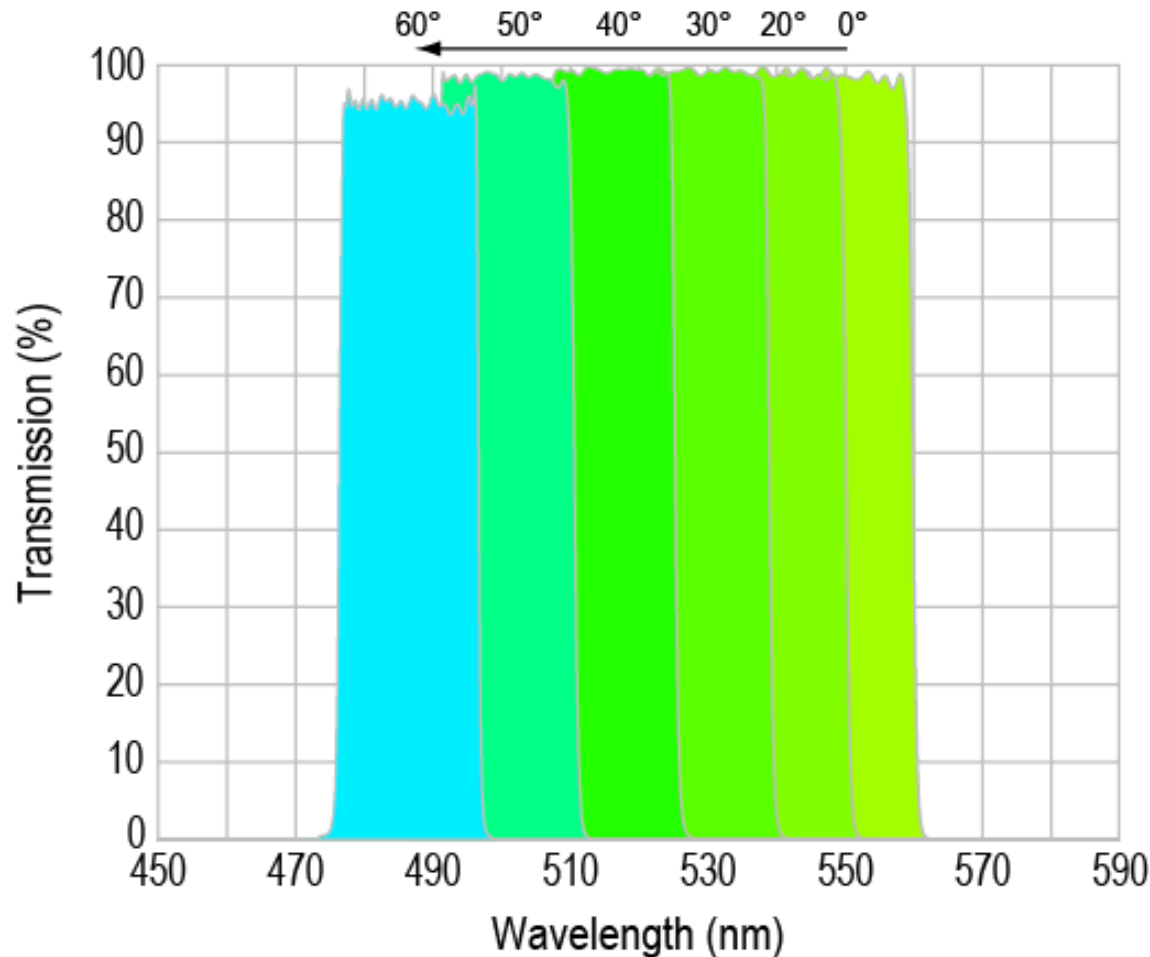
- Spectrum of a **bandpass fluorescence filter** for unpolarized light as it is angle-tuned from 0° to 60°



Spectrum becomes highly distorted even at angles of 20° to 30° and almost unusable for larger angles

Tuning range for VersaChrome – 12%!

- Spectrum of a **Semrock VersaChrome filter** for unpolarized light as it is angle-tuned from 0° to 60°

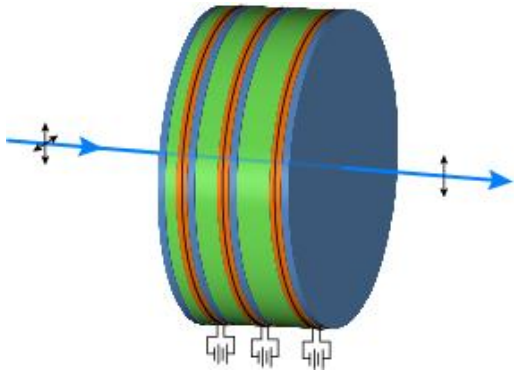


Spectrum maintains high transmission, steep edges, and excellent out-of-band blocking even at 60°!

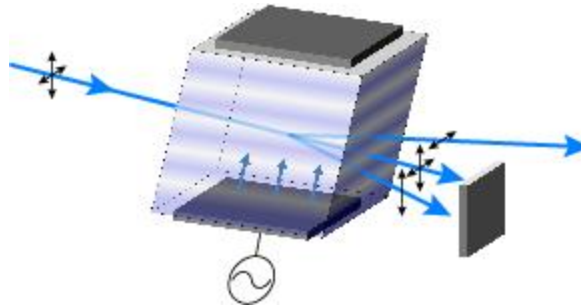
Tunable filters that transmit a 2-D imaging beam

- Variety of tunable optical filter technologies, but all compromise at least some critical performance characteristics

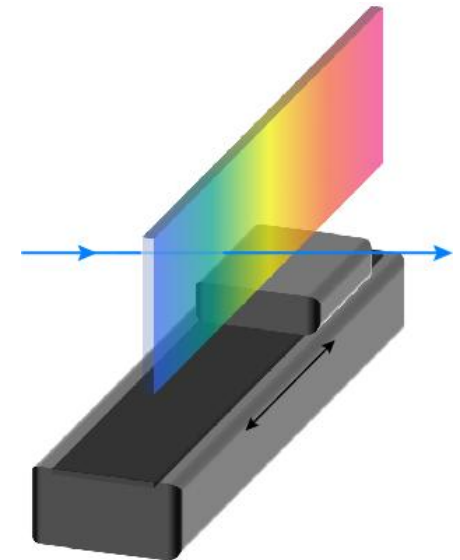
**Liquid-crystal tunable filter
(LCTF)**



**Acousto-optic tunable filter
(AOTF)**

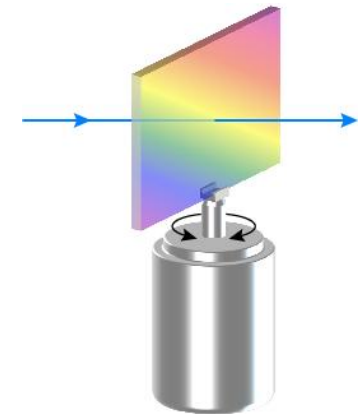


**Linear-variable filter
(LVF)**



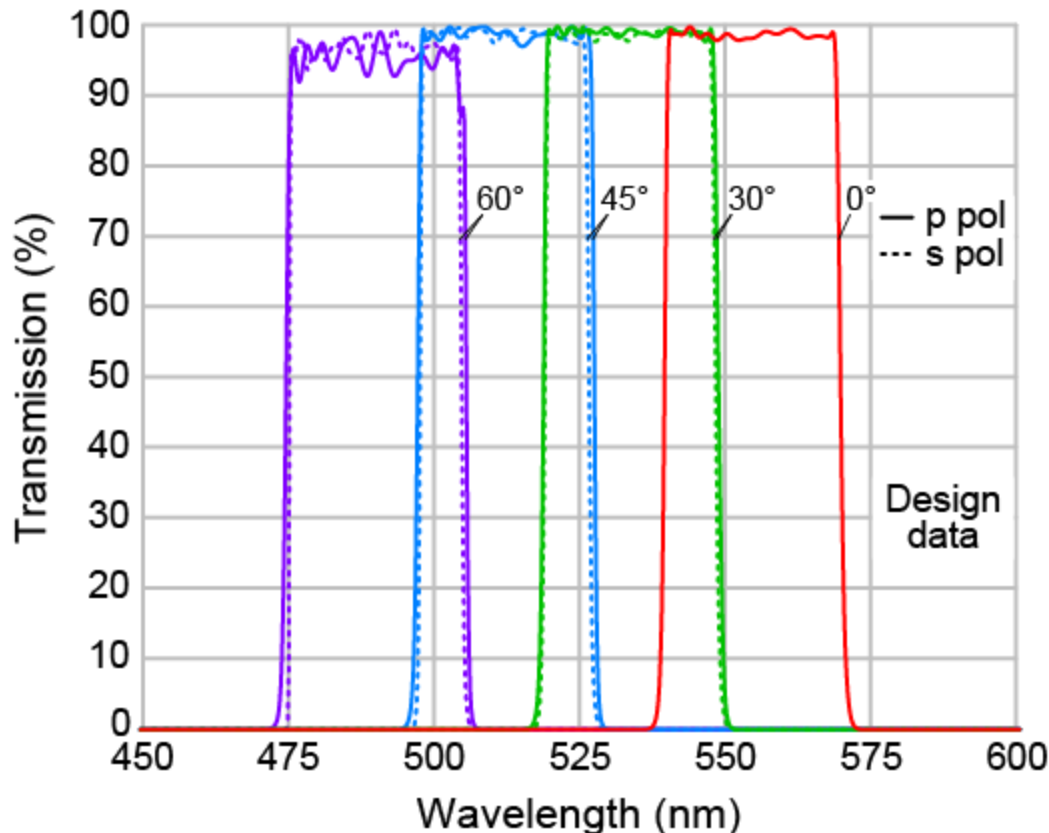
Comparison of tunable filter technologies

Property	Liquid-crystal	Acousto-optic	Linear-variable	Angle-tuned thin-film	Semrock VersaChrome
High passband transmission	+	0	+	+	+
"Top-hat" passband shape	-	-	0	+	+
Steep spectral edges	+	+	+	+	+
High out-of-band blocking	+	+	+	+	+
Constant bandwidth over full wavelength range	-	-	+	0	+
Adjustable bandwidth	+	+	+	-	+
Wide tuning range	+	+	+	+	0
Arbitrary wavelength access	+	+	+	+	+
Fast tuning speed (random access)	-	+	+	+	+
Two-dimensional imaging capability	+	-	0	+	+
Excellent imaging Modulation Transfer Function (MTF)	0	0	+	+	+
Large aperture	+	+	0	+	+
Polarization insensitive	+	+	+	+	+
Wide angular field of view	+	-	-	+	+
High Laser Damage Threshold (LDT)	+	+	+	+	+
High environmental durability/reliability	+	+	+	+	+
Minimal physical thickness	-	-	+	0	0
Low power consumption	0	+	0	0	0



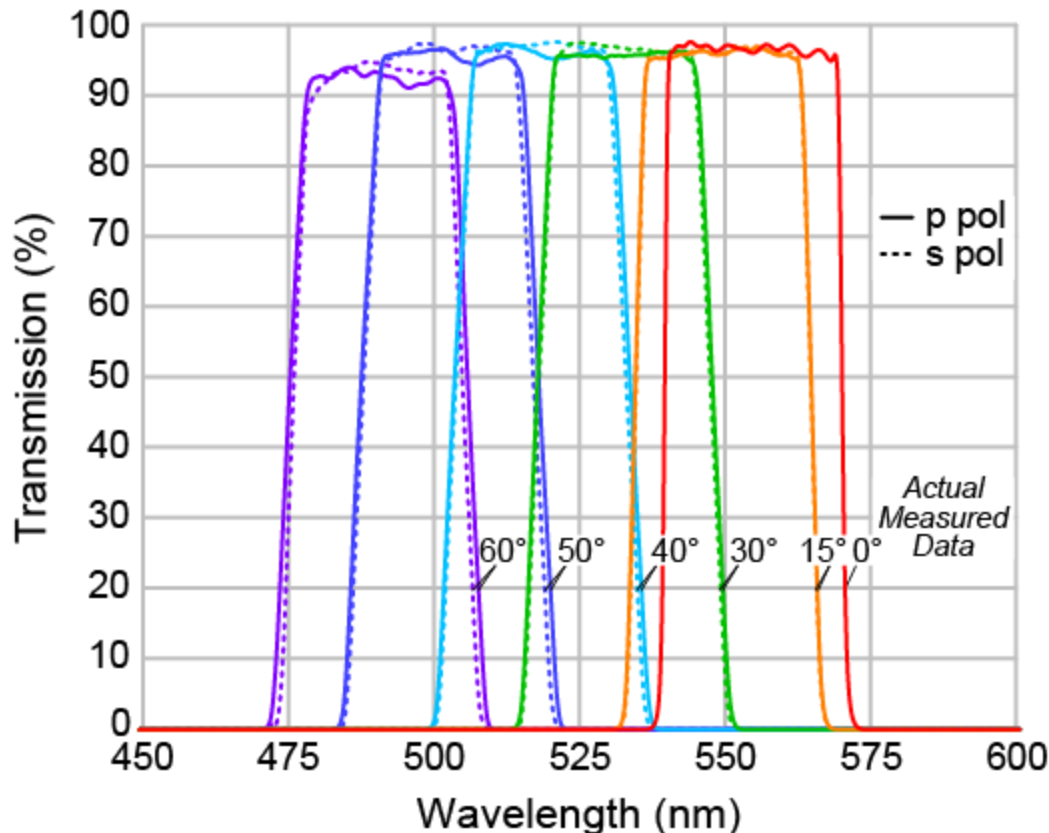
Why are VersaChrome filters so unique?

- At the heart of this invention is Semrock's discovery of a way to make steep edge filters at very high angles of incidence with essentially no polarization splitting and nearly equal edge steepness values for both polarizations
- And, remarkably, these properties maintain over a very wide range of angles!

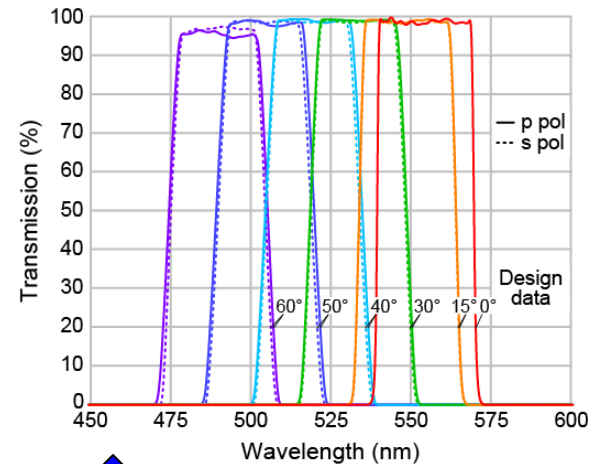


Why are VersaChrome filters so unique?

- And it really works! Measured data of actual (custom) VersaChrome filter:



Note the apparent reduction in the edge steepness at higher angles results from the lack of collimation (i.e. non-zero Cone Half Angle or CHA) of the measurement beam (here it was $\sim 2.5^\circ$)

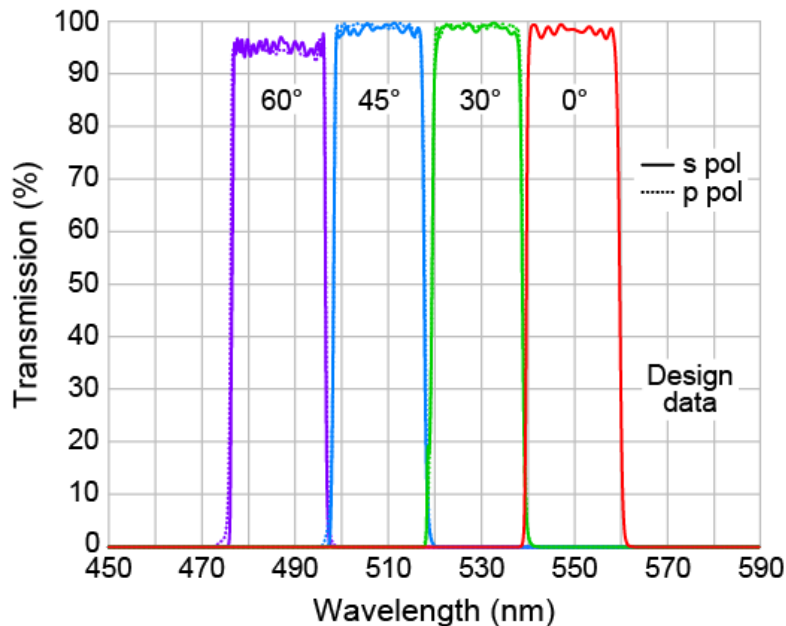


Calculated spectra assuming CHA = 2.5°

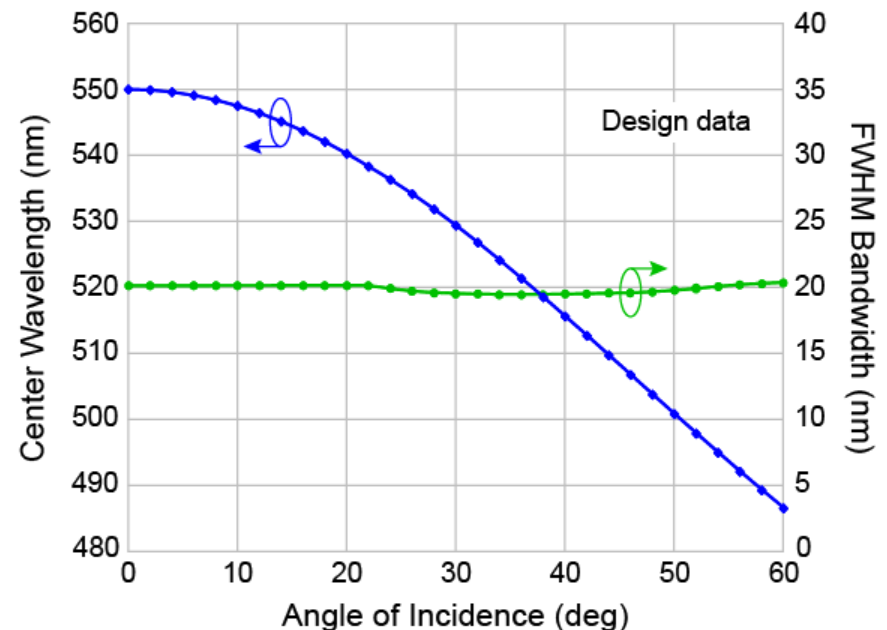
VersaChrome catalog tunable bandpass filters

- Center wavelength tuning range > 12% (50 – 80 nm in visible region)
- $n_{eff} \sim 1.85$
- 20 nm full-width-half-maximum (FWHM) across the full tuning range

TBP01-550/15 example








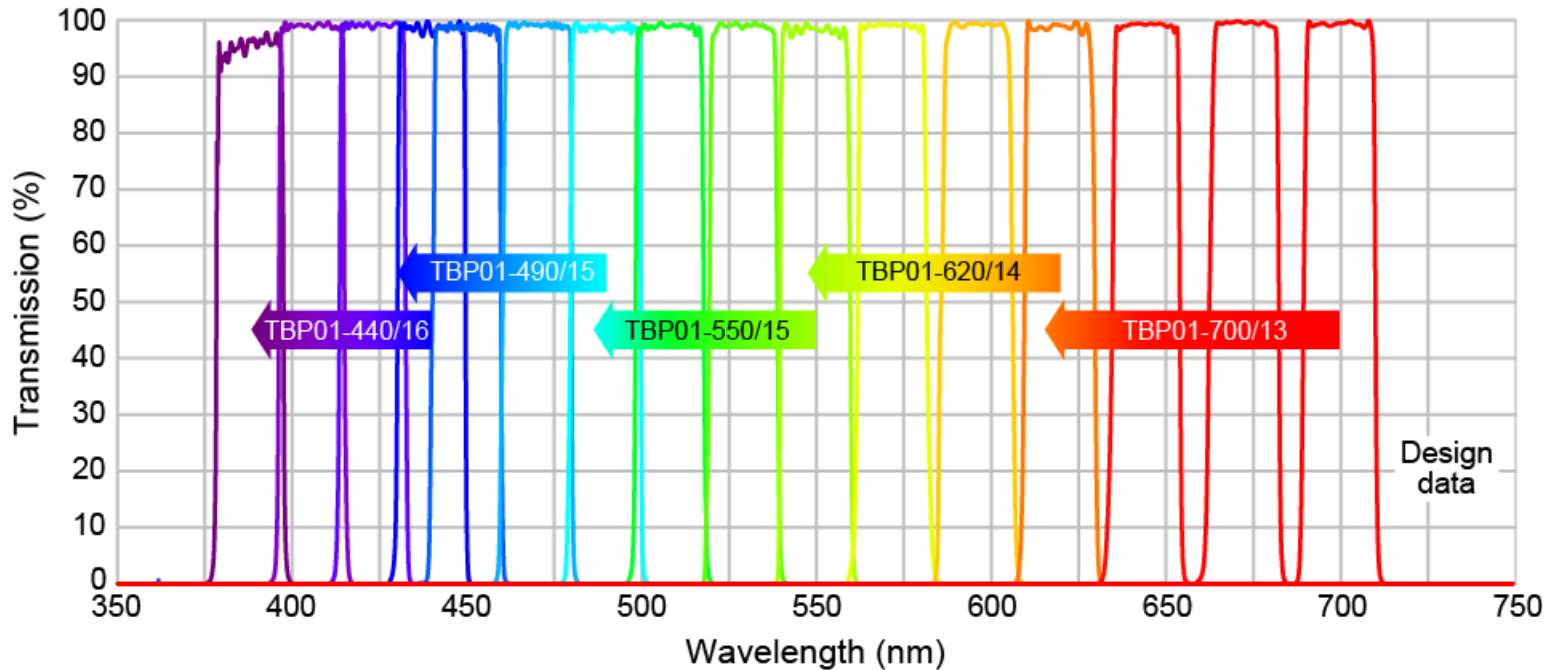
TBP01-550/15 example



First standard catalog VersaChrome filters – 20 nm FWHM

- Just 5 VersaChrome filters cover the entire visible wavelength spectrum!

Tunable Color Range	CWL Range 60° – 0°	Average Transmission / Bandwidth	Size (L x W x H)	Part Number	Price
	390 – 440 nm	> 90% over 16 nm	25.2 x 35.6 x 2.0 mm	TBP01-440/16-25x36	\$645
	440 – 490 nm	> 90% over 15 nm	25.2 x 35.6 x 2.0 mm	TBP01-490/15-25x36	\$645
	490 – 550 nm	> 90% over 15 nm	25.2 x 35.6 x 2.0 mm	TBP01-550/15-25x36	\$645
	550 – 620 nm	> 90% over 14 nm	25.2 x 35.6 x 2.0 mm	TBP01-620/14-25x36	\$645
	620 – 700 nm	> 90% over 13 nm	25.2 x 35.6 x 2.0 mm	TBP01-700/13-25x36	\$645



Applications for tunable filter “systems”

Tunable light sources

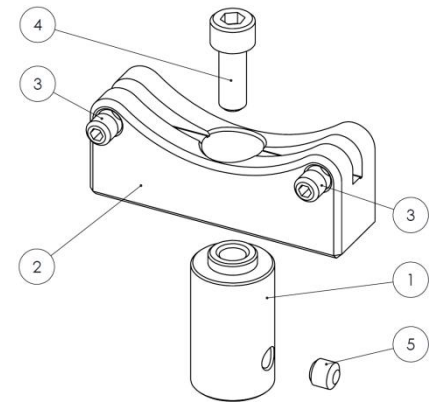
- CCD, CMOS, and other sensor or detector calibration
- Photometric, radiometric, and colorimetric calibration and testing of optical systems
- LCD display characterization
- Fluorescence microscopy
- Laboratory/OEM applications

Spectral imaging systems

- Drug discovery & safety testing
- Research biological microscopy
- Microplate readers
- Plant genomics
- Forensic analysis
- Forgery detection
- Environmental monitoring
- Geological sample analysis
- Gemology
- Semiconductor process/quality control
- Microelectronic & photovoltaic production
- Pulp and paper manufacturing
- Textile production
- Food safety & quality
- Waste recycling & sorting

FH1 holder for VersaChrome (and other filters)

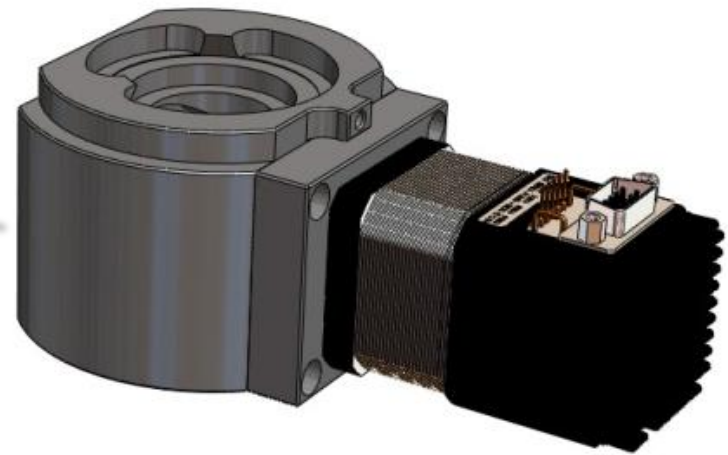
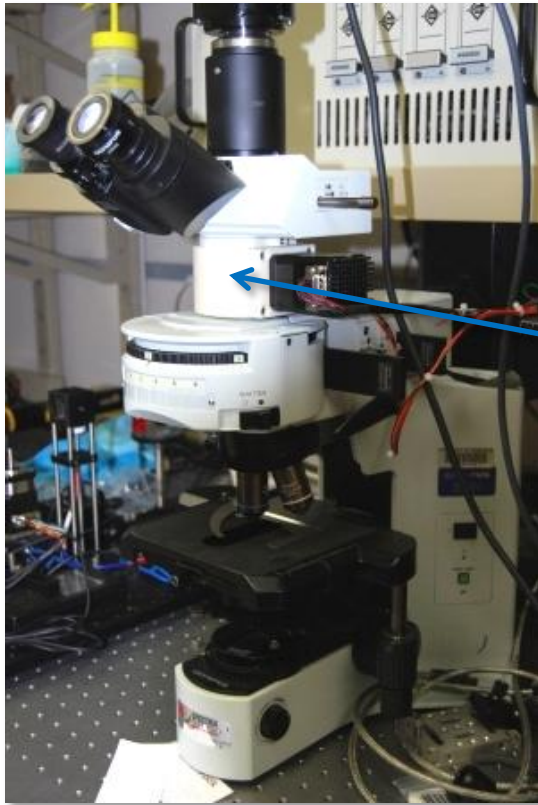
- Easily hold a VersaChrome filter and mount it to a manual or motorized rotational device
 - Simple, low-cost stepper or DC motor
 - Galvanometer scanner (galvo)
 - Manual or motorized rotation stage



- Also a simple, unobtrusive holder for any 25 mm x 36 mm dichroic (for thickness 1 – 2 mm)
 - 1 mm thick dichroic coating is precisely positioned over center of mount
 - 2 mm thick filter is itself symmetrically positioned over center of mount

VersaChrome single-filter implementation

- Example of a simple module for tuning a single emission filter in an Olympus BX fluorescence microscope platform

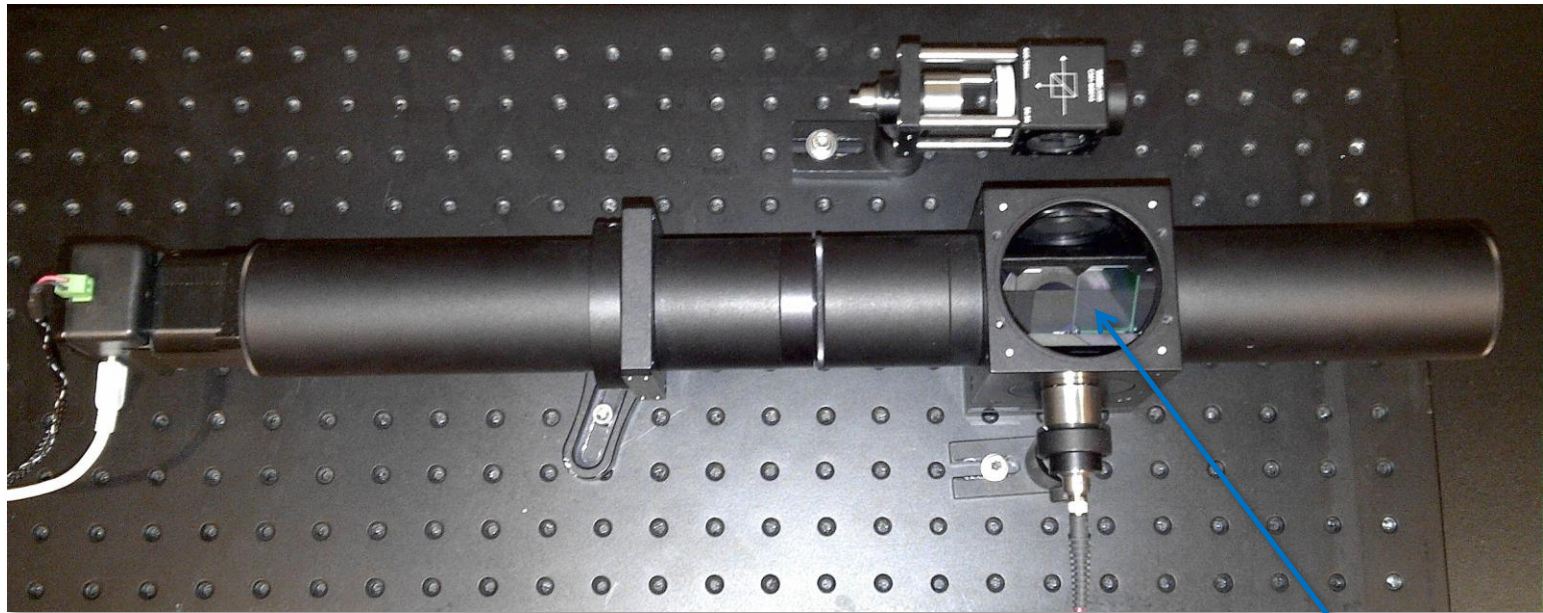


Semrock (prototype)

- For microscope imaging
- Built for demonstration only

VersaChrome multi-filter implementation

- Example of a simple module for tuning up to 5 emission filters in the imaging path of an instrument or fluorescence microscope



Semrock (prototype)

- For imaging (> 20 mm CA)
- Built for demonstration only

VersaChrome
filters

More VersaChrome filter tuners

- More examples of products that utilize VersaChrome tunable filters



AHF TuneBox LC-60

- Very fast (0 – 60° in 16 ms)
- Single filter
- Non-imaging (optical fiber or liquid light guide)



Sutter Instruments (prototype)

- Moderate speed
- Up to 5 filters
- Non-imaging (optical fiber or liquid light guide) or small aperture imaging applications

Thank you!