Optical Filters: Tunable Filters

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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)

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

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

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 $0^\circ$ to $60^\circ$

Spectrum maintains high transmission, steep edges, and excellent out-of-band blocking even at $60^\circ$!
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

<table>
<thead>
<tr>
<th>Property</th>
<th>Liquid-crystal</th>
<th>Acousto-optic</th>
<th>Linear-variable</th>
<th>Angle-tuned thin-film</th>
<th>Semrock VersaChrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>High passband transmission</td>
<td>-</td>
<td>O</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>&quot;Top-hat&quot; passband shape</td>
<td>-</td>
<td>-</td>
<td>O</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Steep spectral edges</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>High out-of-band blocking</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Constant bandwidth over full wavelength range</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>O</td>
<td>+</td>
</tr>
<tr>
<td>Adjustable bandwidth</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Wide tuning range</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>O</td>
</tr>
<tr>
<td>Arbitrary wavelength access</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Fast tuning speed (random access)</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Two-dimensional imaging capability</td>
<td>+</td>
<td>-</td>
<td>O</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Excellent imaging Modulation Transfer Function (MTF)</td>
<td>O</td>
<td>O</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Large aperture</td>
<td>+</td>
<td>-</td>
<td>O</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Polarization insensitive</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wide angular field of view</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High Laser Damage Threshold (LDT)</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>High environmental durability/reliability</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Minimal physical thickness</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Low power consumption</td>
<td>O</td>
<td>+</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>
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 ~ 2.5°)

Calculated spectra assuming CHA = 2.5°
VersaChrome catalog tunable bandpass filters

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

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

<table>
<thead>
<tr>
<th>Tunable Color Range</th>
<th>CWL Range 60° - 0°</th>
<th>Average Transmission / Bandwidth</th>
<th>Size (L x W x H)</th>
<th>Part Number</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purple</td>
<td>390 – 440 nm</td>
<td>&gt; 90% over 16 nm</td>
<td>25.2 x 35.6 x 2.0 mm</td>
<td>TBP01-440/16-25x36</td>
<td>$645</td>
</tr>
<tr>
<td>Blue</td>
<td>440 – 490 nm</td>
<td>&gt; 90% over 15 nm</td>
<td>25.2 x 35.6 x 2.0 mm</td>
<td>TBP01-490/15-25x36</td>
<td>$645</td>
</tr>
<tr>
<td>Cyan</td>
<td>490 – 550 nm</td>
<td>&gt; 90% over 15 nm</td>
<td>25.2 x 35.6 x 2.0 mm</td>
<td>TBP01-550/15-25x36</td>
<td>$645</td>
</tr>
<tr>
<td>Yellow</td>
<td>550 – 620 nm</td>
<td>&gt; 90% over 14 nm</td>
<td>25.2 x 35.6 x 2.0 mm</td>
<td>TBP01-620/14-25x36</td>
<td>$645</td>
</tr>
<tr>
<td>Red</td>
<td>620 – 700 nm</td>
<td>&gt; 90% over 13 nm</td>
<td>25.2 x 35.6 x 2.0 mm</td>
<td>TBP01-700/13-25x36</td>
<td>$645</td>
</tr>
</tbody>
</table>
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
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!