Technical note

Tunable Bandpass filters with wide deep out-of-band blocking

Introduction

Tunable bandpass filters have many applications in photonic instruments. Some common examples are exciter and emission filters of spectrofluorometers and tunable light sources.

Traditionally, tunable filters are constructed based on a rotating diffraction grating or prism using a precise angular motor to tune the desired wavelength and a variable slit to select the bandwidth. However, such systems are very sensitive to environmental conditions like temperature and vibration as well as wear in the motor parts.

Recently, a new kind of tunable bandpass filter has been introduced that utilize a set of Continuously Variable Interference Filters (CVFs) – also known as Linear Variable Filters. This construction is simpler and more stable than the rotating grating type since it only requires linear translations along one axis.

For many applications, it is desirably to cover the full wavelength range of silicon-based detectors (350 – 1100 nm). Constructing CVFs with high out-of-band blocking for such a wide wavelength range is a challenge. However, in this technical note we will describe how tunable bandpass filters with wide and deep out-of-band blocking can be built using CVFs combined with homogeneous blocking filters.

Continuously Variable Filters

A Continuously Variable Filter is an optical component where the filter edge varies continuously along one physical dimension of the filter as illustrated on Figure 1 for a Continuously Variable Long Wave Pass edge Filter (CVLWP). At position 1 the filter edge is in the blue wavelength region and basically the entire spectrum is transmitted through the filter. At position 2, the edge is in the green wavelength range and thereby wavelengths longer than the green are transmitted only. Finally, at position 3, the edge is in the red wavelength region letting only the red wavelengths of the spectrum through.

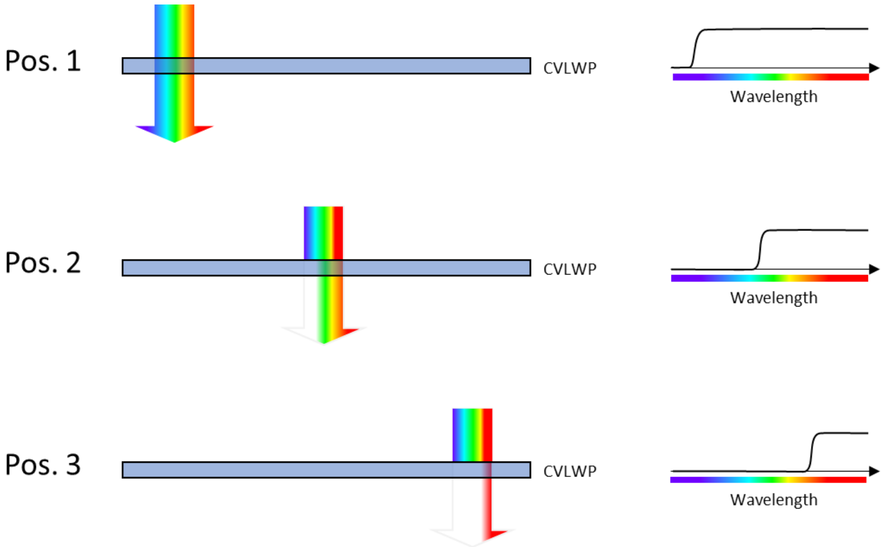

Figure 1: Illustration of a Continuously Variable Edge Filter. The filter wavelength edge dependents on the position on the filter.'

It is worth noting that the function of the filter also depends on the beam spot size as well the Angle-of-Incidence on the filter. This is explained in a separate technical Note.

Tunable Bandpass filters constructed using Continuously Variable Filter sets

By combining a Continuously Variable Long-Wave Pass (CVLWP) filter with a Continuously Variable Short-Wave Pass (CVSWP) filter and sliding the two, it is possible to construct a tunable bandpass filter.

Figure 2 shows how the bandwidth of the filter can be adjusted by sliding the two filters relative to each other

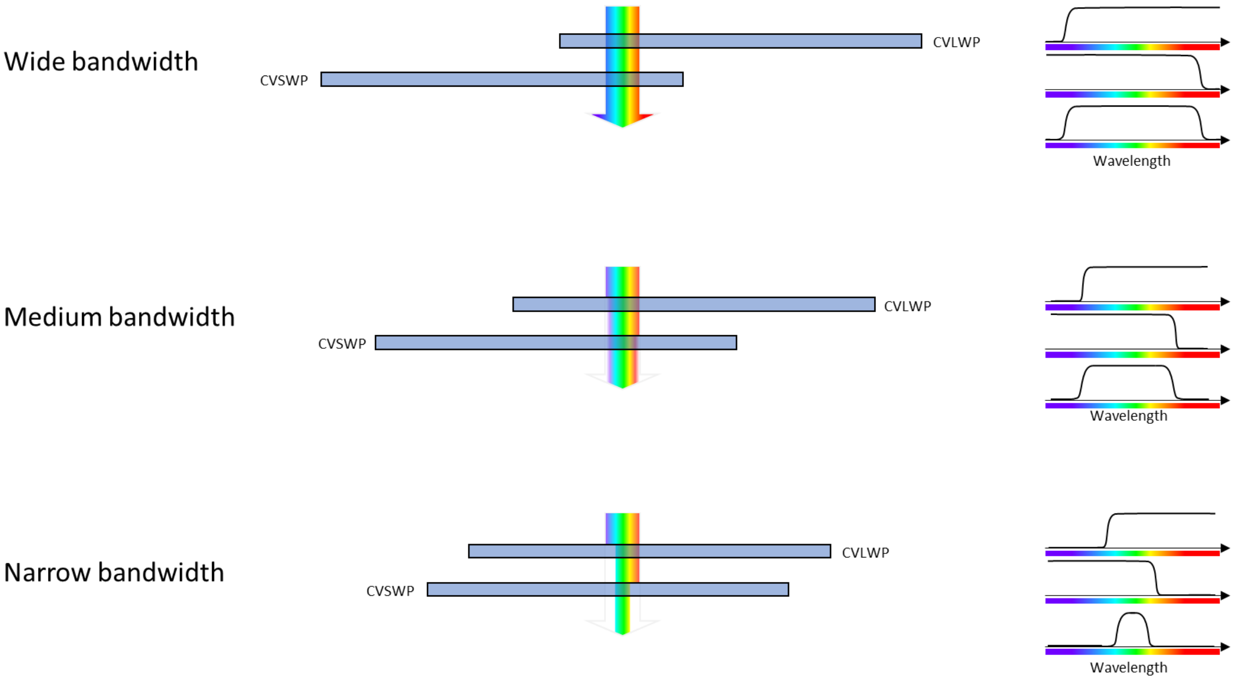

Figure 2: Tuning bandwidth by sliding CVSWP and CVLWP relative to each other.

Figure 3 shows how the center wavelength of a bandpass filter with fixed bandwidth can be tuned by sliding the two filters in parallel.

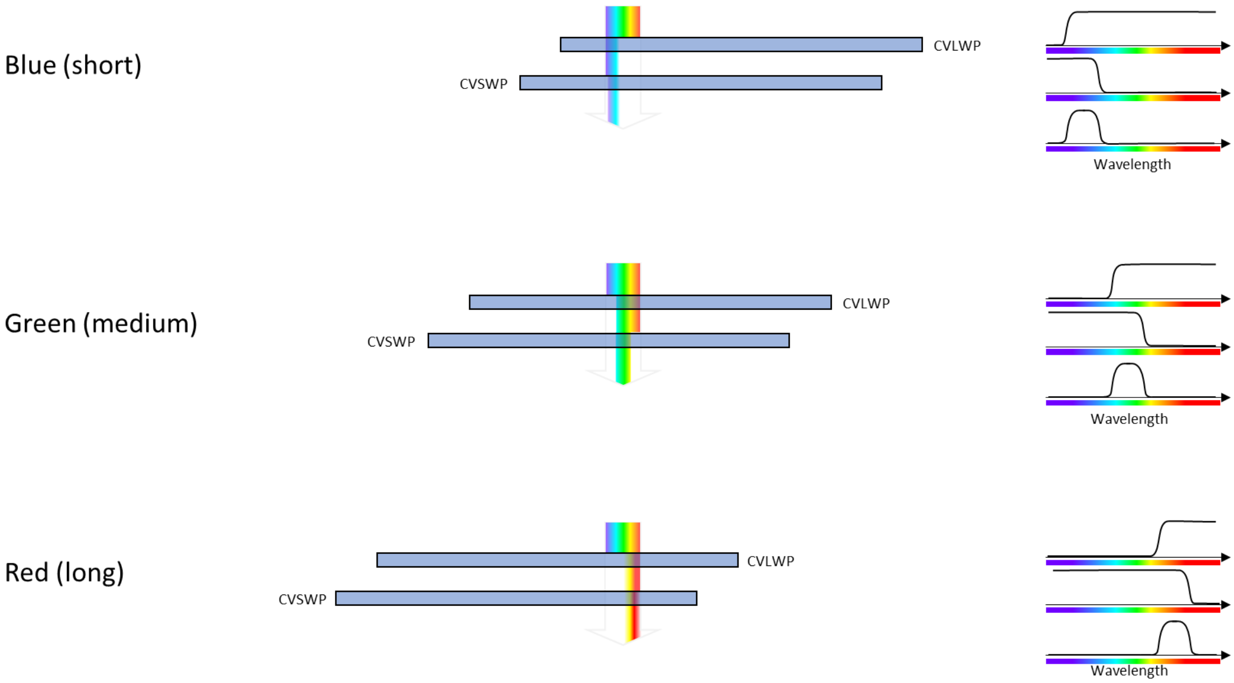

Figure 3: Tuning center wavelength with constant bandwidth by sliding CVSWP and CVLWP parallel to each other.

Bandwidth constraints of Continuously Variable Filters

An interference filter consists of a number of thin layers of dielectric materials with alternating high and low refractive indices. Wavelengths that experience constructive interference through the dielectric layers are transmitted and the remaining wavelengths are reflected.

Interference filters do by nature only function in a limited wavelength range. Outside this range the filter will often be partially transmitting and reflecting.

This is illustrated on Figure 4 for a CVLWP and a CVSWP with an edge at λ_{50} and a working range from λ_{min} to λ_{max}. As can be seen from the figure of the CVLWP as an example, the blocking of short wavelengths is not effective below λ_{min} and the transmission is decreased for wavelengths longer than λ_{max}. The opposite is the case for the CVSWP.

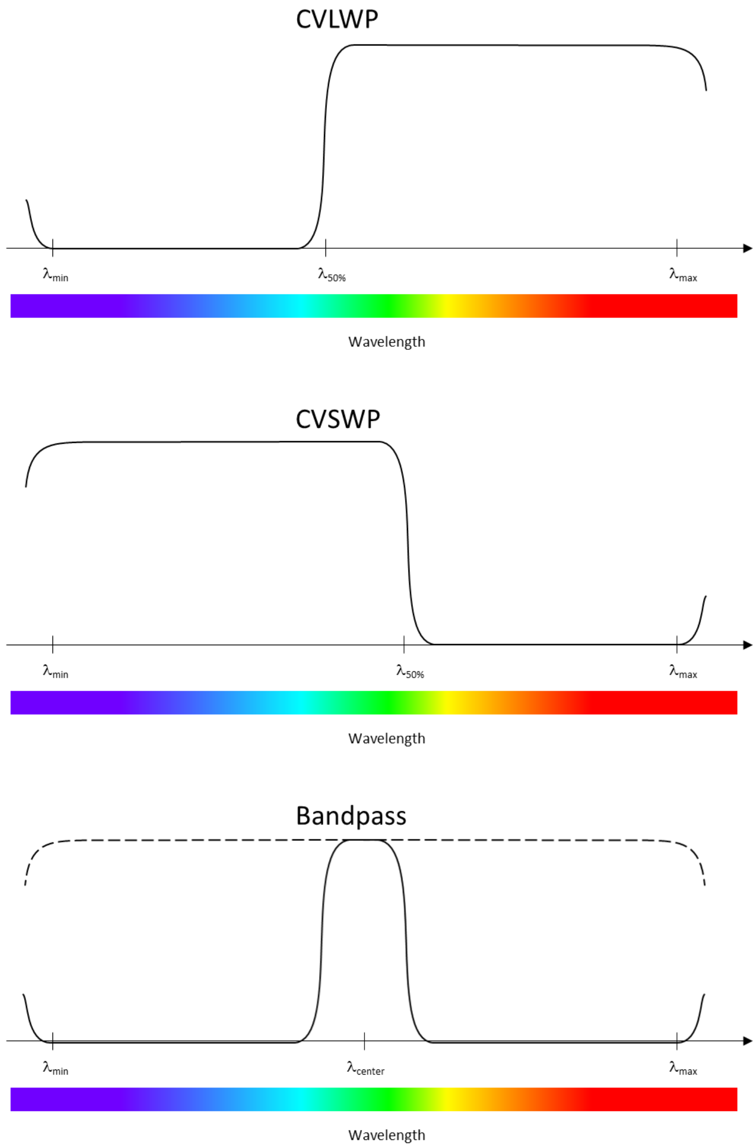

Figure 4: Working range from λ_{min} to λ_{max} for a CVLWP, CVSWP filter and the combined bandpass filter.

The working range of a CVF changes with position (or edge wavelength) on the filter.

When a CVLWP and a CVSWP is combined to form a tunable bandpass filter λ_{min} and λ_{max} influences both the maximum bandwidth and the range with high out-of-band blocking. Figure 5 shows an example of how the working range depends on the center bandwidth of a tunable bandpass filter with a FWHM of 50 nm.

If the tunable filter is going to be used in the entire wavelength range of silicon detectors (350 – 1100 nm), the working range needs to be wide. Although it is possible to design a filter with a very wide working range, it may not be the optimum choice. First of all, the filter will be very complex requiring a lot of layers and material to be deposited as well as a long processing time. Secondly, performance parameters like passband transmission and edge steepness might have to be compromised in order to obtain a wide working range.

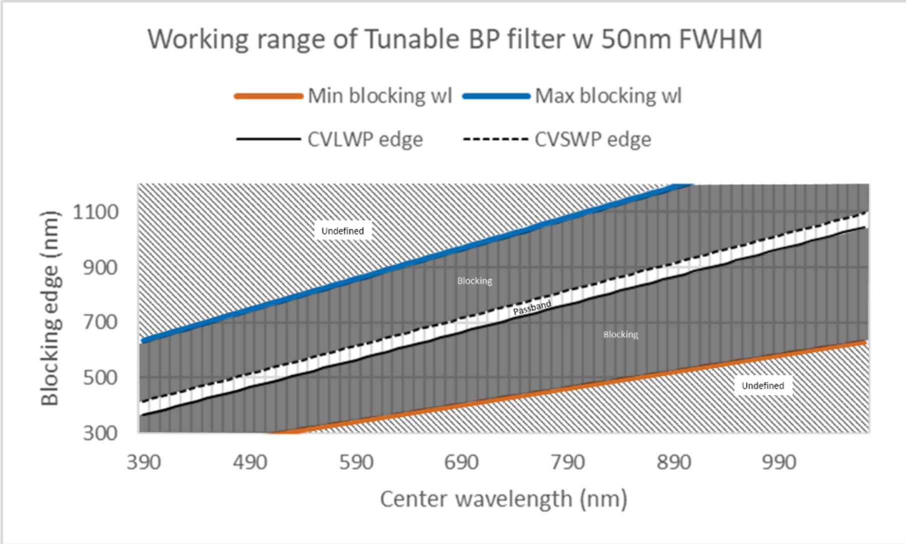

Figure 5: Example of how the working range depends on center wavelength for a tunable bandpass filter with a bandpass of 50 nm.

Wideband blocking using homogenous blocking filters

As explained above, it may not be practical or economically viable to produce CVFs with a working range covering the entire 350 – 1100 nm range where Silicon detectors are sensitive.

A simple way to extend the blocking range of a tunable bandpass filter is to slide in a small, fixed (homogeneous) wide-band bandpass filter as illustrated on Figure 6. The bandpass filter (BP) transmits almost 100% in the tuning range and blocks typically OD5-6 outside the tuning range.

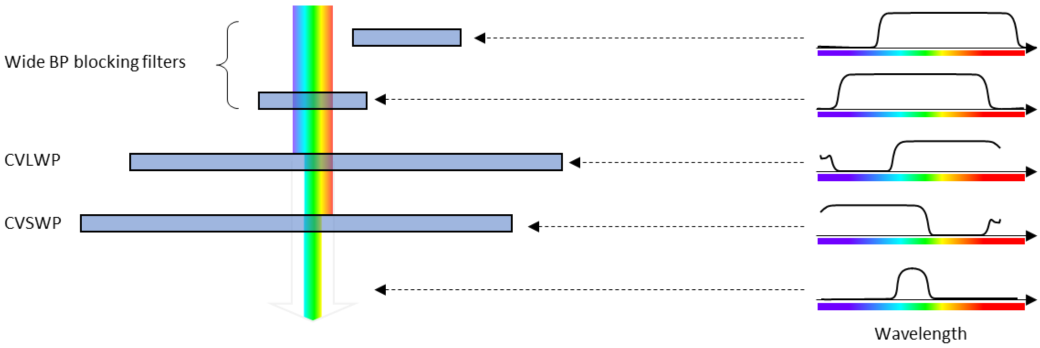

Figure 6: Extending the blocking range of a tunable bandpass filter with a wide band homogeneous bandpass filter.

From Figure 5 it can be seen that it is not possible to choose a single wide-band fixed filter to cover the complete tuning range from 400 - 1000 nm. At short center wavelengths, say 400 – 600 nm, we obviously need **transmission below 600 nm** and **blocking above 600 nm**. But, for longer center wavelengths, say 600 – 1000 nm, we need **blocking below 600 nm** and **transmission above 600 nm**.

For a practical implementation, it is therefore beneficial to use a range of blocking filters that we use one at a time dependent on the center wavelength of the tunable filter. The transmission ranges of the different blocking filters overlap to enable both narrow and wide bandwidths.

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Delta Optical Thin Film has manufactured several Filter sets for design of widely tunable bandpass filters with high out-out band blocking. Figure 7 shows an example of a filter set for the 400 – 1000 nm range with 4 different blocking filters. With this filter set transmission can be above 90% at the center wavelength and blocking is typically better than OD5 outside the filter bandwidth.

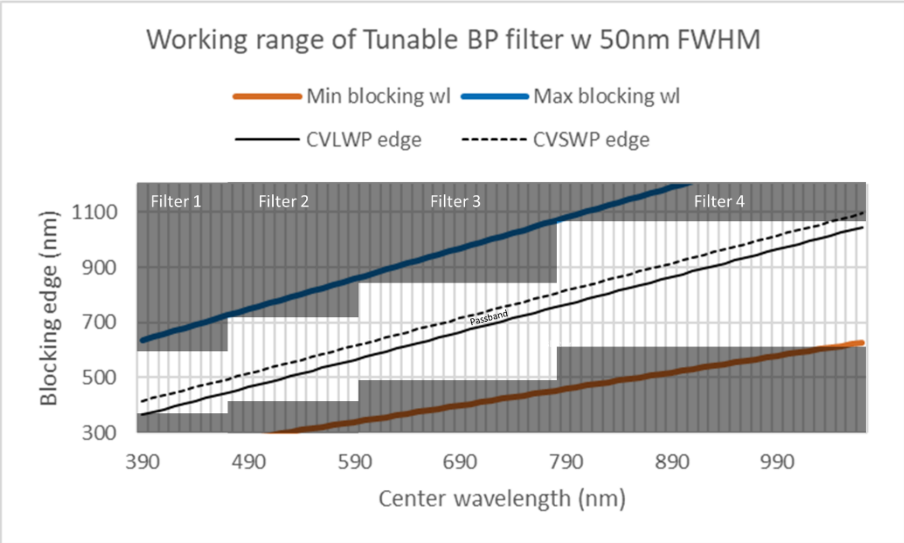

Figure 7: Example of filter set for building a tunable bandpass filter for the 400 – 1000 nm range.

The table below lists an example of a filter set that Delta Optical Thin Film manufactures. This filter set consist of 6 filter, a continuously variable long wave pass filters, a continuously variable short wave pass filters and 4 homogeneous blocking filters for various wavelength regions. CVLWP 383-1000 (LF104550) can be combined with CVSWP 386-1005 (LF104555) to make a continuously variable bandpass filter for the range 385 nm to 1000 nm with a tunable bandwidth between 10 – 75 nm.

Product Number	Product Type	$\lambda_{50\%}$ Min	$\lambda_{50\%}$ Max	Max dimensions
LF104555	CVLWP	383 nm	1000 nm	110 mm x 17 mm x 2 mm
LF104550	CVSWP	386 nm	1005 nm	110 mm x 17 mm x 2 mm
LF104551	Blocking	370 nm	590 nm	80 mm x 55 mm x 1 mm
LF104552	Blocking	410 nm	710 nm	80 mm x 55 mm x 1 mm
LF104553	Blocking	490 nm	850 nm	80 mm x 55 mm x 1 mm
LF104554	Blocking	615 nm	1040 nm	80 mm x 55 mm x 1 mm

You can find more details about this filter set on our web-page here: https://deltaopticalthinfilm.com/products/continuously-variable-filters/continuously-variable-filter-sets/.

If our range of filter sets does not match your exact requirements, you can always contact Delta Optical Thin Film if you need a customized design.