Highly efficient tunable filter for broadband light source

Jun Hee Kang, Spectrolight Inc. 19800 MacArthur Blvd., Suite 300, Irvine, CA 92612

Abstract
A new simple and compact approach to tunable wavelength filtering combines the flexibility of a monochromator with the imaging functionality of a thin-film filters, and is ideal for use in both illumination and image acquisition.

Traditional tools for wavelength filtering, such as monochromators and filter wheels, all have some type of limitation that often compromises their use in scientific and industrial settings. However, a new type of wavelength filtering device called Flexible Wavelength Selector (FWS) now offers a combination of advantages for both illumination and image filtering. Specifically, FWS devices combine the wavelength tunability and bandwidth control of a monochromator with the circular uniform aperture of a filter wheel. These devices are highly efficient, simple, and cost-effective. In this article, we describe this innovative product and show its application with broadband lamp.

Figure 1. FWS Poly

Methods for filtering light according to wavelength can be divided into three groups: filters (cut-off, dichroic, etc.), monochromators, and newer “niche” technologies. Each method has its advantages.

Filters. In the detection part of a micros cope, filters and dichroic beamsplitters are the commonly used means of wavelength filtering just prior to the camera or eyepiece. Similarly, these filters can be used with a broadband light source for wavelength-selective illumination instead of an LED or laser. The filter is typically based on thin film dielectrics sometimes incorporating colored glass for extra wavelength blocking. The limitation of filters and filter wheels is their lack of flexibility since the bandpass and center wavelength are fixed for each filter. So images cannot be scanned as a function of wavelength nor can the wavelength and bandwidth be iteratively adjusted to find the optimum (e.g., high contrast) viewing conditions for a specific sample.

Monochromators. Conversely, the monochromator is very flexible. It relies on a either a diffraction grating or a dispersive prism in which incident light is deflected at a wavelength-dependent angle. In the typical setup, light is directed to an input slit before being deflected towards the output port. For filtering a light source, an output slit or fiber is used to select only a targeted wavelength window; the center of this band can be continuously tuned by rotating the grating (or prism) angle. And by adjusting the width of the input and output slit, the bandwidth of the transmitted light also can be smoothly varied.

Recent filtering technologies. There are also a couple of other niche wavelength filtering technologies: the acousto-optic tunable filter (AOTF) and liquid crystal filters. The AOTF is a solid state component based on applying radio frequency (RF) input to an exotic crystal such as tellurium dioxide (TeO_2). The resultant acoustic vibrations act as a moving diffraction grating. The main advantage of the AOTF is that it has a square or rectangular aperture that can be used for direct imaging. However, it has numerous well-documented drawbacks. First, it is a complex RF-powered system that is relatively costly. Plus, this cost increases non-linearly with aperture size. The AOTF also has poor out-of-band extinction, typically $<10^2$. In addition, there is a fixed relationship between bandwidth and center wavelength, and, in many devices, the output angle shifts with wavelength.

In liquid crystal based devices, the phase of linearly polarized light is manipulated in a liquid crystal cell sandwiched between wave plates. The use of polarizers means that only a certain wavelength band can pass through the device. These are useful niche devices, but they have some limitations: the bandwidth is fixed, the input must be linearly polarized, and for un-polarized light the total throughput efficiency is <25%.

In addition, the out-of-band extinction is much lower than a monochromator or bandpass filter, and the transmission edge slope is poor. For some illumination applications the low damage threshold can be another limitation.

Flexible Wavelength Selectors (FWS). A new tunable filter now combines the advantages of all these earlier methods without most of the drawbacks. Specifically, FWS provides the wavelength flexibility and precision of a monochromator with the large clear aperture of a filter. Moreover, it is simple, economical, robust, and it can be packaged as a compact device for microscopy. The main advantages are high out of band blocking (>OD 6), high transmission efficiency (>75%) and independent control of center wavelength and bandwidth. Tuning range varies from around 350 to 900 nm depending on the model and minimum bandwidth is 2 to 4 nm while maximum bandwidth varies from 11 to 16 nm depending on the center wavelength.

FWS can be used with any type of broadband illumination sources such as tungsten halogen lamps, supercontinuum lasers and Energetiq Laser-Driven Light Sources (LDLS™). In addition FWS can be very accurate when filtering light. The accuracy will fall under 0.5 nm when selecting center wavelength and bandwidth for the output. The ability to smoothly vary the center wavelength and bandwidth for both illumination and imaging in real time, is expected to lead to widespread use in a variety of applications - from neuroscience to materials research to clinical biopsies.

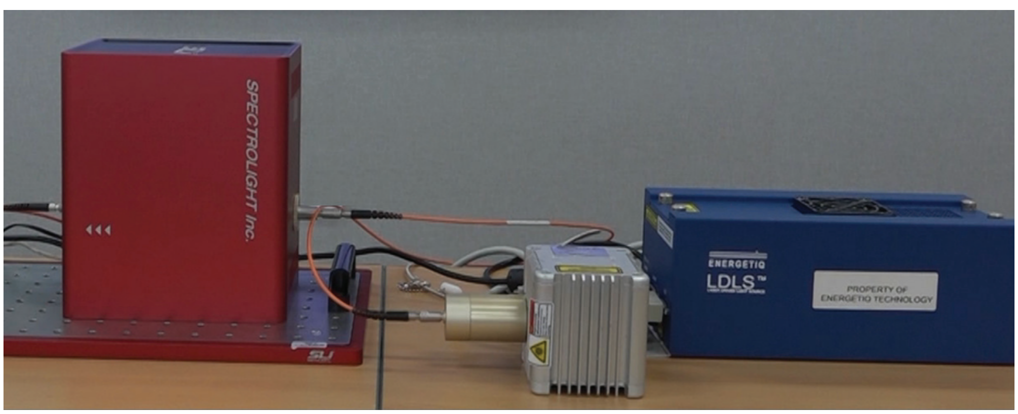

Figure 2. Energetiq Laser-Driven Light Sources (LDLS™) EQ-99X connected to FWS Poly.

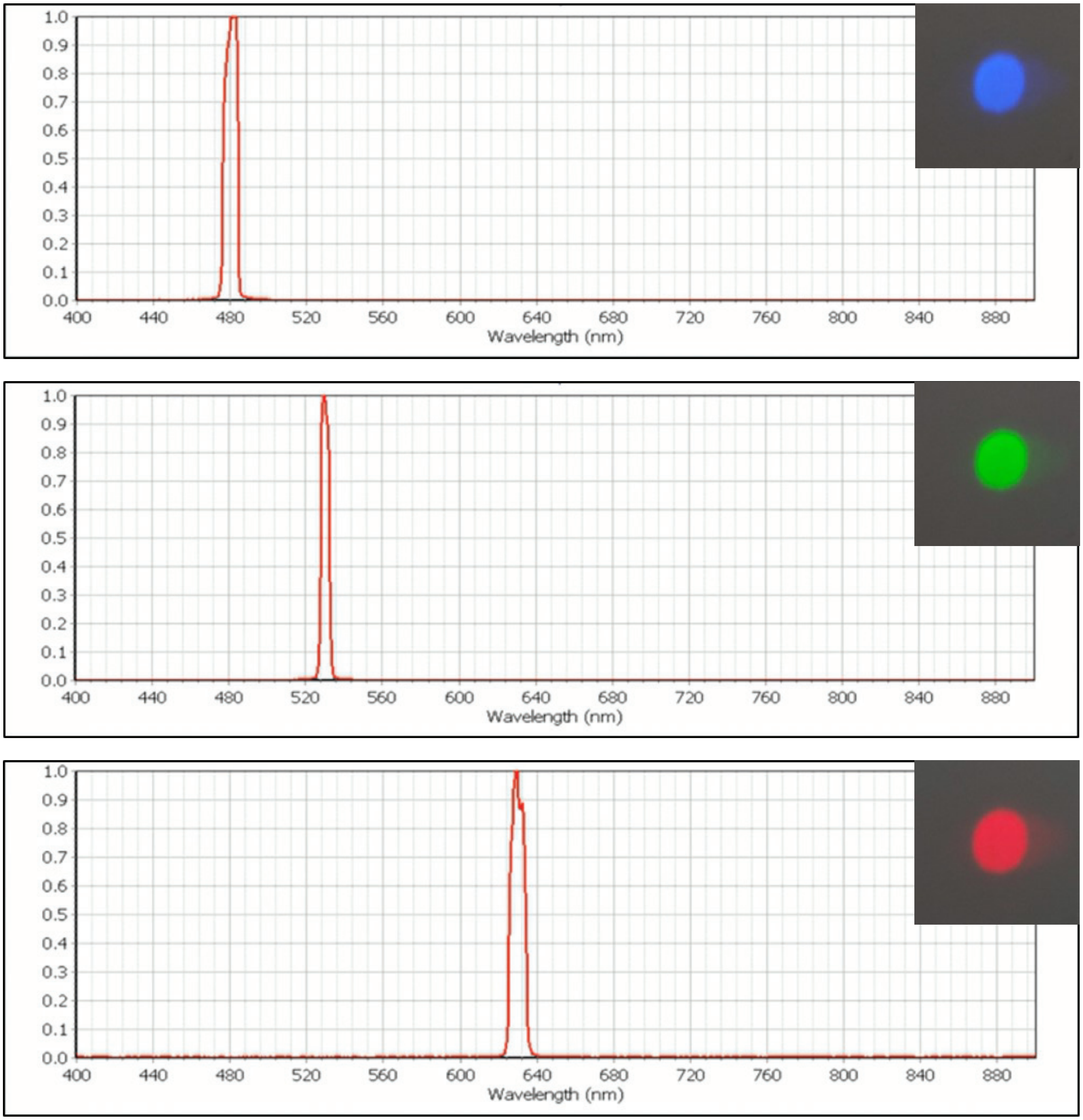

Figure 3. Output of Energetiq Laser-Driven Light Sources (LDLS™) EQ-99X filtered with FWS Poly measured with a spectrometer. The size of the output is around 10 mm with transmission efficiency higher than 75%. Center wavelength and bandwidth were chosen arbitrarily to cover the visible range. From top to bottom (center wavelength/bandwidth, in nm): 480/8, 530/5, 630/8. Insets are actual output.

References

[1] Jun Hee Kang, Cathy Fitzpatrick, "Tunable Filters: Wavelength filtering technology improves spectral imaging". LaserFocusWorld. Optics. (May 2017, pp. 48-51)

[2] https://www.spectrolightinc.com/spectrolight-technology/twinfilm-technology/