Fully automated compact wavelength selection for broadband light sources

A newly developed technique based on rotatable optical broadband filters helps with the selection of wavelengths and adjustment from the UV to near-IR range when using a broadband light source.

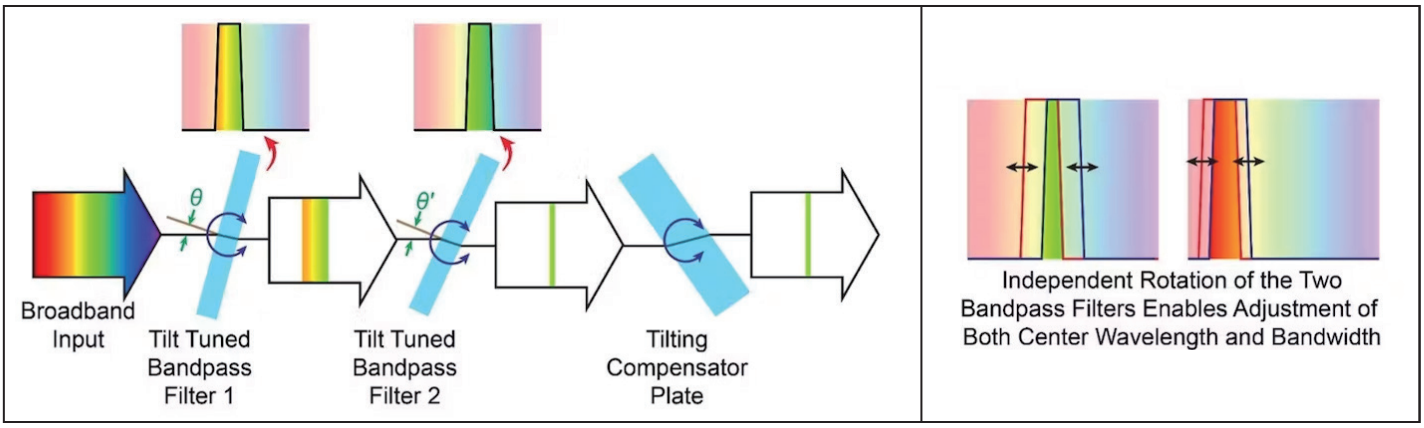

FIGURE 1. Schematic diagram of TwinFilm technology

Selecting a proper wavelength is a critical procedure for spectroscopy and microscopy. Traditional methods such as filters, monochromators, and acousto-optic tunable filters have advantages and disadvantages. Users choose the best item suited to their purpose of use, costs, required properties, and compatibility with their system. A newly developed technique based on rotatable optical broadband filters allows users to select a wavelength and adjust width from ultraviolet (UV) to the near-infrared (near-IR) range when using a broadband light source.

Spectroscopy and microscopy, which both use light to obtain physical and chemical information through interaction with objects, have continued to progress with the development of various light sources, improvement of detector sensitivity and processing speed, and development of optics manufacturing technology. They are used in a wide range of fields, such as academic research as well as medical and industrial applications.

In the case of spectral imaging, physical values for different variables in a sample can be measured through mapping, leading to active use in food processing, climate, medical imaging technology, and machine vision. Since the wavelength of light used varies according to the purpose of the techniques, there is a close relationship between the diversity of available excitation wavelengths and the amount of information provided by the resulting spectrum. A laser, a monochromatic light source, is ideal because of its very small full width at half maximum (FWHM), strong intensity, and coherent properties, but it comes at a high price to cover the entire usable light range. Therefore, optics or devices that can select and use the required wavelength region from a broadband light source were developed.

Filter wheels

Inside a fluorescence microscope widely used in chemistry and biotechnology, about six filter cubes are installed in the turret, each acting as an excitation filter, dichroic beamsplitter, and emission filter. In some cases, a filter wheel is also installed before the objective lens or the camera to enable selection of specific excitation and emission wavelengths. Usually, 3–12 filters can be mounted on the filter wheel. For example, if six filters are installed on dual filter wheels, a total of 6 × 6 = 36 combinations can be used. When an automated filter wheel with a motor is used, it has a switching time of 30 to 100 ms, depending on the shutter speed.

In the case of organic fluorescent dyes or fluorescent proteins widely used for cell imaging, various filter types were developed for use in the UV and visible to the near-IR range. Therefore, the more diverse the combination of filter sets, the wider the application range. Also, the aperture size is large and can be configured at a relatively low price. But the disadvantages of using filters are that only specified excitation and emission ranges can be used (low flexibility). Damage thresholds are not high so if a strong light source is used, the surface coating may be damaged. And, in general, the filter has a broad bandwidth, so it is not suitable for spectral imaging that needs a light with a sharp bandwidth. It is also impossible to scan for a wide wavelength range.

There is a limitation in constructing filter sets due to Stokes shift. According to the statistical analysis of information on fluorescent dyes provided by Zeiss, dyes with a Stokes shift of 20 nm or less accounted for 26%, while those with a Stokes shift of less than 40 nm accounted for 73% of the total (276 dyes). When using a fluorophore with a small Stokes shift, there must be a spectral overlap between the excitation window and the emission window. To avoid this, it is necessary to transmit light away from the maximum wavelength of excitation, or emission is needed, leading to a certain amount of loss. But new products can adjust any excitation/emission range and spectral width.

Monochromators

Relying on prisms or gratings, the monochromator is another wavelength selection system, widely used for spectroscopy. When light from a broadband light source passes through an entrance slit and a grating or prism, the angle of refraction (or diffraction) is different depending on the wavelength. By properly rotating the grating or prism, only a certain wavelength can exit the narrow slit. The monochromator adjusts the bandwidth according to the width of the slit, scans over a wide wavelength range, and selects the desired wavelength.

It is also possible to prevent leakage of strong excitation light, which is a problem when using a filter. But to obtain a 2D image, a line-by-line or point scan is required, which is more expensive than a filter and the device configuration is complicated. It is also impracticable for wide-field imaging and has poor throughput compared to filters.

Acousto-optic tunable filters

The acousto-optic tunable filter (AOTF) is an electro-optical device that modulates light from a broadband light source to various wavelengths and intensities. Birefringent crystal—tellurium dioxide (TeO_2) or quartz anisotropic crystal—is used and the refractive index of the crystal changes via interaction with an acoustic wave (radio frequency). Tuning the acoustic wave allows only a specific wavelength to pass through the aperture and intensity can also be adjusted. Although an AOTF is a compact device, it has a very wide tuning range and offers advantages such as fast tuning speed and high spectral resolution. It does have disadvantages, including high purchase cost, much smaller aperture compared to filters, and poor out-of-band extinction. Another challenge is that the angle of refraction varies depending on the output wavelength.

Spectrolight developed a device to combine the advantages of existing equipment. The underlying technology is TwinFilm technology, which consists of broadband angle dependence bandpass filters and a compensator plate (see Fig. 1). The bandpass filters are independently rotatable, converting collimated broadband light into any desired combination of center wavelength and bandwidth. The compensator plate offsets the slightly misaligned beam pass by two rotating bandpass filters. This technology shows out-of-band extinction suppression effect (10-6) like a monochromator and has a uniform property of about 95% at a clear aperture of up to 10 mm, similar to a filter. The transmission efficiency is more than 75%, which is significantly higher than an AOTF or grating, and the walk-off phenomenon in an AOTF does not occur due to the role of the compensator plate. It has very sharp excitation and emission windows, and the bandwidth can be adjusted from 3 to 15 nm in FWHM. Also, its tuning range covers the UV to near-IR. These advantages make it suitable for wide-field imaging.

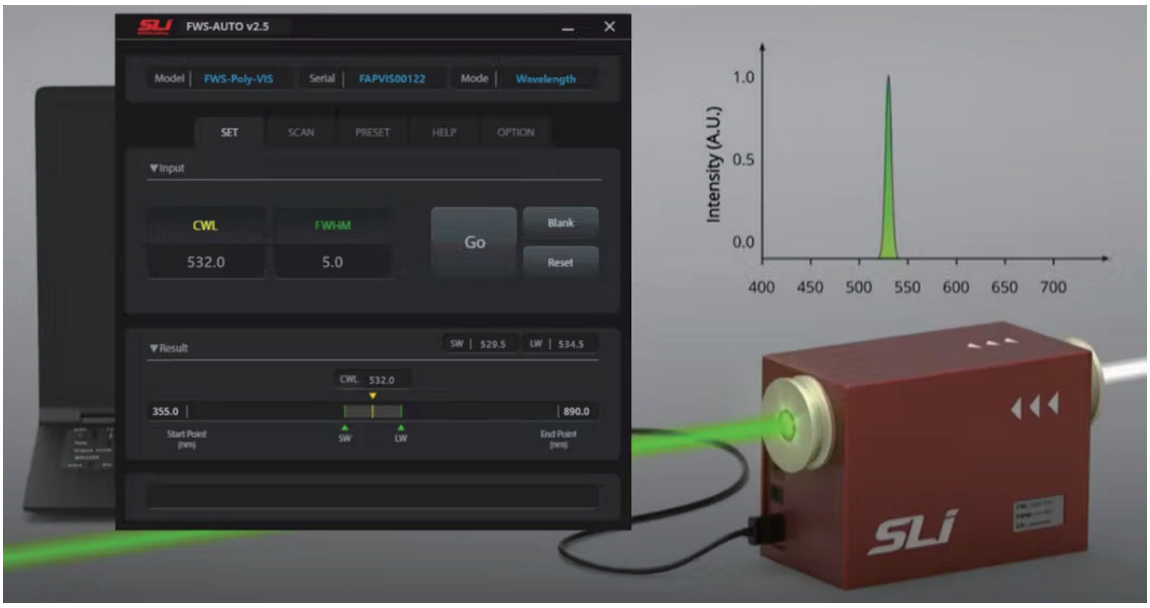

FIGURE 1. Schematic diagram of TwinFilm technology

TwinFilm technology is used to build Spectrolight's flexible wavelength selector (FWS) line, which includes the Automated FWS. The Automated FWS features two versions: Auto Mono and Auto Poly. In earlier models, Auto Mono had a tuning range of ~100 nm; Auto Poly has a broader tuning range. Automated FWS can adjust bandwidth and center wavelength automatically by rotating two bandpass filters by two DC actuators. It is easy to use, with an intuitive GUI (see Fig. 2).

The FWS-Poly can be connected to the computer via a USB interface. Center wavelength, FWHM, etc. can be easily adjusted independently through simple software. FWS-Poly can control the center wavelength within a wide range of ~500 nm, and it is generally adjustable to have a FWHM in the range of 3 to 15 nm. In addition, the center wavelength resolution is very high—about 0.5 nm—and FWHM resolution is accurate to about 1 nm. In the range of 255 to 1650 nm, the extinction coefficient is ~ODavg 12. The IR blocking range is about optical density (OD) 6 in the range of 930 to 1600 nm. It is also resistant to coating damage by a strong light source, which is one of the disadvantages of the optical filter. This means it can be safely used for light sources since the damage threshold is high. Furthermore, the size of the device is very compact, even with this specification, 170 × 129 × 200 mm, and the aperture size reaches up to 5 mm. The rated voltage and current are DC 12V and 5A, respectively.

Connectable to any light source, FWS-Poly is compatible with a wide variety of light sources such as plasma light, halogen lamps, tungsten lamps, supercontinuum sources, and energetic laser-driven light sources (LDLSs).