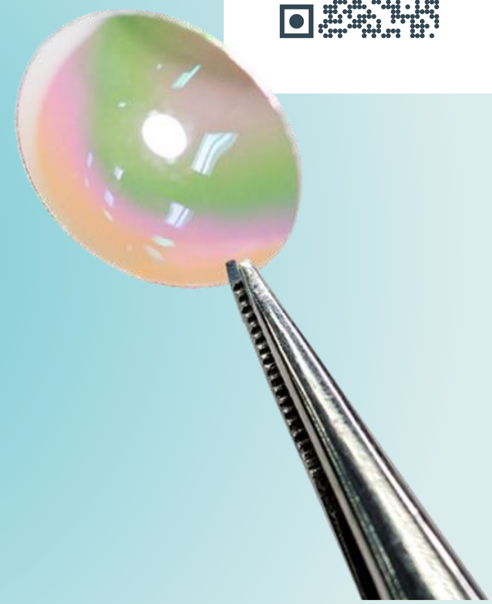
EVERIX Application note

Using curved filters for wide-angle narrow-wavelength LED illumination in fluorescence applications

Curving filters to match the wavefront of an LED or other light source opens up new possibilities for optical design and optimization.



Everix Optical Filters has been refining the production of thin, lightweight optical filters since 2015. One of the unique properties of these thermoplastic-based filters is their ability to be formed into shapes that can solve a fundamental problem in thin-film optics – angle-of-incidence dependence. In this note, we highlight one potential application of such a curved filter – to optimize the spectral performance of an LED light source.

Light-Emitting Diodes have been gaining popularity in applications over the last two decades as the output power and number of available wavelengths has increased. Their small form factor, narrow emission range and directionality make them attractive for small and portable devices, especially in applications that use fluorescence detection.

In a fluorescence detection system, the excitation light hits the molecules of interest, inducing fluorescence which comes out in all directions, some of which enters the detector. Some excitation light is also scattered into the detector and is a source of noise. Most detectors in small fluorescence systems, like point-of-care diagnostics, are single-element detectors which detect total light intensity. In

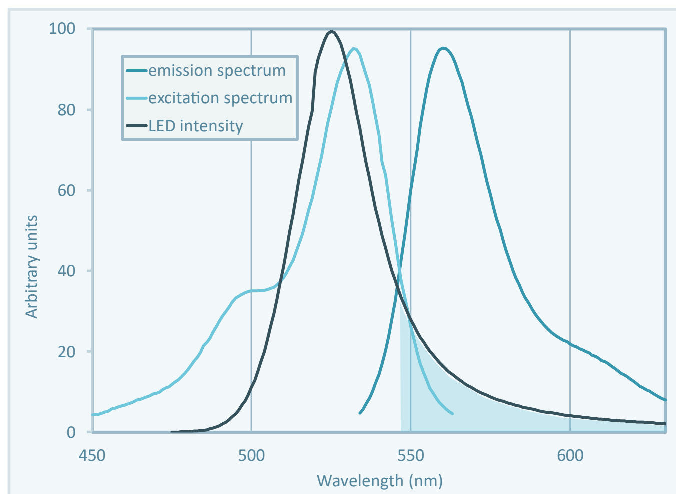


Figure 1. LED emission overlaps with fluorescence emission

contrast, larger systems like those used in fluorescence-guided surgery illuminate a wide area and collect signal into a camera system. In both cases, emission wavelength selection is provided with an optical filter.

Because LEDs have spectral output curves that resemble a Gaussian profile they closely match the excitation curve of the fluorophore (Figure 1). While the LED spectral output is very narrow when compared to white light filament-based lamps, it often still needs to be filtered to increase signal-to-noise, especially in systems with multiple excitation and emission bands. The long wavelength "tail" of the LED spectrum can cause problems if it overlaps with the fluorescence emission of the molecules of interest (Figure 1, blue shaded area), causing an

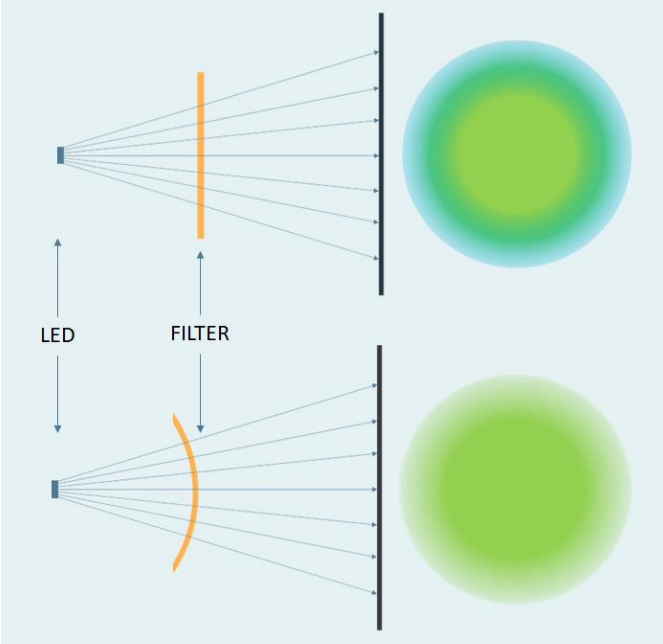


Figure 2. A curved filter prevents angle-dependent wavelength shift

increase in background signal if it is not filtered out at the source. Typically band-pass interference filters are used for this purpose. Short-pass filters are another option if there is only one LED for excitation in the system.

To save space, LED light sources are sometimes used without any collimating or focusing optics. In this case, the LED can be approximated as a point-source where light is emitted in many directions with some intensity distribution (Figure 2). When using a flat excitation filter in front of such a source, the filter

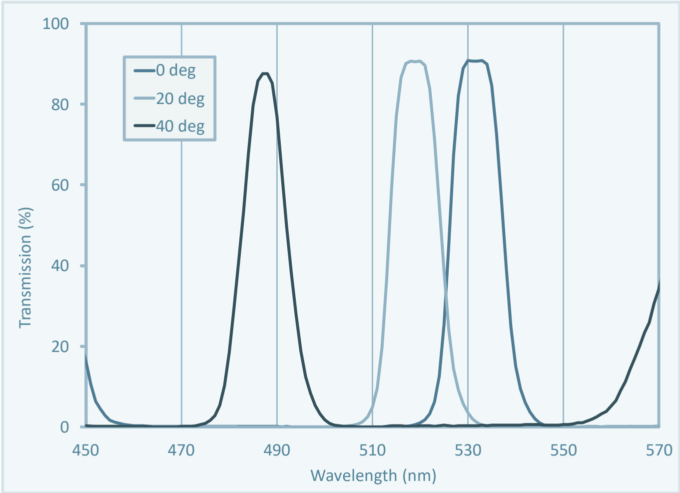


Figure 3. Increasing AOI shifts the filter to lower wavelength

interacts with light from a number of angles of incidence (AOI) simultaneously. In optics, AOI is measured with respect to the normal of the filter surface. Illumination with a flat filter configuration like this results in a spectral bulls-eye pattern where the center of the illuminated field is illuminated by the longest wavelength and the edges are illuminated by the shortest wavelength (Figure 2, top). As the AOI increases, the spectral curve shifts to lower wavelengths and the performance suffers (Figure 3). In fluorescence imaging applications, such as guided surgery, this spectral distribution can reduce the excitation of fluorophores and reduce the emission signal coming back to the camera, reducing the signal-to-noise ratio, especially at the edges of the field-of-view. **The angular shift can be eliminated by forming the filter into a spherical dome to maintain an AOI of 0º** with the LED at the center of curvature of the dome (Figure 2, bottom).

In single-point systems using a raw LED without focusing optics and a flat filter, such as PCR devices, the LED + filter will give an integrated spectral response over all angles and intensities that the LED is emitting. For the LED depicted in Figure 1, the light intensity drops 73% from AOI = 0 to AOI = 40. The total integrated response of the filter over these angles and intensities is altered as shown in Figure 4. The peak transmission is much lower, shifted to lower wavelengths and the shape of the bandpass is severely degraded. Further, the blocking region shifts to lower wavelengths and begins to let the red tail of the LED emission into the fluorescence

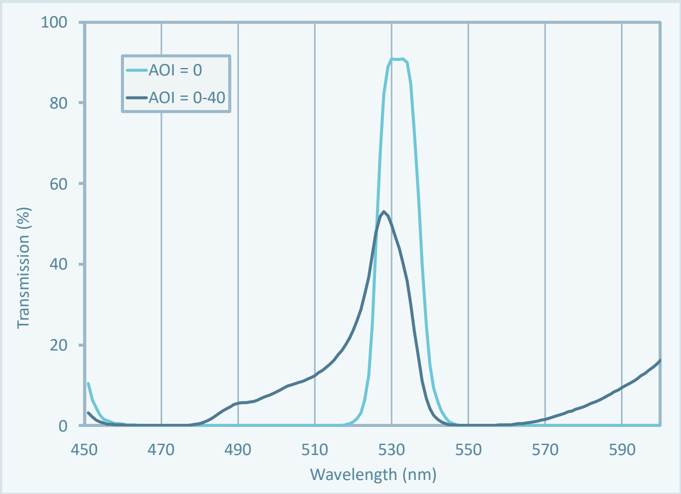


Figure 4. Filter spectrum at normal and integrated 0-40º AOI

emission detector, further reducing signal to noise ratio. As discussed above, **CURVING the filter to match the spherical wavefront of the LED light alleviates the spectral distortion**. When a filter is curved, the light from a point source at the center of curvature will always hit the filter at normal incidence to provide the best spectral performance. Figure 5 illustrates the spectral irradiance profile of the filtered LED using a flat filter and a curved filter, both over a 40 degree angle range. The curved filter

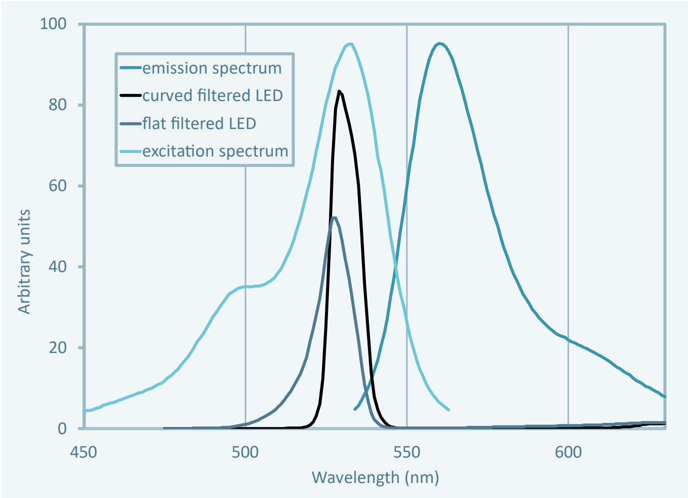


Figure 5. Filtered LED with excitation and emission

maintains high transmission and tight spectral response, while the flat filter shows less throughput over a wider wavelength range. This can become very important in systems with multiple LEDs and fluorescent labels being detected simultaneously.

The use of curved filters enables filters to maintain their spectral fidelity at very high angles. Everix is positioned to develop custom-curved filters unique to your geometry and optical system, including embedded curved filters and adhesive-backed filters. The curved filter concept also opens up new possibilities in optical design and miniaturization. Contact Everix to learn more about our unique capabilities.