Divide to Conquer: Practical considerations for measuring the output of commercial UV LED sources

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The first commercial UV LEDs were mainly 395 nm with low intensity levels. In a short time, LED sources continue to evolve in irradiance (W/cm^2) and energy density (J/cm^2) values as diode output increases (approaching 30W/cm^2) and array sizes become larger. A broader selection of LEDs with spectral output in the 365 nm, 385 nm, 395 nm and 405 nm regions are commercially available while work continues in other bands including shortwave (278 nm) UVC LEDs (spurred by interest in germicidal applications).

The output levels of commercially available LEDs give users more flexibility than was previously available. The choice of appropriate LED band to be used depends on the application, chemistry and desired cure characteristics required for the final product.

In some regions, a 395 nm LED source is more common than a 385 nm source, while in other areas, the 385 nm LED is the first choice. Are such differences a case of "follow the leader" or a regional formulator preferring to work with one particular LED band? In the past, it was not uncommon for a particular UV source to be specified, not because it was necessarily the optimum lamp, but because it was the UV source available in the formulator's own laboratory. Or, is a 385 nm LED preferred in some applications because the chemistry is further away from the visible spectrum?

Given the pace of technological improvement and the emergence of a vast number of LED source choices now available, the following trends have been noticed:

1. The time when you could assume that an LED that you encountered was a 395 nm source is long gone. In the course of a day, a coating formulator, field service technician, corporate R&D team and/or LED source supplier may work with a 395 nm source in the morning and a 365 nm source in the afternoon.

2. LED uniformity and commercial binning practices to a stated bandwidth (+/- 5 nm) can vary markedly from supplier to supplier. Variations in spectral output and intensity between modules might cause issues if working across multiple lines, multiple locations and with multiple suppliers.

3. It has been common practice for production lines to utilize multiple broadband mercury sources optimized to take advantage of the spectral output for different type (such as mercury, mercury-iron, or mercury-gallium) bulbs. With broadband sources, it is important to make sure that the right bulb is in the correct location and the output meets desired process values. Customers utilizing multiple LEDs have also started to optimize production lines and use different wavelength LEDs in different locations on the production line. With LEDs, it is also important to make sure that the proper LED is in the correct location and that its output meets desired process values.

Given these industry trends, proper measurement has become an even more important consideration on the production floor. There are two common approaches to measuring UV LED light sources: a one-size-fits-all, wide-band, response and a more selective, narrow-band response alternative. Note: The term 'wide-band' was purposely used to avoid confusion with the term 'broadband' which is used in this paper to describe mercury-based sources which emit energy over a 'broad' (UV, visible, IR) band or portion of the electromagnetic spectrum.

Wide Band Response
The wide band response features an instrument response that may be 100-200 nm wide, with the instrument manufacturer determining the actual width and response shape of the band. The attraction of the wide band response approach is that it allows the user to have one instrument. Instruments with wide band responses have been used for many years with mercury-based sources.

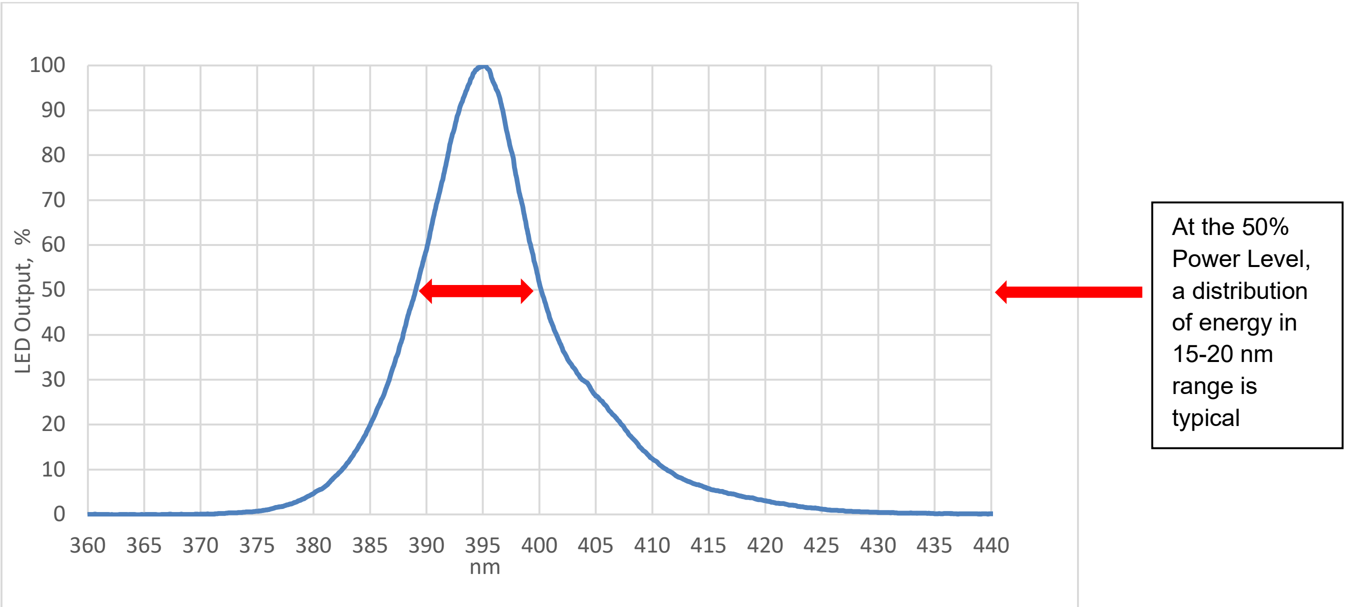
Narrow Band Response
The narrow band response features an instrument response approximately 50-60 nm wide, with the instrument manufacturer determining the actual width and response shape of the band. Consequently, if you cure using UV LEDs that have different spectral outputs, a narrow band approach requires that the user to either have an instrument for each LED band or have a multiband LED instrument.

Multiband instruments have been available for broad band mercury sources for almost 30 years. They allow the user to track both irradiance and energy density values in multiple bands (historically designated as UVA, UVB, UVC, UVV) with one reading. By tracking the broadband values and their ratio to each other; bulb types (mercury, mercury-iron, mercury-gallium), aging in bulbs and the reflector cleanliness (UVA:UVC ratio) can be identified. Monitoring the ratios of output across the various bands can be useful with predictive maintenance.

Figure 1: Display screens from broadband (left) and LED (right) multichannel radiometers

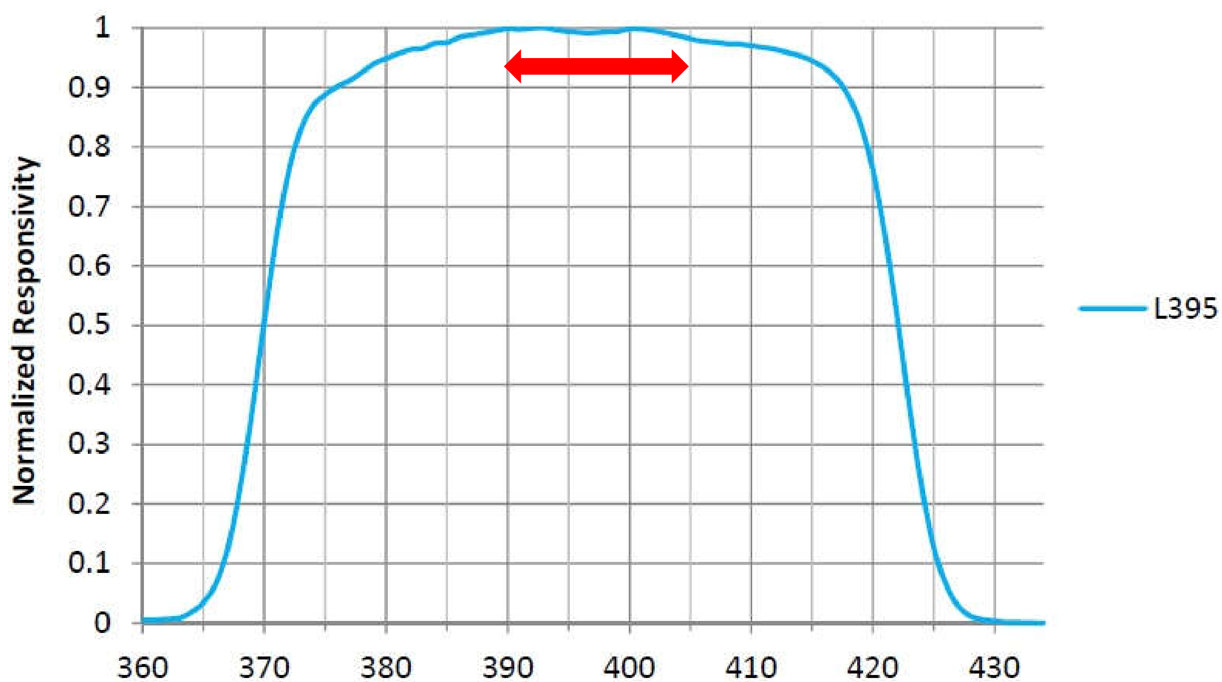
Comparison of Wide Band and Narrow Band Response Instruments for LEDs
Most commercial LEDs are specified according to a Center Wave Length (CWL) with a typical tolerance of +/- 5 nm. The CWL represents the expected center point of the peak power. It is important to verify this specification with your source supplier. For a 395 nm LED, the CWL is expected to fall between 390-400 nm. At the 50% power level, the spectral output may spread to out to a total distribution of 15-20 nm and at lower levels, to 40 or more nanometers as shown in Figure 2 below.

Figure 2: Typical 395 nm UV LED Energy Distribution (Courtesy EIT LLC)



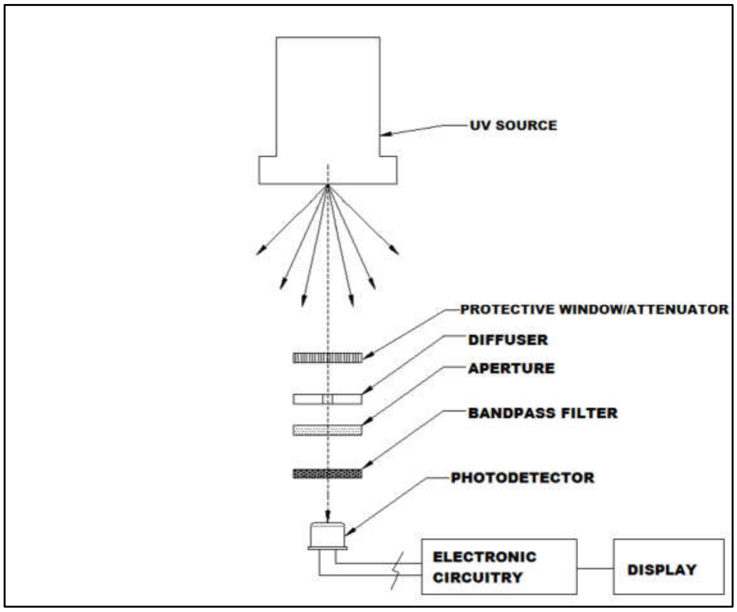
Therefore, to obtain accurate irradiance readings, it is important to use a radiometer with a response as flat as possible over the 10 nm CWL range of interest. It is important to recognize that it is easier and more reliable to achieve a flat response over the width of a narrow band than it is to achieve a flat response over a wide band.

Figure 3: EIT L 395 response showing flat response over the CWL range target of 390-400 nm (Courtesy EIT LLC)



This is easier to understand when you consider the many components that constitute the stated instrument response. Traditionally the response of just the optical filter has been used to describe the overall instrument response. However, a more realistic approach to instrument response, pioneered by EIT in LED instruments is to specify an instrument's response based on all optical components in the instrument and not just the optical filter. Figure 4 is a representative diagram of the optics in a typical instrument.

Figure 4: Representative diagram of the optical components in a radiometer. (Courtesy EIT LLC)



Each component in the path of the UV shown in Figure 4 has its own optical response. Thus, to produce an instrument with a flat total, or overall combined response, engineers face the challenge of considering how all the components behave when integrated together. It was challenging to generate a flat overall response of all optical components with a narrow response, and not practical to generate a flat response utilizing all optical components over a very wide band.

The result is that EIT's patented *Total Measured Optic Response* is a device with excellent run to-run repeatability on single sources, multiple sources and with different instruments.

Instruments perform best in a production environment when the calibration is performed using a similar or the same type source that the instrument will measure in production.

A wide band source will use an UV source and a point somewhere along the instrument response curve to generate values in the instrument. Similarly, for a wide band instrument, if a 395 nm LED source is used, the instrument will match best when it measures a 395 nm source.

A narrow band instrument will use a calibration source that closely matches the instrument response. A 395 nm LED is used to calibrate the L395 band and 365 nm LED source is used to calibrate the L365 band. This leads to better instrument performance in a production environment.

With a wide band instrument, there is one irradiance value and one energy density value. This makes it easy to use and understand but it does not identify the LED type. However, if multiple LEDs are present, the reading will be a combination of all sources the instrument has been exposed to.

Figure 5: Irradiance and Energy Density values-single band instrument, single LED

A narrow band instrument with one band will also show one set of irradiance and energy density values. (Figure 5).

Figure 5 shows that the instrument passed under one LED Source.

Figure 6: Irradiance and Energy Density values-single band instrument, dual LED

In the case of multiple sources (Figure 6) the Irradiance value will be the peak of the highest LED source while the Energy Density value will be the sum of the two LEDs.

Note: A Profiler-enabled unit will allow you to download the irradiance Profile and separate out the values from each LED.

A narrow band instrument with multiple LED bands has multiple optics stacks in order to measure the UV in the multiple bands. The EIT approach is to center each L-Band response over the Center Wave Length (CWL) of common LED Sources (so that a popular configuration would include L365, L385 L395 and L405).

Figure 7: Image of multiband LEDCure® Four Band Profiler (Courtesy EIT LLC)

The *Total Measured Optic Response* of each EIT L-Band is shown in Table One below

Table One: EIT L-Band Responses

L-Band	Optics
L365	340-392 nm
L385	360-412 nm
L395	370-422 nm
L405	380-432 nm

Figure 8: Display of Multi-band LEDCure instrument

There is overlap in the EIT L-Bands. Because of this, energy from a 365 nm LED will also show up in other bands.

The values collected on the display in Figure 8 were from a 365 nm LED. The irradiance values are highest in the L365 band and the L365 values should be the ones recorded for the source.

Because of the band overlap, you cannot add the values together from each of the four bands to come up with a total UV value. If the source type is known you should use that value.

LED sources and the quality of their 'chip' binning vary from manufacturer to manufacturer. A 395 nm LED with +/- 5 nm binning should have its peak output between 390-400 nm. We would expect the peak irradiance value to be on the L395 section of the display. If the LED has been assembled using 400+ nm chips, the L405 value may be higher.

Compared to a spectral radiometer, the multiband LEDCure offers an easy way to gauge the uniformity of the CWL on LED sources based on the binning.

This may be important if there are multiple LEDs used in a process, either across a wide production line or in a sequential manner.

A multiband LED radiometer is not for everyone but will be beneficial for coating formulators, field service technicians, corporate R&D teams and LED source suppliers who routinely deal with multiple LEDs in the course of a day.

Another important function of the LEDCure is the Profiling function. The irradiance profile (Watts/cm^2 as function of time) can be transferred to a computer for further analysis.

The Profiler will allow you to break down individual passes under an LED to get the irradiance and energy density values from that LED. This can be as simple as isolating two passes on a conveyor (Figure 9) or 30 passes from a digital printer (Figure 10)

Figure 9: Two passes under an LED. Cursors around the LED on the left to determine the values from that LED.

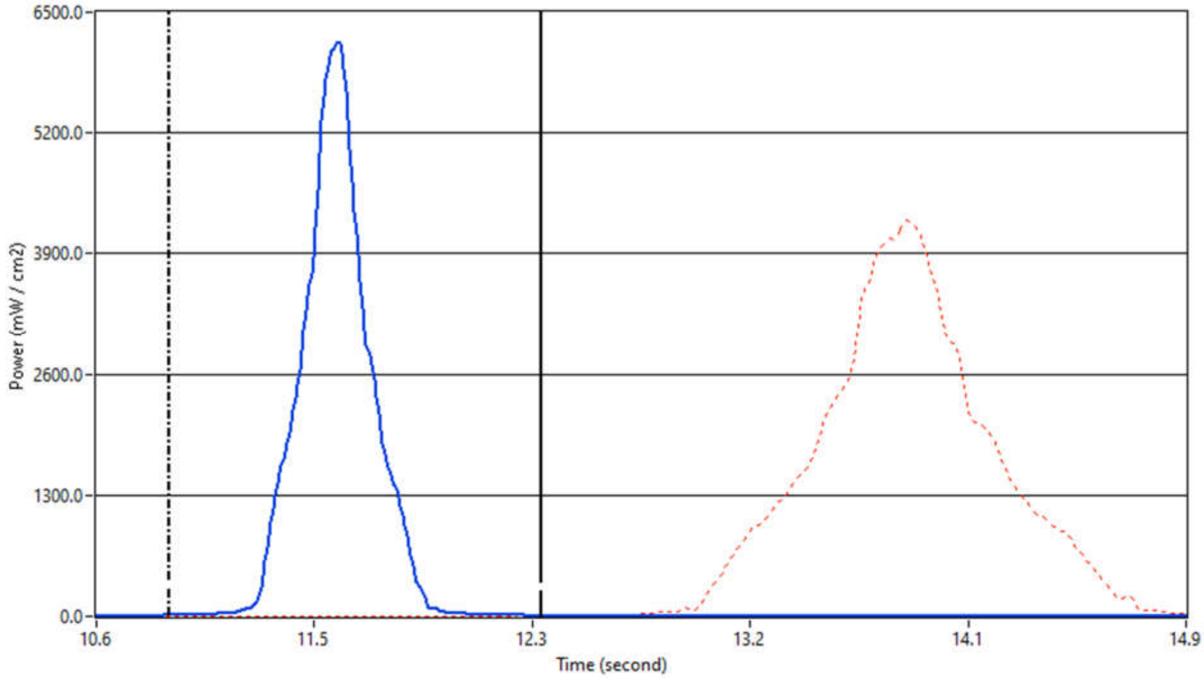
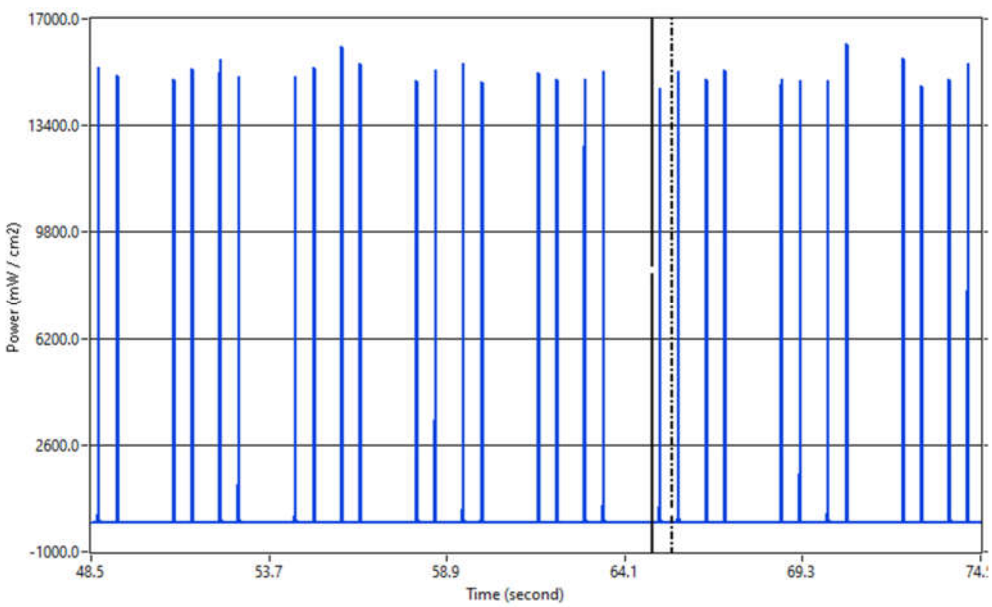


Figure 10: 30 passes collected with LEDMAP under a high-speed digital printer



Production lines with LEDs are starting to use LEDs with multiple wavelengths.

Figure 11 shows the layout of a wood production line using seven LED sources and five mercury sources. The LED sources are a combination of 365 nm, 395 nm and 405 nm sources. Overall the line represents a significant reduction in the total number of UV sources needed.

Figure 11: Layout of wood curing line using multiple LEDs and mercury bulbs developed by Efsen UV & EB Technology. Image courtesy of Efsen UV & EB Technology

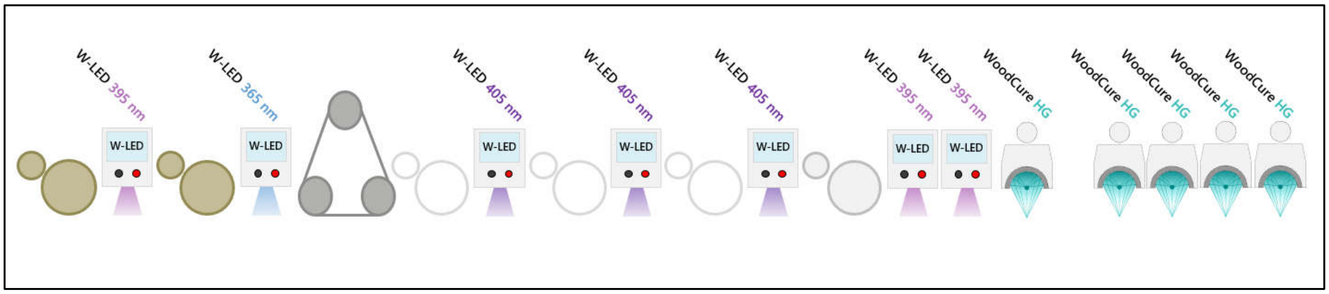


Figure 12 shows the corresponding irradiance profile from this production line that was collected with the LEDCure Four Band Profiler. On the screen, the peaks of the different LED units are shown in different colors. One instrument run down the line identifies the different LED types. The Profiler function and use of cursors allows you to isolate each lamp and compare it to the values established when the process window was established. The mercury sources also show up at the end of the run.

Figure 12: Irradiance Profile collected on wood line with multiple LED types with the LEDCure Four Band Profiler. Image and data file courtesy of Efsen UV & EB Technology

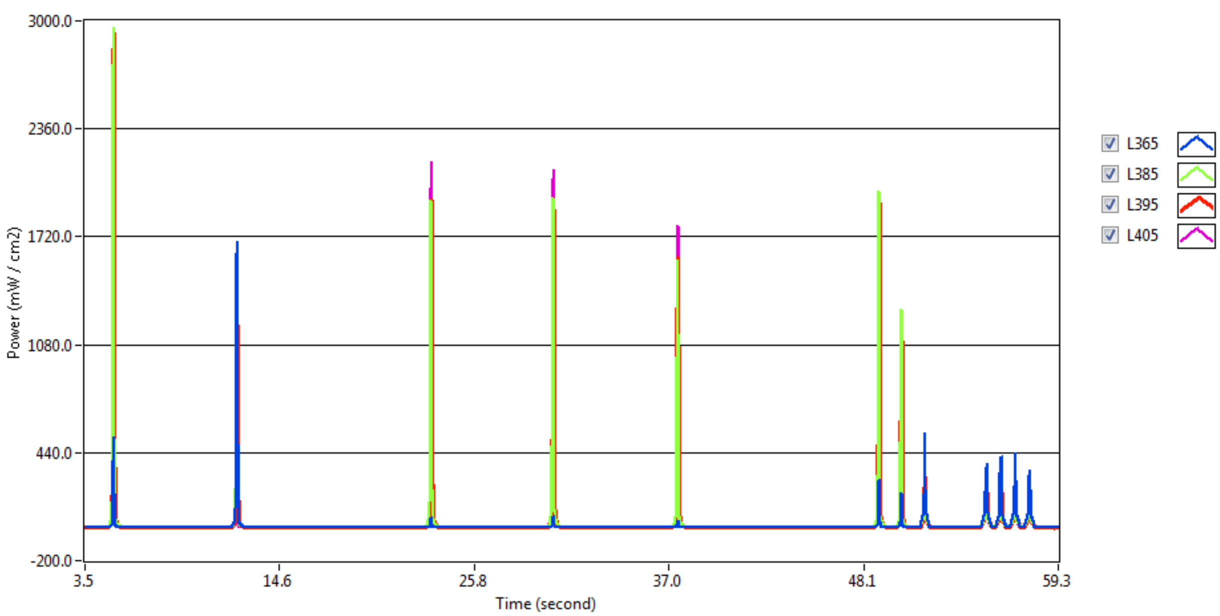
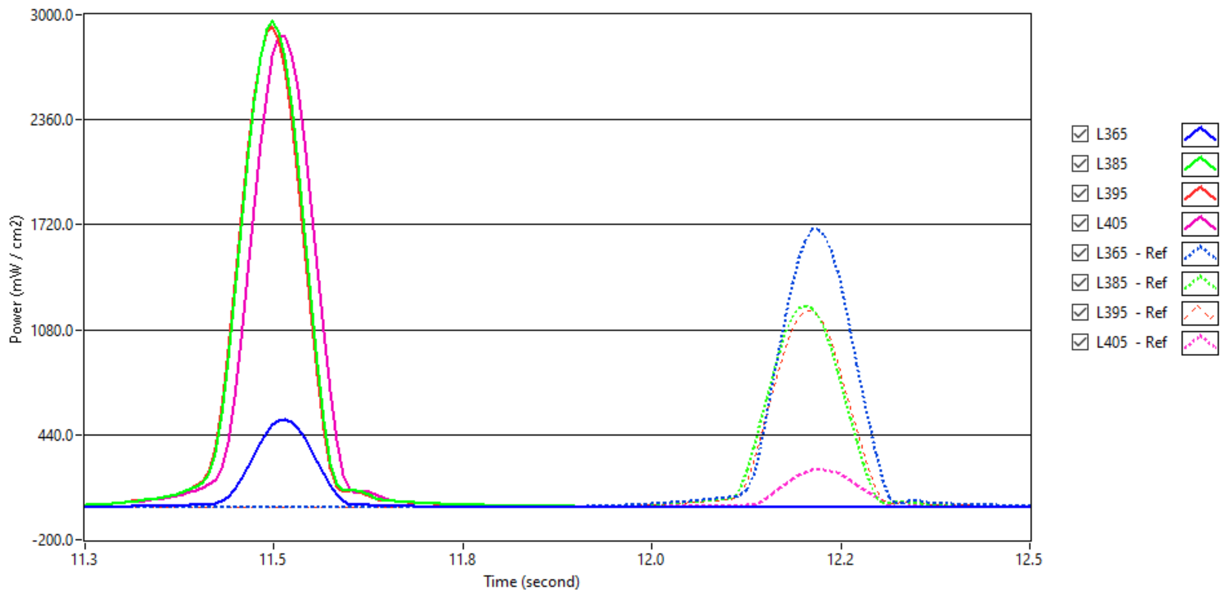


Figure 13: Two different LED types from the file above shown. The LED on the left is a 395 nm LED while the LED on the right is a 365 nm LED. Image and data file courtesy of Efsen UV & EB Technology



Summary

Given the inherent variation of the many components needed to make accurate UV measurements, user's will need to decide if a wide band or narrow band radiometer better suits their needs as there are advantages and disadvantages with each approach.

The Profiler function in a radiometer will help users to isolate and measure the parameters of individual LED lamps.

This paper introduces a new product, a multi-band LED with a profiler feature. Early feedback and data collected provides empirical evidence that such an instrument provides beneficial information in terms of process control.

This type of information will be of particular value to raw material providers, for coating, ink and adhesive formulators, field service technicians, corporate R&D teams and LED source suppliers who routinely deal with multiple LED types in the course of a day.

The multiband approach with profile feature will help identify LED types in the production lines and allow isolation of each source for better analysis and troubleshooting.