Measuring the Output of UV Light Emitting Diodes (LEDs)

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Abstract: As UV lamp technology changes, so must the tools we use. The evolution of UV LEDs to cure inks, coatings and adhesives is having an effect on UV measurement equipment and technique. UV LEDs are narrow bandwidth sources with typical emission in the 365-405 nm region. Contrasted to medium pressure UV microwave and arc lamps, which emit across a broad spectrum, UV LEDs have high output in a very limited spectral region. This paper will address some of the confusion arising from the specification and measurement of UV LED sources. The paper will address the need for correct filtering, the complications posed by LED optics and other characteristics of LEDs that has led to the development of new radiometers and the establishment of a new spectral band designation, UVA2, for these devices.

Introduction

Are visible LEDs here to stay? A Google™ search of "LEDs" returns over 17 million results and LEDs have penetrated into all sorts of visible applications.

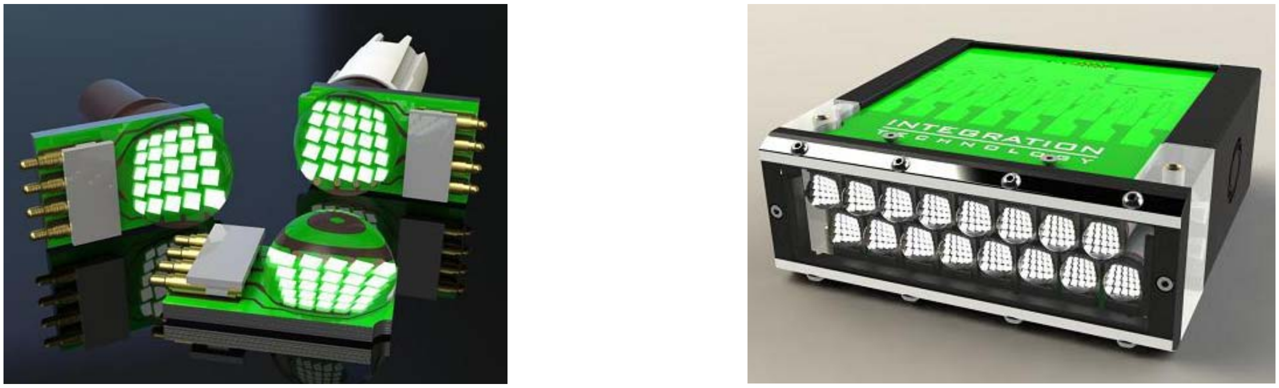


Figure 1: LED Modules (left) and LEDZero Solidcure™ (right) from Integration Technology
Images courtesy of Integration Technology

What about UV LEDs? A Google™ search of "UV LEDs" returns over 4.8 million results. Keep in mind that not all "UV LED" 'hits' are applicable to 'curing' applications, but there are a number of commercial curing applications already using UV LEDs. UV LEDs are being used in wide format digital printing, printing brand logos on products and coding information on sales tags and gift cards.

Several articles are available that discuss UV LED sources, applications, and formulations as well the economics of curing with UV LEDs. This paper is not intended to discuss the merits, advantages and disadvantages of UV LEDs but instead is intended to educate and inform on the key aspects of UV LEDs measurement.

LED History & Trends

How many of the ‘mature’ folks reading this paper had their first ‘LED’ experience when they put down a slide rule and picked up a (very expensive at the time) hand held calculator in the early to mid 1970’s? This same calculator can now be bought in many cases for less than the cost of a large cup of specialty coffee. Looking at the history of LEDs/UV LEDs helps us understand the challenges of measuring them.

LED Lighting History

1907 – First Light Emitting Solid
1955 - Infrared LED
1962 - Red LED
1971 - Blue LED / 1993 production
1972 - Yellow LED / 90's production
1972 - Amber LED / 90's production
1995 - White LED / late 90's production
Late 90's - UV LED / late 90's production

www.refraction.net/Question/LED/LED_history.php

Figure 2: History of LEDs/UV LEDs

Figure 3: Array of UV LEDs from Phoseon Technology. Images courtesy of Phoseon Technology

LED Output Power-Déjà vu all over again?

UV LED sources continue to increase in power. The output of UV LED’s has gone from milliWatts/cm^2 of irradiance to Watts/cm^2 of irradiance with some systems in the neighborhood of 10W/cm^2. Output irradiance is usually one of the first numbers an LED manufacturer will share with you. Do the discussions (and claims) of increased output from UV LEDs sound similar to discussions on computer processor speeds and memory? A little closer to our UV world, do the discussions (and claims) sound similar to discussions (and claims) that were held in the 70’s and 80’s with traditional UV arc lamps? In the 70’s and 80’s, a lamp with more applied electrical power certainly ‘had’ to be better than a lamp with less applied electrical power. A system with 400 watts/inch of applied power was certainly better than a system with 200 watts/inch of applied power. Which company would be the first to reach 600 watts/inch of applied power? 800? 1000?

Many were quick to realize that comparing the power applied to the lamp is not as meaningful a measure in the curing process as measuring the amount of useful UV energy delivered to the product. Sometimes, for design and engineering reasons, a UV source with higher applied power actually delivered less useable UV.

As discovered with arc lamps, increasing the applied power or amount of UV delivered to the cure surface was not always beneficial to the cure process or substrate. For each application, a balance between the amount of UV and other types of radiation (visible, IR) produced along with the formulation, substrate, application, needed processing speed and desired results needed to be found. This balance or ‘process window’ also needs to be found with applications using UV generated from LED sources.

With traditional UV sources, it is important to understand, document and maintain your UV system. This includes bulb type (mercury, mercury-iron, mercury-gallium), how the system is set up (focused, non-focused, additional equipment such as quartz plates) and the irradiance (W/cm^2) and energy density (J/cm^2) values expected.

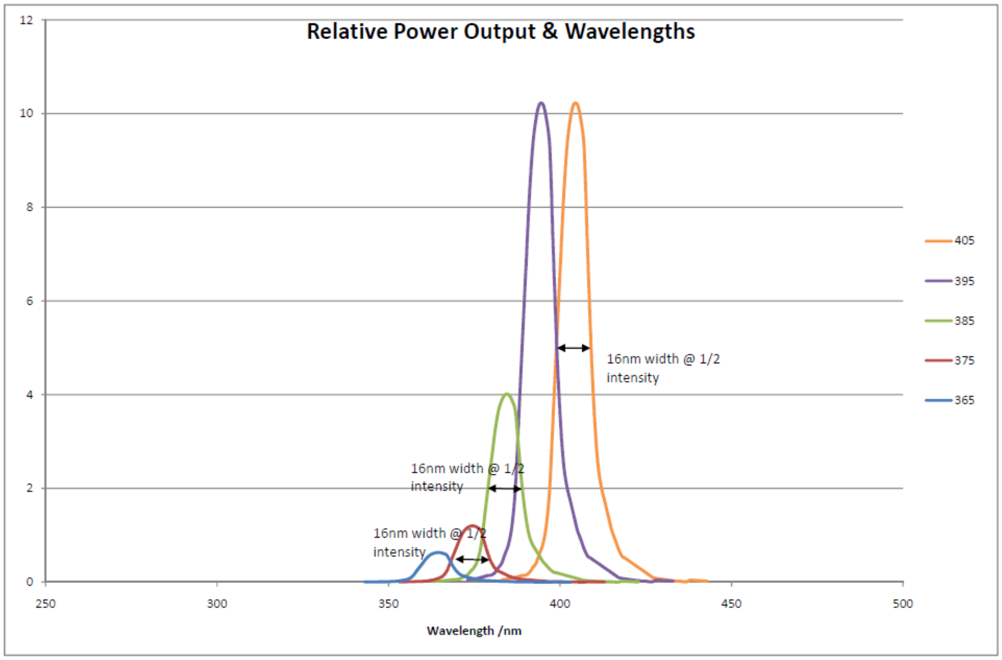


Figure 4: Relative UV LED output for various wavelengths.
Courtesy Integration Technology

It is also important to understand, document and maintain your UV LED system. The spectral output of LEDs is described in nanometers (nm) such as 390 nm. The actual plus/minus (+/-) range of the spectral output of the LED will vary from manufacturer to manufacturer.

Though many of us think of LEDs as those ‘Radio-Shack’ type of discrete lamps used in our consumer electronics such as a garage door remotes, UV LEDs are being packaged in a wide range of shapes and sizes, from large discrete devices to hundreds of nearly microscopic individual LED dies arranged into powerful arrays.

Lamp suppliers use a variety of techniques to assemble, direct and deliver the UV energy to the cure surface from the actual LED ‘chip’ or ‘die’. Manufacturers have proprietary processes to ‘bin’ LEDS by their spectral output, forward voltage and intensity. There are a wide variety of LED array shapes available.

Many UV LED systems were developed for a specific application and fit into areas that will not support other types of UV technologies. Manufacturers are concerned with keeping the array stable over time. Ask questions and evaluate the equipment carefully. In the ‘more is better’, manufacturers of LED systems may use different techniques to determine the power rating of their systems. The techniques can include theoretical calculations of the output and measurement of the UV at different points. Some manufacturers may measure the output at the chip surface while others at the cure surface. Ask questions and evaluate the equipment carefully; making apples-to-apples comparisons.

The Lab to Production Transition Is Work

How a specific UV LED system performs for your application is more important than the maximum power output number on a sheet of product literature. Do you get the results that you are looking for at the manufacturing speed that you need for production?

There has been impressive recent progress made in the development of coatings that specifically formulated to work with LED systems. LEDs, because they are monochromatic, lack the shorter UVC wavelengths that are traditionally used to establish the surface cure properties such as tack, scratch, stain and chemical resistance. This is not the show limiter/stopper that it once was and you need to work with both your formulator and the LED supplier to achieve the properties desired in the final cured product.

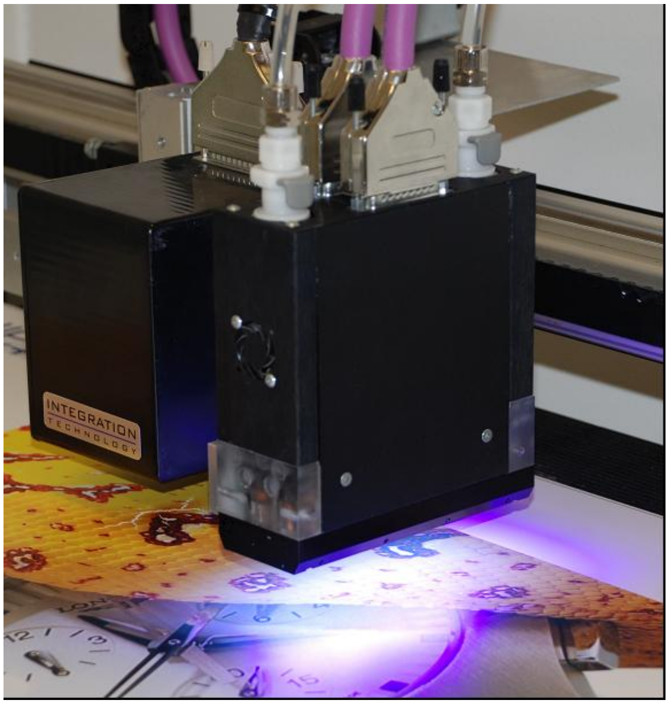


Figure 5: UV LEDs at work

You do not get a free ‘go directly to production manufacturing’ pass when working with LEDs. The laws of physics, photochemistry and Mr. Murphy do not cease to exist when you use LEDs. They are present and lurking but can be minimized by taking some precautions:

- During process design and testing, establish how you are going to measure the UV output of the LED.
- Define the key process variables that need to be monitored and controlled in production?
- Establish your process window in the lab and carry it over to production.
- Exercise caution when you communicate radiometric values either within your company or to your supply chain. Specify the process you used to obtain the readings and the instrument/bandwidth used.
- Determine how often you need to take readings; based on your process.
- While it is true that LEDs will last longer than many other types of UV sources, be aware of anything in the process between the LEDs and the cure surface that could change and alter the amount of UV delivered to the cure surface.

Absolute values established during the design phase often become relative readings during day to day production. With relative readings, you are looking for day-to-day or week-to-week changes and working to make sure that the UV levels stay within the process window established during process design and testing.

Measurement of UV Arc and Microwave Sources

Radiometers used for measurement of UV arc and microwave sources have bandwidths (UVA, UVB, UVC, and UVV) that match the broad band arc and microwave sources. Instrument bandwidths vary from manufacturer to manufacturer. Some instruments have ‘narrow’ bands (UVA classified between 320-390 nm) while others have ‘wide’ bands (UVA classified between 250-415 nm). Because of these differences, it is important to specify the instrument used to obtain the reading.

Figure 6 shows the output from a mercury or H bulb in 10 nm segments with EIT UVA, UVB, UVC and UVV instrument responses overlaid on the lamp spectral irradiance distribution chart.

What happens if you use these popular radiometers to measure the output of an LED source? Will you get a reading with one of the radiometer bandwidths above with a UV LED? It depends on the type of UV LED and the bandwidth(s) of the instrument. Just because there are values on the instrument display does not mean that the UV LED has been properly characterized.

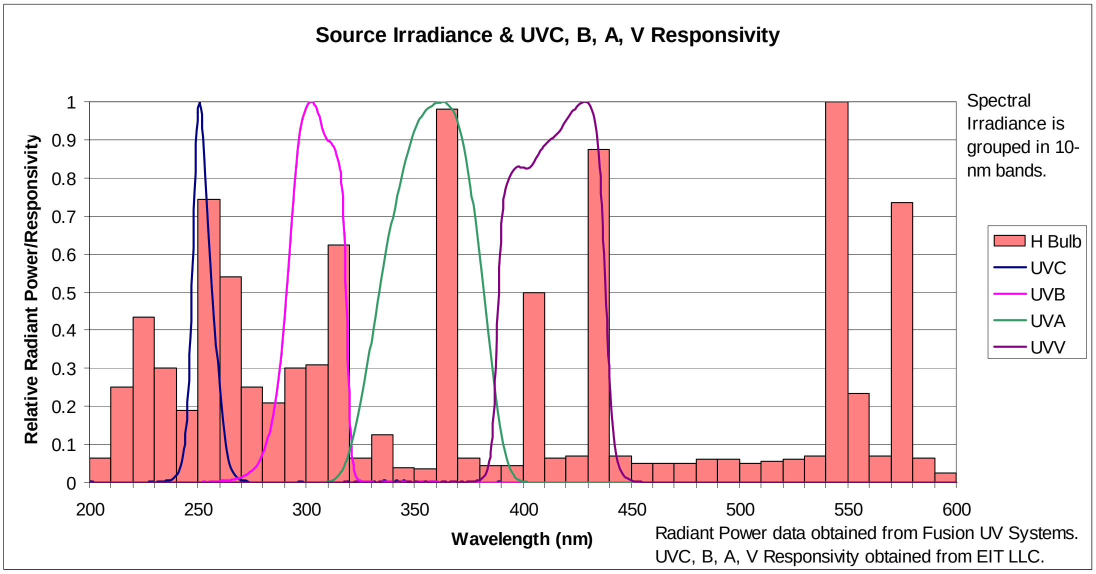


Figure 6: Spectral output of an H bulb and Spectral Response of different UV bands of EIT Radiometer

LED Intensity Measurement and Challenges

In the last ten years, development and application of Light Emitting Diodes (LED) have increased many folds. This dramatic increase in UV intensity has led to an increase in successful commercial applications, and a rise in demand for techniques to gauge properties of LEDs. In principle, light emission from an LED is vastly different than a point source. This poses various challenges in quantifying its intensity. The limitations in standardizing the measuring techniques of LEDs include:

- A point source by definition has a constant radiant flux in all directions but LEDs do not follow equal radiant flux rule. This is because most of the LEDs have micro-optics built into the LED packaging.
- LEDs do not follow the inverse square law (i.e. intensity of light reduces by square of the distance) similar to extended sources. That means that even for the same solid angle, intensity measurements could vary with distance and could be unpredictable.

There has been an incredible amount of research done in recent years at various public and private organizations for developing measurement techniques. Due to several variances affecting intensity measurement of an LED, the Commission on Illumination (CIE) established a standard method guide for LED measurement document (CIE 127:1997).

From the RadTech UV Glossary

flux (radiant flux): The flow of photons, in einstein/second; one einstein = one mole of photons.

One of the most popular ways of measuring radiant flux for an LED is using a photometer at a specified distance and specified area recommended by CIE. Individual LEDs may be characterized this way under controlled laboratory conditions, but the recommended procedure cannot be easily applied to LED clusters and arrays, the arrangement of UV LEDs used for UV production curing applications.

In order to measure total radiant flux, an integrating sphere is used. CIE 127:1997 describes the placement of an LED in a calibrated integrating sphere and measuring total radiant flux. When performing a measurement using an integrating sphere, the intention is to capture all energy.

In real world applications, the user might be more interested in capturing the LED radiant flux for a small solid angle which is also sometimes referred as “useful radiant flux”. In order to make this measurement, CIE’s updated their guidelines in the recently published CIE 127:2007 document include the term “partial” radiant flux.

Traditionally, intensity measurements of a point source are done using Luminous intensity. As described earlier, most LEDs are not point source and do not follow the inverse square law. LED intensity measurements claimed by a manufacturer could vary when the end user performs a similar measurement. When performing a measurement it is always important to know conditions and uncertainties associated with the measurement. Sources of uncertainties that can contribute to the uncertainty of the measurement include:

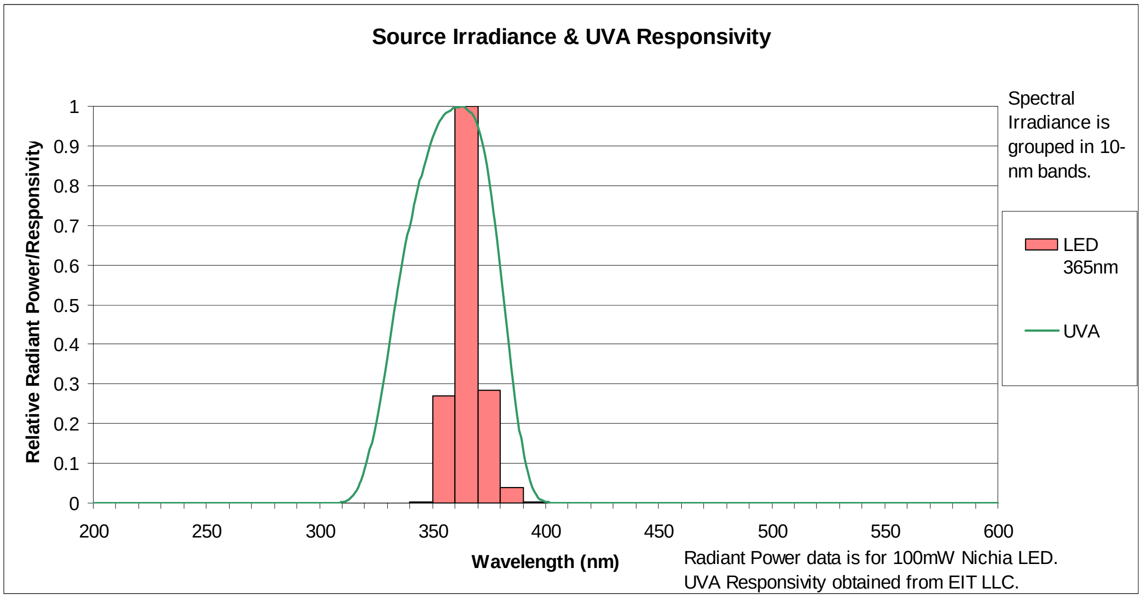
- Radiometer calibration uncertainties
- LED short term wavelength drift
- LED temperature drift
- DC current regulation for LED
- Optical alignment

Industrial applications and setups make it more challenging to easily control and measure the above parameters.

As stated, LED’s have a narrow band emission and hence could have short term or long term wavelength drifts due to temperature variations or degradation over a period of time. Most integrating type radiometers were originally designed for UV arc and microwave sources and have a bell shaped response curve across the UV band of interest.

365 nm LED

Using a radiometer designed for arc and microwave sources can lead to large errors in measurement if UV LED output happens to fall on the rising or falling edge of the optical stack response. Figure 7 shows a 365 nm (UVA) LED source and EIT’s UVA response. The responses have been normalized. If the LED is binned very close to 365 nm, the EIT UVA response does a good job of measuring this source.



Spectral Irradiance is grouped in 10-nm bands.

Radiant Power data is for 100mW Nichia LED.
UVA Responsivity obtained from EIT LLC.

Figure 7: Spectral output of 365 nm LED source and EIT UVA radiometer Spectral Response

But even a small drift in the LED spectral output or variations in how the LED dies are binned can generate different responses in the radiometer, which can have a pronounced impact on the measurement.

395 nm LED

Measuring the output of a 395 nm LED with a radiometer utilizing an EIT UVA or EIT UVV response can lead to wide variations in the reported irradiance values

The output of a 395 nm source is grouped “around the 395 nm line” with variations based on the how individual LED dies are binned, how the array is assembled and the stability of the product over time. These slight variations are normal. It is also normal to expect slight variations in each radiometer due to slight variations in the optical components (filters, detectors, etc) and electronics.

In Figure 8, the output from a 395 nm LED clearly falls between the EIT UVA and EIT UVV response curves. The steepest part of the shoulder of each optical response curve is in the output range of the 395 nm LED. So while it is possible to get a reading with a UVA or UVV bandwidth radiometer, the sharp cutoff at this wavelength means that the readings may reflect only 5-50% of the actual 395 nm LED. The large variation can result from the output being on the steep slope of the response curve, variations between measuring instruments and variations between the LEDs themselves. Because of these variables and their combinations, it is hard to apply a correction ‘factor’ to the UVA reading or UVV readings to any single instrument.

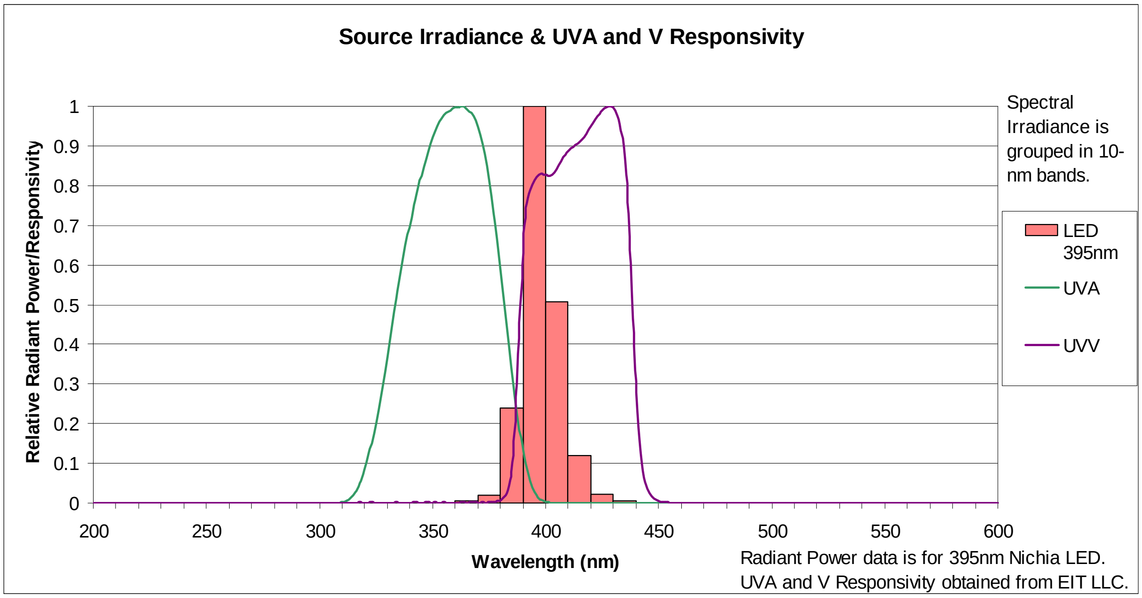


Figure 8: Spectral output of a 395 nm LED source and EIT UVA and EIT UVV radiometer Spectral Response

A better approach to measuring LED's in the 395 nm range is to use an instrument with a response curve that better matches the source. EIT has developed a subset of our 320-390 nm UVA bandwidth now designated as UVA2 (Figure 9). EIT's UVA2 response curve is especially sensitive in the 380-410 nm region. This region better covers the 395 nm LED since under normal conditions the source does not fall on the steep shoulder of the response curve. Extensive testing was done to get the UVA2 radiometer optical response to proximate a "flat top" response. A "flat top" response limits the shifts in the measured values due to slight spectral variations in the source.

The EIT UVA2 response bandwidth inherits a Lambertian spatial response by design from early generation EIT radiometers which further reduces measurement errors due LED alignment.

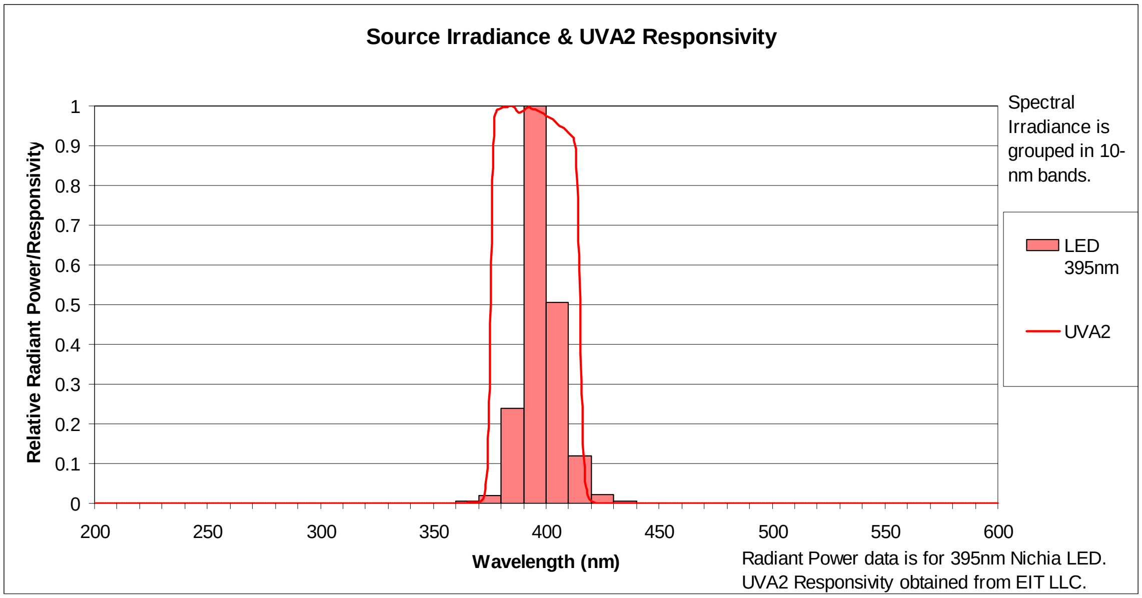


Figure 9: Spectral output of a 395 nm LED source and EIT UVA2 Spectral Response

The UVA2 bandwidth is currently available as a single band instrument (UviCure Plus II) or in a Power Puck II with UVB, UVA, UVA2 and UVV bandwidths.

Acknowledgement

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