Measuring the Output of Ultraviolet Light Emitting Diodes

By Jim Raymont and Abhinav Kashyap

This article is based on a submitted paper and presentation delivered at the RadTech 2010 Conference in Baltimore, Md.

Multiple articles and papers are available that discuss the construction, advantages and disadvantages of Ultraviolet (UV) Light Emitting Diodes (LEDs) sources. This article will focus on understanding and measuring the output of UV-LEDs.

Medium-pressure UV lamps (microwave and arc) emit radiation across a broad electromagnetic spectrum. Output from these types of sources includes UV, visible and infrared (IR) energy.

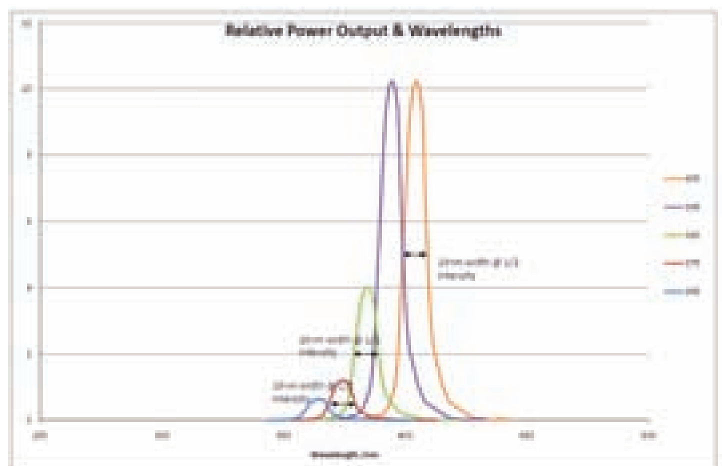
UV-LEDs are narrow band sources. Production UV-LED sources have their spectral emissions somewhere in the 365 to 405-plus nm region. UV-LEDs are described and identified by their most dominant (395 nm, etc.) spectral output. If measured with a spectral radiometer, the user would see that the manufacturer has binned the individual LED chips so that the most intense UV output is clustered around the dominant name line (i.e., 395 nm if the source is a 395 nm source). It would be very expensive to only use 395 nm LED chips in this example and, in reality, it is common for the actual spectral emission of a UV-LED to extend plus/minus 8-15 nm in either direction at the half-maximum power point from the maximum.

Autobond inkjet spot varnish system with UV-LED curing.

Courtesy of Autobond Ltd.

FIGURE 1

Relative UV-LED output for various wavelengths



Courtesy of Integration Technology

Measuring and characterizing LEDs requires an understanding of your UV source and UV measurement instrument. Instruments used to measure broadband, medium-pressure UV microwave or arc lamps may or may not be suitable for use with UV-LED sources.

UV LED Output Power—Déjà Vu All Over Again?

UV-LED sources continue to increase in power. The output of UV-LEDs has gone from milliWatts/cm² of irradiance to Watts/cm² of irradiance, with some systems going over or in the neighborhood of 10W/cm².

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, computer memory sizes or the number of megapixels from a digital camera?

A little closer to our UV world, do the discussions (and claims) sound similar to discussions (and claims) that were held in the '70s and '80s with traditional UV-arc lamps? In the '70s and '80s, 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 electrical power was certainly better than a system with only 200 watts/inch of applied power. Which company would be the first to reach 600 watts/inch of applied power? 800? 1,000?

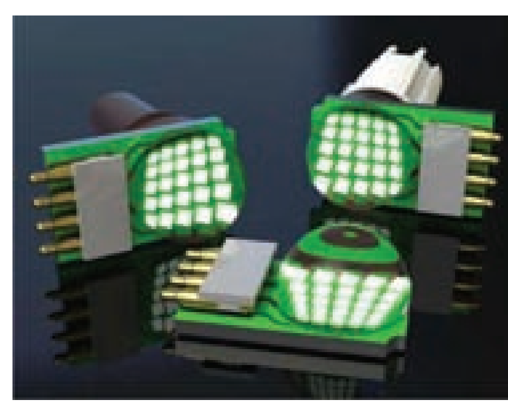
Many were quick to realize that comparing the power applied to the lamp is not as meaningful a measure in the curing process as measuring the amount of useful UV energy delivered to the product. Sometimes, for design and engineering reasons, a UV source with higher applied electrical power actually delivered less usable 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 needed to be found 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. 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/cm²) and energy density (J/cm²) values expected.

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 395 nm. The actual plus/minus range of the spectral output of the

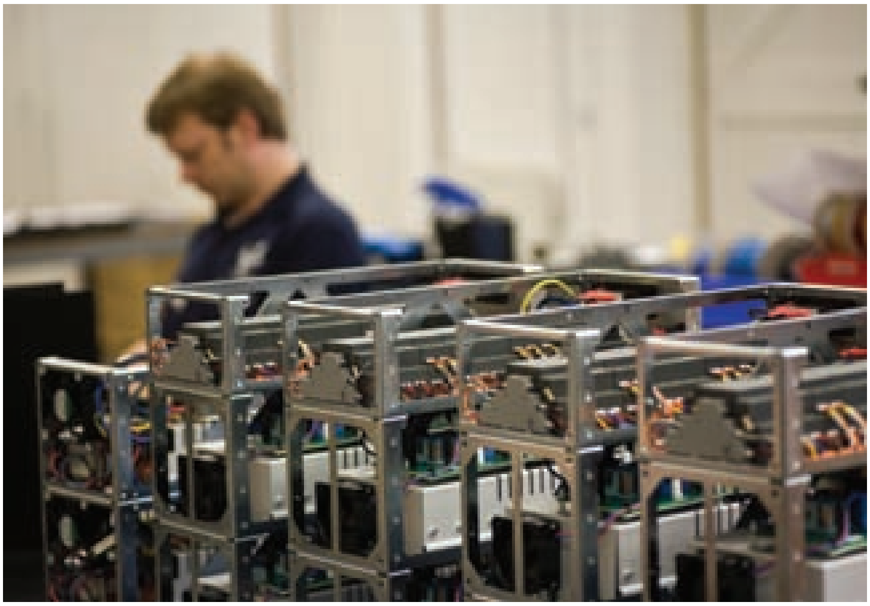


Courtesy of Integration Techonology

UV-LED modules.

Courtesy of Integration Techonology

LEDZero Solidcure™ assembled modules.



Power supplies being assembled for a UV system.

LED will vary from manufacturer to manufacturer.

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. Manufacturers of UV-LED sources 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.

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" approach, 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 measure 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 progress made in the development of coatings that are specifically formulated to work with LED systems. Because LEDs are relatively monochromatic, they lack the shorter UV-C wavelengths that are traditionally used to establish 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.

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

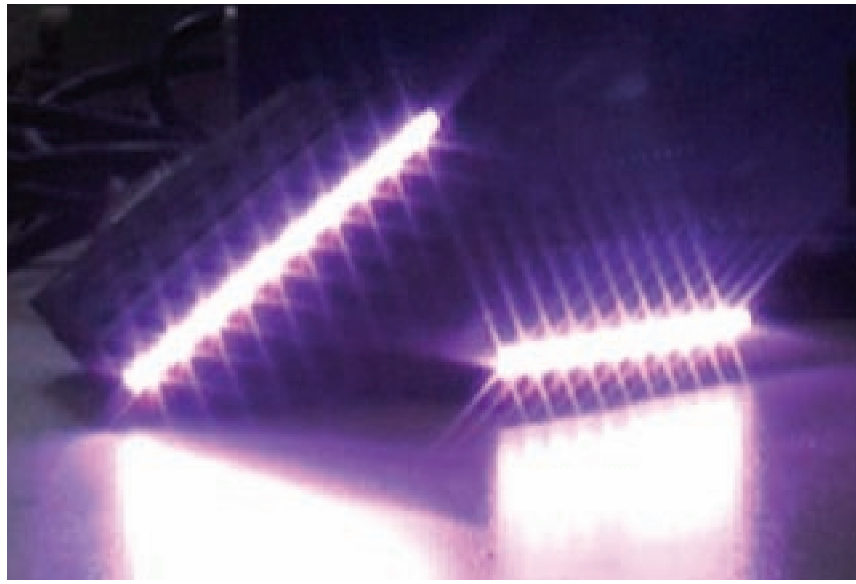
- During process design and testing, establish how you are going to measure the UV output of the LED.
- Define the key process variables that need to be monitored and controlled in production.
- Establish your process window in the lab and carry it over to production.
- Exercise caution when you communicate 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 (UV-A, UV-B, UV-C, and UV-V) that match the broadband arc and microwave sources. Instrument bandwidths vary from manufacturer to manufacturer. Some instruments have “narrow” bands (UV-A classified between 320-390 nm) while others have “wide” bands (UV-A classified between 250-415 nm). Because of these differences, it is important to specify the instrument used to obtain the reading.

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.



UV-LED arrays.

Courtesy of Integration Techonology

LED Intensity Measurement and Challenges

The same challenges that exist for measuring visible LEDs also exist for measuring UV-LEDs. The light emission from an LED is vastly different than a point source. This poses challenges in quantifying its intensity. 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.

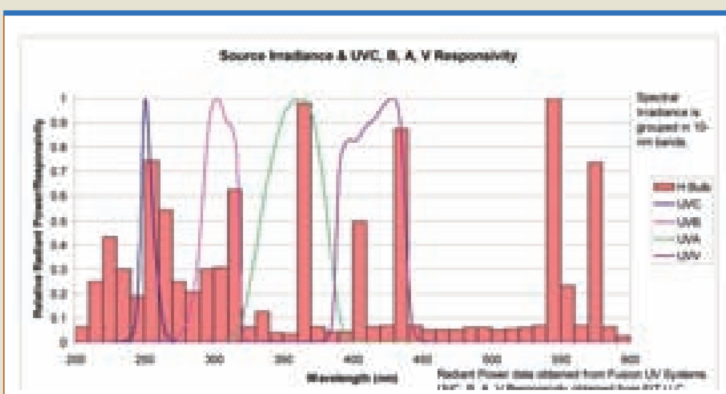
There has been an incredible amount of research done in recent years at various public and private organizations for developing measurement techniques. Due to several variances affecting intensity measurement of an LED, the Commission on Illumination (CIE) established a standard method guide for LED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

RadTech UV Glossary Definition:

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

Figure 2

Spectral output of H bulb and spectral response of different UV bands of radiometer



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 the 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 that is also sometimes referred to as "useful radiant flux." In order to make this measurement, the CIE updated their guidelines in the recently published CIE 127:2007 document to 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:

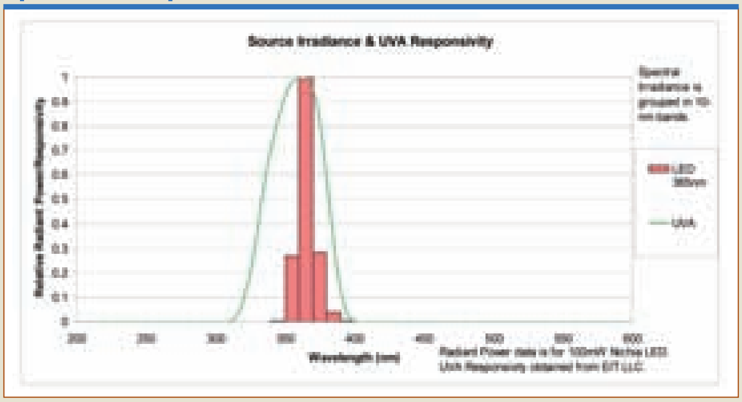
- Radiometer calibration uncertainties
- LED short-term wavelength drift
- LED temperature drift
- DC current regulation for LED
- Optical alignment

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

As stated, LEDs 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.

FIGURE 3

Spectral output of 365 nm LED source and EIT UV-A spectral response



Courtesy of Integration Techonology

UV-LEDs used in UV coating.

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 3 shows a 365 nm (UV-A) LED source and EIT's UV-A response. The responses have been normalized. If the LED is binned very close to 365 nm, the EIT UV-A response does a good job of measuring this source.

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

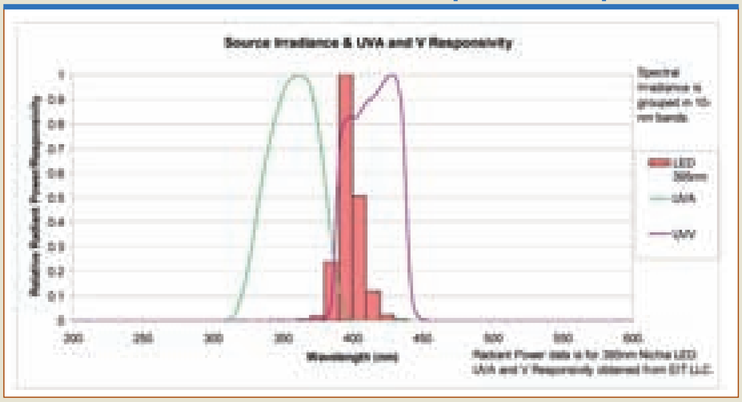
Measuring the output of a 395 nm LED with a radiometer utilizing an EIT UV-A or EIT UV-V response can lead to wide variations in the reported irradiance values.

The output of a 395 nm source is grouped "around the 395 nm line" with variations based on 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 4, the output from a 395 nm LED clearly falls between the EIT UV-A and EIT UV-V response curves.

Figure 4

Spectral output of a 395 nm LED source and EIT UV-A and EIT UV-V radiometer spectral response



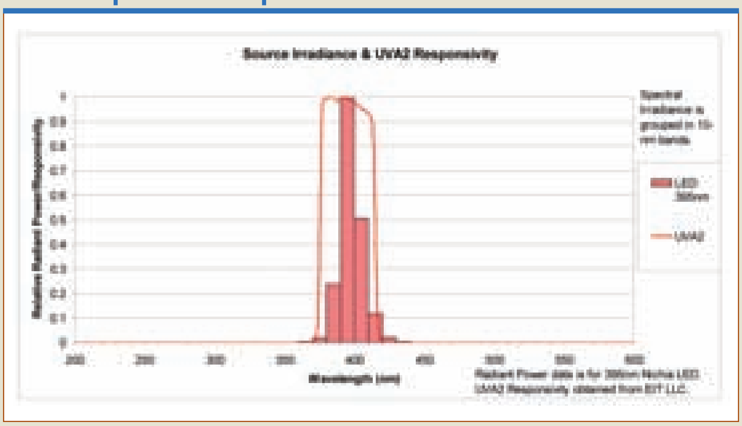
The steepest part of the shoulder of each optical response curve is in the output range of the 395 nm LED. So, while it is possible to get a reading with a UV-A or UV-V bandwidth radiometer, the sharp cutoff at this wavelength means that the readings may reflect only 5-50% of the actual 395 nm LED. The 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 UV-A reading or UV-V readings to any single instrument.

A better approach to measuring LEDs 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 UV-A bandwidth now designated as UV-A2 (Figure 5). The UV-A2 response curve is especially sensitive in the 380-410 nm regions. 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 UV-A2 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 UV-A2 response bandwidth inherits a Lambertian spatial response by design from early generation radiometers that further reduces measurement errors due to LED alignment.

Figure 5

Spectral output of a 395 nm LED source and EIT UV-A2 spectral response



Acknowledgements

The authors wish to thank Phoseon Technology, Integration Technology, Solid UV and Summit UV for their contributions to this paper and for their assistance during the development of the UV-A2 bandwidth.

References

1. C. Cameron Miller, Yuqin Zong, Yoshihiro Ohno, *LED photometric calibrations at the National Institute of Standards and Technology and future measurement needs of LEDs,* Preprint: Proc., SPIE Fourth International Conference on Solid State lighting, Denver, CO, August 2004, 5530, 69-79 (2004)
2. C. Cameron Miller and Yoshi Ohno, *Luminous Intensity Measurements of Light Emitting Diodes at NIST*, Abstract for the 2nd CIE Expert Symposium on LED Measurement

—Jim Raymont is director of sales and Abhinav Kashyap is calibration engineer for EIT Instrument Markets in Sterling, Va.