A New Radiometer for UV LED Sources

RadTech Europe
Prague, Czech Republic

October 18, 2017

Joe T. May
Jim Raymont
Mark Lawrence
EIT, Leesburg, VA
USA

<u>UV LED Radiometers</u>

JTM
10/12/17

Background

Ultraviolet (UV) wavelengths have been used to affect polymerization in certain materials for many years. Measurement of the total number of UV photons (dose in joules/cm^2) and intensity (Watts/ cm^2) available at the work surface has been performed since about the 1980's with small, hand held instruments called radiometers. A typical radiometer from that period is shown in Figure 1.

Figure 1 – 1980's UV radiometer

The sensor, which is the small right circular cylinder at the end of the electrical cable, is designed to be placed in a position which replicates a workpiece under the UV lamp. It contains an optical stack which selects the desired wavelength(s) and a photodetector which converts the UV to an electrical signal proportional to UV intensity. An optical stack and photodetector is the basis for nearly all radiometers. While early radiometers were useful in process control there were a number of opportunities for improvement.

The major issue with early designs was that one instrument could only be reliably used with one source. Because the optical stacks (and sometimes photodetectors) varied substantially unit to unit, two same model radiometers measuring the output of the same source would usually provide dramatically different numerical results even though they were advertised as "traceable." Further, the numerical results were relative, not absolute energy units which made it nearly impossible to provide process control numbers for separate operations.

So, the early radiometers were useful but only when used on one source with one instrument. They were much more convenient to use than laboratory instruments.

In the late 1980's EIT developed an optical stack and photodetector combination for radiometers which were optically closely matched. The result was a design which provided excellent matching of numerical results between any two sources and any two radiometers. The numerical results were still in proportional energy units unless special attention was paid to calibrating the radiometers. Figure 2 shows a typical second generation UV radiometer. Although not visually obvious it contains the optically matched and ruggedized components.

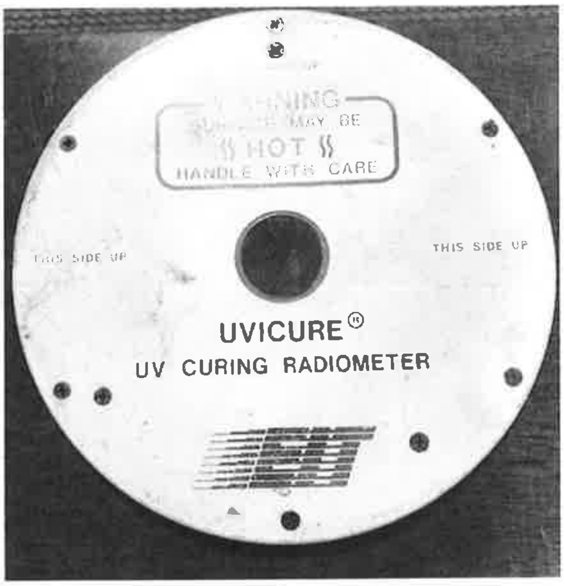


Figure 2 – Second Generation UV Radiometer with Matched and Optically Rugged Components

Matching of optical stack and photodetector components as well as improvements in solarization resistance has produced a very useful tool for the UV processing industry.

LED UV Sources and Measurement

The advent of high power LED UV sources produced a new measurement challenge which created considerable debate within the industry as a whole.

LED UV sources are spectrally much different from mercury (Hg) sources. Figure 3 shows a typical mercury spectrum and Figure 4 a typical L365 spectrum. Note that the mercury spectra are very narrow, 1 to 2nm, while the L395 spectra are much broader, approximately 25 nanometers to the 10% power point. Further, the distribution of LED wavelengths can and do shift as much as ten nanometers. The width of the distribution and the shift in wavelength makes accurate measurements all the more difficult if one is using traditional measurement techniques [Reference 1 provides a more detailed explanation of why this is so]

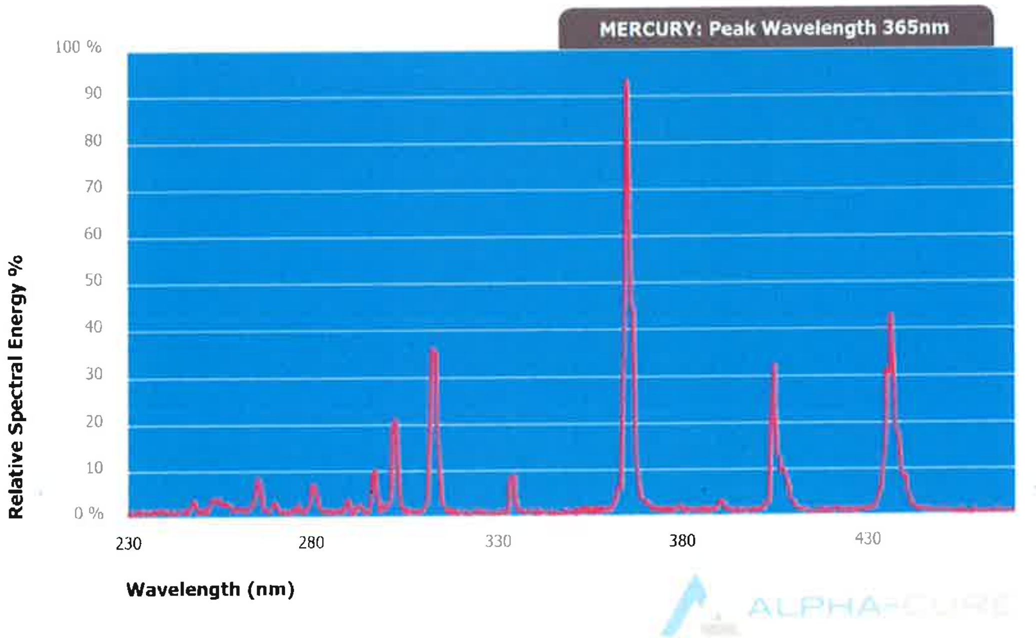


Figure 3 – Typical Mercury Spectra

EIT has designed a new LED UV radiometer which provides an optical response which is nearly flat through the entire passband. The passband, which is about 50 nanometers, is wide enough to capture all of the energy for the LED array even though the center wavelength shifts as much as 10 nanometers.

Figure 4 shows the LED spectra as well as the response curve for the optics.

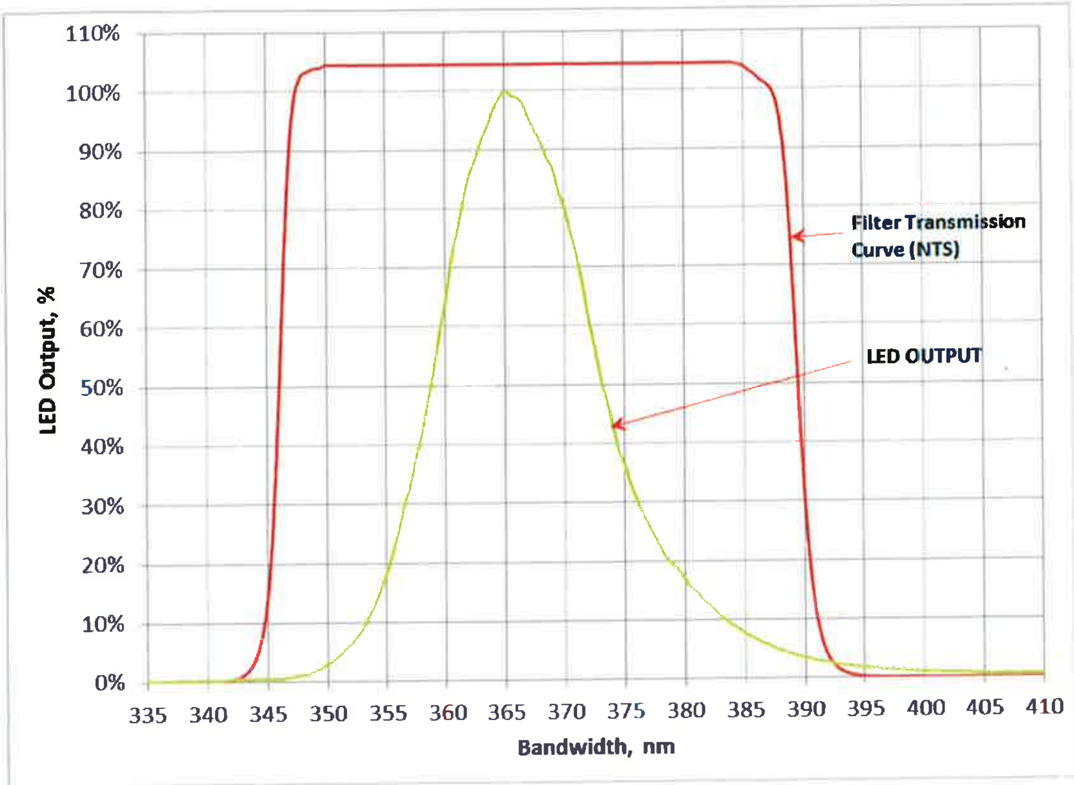


Figure 4- **Typical 365nm LED Spectra**

Note that the optical response allows the radiometer to make high accuracy, highly repeatable, absolute value UV measurements. It does not require the instrument to be calibrated from a source whose spectral makeup is identical to the source being measured in order to obtain good accuracy and repeatability.

A variety of independent tests and evaluations have been conducted with excellent results. A small sample follows:

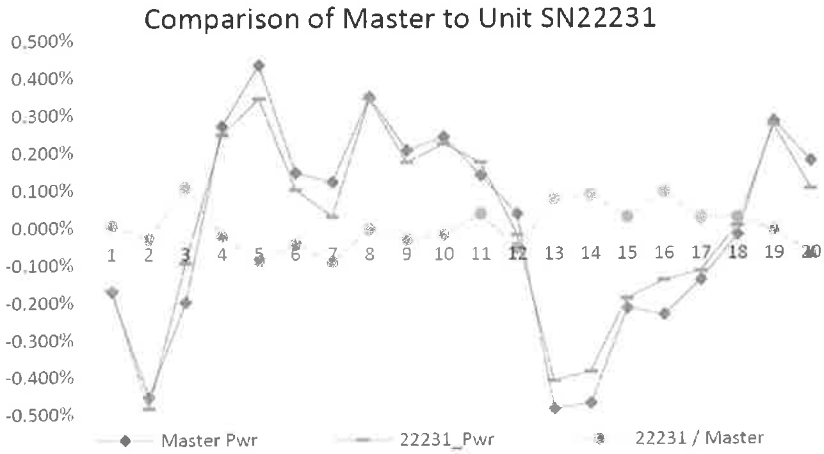


Figure 5 – Comparison of Results From Two L395 Radiometers, Same Source

Figure 5 shows the results of measurements from two EIT new L395 Radiometers on the same 395nm source. Note that resolution and accuracy are good enough to allow the radiometers to track minute changes ($\pm$0.5%) in source intensity.

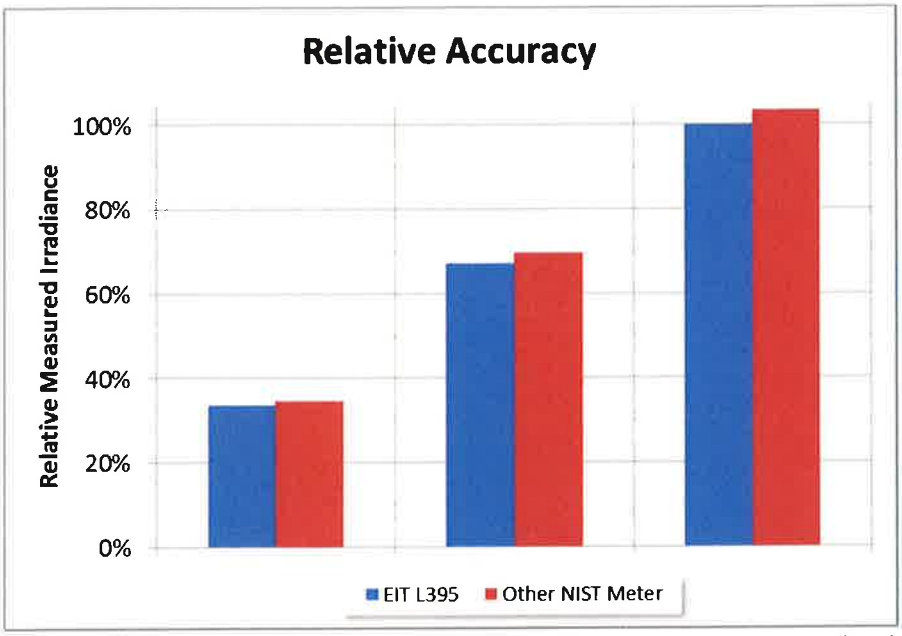
Figure 6 is a table which compares L395 readings of a Lumen Dynamics source with readings from a primary standard maintained by Lumen Dynamics. Note the really excellent agreement between the L395 readings versus primary standard readings. The worst disagreement is 2.4% and the best, no difference.

Working Distance (mm)	Primary Standard Integrating Sphere (W/cm^2)	LEDCure L395 (W/cm^2)	Difference
5	9.01	9.23	2.4%
10	7.74	7.74	0.0%
15	6.66	6.63	-0.5%
20	5.74	5.83	1.6%
25	5.04	5.08	0.8%

Data Courtesy Lumen Dynamics/Excelitas

Figure 6 – Comparison of L395 Readings with National Standard

Figure 7 illustrates the agreement of the L395 results with another NIST traceable radiometer. The agreement is quite good at about 4% over a 3:1 range. The L395 was calibrated on an EIT source located some 3,000 miles away and with special preparation for the test.



Data Courtesy of Phoseon Technology

Figure 7– Comparison of L395 With NIST

Note that the previous examples are from three different sources and two or more instruments with no recalibrations made which illustrates that the design is very accurate and very stable.

The new design which recently received formal patent coverage has been in production for more than a year. The design virtually eliminates previous issues that were associated with earlier Hg source based designs. It provides:

- Ability to accurately measure output in absolute energy units from multiple LED sources with a common central wavelength
- Excellent agreement reading-to-reading and radiometer to radiometer
- Excellent rejection of any out-of-band energy

Conclusion

- The "L" series radiometers will accurately measure absolute energy from multiple LED sources.
- The "L" series radiometers provide near metrology lab accuracy with a package small enough to fit into 5/8" thick process machine
- The same technology which produces rectangular spectral response is applicable to most LED UV measurement applications.

References:

1. "Discussion of Ultraviolet Energy Definitions and Measurements."
   Joe T. May, EIT, LLC, Sterling, VA 10/1/2014
2. "Introduction of New UV LED Radiometer."
   Joe T. May, Mark L. Lawrence, EIT, LLC, Sterling VA, March 2016
3. "A New Approach to UV LED Measurement for Printers: Total Measured Optical Response," SGIA Journal, September/October 2017
   Paul Mills and Jim Raymont, EIT Instrument Markets, Leesburg, VA, USA