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UV & EB TECHNOLOGY

RECENT ADVANCES IN UV PROCESS CONTROL - USING INLINE CONTINUOUS AUTOMATED DYNAMIC (ICAD™)TECHNOLOGY

Radtech 2018 Conference - Thomas Efsen

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Summary

UV LED Systems consists of numerous UV LED dies, which are bundled into boards (emitter section) that are mounted side by side to make an array of emitters, forming the UV LED Lamp of a certain length. When measuring a conventional UV lamp measuring is done perpendicular to the length of the lamp and this measure is representative of the condition of the lamp as it is one envelope. When measuring perpendicular to a UV LED Lamp this value is only representative of one section of the lamp and does not reveal the conditions of the rest of the lamp. To measure the output of the UV LED lamp, one would have to measure as many times as there are emitter sections – this is not practical. This paper will give an overview of how ICAD™-Technology[1] is a solution to safe operation of UV LED Lamps in any width while logging always the full output situation. This paper will further show the ICAD™-Technology applied to microwave powered medium pressure UV lamps.

Introduction

The last decade has seen a rising demand for process control of UV Curing system in production environments. Increasingly manufacturers shorten the interval between controlling and measuring UV lamps, to minimize the risk of insufficient cure at their end product.

As an example, the wood industry is now measuring before every shift (every 8 hours) as compared to weekly or monthly some years ago. This demand for increase measurement frequency is time consuming and leads to more downtime as it is difficult to measure during actual production.

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[1] Patent pending

In the printing industry, this process control is even more difficult as it is in most cases impossible to get an instrument to travel on the web as the instrument is heavy and sometimes the web is on a roller, where instruments can't travel. Some static solutions are used, but again they do only give an indication at the specific location they are measuring. If they are constantly monitoring, they either shadow for the product, or measure in a position not comparable with what the product sees.

UV LED Technology and chemistry is now developed to a level where it is a viable alternative to conventional medium pressure UV lamps. As UV LED brings many benefits to the market, it also has some challenges that must be overcome. One of these challenges is the process control. UV LED systems consist of several UV modules (UV-LED boards - see picture 1) compared to conventional mercury based lamps that consists of a singular UV source (bulb).

Picture 1. Close-up of 9 UV LED sections with one (no.4) being faulty (Curtesy of Excelitas/OmniCure)

Some conventional mercury based systems have several UV systems placed side by side, mostly seen with microwave UV systems (Picture 2). In these cases, cross web control is also a cumbersome action and we have seen a rising interest for inline measuring of the irradiated UV power in these applications.

Picture 2. 2x6 Microwave systems in a closed chamber (Curtesy of Heraeus Noblelight North America)

The interest and demand for an automated, inline process control as well as the increasing use of UV LED Technology has led to the development of the ICAD™ technology.

This paper seeks to demonstrate current performance of the ICAD™ technology as it can be applied to UV LED and mercury based medium pressure UV systems.

ICAD™-technology how it works:

ICAD™ technology stands for Inline, Continuous, Automated and Dynamic sensing technology. It is designed to be able to measure UV output uniformity during production. It can do this continuously with a certain interval setup. An automated process where measurement can be made at specified intervals e.g. every hour or every 10 minutes. The ICAD™ technology includes a software based algorithm that considers the impact of heat and background reflectivity, among others, in the measurement.

ICAD™ works with a specially designed optical rod that travels along the UV source, which can be an array of UV LEDs, a conventional UV arc lamps, or an array of microwave UV lamps. During the transportation, the rod samples the UV output and profiles the exposure from the UV source.

The resultant output profile can be used to evaluate the status of the lamp, it can activate alarms or warnings if certain low or high levels are reached and in it can include the capability to control the UV source and continuously regulate the output so uniformity and constant output is given always.

An ICAD™ system consist of 4 main components:

- Digital signal processor unit (DSP)
- Sensor
- Light delivery system (the rod)
- Mechanism for movement of sensor (Slider)

The DSP-unit controls all communication between lamps, sensor, sensor movement and user interface. It also does all the processing of the data and through different algorithms, generates lamp output values, or lamp errors, such as failed UV LED's etc.

The sensor, light delivery and slider, work together as one. It uses the slider system to transport a light guiding rod under the UV LED's thereby guiding the light up and into the sensor head.

Test Objectives and Setup

We have completed several prototyping solutions to test our thesis for an inline, continuous, automated and dynamic sensor that constantly travels in front of UV & UV LED lamps to monitor the output of the system.

We have evaluate the following parameters:

- UV LED-array measurement: how accurate can we monitor and measure an array of UV LEDs?
- W-LED[2] "Calibration": to what level is it possible to measure the UV LED array and afterwards rapidly adjust it to linearity?
- Microwave UV mercury lamps placed side by side: how is the uniformity along the row of microwave powered UV lamps?
- "Shadow" effect of ICAD™ Sensor: We want to evaluate the effect of the shadow generated by the rod travelling in front of the UV source with regards to irradiance drop and UV energy loss.

Equipment

To test the above, we developed a 1500mm long ICAD™ rig (Picture 3). The ICAD™ Unit consists of a flexible sampling rod connected to an EIT compact sensor mounted under rails that supports the UV light to be monitored. The rod will travel along and under the UV light, indexing and sampling UV irradiance using different EIT Compact Sensors in different distances from the light source. This way it is possible to measure irradiance in different distances, with different speeds and with different UV sources with the same setup, just changing values in the ICAD™-Software.

Picture 3. Close-up of ICAD™ rod in front of UV LED Array

We used two different UV sources for this test. First, we tested a UV LED source at 395nm from OmniCure and then we tested a microwave powered medium pressure mercury lamp from Heraeus Noblelight America.

To measure and control the UV LED we used 5pcs OmniCure AC8300-395nm-series LED with a wavelength of 395nm build into the W-LED solution from Efsen. The OmniCure AC-series has the benefit that we can control the output of each segment and the W-LED has the benefit of having all equipment encapsulated, hence it gives us the possibility to have full control of the entire system

Picture 4-5 Inside W-LED where power supplies are also mounted and W-LED with W-AIR

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[2] W-LED is a fully integrated UV LED system with Power Supply, control and ICAD™ technology all working together from Efsen

To measure medium pressure mercury lamps, we used 2 Heraeus F300 lamps with H-bulb and standard R500 reflector. Heraeus F300 has the benefit of a very stable output as well as a well-defined irradiance profile that we could compare our findings to.

Picture 6. Heraeus F300 system with modular blower

UV LED array measurement and W-LED “Calibration”

Ideally, we could integrate the ICAD™ technology into a UV or UV LED system so that ICAD™ could also control the output after a measurement. To undertake this test, we installed a 1500mm long ICAD™ Sensor unit into a 1500mm long W-LED and ran first a measure of the array in intervals of 25mm which compares to one LED section. We intentionally adjusted the output on each section to a known value and measured it with ICAD™ to see if we would get the same value.

The result of the measure was used to adjust the individual section on the AC-series LED heads and then we used the ICAD™ Sensor to control the so called “calibrated” LED Array.

In figure 1 we can see that the third LED head overperforms and the fifth head has an erroneous section 6.

In figures 2 we see the control measure made after the W-LED has adjusted the sections in each LED head to a required 40% level. Evaluating each section, we now see that we have a uniformity within +-1,5% on the entire 1500mm array.

Figure 1 measurement of 5 pcs AC8300-395 UV LED heads.

Figure 2 measurement of 5 pcs AC8300-395 UV LED heads after "calibration" of heads

<u>Conclusion:</u>
We conclude that it is possible to measure a UV LED array to an accuracy level of 1% from emitter section to emitter section. This information can, if equipment permits, be used to adjust output to a degree of uniformity of +-1,5%.

Hence, UV LED technology coupled with ICAD™ technology offers the opportunity to improve and align irradiance along the total curing width. This can be done on a UV LED emitter mounted on conveyor or web.

This is a significant improvement in exposure performance and quality and contributes to greater control and improves product performance.

ICAD™ Sensor on Microwave UV Mercury lamps

When measuring under a UV LED emitter, heat has a minimal influence on the results and we wanted to compare ICAD™ Measures on a medium pressure mercury based UV lamp to evaluate if ICAD™ technology would also be reliable on conventional UV lamp. The extensive amount of documentation from Heraeus Noblelight America Microwave lamps, shows us what we should measure if ICAD™ sensor would perform correctly under medium pressure mercury lamps.

Tech note on cure width from Heraeus (former Fusion UV) shows us the uniformity on a 6" lamps with no end reflectors in figure 3 below. From table 1 we see that the relative value at the 6" point is 55% of what is measured on the middle of the lamp.

From table 1 we also read that the expected value at the joint of two 6" lamps butted end to end is 85% of what is in the middle of each lamp head.

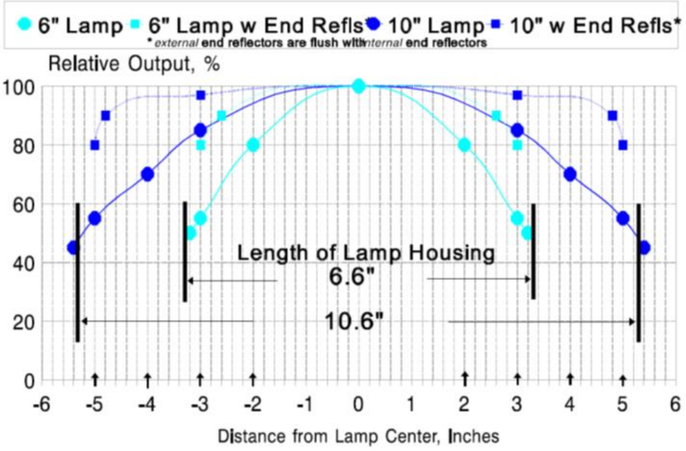

Figure 3 irradiance variance over 300mm cure width on a Heraeus Microwave 6” lamps[3]

FUSION UV SYSTEMS, INC.

“CURE WIDTH”

PERCENT ENERGY vs WIDTH

6" Lamp		**10" Lamp**	
Single, Standard Lamp, In Focus			
center	100 %	center	100 %
4" width	80 %	6" width	85 %
5" width	65 %	8" width	70 %
6" width	55 %	10" width	55 %
6.6" (housing width)	50%	10.6" (housing width)	45-50 %
With 2" external end reflector (flush w internal)			
5.4" width	90 %	9.4" width	90 %
6" width	80 %	10" width	80 %
With 2" external end reflector (flush w housing end)			
6" width	70 %	10" width	70 %
Lamps butted end-to-end, BETWEEN LAMPS*			
at joint*	85%	at joint*	80-85%

Table 1 values of plot from uniformity test of a Heraeus Microwave 6” lamps[4]

We tested if we would get the same relative value at the 6” point of an Heraeus F300 lamp with no end reflectors and from figure 4 below we can see that the ICAD™ sensor measures the values around 55-56% which is equal to what is referenced from Heraeus.

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[3] R.W.Stowe, Tech Note, Cure Width

[4] R.W.Stowe, Tech Note, Cure Width

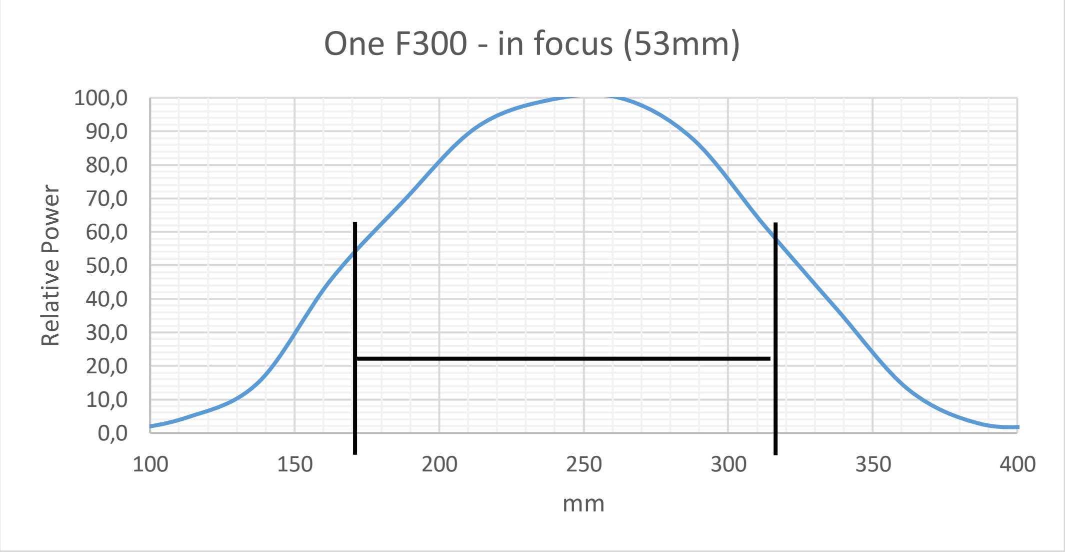


Figure 4 ICAD™ Sensor values of uniformity on a Heraeus Microwave 6" lamps (F300)

Furthermore, we wanted to see if we butted two F300 end to end, if we could get the same reading at the joint as the documentation states at 85%. Below is the graph with the ICAD™ measure, and we find a drop to around 84% a little to the left side of the joint. We also see a slight difference in the peak output between the two lamps, with the left lamp performing some 2-3% lower than the right, which influences left direction of this joint.

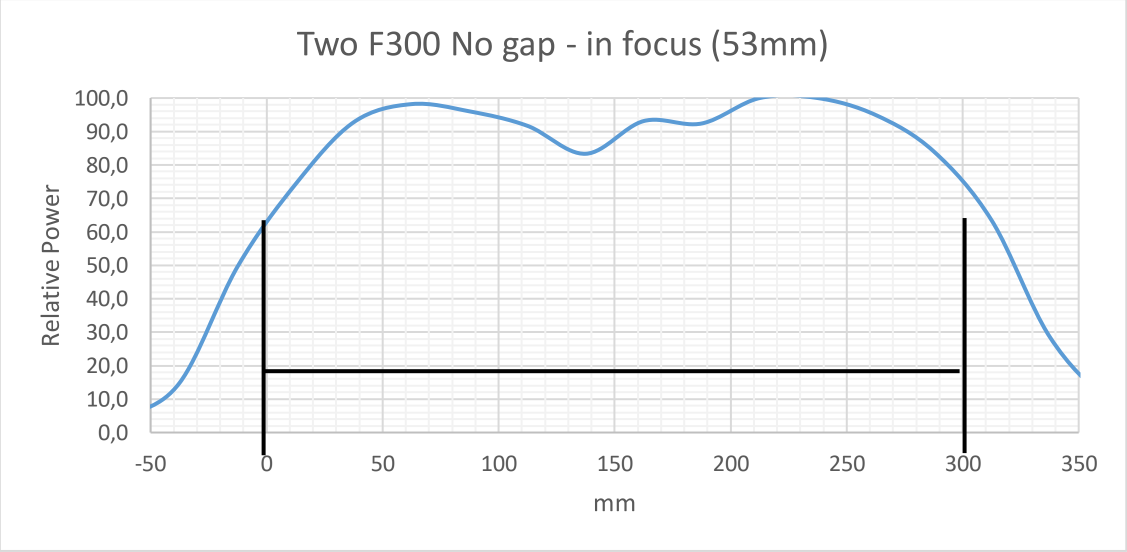


Figure 5 ICAD™ Sensor values of uniformity on 2 adjacent Heraeus Microwave 6" lamps (F300)

Out of curiosity we tried to move the two F300 lamps away from each other, and we found that we could measure the drop that occurred between these two lamps with different distances. The profile of each lamp continuous to resemble the one from the documentation, indicating that we do not have a change in performance of the sensor when exposed to different energy "intervals"

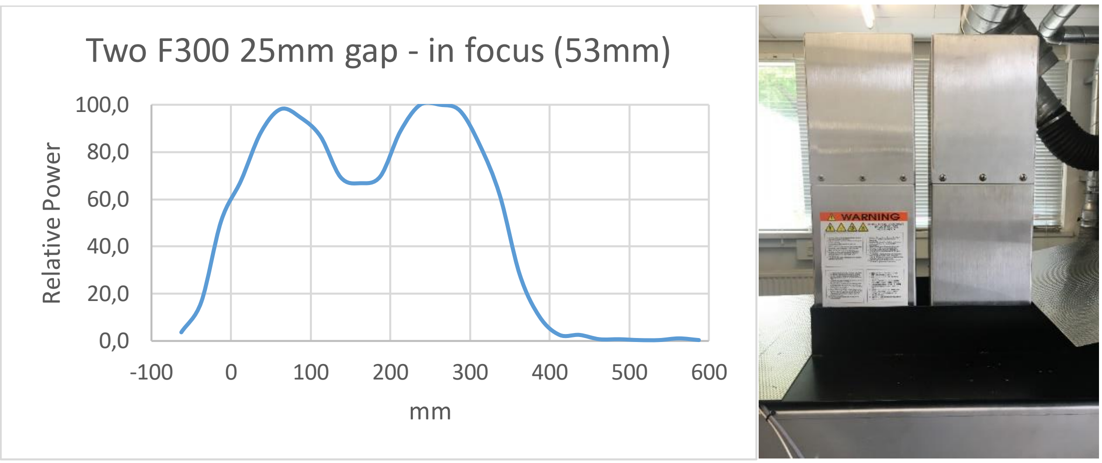


Figure 6 ICAD™ Sensor values of uniformity on 2 adjacent Heraeus Microwave 6" lamps (F300) with a 25mm gap between lamps

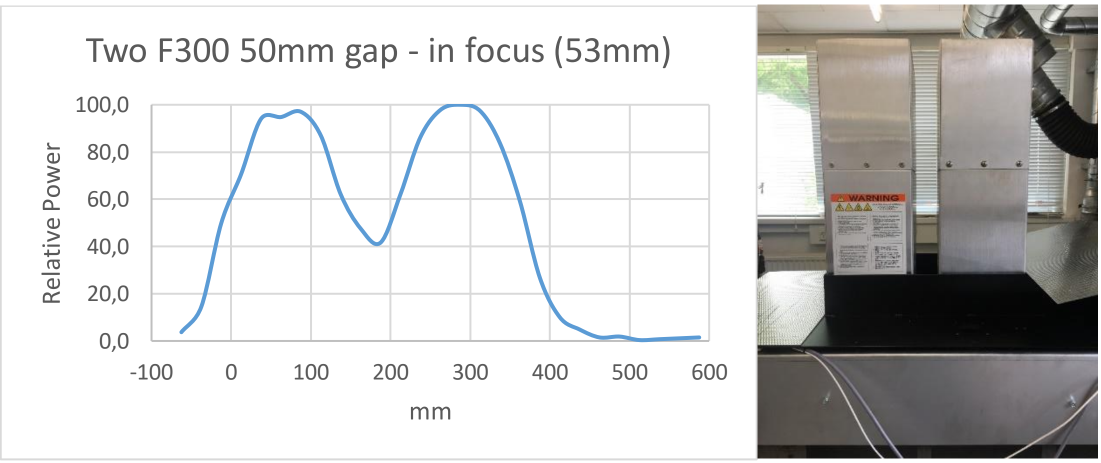


Figure 7 ICAD™ Sensor values of uniformity on 2 adjacent Heraeus Microwave 6" lamps (F300) with a 50mm gap between lamps

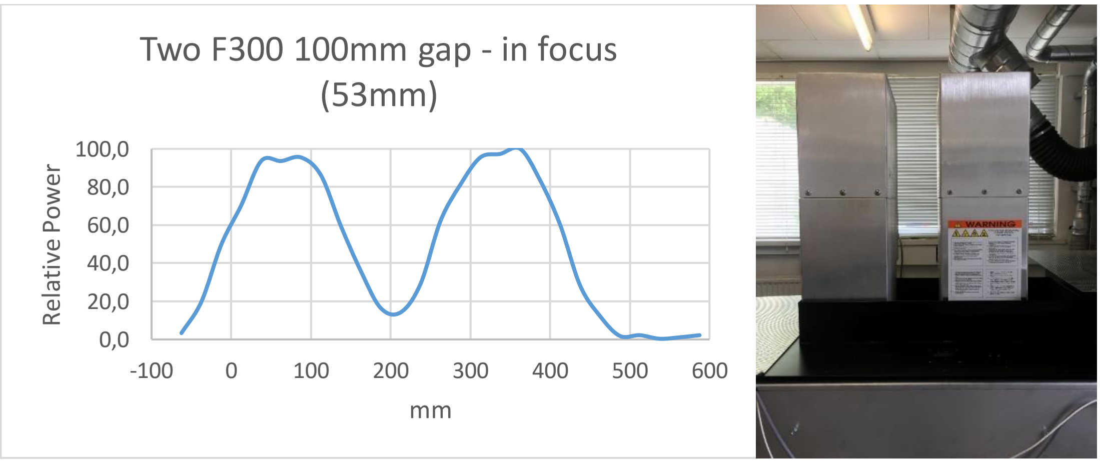


Figure 8 ICAD™ Sensor values of uniformity on 2 adjacent Heraeus Microwave 6" lamps (F300) with a 100mm gap between lamps

<u>Conclusion:</u>

In general, we can say that ICAD™ technology seems capable of illustrating the performance of a microwave medium pressure mercury lamp in the focal plane.

“Shadow Effect” of ICAD™ Sensor on UV LED Systems

Continuous measurement during production in some applications has been a highly sought-after process control mechanism. For that a problem has always been that the sensor or measurement instrument would shadow the product that had to be cured. Therefore, we are interested in evaluating the effect of the shadow from the sensor rod when travelling in front of the UV source (in this test a 395nm UV LED)

As seen on picture 7 below, we placed and EIT LEDCure L395 Profiler directly under the W-LED. We placed the EIT LEDCure L395 Profiler at two distances to evaluate the impact of changes in distance.

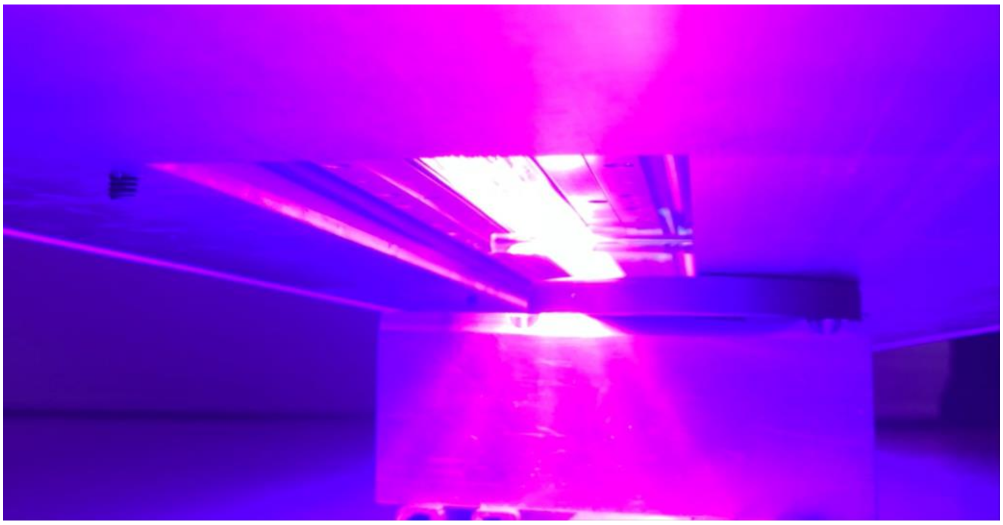
First, we placed it right under the W-LED, which equals 13mm from UV LED lens front to EIT LEDCure L395 Profiler filter front, this is expected to give the highest shadow effect due to largest influence of sensor rod vs. distance.

Second, we placed the EIT LEDCure L395 Profiler in 25mm distance from the W-LED bottom, which equals a total of (13+25) 38mm from UV LED lens.

We turned on the EIT LEDCure L395 Profiler, and then started the W-LED. The ICAD™-sensor then started traveling under the 1500mm wide UV LED array.

In the profiling software (figures 9-10), we could see a constant exposure and then a drop when the sensor passed over the EIT LEDCure L395 Profiler in a distance of 13mm

In the profiling software (figure 11-12), we could see a constant exposure and then a drop when the sensor passed over the EIT LEDCure L395 Profiler in a distance of 38mm.



Picture 7 EIT LEDCure placed under UV LED source when ICAD™ sensor passes in between

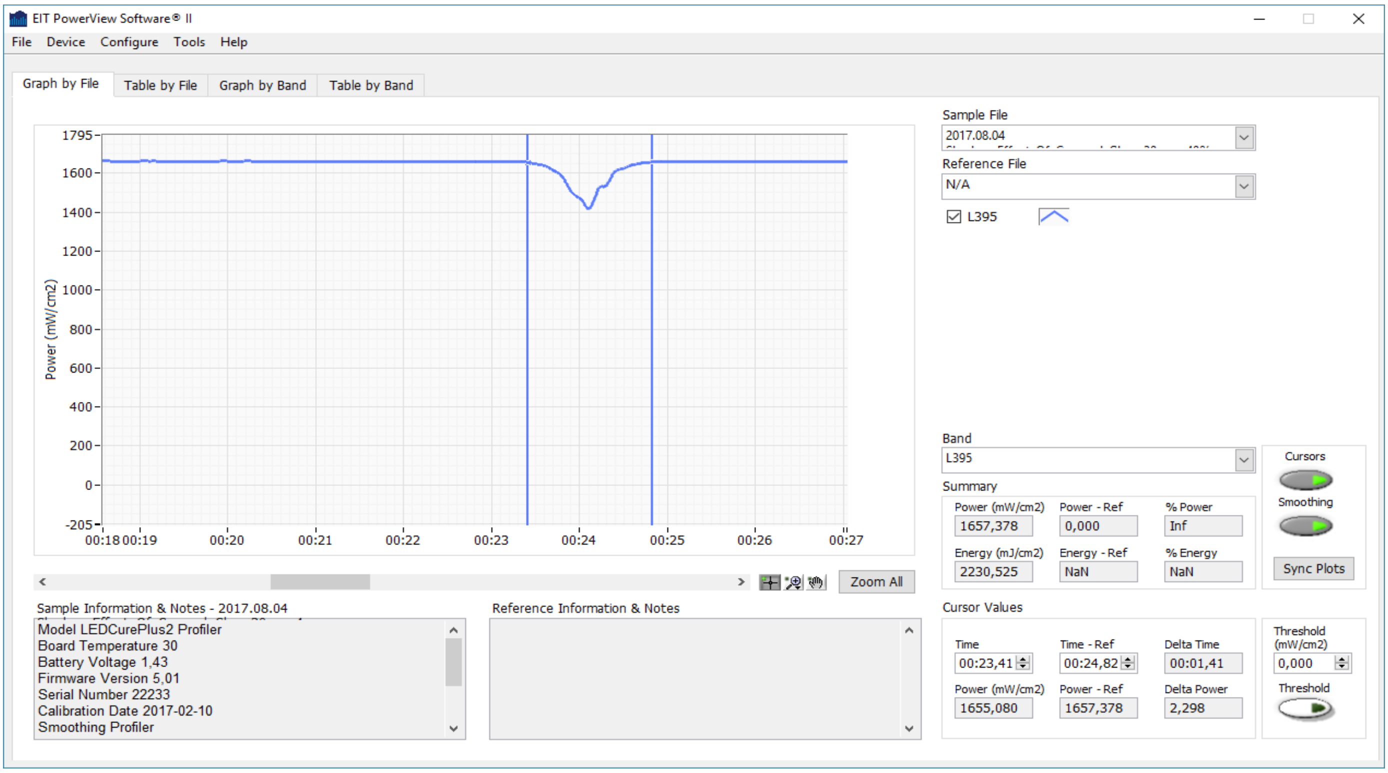
In the profiling software, we set the cursors just when the drop started and when it ended. We saw this was a time interval of 1,41 seconds for the 13mm test and 2,36 seconds for the 38mm test. We read the energy value to be 2.230 mJ/cm2 for the 13mm test and 2.512mJ/cm for the 38mm test. We then placed the cursor just before the drop and 1,41second before that to get a “non-shadowed” energy reading of 2.343mJ/cm2 for the 13mm test and we placed it 2,36seconds before the start of the drop to get the “non-shadowed” energy reading of 2.531mJ/cm2 for the 38mm test.

We could then calculate the energy loss to be (2.230/2.343) = 4,83% during the whole pass of the sensor for the 13mm test and (2.512/2.531) = 0,8% during the whole pass for the 38mm test.

We also evaluated the peak irradiance loss during expose and saw that the irradiance at the lowest point was 1.430mW/cm2, compared to the non-shadowed irradiance at 1.660mW/cm2. This gives us a peak irradiance loss at (1.430/1.660) = 13,85% for the 13mm test and the peak values for the 38mm where (1.048/1.073) = giving a 2,3% peak intensity loss at 38mm distance.

<u>Conclusion of shadow effect:</u>

In conclusion, we see that in the worst case where the ICAD™ sensor is placed as close as possible to the UV LED head, the shadow effect on the underlying product is less than 5% energy. The maximum irradiance drop with a 6mm sensor is less than 14%. These values are expected to be greatly minimized with smaller sensor diameter and larger distances.



Sample File: 2017.08.04

Reference File: N/A

☑ L395

Band: L395

Summary

Power (mW/cm2): 1657,378
Power - Ref: 0,000
% Power: Inf
Energy (mJ/cm2): 2230,525
Energy - Ref: NaN
% Energy: NaN

Sample Information & Notes - 2017.08.04

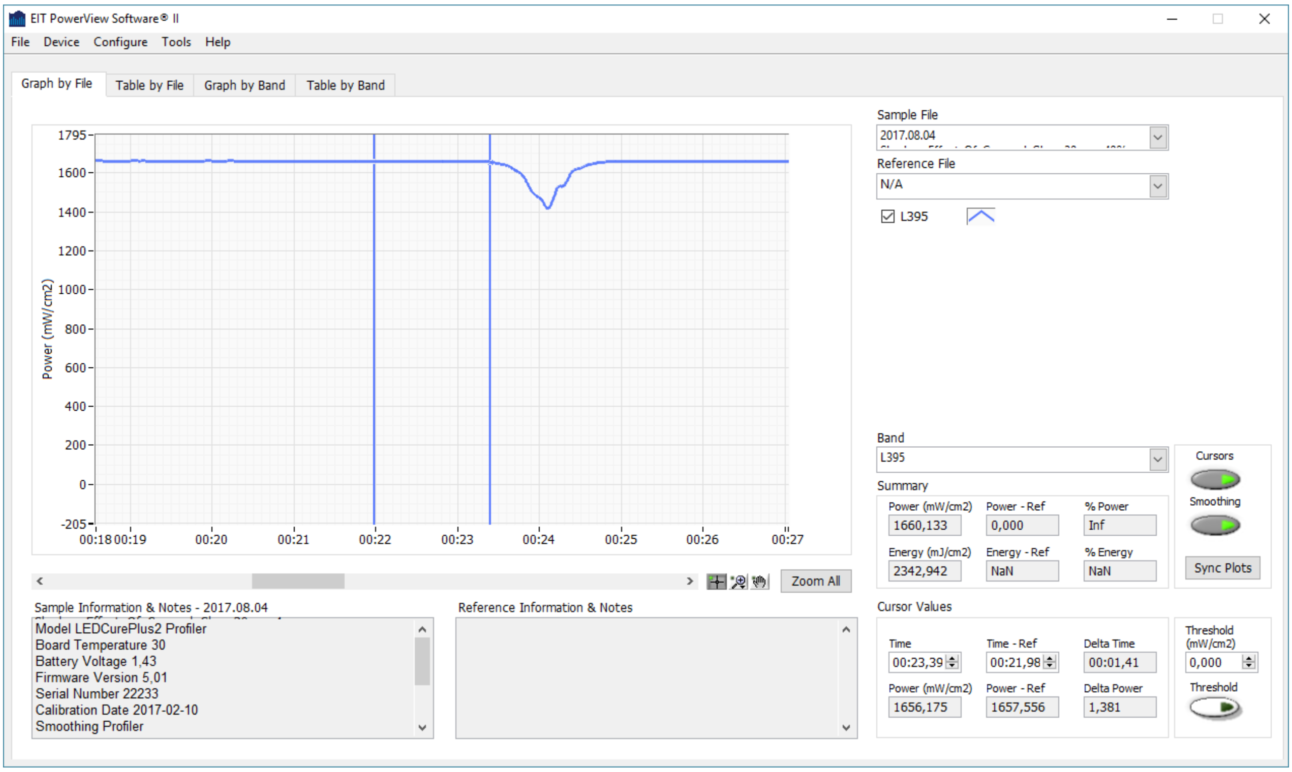
Model LEDCurePlus2 Profiler
Board Temperature 30
Battery Voltage 1,43
Firmware Version 5,01
Serial Number 22233
Calibration Date 2017-02-10
Smoothing Profiler

Reference Information & Notes

Cursor Values

Time: 00:23,41
Time - Ref: 00:24,82
Delta Time: 00:01,41
Power (mW/cm2): 1655,080
Power - Ref: 1657,378
Delta Power: 2,298
Threshold (mW/cm2): 0,000

Figures 9 screen dump of PowerViewII from LED Cure where cursors are placed at beginning and end of shadow effect. This is for the 13mm test



Sample File: 2017.08.04

Reference File: N/A

☑ L395

Band: L395

Summary

Power (mW/cm2)	Power - Ref	% Power
1660,133	0,000	Inf
Energy (mJ/cm2)	**Energy - Ref**	**% Energy**
2342,942	NaN	NaN

Cursor Values

Time	Time - Ref	Delta Time
00:23,39	00:21,98	00:01,41
Power (mW/cm2)	**Power - Ref**	**Delta Power**
1656,175	1657,556	1,381

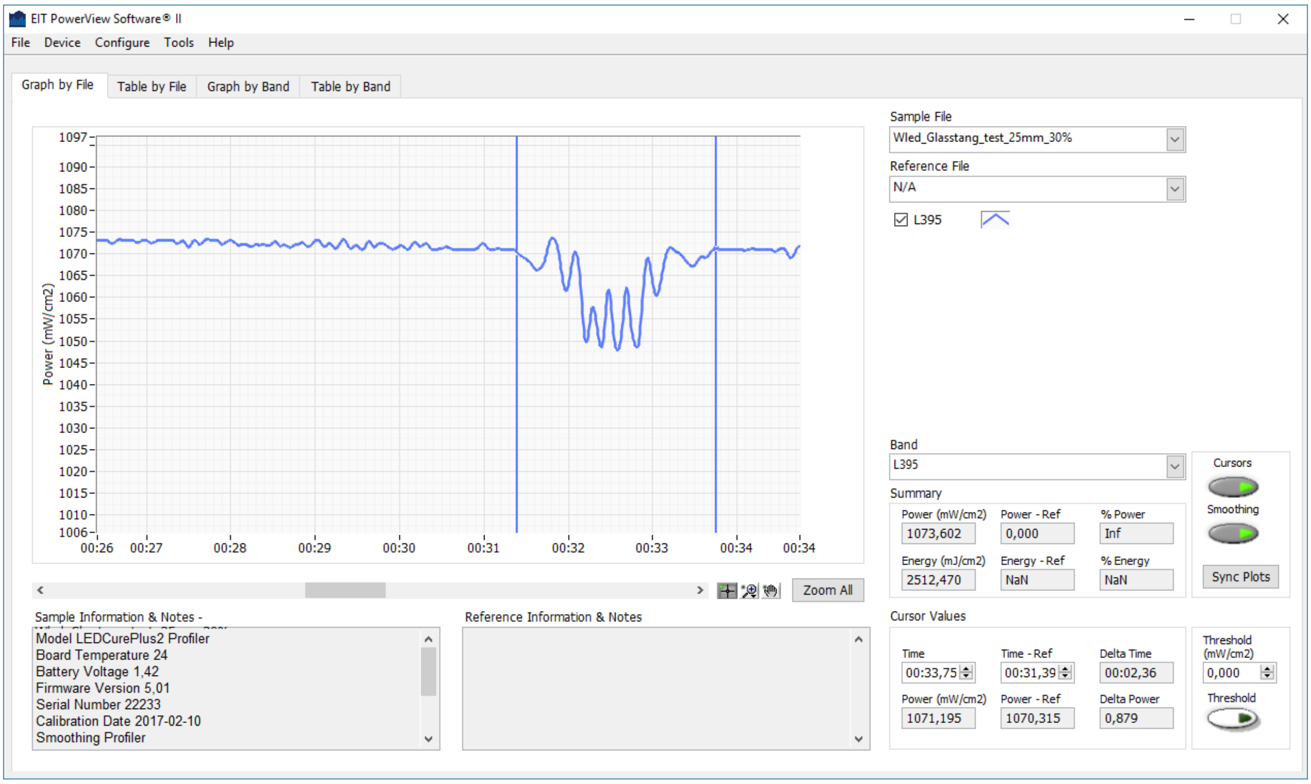
Threshold (mW/cm2): 0,000

Sample Information & Notes - 2017.08.04

Model LEDCurePlus2 Profiler
Board Temperature 30
Battery Voltage 1,43
Firmware Version 5,01
Serial Number 22233
Calibration Date 2017-02-10
Smoothing Profiler

Reference Information & Notes

Figures 10 screen dump of PowerViewII from LED Cure where cursors are placed in same interval as shadow effect, but outside shadow to get a reference value. This is for the 13mm test



Sample File: Wled_Glasstang_test_25mm_30%

Reference File: N/A

☑ L395

Band: L395

Summary

Power (mW/cm2)	Power - Ref	% Power
1073,602	0,000	Inf
Energy (mJ/cm2)	**Energy - Ref**	**% Energy**
2512,470	NaN	NaN

Cursor Values

Time	Time - Ref	Delta Time
00:33,75	00:31,39	00:02,36
Power (mW/cm2)	**Power - Ref**	**Delta Power**
1071,195	1070,315	0,879

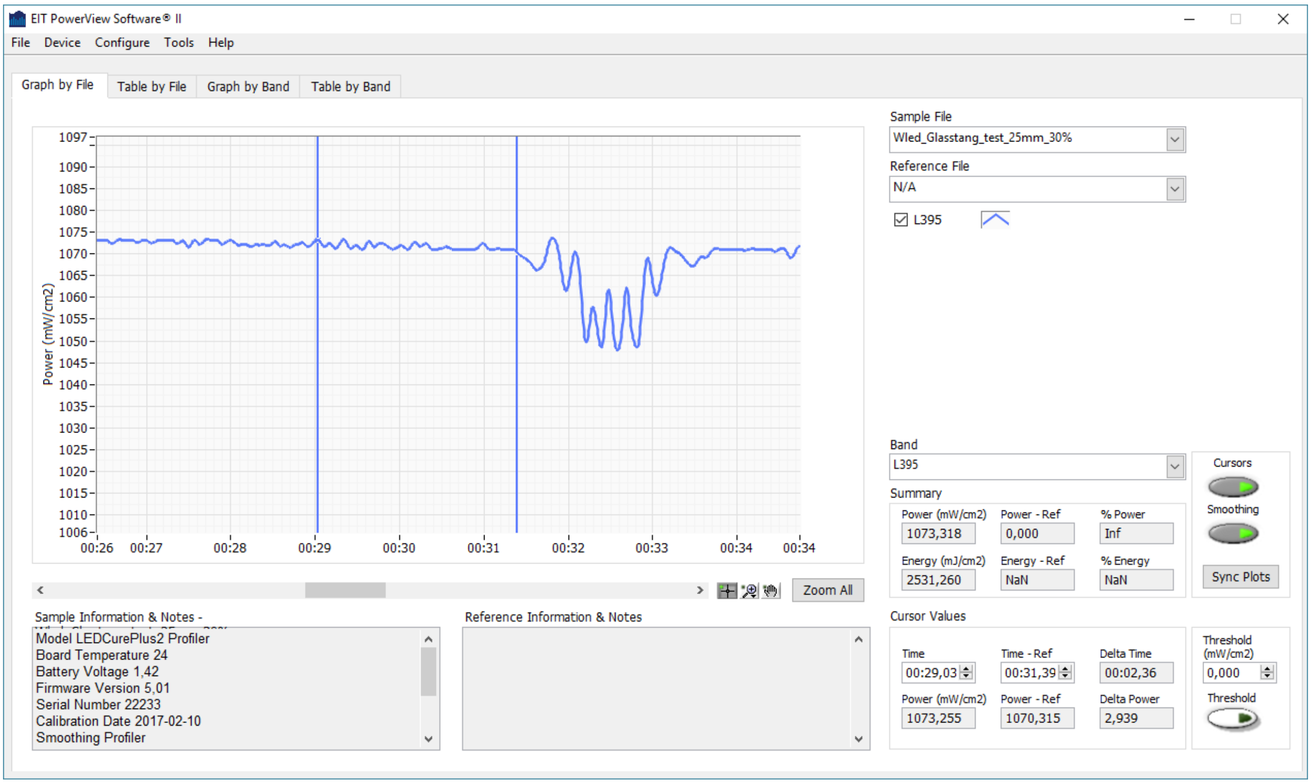
Threshold (mW/cm2): 0,000

Sample Information & Notes -

Model LEDCurePlus2 Profiler
Board Temperature 24
Battery Voltage 1,42
Firmware Version 5,01
Serial Number 22233
Calibration Date 2017-02-10
Smoothing Profiler

Reference Information & Notes

Figures 11 screen dump of PowerViewII from LED Cure where cursors are placed at beginning and end of shadow effect This is for the 38mm test



Sample File: Wled_Glasstang_test_25mm_30%

Reference File: N/A

☑ L395

Band: L395

Summary

Power (mW/cm2)	Power - Ref	% Power
1073,318	0,000	Inf
Energy (mJ/cm2)	**Energy - Ref**	**% Energy**
2531,260	NaN	NaN

Cursor Values

Time	Time - Ref	Delta Time
00:29,03	00:31,39	00:02,36
Power (mW/cm2)	**Power - Ref**	**Delta Power**
1073,255	1070,315	2,939

Threshold (mW/cm2): 0,000

Sample Information & Notes -

Model LEDCurePlus2 Profiler
Board Temperature 24
Battery Voltage 1,42
Firmware Version 5,01
Serial Number 22233
Calibration Date 2017-02-10
Smoothing Profiler

Reference Information & Notes

Figures 12 screen dump of PowerViewII from LED Cure where cursors are placed in same interval as shadow effect, but outside shadow to get a reference value. This is for the 38mm test

Conclusion

We have seen that ICAD™ technology is applicable to both medium pressure microwave power UV lamps as well as UV LED systems. ICAD™ technology can profile the output to a very comparable level of what manufactures document with their systems.

ICAD™ technology can also be used to assure the required setting on UV LED heads, in order to align all output from adjacent heads, so that linearity of +-1,5% is obtained on the entire UV LED array.

Compared to the current irradiance variances over a full curing width seen on medium pressure UV lamps, the maximum shadow effect from the ICAD™ Sensor of up to 4,8% (+-2,4%) is regarded as irrelevant with regards to cure performance. It is therefore expected that ICAD™ technology will be a very usable tool for inline measurement of UV systems.