CHARACTERIZATION OF SOLID STATE LIGHTING PRODUCTS FOR MEASUREMENT INTERCOMPARISONS

Miller, C. Cameron

National Institute of Standards and Technology

ABSTRACT

To meet the request of the United States Department of Energy, the National Institute of Standards and Technology and the National Voluntary Laboratory Accreditation Program has developed Handbook 150-1A:2009 NVLAP Energy Efficient Lighting Products – Solid State Lighting. NIST was tasked to develop the protocol for bi-lateral and round robin comparisons and to obtain and characterize appropriate solid state lighting products to be used as proficiency artifacts. The proficiency test protocols and solid state lighting product characterization results are presented.

Keywords: NVLAP, Round Robin, Solid State Lighting

1. ENERGY STAR AND NVLAP

As part of new energy efficiency standards created by the United States Energy Policy Act of 2005, the program known as ENERGY STAR® was formally recognized. This program is to identify and promote energy-efficient products and buildings in order to reduce energy consumption, improve energy security, and reduce pollution through voluntary labeling of products and buildings that meet the highest energy conservation standards [1]. As part of the ENERGY STAR® program for solid state lighting (SSL) products, the U.S. Department of Energy (DOE) requested the National Voluntary Laboratory Accreditation Program (NVLAP), which is the Laboratory Accreditation Group within the National Institute of Standards and Technology (NIST), to add to the NVLAP Energy Efficient Lighting Products (EEL) Laboratory Accreditation Program specific test methods used in testing certain types of SSL products [2].

To meet the request of the DOE, NVLAP developed NIST Handbook 150-1A:2008 Energy Efficient Lighting Products – Solid State Lighting [3], which is a supplemental handbook and checklist to NIST Handbook 150:2006 Procedures and General Requirements [4]. In NIST Handbook 150-1A is the requirement that laboratories will participate in two levels of proficiency testing. When a laboratory initially applies for accreditation, a bilateral proficiency test between the laboratory and NIST will be conducted. In following years, the laboratory will participate in round robin testing with the other accredited laboratories. NIST was tasked to develop the protocol for the bi-lateral and round robin comparisons and to obtain and characterize appropriate SSL products to be used as proficiency artifacts. The proficiency test protocols and the characterization results of the artifacts chosen are presented in this paper.

2. PROFICIENCY TESTING PROTOCOLS

The protocol for the bilateral proficiency test begins with NIST selecting and characterizing a variety of SSL products that qualify as different niche products defined in the ENERGY STAR guidelines. The SSL products along with instructions for specimen handling, preparation, conditioning, mounting, and testing, as well as data forms are provided to the participating laboratory. The completed test data forms and SSL products are sent by the participating laboratory to NIST where the SSL products will be measured again. Generally, the specific proficiency test procedure is conducted in accordance with the applicable standard test method (e.g., IES LM-79 for luminous flux [5]). At times, however, NVLAP may specify special conditions or provide out of scope products in order to evaluate the operation of a laboratory.

For the round robin testing, four identical sets of various SSL products will be distributed to laboratories simultaneously. As with the bilateral comparison, SSL products along with instructions for specimen handling, preparation, conditioning, mounting, and testing, and data forms will be provided to the participating laboratory. The SSL products in the sets are representative of the ENERGY STAR niche applications. The completed test data forms will be sent by the participating laboratory to NVLAP. As the sets are returned to NIST, they will be crosschecked and sent to the next laboratory. This flower or star approach minimizes time waiting if a laboratory is delinquent in returning the set. The results of all participants are summarized in a Technical Brief, which is edited and sent by NVLAP to the participants. The identity and performance of individual laboratories are kept confidential.

3. ARTIFACT SELECTION AND INITIAL CHARACTERIZATION

The SSL products selected are all available commercially. The initial selection of products were purchased based on the results of the DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) program [6]. The intention was to select the SSL products that are most reproducible, represent a wide range of niche markets, and have a wide range of spectral and photometric qualities.

Each product that was purchased was measured for total luminous flux and total spectral flux before aging. Each product was operated at a fixed voltage and allowed to thermally stabilize. Figure 1 shows a typical stabilization curve for one of the models. LM-79 suggests stabilization is reached when the maximum signal minus the minimum signal for the luminous flux, current and voltage of three consecutive readings separated by 15 minutes is less than 0.5%. For the model in figure 1 the stabilization time is 60 minutes. If the three readings are separated by 10 minutes instead of 15 minutes, the stabilization time is 45 minutes and the measured luminous flux is different by only 0.04%. It is important to note that all three parameters voltage, current and luminous flux shall be stabilized. As shown in Figure 2, the model based on red-green-blue mixing stabilizes with respect to luminous flux rather quickly, but the current stabilization requires twice the time.

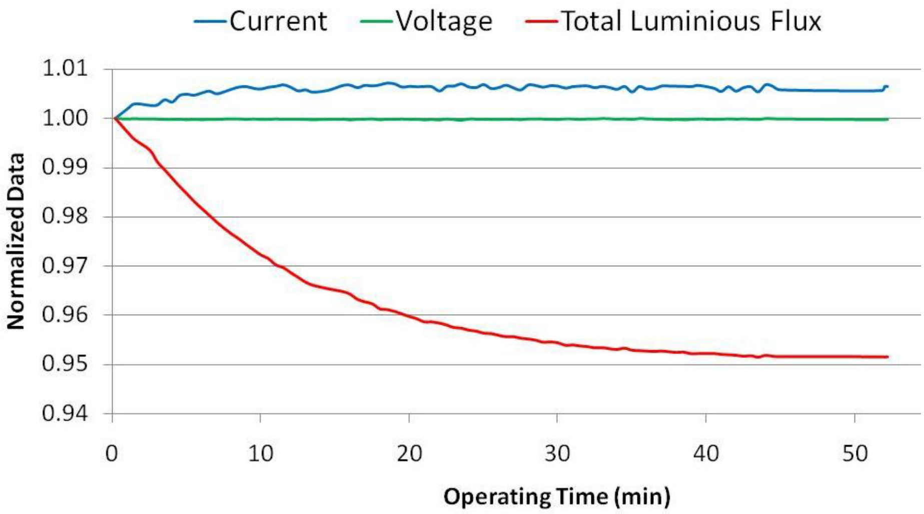

Figure 1. Voltage, current and luminous flux stabilization curves for an SSL product.

The total luminous flux was then measured after total aging times of 24 h, 150 h, 500 h, 1000 h, 2000 h and 3000 h. The typical seasoning time was found to be roughly 1000 h. A few of the SSL products aged too quickly to include as round robin artifacts. Figure 3 shows a few representative aging curves for the devices. After the aging cycle, the SSL products were measured three times over two days to determine measurement reproducibility. Table 1 summarizes the results for the electrical conditions and the luminous flux. The reproducibility of the SSL products is on the order of the reproducibility of the NIST Absolute Total Luminous Flux Sphere Photometer [7].

Table 1. Representative reproducibility of typical SSL products for round robin testing.

	Current	Voltage	Power	Flux	Efficacy
Model 1	0.024%	0.005%	0.035%	0.024%	0.012%
Model 2	0.139%	0.005%	0.101%	0.015%	0.086%
Model 3	0.031%	0.002%	0.042%	0.082%	0.071%
Model 4	0.014%	0.002%	0.016%	0.054%	0.038%

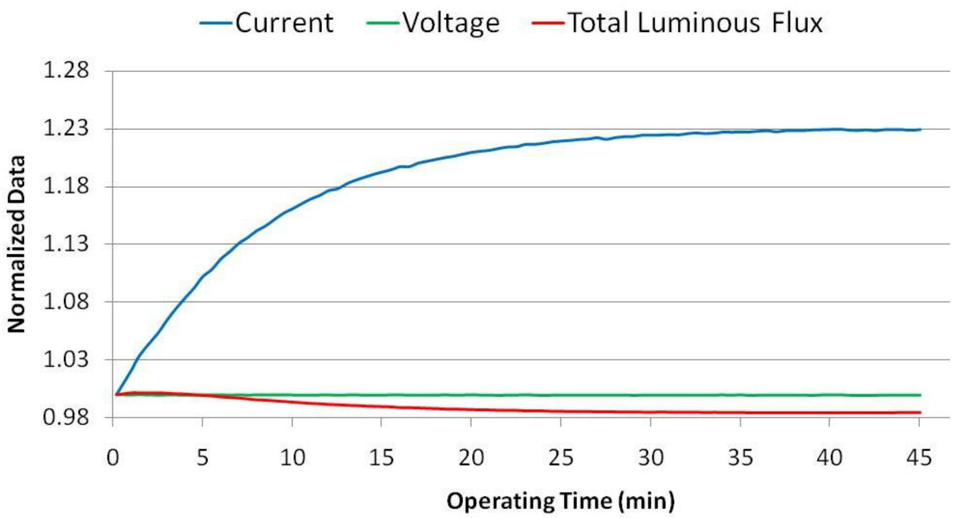

Figure 2. Voltage, current and luminous flux stabilization curves for an SSL product where the luminous flux stabilizes much faster than current.

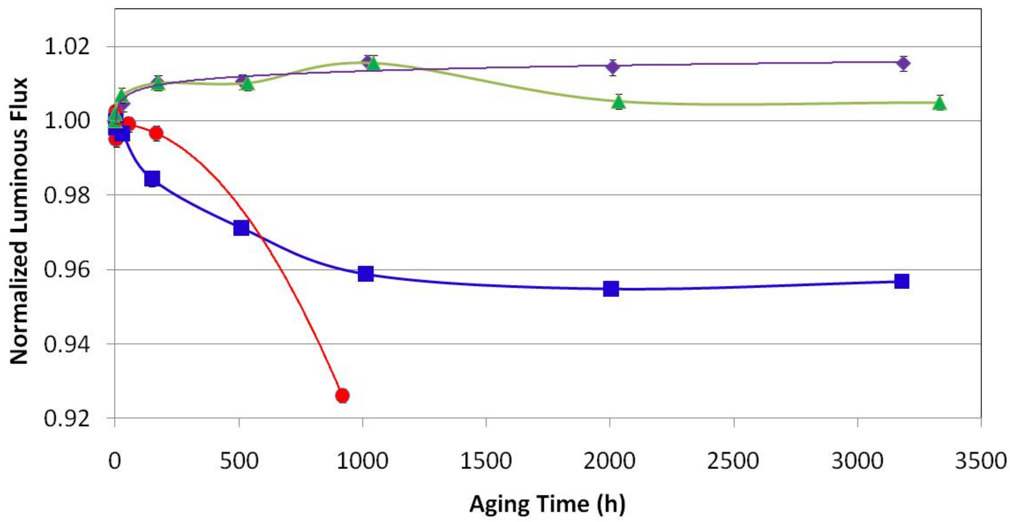

Figure 3. Representative seasoning and aging curves for SSL products tested. The symbols represent data for different SSL products and the lines are to guide the eye.

4. COLOR CHARACTERISTICS AND MEASUREMENTS

The measurement of SSL products is different than traditional lamps in their the spectral distribution. Figure 4 shows the spectral power distributions (SPDs) for the SSL products chosen to be used as round robin artifacts. Many of these devices have spectral valleys, no light is emitted below 400 nm, and a few do not emit light above 680 nm. To measure the chromaticity coordinates or the correlated color temperature, the SPD for an SSL product is typically measured in a sphere using an array spectrometer. Two significant contributions of uncertainty to this system are the potential of fluorescence emitted from the sphere wall initiated by the blue wavelengths and spectral stray light within the array spectrometer system. Figure 5 shows the SPD of a SSL product based on red-green-blue technology. The left frame shows on a linear scale the SPD from the calibrated sphere spectrometer system and the stray-light and fluorescence corrected SPD. On a linear scale the differences are very small. The right frame shows the two SPDs on a logarithmic scale. The most striking feature is the stray light level below 400 nm and above 700 nm. This change in the stray light with addition small changes in the spectral valleys accounts for a chromaticity coordinate increase of 0.0014 for both x and y, which is a 30 K change in the correlated color temperature. The expected results for the round robin are a bimodal distribution of laboratories with stray light correction and those without.

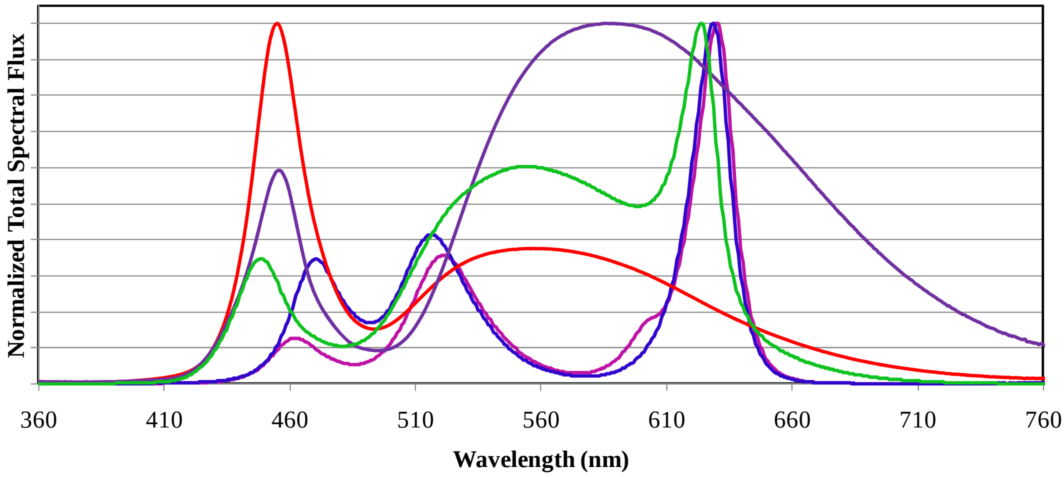

Figure 4. Representative SPDs for SSL products normalized to the peak spectral flux.

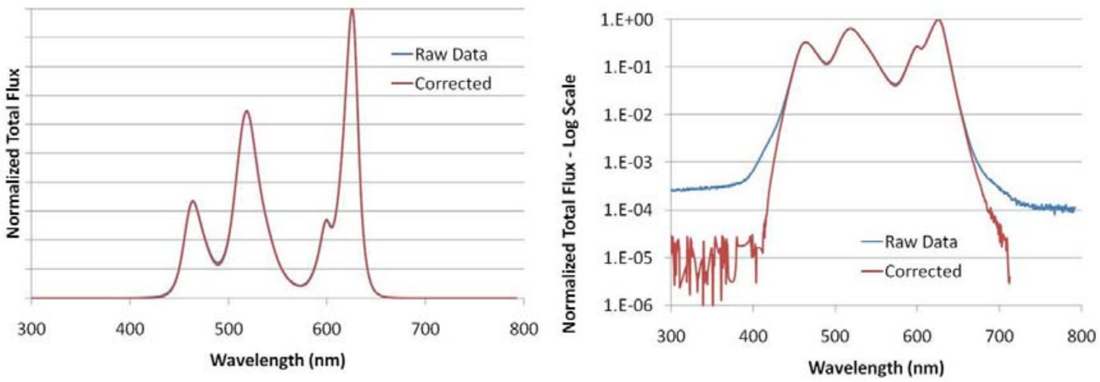

Figure 5. SPD from a calibrated sphere spectrometer system and the stray-light, fluorescence corrected SPD for a SSL product based on red-green-blue technology. The left frame shows the SPDs on a linear scale and the right frame shows the two SPDs on a logarithmic scale.

In order to better assess this situation four quasi-monochromatic SSL products (blue, green, amber and red) are included in the bi-lateral comparison with NIST. By having each laboratory measure such special products, the fluorescence within their system and the level of stray light can be assessed. Figure 6 shows the raw and the corrected SPD for a blue SSL product. The slight bump in the SPD at 600 nm is evidence of the fluorescence in the sphere system. The chromaticity shifts are 0.0020 in x and 0.0026 in y. The allowable upper limit for fluorescence in the testing laboratories equipment has yet to be decided by NVLAP.

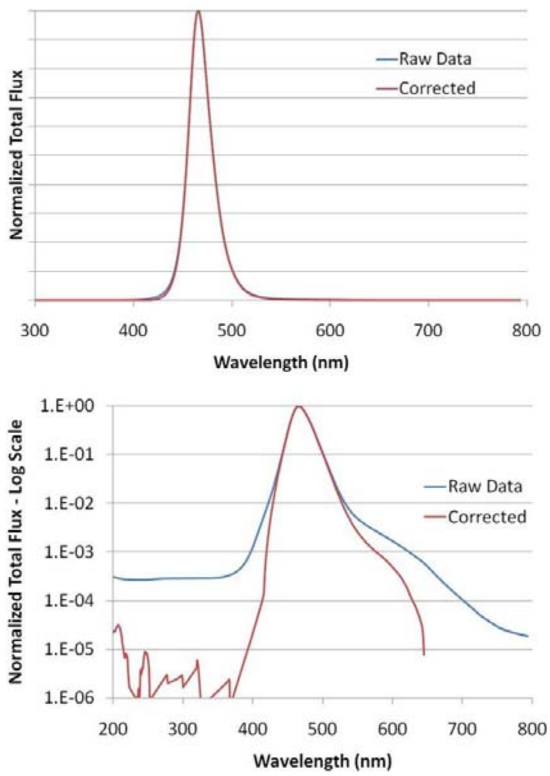

Figure 6. The raw and stray-light and fluorescence corrected SPDs for the blue SSL product plotted on a linear scale (left frame) and on a logarithmic scale (right frame).

Additionally, the quality of test laboratories' wavelength calibration can be assessed if they use spectral detection or the quality of the spectral mismatch correction can be assessed if photopic detection is used.

5. ADDITIONAL TESTING

All of the SSL products that passed the seasoning and reproducibility testing were then characterized for power sensitivity. The SSL products are measured for sensitivity to the operating AC voltage or DC voltage and the AC frequency. The AC frequency was varied from 50 Hz to 65 Hz to determine its effect. The SSL products were then measured for temperature sensitivity in a temperature controlled photometric sphere. The sphere was operated from 20° C to 35° C to determine the temperature sensitivity. After determining these sensitivities the SSL products were operated for an additional 500 h and then measured before sending to the first bi-lateral or round robin participant.

REFERENCES

[1] Section 131 of the Energy Policy Act, Public Law 109-58, United States Federal Government Federal Register, 2005.

[2] Miller, C.C. & Knab, L.I. "National Voluntary Laboratory Accreditation Program - Energy Efficient Lighting Products," NIST Handbook 150-1:2008, Gaithersburg, MD (2008). http://ts.nist.gov/Standards/Accreditation/upload/NIST_HB_150_1_2008.pdf

[3] Miller, C.C., Knab, L.I., Thompson, A., Crickenberger, J. "National Voluntary Laboratory Accreditation Program - Energy Efficient Lighting Products," NIST Handbook 150-1A:2009, Gaithersburg, MD (2009). http://ts.nist.gov/Standards/Accreditation/upload/NIST-HB-150-1A-2009.pdf

[4] Faison, C.D., Horlick, J., Merkel, W.R., White, V. R., Editors "National Voluntary Laboratory Accreditation Program – Procedures and General Requirements," NIST Handbook 150:2006, Gaithersburg, MD (2006). http://ts.nist.gov/Standards/Accreditation/upload/nist-handbook-150.pdf

[5] LM-79-08, "Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products," Illumination Engineering Society, (2008).

[6] http://www1.eere.energy.gov/buildings/ssl/caliper.html - U. S. Department of Energy

[7] Ohno, Y. & Zong, Y., Detector-Based Integrating Sphere Photometry, Proceedings, 24th Session of the CIE Vol. 1, Part 1, 155-160 (1999).

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy. The author would like to thank Qui (Nancy) Ri and Vyacheslav Podobedov for their help in making the measurements.

Author:
C. Cameron Miller
National Institute of Standards and Technology
100 Bureau Drive Stop 8442
Gaithersburg, MD 20899
301-975-4713
c.miller@nist.gov