OP30

DEVELOPMENT OF A FULLY AUTOMATED LED LIFETIME TEST SYSTEM

Zong, Y.[1], Hulett, J.[2]

[1] National Institute of Standards and Technology, Gaithersburg, MD, UNITED STATES.

[2] Vektrex, San Diego, CA, UNITED STATES.

yuqin.zong@nist.gov

Abstract

A fully automated system for light-emitting diode (LED) lifetime test has been developed and is undergoing validation. This system uses a 1 m integrating sphere for both ageing and optical measurements of 480 LEDs. It features six test zones, each of which holds an LED load board with 80 LEDs. Each zone operates independently, executing a user-entered recipe that defines current (to 5 A), voltage (to 200 V), mode (continuous on, pulsing, or cycling), and temperature (from 25 °C to 115 °C). LED ageing and light measurement occurs without the requirement to move the LED load board since the Thermal Electric Cooler (TEC) based temperature zones are enclosed within the sphere. This fully automated system addresses several challenges inherent with existing methods that require costly labour to move LED load boards from thermal control chambers to light measurements spheres. Using the new system, frequent light measurements are possible with small measurement uncertainties and a reduced operating cost. The fully automated LED lifetime test system is designed to operate for 3 – 5 years, producing long-term luminous flux depreciation data that can be applied to validate existing lifetime models and to develop new models for predicting LED lifetime.

Keywords: LED, Lifetime, Ageing, Testing.

1 Introduction

Prediction of light-emitting diode (LED) lifetime is a difficult issue facing LED manufacturers, solid-state lighting (SSL) product manufacturers, and government regulators. Lifetime of an LED encompasses many factors; the primary one being the *Lumen Maintenance Life*, defined as the total operation time of an LED before its total luminous flux output drops to a defined level (e.g., 70 % of its initial total luminous flux output) [1]. LEDs typically have a low luminous flux depreciation rate and thus have a long lifetime. Some LED manufacturers suggest that an LED's lifetime can be as long as 50 000 hours or more – corresponding to 5,7 years of continuous operation. It is unrealistic to determine the lifetime of an LED by performing a test over its entire lifetime. Therefore, many researchers and standardization task groups are actively working on methods/models that can be used for accurate prediction of an LED's lifetime using test times as short as 6 000 hours. However, they sometimes have difficulties due to the limited number of measurement samples – typically under a dozen – that are available with standard batch testing methodologies. Furthermore, these samples often suffer from large uncertainties caused by small changes in the measurement setup [2].

Currently, a typical batch test system for LED lifetime is composed of one or more thermal chambers used for ageing (or called stressing) LEDs and a separate integrating sphere used to perform optical measurements. Test LEDs are usually mounted on carriers called *Load Boards*; these must be cooled down to room temperature and then manually moved from the thermal chamber to the integrating sphere periodically for required optical measurements. Such a system is suitable for LED manufacturers who often test a large number of LEDs under a single temperature condition. But it is usually impractical to perform frequent optical measurements due to the difficulty of cooling the load boards and transporting them to and from the integrating sphere. The batch system has some other drawbacks: 1) it is often difficult to duplicate the measurement setup exactly each time the load board is remounted in the integrating sphere, which introduces measurement uncertainties; and, 2) the batch system with its large capacity chambers is sometimes too costly for research laboratories and small testing labs where a limited number of LEDs are often tested under many different conditions; in this case, each of which would require a separate thermal chamber.

To address the need for measurement of luminous flux depreciation with small uncertainties, a compact system consisting of an integrating sphere that includes six built-in temperature zones was developed. This system allows LEDs to be alternately stressed and measured without any mechanical movement – thus frequent optical measurements can be made to acquire a large number of test data points without the risk of introducing measurement errors due to changes in the measurement setup. It is fully computer-controlled so that acquisition of data can be as frequent as daily, allowing it to operate economically over a long period of time. The system is designed to operate continuously for at least 3 - 5 years. The large data sets it produces will be useful for developing new models and for validating existing models used to predict LED lifetime.

2 Design of the Automated LED Lifetime Test System

The automated LED lifetime test system is composed of a 1 m integrating sphere/chamber for ageing and optical measurement and a 2 m tall instrument rack containing the LED drive, temperature control, and measurement electronics. A photograph and schematic of the system are shown in Figure 1 and Figure 2, respectively. There are a total of six temperature zones – each holds one LED load board, which has 80 LEDs, thus total 480 LEDs are tested. The temperature in each zone is maintained by a separate high power Thermal Electric Cooler (TEC or TE cooler) that is mounted on the top of the sphere. Each TE cooler is operated independently at an ageing temperature ranging from 25 °C to 115 °C and an ageing mode of either continuous on or cycling. The temperature of the LED load board is controlled to be with ± 0,05 °C of the specified temperature for LED optical measurements. The LED load board is mounted facing down at the top of the sphere. With this arrangement the temperature of air near the LEDs is close to that of LED load board — a preferred and required test condition [1] that duplicates conditions in SSL products.

Figure 1 – Automated LED Lifetime Test System

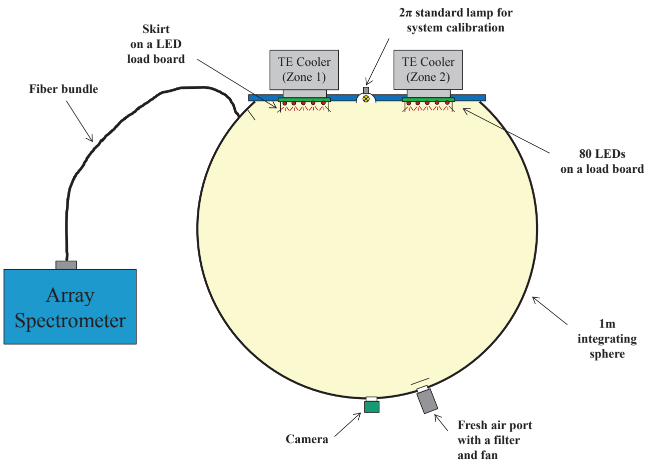

Figure 2 – Schematic Of The Automated LED Lifetime Test System

Filtered fresh air is pumped into the 1 m sphere to prevent the sphere from being contaminated by harmful outgassing from any of the LEDs under test, and also to keep test LEDs in a normal room air environment. A digital camera is mounted at the bottom of the sphere; using it, operators can visually monitor the status of the test LEDs. The test system is calibrated against four 2π total spectral radiant flux standard lamps mounted on the top of the sphere for total spectral radiant flux responsivity (see Figure 3). All LEDs are powered on during elevated temperature stress, and only one at a time is powered on when an optical measurement takes place. Spectral radiant flux is measured using an array spectroradiometer to obtain total luminous flux and colorimetric quantities.

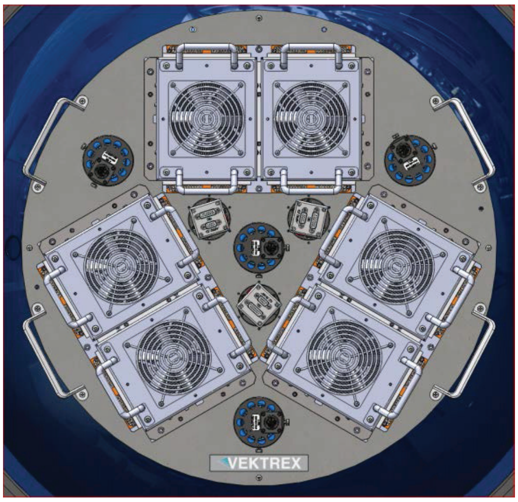

Figure 3 – Sphere Top View Showing Six TE Coolers And Four Calibration Sources

2.1 High Accuracy Electronics

The system electronic diagram is shown in Figure 4. The system features first class electronics including a 100 MHz timing system that precisely synchronizes the current source, sampling voltmeter and spectroradiometer. This timing system ensures pulse measurements are always made quickly in precisely the same way. It allows an 80 LED load board to be measured using pulse techniques in about 10 minutes with 0,05 % flux repeatability.

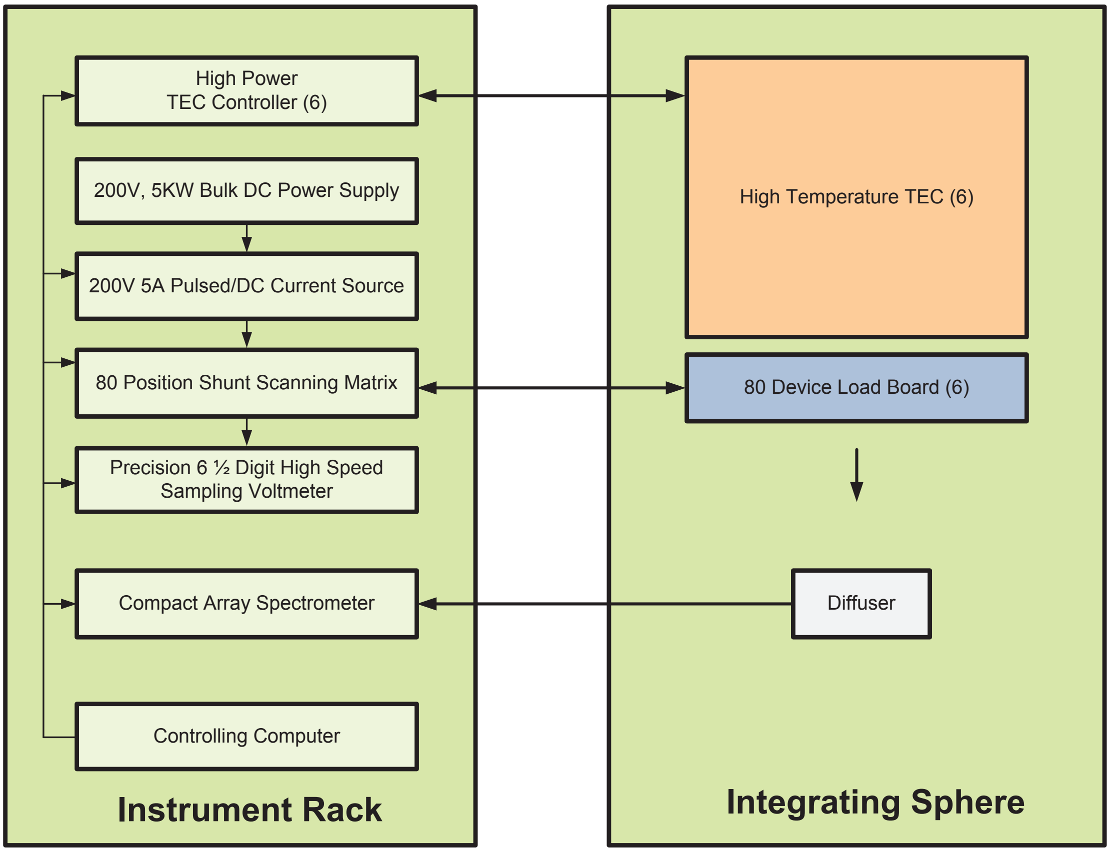

Figure 4 – Electronic Block Diagram (Calibration Equipment Not Shown)

2.2 Interchangeable N+1 Load Board

Test LEDs are mounted on interchangeable 150 mm × 150 mm Metal Core Printed Circuit Board (MCPCB) load boards. Typical high capacity load boards require four electrical connections per LED – 320 connections for a typical 80 LED load board. These connections complicate the system design and reduce reliability. To combat this, the LED Lifetime Test System utilizes a unique circuit arrangement that wires groups of 10 LEDs in series. Using this arrangement, it is possible to individually power and monitor any group of n LEDs with n+1 connections. Thus an 80 LED load board requires only 88 connections.

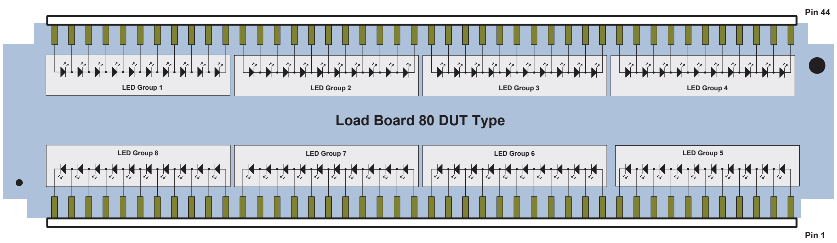

Figure 5 – Interchangeable N+1 Load Baord

3 Planned Experiments

Initially two experiments are planned: 1) A lumen maintenance test adhering to the LM-80 protocol, and 2) a lumen maintenance test similar to LM-80 with power/temperature cycling. The power cycling test is intended to more closely duplicate actual SSL operating conditions. Test temperatures of 55 °C, 85 °C, and 115 °C nominal were chosen in order to allow comparison of the results with industry-supplied LM-80 data. Test conditions for both experiments are listed in Table 1. The tests are planned to last for three 3 - 5 years.

Table 1 – Experimental Test Conditions

Experiment	Load Board Serial Number	Protocol	LED Samples	Temperature (°C)	Current (mA)
1	1	LM-80	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	55	700 all samples
1	2	LM-80	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	85	700 all samples
1	3	LM-80	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	115	700 all samples
2	4	LM-80 with 12 hour on/off power/temperature cycling	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	55	700 all samples
2	5	LM-80 with 12 hour on/off power/temperature cycling	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	85	700 all samples
2	6	LM-80 with 12 hour on/off power/temperature cycling	20 Mfg. A, 20 Mfg. B, 20 Mfg. C, 20 Mfg. D.	115	700 all samples

3.1 Test Samples

A total of 480 test samples were gathered from four different LED manufacturers. The samples received were mature production white LEDs with approximately the same characteristics. 20 samples of each model were mounted on to each MCPCB load boards using a soldering profile that fit all four manufacturers. See Figure 6.

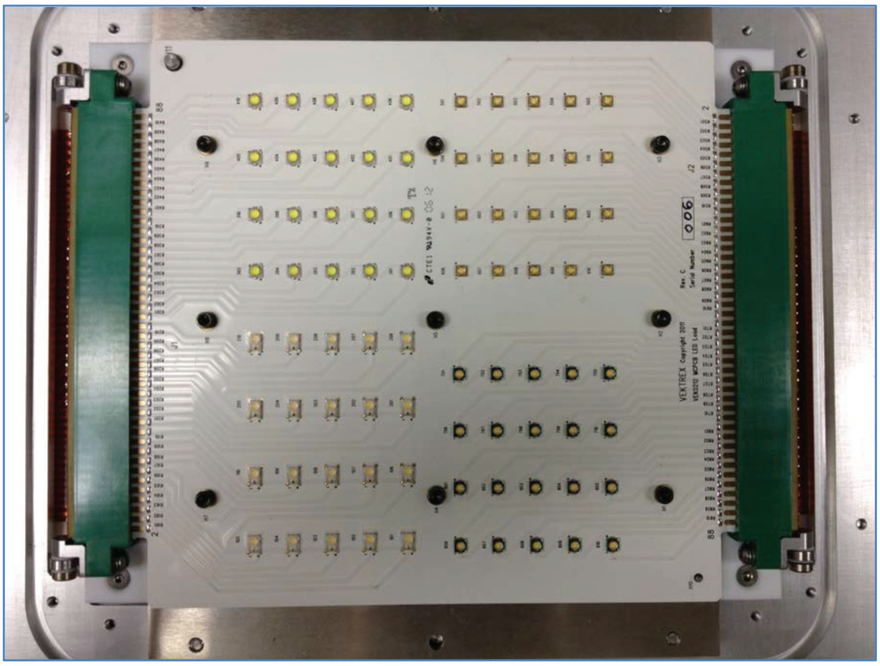

Figure 6 – Test Samples Mounted On Load Baord

3.2 Thermal Resistance Testing

Thermal resistance is a key parameter that influences the LED's junction temperature during operation. The LM-80 protocol specifies a one-sided operating temperature range with the LED temperature measured at the solder point of the LED. LM-80 states it is acceptable to operate LEDs at temperatures as low as 2 degrees C below the nominal testing temperature; it places no upper limit on the operating temperature. In practice though, it is desirable to maintain individual LED sample temperatures close to the nominal temperature so that the test accurately reflects the luminous flux maintenance associated with that temperature. For LEDs mounted on a load board, this is best done by keeping the overall thermal resistance consistent and low.

The thermal resistance of each load board was evaluated using the electrical test method specified in the Electronic Industries Association EIA/JEDEC JESD51-1 specifications [3]. The results showed thermal resistance for all devices to be within acceptable ranges, indicating that the soldering was good for all devices.

Thermal Resistance test results of each LED type are shown in the tables below:

Table 2 – Manufacturer 1 LED Test Results

Parameter	Value (°C/W)
Average Thermal Resistance	9,50
Maximum Thermal Resistance	11,1
Minimum Thermal Resistance	8,30
Thermal Resistance Standard Deviation	0,77

Table 1 – Manufacturer 2 LED Test Results

Parameter	Value (°C/W)
Average Thermal Resistance	11,0
Maximum Thermal Resistance	12,0
Minimum Thermal Resistance	10,4
Thermal Resistance Standard Deviation	0,49

Table 2 – Manufacturer 3 LED Test Results

Parameter	Value (°C/W)
Average Thermal Resistance	12,1
Maximum Thermal Resistance	13,4
Minimum Thermal Resistance	10,6
Thermal Resistance Standard Deviation	0,73

Table 3 – Manufacturer 4 LED Test Results

Parameter	Value (°C/W)
Average Thermal Resistance	12,1
Maximum Thermal Resistance	12,9
Minimum Thermal Resistance	11,1
Thermal Resistance Standard Deviation	0,45

4 Summary

A new system for LED lifetime test has been developed and installed at the National Institute of Standards and Technology. This system uses a 1 m integrating sphere for both ageing and optical measurements, and it is capable of testing a total of 480 LEDs at six testing conditions spanning operating temperatures from 25 °C to 115 °C. The temperature of the test LEDs is controlled to within ± 0,05 °C during optical measurements. This stability, along with the system's ability to make frequent optical measurements with no changes in the measurement setup, should enable it to produce high resolution data sets that will be useful for improving SSL lifetime predictive models that are presently based upon a limited number of imperfect sample points.

As of this writing the load boards have been prepared for testing. Final tuning of the thermal skirting is underway. The 2π total spectral radiant flux standard lamps needed for calibration of the system are also under development – these must be mounted before the test can commence. This system will then undergo a robust validation and calibration procedure. It is expected to start the lifetime tests within next three months. The tests will span 3 – 5 years.

Acknowledgements

This research is funded by the US Department of Energy. The authors would like to thank Dr. Cameron Miller and Dr. Yoshi Ohno of NIST, Ms. Melissa Ford of Vektrex, and Mr. Greg McKee of Labsphere for their valuable contributions.

References

1. IES LM80-08, Approved Method: Measuring Lumen Maintenance of LED Light Sources. Illuminating Engineering Society, New York, New York, USA. ISBN: 978-0-87995-227-3. (2008)

2. IES TM-21-11, Projecting Long Term Lumen Maintenance of LED Light Sources. Illuminating Engineering Society, New York, New York, USA. ISBN: 978-0-87995-259-4. (2011)

3. JESD51-1, Integrated Circuit Thermal Measurement Method – Electrical Test Method (Single Semiconductor Device), JEDEC Solid State Technology Association, 01-Dec-1995 specification. (1995)