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Note: An online testing method for lifetime projection of high power light-emitting diode under accelerated reliability test

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In recent years, due to the fast development of high power light-emitting diode (LED), its lifetime prediction and assessment have become a crucial issue. Although the *in situ* measurement has been widely used for reliability testing in laser diode community, it has not been applied commonly in LED community. In this paper, an online testing method for LED life projection under accelerated reliability test was proposed and the prototype was built. The optical parametric data were collected. The systematic error and the measuring uncertainty were calculated to be within 0.2% and within 2%, respectively. With this online testing method, experimental data can be acquired continuously and sufficient amount of data can be gathered. Thus, the projection fitting accuracy can be improved ($r^2 = 0.954$) and testing duration can be shortened. © *2014 AIP Publishing LLC*.
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Light-emitting diode (LED) lighting technologies have achieved massive advancement in recent years as a result of dedicated efforts on research and development from manufacturers and research institutes all over the world. LED is valued over conventional light source because of its overwhelming advantages such as high efficiency, compact size, environmental protection, and long lifetime.[1–3] In today's world, we can see LED luminaires around us every day and everywhere. Among LED's advantages, long life or good reliability plays an important role because the fantasies of the other advantages are all based on the fact that the luminaire is alive. Thus, much attention must be paid to the reliability issues of LED.

Many researchers and organizations have been working on LED's reliability issues. Among these, the Illuminating Engineering Society (IES) focuses on establishing industrial standards based on which manufacturers can assess their LED products before marketing them. The LM-80 Standard[4] specifies rules that must be strictly followed for right and proper report. However, the LM-80 standard does not specify the curve fitting methods, sample size, extrapolation, and L70 prediction methods. Another standard, the TM-21 Standard[5] solves the above questions. With the approved methods recommended by these two standards, manufacturers are able to publish more convincing LED product reports.[6–8] Nevertheless, both two standards require at least 6000 h testing duration, and this is obviously too long for most researchers and companies. In addition, the curve fitting accuracy in TM-21 Standard is relatively low.

To solve these problems, many researchers have been attempting to develop effective *in situ* measurements since *in situ* method can provide more data and shorten testing time. Svilainis[11] worked out an LED directivity *in situ* measurement, with which the LED far-field pattern can be measured quickly without dismantling the LEDs from the tile. Zhou *et al.*[12] developed an instrument for LED transient measurement, which can be used to inspect the quality of LED packaging, and it can simultaneously measure photometric, colorimetric, and electrical parameters from the electroluminescence of the LEDs in a matter of millisecond. Unfortunately, little literature talks about methods which can be used for life projection.

As a member of the semiconductor family, the principle of LED is more or less similar to that of the laser diode (LD). So we can get design hints from LD society. There are many studies on LD's performance and degradation in reliability characterization.[9,10] In these references, they used online testing method and conducted reliability experiment. It is proved that with accelerated aging test and continuous monitoring, the testing duration can be shortened and the extrapolation accuracy can be improved.

In this paper, we presented an online testing method for life projection of high power light-emitting diode (HPLED) under accelerated reliability test. A fiber coupled remote data collection system was designed, which could be used under harsh ambient conditions like high temperature, thermal shock, and so on. The systematic error and the measuring uncertainty were calculated to be within 0.2% and within 2%, respectively.

Fig. 1 shows the connection of the components used in this online testing method. LED modules are placed in the thermal chamber (5 specimens at a time), in which they are lumen-isolated with each other by light-tight boxes. One side of the optical fiber cable which is heat resistant is sticked inside the box and fixed coaxially with the LED module by a manual fixture. The other side is connected with a multichannel illuminance acquisition system, through which the

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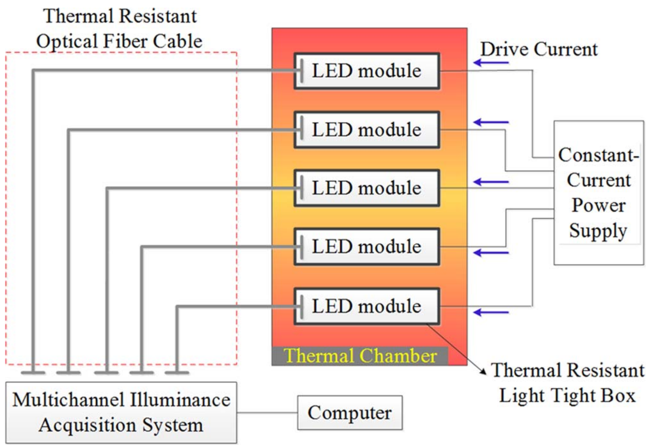

FIG. 1. Schematic of placement and connection of the experimental components.

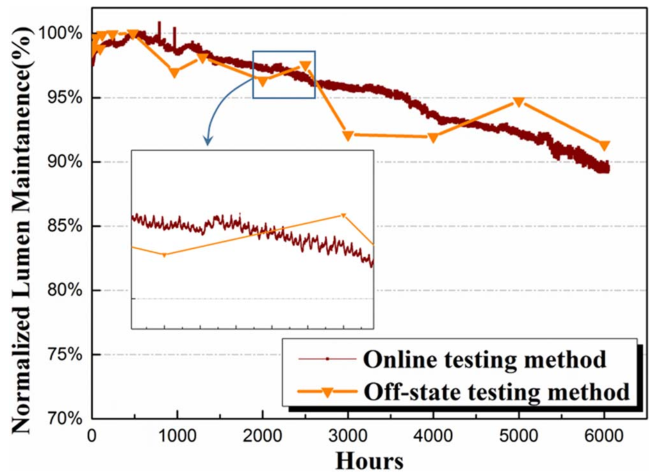

FIG. 2. Data collection of the online method and the off-state method.

illuminance data can be monitored and stored. The LED modules are driven by a constant-current power supply.

In our experiment, the operating temperature inside the chamber remains 120 °C. In accordance to the LM-80 Standard, the air temperature change is controlled within +/−5 °C, the case temperature change is controlled within +/−1 °C. The relative humidity (RH) is less than 65%. The power supply is set at a constant current of 350 mA for LED modules. The LED emitted light is transmitted to the data acquisition system through the optical fiber cable. The computer software is set to measure and store the illuminance data at a certain time interval.

Since the thermal chamber and computer software can work stably for a long time, the whole system can be used for LED life projection with continuous monitoring under long time operation.

In off-state accelerated reliability test for life projection, it is essential that the LED samples are aged for a quite long duration and the lumen maintenance is measured periodically. This sampling time interval can have a big influence on the consistency of the aging process. Large time interval is usually adopted to minimize the influence. However, at the beginning of the whole aging operation, the sampling time interval should be shortened for the detection of the annealing effect on the packaging materials.[13] This means that with periodic sampling, initial anomalous aging data can have a disproportionate impact on determining the longer term aging characteristics.

For the present online testing method, it has the ability to continuously acquire experimental data without worrying about the influence on the aging process caused by removing operation. In Fig. 1, it can be seen that the illuminance data are measured and saved by the multichannel illuminance acquisition system outside the thermal chamber. The time interval for data capturing can be set to as short as 2 s. Thus, continuous data acquisition can be achieved.

To specify this advantage in details, a benchmark was done. We selected ten commercial white LED modules, and they were driven by 350 mA forward current under an ambient temperature of 55 °C. The initial junction temperature of these samples was about 105 °C. The illuminance data were collected both by the online method and off-state method, respectively. Fig. 2 reports the results after 6000 h aging. The experimental data were averaged and normalized to the initial values of the original samples. It can be seen that both optical degradation curves exhibit the same decay mode. However, compared with the data obtained by off-state method, more details are displayed by the online method. And also, it seems that smaller measurement uncertainty can be achieved by the online testing method.

Comparison error analysis was carried out to discuss the measuring accuracy of the online testing method. An

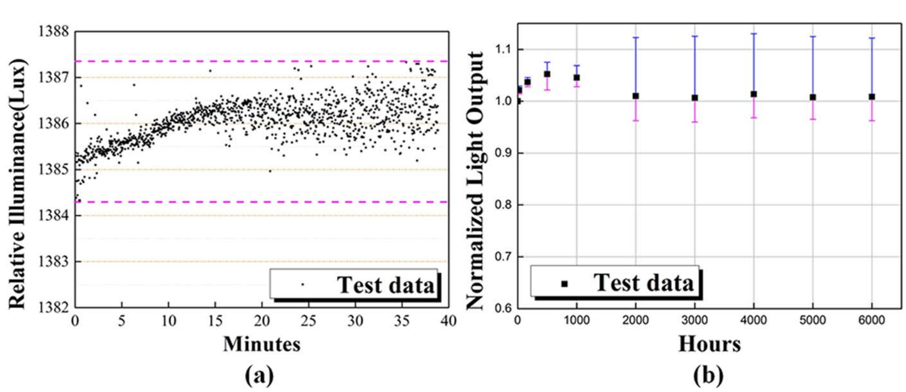

FIG. 3. Systematic errors of (a) online testing method and (b) off-state testing method.

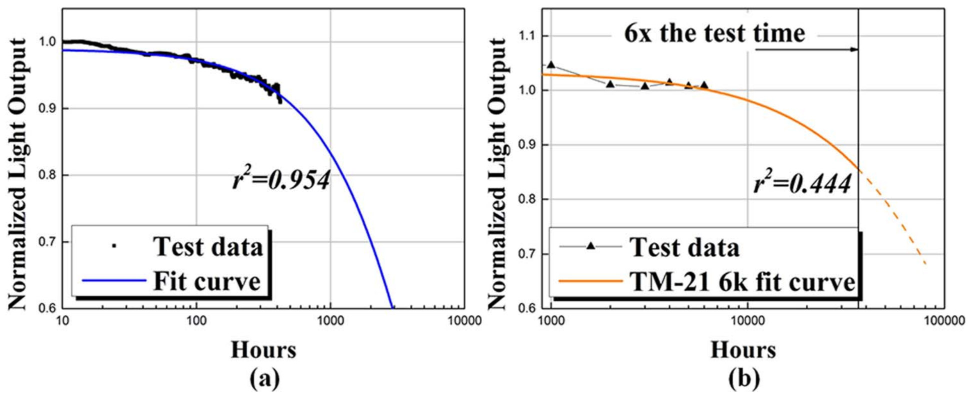

FIG. 4. Random errors of (a) online testing method and (b) off-state testing method.

accelerated aging life test was executed by the online testing method. Blue LED modules were placed in an isothermal chamber. The ambient temperature and the forward drive current were set to 125 °C and 350 mA, respectively. The illuminance data were collected at an interval of 30 s. As a reference, partial data from LUXEON Rebel IES LM-80 test report was used.[8] The results were displayed in Figs. 3 and 4.

The measurement error can be divided into two parts: systematic error and random error. For the first one, it can be calculated by the formula below:

$$e_{sys} = \frac{\Delta_{max}}{F_0} \times 100\%, \tag{1}$$

where Δ_{max} is the maximum illuminance difference and F_0 is the average illuminance value. As shown in Fig. 3(a), it can be calculated that $e_{sys} = 0.2\%$ for the online testing method. However, for the off-state method, it is found that after 1000 h of aging, the systematic error increases to be around 16%, as displayed by the error bars of Fig. 3(b).

The random error can also be identified as the system uncertainty, which can be simply reflected by the standard deviation of the system. For data analysis, the lifetime extrapolation was carried out based on the experimental data obtained by the online testing method and from the literature, respectively. The extrapolation formula recommended by TM-21 standard was adopted, which can be expressed as follows:

$$\Phi(t) = Be^{-\alpha t}, \tag{2}$$

where t is the operated time, $\Phi(t)$ is the relative light output, B is the initial constant, and α is the degradation rate. The results were reported in Fig. 4. It can be calculated that for the online testing method, the standard deviation is 0.21% and the correlation efficiency is $r^2_{online} = 0.954$. Comparatively, for the off-state method, the standard deviation and the correlation efficiency are 1.02% and 0.444, respectively. So a better uncertainty of measurement can be achieved by this online testing method.

An online testing method for LED life projection under accelerated reliability test was proposed in this paper. By comparing with off-state testing method, the advantages of this online testing method were reported. The systematic error and the measuring uncertainty are calculated to be within 0.2% and within 2%, respectively. This precision is better than or as high as that of off-state testing method. Besides, the online testing method can be used for continuous monitoring, which means that sufficient data amount can be gathered and high curve fitting accuracy can be achieved ($r^2 = 0.954$).

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