ISA Recommendation

Prediction for Color Maintenance of LEDs Based on A Spectral Power Distribution Decomposition Method

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International Solid State Lighting Alliance

Technical Committee on Standardization

This recommendation is prepared by ISA Technical Committee on Standardization.

Working Group 1:

"Recommendation on the Color Shifting of LED Lighting Product"

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Introduction

The color shift is one of the dominant degradation modes of LEDs. In a long period, lumen efficacy is considered as the primary pursuit, resulting in an impression that the luminous flux degradation is the only crucial reliability concern. Nowadays the LED products are faced with a new era of not only replacing but also exceeding their traditional counterparts (such as incandescent lamps and cold cathode fluorescent lamps). Under this circumstance, the requirements of the color consistence in LEDs become more important than those of lumen maintenance in many applications (such as supermarket, shopping mall, museum, and healthcare lightings). Energy Star, affiliated to the U.S. Environmental Protection Agency, firstly require that a shift of color coordinates (represented by the Euclidean distance d'u'v' in the CIE 1976 chromaticity diagram) should not be larger than 0.007 for general lighting applications. In some particular cases, a smaller threshold such as 0.004 or even 0.002 might be adopted for stricter requirements. Nevertheless, the lifetime prediction models for the color shift failure are quite limited.
As a matter of fact, the color shift of a LED is linked by the degradation of its Spectral Power Distribution (SPD), since the colorimetric parameters of the LED, such as color coordinates, Correlated Color Temperature (CCT), are calculated according to its SPD curves.
The purpose to draft this document is to develop a method for predicting color maintenance of LEDs. The method enables prediction of spectral change trends of LEDs over product lifetimes and is of great significance for researching product reliability.

Scope

This document specifies a method of prediction for color maintenance of LEDs product.
This document is applicable to LED based products, which contain products using phosphor converted white LED, products using RGB based LED and products using single color LED.
This document is also applicable to white laser diode (LD) lighting products.

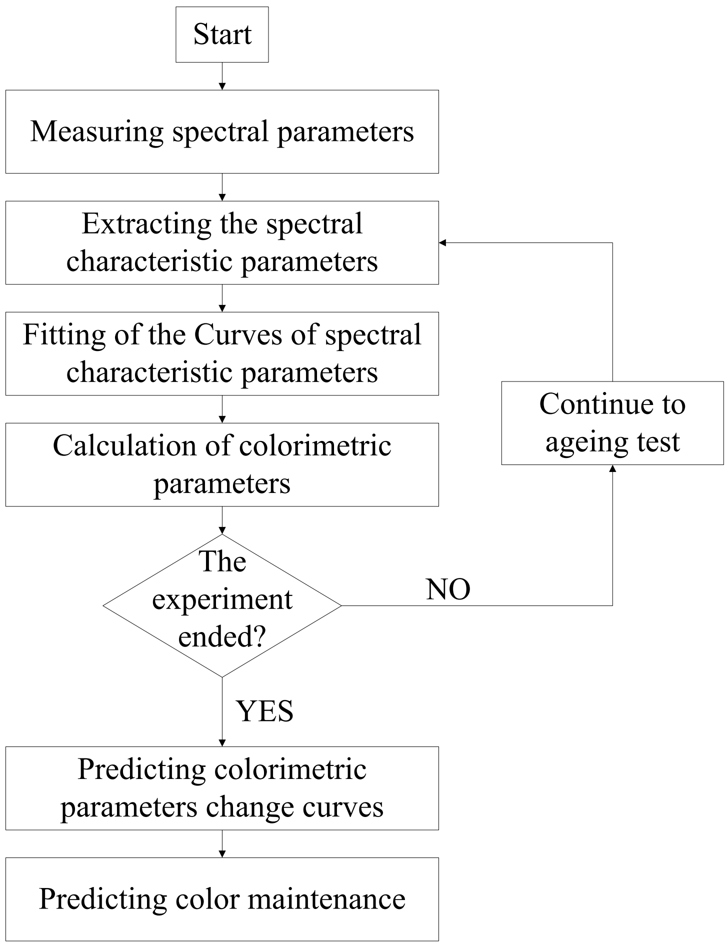
Methodology

The method comprises the following steps:

1) measuring the SPD curves of the test sample at various time points during the ageing process;
2) extracting the spectral characteristic parameters from the SPD curves and predicting their degradation trends in terms of the ageing time;

3) predicting the SPD curves of the test sample beyond the ageing process;
4) predicting the color shift values of the test samples based on the predicted SPD curves obtained from the last step.

The flow chart of the method is as follow:



Proposed definitions

Color shift

The changes of the color consistency of LEDs which can be represented by the chromaticity coordinate.

SPD curve

The relation curve between the spectral wavelength and other variables such as spectral intensity.

Asymmetric SPD model

Asymmetric models such as asymmetric Gaussian function and asym2sig function which are used to depict the decomposed SPD curves.

Discomposed SPD peak

The single-peak spectrum discomposed by the spectrum of LEDs using asymmetric models. White LEDs, such as PC-LED, RGB-LED, have multi-peak spectrum.

Proposed technical requirements

1. Requirements for measurement

Shall comply with the requirements of IES-LM-79-08 and CIE127:2007.

2. Requirements for ageing test

2.1 ageing test

The ageing test time of LED product shall equal to or more than 3000 hours, the number of measurement time point shall be greater than 4, the interval shall be no more than 1000 hours.

2.2 test termination condition

The ageing test shall be terminated when one any of the following conditions are met.
(1) The differences between all of four consecutive predicted values of color shift and its algebraic means are no more than 5%.
(2) The ageing test has reached a specified time which shall be longer than 3000 hours.

3. Requirements for the fitting of spectra

3.1 Decomposition of the SPD curve

Suppose that the spectrum of a LED lighting product is composed of several single-peak spectrums with different peak wavelength, equation (1) is used to decompose the spectrum of LED products.

$$SPD_{LED}(\lambda) = \sum_{i=1}^{n} SPD_i(\lambda) \tag{1}$$

Where SPD_{LED}, SPD_i, i, n, λ are the spectrum of LED products, the single-peak spectrum of number i, the total number of single-spectrum, wavelength, respectively.

3.2 Extracting the spectral characteristic parameters

The single-spectrum SPD_i shall be fitted by asymmetric SPD model equation (2) or equation (3).

$$SPD = \begin{cases} a\exp\left(-\frac{(\lambda-\lambda_c)^2}{w_1^2}\right) & \lambda \le \lambda_c \\ a\exp\left(-\frac{(\lambda-\lambda_c)^2}{w_2^2}\right) & \lambda > \lambda_c \end{cases} \quad (2)$$

$$SPD = a\frac{1-\frac{1}{1+\exp\{-(\lambda-\lambda_c)/w_1\}}}{1+\exp\{-(\lambda-\lambda_c)/w_2\}} \quad (3)$$

Equation (2) and equation (3) each have four spectral characteristic parameters (*i.e. a,* λ_c*,* w_1 *and* w_2) which can completely represent the single-spectrum SPD_i. After fitting, the spectral characteristic parameters can be acquired. Therefore, the spectrum of LED products with *n* single-spectrum(s) need 4 * *n* spectral characteristic parameters.

3.3 Fitting of the curves of spectral characteristic parameters

The spectral characteristic parameters shall be fitted by the candidate models expressed by equation (4).

$$y = C_1\exp(C_0 t) \quad (4)$$

Equation (4) is empirical models in which *par* denotes one of the SPD parameters, *t* is the ageing time, C_0 and C_1 are the fitting parameters estimated by the Maximum Likelihood Estimation (MLE) method. Equation (4) enable to describe the tendency of spectral characteristic parameters over time.

4. Requirements for calculation of colorimetric parameters

A set of colorimetric parameters of the LED products shall be calculated by Equation (5) to Equation (9).

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z} \quad (5)$$

$$X = \int_{380}^{780} SPD_{LED}(\lambda)\bar{x}(\lambda)d\lambda, \quad Y = \int_{380}^{780} SPD_{LED}(\lambda)\bar{y}(\lambda)d\lambda, \quad Z = \int_{380}^{780} SPD_{LED}(\lambda)\bar{z}(\lambda)d\lambda$$

in which *X*, *Y* and *Z* are the tristimulus values corresponding to the red, green and blue colors, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the color matching functions.

$$u' = \frac{4x}{-2x+12y+3}, \quad v' = \frac{9y}{-2x+12y+3} \tag{6}$$

$$du'v' = \sqrt{\left(u' - u_0'\right)^2 + \left(v' - v_0'\right)^2} \tag{7}$$

in which u_0' and v_0' are the initial values of u' and v', respectively.

5. Requirements for predicting color maintenance

The color maintenance shall be predicted by interpolations of the corresponding failure thresholds along the degradation curves of colorimetric parameters changing curves.