Study on a system for LED's photometric and colorimetric measurement based on a multi-channel spectrometer

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Abstract: -Light Emitting Diode (LED) is quite different from traditional light sources in many aspects. In this paper the practical aspects of LED's measurement and problems are discussed. An integrating sphere system is designed and implemented for LED measurement based on a multi-channel spectrometer. The principle and procedure of the measurement are presented, and then the measurement errors are analyzed. The spectrometer uses a Self-scanning Photodiode (SPD) Array device as the detector which has 256 pixels and ultra-high sensitivity. The system can fulfil fast and accurate measurement for LED's photometric and colorimetric quantities such as total luminous flux, Color Temperature, Color Rending Index (CRI) and color coordinate. This method can avoid the measurement errors by self-absorption effect and mismatch of V (λ).

Key-Words: - Light Emitting Diode (LED), spectrometer, photometric, colorimetric, SPD, integrating sphere

1 Introduction

There have been significant developments of light-emitting diodes (LEDs) in the last decades [1]. High brightness LEDs are now available in many shapes, sizes, light output levels and colors; their efficiency has recently been greatly improved. LEDs are being utilized in many applications such as traffic lights, roadway barricade lights, automobile lights, marine and airport signaling, and color displays. White LEDs are also now available; their performance is improving year by year and their price is declining gradually. White LEDs can be produced by three methods- mixture of three or more monochromatic LEDs (e.g., RGB combination), use of a phosphor excited by blue LED emission or multiple phosphors excited by UV LED emission [1-2]. With efficacies greater than incandescent and approaching that of fluorescent lamps (Many of white LEDs currently commercially available have a luminous efficacy of 100 lm/W) along with their durability, small size, and light weight, LEDs are finding their way into many new applications within the lighting community, and it is expected that LEDs will be increasingly used in general lighting applications[3].

These new applications have placed increasingly stringent demands on the photometric and colorimetric measurement of LEDs, which serves as the fundamental baseline for product quality and product design. However, there are large variations in measurements reported (40 % to 50 % discrepancies in luminous intensity and total flux measurement in the industry) [4], in contrast to typical traditional lamp measurements, which agree typically within a few percent between different companies. Characteristics of LEDs, including physical size, flux levels, spectrum and spatial distribution, separate them from typical element sources, which are generally employed and measured for photometric and radiometric quantities. With an LED, it is often difficult to achieve a high level of photometric or radiometric measurement accuracy due to uncertainties within the measurement equipment and improper test setup. In addition, traditional photometers, because of their inability to simulate the response of the human eye at the ends of the visible spectrum generate significantly flawed data when testing red, blue, and some styles of white LEDs. Specific expertise in LED metrology is needed in order to obtain accurate and reproducible results.

This paper discusses the special optical characteristics of LEDs and provides a photometric and colorimetric measurement system based on a multi-channel spectrometer, which is introduced to measure LED's relative spectral power distribution, and then calculate LED's photometric and colorimetric quantities such as total luminous flux, Color Rending Index (CRI), Correlated Color Temperature (CCT), and Chromaticity coordinates, etc. This method using a multi-channel spectrometer

to measure LED's photometric and colorimetric parameters can solve the mismatch between R(λ) and V(λ), eliminate the self-absorption effect, and get accurate results.

2 LED's property and measurement issues

2.1 Introduction of LED and its property

LED is a solid-state (p-n junction semiconductor) device that converts electrical energy directly into light (electroluminescence). LED has potentially high efficiency because most of the energy radiates in the visible spectrum. In comparison, incandescent bulbs convert about 5 percent of their power into visible light. Incandescent lamps radiate much of their energy in the non-visible spectrum, generating heat as well as light. For example, the package of an LED may be 10° to 25° C hotter than ambient, but under the same conditions, the envelope of an incandescent bulb can be several hundred degrees hotter.

An LED in its simplest form is semiconductor P-N junction devices (chip) that, when forward biased, emits photons (light) as the electrons and holes recombine near the junction. The energy of the photons is determined primarily by the energy band gap of the semiconductor where the recombination occurs. Since the eye is only sensitive to light with photon energy from 3.1 eV to 1.6 eV (0.40 to 0.78 μm), compound semiconductor materials composed of column III and V elements are the materials of choice for LEDs because they have the direct band gap properties and energies necessary for efficiently producing visible photons. To convert the wavelength (λ) in microns to photon energy, the relationship λ = 1.24 / eV can be used.

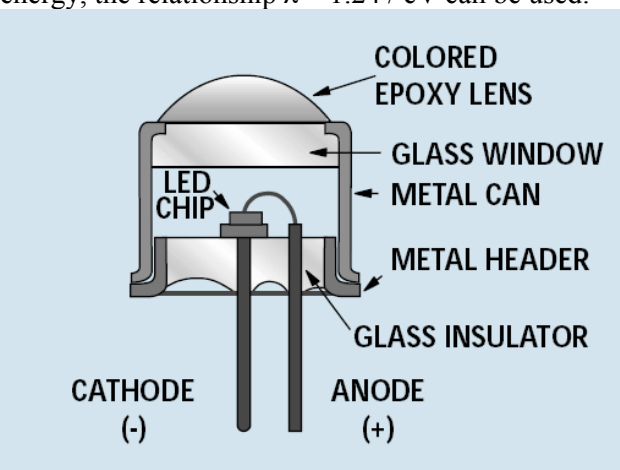


Fig.1 LED lamp construction

Fig.1 depicts a diagram of a typical LED lamp. An LED lamp contains an LED chip and an epoxy molded lens encapsulate. The lens is used to change the direction and control the distribution of light rays (spatial distribution pattern) or colored to serve as an optical filter to enhance contrast. The epoxy encapsulates and lead frame occupy most of the volume.

2.2 LED measurement issues

LEDs have large differences in spectral and spatial characteristics compared with traditional light sources [5]. CIE published a recommendation on the measurements of LEDs in 1997 (CIE Publication 127), and revised it in 2007[6]. But it is not sufficient; there is not yet an international standard method for LED's measurement. There are some challenging problems for measurement of LED, such as it will veritably bring errors using traditional method to measure LED's total photometric and colorimetric quantities.

2.2.1Spectral mismatch of the system

Optical detectors are often designed to mimic different wavelength selective physiological functions using optical filters. Examples of such detectors are photometers and broadband ultraviolet meters. Spectral responsivities of photometers are optimized to match the V (λ) function, defined by the International Commission on Illumination (CIE). The V (λ) function represents the spectral sensitivity of the human eye for photopic vision. Because a perfect matching to a certain desired physiological curve is not possible in practice, Fig.2 shows the mismatch of the photometer to V(λ).

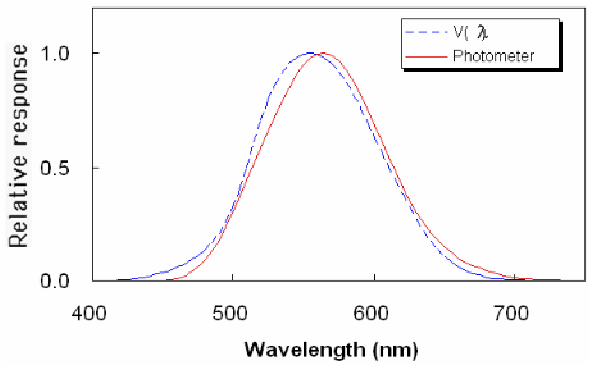


Fig.2 the mismatch of the photmeter to V(λ)

We usually use incandescent lamp for calibrating photometer currently and evaluate the

mismatch error (refer as SCF) in average value over the whole visible range, this evaluation defines the average error in percentage for whole visible range while the percentage error in blue wavelength is possibly quite bigger than SCF since the absolute value of V (λ) is very small in the blue wavelength range, similar situation occurs in red wavelength range. Photometer with good SCF calibrated in the methods is good for measuring light sources with continuous spectrum. However, LED is available in wide variety of peak wavelengths covering the visible and adjacent wavelength range, and LED's narrow bandwidth is typically 20nm to 40nm. Therefore, it will cause a significant error in total flux measurement for blue/red LED by a photometer even with a good SCF correction like. Fig.3 shows the measurement errors of total luminous flux by spectral mismatch errors, this case will cause about 45% errors.

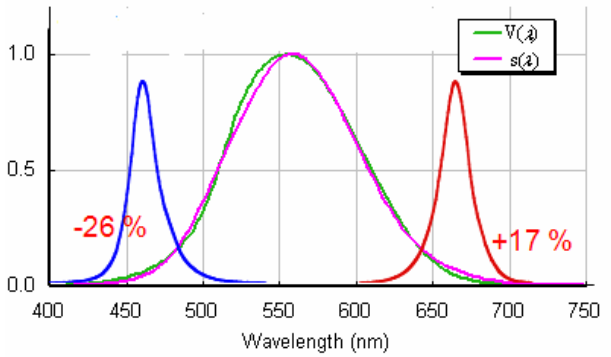


Fig.3 spectral mismatch errors

2.2.2 Spatial nonuniformity of the integrating sphere response

Integrating spheres have non-uniform surface reflectivity due to uneven thickness and possible contamination of the coating, along with structures such as baffles, the gap between the two hemispheres and a lamp holder. There are inevitably cause measurement errors because different LEDs have different spatial distributions. Fig.4 is the spatial nonuniformity of the sphere response.

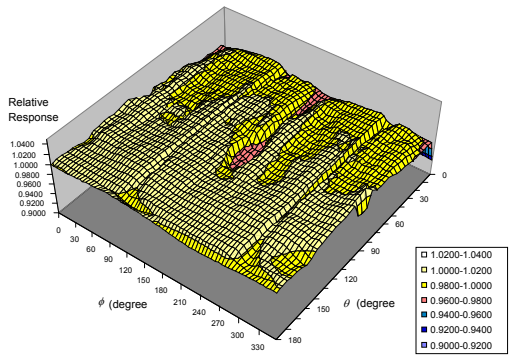


Fig.4 Spatial nonuniformity of the sphere response

2.2.3 Self absorption effect

For an ideal sphere calculation, it is assumed that there are no objects in the sphere. However, when we use a sphere, we need to put objects (the light sources, baffles and the holders) into it, these objects will inevitably cause disturbance of light distribution within the sphere and error in measuring of LED's total luminous flux.

We use Tracepro to establish the model shown in Fig.5, and then simulate the influence of the baffle, holder and test LED itself on the luminous flux, the results is depicted in Fig.6.

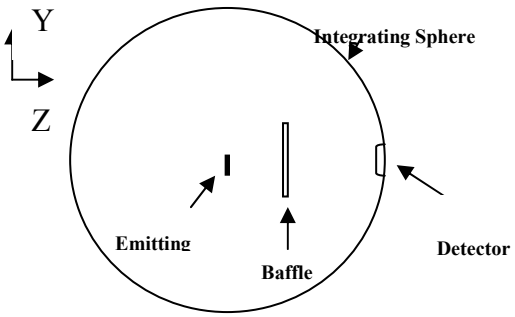
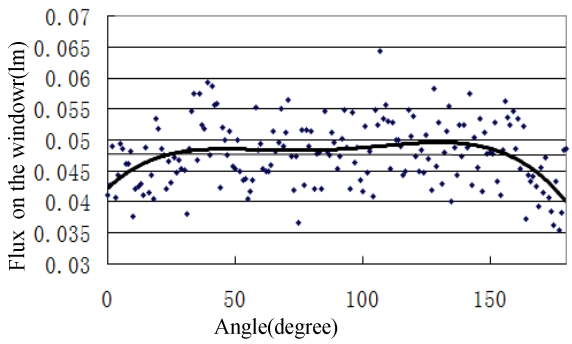
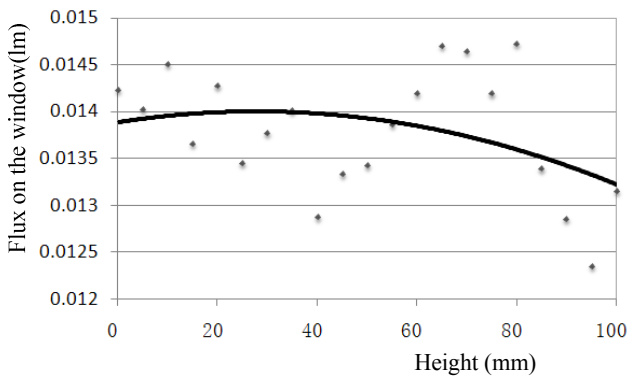


Fig.5 Schematic drawing for simulation



(a)



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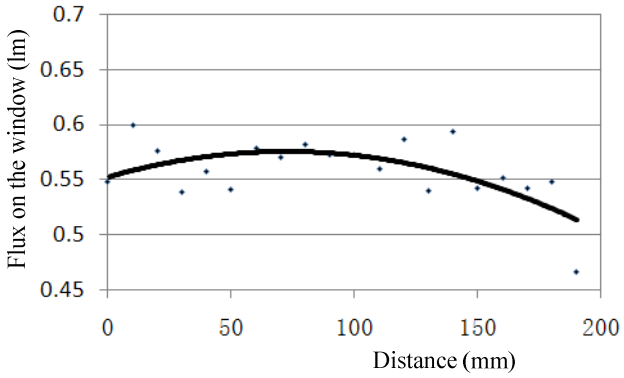

(c)

Fig.6 Simulation results of self-absorption effect. (a) is the baffles influence, (b) is the holders influence, and (c) is LED's absorption.

From Fig.6(a) we can see that the flux illuminated on the detector through the window varies with the direction of radiation, lower in the angels nearly vertical to the baffle; Fig.6(b) shows that the higher the holder is, the smaller the detected flux is. This is because the holder is not a 100% reflector; it will absorb some fraction of the light; while Fig.6(c) notified that the closer LED approaches the bottom, the more it absorbs the reflected light, so the smaller of the detected flux is.

2.2.4 Self-heating problems

LED is sensitive to its PN junction temperature [10], Fig.7 shows an example of the relative photometric output to junction temperature of a white LED. So the temperature of LED must stay stable during the measurement. When we place the LED inside the integrating sphere, it can't dissipate its heat easily, which will cause the drop of output luminous flux, and bring measurement errors.

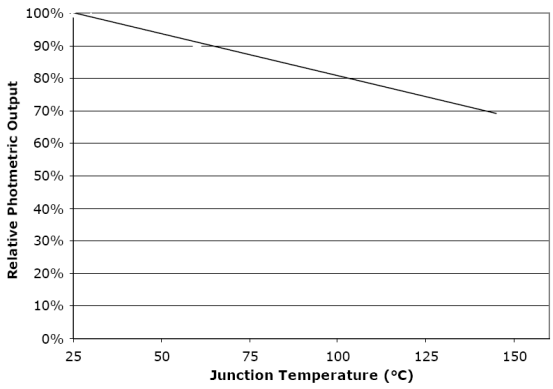

Fig.7 Relative photometric output vs. junction temperature of a white LED.

3 Principle of the measurement

The measurement system is as shown in Fig.8. The LED for measuring and the standard lamp is placed on the interior wall of the sphere; the light is transferred by a narrow aperture fiber to the multi-channel spectrometer, which in turn measures the LED's relative spectral power distribution P (λ), communicates with a computer through USB interface, and transfers the measurement data to the computer for calculation and display.

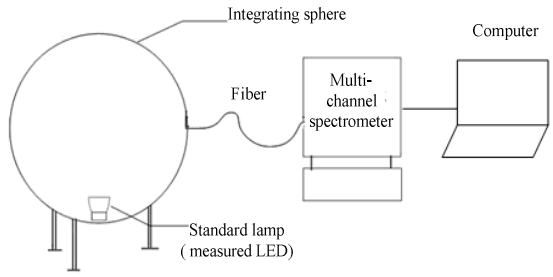

Fig.8 Schematic of LED measurement system

3.1 Measurement of total luminous flux

The luminous flux of a light source represents the total amount of visible optical energy, this source emits in all directions per unit time. The total luminous flux of a light source can be defined as [11, 12]:

$$\phi_v = K_m \int_0^\infty \phi_e(\lambda) \cdot V(\lambda) \cdot d\lambda \qquad (1)$$

The total luminous flux of a light source can be measured by using either a goniophotometer or an integrating sphere. The latter is widely used in industry because the measurement is instant. For an ideal sphere containing an ideal point source emitting total flux Φ, the illuminance E at any point on the interior surface of the sphere is given by

$$E = \Phi \cdot \frac{\rho}{1-\rho} \cdot \frac{1}{4\pi R^2} \qquad (2)$$

Where R is the inner radius of the sphere and ρ is the reflectivity of the inner surface of the sphere, the term $4\pi R^2$ is the surface area of the interior of the sphere, and the term $\frac{\rho}{1-\rho}$ is caused by the multiple reflections of the flux within the sphere.

$$\phi(1 + \rho + \rho^2 + \rho^3 + \ldots) = \phi \cdot \frac{\rho}{1-\rho} \qquad (3)$$

The total flux of the test LED ϕ_x can be got by comparing with a standard lamp like Eq (4).

$$\phi_x = \phi_0 \cdot \frac{E_x}{E_0} \quad (4)$$

Where ϕ_0 is the total flux of standard lamp, E_x is the illuminance of the LED for measuring and E_0 is the illuminance of the standard lamp.

3.2 Measurement of spectral distribution and related photometric quantities

The relative spectral power distribution can be getting by:

$$P(\lambda) = P_S(\lambda)\frac{Y_L(\lambda)}{Y_S(\lambda)} \quad (5)$$

Where $P(\lambda)$ and $P_S(\lambda)$ is the relative spectral power distribution of test LED and standard lamp respectively, $Y_L(\lambda)$ and $Y_S(\lambda)$ is the detector's response for test LED and standard lamp. When we get the relative spectral distribution $P(\lambda)$, then we can measure quantities related to $P(\lambda)$.

First, the following characteristic wavelength and spectral bandwidth are calculated: peak wavelength λ_p, spectral bandwidth at half intensity level ($\Delta\lambda_{0.5}$), centroid wavelength λ_c. The peak wavelength λ_p is the maximum of the relative spectral distribution $P(\lambda)$. $\Delta\lambda_{0.5}$ is calculated from the two wavelengths $\lambda_{0.5}'$ and $\lambda_{0.5}''$ on either side of λ_p, where the intensity has fallen to 50% of the peak value.

$$\Delta\lambda_{0.5} = \lambda_{0.5}' - \lambda_{0.5}'' \quad (6)$$

The centroid wavelength λ_c is calculated as:

$$\lambda_c = \int_{\lambda_1}^{\lambda_2} \lambda \cdot P(\lambda) d\lambda \Big/ \int_{\lambda_1}^{\lambda_2} P(\lambda) d\lambda \quad (7)$$

3.3 Measurement of colorimetric quantities

Table 1 shows typical colorimetric quantities used for LEDs. These quantities are officially defined in CIE publications12, 13. Chromaticity coordinates (x, y) and (u', v') are both current CIE recommendations and are widely used. The (x, y) diagram, however, is very non-uniform in terms of color differences. Fig.9 shows the minimum perceivable colour differences (magnified 10 times), known as Macadam Ellipses, plotted on both diagrams. For example, the colour differences of green LEDs would be much exaggerated on the (x, y) diagram. The (x, y) diagram has a long history and widely used. The non-uniformity is less problematic for white light sources, but it should be noted when the (x, y) diagram is used for single-colour LEDs. The (u', v') diagram is generally recommended for all colored light sources.

Table 1. Colorimetric quantities for LEDs

Color quantity	applicability
Chromaticity coordinates(x,y), (u,v)	For all color LEDs
Correlated color temperature (K)	For white LEDs
Color rendering index	For white LEDs
Dominant wavelength (nm)	For single-color LEDs
Peak wavelength (nm)	For single-color LEDs

The following colorimetric quantities are determined from the spectral distribution: chromaticity coordinates (x, y) and (u, v), correlated color temperature CCT, color rending index Ra.

3.3.1 Calculation of the chromaticity

For calculating the chromaticity coordinates (x, y) and (u, v), the spectral tristimulus values must be calculated first [13]:

$$X = K\int_{380}^{780} P(\lambda)\bar{x}(\lambda)d\lambda = K\sum_{380}^{780} P(\lambda)\bar{x}(\lambda)\Delta\lambda \quad (8)$$

$$Y = K\int_{380}^{780} P(\lambda)\bar{y}(\lambda)d\lambda = K\sum_{380}^{780} P(\lambda)\bar{y}(\lambda)\Delta\lambda \quad (9)$$

$$Z = K\int_{380}^{780} P(\lambda)\bar{z}(\lambda)d\lambda = K\sum_{380}^{780} P(\lambda)\bar{z}(\lambda)\Delta\lambda \quad (10)$$

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the CIE 1931 colour matching functions which are internationally agreed functions. (x, y) are calculated as:

$$x = \frac{X}{X+Y+Z} \quad (11)$$

$$y = \frac{Y}{X+Y+Z} \quad (12)$$

(u, v) can be calculated based on the CIE 1960 Uniform Color Space (UCS) or the 1970UCS.

$$(u,v)_{CIE1960} = \left(\frac{4x}{x+15y+3z}, \frac{6y}{x+15y+3z}\right) \quad (13)$$

$$(u,v)_{1976} = \left(\frac{4x}{3-2x+12y}, \frac{9y}{3-2x+12y}\right) \quad (14)$$

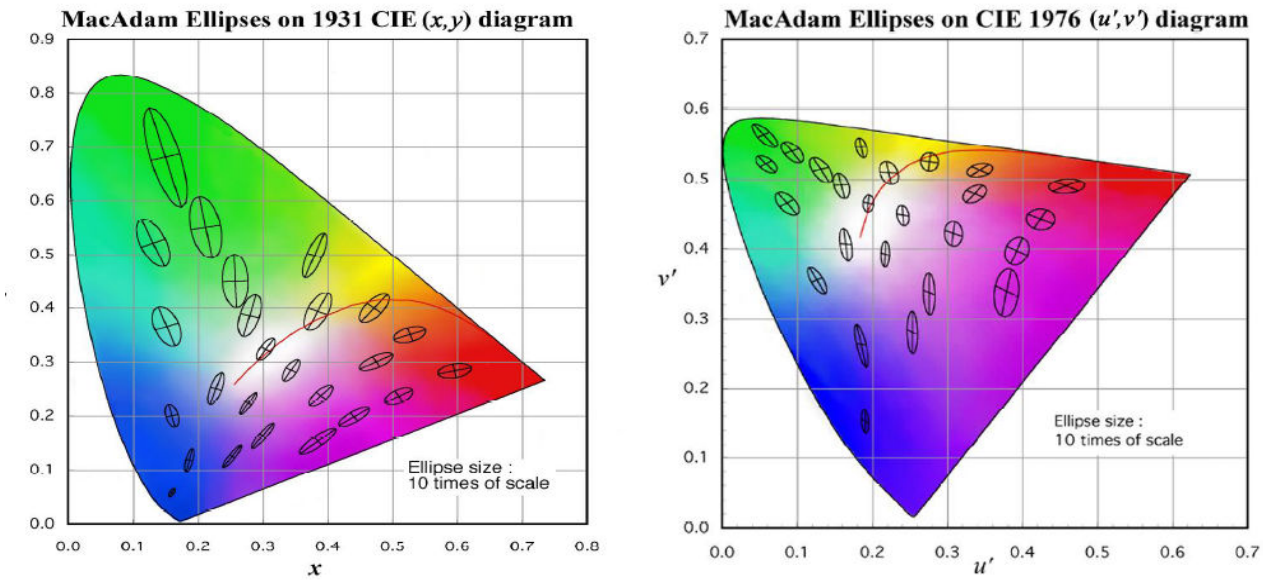

Fig.9 MacAdam Ellipses on CIE (*x, y*) and (*u'. v'*) diagrams.

3.3.2 Calculation of CCT

CCT is defined as the temperature in degrees Kelvin of an ideal black-body radiator whose chromaticity is closest to the unknown and when closeness is measured in CIE1960 UCS.

The definition given by the CIE, for the distribution temperature can be written as [14]:

$$\int_{380\text{nm}}^{780\text{nm}} \left[1-\frac{S'(\lambda)}{\text{a}S(\lambda,T)}\right]^2 \cdot d\lambda \rightarrow \min \qquad (15)$$

Where $S(\lambda,T)=c_1\lambda^{-5}\left[\exp(c_2/\lambda T)-1\right]^{-1}$ represents the spectral power distribution of a black body, c_1 is a constant whose value depends on the radiometric quantity being considered, but not relevant for the aim of the calculation itself, $c_2=1.438\times10^{-2}\,m\cdot K$, $S'(\lambda)$ represents the spectral concentration of any radiometric quantity of the source under test, which can be its power distribution, but not necessarily, T is the temperature of the Planckian radiator and a is a normalization factor such that when the integral in Eq.(15) reaches its minimum, the corresponding T value represents the source distribution temperature.

In this paper, we look for the minimization of the difference between the relative spectral distribution of the Planckian radiator and the source under test $A(a,T)$, and then Eq. (15) is particularly written for this quantity as:

$$A(a,T)=\int_{380\text{nm}}^{780\text{nm}} \left[1-\frac{P(\lambda)}{\text{a}S(\lambda,T)}\right]^2 \cdot d\lambda \rightarrow \min \qquad (16)$$

Where $P(\lambda)$ is the relative spectral distribution of the test source.

In the measurement, since the data acquisition in laboratory is usually discrete, the integral of the Eq. (16) is replaced by the following sum:

$$A(a,T)=\sum_{380}^{780}\left[1-\frac{P(\lambda)}{aS(\lambda,T)}\right]^2 \qquad (17)$$

That after some algebraic consideration leads to the relation:

$$A(T)=\sum_{380nm}^{780nm}\left\{1-\frac{P(\lambda)\sum_{380nm}^{780nm}\left[\frac{P(\lambda)}{S(\lambda,T)}\right]}{S(\lambda,T)\sum_{380nm}^{780nm}\left[\frac{P(\lambda)}{S(\lambda,T)}\right]}\right\}^2 \qquad (18)$$

Which when minimized gives the value of T corresponding to the distribution temperature of the test source.

3.3.3 Calculation of colour rendering index

Colour rendering index (CRI) is defined as description of the effect of a light source on the colour appearance of objects, compared to a reference source of the same colour temperature. It serves as a quality distinction between light sources emitting light of the same colour. The highest CRI attainable is 100.

The CRI is currently the only internationally agreed-upon metric for color rendering evaluation. The procedure for the calculation is, first, to calculate the colour differences ΔEi (in the 1964 W*U*V* uniform color space – now obsolete) of 14 selected Munsell samples when illuminated by a reference illuminant and when illuminated by a

given illumination. The first eight samples are of medium chromatic saturation, and the last six are highly saturated colours (red, yellow, green, and blue), the typical color of a Caucasian complexion, and the typical color of a green leaf. The reference illuminant is matched to the CCT of the test source and is the Planckian radiation for test sources having a correlated color temperature (CCT) < 5 000 K, or a phase of daylight for test sources having CCT≥ 5 000 K. The process incorporates the von Kries chromatic adaptation transformation. The Special Color Rendering Indices Ri for each color sample is obtained by:

$$R_{\mathrm{i}} = 100 - 4.6\Delta E_i ; (i = 1, 2..., 14) \qquad (19)$$

This gives the evaluation of color rendering for each particular sample. The *General Color Rendering Index* R_a is given as the average of the first eight color samples:

$$R_a = \sum_{i=1}^{8} \frac{R_i}{8} \qquad (20)$$

The score for perfect color rendering (zero color differences) is 100. For near monochromatic sources, the score can become negative. The CRI, however, is known to have deficiencies, and fails to work properly for many white LED light sources. The W*U*V* object color space is obsolete and very nonuniform. The standard eight samples used for the calculation of the General Color Rendering Index are all medium saturated colors, and even if Ra is high, saturated colors can appear very poorly. This problem is prominent for sources having narrow band peaks such as RGB white LEDs. Also, the CRI does not take into account the direction of color shifts. Decreases of chroma produce negative effects while increases of chroma often have positive effects.

4 Multi-channel spectrometer design

The designed spectrometer is high-performance, small-size, portable device, which can achieve fast measurement (4ms~2s) from 200nm to 1000nm, the stray light is below 0.05%, and its Wavelength resolution is 2nm. The spectrometer includes four parts: optical bench, Self-scanning Photodiode Array (SPD) device for photoelectric conversion; A/D conversion, and the software processing [15].

4.1 optical designs

Fig.10 is a diagram of the optical bench for the Spectrometer. This spectrometer uses Czenny-Turnner structure to make the system compact and get good aberration property. Light from the integrating sphere funnels to an optical quartz glass fiber then enters the optical bench through a SMA connector. To enhance the measurement accuracy silt, which acts as the entrance aperture, is used. The light passes through the installed slit, and directly enters the collimating mirror which reflects the light as a collimated beam toward the diffraction grating. The multi color light from the grating is focused in the photosensitive plane of array detector self-scanning photodiode (SPD) through the reflex of the focusing mirror. Each pixel of the SPD detector responds to the wavelength of light that strikes it. Electronics bring the complete spectrum to the software.

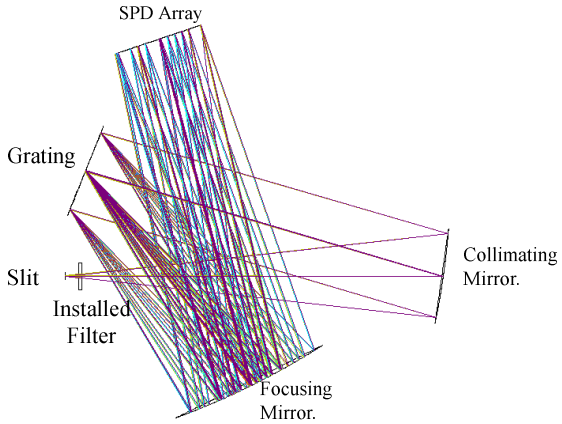

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Fig.10 Schematic of optical bench of the spectrometer

4.2 SPD Array

This paper uses a NMOS linear image sensor S3902-256Q of HAMAMATSU Company. S3902-256Q is a self-scanning photodiode array designed specifically as detector for multi-channel spectroscopy and has 256 pixels. The scanning circuit is made up of N-channel NMOS transistors, operates at low power consumption and is easy to handle. Each photodiode has a large active area, high UV sensitivity yet very low noise, delivering a high S/N even at low light levels. NMOS linear image sensors also offer excellent output linearity and wide dynamic range. S3902 has a height of 0.5mm and is arrayed in a row at spacing of 50μm. Fig.11 shows the equivalent circuit of S3902-256Q, its spectral response is as shown in Fig.12.

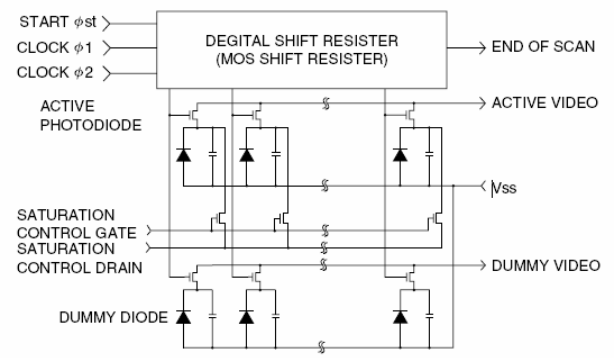


Fig.11 Equivalent circuit of S3902

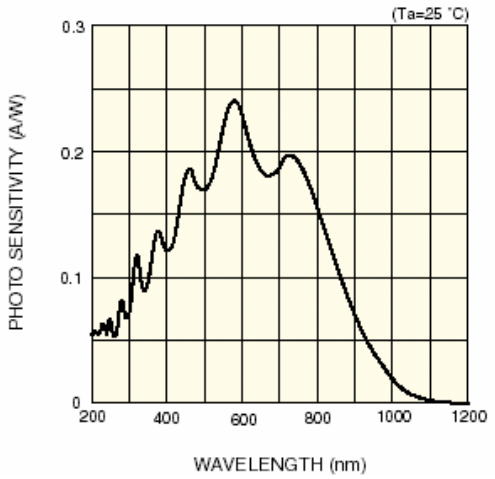


Fig.12 Spectral response of S3902

S3902 does not require any DC voltage supply for operation. However a start pulse Φst and 2-phase clock pulses Φ1, Φ2 is needed to drive the shift pulses and CMOS logic compatible. A clock pulse space(X1 and X2 in Fig.13) of a "rise time/fall time -20"ns or more should be input if the rise and fall time ofΦ1, Φ2 are longer than 20ns. TheΦ1 and Φ2 clock pulses must be held at "High" at least 200ns. Fig.13 shows the driver circuit of S3902. In this paper a MCU PIC16F84A is used to produce the driver clock signals.

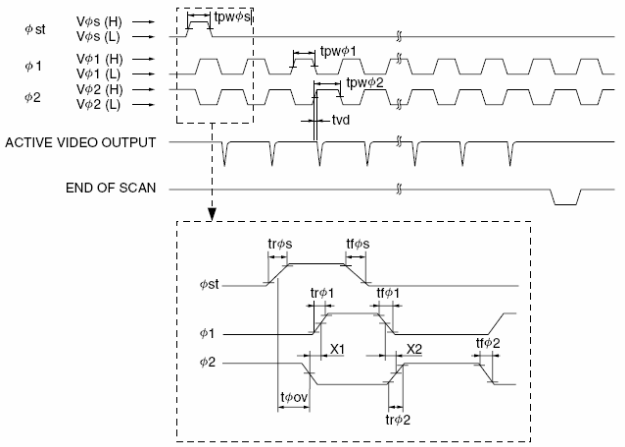


Fig.13 Timing chart for driver circuit

4.3 A/D converter and interface

Photocurrent from SPD is amplified and then enters into a 16-bit A/D to convert it into a digital signal, and then enters a MCU to achieve the measurement and calculation [16].

4.4 Software design

The function of the software includes Photometric measurement, system calibration, data storage, spectrum analysis, A/D controlling, and photometric parameters including total luminous flux, CCT, CRI, Chromaticity coordinates (x,y), (u,v),etc. The software also transfers the sampled data to a computer which displays the relative spectral power distribution and photometric and chromatic parameters on the screen.

4.5 Filtering process

The gain of SPD output signal can be adjusted by the exposal time [17, 18]. But the longer exposal time is set, the more noise will be added into the output signal. Some LEDs have very dark light emitted and their spectral output have lower signal to noise ratio (SNR). We proposed two methods to compensate and filter noise. One is hardware method including high frequency filter circuit and dark voltage balance compensated circuit, another is software smoothing and filtering method.

5 Measurement examples

5.1 Standard Lamp

CIE and many other institutes suggest using standard LED for calibration the total flux. They proposed that the calibration standard LED should be similar to the test LED both in spatial and spectral power distribution. In this circumstance it needs lots of standard LEDs for calibrating since LED is available in variety of spectral distribution.

A narrow beam standard lamp is used in this paper to complete the calibration, which is not to simulate LED, but to make all the lights emitted from the standard lamp enter the integrating sphere. The light exit aperture of this narrow beam must match the entrance of the integrating sphere. At the same time, this standard lamp must obtain good stability, have a wide spectrum, and it must be easy to calibrate. We use a halogen lamp with a color temperature of about 2800K, which emits narrow beam through optical design as shown in Fig.14.

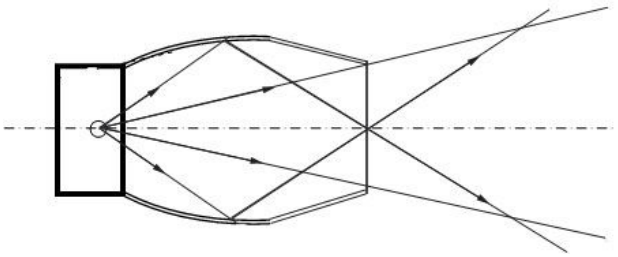


Fig.14 Optical design of narrow beam standard lamp

5.2 Wavelength calibration

There will be an approximately linear relationship between array position and tuned wavelength in a diode array type of instrument and in a conventional scanning instrument the sine-bar mechanism will yield a linear relation between lead-screw rotation and tuned wavelength. However, the relation may not be exactly linear and will exhibit some wavelength offset errors.

The wavelength scale is established by scanning a source which exhibits strong line-spectrum emissions at a few suitable wavelengths. Analysis of the wavelength errors at each spectral line provides the coefficients of an error polynomial which are stored and invoked for all subsequent measurements.

Here, the mercury lamp provides spectral line suitable for spectroradiometer wavelength calibration. See Fig.15.

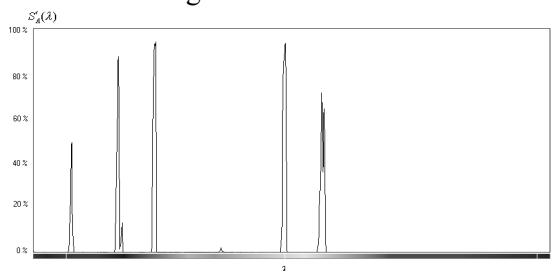


Fig.15 Spectral lines of the mercury lamp

5.3 Assembling process of the equipment

Assemble the components as Fig.8, the LED for measuring or the standard lamp is placed on the surface of the sphere, there is no baffle in the sphere, the narrow aperture fiber transfers the light to the multi-channel spectrometer, which measures the spectrum distribution, and then calculates the photometric and chromatic characteristics and thus carries out an accurate measurement.

The measurement method contains three steps: calibration of the standard light source, measurement of LED sample lamp and processing of measurement results.

5.3.1Calibration of the narrow beam standard lamp

Because this standard lamp is the standard lamp for both spectrum and luminous flux, this lamp's calibration for spectrum and total luminous flux must be taken into account.

Luminous flux calibration: a small goniophotometry is used in the measurement, its angular resolution is no bigger than 0.2 degree, detector's V（λ）matching error is less than 3%, and it must have a good stability. This method is suitable for transfer the luminous flux.

Spectrum calibration: a small integrating sphere is used for the calibration; there is a hole on the surface of the sphere for placing the narrow beam standard lamp, and a conventional color temperature (spectral distribution) standard lamp of close color temperature for transfer the spectrum distribution, as shown in Fig.16.

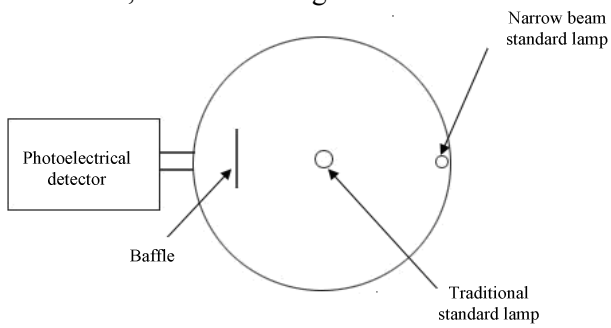


Fig.16 Calibration for the narrow beam standard lamp

5.3.2 Measurement of the LED

The measurement equipment is shown in Fig.8. At first, place the narrow beam standard lamp on the surface of the integrating sphere and light it, then complete the measurement with the spectrometer, input the value of standard lamp's luminous flux and color temperature, record standard lamp's spectrum, and save standard lamp's spectral power distribution as the standard value of the measurement; then place the LED for measuring on the surface of the same integrating sphere and light it, use the spectrometer to calculate the relative spectrum distribution of the LED for measuring, and then by comparing with the standard lamp, calculate the value of photometric parameters of test LED.

5.3.3 Measurement results

Take a 1W white LED for example. The measurement result is shown in Fig.17; its luminous flux is 29.06lm. In this figure, the horizontal axis is wavelength, unit is nm, and the vertical axis is relative spectral power. And it also displays color

temperature, Color coordinates, color rendering index and so on in the software as shown in Fig.17.

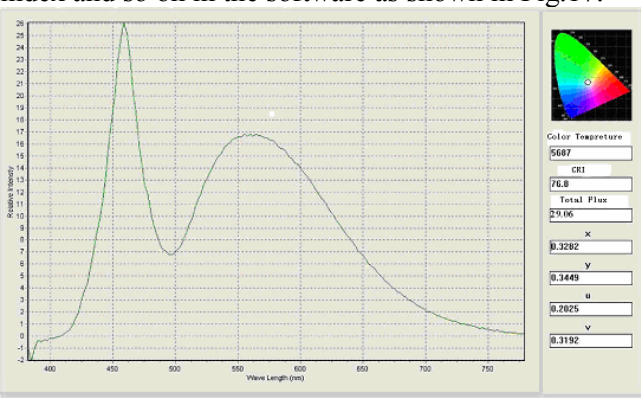
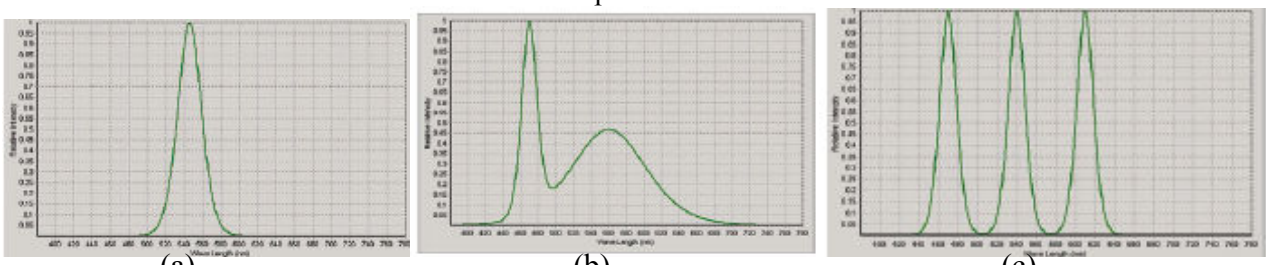


Fig.17 The result of LED measurement

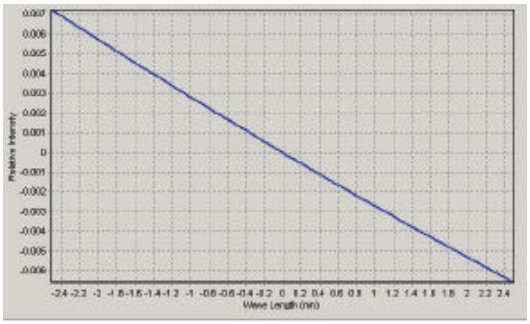
6 Error analysis of the measurement

We use three types of LEDs to simulate the measurement errors. Gauss line shape LED(Fig18(a)), phosphor-converted LEDs(pc-LEDs, Fig.18(b)), and RGB tricolor LEDs(Fig.18(c)).We use Gauss line shape to simulate the spectrum shape of LED by programming software in PC. In order to approach the real spectrum distribution by this method, the width of the Gauss line shape is carefully decided by comparing the spectrum actually acquired and the simulation result. At present, the white LED is seldom made by the combination of tricolor LED. Because the spectrum color generated is not so stable to control and the price is another problem. So, recently the most popular method to get white LED is using blue LED with yellow phosphor. All these three types of LED Spectrum mentioned are listed in Fig.18, and will be further used in error analysis.

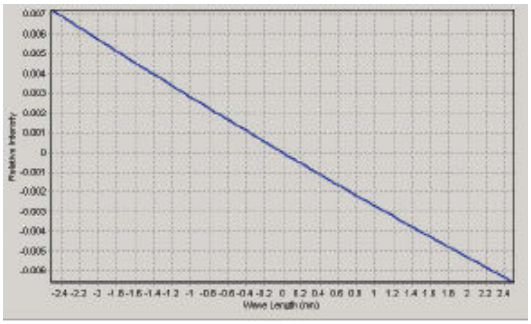


(a) (b) (c)

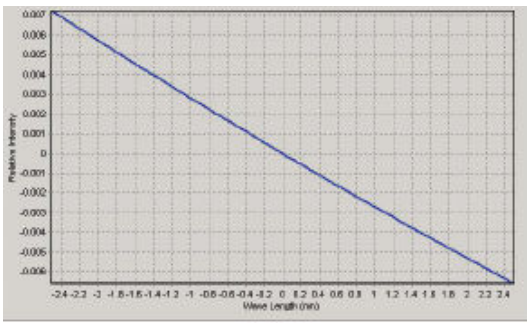
Fig.18 Three types LEDs for simulation. (a) is Gauss line shape LED, (b) is pc-LED, and (c) is tricolor LED



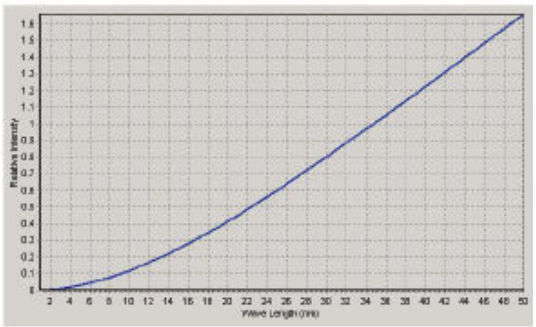
(a)



(b)



(c)



(d)

Fig.19 Calculation results of the measurement results.(a) is coordinate errors caused by wavelength shift, (b) is CCT measurement errors caused by relative spectral distribution,(c) is the luminous flux errors caused by relative spectral distribution, and (d) is CRI errors caused by relative spectral distribution.

After get the LED spectrum by the simulation method, we can now analyze the color of it by calculating the color coordinate, correlative color temperature, color rendering index. As we know the spectrophotometer will bring in errors because of wavelength shift, relative spectral response and so on. The difference between the original LED spectrum and the one after wavelength shift or relative spectral distribution effect in color measurement can be easily estimated by the software. Some calculation results are show in the Fig.19.

7 Conclusion

This paper introduced LED's property and some challenge problems for measurement the photometric and colorimetric quantities of LED, developed a multi-channel spectrophotometer for measuring LED's relative spectral power distribution and then calculates its photometric and chromatic parameters. The LED for measuring and the standard lamp is placed on the interior wall of the sphere, and there is not any baffle in the sphere. This method can solve the mismatch of the V（λ） and self-absorption effect, while it can get more accurate results comparing with the traditional methods.

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