Light Emitting Diode

Key Characteristics of Light - Brightness and Color

Table of contents

1. Overview 2
2. Properties of Light 2
3. Brightness 2
4. Color Evaluation Methods 8
5. Summary 10

1. Overview

LEDs are used in products in various fields such as luminaires, home appliances, and automobiles. Since the environments/conditions where the LEDs are actually used vary depending on different applications, LEDs are required to have various performances. Nichia offers a wide variety of LEDs designed for different types of applications to maximize the required performance.
When designing luminaires, it is necessary to use design and evaluation methods that are suitable for the chosen application. In order to select the most suitable methods, customers should fully understand the concepts of light and use suitable photometric properties and units for the chosen application.
This application note explains the most basic concepts of light which are “Brightness” and “Color”.

2. Properties of Light

The basic concepts of light properties are “Brightness” and “Color”.
“Brightness” indicates the intensity/amount of light emitted from a light source and light reflected off an object (e.g. floor or wall). In darkness, the absence of any light, humans cannot see objects or move freely. For any environment or circumstance, a suitable level of brightness is essential for humans to live.
“Color” represents the appearance of an object’s surface such as “an apple is red.” Humans perceive the difference in intensity of each wavelength of light reflected off an object surface as color. Color is dependent on not only the wavelength components of irradiated light but also the reflective characteristics of an object’s surface.
White light is generally used in homes, offices, etc. White light consists of various colors (wavelengths) and is the color appearance that allows humans to perceive the color of an object without discomfort. On the other hand, monochromatic light such as red or blue light is used to accentuate a particular color for decorative and display purposes. Sections 3 and 4 explain photometric properties and units.

3. Brightness

3.1. Luminous Flux (Total Luminous Flux)

3.1.1. Luminous Flux – Photometric Property and Unit

Luminous flux is a measure of the total amount of light emitted from a light source and is the most commonly used photometric property to indicate the brightness of LEDs, luminaries, etc. The SI unit for luminous flux is the lumen (lm). Nichia uses luminous flux to sort most of Nichia’s LEDs into the sorting ranks for each specification by measuring the brightness of the LEDs[1].

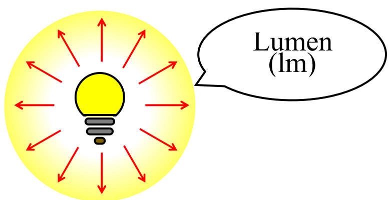

Figure 1. Image of Luminous Flux

[1] Some of Nichia’s LEDs are sorted by luminous intensity. The sorting ranks vary depending on the product type. See the applicable specification for the details.

3.1.2. Definition of Luminous Flux

In order to obtain the luminous flux, it is necessary to measure the amount of radiant energy that is emitted from the light source and received by a certain surface per unit of time.

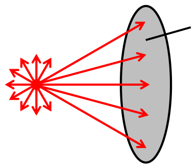

Figure 2. Definition Image of Luminous Flux

This radiant energy is referred to as radiant flux and its SI unit is the watt (W). The luminous flux is obtained by multiplying the amount of radiant flux within the wavelength range of visible light (380nm to 780nm) with the spectral luminous efficiency function (human eye's spectral sensitivity). Generally, radiant flux is used to represent the light emitted from a light source as energy, and luminous flux is used to represent the light emitted from a light source as brightness with consideration of the human eye's spectral sensitivity.
The equation for calculating luminous flux is shown in Equation 1, and an image of the calculation is shown in Figure 3.

Equation 1: $$\Phi_v = K_m \int_{380}^{780} \Phi_{e,\lambda}(\lambda) \cdot V(\lambda)\, d\lambda$$

Φ_v = Luminous flux (lm)
K_m = The maximum spectral luminous efficacy (lm/W)
$\Phi_{e,\lambda}(\lambda)$ = Spectral radiant flux in wavelength (W/nm)
$V(\lambda)$ = Spectral luminous efficiency function
$d\lambda$ = Wavelength difference (nm)

K_m refers to the maximum spectral luminous efficacy, which is K_m=683lm/W at a wavelength of 555nm (507nm in scotopic vision) where the spectral luminous efficiency function is 1.0.
$\Phi_{e,\lambda}(\lambda)$ and $V(\lambda)$ represent the spectral radiant flux in wavelength and the spectral luminous efficiency function at a given wavelength, respectively.

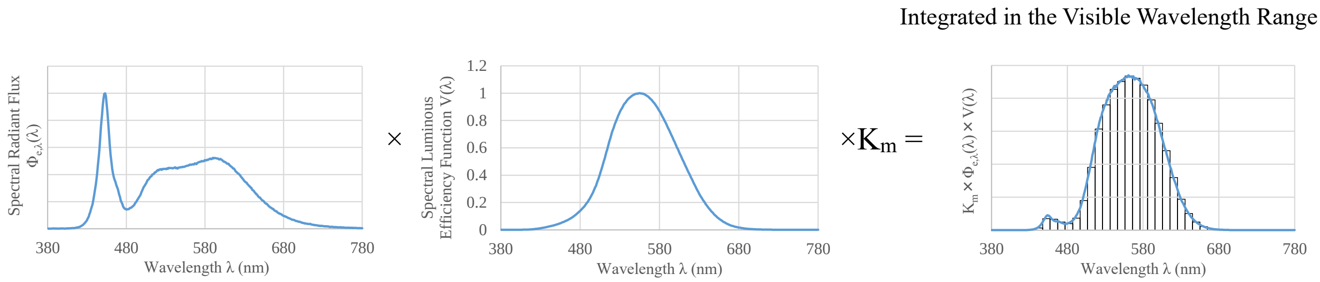

Figure 3. Image of Luminous Flux Calculation

The term "luminous flux" is sometimes called "total luminous flux" to emphasize the fact that it is the total for all directions from the light source. The term "luminous efficiency" usually refers to the value obtained from dividing the total luminous flux by the input power (see Equation 2).

Equation 2: $\eta = \Phi_v / P$

η = Luminous Efficacy (lm/W)

Φ_v = Total Luminous Flux (lm)

P = Input Power ($I_F \times V_F$) (W)

I_F = Forward Current (A), V_F = Forward Voltage (V)

3.2. Luminous Intensity

3.2.1. Luminous Intensity – Photometric Property and Unit

Luminous intensity is a measure of the amount of light emitted from a light source in a particular direction. The SI unit for luminous intensity is candela (cd). For a light source that has directivity characteristics (i.e. the brightness varies depending on the illumination direction) such as a flashlight, luminous intensity is used to evaluate whether the intended brightness is emitted in the intended direction.
LEDs also have directivity characteristics. The directivity characteristics of Nichia's LEDs vary depending on the LED type. For some of Nichia's LEDs, the amount of light in the direction perpendicular to the light emitting surface has been defined as the maximum luminous intensity (typical value) and stated in the specification. Refer to the applicable specification for the details.

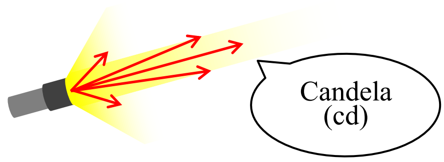

Figure 4. Image of Luminous Intensity

3.2.2. Definition of Luminous Intensity

Luminous intensity is defined as the luminous flux emitted by a light source in a particular direction per unit solid angle (see Figure 5). The solid angle ω is defined as the value obtained from dividing the surface area A (m^2) on the entire sphere of a radius r (m) by r^2 (see Equation 3). The SI unit for the solid angle ω is steradian (sr).

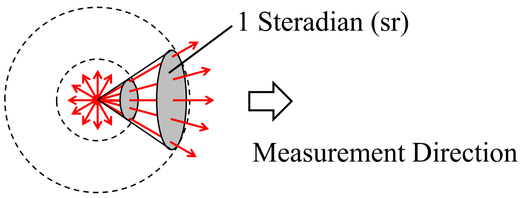

Figure 5. Definition Image of Luminous Intensity

Equation 3: $\omega = A / r^2$

ω = Solid Angle (sr)

A = Surface Area on the Entire Sphere of a Radius r (m^2)

r = Radius of the Sphere (m)

The surface area of the entire sphere is $4\pi r^2$ (m^2) and its solid angle is 4π (sr). For a light source with uniform brightness in all directions, the luminous flux (the intensity of light) per steradian, which is called "luminous intensity", can be obtained from dividing the total luminous flux by 4π. (see Equation 4).

Equation 4: $I_V = \Phi_v / 4\pi$

I_V = Luminous Intensity of a Non-directional Light Source (cd)

Φ_v = Total Luminous Flux (lm)

4π = Solid Angle of the Surface Area of the Entire Sphere (sr)

When a light source has directivity characteristics and its luminous intensity is not uniform, the luminous intensity cannot be calculated from the total luminous flux by using Equation 4; however, the total luminous flux can be obtained by measuring the luminous intensity in each segment of the entire surface and summing them up.

3.3. Illuminance

3.3.1. Illuminance – Photometric Property and Unit

Illuminance is a measure of the luminous flux incident on a surface, per unit area and its SI unit is the lux (lx). Unlike luminous flux and luminous intensity, illuminance is not a measure to indicate the performance of a light source, but it is commonly used to evaluate the spatial lighting.
For example, when designing office lighting, the number of luminaries and the installation interval are determined to meet the desk illuminance of 750lx recommended by JIS (Japanese Industrial Standard).

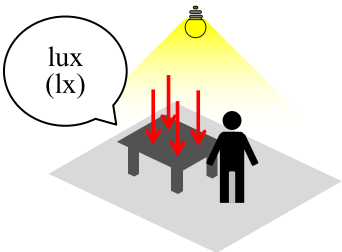

Figure 6. Image of Illuminance

3.3.2. Definition of Illuminance

Illuminance is defined as the luminous flux incident on a surface, per unit area ($1m^2$). In the case of the point light source[2] shown in Figure 7, as the distance from the light source becomes farther, the amount of light falling on the unit area decreases, leading to low illuminance.

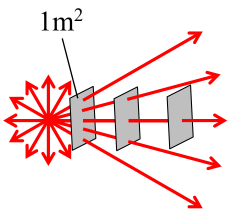

Figure 7. Definition Image of Illuminance

[2] The actual light source has a certain emitting area. When the illumination distance is larger than the emitting area, it can be considered to be a point light source.

Figure 8 explains the relationship between the illumination and the illumination distance, where the light source has a uniform light intensity in all the directions and the total luminous flux is 1lm. The illuminance at the illumination distance of 1m can be obtained using a sphere with a radius (r) of 1m and an area A (unit area) of $1m^2$. In this case, the solid angle ω is calculated as follows:

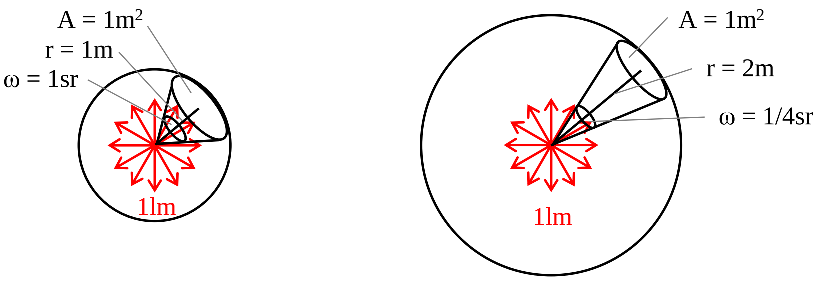

Figure 8. Illuminance Calculation

Equation 3: $\omega = A / r^2$

$= 1 / 1^2$ Substituting A=1 and r=1 into Equation 3 = 1

The value of ω is 1.

The light incident per unit area through this solid angle (1sr) is called "illuminance" and it is obtained from dividing the total luminous flux (1lm) by the solid angle of the entire sphere (4π). Hence, the illuminance at the illumination distance of 1m is 1/4πlx.

In the same manner as the above, the illuminance at the illumination distance of 2m can be calculated by substituting A=1 and r=2 into Equation 3. As a result, the value of ω is 1/4. Since the solid angle is reduced to 1/4 compared with that at the illumination distance of 1m, the luminance is decreased to 1/4 accordingly.

Therefore, the illuminance at the illumination distance of 2m is 1/16πlx.

When the illumination distance is increased by 2 times (from 1m to 2m), the illuminance decreases to 1/4 (from 1/4π to 1/16π), which is called "inverse-square law". Note that the inverse-square law does not apply when a light source does not have uniform directivity characteristics or the illumination distance is close to the light source.

Light Emitting Diode

3.4. Luminance

3.4.1. Luminance – Photometric Property and Unit

Luminance is a measure of the light perceived by the human eye. The SI unit of luminance is candela per square meter (cd/m^2). Luminance is used to quantify the light from a light source with a certain size of the emitting area viewed by the human eye directly (e.g. display screen). The major difference from luminous intensity is that luminance is used to evaluate a surface light source, not a point light source.
Note that the term "nit" is sometimes used for display screens. Though they are different words, nit and luminance can be used interchangeably (1 nit = 1 cd/m^2).

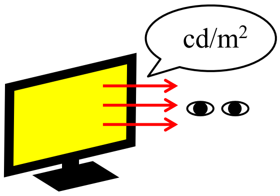

Figure 9. Image of Luminance

3.4.2. Definition of Luminance

When a light source is a surface light source with a certain size for the emitting area, not a point light source, the luminance is defined as the luminous intensity per unit area. Considering that the surface light source is a collection of point light sources as shown in Figure 10, the luminance is obtained from dividing the luminous intensity in a particular direction by its apparent area (area B) of the emitting surface.

Equation 5: $L = I_v / B$

L = Luminance (cd/m^2)

I_v = Luminous Intensity (cd)

B = Apparent Area (m^2)

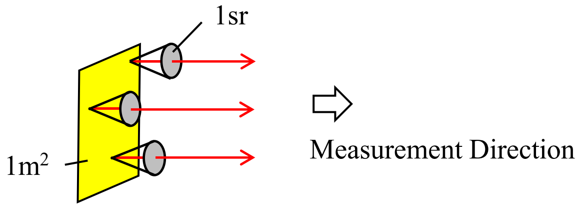

Figure 10. Definition Image of Luminance

The apparent area is the emission area viewed in a particular direction. As shown in Figure 11, the apparent area of the light source with the same size of the emission area varies depending on the viewing direction.

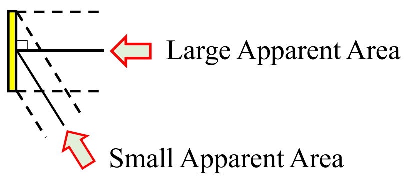

Figure 11. Apparent Areas

3.5. Connection between the Photometric Properties

Figure 12 shows the connection between these photometric properties.

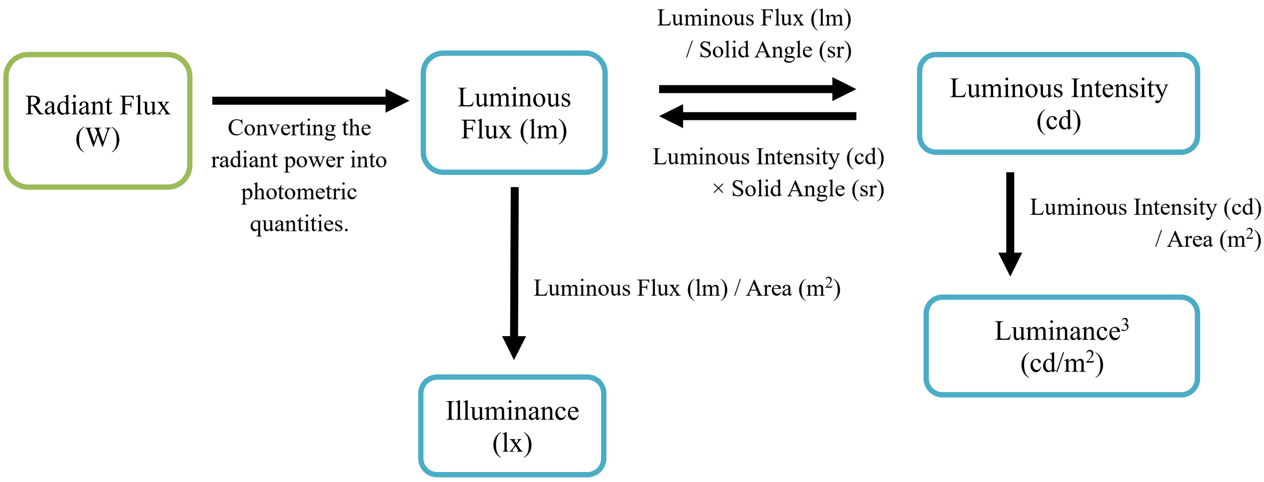

Figure 12. Connection between the Photometric Properties

4. Color Evaluation Methods

4.1. CIE 1931 standard XYZ colorimetric system (xy Chromaticity Diagram)

The xy chromaticity diagram of CIE 1931 standard XYZ colorimetric system is the most widely used to represent the color of a light source. Nichia's LEDs are sorted into the color ranks using the xy chromaticity coordinates.

CIE 1931 standard XYZ colorimetric system was developed by International Commission on Illumination (CIE) in 1931 and the RGB color space was originally created with the three primary colors of light: red, green, and blue; however, it was realized to have inconveniences such as negative numbers; therefore, the CIE revised its colorimetric system. The normalized tristimulus values are represented as the x, y, and z chromaticity coordinates, and when the two parameters x and y are specified, the parameter z is defined, accordingly. The xy chromaticity coordinates without z values are mapped into two dimensions, which is the xy chromaticity diagram. This xy chromaticity diagram represents all colors in nature and its chromaticity coordinates fall within the horseshoe-shaped figure shown in Figure 13. The area near the edge of this figure represents monochromatic colors with a higher colorimetric purity and the area closer to the center represents colors with a lower colorimetric purity, showing colors close to white.

As explained above, colors are plotted on the xy chromaticity diagram; however, for the color difference between two colors, the distance between their chromaticity coordinates does not correspond to the difference in the visual perception. For instance, even when the distance between the chromaticity coordinates of two colors within the near-green region is equivalent to that of near-blue region, the color difference within the near-green region is less perceptible to the human eye than that within the near-blue region. In order to improve this color difference inequality, various colorimetric systems were derived from CIE 1931 standard XYZ colorimetric system; however, the xy chromaticity diagram has continued to be commonly used.

[3] Only luminance is measured as a surface light source.

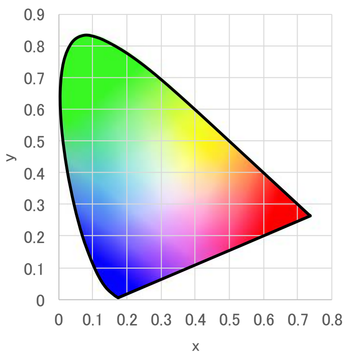

Figure 13. xy Chromaticity Diagram[4]

4.2. Color Temperature

Color temperature is a measure used to describe the hue of white light. The SI unit of color temperature is kelvin (K). The color temperature is defined as the value of the absolute temperature of a blackbody[5] for the light emitted when the blackbody is heated to a certain level. As the temperature increases, the color emitted from the blackbody changes from red to yellow to white to blue as shown in Figure 14. Unlike other colorimetric systems, color can be represented by a single numerical value, which is kelvin, and this enables an intuitive visualization of colors. For this reason, the color temperature is often used to simply describe the hue of white light.

For instance, a yellowish light with a low color temperature (2700K to 4000K) is used for residential lighting, which is called "warm white" or "traditional light bulb color". The yellowish light creates a calm, inviting, and relaxing atmosphere. On the other hand, a bluish light with a high color temperature (5000K to 6500K) is called "bright white" or "daylight" and creates a crisp atmosphere. This bluish light is commonly used in offices and environments that require bright light to perform tasks correctly.

For a blackbody with the ideal radiation characteristics, the chromaticity coordinates of the color temperature are plotted on the blackbody locus, which is also called the "Planckian locus" (see Figure 15). However, actual various white lights in nature have different radiation characteristics from the blackbody and most white lights have chromaticity coordinates that do not fall exactly on the blackbody locus. The color temperature is defined to correspond to only the colors on the blackbody locus; however, for the other colors, the correlated color temperature (CCT) that corresponds to the closest temperature of the blackbody is used for convenience. Along with the CCT, the deviation (duv) from the blackbody locus is used to describe the white hue more precisely.

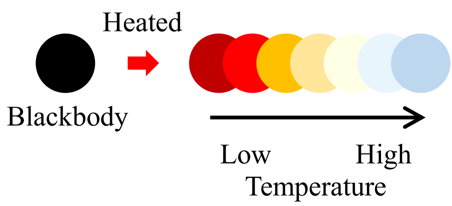

Figure 14. Image of Colors of Light Emitted from the Blackbody

[4] The colors on this diagram are illustrated for reference only and differ from the actual colors.
[5] The blackbody is defined as an ideal physical body that can absorb all electromagnetic radiation.

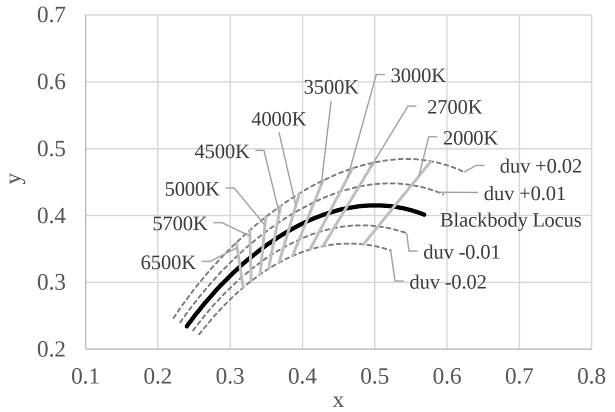

Figure 15. Color Temperatures on the xy Chromaticity Diagram

4.3. Color Rendering Index (CRI)

Color rendering index (CRI) is a measure to describe how accurately a light source can reproduce the color of an object it illuminates, instead of representing the color of the light. The color reproducibility of luminaires is indicated by a numerical value based on the color illuminated by a reference light with characteristics similar to sunlight. The higher the color reproducibility, the higher the CRI. The highest CRI is 100. For residential LED lighting, the average CRI (Ra) has generally been about 80; however, luminaries with ultra-high CRI (the Ra is nearly 100) have become available in recent years. For the details, see the application note "Color Rendering Evaluation for LEDs for General Lighting".

5. Summary

This application note explains various photometric properties indicating brightness and color. These photometric properties are important when designing luminaries. A thorough understanding of their definitions and differences helps to maximize the performance of the LEDs.
Nichia offers a wide variety of LEDs that are ideally suited for applications such as luminaries with high luminous flux (luminous efficacy) and display screens with high luminance. If customers require help selecting the LEDs, contact a local sales representative.

References:

- JIS C 8152 Photometry of white light emitting diode for general lighting
- JIS Z 8113 Lighting vocabulary
- JIS Z 8781 Colorimetry
- JIS Z 9110 General rules of recommended lighting levels

Light Emitting Diode

Disclaimer

This application note is a controlled document of Nichia Corporation (Nichia) published to provide technical information/data for reference purposes only. By using this application note, the user agrees to the following:

- This application note has been prepared solely for reference on the subject matters incorporated within it and Nichia makes no guarantee that customers will see the same results for their chosen application.
- The information/data contained herein are only typical examples of performances and/or applications for the product. Nichia does not provide any guarantees or grant any license under or immunity from any intellectual property rights or other rights held by Nichia or third parties.
- Nichia makes no representation or warranty, express or implied, as to the accuracy, completeness or usefulness of any information contained herein. In addition, Nichia shall not be liable for any damages or losses arising out of exploiting, using, or downloading or otherwise this document, or any other acts associated with this document.
- The content of this application note may be changed without any prior or subsequent notice.
- Copyrights and all other rights regarding the content of this document are reserved by Nichia or the right holders who have permitted Nichia to use the content. Without prior written consent of Nichia, republication, reproduction, and/or redistribution of the content of this document in any form or by any means, whether in whole or in part, including modifications or derivative works hereof, is strictly prohibited.

NICHIA CORPORATION
491 Oka, Kaminaka-Cho, Anan-Shi, TOKUSHIMA 774-8601, JAPAN
http://www.nichia.co.jp Phone: +81-884-22-2311 Fax: +81-884-21-0148