

LED Characteristic Measurement Methods

LED product characteristics are primarily specified in terms of their optical and electrical characteristics. This document describes the methods by which these characteristics are expressed numerically, looking specifically at the measurement methods and units used. And because Stanley specifies the thermal resistance requirements of packages for LEDs intended for automotive use, measurements methods for that characteristic are also discussed.

Optical Characteristics

Two units are used to express the amount of light emitted by an LED. One is used for light emissions in the form of energy, which is a physical quantity, and the other is a photometric quantity that takes into account the characteristics of the light as perceived by the human eye. The former is generally used for stipulating the specifications of infrared LEDs. The latter is used for visible-light LEDs, since they emit light in wavelengths visible to the human eye and are used in applications such as indicators and LCD backlights. The human eye perceives light with wavelengths between 380 and 780 nm, though the actual visible wavelengths vary from person to person depending on the sensitivity of their eyes. This perception by the human eye according to wavelength is referred to as visibility and was agreed upon by the Commission Internationale de l'Eclairage (CIE) in 1924. In 1933, the International Committee of Weights and Measures (CIPM) adopted $V[\lambda]$ as the standard visual spectral sensitivity. In 1972, CIPM revised the value of $V[\lambda]$ to be the visible wavelengths from 360 to 830nm. Fig.1 shows the spectral luminous efficiency of $V[\lambda]$. According to this curve, the human eye experiences light with a wavelength of 555nm most brightly. When we compare a 1mW luminous flux at 555nm (green) with a 1mW luminous flux at 470nm (blue), we perceive the 470nm light as being only one-tenth as bright as the 555nm light.

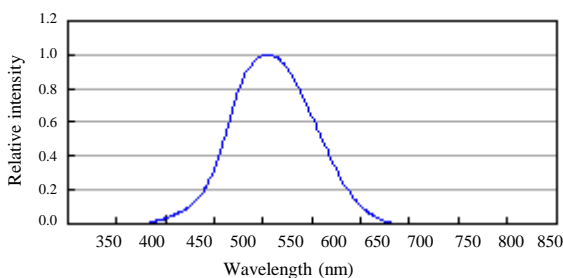


Fig.1 Spectral luminous efficiency

Luminous Flux [Visible LED]

Luminous flux is a beam of radiated light taking its spectral luminous efficiency for humans into account. The only difference between a beam of light and luminous flux is that the former is expressed as a physical quantity and the latter as a photometric quantity. For light sources such as LEDs that provide a specific band of the spectrum, the luminous flux can be calculated for each wavelength by applying and integrating the spectral luminous efficiency.

Luminous flux is measured using an integrating sphere.(Fig.2) At Stanley, we normally use a 2π integrating sphere. The inside of the integrating sphere is coated with special paint that has a reflectivity close to 100%, effectively ensuring that all the light from the LED is uniformly distributed inside the sphere. A photo sensor converts some of the light into electricity and measures it.

Radiant Flux [UVLED•IRLED]

Radiant flux is quantity of the energy to move from the outbreak source of a certain energy to the free space during a given period of time. A Unit is international unit system, and a watt (W) is used Radiant flux measurement is used a π integrating sphere of as well as Luminous flux .(Fig.2)

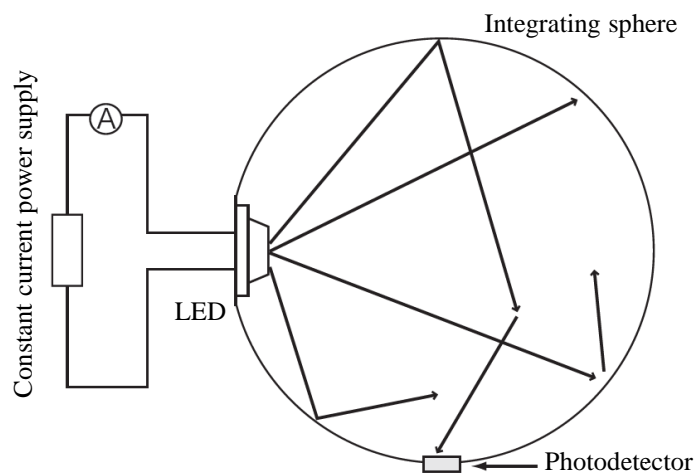


Fig.2 Luminous Flux • Radiant Flux measurement

Luminous Intensity [Visible LED]

Luminous intensity refers to the luminous flux per unit solid angle of light emitted by a point light source. The unit used to express luminous intensity is the candela (cd). A candela (cd) is a photometric quantity and is part of the International System of Units (SI). It is defined as follows:

“1 candela (cd) is the luminous intensity, in a given direction, of a point source that emits monochromatic radiation with a frequency of 540×10^{12} Hz (at a wavelength of 555nm) and that has a radiant intensity in that direction of 1/683 watt per steradian.”

This is the luminous flux per unit solid angle, so $cd = 1 \text{ m/sr}$. Luminous intensity is measured using a measuring instrument that complies with Condition B in the CIE 127 technical report issued by the Commission Internationale de l’Eclairage (CIE). Under Condition B, the measuring instrument has a light intake angle of 0.01sr at a distance of 100mm from the top of the LED lens. (Fig.3)

Radiant intensity [IRLED]

With radiant intensity, I am expressed in the radiant flux per unit solid angle with physics quantity to express the energy per unit solid angle emitted in a certain direction by the emission source of the energy. A Unit is international unit system, and W/sr (W/sr) is used. The measurement of the radiant intensity uses measuring equipment like the Luminous intensity. (Fig.3)

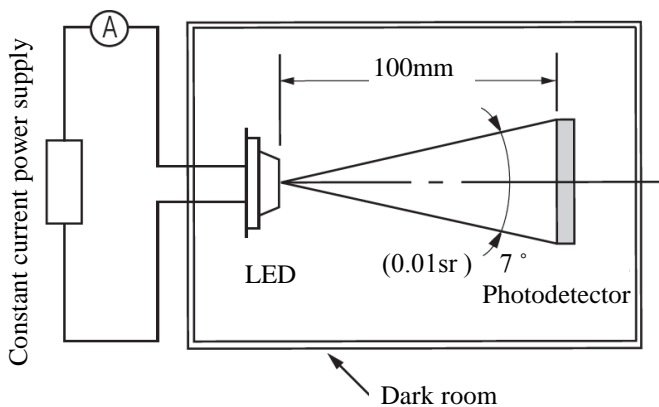


Fig.3 Luminous Intensity / Radiant intensity measurement

Dominant and Peak Wavelengths

The light emitted by an LED does not have just one wavelength. It occupies a set band in the spectrum. Fig. 3 shows the principles involved in measuring the wavelength characteristics of emitted light. The light from the LED is separated into its component wavelengths by a diffraction grating and prism. A photo sensor converts the light into electricity to ascertain the intensity in that wavelength. The spectral intensity in a specific range of wavelengths can be obtained by rotating the diffraction grating and prism. (Fig.4) The peak wavelength can be calculated quite simply from the spectral characteristics obtained in this way. However, the dominant wavelength is calculated as an averaged value for the wavelengths and intensities of the obtained spectral characteristics. Because the human eye sees colors as area mean values in the spectral distribution, it is possible to express spectral characteristics that match human perceptions. In recent years, it has become the norm for the color characteristics of visible light LEDs to be expressed in terms of the dominant wavelength.

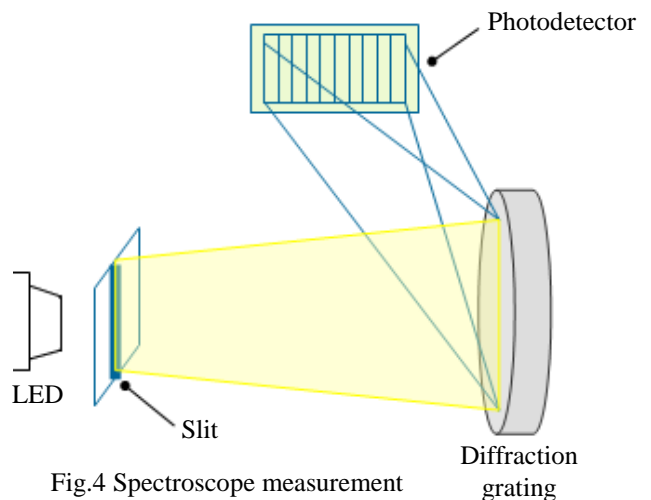


Fig.4 Spectroscopy measurement

Directional Characteristics

The directional characteristics of an LED are obtained by rotating the LED around the top of its lens with a light intake angle of 0.001sr, as shown in Fig.5. The characteristics are normally expressed relative to a value of 1 for the angle with the highest output intensity.

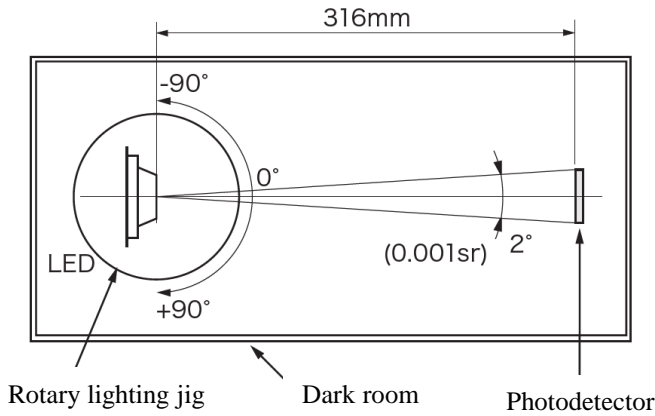


Fig.5 Directional measurement

Response speed

Response speed is the measure of the time that it takes generated carriers to move into an external circuit, and is generally expressed in terms of rise time or fall time. The rise time and fall time is defined as the time for a photo current to rise or fall from 10% to 90% or from 90% to 10% of its maximum value, respectively, with respect to a pulsed light input. (Fig.6)

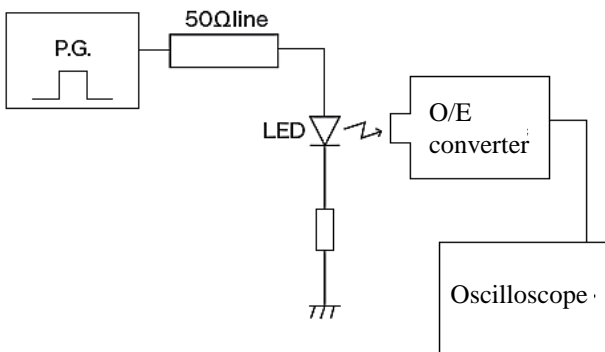


Fig.6. Response speed measurement

Cutoff frequency

Cutoff frequency expresses the limit to an LED's response to electric signals. When electric signals are faster than this limit, the LED cannot convert electricity to light. Cutoff frequency is measured by applying a certain bias current to the LED and superimposing AC signals to it while changing its frequency, and evaluating the LED's response to the AC signals. The frequency at which the response drops by 3dB is defined as the cutoff frequency. The unit that is used to express cutoff frequency is MHz. (Fig.7)

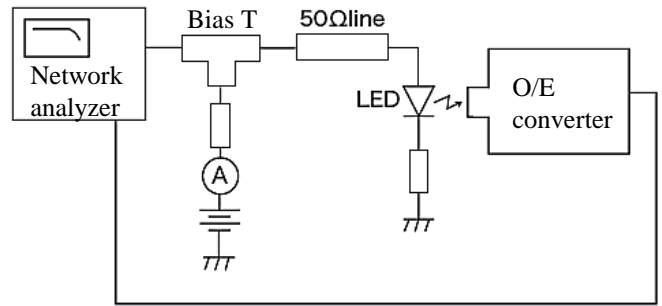


Fig.7 Cutoff frequency measurement

Electrical Characteristics

Forward voltage

When a specified forward current flows, the voltage generated between the LED anode and cathode is measured Fig.8. The voltage is specific to the material of the semiconductor die and is determined by the internal resistance and potential barrier in the junction. The forward voltage is measured using a voltmeter while a constant-current power supply is used to apply a forward current.

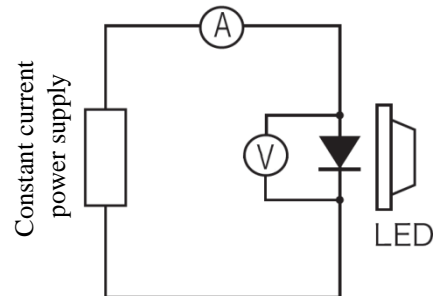


Fig.8 Forward voltage measurement

Reverse current

An LED is essentially the P-N junction, so, like a rectifying diode, it has the characteristic of showing almost no current flow for reverse bias. However, unlike an ordinary diode, the larger the reverse current (in the order of several μA), the smaller the breakdown voltage. The reverse current is measured using an ammeter while a constant-voltage power supply is used to apply a reverse bias. (Fig.9)

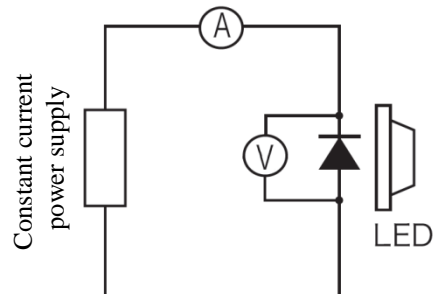


Fig.9 Reverse current measurement

Thermal Characteristics

Thermal Resistance Measurement Methods

It is not possible to directly measure the temperature of the LED junction, but the forward voltage is temperature-dependent and this characteristic can be used to estimate the die's junction temperature. This temperature dependency varies depending on the materials used in the die and a number of other factors, so the dependency itself is measured first.

First, the LED is placed in a low-temperature atmosphere of -10°C and the forward voltage is measured for a very small current (normally $100\ \mu\text{A}$) that is unlikely to have any effect on the temperature of the die's junction. Then, the LED is placed in a high temperature atmosphere of 60°C and the forward voltage is measured for the same very small current. The voltage obtained can be used to determine the forward voltage temperature dependency. The value is normally around $-2\text{mV}/^{\circ}\text{C}$.

The next step is to measure the correlation between the junction temperature and the time for which current is applied. Using the current waveform shown in Fig.10, the forward voltage (V_{F1}) is first measured for the same very small current used when measuring the temperature dependency. Then, the forward voltage (V_{F2}) is determined in the same way when the level of current that will actually be used is applied in set pulses or as a direct current. After set pulses have been applied, the forward voltage is obtained for the very small current (V_{F3}).

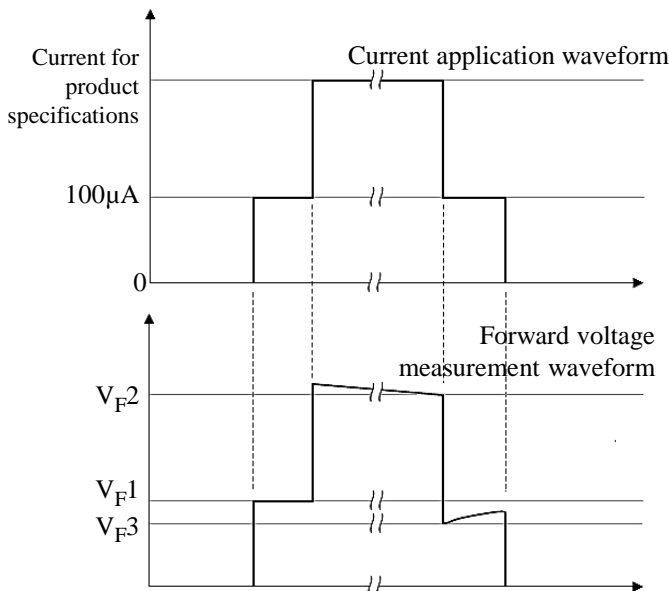


Fig.10 Current application waveform / Forward voltage measurement waveform

The voltage difference between V_{F3} and V_{F1} indicates the increase in the junction temperature due to the application of the heating current. The temperature derived using Equ.1 indicates the extent to which the junction heats up due to the ambient temperature during measurement. The duration of the applied pulse current is then varied and Equ.2 is used to calculate the thermal resistance, which normally gives the characteristics shown in Fig.11.

$$\Delta T_j = \frac{(V_{F3} - V_{F1})}{\text{die temperature coefficient}} \quad \text{Equ.1}$$

$$R_{th} = \frac{\Delta T_j}{I_F \times V_{F2}} \quad \text{Equ.2}$$

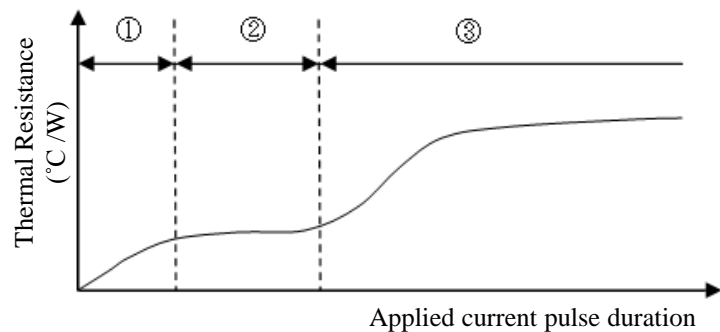


Fig.11 Applied current pulse duration / Thermal Resistance

Temperatures that arise in the junction are primarily dissipated through the device substrate, die-bonding material, lead frame, soldering or mounting substrate. Section ② in Fig.12 indicates the thermal time constant in the lead frame. The value for this section of the graph and the pulse or direct current are evaluated as parameters when the specifications for the thermal resistance are determined.

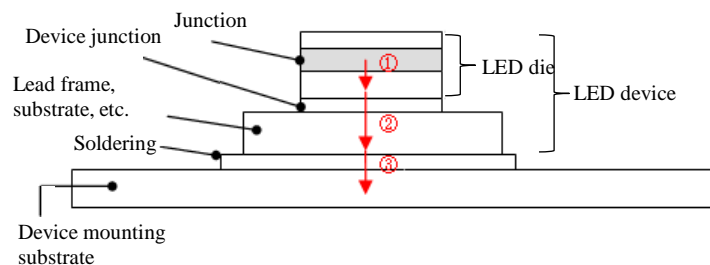


Fig.12 Heat conduction course