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A Study on Optics and Spectral Energy Distribution Characteristics of LEDs lamp

LED램프의 광학 및 분광분포 특성 연구

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Key words : Chromaticity coordinate(색도좌표), High brightness LED(고휘도 LED),
CIE(Commission Internationale de l'Eclairage, 국제조명위원회),
CRI(color rendering index, 연색평가수), SED(spectral energy distribution, 분광분포)

Abstract

본 논문에서는 파랑, 녹색, 호박색, 빨강색, 백색 등 고휘도 5mm LED(light emitting diode)의 기본적인 분광분포(SED:spectral energy distribution) 특성을 분석하였으며, LED램프의 중요한 광학 특성인 광속, 효율, 피크 파장(λp), 가중치 평균 파장, 반치폭(FWHM, $\Delta\lambda$), 색도좌표, 주 파장, 자극순도(Pe)와 휘도순도(Pc) 등을 측정 및 실험하였다. 제시된 LED램프의 특성 데이터는 앞으로 LED램프를 사용한 새로운 조명등기구를 개발하는데 많은 도움을 줄 것이며, 이러한 측정 데이터들은 조명용 광원으로서 LED램프의 사용·대체 가능성을 나타낸다.

I. INTRODUCTION

LEDs(light emitting diodes) are used in various purposes as tail lamps of motor vehicles, sign boards on street, exit signs, etc. in conventional electrical, electronic and communication areas. Therefore conventional traffic signals are supposed to be replaced with them made of high brightness LEDs. These LEDs represent characteristics of low power consumption, long life, small size, high reliability, and simple operation procedures. LEDs do not emit ultraviolet rays, infrared. In addition, we can handle LED's colors of red, green and blue when developing products. [1]

In the countries such as the United

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States, Canada, Australia and European Union, high brightness LEDs are already used as traffic signal purpose and the use of them is increasing in terms of energy-saving view point. In addition, the use of LED as an illumination source reached a successful stage. [1],[2],[3]

Since Hewlett Packard(USA) and Nichia (Japan) invented both the blue and white high brightness LEDs at 1990, many lighting companies have been commercializing the LEDs as illumination source, namely digital lighting.[3],[5]. Each high brightness LED achieving ON/OFF and duty control using microcontroller to have color variableness control circuit compose.[6]

Recently, worldwide enormous illumination companies and LED manufacturers have established joint ventured companies each other such as LumiLeds (Agilent Technologies and Philips Lighting), GELCore (GE lighting part and Emorce) and mutual corporation between Osram and Siemens.[3], who have been developing ultra high brightness LEDs as illumination sources. In Korea Samsung, LG, Hyundai and Seoul Semiconductor are trying to develope high brightness LEDs.

In this paper, integrating sphere with 100 mm diameter was used for measuring a luminous flux and SED(spectral energy distribution), etc. Standard LED used for this measurement was in 5 mm diameter and certified by NML(national measurement laboratory) in the Australia. LEDs for experiments were made by Seoul Semiconductor Co., Ltd. and selected randomly. The LEDs tested under ambient temperature of 25 ℃ and fixed current of DC 20 mA.[8],[9]

Ⅱ. EXPERIMENT

A. Experiment preparation

The spectral data acquisition system used for measuring the basic properties of LED consists of monochromator, optical fiber input, filter wheel system and CCD(charged couple device)array.

We considered measurements of the optical characteristics of LEDs as belows.

- Luminous flux
- Luminous efficacy
- Peak wavelength(λp)
- Weighted average wavelength
- FWHM(full width at half maximum, $\Delta\lambda$)
- Chromaticity coordinate(x, y)
- Dominant wavelength(λ_D)
- Excitation purity(Pe)
- Colorimetric purity(Pc)

The optical fiber and dispersive spectrometer CCD array was installed to measure relative spectral power at each wavelength.

Table 1. The specification of standard LED

Size (mm)	Supply Voltage (V)	Supply Current (mA)	Maximum Wavelength (nm)	Luminous Flux (lm)
5	2.091	20	591	0.577

Figure 1. show the development transform of light source, and figure 2. shows actual experimental set up block diagrams, table 2. represents the LEDs for this uncertainty of measurement.

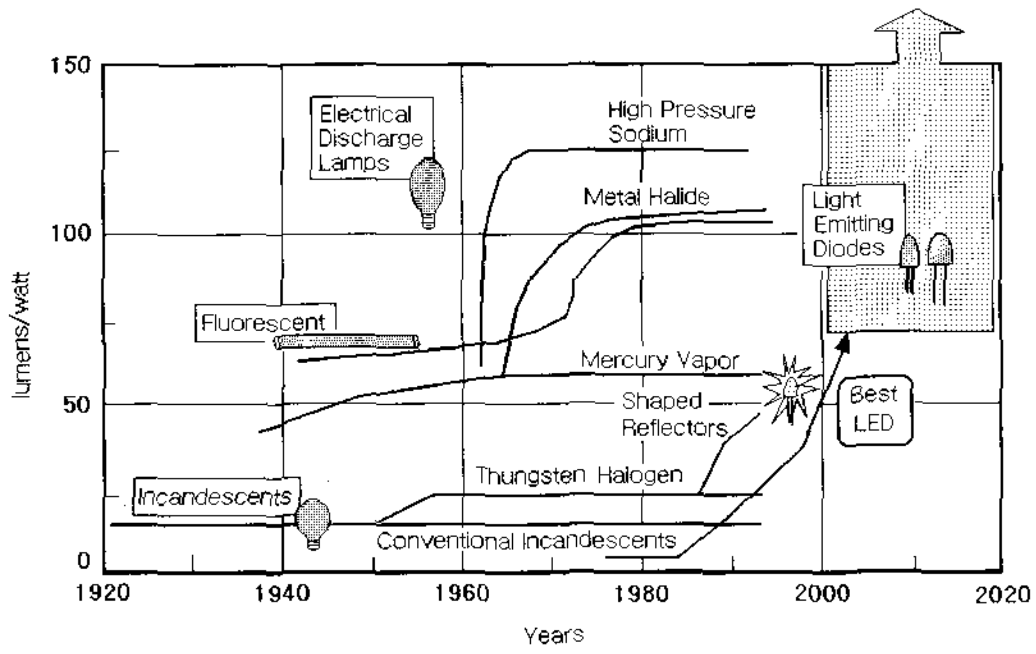


Fig. 1 The future of LEDs. Source: "A New World of Lighting." Hewlett Packard. 〔12〕

Table 2. Uncertainties associated with the absolute integrating sphere photometers and calibration facility

Items	Uncertainty of measurement
Temperature	±0.1〔℃〕
Voltage	±0.1〔%〕
Current	±0.1〔%〕
Power	±0.1〔%〕
Wavelength	±0.1〔nm〕
Relative spectral energy	±0.005〔units〕

For the measurement of the luminous flux of very small source, such as LEDs, it is impracticable to use either of the larger integrating spheres. Additionally, 100 mm integrating sphere is too small to permit the fitting of a very fine V(λ) corrected photocell without affecting the performance of the integrating sphere.

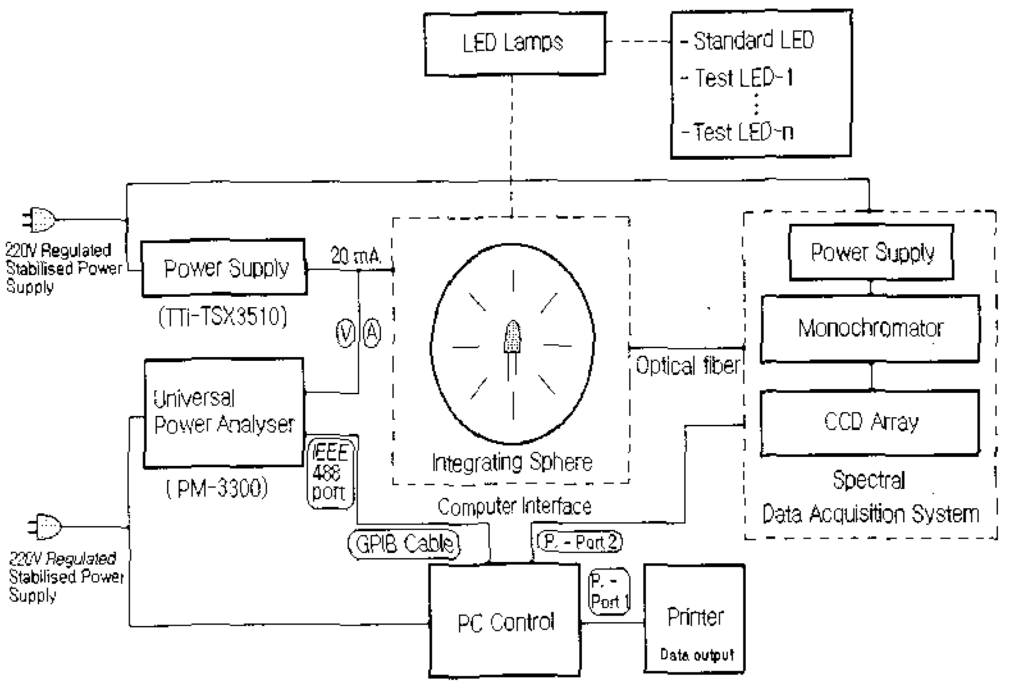


Fig. 2 The actual experimental set up block diagrams.

Therefore the luminous flux measurements of LEDs are conducted spectrally.

1) A standard LED of known luminous flux, Φ_N, is placed inside the integrating sphere.
2) The standard LED's spectral power distribution is measured from 380 to 780 nm in steps of 10nm. The area, A_N, under the graph of spectral power vs wavelength is integrated. This area is proportional to the luminous flux.
3) The standard LED is replaced in the integrating sphere with the test LED.
4) The test item's spectral energy distribution is measured in the same spectral range and using an identical CCD integration time as the standard LED. The area A, under the graph of spectral power vs wavelength is integrated.
5) The luminous flux of the test LED is then calculated by:

$$\Phi = \Phi_N \times A / A_N$$

B. Experiment procedure

The small integrating sphere with 100 mm diameter was used. The luminous flux was calculated by integration of distribution over whole wavelength range after measuring relative spectral energy distribution. An optical fiber of 1.5 m length was used to deliver lights between integrating sphere and input port of the monochromator. A CCD array is attached to the output port of the monochromator.

The monochromator contains two diffraction grating. The first grating has a blaze angle, or maximum efficiency, of 250 nm and is suited to ultraviolet band measurements. The second grating has a blaze angle of 500 nm and is best for visible band measurements. We chose the second one for this experiment.

These details should be entered as thoroughly as possible so that the test LED can be uniquely identified at a later date. The test is then carried out in the following manner.

1) First the standard LED is placed in the integrating sphere. It is preferable that the standard LED is close in color to the test LED. PC control will quickly scan the spectrum to determine the maximum spectral power present, and then choose an integration time so that this maximum level will be about half of the saturation level for the CCD. Then the SED of the standard LED is obtained, from 380 to 780nm in intervals of 10 nm. The area beneath the graph of SED as a function of wavelength is calculated.
2) Then the test LED is placed in the integrating sphere. It is SED is likewise obtained using the same integration time as in the first test, and the area beneath the graph integrated. The luminous flux is then calculated by multiplying the luminous flux of the standard LED by the ratio of the areas beneath the graphs of SED vs wavelength for the two LEDs.
3) If the test LED contains a significantly higher maximum spectral power than the standard, than the CCD may saturate. In this case, the test will be repeated, with the test LED measured first, followed by the standard LED.

Ⅲ. EXPERIMENTAL RESULTS AND CONSIDERATION

We acquired the below results from the experiments of several LED. Figure 3. in chromaticity coordinate of white LED x, y coordinate value as 581nm that special quality such as CIE standard illuminant D_{65} and dominant wavelength are visible ray area by lighting fitness through an experiment know can. Figure 4. that display photopic vision and scotopic vision as that write SED measure values in wavelength that is visible ray of course blue/green/amber/red/white LEDs white LED whole visible ray inclusion box through an experiment know can.

Table 3. The electro-optical characteristics for LEDs

Items \ Radiation colors Characteristics		Symbol	Unit	Blue	Green	Amber	Red	White
Forward voltage	Min.	VF	V	-	-	-	-	2.6
	Typ.			3.7	3.7	2.2	2.2	3.2
	Max.			4.0	4.0	2.5	2.7	4.0
Luminous intensity	Min.	Iv	mcd	700	2,500	600	600	-
	Typ.			1,200	5,000	1,000	1,200	930
Peak wavelength		λ_P	nm	470	-	-	635	465
Dominant wavelength		λ_D	nm	-	525	587	-	555
FWHM		$\Delta\lambda$	nm	35	35	-	-	32
Chromaticity coordinate		x, y	-	-	-	-	-	0.29, 0.30

Condition : IF = 20 mA, Ta = 25 ℃ (Type:SH50)

Each LED shows its peak wavelength at 471, 527, 593, 632, 581nm, excitation purity value is 0.91, 0.78, 0.99, 0.98, 0.07 and colorimetric purity value is 148, 16, 35, 48, 3% each in the order of blue, green, amber, red and white LED.

The colorimetric purity value was ranged in blue, red, amber, green and white. Colorimetric distribution of the blue color LED represented the highest value of 148%, while the white color LED showed the lowest value of 3% from these results, we knew that colorimetric purity ratio between the blue and white color LED is 50 times in their values.

Table 4. show the results of measurement of color coordinate, dominant wavelength, excitation purity and colorimetric purity.

Through this measurement, average luminous flux of LEDs was 1.646 lm, we knew there were big differences by LED's radiation color in luminous flux. Table 5. shows the measured luminous flux and efficacy values and peak wavelength, weighted average wavelength, FWHM. In table 5, the red color LED represents the maximum value of 4.30 lm in luminous flux. Average efficacy of the LEDs was 35.38 lm/W and the efficacy of the red color LED was 108 lm/W.

Table 4. Measured of color coordinate, dominant wavelength, excitation purity and colorimetric purity

Items \ Radiation colors	Chromaticity coordinate x	Chromaticity coordinate y	Dominant wavelength (nm)	Excitation purity, Pe	Colorimetric purity, Pc (%)
Blue	0.137	0.088	471	0.91	148
Green	0.173	0.710	527	0.78	16
Amber	0.589	0.407	593	0.99	35
Red	0.703	0.291	632	0.98	48
White	0.327	0.340	581	0.07	3

Table 6. show the symbol and wavelengths, complementary color for brightness color, and table 7. show results of measurement the color temperature value for white LED lamp.

Table 5. Measured values of luminous flux and efficacy, peak wavelength, weighted average wavelength, FWHM.

Items \ Radiation colors	Burning time (min.)	Supply voltage (V)	Luminous flux (lm)	Luminous efficacy (lm/W)	Peak wavelength (nm)	Weighted Average Wavelength (nm)	FWHM (nm)
Blue	15	3.19	1.28	21.3	38	468	460
Green	14	3.25	1.41	23.5	38	527	520
Amber	16	2.15	0.59	14.8	34	596	600
Red	13	2.11	4.30	108	24	640	640
White	14	3.48	0.65	9.29	35	555	470

Table 6. The symbol and wavelengths, complementary color for brightness color

Radiation colors Items	Blue	Green	Yellow	Amber	Red
Symbols	B	G	Y	A	R
Wavelengths (nm)	380~ 490	490~ 570	570~ 590	590~ 620	620~ 780
Complementary colors	Yellow	Purple	Blue	Green-Blue	Blue-Green

Table 7. The CCT value for white LED lamp

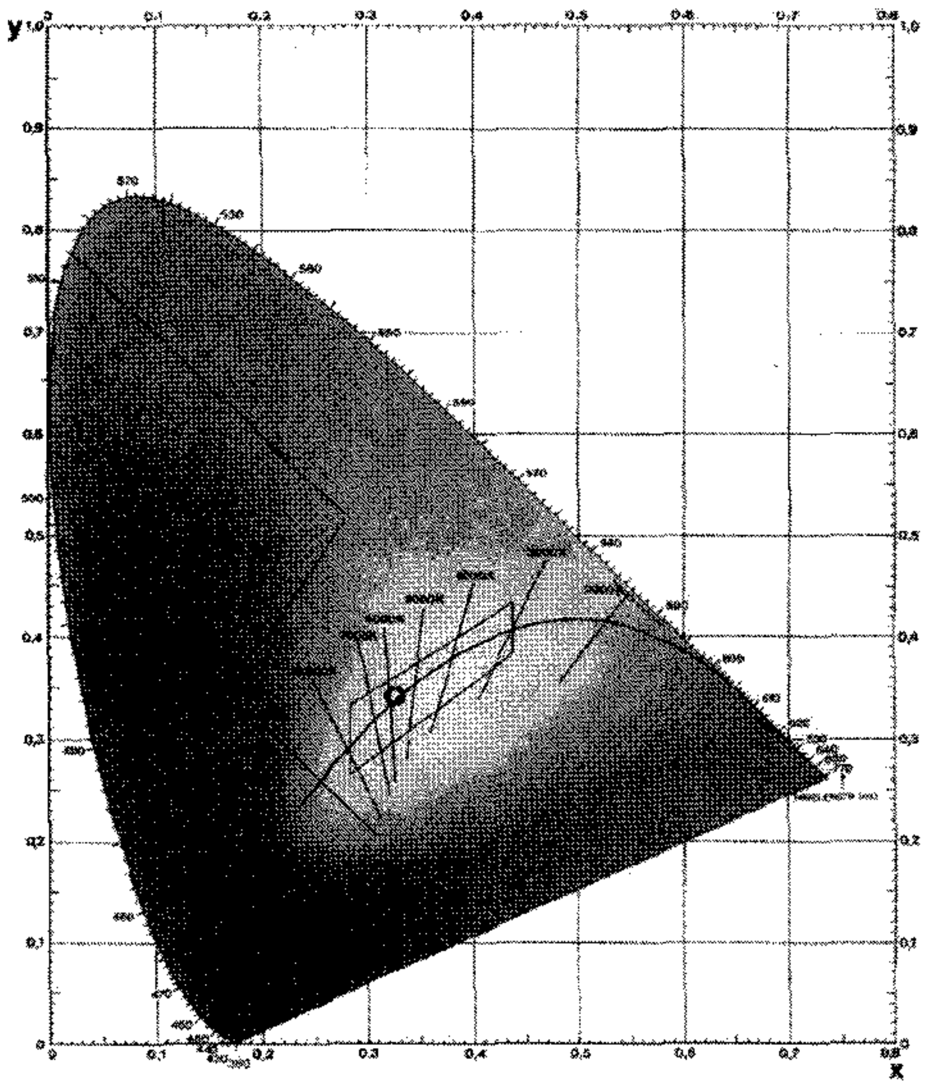
CCT(Correlated Color Temperature)	5,070 (K)

Table 8. The color rendering index of high intensity white LED

Items	No.	Symbols by colorimetric system	Measu-red values	ISCC-NIST*
Color rendering properties	R1	7.5R6/4	93	light grayish red
	R2	5Y6/4	87	dark grayish yellow
	R3	5GY6/8	74	strong yellow green
	R4	2.5G6/6	64	moderate yellowishgreen
	R5	10BG6/4	85	light bluish green
	R6	5PB6/8	85	light blue
	R7	2.5P6/8	69	light purple
	R8	10P6/8	69	light reddish purple
General CRI	Ra	78		
Special CRI	R9	4.5R4/13	57	strong red
	R10	5Y8/10	76	strong yellow
	R11	4.5G5/8	64	strong green
	R12	3PB3/11	66	strong blue
	R13	5YR8/4	97	light yellowish pink
	R14	5GY4/4	86	moderate olive green
	R15	1YR6/4	87	-
	Ri	76		

* ISCC : International Society Color Council - National Bureau of Standards

Measured Chromaticity Coordinate: *x = 0.327, y = 0.340*



Colorimetric Properties (with reference to Illuminant D65)

Dominant Wavelength: *581 nm*
Excitation Purity: *0.07*
Colorimetric Purity: *3%*

Fig. 3 Measured white LED lamp, shown on the CIE 1931. supplementary standard colorimetric system.

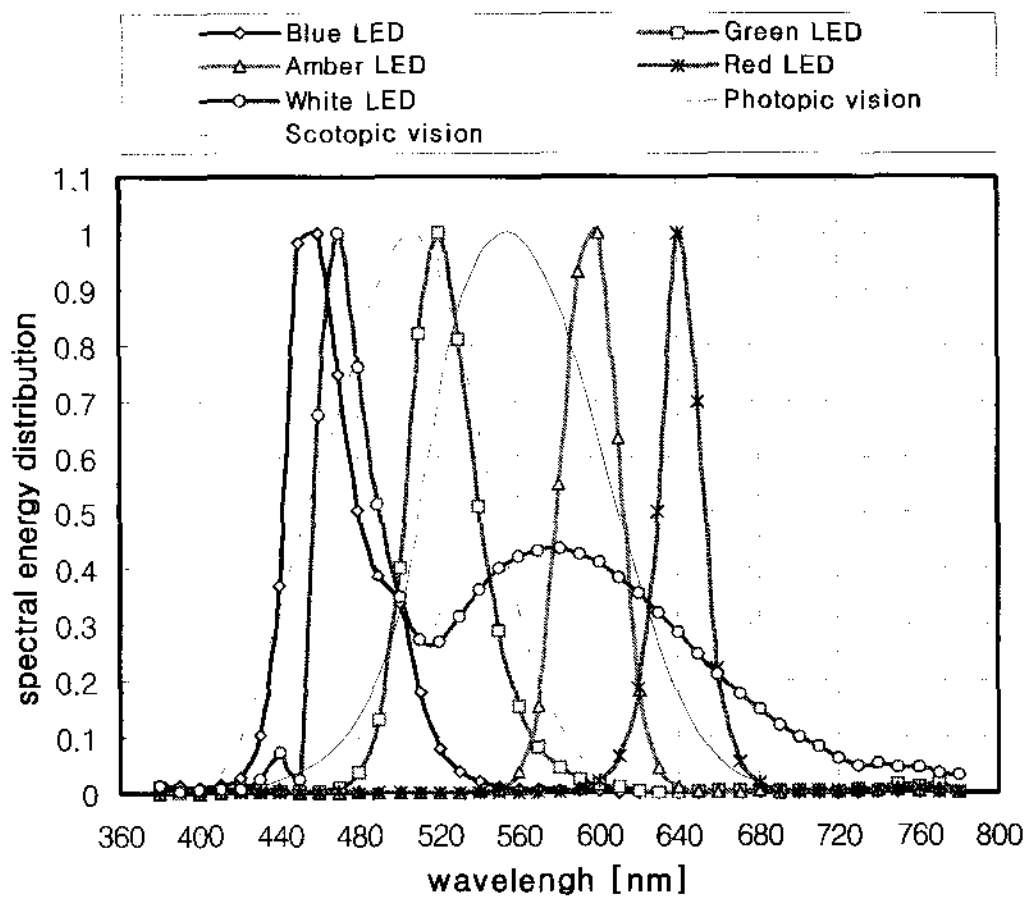


Fig. 4 The Spectral energy distribution of tested LEDs.

Each FWHM(Δλ) of LED was 38, 38, 34, 24, 35 nm and average FWHM was

33.8 nm, chromaticity coordinate values of the white LED were x=0.327 and y=0.340, which are close to standard illuminant D_{65} value of CIE 1931.

Ⅳ. CONCLUSIONS

The optical characteristics data of LED can give a lot of advantages to design LED lighting appliances. We acquired the below results from the optical characteristics of various LED.

1) Average luminous flux of the experimental LEDs was 1.646 lm, the maximum value of these was 4.3 lm in red color LED and the minimum value was 0.59 lm in amber color LED. We knew that pencil of light values have big difference of 7 times.
2) Source of light efficiency of red color LED measured 108 lm/W as 200 times higher worth than existent general LED.
3) Each dominant wavelength was 471, 527, 593, 632 and 581 nm in the order of blue, green, amber, red and white color. From this results, we knew that is in extent of portion that this wave lengths are registered visually. Excitation purity values of the LEDs were shown between 0.78 and 0.98, except the white LED. The colorimetric purity of blue color LED had 148%, while the white LED showed 3%. We knew that the excitation and colorimetric properties of high brightness LEDs depend on their radiation colors.
4) Each FWHM value of LEDs was 38, 38, 34, 24 and 35 nm in the order of blue, green, amber, red and white color. Average FWHM value was 33.8 nm and average CRI value of the white color LED showed 78. This results mean the LEDs have good CRI value. The chromaticity coordinate $x=0.327$ and $y=0.340$ were close to standard illuminant D_{65} of CIE 1931. It may mean that this can be used as source of lighting using LED.

Hereafter, The object of research will study the electrical and optical characteristics of LED lighting fixtures on PV(photovoltaic) solar system.

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