

LEDs for Flash Applications

Application Note

Abstract

This application note introduces LEDs with optimized characteristics which are primary suitable for use as a camera flash.

In addition to a short summary of the common advantages of LEDs and the requirements of camera flashes, the most important parameters are described with reference to the operating mode.

Beyond that several assembly possibilities are shown including their thermal descriptions and some simulation results for the LUW FQ6N in flash operating mode are provided.

Introduction

The ambient light available for taking a picture often is insufficient in everyday situations, so it requires the use of a flash unit as an additional light source.

Due to their increasing brightness, LEDs are suitable to replace, for example, the conventional flash tubes used in flash units of mobile phones or digital cameras. During the last few years LEDs as camera flashes became more and more state-of-the-art in mobile phone applications.

In comparison to flash tubes, LEDs provide several advantages. A Traditional flash unit consists of a flash tube in which a flash is created by means of a gas discharge. The flash tube contains an inert gas, usually xenon or krypton.

Using a suitable circuit, the battery charges a capacitor to a level of a few hundred volts. This is then stepped up to a secondary voltage in the kV range by means of an ignition coil. This ignition voltage is released in the flash tube, causing the gas to ionize.



The flash arises through recombination and lasts only a fraction of a second. During this time a few hundreds amperes of current flow.

The light emitted from the flash tube exhibits a continuous spectrum which is similar to the sunlight's spectrum (a Planck emitter in the color temperature range of 5500 – 6500K). Modern flash units contain a sensor, in which the reflected light from the subject is measured by means of a photodiode. The flash is automatically switched off after a predetermined amount of light is sensed.

In this case, LEDs offer a particularly optimal light source for mobile devices. Due to the rapid development in the area of semiconductor technology in recent years, LEDs possess a very high brightness and additional key features:

Advantages of LEDs

- High mechanical stability
- Small dimensions
- Low voltage required to create a flash, compared to flash tubes
- No charging time – the flash is immediately available
- Longer lifetime than conventional flash tubes

- Longer flash duration possible, up to continuous mode
- Multichip-LED adjustable color temperature, adaptable spectrum

Flash Requirements

Depending on the application, various demands are placed on the camera flash in order to achieve a correct exposure. This leads to differing requirements which must be fulfilled, however.

1. Conventional Xenon Flash

Xenon photographic flash units are capable of illuminating subjects up to 45 meters away. The coverage range is regulated by the flash power.

Figure 1 shows the discharge curve for a typical conventional flash unit at maximum power.

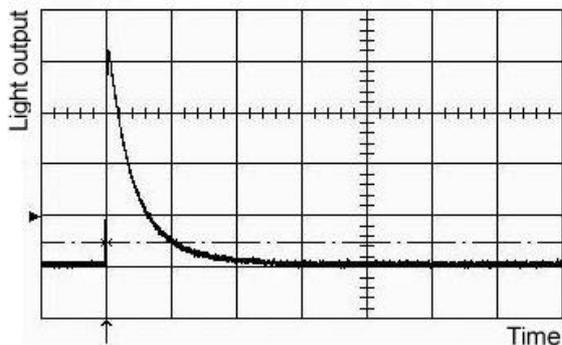


Figure 1: Light output over time of a Xenon flash unit at maximum power

A sharp rise in light intensity is visible, followed by decay. Depending on the distance between the camera and the subject, a particular quantity of light is required for a proper exposure.

The quantity of light is defined to be the product of the illuminance and the flash duration, which corresponds to the integral of the area under the discharge curve. The quantity of light (flash power) can be controlled by the flash duration. For that purpose, the flash discharge and thus the discharge curve is prematurely interrupted.

Conventional flash units illuminate a subject with an illuminance of more than $E_v > 1000 \text{ lx}$. The flash duration varies from $15\mu\text{s}$ to 2ms , depending on the coverage range. The period between two flashes ranges from 1s to 5s . This period is necessary in order to recharge the capacitor.

The color temperature of the flash is between 5500K and 6000K .

Conventional flash units have a lifetime of about 5,000 flashes. Afterwards, the brightness is reduced to a level of 90%.

Table 1 summarizes the requirements of a flash unit used for conventional applications.

Flash unit for conventional applications	
Subject illuminance E_v	$> 1000 \text{ lx}$
Flash duration	$15\mu\text{s} - 2\text{ms}$
Flash coverage	$2\text{m} - 35\text{m}$
Lifetime	5,000 flashes
Time between flashes	$1\text{s} - 5\text{s}$
Viewing angle	100°
Color temperature	$5500\text{K} - 6500\text{K}$

Table 1: Flash unit for conventional applications

2. Flash units for mobile phones

In mobile phones, the minimal illuminance depends on the optical resolution of used camera chip (Fig. 2).

Nowadays, camera modules with between 3 and 5MPixel are used as standard for most mobile devices. For these, the minimal center illuminance should be from 80 lx to 200 lx at 1m .

For the currently high end devices with 8MPixel or more, the light requirements are even higher, starting at 300 lx .

However depending on the customized uniformity demand of the illuminated target area the light level in the center can vary from the given values.

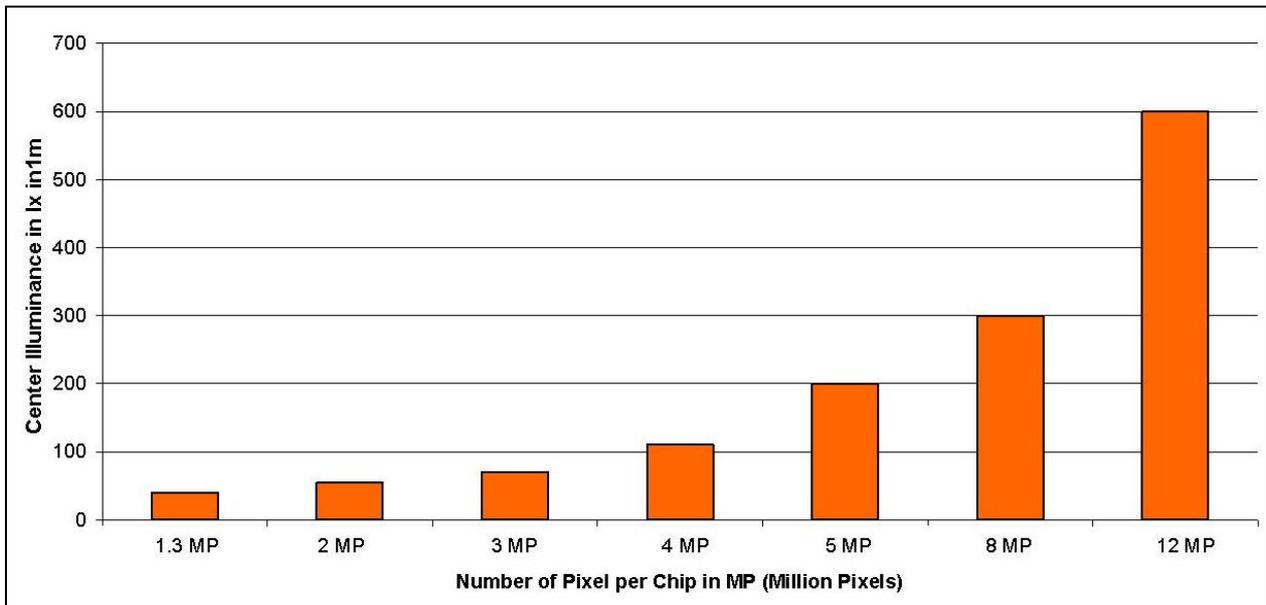


Figure 2: Typical center illuminance in 1m vs. resolution of the camera chip

Moreover in most applications, the flash should cover a rectangular field of view, e.g. $55^\circ \times 43^\circ$. In the center of this field, the requested illuminance level should be achieved. The illuminance in the corner of this field of view is, dependent on the desired homogeneity, around 20% to 40%.

The required flash duration is in the range of up to 400ms. Depending on the processing rate of the mobile phone, the time between flashes is usually about 2.5s, although this can be shorter. The duty cycle of a flash is given by pulse duration divided by the cycle time (pulse duration plus break).

Due to the long integration time of typical CMOS image sensors (around 300 ms), an appropriate light source should ideally be capable of outputting a flash in the form of a square impulse (Fig. 3).

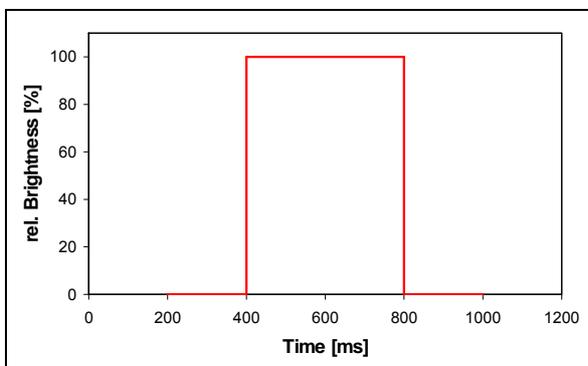


Figure 3: Ideal square impulse of a flash module

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The lifetime of the flash unit is assumed to be higher than 30,000 flashes.

LEDs for Flash Applications

Currently in the market only white LEDs from the multitude of available LED-types are used for camera flashing.

White LEDs are typically based on the principle of color addition, in which the primary color blue (blue semiconductor chip) and the appropriate complimentary color yellow (yellow converter) are used to create white light. The resulting color mixture respectively the color temperature is thereby already specified during production. The typical color temperature of white LEDs is in the range of 5000K to 7000K.

In addition to the function of digital image sensors (CCD or CMOS), multi color LEDs may be also suited for use as camera flash.

In the following, white LEDs which can be considered for use as a substitute for flash tubes are presented.

Like all LEDs from OSRAM Opto Semiconductors, these LEDs fulfill the applicable RoHS guidelines and contain neither lead nor other banned substances.

All shown LEDs are compatible with existing industrial SMT processing methods, so that all current populating techniques can be used for the mounting process. The individual soldering conditions according to JEDEC can be found in the respective data sheet. To reach the optimal performance of the LEDs, thermal management should be considered.

Since OSRAM Opto Semiconductors continually makes improvements to the semiconductor chip technology, especially at the luminous intensity of LEDs, please check the data sheets of the following LED types for further details and the latest performance data (www.osram-os.com).

OSLUX - LUW FQ6N

The LUW FQ6N is especially developed for camera flash applications with high demands on brightness combined with limited dimensions (4mm x 3.9mm x 2.45mm).

The LED is constructed with a metal lead frame (Cu-Alloy) in contact with a semiconductor chip and housing with an integrated lens (Fig.4). The electrical contacts are located underneath the lead frame.

The chip bases on the newest ThinGaN technology and provides excellent color uniformity as a result of the front emitter behavior combined with color conversion at the chip level.



Figure 4: OSLUX LUW FQ6N

The integrated optics consists of a molded lens which is fixed to the LED frame. According the specification the target of the lens design is thereby aligned to maximal illuminance in the center with adequacy uniformity of the viewing area (Fig. 5).

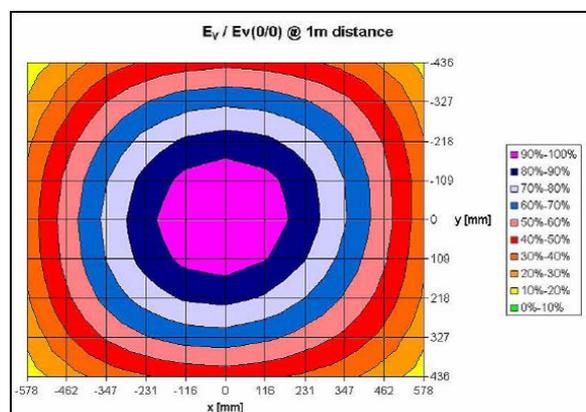


Figure 5: Rectangular Illumination pattern of the OSLUX LUW FQ6N at 1m distance

Table 3 shows the electrical and optical characteristics of the LUW FQ6N.

		OSLUX – LUW FQ6N					
		350mA	500mA	700mA	1000mA	1.5A	2.0A
I_f		350mA	500mA	700mA	1000mA	1.5A	2.0A
Φ_v (typ.)		98lm	130lm	169lm	218lm	300lm	350lm
$E_{v\text{ avg.}}$ at 1m		120lx	159lx	206lx	266lx	366lx	427lx
U_f (typ.)		3.25V	3.3V	3.45V	3.55V	4.0V	4.2V
Max. Pulse duration [$T_a=25^\circ\text{C}$, $D=5\%$]		> 10s	8s	2,5s	600ms	200ms	20ms

Table 3: Characteristics of OSLUX LUW FQ6N

Due to the optimized low thermal resistance, the LED can be driven with a current of up to 2 A in pulse mode.

In line with demand the OSLUX LED is also available in a second version with varied lens design and adapted optical characteristics. The target of the additional lens shape is aligned to a good uniformity of the viewing area with adequacy illuminance level (Fig. 6)

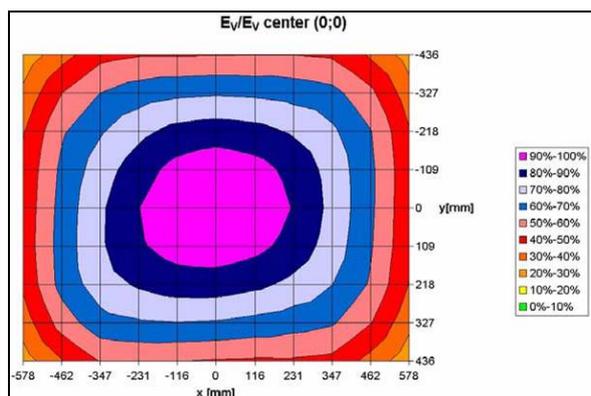


Figure 6: OSLUX with homogenized illumination pattern at 1m distance

Table 4 shows the characteristics for this version of the OSLUX LED.

Overall, the OSLUX LUW FQ6N exhibits a superior efficiency and an excellent thermal characteristic.

CERAMOS - LUW CAEP

This LED is a combination of minimized package and the newest high efficient ThinGaN chip technology with excellent color homogeneity.

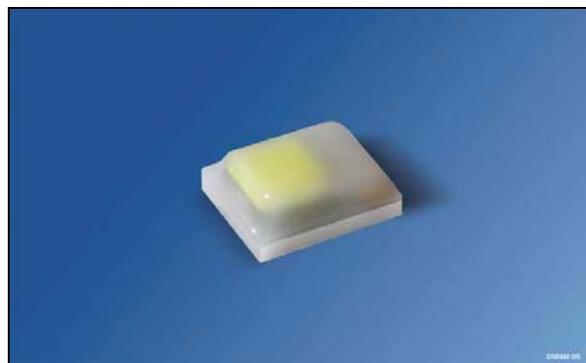


Figure 7: CERAMOS LUW CAEP

Especially designed for applications with extremely limited space the LED exhibits a very high luminous brightness with a dimension of 2.04mm x 1.64mm x 0.75mm.

The LUW CAEP consists of a ceramic substrate with the bonded chip on it, and an encapsulant of silicone. The electrical contacts are located underneath the ceramic substrate (Fig. 7).

The LED is ruggedized and suitable for pulse currents up to 1000mA.

Table 5 shows the optical and electrical characteristics of the LUW CAEP.

		OSLUX with homogenized illumination pattern					
		350mA	500mA	700mA	1000mA	1.5A	2.0A
I_f							
Φ_v (typ.)		98lm	130lm	169lm	218lm	300lm	350lm
$E_{v \text{ avg. at 1m}}$		86lx	114lx	149lx	192lx	264lx	308lx
U_f (typ.)		3.25V	3.3V	3.45V	3.55V	4.0V	4.2V
Pulse duration [$T_a=25^\circ\text{C}$, $D=5\%$]		> 10s	8s	2,5s	600ms	200ms	20ms

Table 4: Characteristics of OSLUX with rectangular illumination pattern

 CERAMOS – LUW CAEP				
I_f	350mA	500mA	700mA	1000mA
Φ_v (typ.)	107lm	142lm	185lm	238lm
E_v avg. at 1m	107lx	142lx	185lx	238lx
	With OSRAM OS reference design lens			
U_f (typ.)	3.25V	3.3V	3.45V	3.55V
Max. Pulse duration [$T_a=25^\circ\text{C}$, $D=5\%$]	DC	DC	2,5s	600ms

Table 5: Characteristics of CERAMOS

Similar to other toplookers without lens, the CERAMOS LED has a viewing angle of 120° with a Lambertian characteristic (Fig. 8).

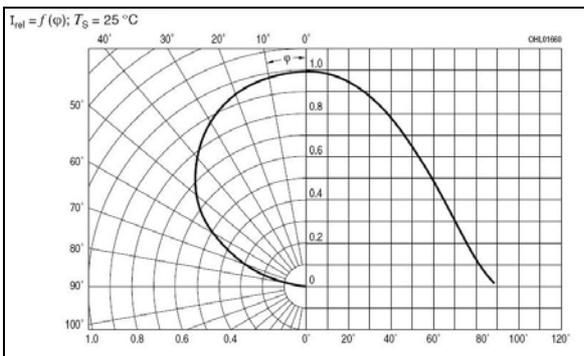


Figure 8: Radiation characteristic of LUW CAEP

The LED can be easily combined with secondary optics e.g. a Fresnel lens to focus the light in the center of the viewing field. This optics is commonly fixed in the cover of the mobile phone.

LED Characteristics Related to Flash Operation

In order to determine whether a LED is suitable for use as a camera flash, various characteristic optical properties should be considered. These include

- Luminous flux of the LED
- Illuminance
- Radiation characteristics
- Flash Duration
- Brightness behavior with respect to flash duration
- Switching time
- Color coordinates

In comparison to other LEDs the interaction of the individual values has also to be observed.

Brightness and Illuminance

When characterizing LEDs, the brightness is usually stated as one of two values - luminous flux Φ_v (units of lm) or luminous intensity I_v (units of cd).

The luminous flux of an LED is defined as the total light output, independent of direction (Fig. 9).

Luminous intensity reflects the amount of light within a specified solid angle in the direction of radiation (e.g. $0.01 \text{ sr} = \pm 3.2^\circ$, see Fig. 9).

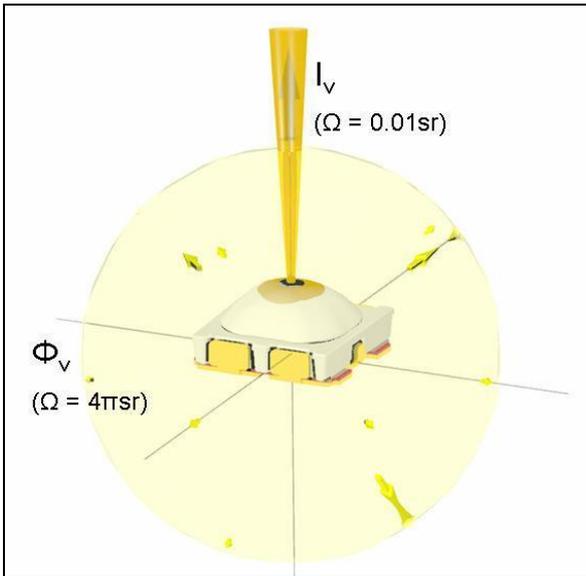


Figure 9: Definition of luminous flux and luminous intensity

The two characteristic values Φ_v and I_v are only conditionally suitable for the characterization of flash LEDs.

With regard to the application, the photometric value for luminous flux density E_v (units of $\text{lx} = \text{lm} / \text{m}^2$) is most often used. Illuminance describes the luminous flux for a specific area at a specific distance (Fig. 10).

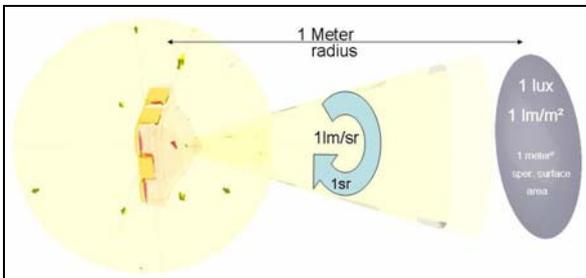


Figure 10: Definition of illuminance E_v

When comparing illuminance values from various LEDs, the distance at which the values were obtained must be taken into account, since illuminance is reciprocal proportional to the square of the distance.

$$E_v(r) = \frac{I_v}{r^2}$$

(photometric distance law)

This means for example, that when the distance is doubled, the illuminance decreases by a factor of four.

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Due to the physical behavior of the semiconductor diode, the luminous flux of an LED does not increase or decrease linearly with the forward current applied and is also temperature-sensitive.

This means that if the luminous flux at a specified value is to be doubled, for example, the forward current must be increased by an additional factor.

Temperature dependency means that at higher temperatures, less light is produced by the LED.

The impact of both effects can be seen in following diagrams (Fig. 11 & 12).

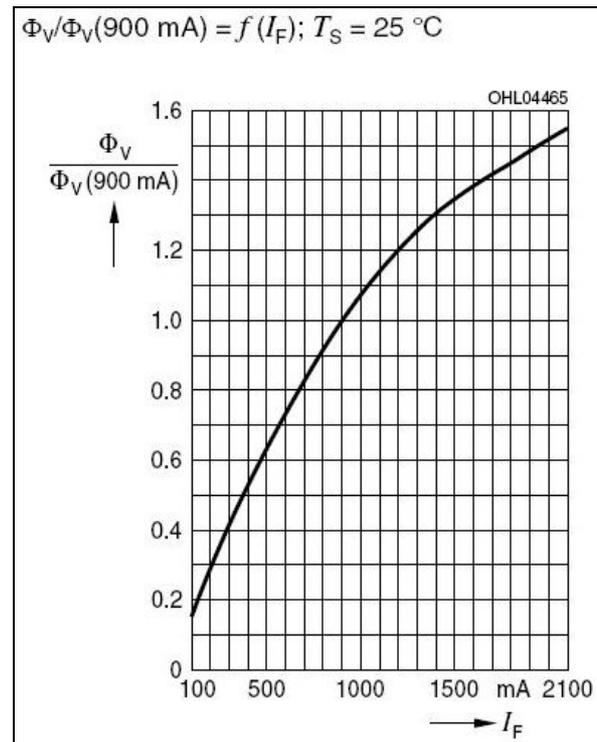


Figure 11: Relative luminous flux vs. current (e.g. LUW FQ6N)

Furthermore, it should be noted that the measured illuminance only represents the brightness at the center of the LED or illumination field. Outside the center, illuminance level falls off more or less sharply, depending on the radiation characteristics of the particular LED or the additionally used lens.

In order to achieve a uniform illumination and thus positively influence the image quality, the entire image area should be nearly homogeneously illuminated.

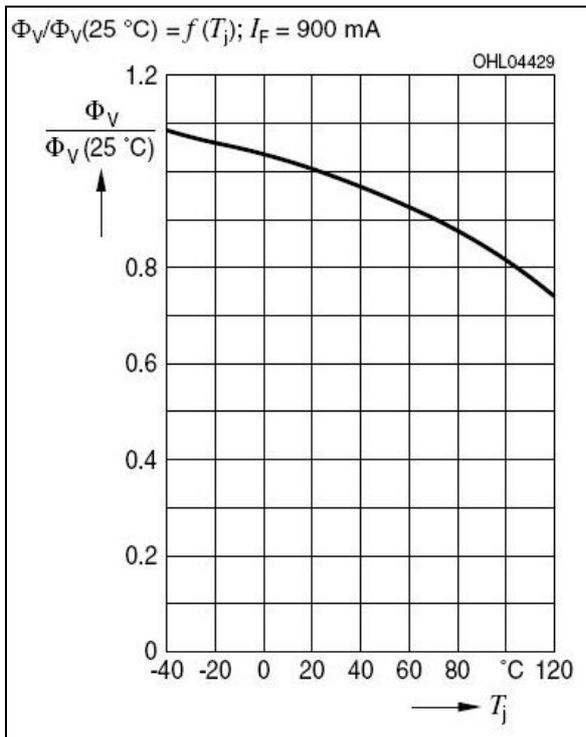


Figure 12: Relative luminous flux vs. temperature (e.g. LUW FQ6N)

Radiation characteristics

Detailed information about the angle-dependent distribution of the luminous intensity respectively radiation is given by the radiation characteristic of the LED (Fig. 13).

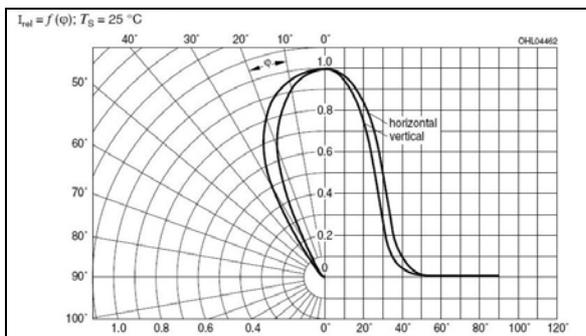


Figure 13: Radiation characteristic of the OSRAM LUW FQ6N

The radiation characteristic of a LED is affected by its respective structure and is component specific for this reason. Thereby the form of the radiation pattern can be influenced within a certain range by a lens directly on the top of the LED or by a separate secondary optics.

For instant SMD LEDs without lens show usually a Lambert' radiation characteristic, SMD LEDs with a simple spherical lens feature a more or less focused radiation.

Generally concerning the lens effect, two different aspects can be purposed - homogenization or focusing.

During the homogenization by an appropriate lens design a leveling of the radiation behavior is strived within a certain angle range. The larger the homogeneous range thereby is the lower is the light and/or density of light in the center.

In contrast during the focusing a collimating of the radiated light is sighted.

In Figure 14 the interrelation between homogeneity and illuminance in the center is once more illustrated on the basis of one LED with different lens characteristics.

Flash Duration

The quantity of light produced by a flash is determined from the product of the flash duration and illuminance E_v . With a higher illuminance of the LED, a shorter flash duration is required for a sufficient exposure. In order to reduce blurring, the flash duration should be kept as short as possible.

Brightness behavior within the flash duration

When power is applied to a LED, the forward voltage reaches a maximum followed by a rapid drop. Initially, the LED is dark and begins operation at room temperature. Due to the current, the brightness decreases as the LED becomes warmer. The slight decline starts when the LED warms up and the heat is transferred within the PCB. The behavior becomes saturated when thermal equilibrium is achieved between the PCB and the surrounding environment.

The higher the LED current is the sharper is the decrease in brightness. The time required to reach thermal equilibrium is dependent on the PCB material used.

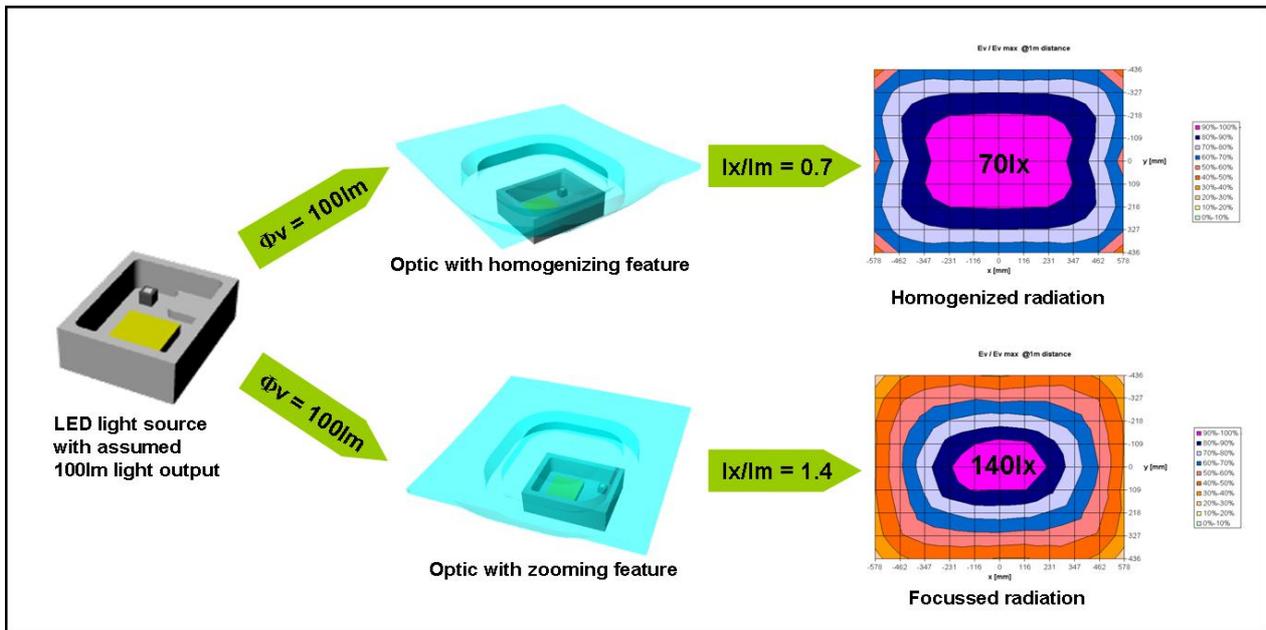


Figure 14: The trade-off between center illuminance and homogeneity

Nevertheless, the drop of brightness during the entire flash is around 10%, resulting in a nearly constant light level (Fig 15). The slight decrease can be compensated by the driving circuitry.

Because brightness decreases slightly over time, it is important to specify at what time

the LED is measured when comparing different flash LEDs.

OSRAM Opto Semiconductors LEDs are measured as follows: After waiting around 5 ms for the current to stabilize, the brightness is measured for a short time period, typically 25 ms.

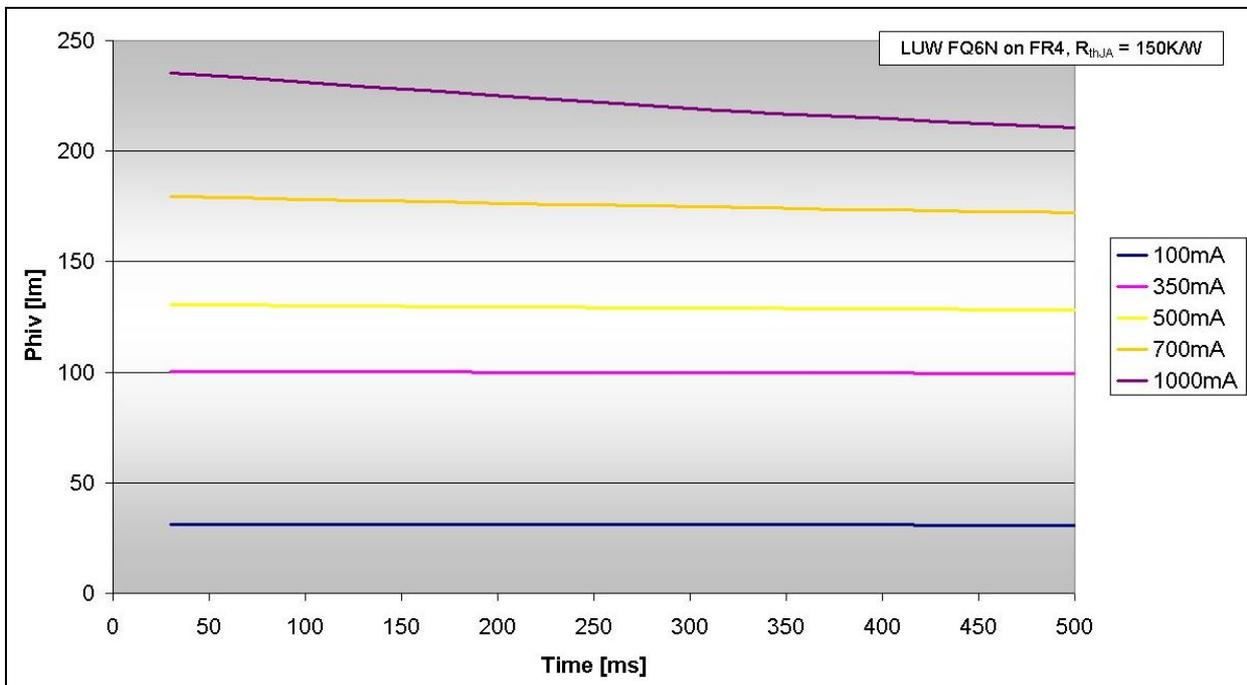


Figure 15: Typical brightness behavior within the flash duration

Switching Time

White LEDs contain semiconductor chips based on InGaN technology. The switching time of InGaN dies is a few tenths of ns.

The yellow converter responds approximately a factor of 10 later. After this time, the light appears white to the eye.

Since the switching time of the converter is a factor of 10^6 shorter than that of the flash duration, the switching time of the converter does not need to be considered. Thus, it can be assumed that during the entire duration of the flash, white light is measured by the detector.

Color Coordinates

For most areas of photography, the color rendering index of white LEDs (typ. 80) is sufficient.

Figure 16 shows the spectrum of a typical ultra white LED. The dashed line indicates the standard eye response curve $V(\lambda)$.

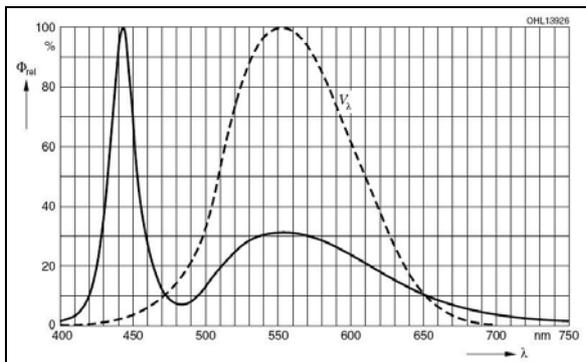


Figure 16: Spectrum of typical ultra white LED (e.g. LUW FQ6N)

Within the professional sector, a higher color rendering index is required.

For these applications, the use of several different single-color or multi color LEDs, as well as white LEDs with multiband converters, is recommended.

By enhancing the chromatic spectrum, the color rendering index can be significantly improved.

The forward current of standard white LEDs influences the chromaticity coordinate, however. This relation can be seen in

Figure 17. With increased forward current, the chromaticity coordinate shifts further into the blue range.

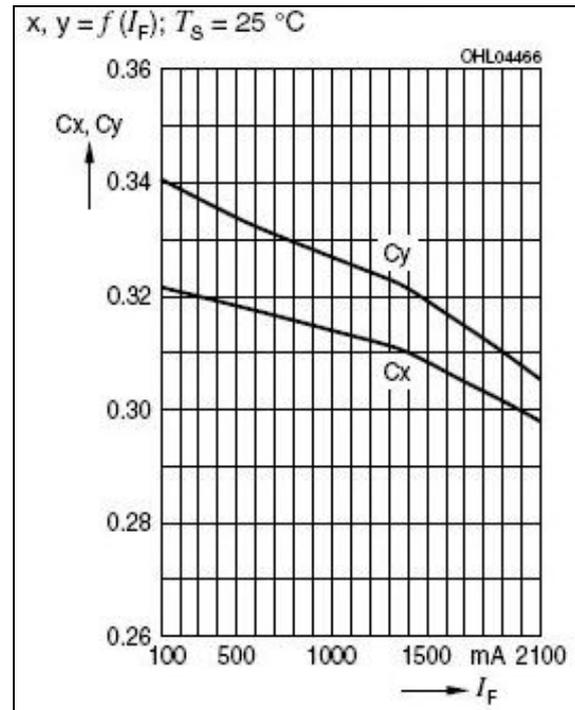


Figure 17: Chromaticity coordinate shift vs. forward current (e.g. LUW FQ6N)

Systems comparison

In the system the two presented LED types show their individual advantages and specifics, wherein they fulfill different requirements and conditions in the end.

Related to the set-up, the OSLUX LEDs have the substantial advantage that due to the lens design no additional optics in application is needed. Thus the assembly and alignment to the window are substantially simplified. However the space requirement for the set-up is larger and the two LED versions provide only two specified radiation characteristics.

The CERAMOS LED in contrast scores in the set-up with its very small dimension and enables a higher flexibility by the determination and definition of the radiation characteristic for the system due to the external auxiliary optics (Fig.18).

If the lens is fixed in the cover, special attention however must be given here to the

alignment of the LED to the lens. A small offset of the LED for example is sufficient that the desired performance is not reached.

In comparison of the total efficiency of both systems, it arises that in a set-up with integrated lens, as with the OSLUX LED, overall a higher luminous flux will be emitted to the target area, than in a system with external secondary lens (Fig. 19).

The main cause is that due to the Lambert' radiation of the toplooker LED only a limited portion of the available light can be collected into the external lens.

Thermal characteristics

An important feature of the LUW FQ6N is that the chip is directly mounted on the Cu-Alloy lead frame. Thus, the heat generated by the chip is transferred through the lead frame and can subsequently flow through the PCB to the environment.

This setup leads to a low thermal resistance for the LED of $R_{thJS} = 10.5 \text{ K/W}$ (typical).

Furthermore, due to the optimized low thermal resistance, the LUW FQ6N can be driven with currents up to 2 A in pulse mode in special cases.

In order to achieve optimal performance, thermal management should be considered.

The assembly methods presented here were further examined with respect to their thermal properties and were thermally simulated in various modes of operation:

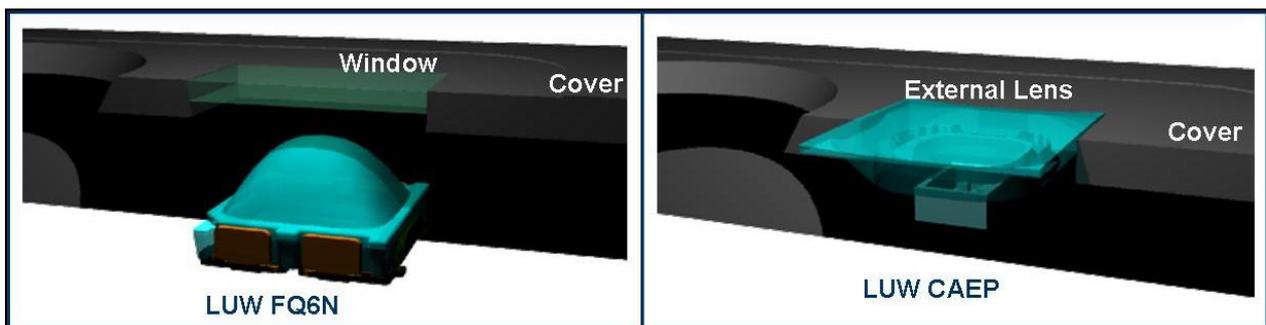


Figure 18: Comparison of assembly systems of the flash LEDs

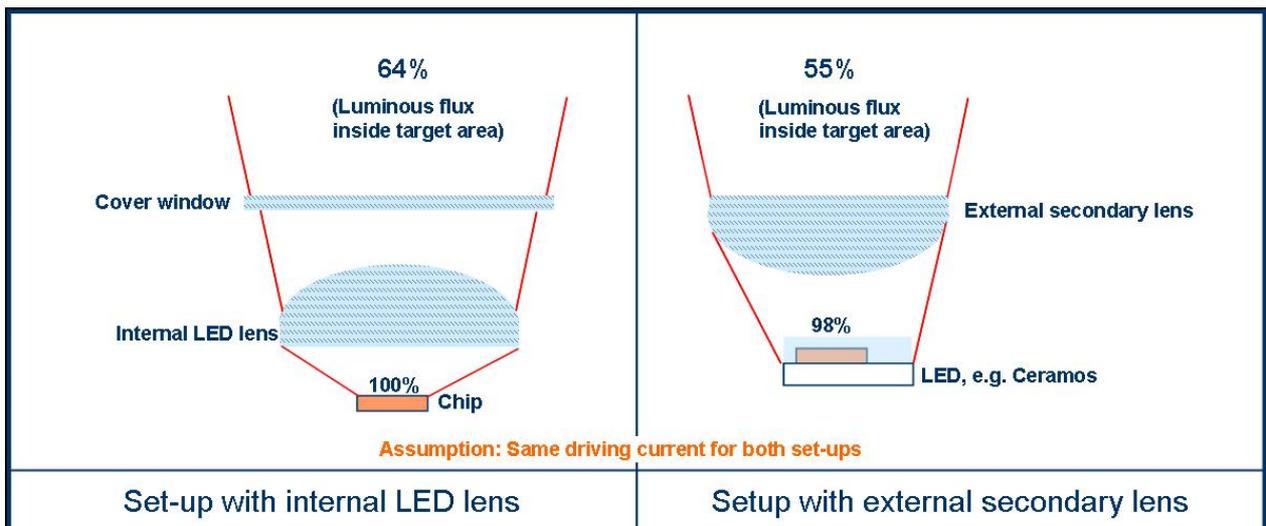


Figure 19: Comparison of system efficacy for the different set-ups

With regards to mounting on circuit boards, three approaches were considered:

1. LED mounted on FR4 main PCB
2. LED mounted on Flex PCB
3. LED mounted on Flex on Al PCB

This resulted in specification of the following boundary conditions for the thermal simulation:

- Ambient Temperature: $T_{amb} = 25^{\circ}\text{C}$
- Heat transfer coefficient of mobile phone cover: $\alpha = 8 \text{ Wm}^{-2}\text{K}^{-1}$

Figure 20, 21 and 22 show the simulation setup of the three different PCB materials on which the LUW FQ6N is mounted. The material characteristics of the PCBs are given below.

The thermal simulation was done for 5 flash cycles with a flash pulse condition of

- $t_p = 300 \text{ ms}$
- $I_f = 1 \text{ A}$
- Interval 2s off

1. FR4 PCB

- LED on multilayer main board
- PCB with 8 layers
- PCB thickness 1.15 mm

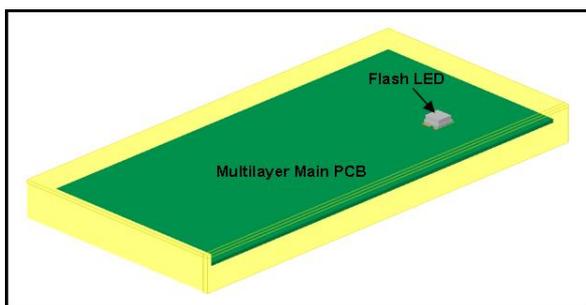


Figure 20: LED on multilayer main PCB

2. Flexible PCB (15x8mm)

- LED on separate Flex PCB
- Flex PCB with 2 layer
- 35 μm Cu, 50 μm PI, 35 μm Cu

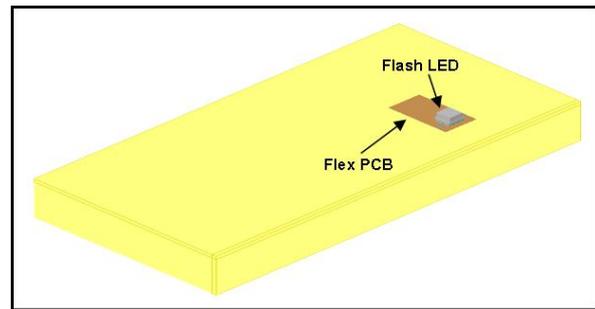


Figure 21: LED on separate Flex PCB

3. Flexible PCB on Aluminum (10x8mm)

- LED on Flex PCB with Al
- PCB with 1 mm Al and 50 μm adhesive
- Flex PCB with 35 μm Cu, 50 μm PI

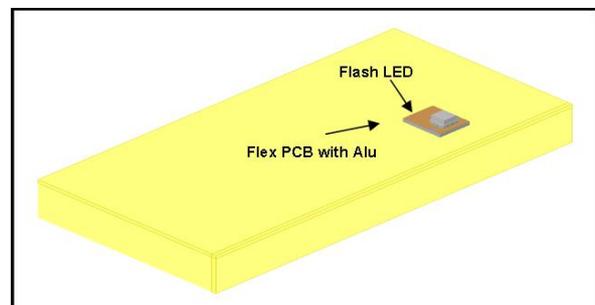


Figure 22: LED on separate Flex on Al PCB

The results of the thermal simulation are shown in Figure 23.

The simulation shows that after 5 pulses the junction temperature of the LED is still below the max. specified value of 175°C for all three set-ups.

Thereby the set-up on flexible PCB with 1mm Aluminum plate features the best thermal behavior and keeps the temperature of the chip nearly constant.

A similar behavior provides the multilayer main PCB with a good thermal conductor for the flash operation, but on a higher temperature level.

In comparison with that the junction temperature of the LED mounted on a Flex PCB increases continuous during the flash operation. Nevertheless after 5 pulses, the maximum allowable junction temperature of 175°C is still not exceeded.

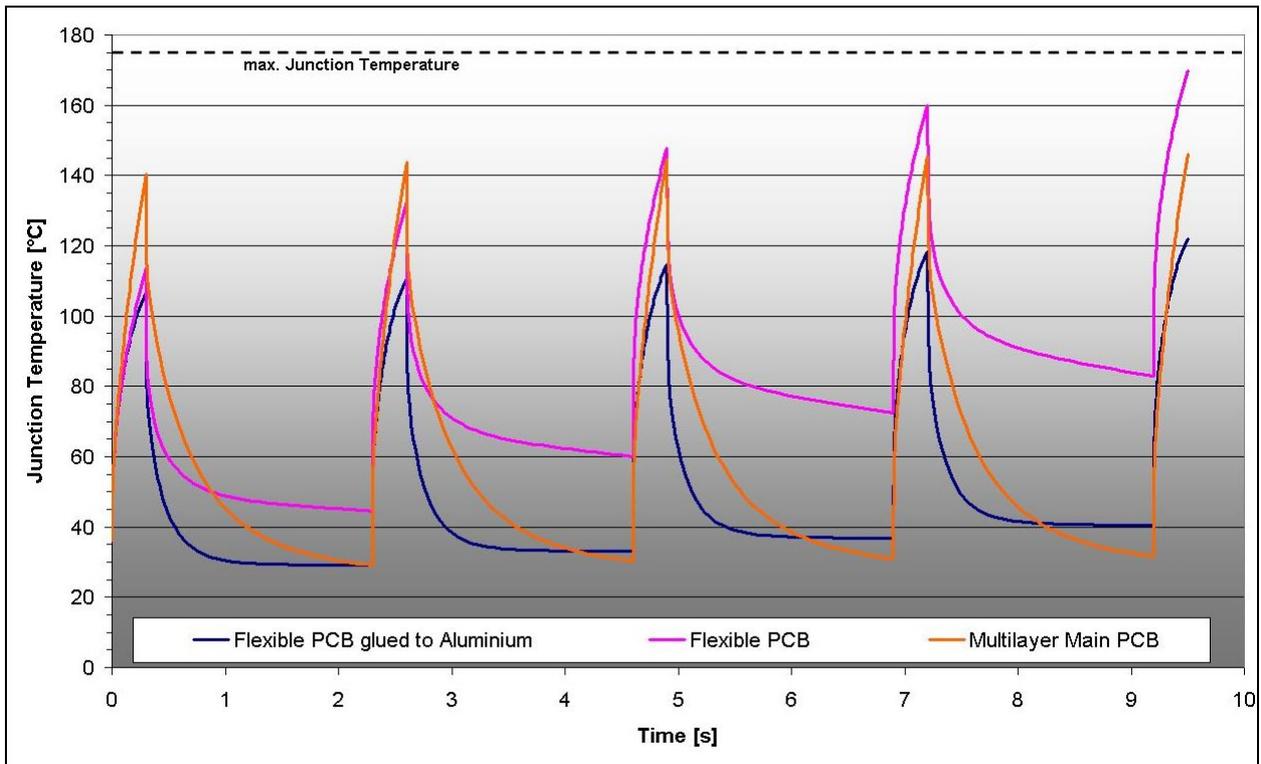


Figure 23: Comparison of different PCB materials for flash operation (LUW FQ6N)

Conclusion/Summary

In general, the requirements for the use of an LED as a camera flash can already be fulfilled and/or exceeded by current LED technology, especially for applications in mobile phones.

Furthermore, in contrast to conventional flash tubes, LEDs exhibit significant advantages such as improved shock resistance, small dimensions, low energy requirements, and a higher lifetime. In addition, no charging time is required for the LED flash.

For best optical and electrical performance of LED camera flashes, the typical properties of the semiconductor chips such as thermal behavior and effects should be taken into account.

The presented LEDs, OSLUX and CERAMOS, are exceptionally suited for use as a camera flash in mobile phones.

Especially developed and optimized for this application, the OSLUX fulfills the requirements regarding brightness, color homogeneity and uniform illumination. With its integrated lens, it exhibits the best optical performance as well as system efficiency.

Depending on the requirements of the application, the CERAMOS LUW CAEP is also suitable for a use as camera flash. Due to its individual advantages, e.g. smaller space requirements, highest luminance and the possibility to generate individual illumination patterns with auxiliary optics it fulfills many requirements for a wide range of applications (e.g. mobile and video).

Besides their use in flash units, the LEDs are also well suited as a flash lamp for video cameras. The advantage in this case is that the flashes can be synchronized to the video frames; the flash only activates during frame capture. Between frames, the flash is turned off. Compared to common video lamps for video cameras, this results in a lower energy usage.

The further development of LEDs will lead to higher efficiency and more light output. At the same time, the required forward current and the dimensions can be reduced.

As OSRAM Opto Semiconductors will continually develop improvements to the LED, please check the data sheets of the LED types for the latest performance data (www.osram-os.com).

Appendix



Don't forget: LED Light for you is your place to be whenever you are looking for information or worldwide partners for your LED Lighting project.

www.ledlightforyou.com

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ABOUT OSRAM OPTO SEMICONDUCTORS

OSRAM is part of the Industry sector of Siemens and one of the two leading lighting manufacturers in the world. Its subsidiary, OSRAM Opto Semiconductors GmbH in Regensburg (Germany), offers its customers solutions based on semiconductor technology for lighting, sensor and visualization applications. OSRAM Opto Semiconductors has production sites in Regensburg (Germany) and Penang (Malaysia). Its headquarters for North America is in Sunnyvale (USA), and for Asia in Hong Kong. OSRAM Opto Semiconductors also has sales offices throughout the world. For more information go to www.osram-os.com.

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