Projection with LED Light Sources

Application Note

Abstract

This application note provides insights into the use of LED light sources for projection applications. An overview of LED projection systems and their benefits is presented, along with a summary of OSRAM Opto Semiconductors LEDs suitable for these applications. Finally, fundamental design issues related to the use of LEDs in projection modules are addressed.

Introduction

Following a sharp increase in visible LED performance in the last few years, in the design of projection systems LEDs are increasingly being considered for the use as a light source. In addition to their robustness and longevity, saturated colors, low power requirements and high integration capabilities are among the benefits that are expanding the use of LEDs in this new application area.

OSRAM Opto Semiconductors products based on thin-film technology are best suited for this application since they can make efficient use of the emitted light due to their surface emission characteristics.

In order to obtain higher efficiency and enhanced durability in the application, some design considerations should be observed, such as matching the LED light source to the optical system and the use of proper thermal management, as described in this application note.

Projection systems using LED light sources

Basically, each projection system can be divided into three main functional components; the light source, the imager and the image projection.

Figure 1: Projector functional scheme

The light source module realizes the generation and shaping of the light to illuminate the imager (Figure 1). In addition to the light source itself, it normally comprises the light collection optics and prisms as well as optical components.
needed for homogenization, and in some cases, polarization of the light prior to image generation. The imager module is the active component that generates the image from the incoming light. Currently there are 3 types of imagers that are widely used, namely DMDs (Digital Mirror Devices), transmissive LCDs (Liquid Crystal Displays) panels and LCOS (Liquid Crystal on Silicon). The imager is a key part of the system since most of the optical limitations are influenced by its properties (dimensions, polarization, acceptance angle, etc.).

The final component of the system is the projection and magnification of the generated image using projection optics. As this does not particularly alter the requirements of the light source, it will not be considered further in this application note.

Unlike conventional high pressure lamps used for projection that are considered to be one-dimensional light emitters, LEDs must be considered as a two-dimensional light source, and thus, the law of etendue applies accordingly:

\[ E_{\text{LED}} \leq E_{\text{System}} \]

This is a limiting property of LEDs since it stipulates that the light etendue (defined as E) of a source cannot be reduced without loss. This has the consequence that for a given imager and optical system, there is a maximum emitting area of the LED surface, above which no additional light can be coupled into the system. This is a key issue in the design of an optical unit for projection systems which employ a LED as a light source, and implies that the etendue of the system (primarily the imager) should match the etendue of the LED. This matter will be addressed in greater detail in the final section of this application note.

**LEDs for projection applications**

All OSRAM Opto Semiconductors LEDs presented in this section are based on efficient thin film technology with nearly pure surface emission and high current capability. They exhibit Lambertian radiation characteristics, providing illumination within a limited space, independent of viewing angle. Besides the pure colors of red, blue and true green, some LEDs are also available in conversion technology with converted green ("CG") or ultra white ("UW").

Depending on the used imager size and application specific brightness level requirement the LEDs are designed as single chip or multi chip array. The chip sizes used vary from about 750µm to 2mm² to fulfill the different power classes.

Figure 2 shows an overview of the LED types of OSRAM Opto Semiconductors particularly suited for projection applications.

All packages have been optimized for heat dissipation and efficient light output with minimal degradation over the lifetime in typical applications.

**OSRAM OSTAR Projection Compact**

The package of the COMPACT product family is based on a ceramic substrate on which the chips are attached and contacted. The chips and the wire bonding are covered by means of an attached glass element. This basically provides protection against physical contact, and does not hermetically seal the component from the environment. The electrical contacts are designed as bottom-only terminations.

Available as single chip or multi chip LED (up to 3) and with different chip sizes the OSRAM OSTAR Projection COMPACT group is suitable and established for pico and pocket projections. The LED is available in color red, true green and blue.
OSRAM OSTAR SMT

This type is also based on a ceramic substrate with a glass window but contains four 1 mm² semiconductor chips. The LED is available as an RGB LED but also as a single color type in amber, blue and true green.

The electrical contacts are designed as edge castellation contacts.

The OSRAM OSTAR Projection SMT group is typically used for viewing application like pico and pocket projection.

OSRAM OSTAR Projection Cube

The OSRAM OSTAR Projection Cube (LCG H9Rx) is only available in the color „converted green“, and with two different chip sizes.

The major technical difference is the used converter technology - a blue chip is covered with a converter tile to obtain green light. This effectuates a higher efficacy than at any other conventional green LEDs available up to now.

Additionally, the package of the OSRAM OSTAR Projection Cube consists of a molded epoxy with a metal lead frame on which the semiconductor chip is mounted and electrical connected. The chip and wire bond is finally encapsulated with a white embedding material.

The electrical contacts are located on the bottom surface of the LED, whereas the exposed cathode serves as thermal pad coevally.

The LED is used for projection applications especially in mobile devices.

OSRAM OSTAR Projection POWER

The OSRAM OSTAR Projection POWER is developed to match optical requirements in the home, industry and office segment.

The high-power LED is available in different configuration levels with two, four or six chips. Basis for the LED is a multi-chip technology in combination with a copper carrier board (IMS).

The semiconductor chips (size 2mm²) are mounted accordingly and wired as light source on a board covered with a glass window.

The IMS-PCB acts as a heat dissipater, providing a large surface area for efficient thermal contact to the system heat sink.

The OSRAM OSTAR Projection POWER is available as a monochrome module with
colors red, true green and blue. Only the six chip module features a plug connector.

**Design considerations**

As previously mentioned in the introduction, when designing an LED projection system it is particularly important to pay attention to the etendue of the light source and that it is properly matched to that of the system. By means of the etendue, it is possible to determine the efficiency of the light source in the system. The etendue describes the required phase space of the area and solid angle that is required in order to guarantee a lossless transfer of light from one point to another within the optical system. Here, etendue is simply defined as the product of the refractive index, solid angle $\Omega$ and area:

$$dE = n^2 \cdot d\Omega \cdot dA$$

For rotationally-symmetric optical systems with a half aperture angle $\alpha$:

$$E = n^2 \cdot \pi \cdot \sin^2(\alpha) \cdot A$$

The etendue thus characterizes each optical element in the system and can be specified for every component. The application of etendue is shown in the following diagram (Figure 3).

In the optical system shown, the etendue of the light source is the limiting factor. If the light from the light source is focused by a lens onto a small area in a lossless system, the following physical limit applies to this area and the associated radiation angle:

$$E = n_1^2 \cdot \pi \cdot \sin^2(\alpha_1) \cdot A_1$$
$$= n_2^2 \cdot \pi \cdot \sin^2(\alpha_2) \cdot A_2$$

It is possible to focus on a smaller area by exceeding the physical limits, but this comes at the cost of efficiency, however. If the dimensions of the optical system are assumed to be constant, a smaller illuminated area of the light source also allows the area onto which the light is focused to be reduced, at a constant luminous flux. This results in the following conclusion:

The greater the luminance of the light source, the smaller the optical system can be designed at the same level of efficiency.

*Figure 3: Etendue example*
Application requirements on the LEDs

As mentioned previously, many optical systems already specify certain physical limits that have a direct effect on the LEDs and their systematic construction.

This can be clearly explained by means of an example for a projection system. In most projection systems which are used for business, pocket or pico-projectors, home theatre and micro-display TVs, the imager is the optically-limiting element.

The cost of the imager generally depends on its size. Because of this, the designer strives to use the smallest imager possible, which also permits the use of small optics, in order to keep the costs of the entire system low.

In contrast to this, however, is the limited luminance of the light source, which due to etendue, limits the brightness of the entire system.

Regardless of the imaging technology, the imager represents the limiting element in many optical systems.

<table>
<thead>
<tr>
<th>0.55” Imager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance angle</td>
</tr>
<tr>
<td>Diagonal</td>
</tr>
<tr>
<td>Aspect ratio</td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Etendue</td>
</tr>
</tbody>
</table>

Figure 4: Typical imager dimensions

The limited etendue of the imager has a direct influence on the etendue of the source.

In selecting the LED light source, two main criteria have to be met; due to etendue, both the area of the emitting medium and the refractive index of the medium through which the light passes must be taken into consideration.

With traditional LED chip technology (so-called volume emitters) light is not only emitted from the top surface but also from the side surfaces of the LED die. This area must also be taken into account when calculating the etendue, which correspondingly increases the total etendue of the light source.

With the thin film technology employed in OSRAM Opto Semiconductors products for projection applications, the emitting portion can be considered to be a pure surface emitter (more than 97% of the light is emitted from the chip surface). In this case, only the top surface of the chip contributes to the etendue value. This technology represents a significant advantage, permitting etendue values which are 30 to 50% lower than those of standard LED technology.

Another important factor in the selection of LEDs as a light source is the packaging technology, particularly the refractivity of the medium through which the light passes. This can be clarified with the following example in which 1 mm² dies are used:

**A LED with a hemispherical lens**

\[ E = n^2 \cdot \pi \cdot \sin^2(\alpha) \cdot A \]

\[ E = (1.4)^2 \cdot \pi \cdot 1\text{mm}^2 \cdot \sin^2(90^\circ) \]

\[ E = 6.16 \text{mm}^2 \]

**A LED with a glass window**

\[ E = n^2 \cdot \pi \cdot \sin^2(\alpha) \cdot A \]

\[ E = (1.4)^2 \cdot \pi \cdot 1\text{mm}^2 \cdot \sin^2(90^\circ) \]

\[ E = 6.16 \text{mm}^2 \]

Figure 5: Sketch of a LED with dome encapsulation

Figure 6: Sketch of a LED with flat glass cover
\[ n_{\text{Air}} = 1 \]
\[ A_{\text{Chip}} = 1 \text{ mm}^2 \]
\[ \alpha = 90^\circ \]
\[ E = n^2 \cdot \pi \cdot \sin^2 (\alpha) \cdot A \]
\[ E = (1)^2 \cdot \pi \cdot 1 \text{ mm}^2 \cdot \sin^2 (90^\circ) \]
\[ E = 3.14 \text{ mm}^2 \]

This comparison illustrates the significant influence of the packaging medium on the total etendue of the LED (approximately a factor of 2).

The LEDs of the OSRAM OSTAR Projection group correspond to the flat technology - LED with glass window - which has been specially optimized to reduce the etendue of the light source for higher efficiency in projection systems.

Once the imager has been chosen, the collimation optics represent an additional factor, allowing different LED light sources to be used depending on the cost / performance constraints of the system as shown in following example.

Referring once again to the formula for etendue and assuming an index of refraction of \( n=1 \) for air and a given etendue of 12.7 mm\(^2\) for the imager, for example, a direct relationship results between the acceptance angle \( \alpha \) of the collimation optics and the usable chip area.

\[ E = n^2 \cdot \pi \cdot \sin^2 (\alpha) \cdot A \]
\[ 12.7 \text{ mm}^2 = \pi \cdot \sin^2 (\alpha) \cdot A \]

As projection systems are etendue limited, it is necessary to pay attention to the radiation characteristics and the reasonable collimation angle \( \alpha \).

Figure 7 shows the radiation characteristics of the OSRAM OSTAR Projection. In Figure 8, the expected transmission curve of a lens system over the radiation angle of the source can be seen. At large radiation angles, the transmission is reduced due to higher losses.

Multiplication of the two curves results in the weighted radiation characteristics of the light source in which the higher losses at large angles in the lens system are taken into consideration (Figure 9).

If this is combined together with the etendue in the diagram shown in Figure 10, the result is the dashed orange curve labeled "Corresponding LED Area". If the light of the LED is collected into an angular range of \( \pm 90^\circ \) with appropriate collimation optics, a chip area of 4 mm\(^2\) can be used. If the angular range is limited to \( \pm 45^\circ \), it is possible to use a chip area of around 8 mm\(^2\).

If one now looks at the luminous flux of the LED over the acceptance angle, the dotted line labeled "Captured Flux from LEDs" is obtained, depending on the radiation characteristics.
The larger the acceptance angle, the greater the relative percentage of total flux amounting to 100% at ±90°. If one now folds the relative luminous flux of the acceptance angle, weighted with the transmission losses at large angles, with the required LED area determined by the etendue, the solid pink line indicated by "Gain Light through Lens vs. from LEDs" is obtained. This curve shows the trade-off between acceptance angle and chip area and the resulting effect on the luminous flux.

If the acceptance angle is reduced, it is possible to increase the chip area for the same etendue. This allows the usable luminous flux to be increased in comparison to the initial values of 4 mm² and ±90°. This increase has a peak at around ±60° and results in a chip area of around 5.5 mm². An even smaller acceptance angle and a larger chip area are employed, the usable amount of luminous flux increases further. The chip area represents a significant cost factor of the LED however, so that practically speaking, an acceptance angle of ±60° appears to be a reasonable trade-off for the design of the optics.

The choice of imager thus plays a key role in the design of a projection system and should therefore be selected at the beginning of the design phase. The optical limitations (primarily etendue) will then be influenced by this decision. In a second step, a balance can be achieved between the LED and the light collection optics, allowing a fine tuning of the cost/performance target.
Thermal and mechanical requirements on LEDs

As mentioned, etendue-limited systems not only require a minimum etendue for the source; the largest possible luminous flux must also be obtained. Using the OSRAM OSTAR Projection as an example, some aspects will be explained that have proven to be essential for use in projection systems. The goal of obtaining the largest possible luminous flux from the smallest possible etendue leads directly to the luminance of the LED. The greater the luminous flux and the smaller the area, the greater the luminance will be. In the above example, it is possible to use an area of 5.5 mm² for an acceptance angle. The brightness of the projector now depends on how much luminous flux can be provided from this emitting area. Therefore, it is necessary to bring the individual chips as close to one another as possible. With the OSRAM OSTAR Projection, only a tiny gap is required between the chips for electrical isolation. This permits the use of cost effective standard chips and very flexible circuitry which can be designed in various ways, depending on the application.

A common method of increasing the luminous flux and thus the luminance is to increase the current that is applied to the chip. The increased current density also has the consequence that the junction temperature of the LED is significantly increased. Since the junction temperature has a strong influence on the lifetime and efficiency of the LED, operation at the lowest possible junction temperature is recommended. Therefore, the thermal resistance from the junction to the backside of metal board must be kept as low as possible.

Transient thermal resistance $Z_{th}$

In most cases, LEDs in the projection system are operated in pulsed mode. For this mode of operation, the dynamic thermal resistance $Z_{th,JB}$ is used instead of the static value $R_{th,JB}$. The $Z_{th}$ curve shows the transient thermal resistance of the LEDs in response to a single pulse of duration $t_p$ (Figure 11).

![Figure 11: $Z_{th}$ curve of the OSRAM OSTAR Projection LED (LE B Q8WP)](image)
If the pulse duration is extended to 10 s or more, a thermal steady state and static condition is achieved, resulting in $R_{th,JB}$. Since $Z_{th,JB}$ is significantly lower than $R_{th,JB}$ in pulsed operation, depending on frequency, a higher forward current is also permissible in pulsed operation. Due to the shorter pulse length, a higher frequency also has a positive effect on the thermal resistance and therefore on the lifetime as well.

**Temperature influence of luminous flux**

The junction temperature does not only influence the lifetime, however. Figure 12 shows that the luminous flux and efficiency are also highly dependent on the junction temperature.

Moreover, this behavior depends on the emission wavelength and material system of the LED. Generally speaking, shorter wavelengths are less temperature sensitive than the longer wavelengths so that the driving conditions need to be adjusted accordingly.

**Temperature dependency on wavelength shift**

For semiconductor based light emitting devices, variations in temperature not only have an influence on brightness, but cause significant changes in the emission wavelength as well.

As illustrated in the Figure 13, this temperature-induced wavelength shift is also dependent on the material system and the emission wavelength. The driving and mounting conditions therefore have to be selected with special care since wavelength variations have a direct impact on the color balance of the projected image.

<table>
<thead>
<tr>
<th>Temperature coefficient [nm/K]</th>
<th>R</th>
<th>G</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC $\lambda_{peak}$</td>
<td>0.14</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>if 750mA (R), 500mA (G,B)</td>
<td>-10°C&lt;T&lt;100°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC $\lambda_{dom}$</td>
<td>0.08</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>if 750mA (R), 500mA (G,B)</td>
<td>-10°C&lt;T&lt;100°C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 13:** Temperature coefficient values with respect to wavelength shift

Since the shift is larger for red LEDs, particular attention must be given to the red color region with respect to changes in temperature, so that the quality of the image is guaranteed.

**High temperature operation**

Figure 14 shows the saturation of luminous flux with respect to operating current for a red emitting OSRAM OSTAR Projection LED driven at a fixed duty cycle (30%) for different board temperatures. Increasing the driving current above a certain point leads to
a so-called "rollover" effect – in such a case, an increase in current density leads to a reduction of the luminous flux. In other words, the increased input power is no longer converted into light but warms up the LED instead. By optimizing the thermal design, this saturation point can be shifted to higher current density levels, which allows a more efficient operation of the LED. This effect is more noticeable for LEDs with longer wavelengths.

**Conclusion**

When designing a projection system which uses LEDs as a light source, the imager and LED cannot be selected and optimized independently, but must be done according to designer constraints such as luminous output, space, costs, power consumption, etc.

In addition, the choice of the operating and mounting conditions of the LEDs has a significant influence on the light source and eventually the system efficiency and therefore should be selected carefully.

Figure 14: Influence of board temperature on luminous flux for an amber LED (e.g. LE A S2W)
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

Authors: Morgott, Stefan; Stich, Andreas;

ABOUT OSRAM OPTO SEMICONDUCTORS

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