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WHITE PAPER

High-Luminance LEDs for Directional Lighting Applications

New LED Designs Help Optimize Directional Lighting Performance and Efficiency

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Overview

What Is High-Luminance Directional Lighting?

High-luminance directional lighting (HLDL) refers to light sources that provide bright illumination (luminance) and are designed to focus (collimate) light rays into a beam shape that points in a specific direction. Compared to more diffuse or general-purpose lighting, HLDL offers designers the ability to create lighting schemes that support demanding visual tasks, accent specific objects or features of a building or environment, and illuminate the darkest nights or underground spaces (Figure 1).

Figure 1 – Everyday examples of directional lighting.

LEDs for High-Luminance Directional Lighting

LEDs offer a wide range of characteristics to meet virtually any of today's lighting needs from the lowest to highest levels of source flux/flux density, from diffuse ambient light to focused task lighting (Figure 2), from broad flood lights to narrow spotlights (Figure 3). Many LED products can be very effective for HLDL applications, combining brightness, energy efficiency, reliability, and flexibility compared to other types of lighting technologies.

This white paper explains the key performance criteria for HLDL and discusses the impact of various LED structural and design factors on performance, such as

- LED chip size and shape (emitting surface)
- LED composition (e.g., white phosphor)
- Optical design
- Beam shape and emitting angle
- Color performance (e.g., CRI)

It also describes how to optimize lighting device design and components to achieve the best performance and provides guidance on selecting the right LED for your HLDL application.

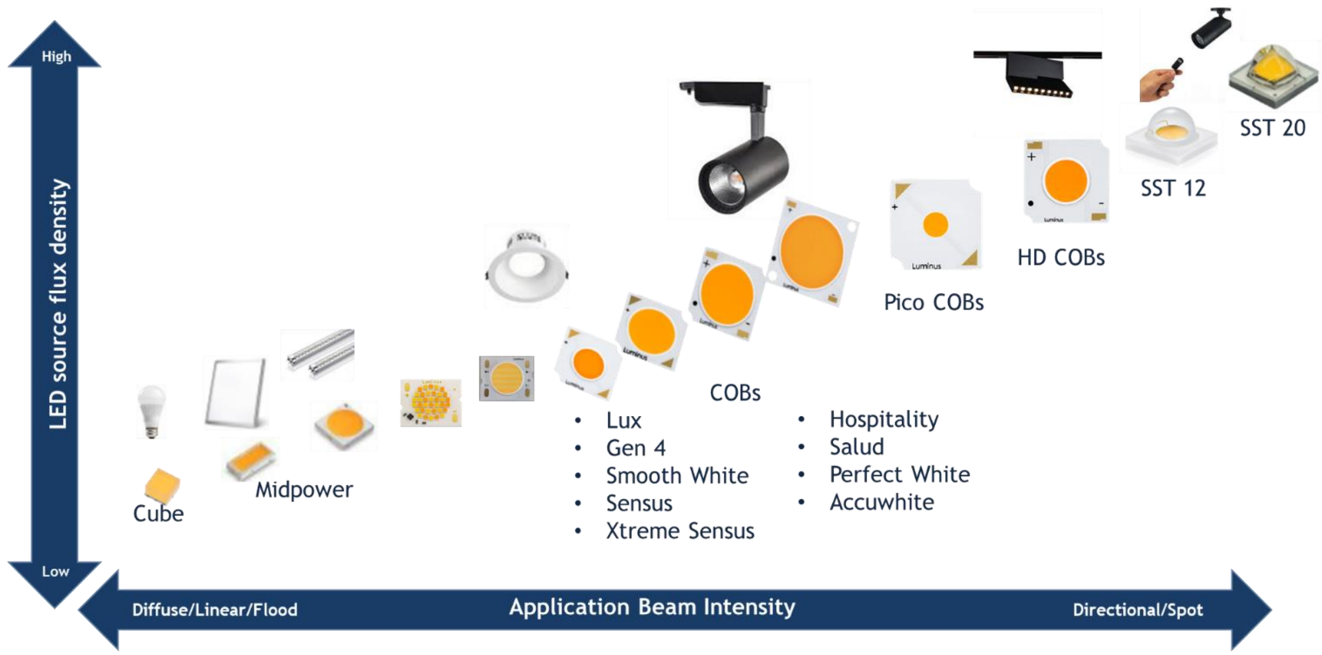

Figure 2 – The Luminus Indoor Lighting Portfolio spans the full range of indoor lighting applications.

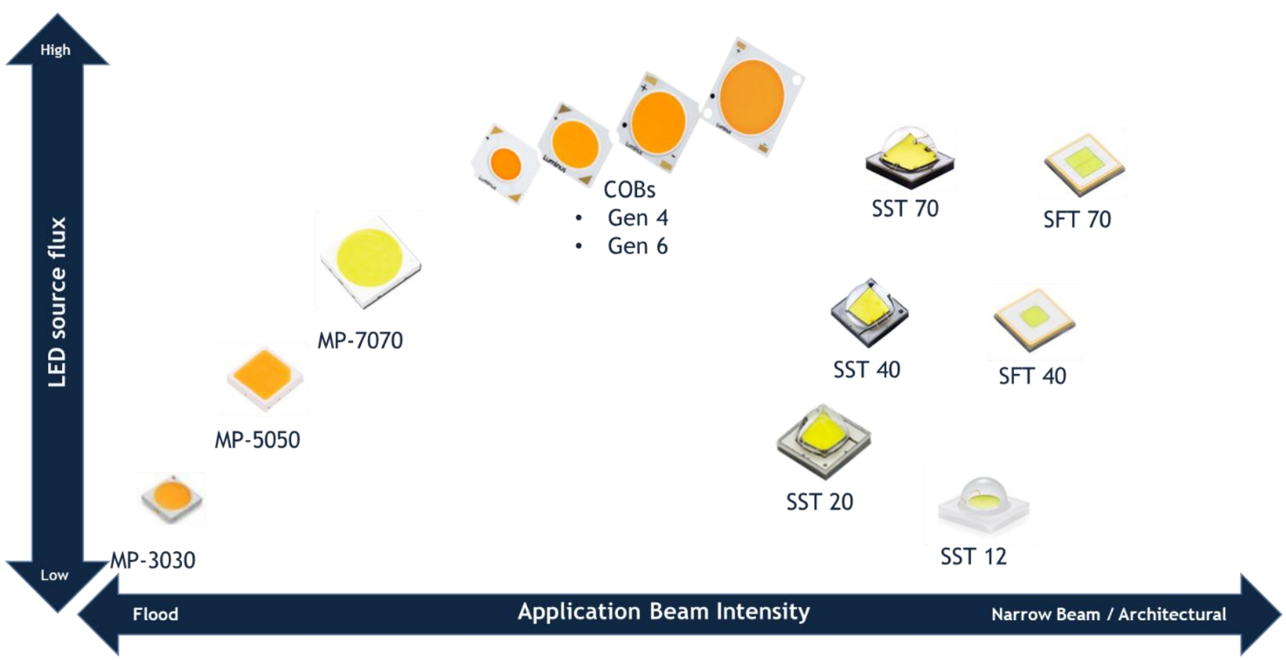

Figure 3 – The Luminus Outdoor Lighting Portfolio includes Chip-on-Board (COB) and specialty HLDL LEDS (our SST and SFT product series)

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1.0 Introduction to High-Luminance Directional Lighting

Flashlights and bike lights that illuminate the path ahead; task lights that shine down on the work area in kitchens, offices, and factories; lighting that enhances architectural features of a building or spotlights works of art; lights for surgical operating rooms and your dentist's chair; outdoor streetlamps and sports field illumination—these are all examples of high-luminance directional lighting that we encounter every day.

Colloquially, people refer to the 'brightness' of a light source when they want to characterize the amount of light emitting from it; the scientific name for this is luminance. Thus, a high-luminance light source simply means it's very bright.(Section 3 below discusses luminance in more precise, mathematical terms.)

Directional means that the light from a source is collimated towards a specific target such as an object or area. Collimation means altering the light beams emitted from the source, so they are parallel, for example, sending the beams through a lens that refracts them at a different angle then their original trajectory (Figure 4 and Figure 5). A lens and/or any other elements that are used to shape the light distribution pattern in this way are called secondary optics.

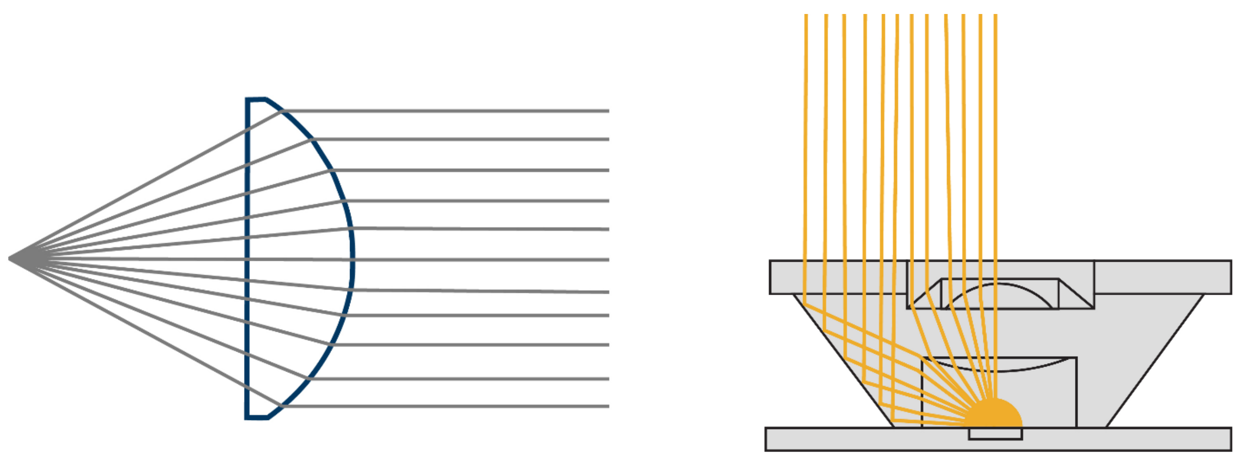

Figure 4 – Collimation uses an optical element such as a convex lens (left), parabolic reflector, or TIR (Total Internal Reflection) element (right) to reshape light from an LED source so that the light beams are reshaped and focused so they are closer to parallel, as if coming from and shining into an infinite distance.

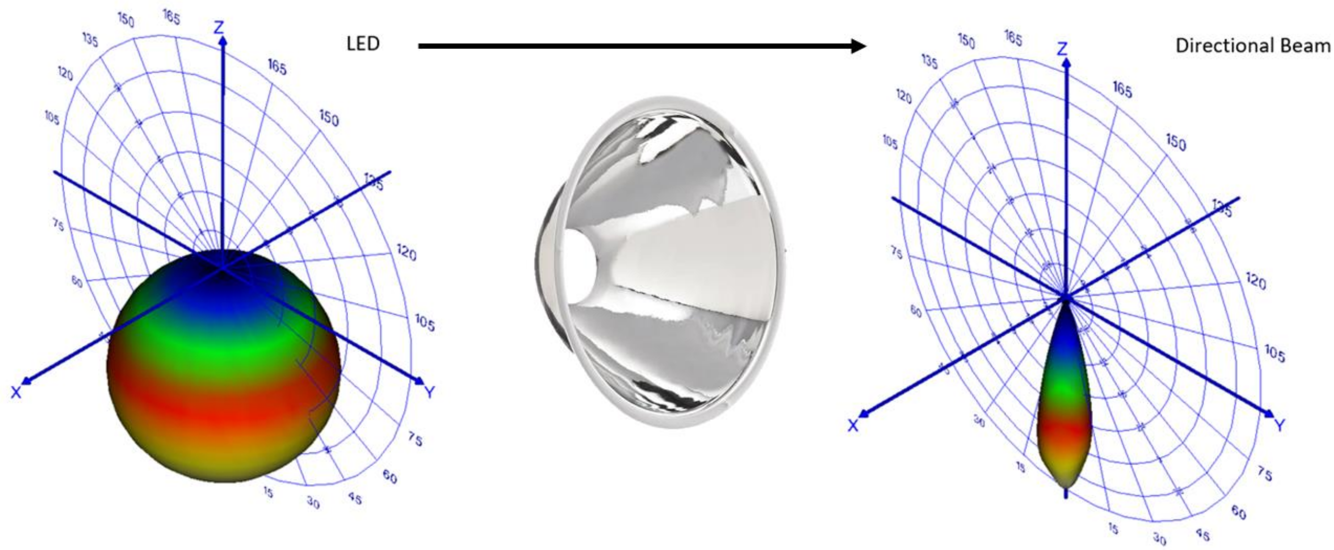

Figure 5 – Illustration of how a parabolic lens reshapes an LED beam distribution pattern (represented by the colored shapes) from a broader spherical shape into a directional beam.

2.0 Applications of Directional Lighting

High-brightness directional lighting is used in a wide range of indoor and outdoor environments to serve multiple purposes. For all applications, the optics, secondary optics such as reflectors or lenses are used to shape the light and deliver a specific beam pattern and brightness.

Some common indoor directional lighting applications are spotlights, wall washers, task lights, and track lighting. Directional lighting is often used outdoors for roadway lighting, street lighting, sports fields and stadiums, and canopy lighting, which shines light downwards to illuminate human activity.

Another large category of directional lighting is portable lighting such as flashlights, bicycle lights, and headlamps. In transportation, directional fixtures are used for vehicle forward lighting such as light bars for off-road vehicles. Portable LED work lights are also very common, mounted on vehicles for agriculture or construction.

There are many medical applications of HLDL also. For example, in a surgical operating room directional light helps create a shadowless environment, or headlamps worn by surgeons and dentists. Industrial uses of HLDL include high-speed camera illumination that requires a narrow angle of the light distribution for machine vision applications.

Many of the typical HLDL applications are summarized in Table 1 and illustrated in Figure 6.

Table 1 – Examples of High-Luminance Directional Lighting Applications

Category	Product/ Application	Indoor/ Outdoor	Typical Use Cases / Requirements
Portable	Professional Flashlights	Both	Tactical jobs by military and police Search and rescue by public safety Work by field engineers
Portable	High-Performance Consumer Flashlights	Outdoors	Hunting and fishing Camping and hiking
Portable	Sports activity	Outdoors	Bicycle Lights
Portable	Sports activity	Outdoors	Helmet lights
Portable	Military/Sports activity	Outdoors	Weapon-mounted lights for military use and hunting
Public Safety	Roadway lights	Outdoors	Highways, roads, and intersections Streets and roadways are continuously illuminated thus energy efficiency is key
Public Safety	Streetlamps		Public sidewalks, parking lots, pedestrian walkways
Architectural and Public Safety	Landscape	Outdoors	Decorative spotlighting of landscape features, and to illuminate pathways and gardens for human safety.
Utility/Industrial	Spotlight	Outdoors	
Utility/Industrial	Work Lights/Task Lights	Both	
Utility/Industrial	Garage & Canopy	Both	
Utility/Industrial	High and Low Bay Lights	Both	
Automotive	Auxiliary lighting		
Automotive	Headlamps and taillights		
Architectural	High CRI	Indoor	Architectural features Museum and art galleries
Architectural	Wall washer		Commercial and residential
Architectural	Spotlight		Commercial and residential
Architectural	Track light		Commercial and residential One of the most common indoor uses of directional lighting
Utility/Industrial	Work lights		High intensity lighting
Medical	Treatment environments		Surgical procedure rooms / operating rooms Patient exam rooms Dental treatment rooms
Medical	Endoscopy		
Other	Digital signage	Outdoor	Need for high brightness for visibility even in direct sunlight, but also requires energy efficiency due to display size

Figure 6 – Applications of high-luminance directional lighting include (clockwise from upper left) premium portable lighting such as bicycle lights, indoor directional lighting such as museum/gallery spotlights, outdoor lighting such as streetlamps, automotive auxiliary lights, work lights, and industrial lighting.

3.0 What Does “High Luminance” Really Mean?

In the field of lighting design and engineering, terms such as *brightness*, *intensity*, *luminance*, and *illuminance* have specific meanings that are important to clarify, along with associated terms and mathematical relationships that are used in directional lighting applications.

Luminous flux is a measurement of the total amount of light that a source (such as a candle or an LED) emits, integrated over the entire angular span of the light (Figure 7). We quantify luminous flux in units of lumens (lm), a photometric unit of measurement.

Luminous intensity is the light that shines from the source in a given direction, measured as a function of angle in units of lumens/steradian (lumens/sr), also called candelas.

Illuminance refers to the amount of light from a source that shines onto a surface, measured as a function of area in lumens per square meter (lm/m^2), also called lux.

Luminance (denoted by the symbol L_v) is a function of both size and angle, measuring the amount of light from an area that shines in a direction. It is a photometric measure describing the amount of light that is emitted directly from a source or passed through or reflected from an object such as a lens or reflector on a particular area in a specific direction.

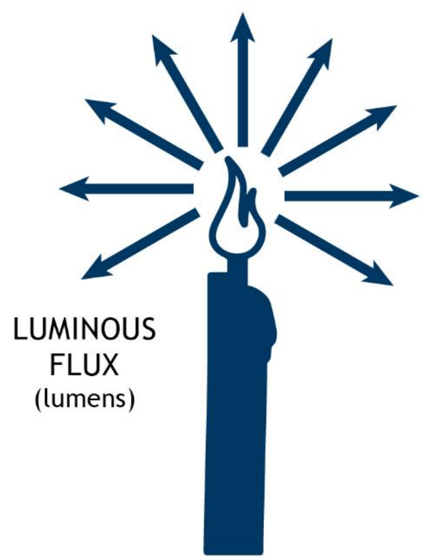

Figure 7 – Luminus flux is the total amount of light emitted in all directions (at all angles).

The SI unit of luminance is candela per square meter (cd/m^2). Recalling that candela = lumens/steradian, luminance can also be expressed as lumens/sr/m^2, which is commonly referred to as "nits." We can also define luminance by a derivative:

$$L_v = \frac{d^2\Phi_V}{dA\, d\Omega\, \cos\theta}$$

Where:

Φ_v is the luminous flux with units of lm
A is the area seen from the source inside the solid angle Ω,
Ω is the solid angle
θ is the angle between the normal and the direction of the light.

Figure 8 illustrates these different terms: luminance (measured in candela/m^2 aka nits), luminous intensity (cd), luminous flux (measured in lumens), and illuminance (measured in lumens/m^2, aka lux).

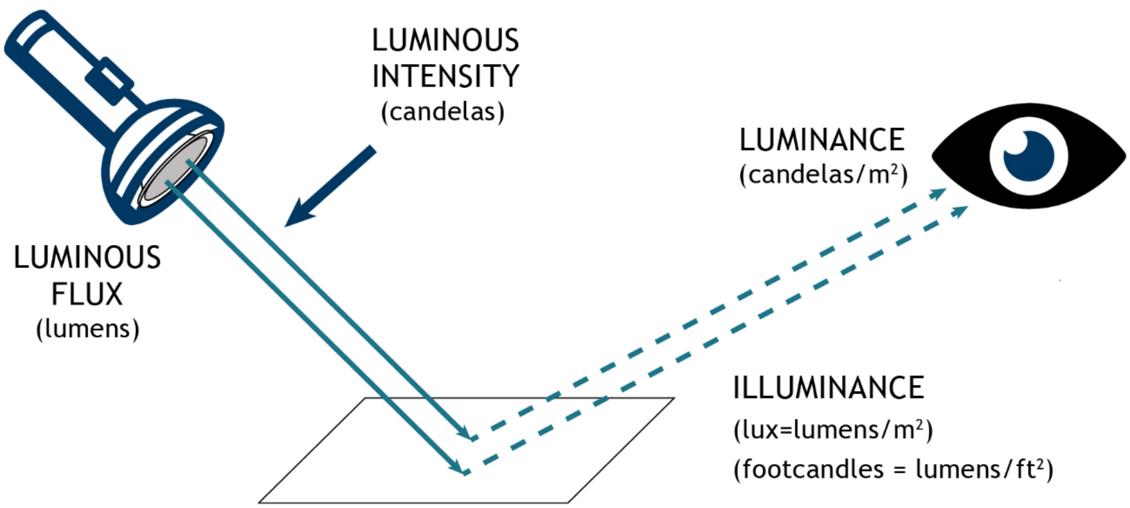

Figure 8 – Illustration of light source measurements and their definitions.

Luminance can be directly measured by luminance meters or simulated by standard optical design software incorporating near-field details of the light source and any optical elements. To evaluate the effectiveness of a directional light source, the lens efficiency factor—which can be called the "K-factor"—is calculated by the maximum luminance (usually at the center of the beam) divided by the total luminous flux of the light source. The unit of K-factor is candela/lumen (cd/lm). Higher values for lens efficiency (higher K-factor values) are preferred for directional lighting.

What do we mean by "K-Factor"?

To compare the performance of different HLDL light sources, the shorthand "K Factor" can be used, in units of candela per lumen (cd/lm). K Factor refers to the lens efficiency factor, which characterizes the convergence of the light source. Higher convergence means a narrower, brighter beam better for HLDL. Some industry sources refer to this as "peak intensity".

Note: K Factor is not the same as the K metric used to characterize light source color, where K is Kelvin (e.g., 3000K).

3.1 Understanding Luminance Factors for Directional Lighting

Of all these metrics, the most important for many directional lighting applications is illuminance, the measure of light that shines on a surface. For a wall spotlight, a designer needs to know the amount of light that will shine on the wall, for example. Similarly, the number of lumens emitted from a light source is less important than the luminance (lumens per solid angle), which more accurately captures the directional characteristics (spatial distribution) of the source

The spatial distribution of a LED is measured by the light radiation over angle with a goniometer. The beam angle is defined when the light intensity is 50% of its maximum value in the observing plane. The light directly emitting from a standard LED has a very broad spatial distribution. A typical viewing angle of an LED is about 120°. The light spatial distribution of LEDs can be generally described by the Lambert's cosine law, or we can call it Lambertian distribution.*

LED size is also a consideration. Intensity of light output (luminous intensity as measured in lumens/sr or candelas) is not a function of the size of the source. However, luminance—what the human eye perceives as brightness—is a function of the size of the source. From this perspective, the amount of light coming out of the surface area of the LED is key, which could be thought of as lumens per square mm, or luminous "exitance" (Figure 9).

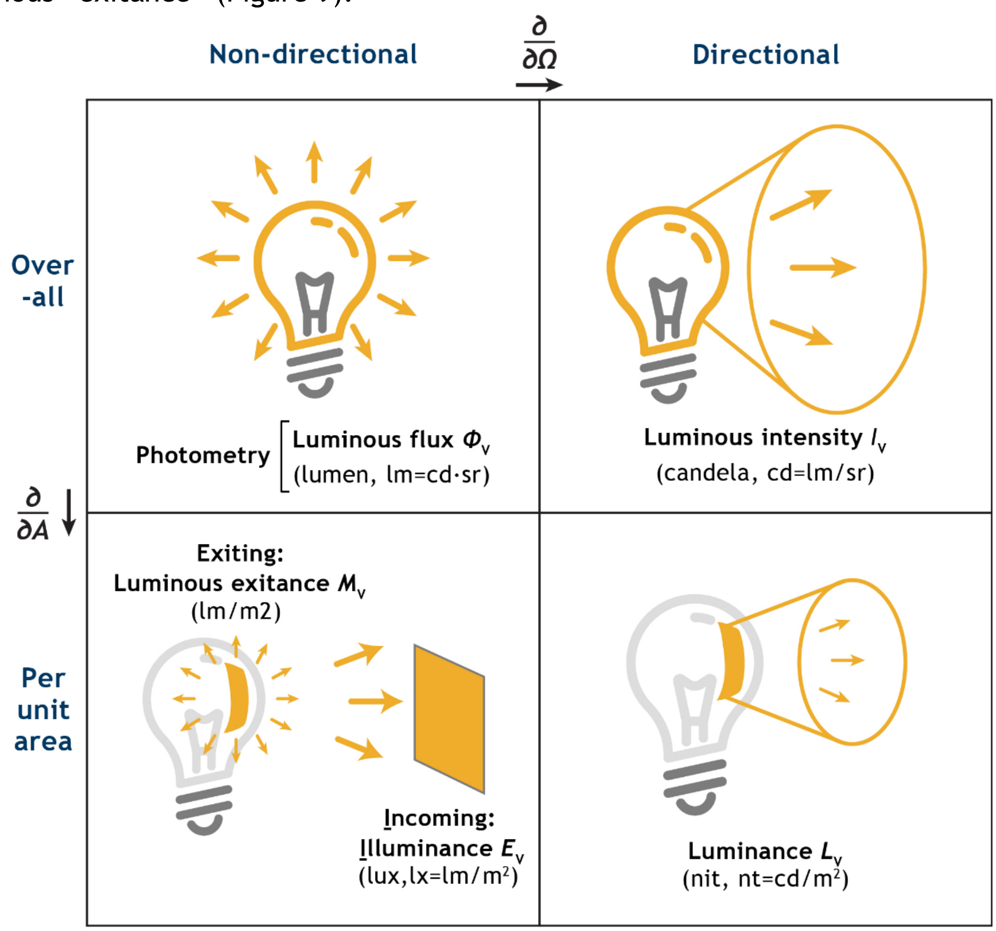

Figure 9 – Differences and relationships between non-directional and directional lighting metrics.

* A Lambertian source is defined as one where the brightness (or luminance) is independent of the angle, meaning on-axis and off-axis luminance is the same. For more information on the radiometry of Lambertian sources refer to: https://uweb.engr.arizona.edu/~dial/ece425/notes7.pdf)

4.0 Performance Criteria of Directional Lighting Products

What does it mean to have a good directional lighting product? Beyond simply brightness, other aspects of a light source design and performance are important for various directional-lighting applications. Multiple criteria are considered that enable designers to achieve their optimal end result. These criteria include:

- **Luminance** (as discussed above in Section 3). High luminance levels are important especially for outdoor safety uses such as flashlights and roadway lighting and in task lighting for performance of demanding activities.
- **Beam angle / spread** (discussed below in Sections 6.1 and 6.2) For some applications, users desire a bright beam spot, i.e., high on-axis intensity.
- **Beam spot quality.** Beyond high luminance in a beam spot, many applications also require a high quality of light. This means that the beam spot provides uniform brightness and color across its entire area.
- **Center Beam Candle Power (CBCP)** (discussed below in section 5.3)
- **Throw distance.*** For some applications a long beam distance (throw distance, also called **lux distance)** is also a key criterion when light needs to reach far from the source. An LED that maximizes illuminance (lm/m^2, aka lux) requires a narrow beam angle combined with high luminance. For example, a high-performance flashlight with a narrow beam provides equivalent lux at a greater distance than a flashlight with a broader beam (Figure 10).

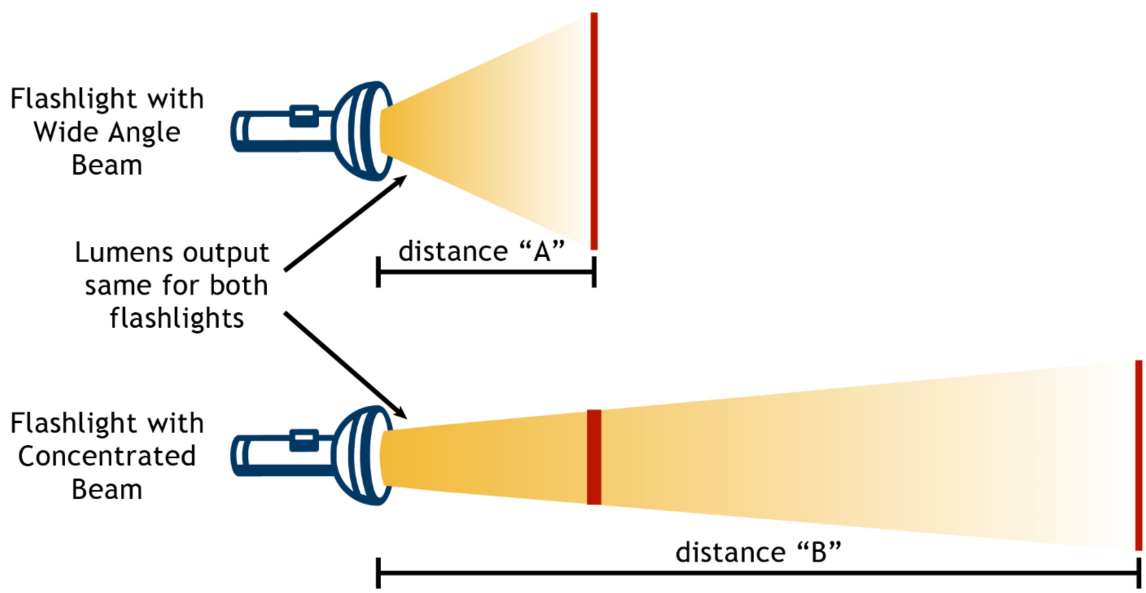

Figure 10 – The lumens output of both flashlights is the same, but lux level and distance are increased with a narrower beam angle. At distance A, the light intensity of the concentrated-beam flashlight (bottom) is much greater than the intensity of the wide-angle beam flashlight (bottom). At distance B, the concentrated beam appears similar to the light intensity of the wide-angle at distance A.

* "Throw" is commonly used in the flashlight field. In the ANSI standard, throw distance is defined as the distance where the illuminance is 0.25 lux; in this document the lux value of 1 is used for simplicity. For more information refer to https://www.slideshare.net/canfang/led-optics-in-flashlight

- **Low profile**. For HLDL devices with small form factors such as flashlights or miniature recessed lighting, a low-profile LED is preferable. The LED itself is smaller, thus smaller optical elements and a small heat sink can be used.
- **Energy efficiency.** Lighting fixtures and devices that use less power to generate equivalent or greater lighting are highly desirable to help reduce electricity cost and support climate goals. For mobile HLDL devices, lower power use also translates to longer battery life. Achieving energy efficiency in HLDL requires a combination of optical, thermal, and electrical design factors.
- **Lifetime performance / reliability**. The benefits of reliability and a long lifespan are obvious: less maintenance, longer time between replacements, lower replacement costs. Consistent performance throughout a device's lifetime ensures that there is no drop-off in brightness or other performance degradation over time.

4.1 Color Considerations

The color of light from a source is another important factor for many HLDL applications as it affects the appearance and visual clarity of objects and the environment. Color rendition (also commonly referred to as color rendering) is the effect of light on the color appearance of objects, specifically how the color is perceived by humans. Every light source emits one or more (or many) wavelengths within the visible spectrum, even light sources we perceive as "white." In fact, white light is always a combination of multiple "colors". The color profile of a source such as an LED is shown in its spectral power distribution (SPD) graph such as the examples in Figure 11.

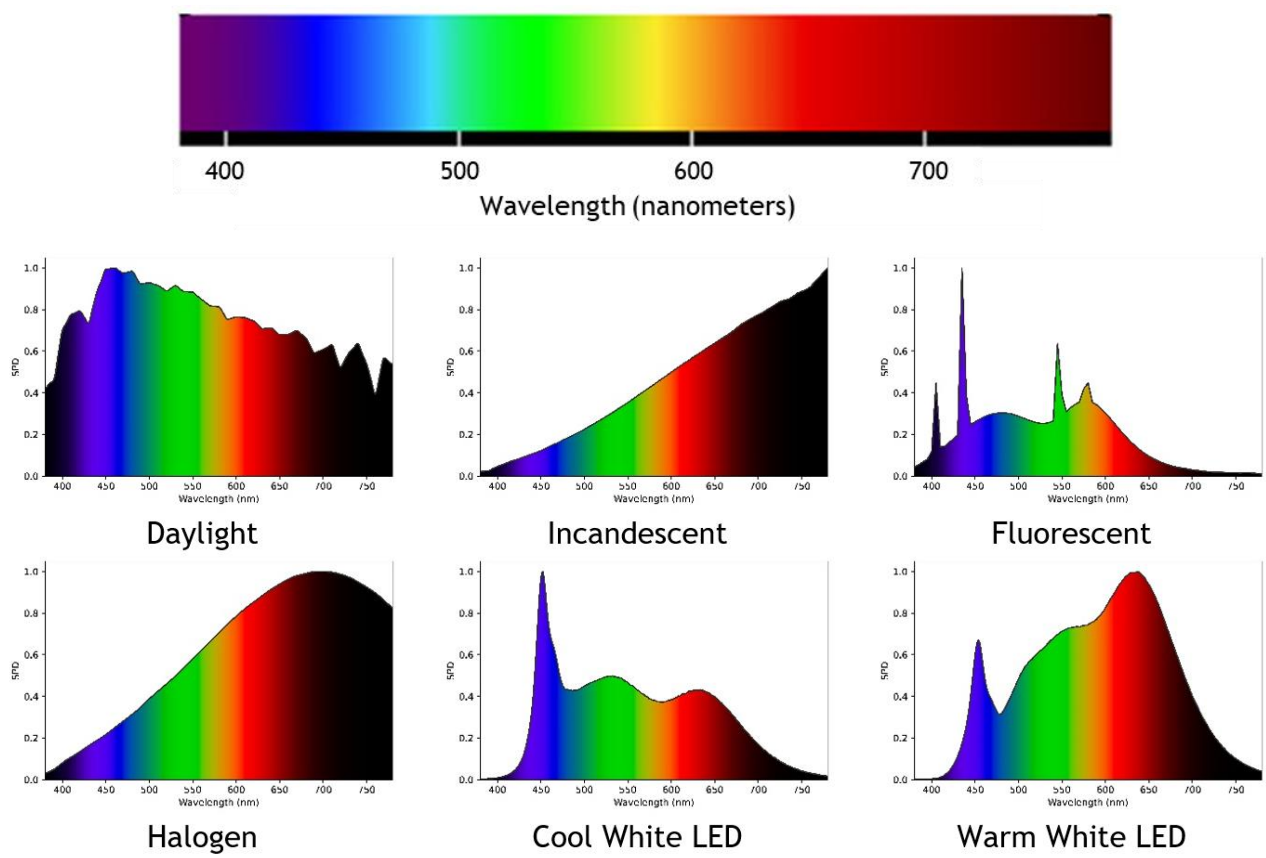

Figure 11 – The spectrum of light that is visible to humans from roughly 380-740 nm (top), and examples of the spectral power distribution (SPD) of different light sources, where the y-axis represents relative intensity of the light at each wavelength on the x-axis.

The color profile of a light source can have a profound impact on how objects and the environment are seen, therefore lighting designers must factor color as a consideration into lighting schemes. In the industry today there are two primary systems used to quantify lighting color characteristics for a given Correlated Color Temperature (CCT), the Color Rendering Index (CRI) and the TM-30 Standards.

CCT is a way to characterize the color appearance of any white light source with a single number. Artificial white light can be produced using combinations of all the colors in the visible spectrum. Different amounts of each wavelength will cause the light to appear “cooler” (more blue/cyan wavelengths) or “warmer” (more yellow/orange wavelengths).

The CRI was the first metric developed to characterize how colors appear under various light sources. It is the most well-known color rendering metric among both the scientific/engineering community and the broader lighting design and consumer markets. The core metric of CRI is measured on a scale where 100 indicates the most accurate color values. The R_a CRI value is based on a light source’s ability to render 8 standard test samples. There are now a total of 15 samples after additions to improve this system. One of these samples is “R9,” a deep red hue that is often used as a benchmark for assessing a source’s color rendition beyond the overall CRI R_a value. Table 2 lists a few of the recommended CRI ranges for some common types of high-luminance directional lighting use cases.

The ANSI/IES TM-30 Standards are an internationally accepted set of guidelines for characterizing the color rendition (color rendering) performance of virtually any light source. These standards were developed to encompass more aspects of light appearance, and to provide a more accurate measure of newer light sources such as LEDs. The TM-30 system uses 99 test color samples (grouped in bins) and evaluates two aspects of light source performance: Fidelity (Rf) and Gamut (Rg).

Different HLDL lighting applications can require a wide range of color characteristics, for example operating room light must illuminate human tissues as accurately as possible, while streetlights need to limit the amount of blue wavelengths so they don’t interfere with human and animal circadian cycles. To learn more about the science of color rendition, CCT measurement, the CRI, TM-30 and others systems used to characterize all facets of lighting color, and how to apply these systems effectively for different applications, refer to the White Paper: “Achieving Optimal Color Rendition with LEDs.”

Table 2– Recommended CRI Values for Directional Lighting Applications

HLDL Category	Typical Uses	Recommended CRI
Professional Portable Lights	Premium flashlights, bicycle lights, etc.	CRI >65, >80
High Flux LED Work Lights	12V/24V work lights, battery or solar operated	CRI >65, >70, >80
Automotive Auxiliary Lights	Aftermarket light bars for vehicles, field vehicle work lights	CRI >65, >70
Indoor Directional Lights	Wall washer, spotlight, track lights, miniature recessed light	CRI >80, >95
Outdoor and Roadway Lighting	Street lighting, sport field spot and flood lights, garage and canopy lights, round and square high bay and low bay lights	CRI >70, >80

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4.2 How LEDs Satisfy HLDL Criteria and Enhance Directional Lighting Performance

All of these desirable HLDL performance criteria can be satisfied effectively with LED products, in many cases more effectively than other traditional lighting technologies. For example, LED flashlights are more energy efficient and provide a significantly longer lifespan (50,000 hours) than incandescent (1,000 hours), halogen (2,000 hours), or xenon bulbs (10,000).[1] LEDs can be designed specifically to optimize their performance for HLDL applications by focusing on these five key attributes:

Five Critical Attributes for Directional Lighting

1. Small Light Emitting Surface (LES)
2. High flux
3. Small emitting angle
4. Low thermal resistance
5. High uniformity of color over angle.

When balanced correctly, these attributes will enable an HLDL source to deliver high performance. High flux per LED (#2) is necessary, but it doesn't always translate directly to performance in directional lighting. Performance also relies on secondary optics to shape the beam pattern to produce an end product with high intensity. What matters is not only flux, but flux per emitting area, called lumen density. A small source (an LED with a small LES (#1)) combined with high lumen density enables an HLDL to deliver high optical efficiency, high on-axis intensity, a narrow beam angle, and small optics as preferable for various applications. For example, emphasizing high intensity and a narrow beam angle will maximize beam throw distance.

Having a smaller emitting angle (#3) (smaller than a typical flip chip, as discussed in Section 6.1) is also important. The optical elements in a device collect the light coming from the source and focus it into the desired beam pattern. If the LED source is already emitting light in a smaller angle, the optics can more efficiently deliver the high intensity and small beam angle needed for HLDL. Thus, a combination of flux emitting area and emitting angle is what characterizes the best LED source. This combination has been defined as candela per lumen (cd/lm), K factor.* The K Factor tells us how much candela is converted by one-lumen flux from the LED source in the specific optics. When evaluating multiple LED sources (before the effect of any secondary optics), compare the K Factor of each LED. The higher the K Factor, the higher the intensity and efficiency and the narrower beam angle the LED will provide.

High flux (#2) is also beneficial in helping reduce the overall number of LEDs needed for an HLDL device. Fewer LEDs means smaller optics and a smaller heat sink. LEDs with low thermal resistance (#4) transfer the heat more efficiently to the heat sink so heat extraction can be optimized. LEDs with low thermal resistance (#4) need a smaller heat sink and offer easier thermal management, which then helps enhance system efficiency Finally, color uniformity over angle (#5) is important to ensure the quality of the beam and beam spot. Figure 12 illustrates how each of these LED design features translates into effective directional lighting characteristics.

* Or also called the "lens efficiency factor" as described in Section 3.

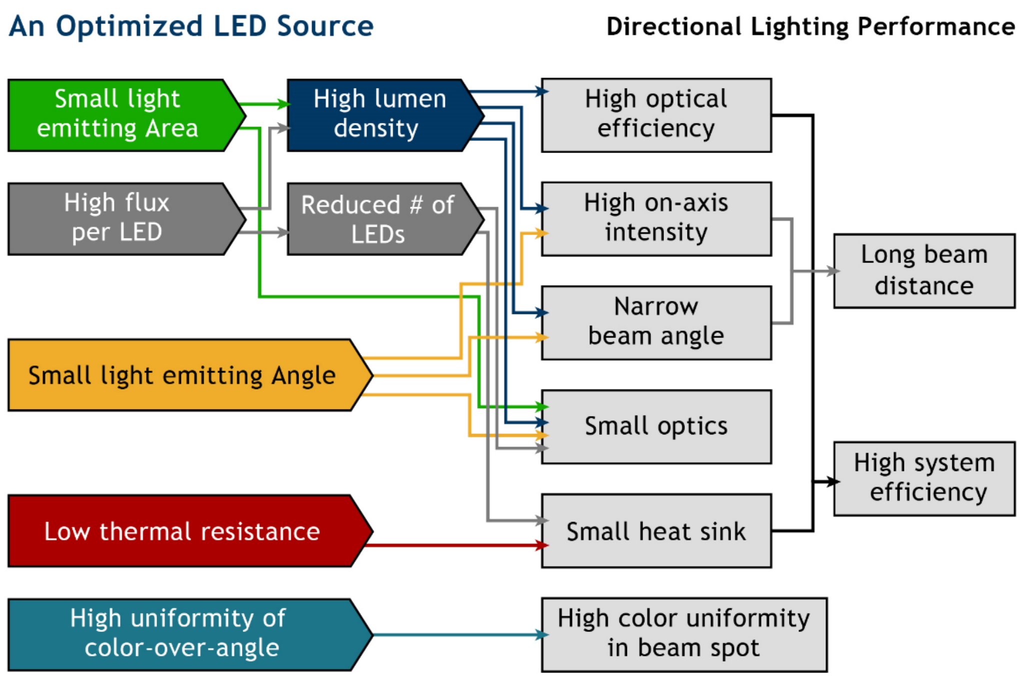


Figure 12 – LED source features that support good directional lighting performance, resulting in a high K Factor.

5.0 Optical Considerations for High-Luminance LEDs

To deliver all of the desirable performance characteristics for HLDL described in Section 4.2, LED manufacturers must consider all aspects of optical design such as LED geometry, lens geometry, secondary optics, and more. These considerations include:

- **Flat optics.** An LED designed with flat optical elements enhances the intensity and beam distance of the source, supporting optimal HLDL performance. Flat optics are discussed in Section 5.1, below.
- **Secondary optics.** Secondary optics collimate light to control the output pattern and help make the light more uniform. Secondary optics may include different formats such as reflectors, total Internal reflectors (TIRs), and lenses.*
- **Size.** Smaller LED chips provide improved performance for HLDL applications; this is discussed in detail in Section 5.2. Larger LED chips require secondary optics with a larger diameter to achieve the same beam angle as a smaller LED. This limits how compact the HLDL device can be and makes it unsuitable for many small form factor HLDL devices such as flashlights.
- **Shape.** Many LED chips are square. However, for the needs of HLDL applications, a round chip shape is better; this is discussed in detail below in Section 5.3.

Different optical designs are suitable for different applications, leading to a wide range of options on the market today, including custom designs for specific uses. For high performance applications, advanced optics are used to deliver critical beam pattern characteristics and high intensity light.

* For more information about lenses compatible with Luminus LEDs, refer to https://www.luminus.com/resource/ecosystem/optical

5.1 Advantages of Flat Optics

LEDs with a flat design are especially well suited for many directional lighting applications. A flat design means, simply that the profile of the LED chip is flat, thanks to the use of a flat window in place of a dome (as seen in Figure 13). The flat window provides a smaller light emitting area than the typical dome lens LED design. The observed emitting area is the refractive index of dome lens multiplied by the actual LED emitting area.

The flat design also means that lenses can be positioned close together, increasing the on-axis intensity of the source. The result is higher lumen density, higher optical efficiency with smaller optics, and an extended beam distance. In terms of the throw, a flat window yields a longer distance than a dome window package LED (refer to the comparison in Figure 13).

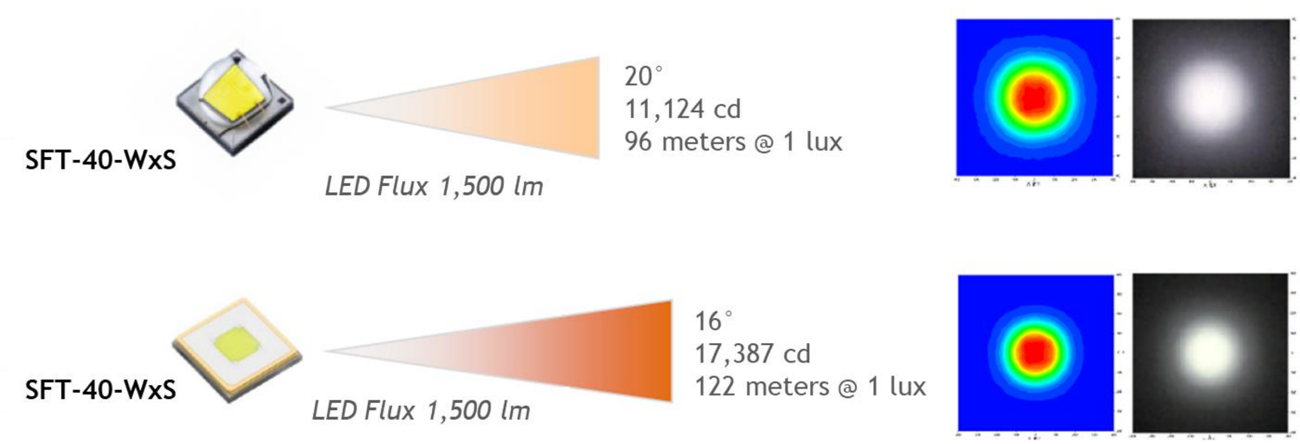


Figure 13 – Comparison of Luminus SST-40-WxS vertical chip with dome lens and Luminus SFT-40-WxS flat-window chip. Both products are designed for HLDL applications, but where beam distance is a key criterion, the SFT ("F" for flat) directs a beam 30 meters farther.

Another advantage of the flat-window LED design over domed is reduced color variation over angle, which is important for beam-quality. For example, refer to Figure 14, showing a graph of the angular performance of a domed LED (SST-40) designed for at CCT of 6500K. It actually reaches >7000K peak CCT at a 0° angle. As the beam angle increases, however, the CCT drops as low as 4750, a significant color difference of roughly 2300K from center to edge.

Compare this with the angular performance of the flat-window chip (SFT-40) in Figure 14, also designed for 6500K. The graph demonstrates a much smaller variation in angular performance—more uniform—between only 5500K to 6750K, a difference of only 1250K from center to edge.

A flat window design also affects the beam quality, improving spot uniformity, as shown in Figure 15 and Figure 16. The LEDs have reflectors roughly the same size and output, but the flat window design produces greater intensity (60% higher candela than the domed LED in Figure 15 and 5X more than in Figure 16), and a larger area of the beam spot is uniform.

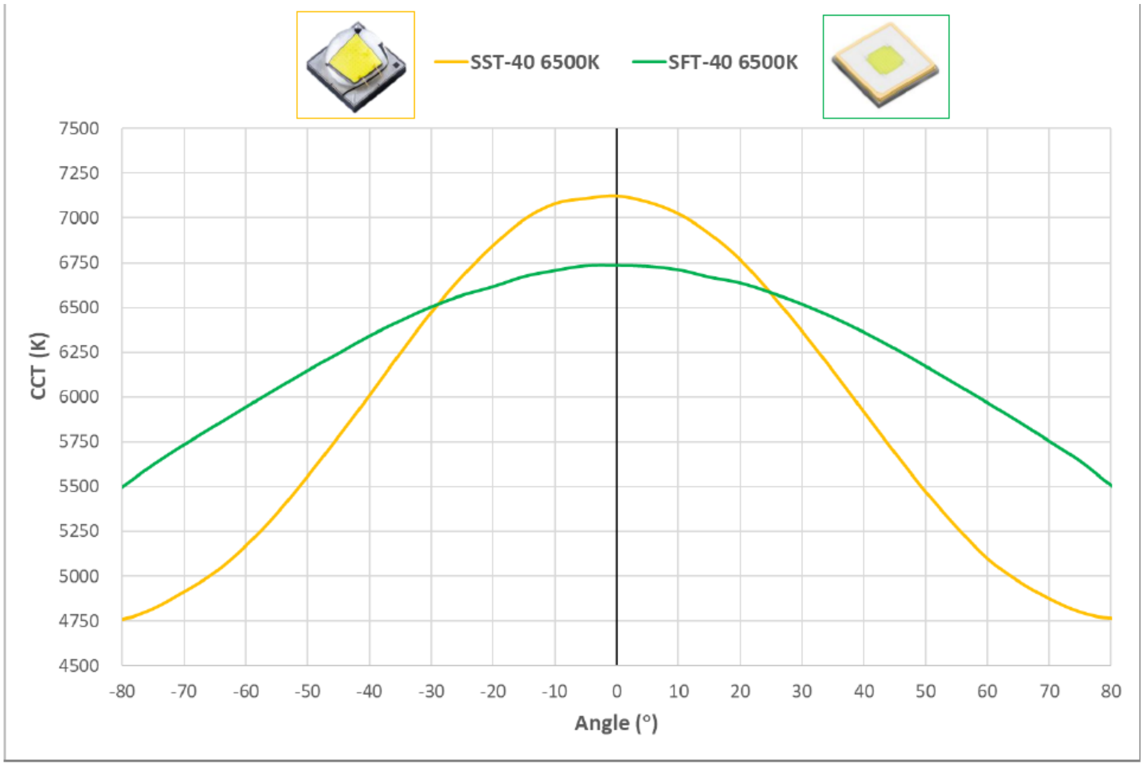


Figure 14 – CCT over angle comparing dome lens LED (SST-40 6500K) with flat window LED (SFT-40 6500) demonstrating superior color uniformity with a flat window design.

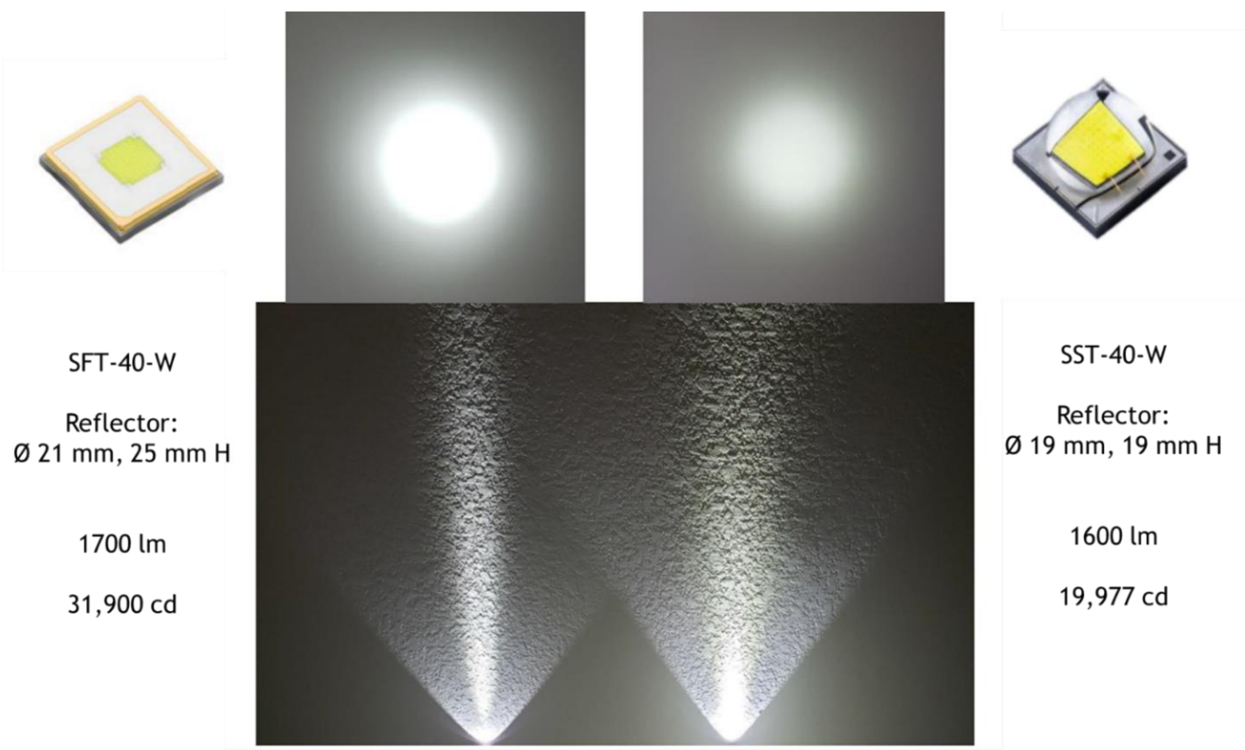


Figure 15 – The beam spot of the flat-window LED (SFT-40-W) is higher quality with a less spill light (a smaller halo ring) than the domed LED (SST-40-W). This means the spot is more uniform, and the uniform beam spot is also larger, and produces 1.6x candela.

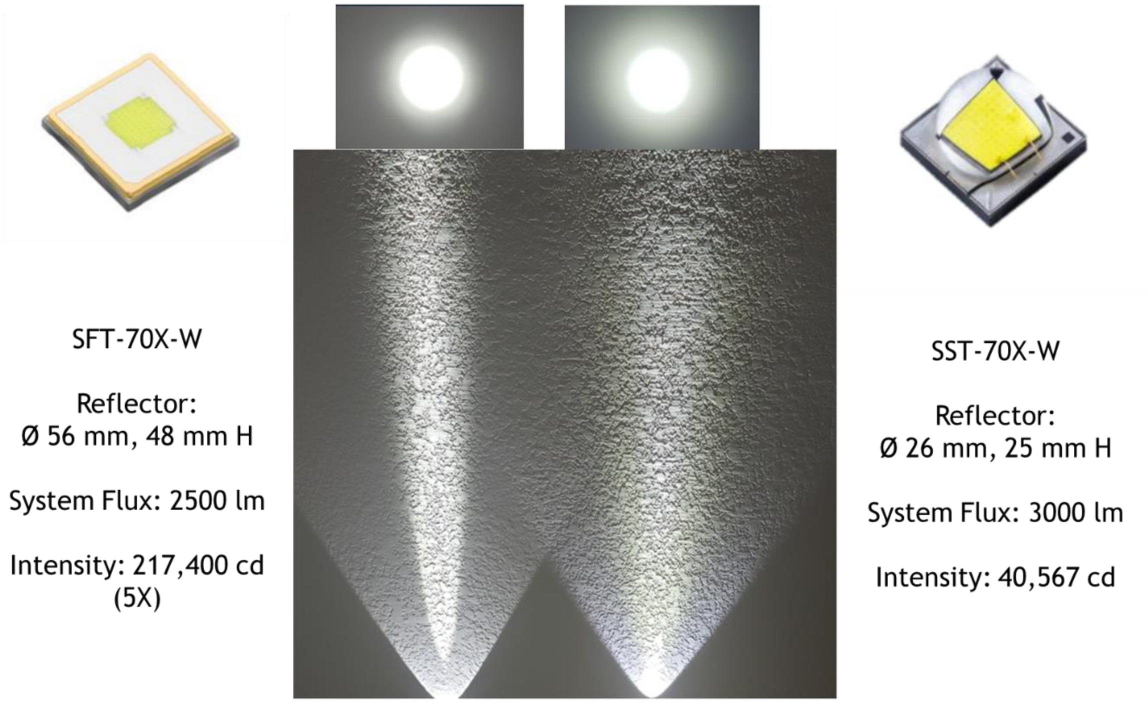


Figure 16 – As in Figure 15, the beam spot of the flat window LED (SFT-7X0-W, left) has less spill light than the domed LED (SST-70X-W, right) a larger spot size and more uniformity across the spot.

5.2 Advantages of Small LED Size

LEDs generally emit broad beams that require secondary optics to reshape the beam. For directional lighting, the optics convert a Lambertian-like light into a focused spotlight with a long throw distance. When designing the optical components, the first-order optics are typically based on an assumption that the lights are point-sources (ideal sources). However, LEDs are not dimensionless, and the off-axis light rays are hard to control resulting in spill light outside the intended beam area. Therefore, if the same secondary optics are used, a smaller emitting area is beneficial with higher ratio of on-axis power and higher center-beam candlepower (CBCP).

5.3. Advantages of High Center Beam Candle Power (CBCP)

As previously discussed, beam pattern is essential is directional lighting to ensure that light is shining precisely on the desired area, and with uniform brightness. Typically, a narrow beam pattern provides the intensity, distance, and high lumen output demanded for HLDL applications. An important measure of an effective directional lighting device is its Center Beam Candle Power (CBCP). Also called center-beam intensity or maximum candlepower, CBCP is a measure of the absolute output (lumen intensity) at the center of a beam (Table 3).

It is a better metric to determine and LED emitter's performance for HLDL than simply the number of lumens output. Recall from Section 3.0 that lumens measure luminous flux, which is the total amount of light emitted by a source in all angles. For directional lighting such as spotlights or downlights, any peripheral or diffuse light isn't relevant, only the light within a narrow angle of the beam. In fact, two different LEDs can have the same lumens, but different CBCP; the higher CBCP is the right choice for a directional application.

Luminus Pico COB LEDs provide very high CBCP within a very narrow beam angle for superior HLDL performance (Figure 17). In fact, a higher CBCP is available from the smaller (4 mm) LES—double the CBCP of the 6 mm LES.

Table 3 – High Center Beam Candle Power (CBCP) Comparison of Pico COB CXM Series*

COB	CBCP	Beam Angle	Flux (lumens) @250 mA in 3000K, 90 CRI
CXM-4 (4 mm)	36000 cd	~ 6 degrees	819 lumens
CXM-6 (6 mm)	18000 cd	~ 8 degrees	1064 lumens
CXM-9 (9 mm)	13000 cd	~ 11 degrees	1129 lumens

* Using 12W PAR 20 with a 62 mm diameter lens and the same driver

Figure 17 – Beam spots produced by Luminus Pico COB CXM-series LEDs. The smaller the source size (CXM-4, 4 mm), the smaller the beam angle and the higher the CBCP (brighter spot center).

The relative CBCP of these chips demonstrates an important concept. Customers who need high CBCP (or longer throw) from their lights may think they need a higher number of lumens from a COB. But in fact, there can be an inverse relationship between lumens and CBCP, as shown in Figure 17: the highest-lumen source (CXM-9) has the lowest CBCP. For HLDL, a smaller source size LED, such as the Pico COB CXM-4, is a more effective solution.

5.4 Advantages of Round Emitters

Most typical SMD* LEDs have a square die (except most COB LEDs). For HLDL applications, new round LEDs demonstrate superior performance and better light quality that standard square emitters, for several reasons. Typical HLDL applications need a round beam spot, which is created via the optical elements that essentially convert the light from a square emitter to a round beam.

If the emitter is round, then less optics are needed and it is easier to deliver high beam spot quality. The round emitter also provides higher on-axis intensity, beam distance, and higher optical efficiency, all with smaller optics (see Figure 18). On-axis intensity (K Factor) is more than 30% higher with the round emitter, which also produces a narrower beam angle (Table 4).

Another effect of using a round emitter is the quality of the beam spot. The beam spot of the square emitter (Figure 18,top) has a halo ring with a somewhat square shape, compared to the round emitter (Figure 18, bottom) which is perfectly round and has a smaller halo, meaning there is more illumination within the center beam spot.

* SMD = surface-mounted device.

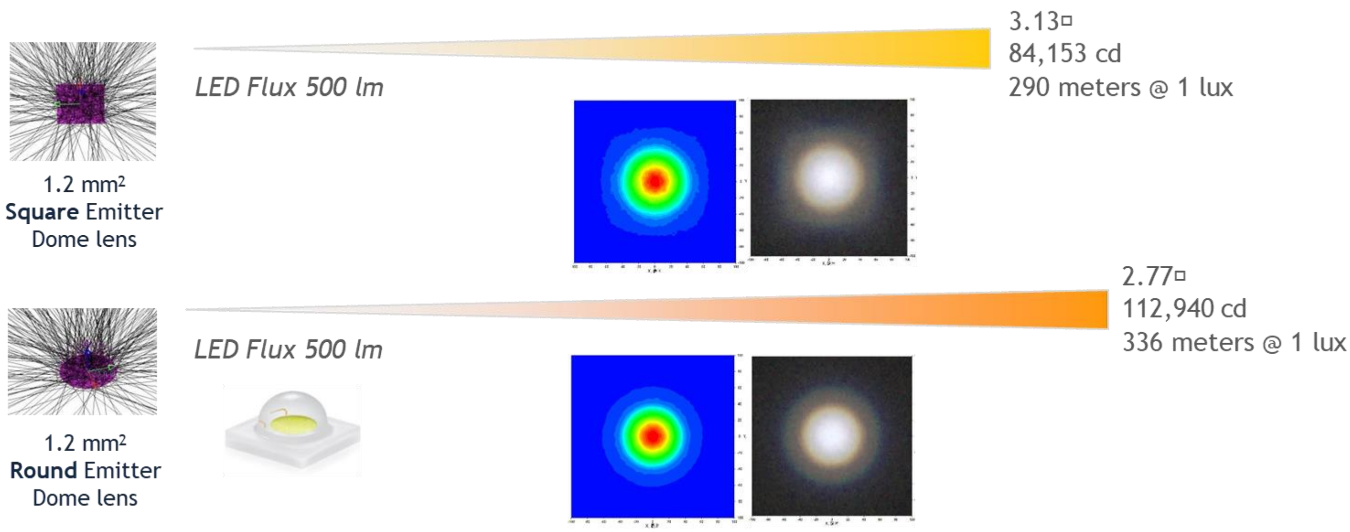


Figure 18 – Comparing LEDs with a square (top) and round (bottom) emitting surface using the same lens, the round emitter provides higher on-axis intensity, a longer throw distance, and more perfectly circular beam spot.

Table 4 –Comparison of LEDs with a square vs. round emitting surface shows K Factor performance improvement of 33% with the round LED.

1.2mm² Emitter Dome Lens	LED Flux (lm)	Output Flux (lm)	Optical Efficiency	Beam Angle (FWHM)	On-Axis Intensity (cd)	K Factor (cd/lm)	1-Lux Beam Distance (m)
Square	500	462	92.4%	3.13°	84,153	182.15	290
Round	500	466	93.2%	2.77°	112,940	242.36	336
		+0.87%	***+0.8%***	***-0.36°***	***+34%***	***+33%***	***+16%***

6.0 Technology Considerations for High-Luminance LEDs

Luminus LEDs offers design innovations that confer additional performance advantages for high-luminance directional applications, such as a vertical chip structure with both round and flat emitters (see Sections 6.1 and 6.2), using white phosphor technology (see Section 6.3), and a high-power ceramic package (see Section 6.4).

6.1 Advantages of Vertical Chip Design

A common LED chip mounting technology used in the market today is wireless* bonding, also called "flip chip" mounting because the active layer (electrical side) is facing down (flipped) while the transparent sapphire layer is facing up. The chip is attached directly to the substrate (e.g., ceramic). The flip-chip approach offers some advantages over earlier SMT (surface-mount technology) approach including better durability and light performance and lower thermal resistance. Thus, flip-chip technology has been widely adopted by many LED and lighting manufacturers.

But for HLDL applications, flip chips are not ideal. Instead, vertical chip technology from Luminus offers superior performance for directional lighting. An important difference between flip chip and vertical chip design is the light emitting plane (the p-n junction, shown as a red line in Figure 19). The whole emitting surface of a flip chip includes both the top and side walls of the chip (the phosphor layer shown in yellow in Figure 19). A vertical chip's only emitting surface is on the top of the chip, thus it has a narrower light emitting angle with more light on axis and higher on-axis intensity.

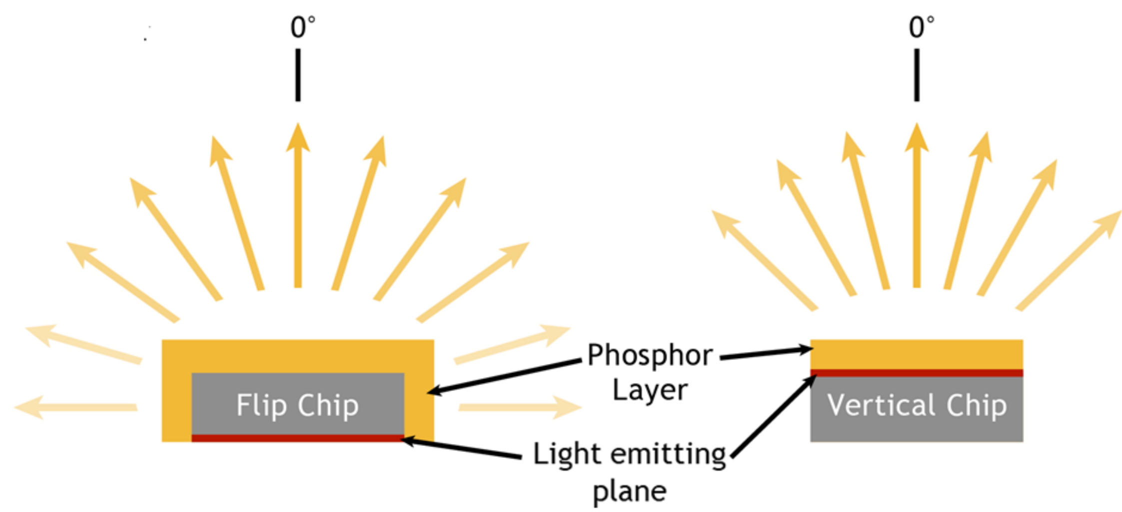


Figure 19 –Illustrating the flip chip vs. vertical chip LED structures, and the relatively narrower angle of light spread from the vertical chip design.

Light output from the sides of a flip chip reduces the performance of the LED for HLDL purposes. It also can degrade light color quality especially for white-light devices, as it tends to create a yellow ring.

The Luminus line of vertical LEDs uses a unique white phosphor technology (discussed in Section 6.3), which delivers high color uniformity for color-over-angle and keeps the emitting area as small as the chip itself. These factors further support the high lumen density needed for HLDL.

* Chip on board (COB) technology uses wire bonding: LED chips are electrically connected to a substrate with wires, in contrast to flip-chips where the electrical connections are bonded directly to the substrate.

The vertical die has lower thermal resistance and the vertical structure transfers heat more efficiently for better dissipation. Many standard flip-chip LEDs cannot support a high current density due to the limitations of horizontal current flow, but the vertical chip can tolerate a higher current intensity—a higher driving current. This means it can deliver higher flux per LED and higher lumen density, or “chip luminance” (the nits of the chip).

Benefits of Vertical Chip Technology for Directional Lighting

- Higher optical efficiency
- Higher on-axis intensity
- Narrower beam angle
- Smaller optics
- Fewer LEDs needed
- Uniform beam color and brightness

The smaller emitting area and narrower beam angle require smaller optics. The absence of side walls also results in better color-over-angle uniformity and on-axis intensity. All these characteristics are ideal for HLDL devices. A vertical chip design can also reduce the number of LED chips needed in a device due to its high flux per LED and the uniform beam color and brightness. Additionally, Luminus has implemented advanced packaging and chip technology to further optimize this product line for directional lighting, including a flat window package, multiple junctions per chip, and a round emitter.

A single vertical chip with multiple p-n junctions offers optical advantages including minimizing or eliminating dark lines in the beam spot and making it easier to collimate the LED light into very tight beam angles (Figure 20).Having multiple junctions per chip eliminates the extra wires required when using separate chips. The multi-junction chip allows the device to be run at a higher voltage, which makes it easier to match to a wider range of power supplies. The multi-junction chips give designers the option to run at low voltage or in series at higher voltages, making them a versatile option for a wide range of applications. For example, the Luminus SST-70X WxS chip is available in two versions with maximum drive current of either 5.25 A (6V) or 2.625 A (12V).

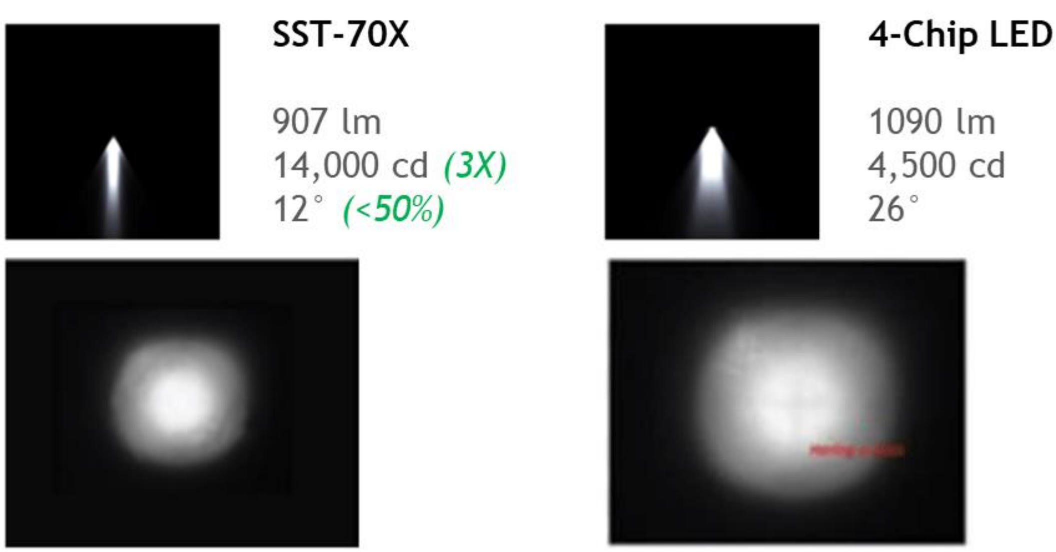
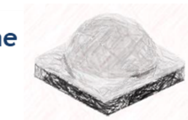
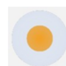


Figure 20 – Comparing the beam characteristics of the Luminus SST-70X multi-junction LED (left) with the beam from a typical 4-chip LED (right)

6.2 Combining Vertical Chip with Round Emitter Design

Section 5.4 described the benefits of round emitters for enhancing directional lighting, and Section 6.1 discussed the HLDL advantages of a vertical chip design. Combining these two features has an additive effect on performance. Table 5 compares vertical chip performance using a round emitter vs. a flip chip with square emitter for several optical configurations. Using the same optics with the same flux of 200 lumens, the vertical chip/round emitter (SST-12-WxH) provides a narrower beam angle, 57% higher on-axis intensity (cd), a higher K Factor (cd/lm), and 19 meters longer throw.

Table 5 – Comparison of square flip chip (3535) vs vertical round emitter chip (SST-12-WxH).

LED	**SST-12-WxH Vertical Chip**		**3535 dome** Flip Chip	
Chip Size	1.20 mm^2		0.93 mm^2	
Chip Shape	Round		Square	
Phosphor	on Chip		Spread	

Secondary Optics	Optics' Flux	LED	Beam Angle FWHM	K Factor (cd/lm)	On-Axis Intensity		1-Lux Beam Distance	
Carclo / 10003 (20 x 10 mm)	200 lm	SST-12-WxH	7.7°	29.8	5,960 cd	*+57%*	79 m	*+30%*
		Flip Chip 3535	11.7°	19	3,800 cd		60 m	
Carclo / 10138 (20 x 10 mm)	200 lm	SST-12-WxH	11.5°	14	2,800 cd	*+56%*	53 m	*+27%*
		Flip Chip 3535	14°	9	1,800 cd		42 m	
Carclo 10139 (20 x 10 mm)	200 lm	SST-12-WxH	23°	3.9	780 cd	*+15%*	28 m	*+11%*
		Flip Chip 3535	25°	3.4	680 cd		25 m	

6.3 Advantages of White Phosphor Technology

Most LEDs consist of a chip that emits blue light (approx. 440-470 nm) with a coating of yellow, green, and/or red phosphor to filter the light to the desired color appearance (e.g., white). In today's market there are primarily two types of phosphor application: on the chip itself or in the cavity of the chip package (Figure 21). On some high- and mid-power LEDs, the phosphor fills the cavity making the phosphor layer larger than the chip (as on the three LEDs on the right in Figure 21).

Figure 21 – Phosphor layer applied to the chip (left) vs. phosphor spread into the cavity of the LED as with typical flip chips.

Phosphor on the chip creates a smaller light-emitting surface favorable to HLDL. Luminus has taken this a step further and developed a unique white phosphor technology that creates an entirely uniform phosphor layer that keeps the emitting area as small as the chip itself. The phosphor layer does not need to cover the side walls, ensuring high color uniformity (color over angle) and uniform color across the light-emitting surface.

6.4. Advantages of High-Power Ceramic Package

Luminus SST and SFT vertical chip design also benefits from a high-power ceramic package (using the latest high-grade ceramic with high thermal conductivity) that enhances LED performance by supporting:

- High flux per LED
- Ultra-high lumen density
- Small light emitting surface
- Low thermal resistance
- Superior color uniformity
- Color over angle
- Color over emitting surface.

7.0 Selecting the Right LED for Your High-Performance Directional Lighting Applications

Luminus offers several product lines that are effective for high-luminance directional light applications. Depending on the specific requirements of your application, Luminus LEDs offer a range of potential benefits that enable customers to tailor a solution that achieves the optimal balance of intensity, beam angle, optical efficiency, optical design, thermal properties, and beam uniformity. All Luminus products provide high-quality performance. Every LED is tested at the factory to ensure reliability before shipping to customers.

7.1 Selecting LEDs for High-Luminance Directional Lighting

Luminus products address a broad array of indoor and outdoor lighting applications All of these chips offer good thermal performance. Detailed product specifications for each of the Luminus products for HLDL applications can be found on our website and in the product data sheets:

Key to Luminus Product Numbers

Each Luminus LED is numbered according to a standard nomenclature that provides information about the product specifications. For the SST/SFT high-power products:

- The first three letters are the product series (e.g., SST)
- The middle two numbers are the size of the emitter(e.g., SST-40 = 40 mm^2 die.
- In SST/SFT products, the middle letter “F” indicates a flat window design and “S” is a dome lens.

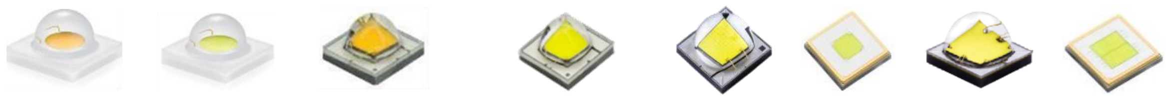
For the CXM Pico-COB and COB products: The first number after the dash is the size of the light emitting surface (e.g., CXM-3 = 3 mm diameter LES). Additional information about part nomenclature is on the data sheet for each product.

Luminus SST and SFT LEDs are high-power, high-luminance white LEDs used for a variety of directional lighting applications. They range from 5-50 watts with light output from 350 lumens up to 3,600 lumens.

The goal of this LED line is to focus on directional lighting applications, enabling our customers' LED investment to yield higher-performance directional lighting systems. The SST and SFT products are very small (e.g., most operate at just 3-4 volts), making them well suited to be used in multiples on a board with optics that blend their output to create high-powered HLDL devices.

All the vertical design chips are compared in Table 6, including those with domed (SST) and flat-window (SFT) emitting surfaces.

Table 6 – Luminus Vertical Design SST and SFT LEDs Comparison



	SST-12-W		SST-20-W				SST-40-W	SFT-40-W	SST-70X-W	SFT-70X-W
Package Size	3535		3535				5050	5050	5050	5050
Rth j	4.9°C/W		1.6°C/W				0.8°C/W	0.7°C/W	0.6°C/W	0.6°C/W
Voltage	3 V		3 V				3 V	3 V	6V / 12V	6V / 12V
Type	**WxH**	**WxS**	**WxH**	**WxF**	**WxE**	**WxS**	**WxS**	**WxS**	**WxS**	**WxS**
CRI	Min. 95	TYP. 70	Min. 95	Typ. 83	Typ. 73	Typ. 70	TYP. 70	TYP. 70	TYP. 70	TYP. 70
CCT	2700-4000K	5000-7500K	2700-4000K	2700-4000K	2700-6500K	5000-7500K	5000-7500K	5000-6500K	5000-6500K	5000-6500K
Max. Current	1.5 A	1.8 A	2 A	2 A	3 A	3 A	6 A	8 A	5.25 A (6V)	7 A (6V)
Max. Wattage	5 W	6 W	7 W	7 W	10 W	10 W	20 W	29 W	35 W	48 W
Max. Flux	350+ lm	600+ lm	500+ lm	700+ lm	1000+ lm	1000+ lm	1900+ lm	2200+ lm	3200+ lm	3600+ lm

The Pico-COB LEDs (CXM-3 and CXM-4) are the smallest products in the Luminus COB line. Along with the CXM-6 and CXM-9 LEDs (Table 7), this series of COBS can optimize HLDL devices that use a chip-on-board design.

Table 7 – Luminus CXM-3 and CXM-4 (Pico COBs), CXM-6 and CXM-9 COB LED Comparison

	Product Family	LES (mm)	Substrate Size (mm)	Power Range (W)	Flux Range @ 3000K 90CRI
	**CXM-3 (Pico-COB)**	3.5	13.5 * 13.5	2.75 - 7.7	290 - 600
	**CXM-4 (Pico-COB)**	4.5	13.5 * 13.5	4.0 - 15.7	440 - 1150
	**CXM-6**	6.3	13.5 * 13.5	5 - 17.1	700 - 1800
	**CXM-9**	9.8	13.5 * 13.5 (AC) 15 * 15 (AA)	12.1 - 41.9	1600 - 4300

With such a variety of power, performance, and color characteristics, Luminus offers an ideal LED for virtually any HLDL application. For an overview of all the directional lighting products (SST, SFT, and CXM) and a list of their typical applications, refer to Table 8.

Table 8 – SST, SFT, and PICO COB Application Summary

LED Product Line	Description	Color Metrics	Applications	Product Specs
SST Warm White	Dome LED to maximize the flux from the die.	CCT from 2700K - 4000K and 95+ CRI	Ideal for architectural directional light fixtures such as: ○ Wall washer ○ Track light ○ Spotlight ○ Miniature high-output recessed lights ○ Landscape spot and flood lights ○ Stage & studio lighting	Learn more
SST Cool White	Vertical chip with superior phosphor uniformity and high lumen density to increase optical efficiency and reduce optics size	High CCT (5000k - 7500k) CRI minimum 65, typically 70	Ideal for outdoor directional light applications such as: ○ Portable lights ○ Bicycle lights ○ Automotive auxiliary lights ○ LED work lights ○ Outdoor and roadway lighting ○ High bay industrial lighting	Learn more
SFT White	A flat window design to further reduce the emitting area and increase the lumen density for a higher lumen per dollar value	CCT from 5000K - 6500K. CRI minimum 65, typically 70	Ideal for applications requiring a longer beam distance and on-axis intensity such as: ○ Premium portable lights ○ Work and professional flashlights ○ High-performance flashlights ○ Bicycle lights ○ Automotive auxiliary lights ○ LED work lights ○ Directional light fixtures	Learn more
CXM Pico-COB	Small, high-performance LEDs that deliver high lumen efficacy. LES as small as 3.5 mm	High color quality for a full array of CCT/CRI options.	Operating at 18 or 36 volts, are easy to drive for applications that require an intense, narrow beam such as: ○ Retail/Hospitality/Commercial ○ Track/Spot/Bulb ○ Architectural/Museums/Exhibits ○ Roadway/Parking/Tunnel Lighting ○ High/Low Bay ○ Canopy/Awning/Wall Pack	Learn more
CXM COB	Small, high-performance LEDs with 6 mm and 9 mm LES	AccuWhite LED line, one of our highest-fidelity color rendering products, typically 97 CRI.	Very high thermal efficacy and lumen output suitable for: ○ Retail/Hospitality/Commercial ○ Track/Spot/Bulb ○ Architectural/Museums/Exhibits ○ Roadway/Parking/Tunnel Lighting ○ High/Low Bay ○ Canopy/Awning/Wall Pack	Learn more

7.2 LED Color Performance

Luminus LED provide excellent color performance with typically high CRI values indicating color fidelity, as discussed in Section 4.1. Their color rendition makes the SST series LEDs especially popular for high-performance indoor uses such as wall washers, spotlights, and miniature recessed lighting.

Their size and high CRI enable them to be used in small form factor devices to deliver a “punch” of light. For example, refer to the TM-30 report (Figure 22) for the SST-20 LEDs.

Part Number	CCT	DC Current	Rf	Rg	Rcs,h1	Rf,h1	Preference (P)	Vividness (V)	Fidelity (F)
SST-20-W27H	**2700K**	0.35 A	95	103	-2.0%	96	**P2**	**V-**	**F1**
		0.70 A	94	103	-2.0%	95			**F2**
SST-20-W30H	**3000K**	0.35 A	94	102	-2.0%	96	**P2**	**V-**	**F2**
		0.70 A	94	102	-2.0%	95			
SST-20-W35H	**3500K**	0.35 A	95	102	-1.0%	97	**P1**	**V-**	**F1**
		0.70 A	95	102	-1.0%	97			
SST-20-W40H	**4000K**	0.35 A	91	98	0.0%	93	**P1**	**V-**	**F2**
		0.70 A	93	99	-0.5%	94			

TM-30 was calculated with 2 samples’ SPD.

Design Intent
(The desired effect of color rendition on the illuminated environment)

Priority Level (The balance between allowing for tradeoffs and increasing the likelihood of meeting the design intent)	Preference (P)		Vividness (V)		Fidelity (F)	
1	P1	$R_f \geq 78$, $R_g \geq 95$, $-1\% \leq R_{cs,h1} \leq 15\%$	V1	$R_g \geq 118$, $R_{cs,h1} \geq 15\%$	F1	$R_f \geq 95$
2	P2	$R_f \geq 75$, $R_g \geq 92$, $-7\% \leq R_{cs,h1} \leq 19\%$	V2	$R_g \geq 110$, $R_{cs,h1} \geq 6\%$	F2	$R_f \geq 90$, $R_{f,h1} \geq 90$
3	P3	$R_f \geq 70$, $R_g \geq 89$, $-12\% \leq R_{cs,h1} \leq 23\%$	V3	$R_g \geq 100$, $R_{cs,h1} \geq 0\%$	F3	$R_f \geq 85$, $R_{f,h1} \geq 85$

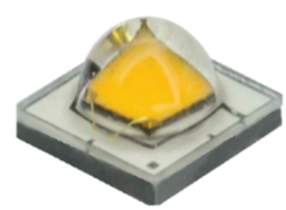


Figure 22 – TM-30-18 report for SST-20-WxH series LEDs.

8.0 Conclusion

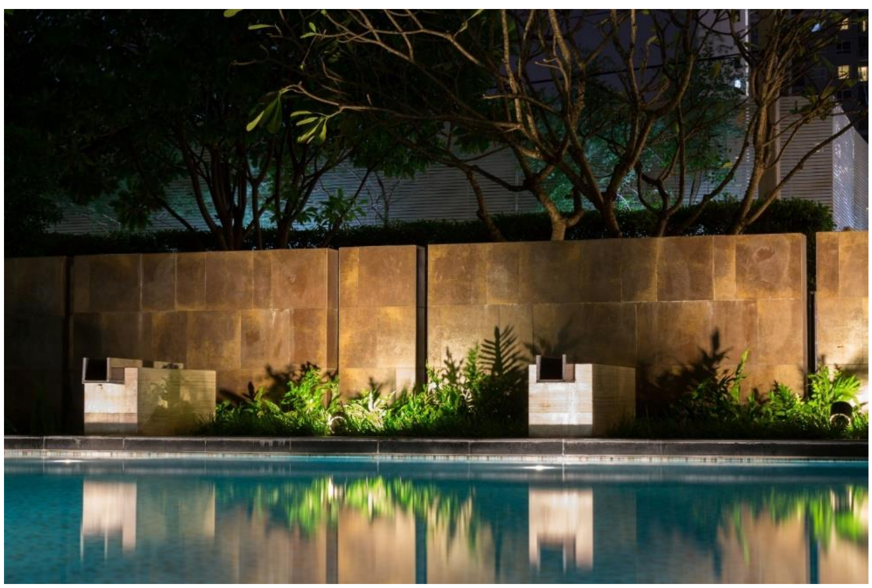
The performance requirements for HLDL applications typically include:

- High lumen density
- High K Factor (cd/lm)
- Superior color over angle uniformity
- High on-axis intensity
- Tight beam angle
- High beam-spot quality
- Energy efficiency

LEDs are well suited to meet these requirements due to their brightness, power efficiency, and the range of optical and color parameters they can be designed to meet. Luminus provides several LED product lines that not only meet the essential parameters of high-luminance directional lighting applications, but that enable lighting engineers to optimize. Design innovations such as our vertical chip and phosphor-on-chip technologies, flat-window and round emitter chips provide superior performance for a wide range of HLDL uses.

Talk to a Luminus specialist about your directional lighting needs today!

Phone | +1 408-429-2774
Email | sales@luminus.com



9.0 Resources

For additional information, we recommend the following resources:

About High-Luminance Directional Lighting

- Collins, M., "Choosing an Optimized High Intensity White LED for High-Performance Directional Lighting." LEDs Magazine Webinar, December 1, 2022. https://www.ledsmagazine.com/home/webinar/14285757/choosing-an-optimized-high-intensity-white-led-for-highperformance-directional-lighting

About Luminus Products

- **Luminus Product Datasheets:** on website https://www.luminus.com/products/white
- **Optical and Mechanical Design Files**: on website https://www.luminus.com/products/white
- **ECO Systems** – Optics, Starboard samples, etc.: on website https://www.luminus.com/resource/ecosystem/search#searchResult
- **LM-80 Test Reports** – request through Luminus Sales: sales@luminus.com
- **TM-21 Calculators** – request through Luminus Sales: sales@luminus.com
- **TM-30 Color Rendering Reports -** request through Luminus Sales: sales@luminus.com

In-Depth Information About LED Design & Performance, Applications, Safety, and More

- **Luminus Application Notes, Product Briefs, White Papers, and FAQ**: https://luminusdevices.zendesk.com/hc/en-us

Questions

For assistance with your high-luminance directional lighting design and engineering questions, please contact:

- **Application Engineering Support**: techsupport@luminus.com

11. References

[1] "LED Versus: Incandescent, Halogen, and Xenon – The Big Bulb Guide," STKR Concepts, STKRconcepts.com, December 2, 2020.

[2] Setchell, J., "Chapter 4: Colour description and communication," pages 99-129 in *Colour Design (Second Edition)*, Janet Best (Ed.), Woodhead Publishing, 2012. DOI: 10.1016/B978-0-08-101270-3.00004-7

[3] Jory, T. and Zhai, J., "Retail abandons CMH lamps in favor of flexible solid-state lighting," LEDs Magazine, June 9, 2016. https://www.ledsmagazine.com/architectural-lighting/retail-hospitality/article/16696094/retail-abandons-cmh-lamps-in-favor-of-flexible-solidstate-lighting-magazine

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