

Cree® XLamp® XB-D and XT-E LED Optical Design Considerations

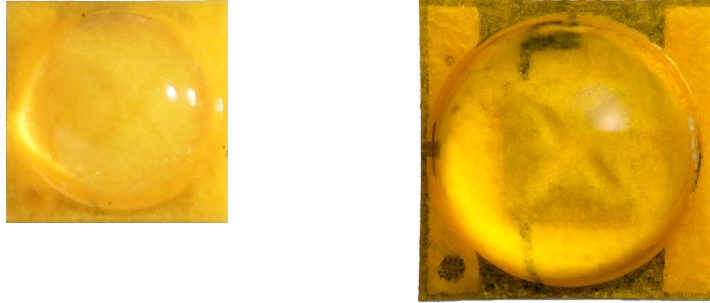


Figure 1: Cree XLamp XB-D (left) and XT-E (right) Direct Attach™ LEDs

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INTRODUCTION

Cree XLamp® XB-D and XT-E LEDs are built with the latest Cree SC³ Technology™ Platform. At the core of the SC³ Technology Platform is Cree's latest generation of silicon carbide based Direct Attach (DA) LED chips that deliver the highest flux and efficacy and industry-best reliability.

Cree's DA LEDs are solid-state LED emitters, combining highly efficient indium gallium nitride (InGaN) materials with Cree's proprietary device technology and silicon carbide (SiC) substrates to deliver superior value for the general-illumination market.

Though the XLamp XB-D and XT-E DA LEDs offer superior performance, they can also present optical design challenges. This application note describes these challenges and explains methods to effectively overcome them.

Figure 2 is a conceptual drawing of a side view of a DA chip showing the various composition layers. Combining gallium nitride (GaN) with a substrate is not uncommon. The noteworthy aspect is Cree's use of silicon carbide (SiC) as the substrate.

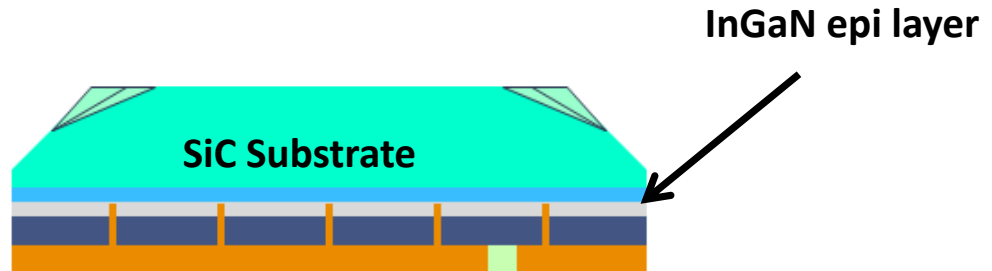


Figure 2: Drawing of side view of DA chip

As shown in Figure 3, compared to a sapphire substrate, a silicon carbide substrate creates fewer dislocations. Each dislocation becomes a microscopic dark spot on the chip surface. Fewer dislocations means fewer dark spots, more light, higher lumen values, and therefore higher efficacy (lumens/watt). This is why Cree builds chips on SiC and why Cree continues to lead the industry in LED performance. Silicon carbide also has better index matching of GaN to the substrate and results in more light extraction. These advantages combine to give a DA chip LED a 5 to 10% efficacy advantage over chips with a sapphire substrate. Another advantage is fewer epi defects, producing LEDs that are more reliable. Figure 3 is a simplified 2-D diagram showing the lattice mismatch between GaN on SiC and GaN on sapphire.

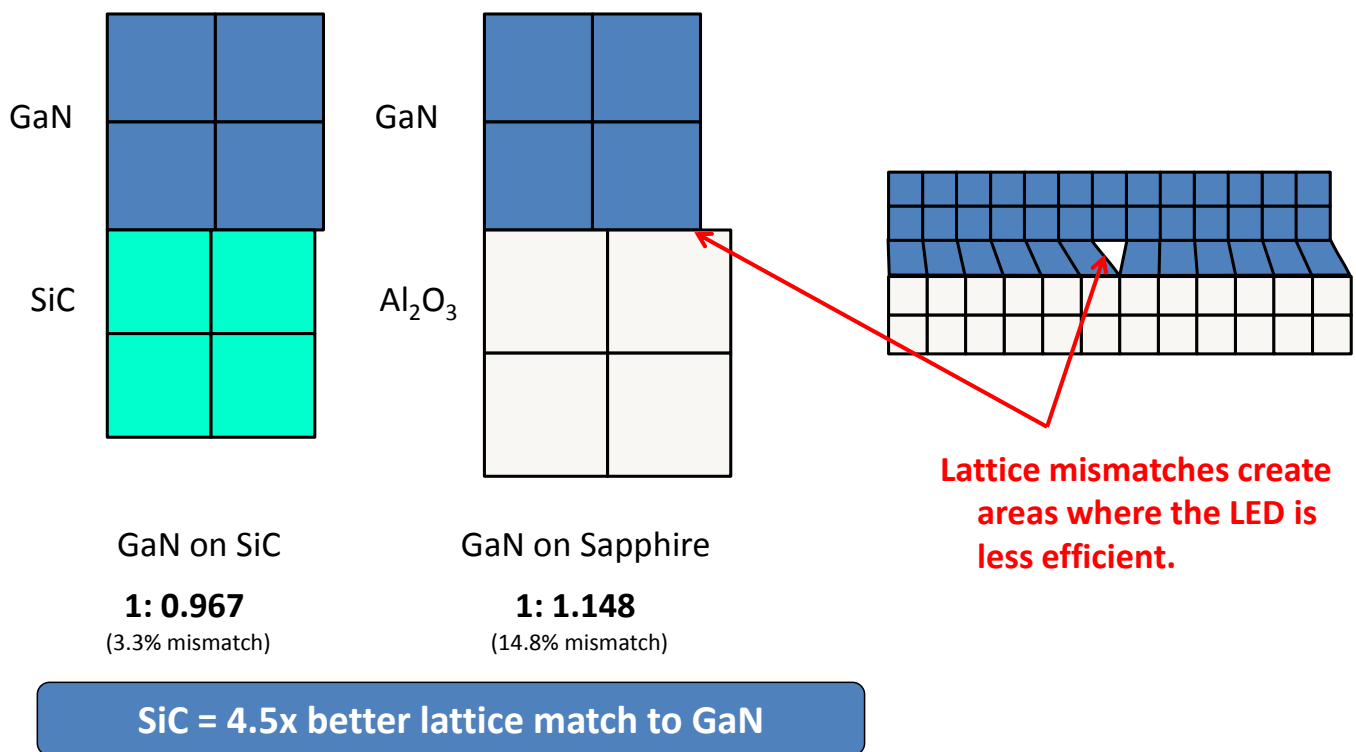


Figure 3: Lattice mismatch comparison

The DA chip architecture delivers the best combination of light extraction, robustness, reliable design and manufacturability.

XLAMP® XB-D AND XT-E LED OPTICAL MODELS

Cree XLamp XB-D and XT-E white LEDs are based on DA chip technology. With the unique structure of a DA chip, the optical models of XLamp XB-D and XT-E LEDs have some special optical characteristics.

Figure 4 is a view of a DA chip. To maximize light extraction, the top of the chip has a bevel-cut surface that may pose challenges for LED secondary optics design.

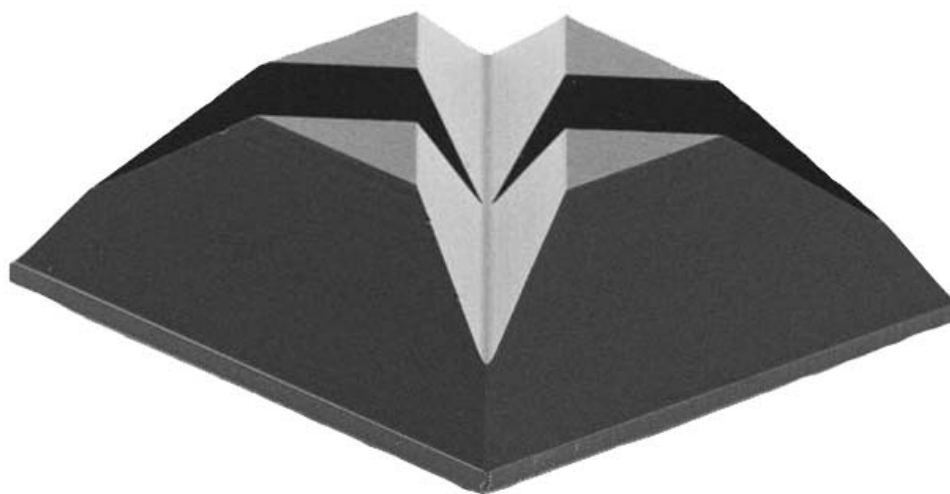


Figure 4: Perspective view of DA chip

The XLamp XB-D and XT-E LEDs have a Lambertian beam pattern. Figure 5 and Figure 6 show typical XLamp XB-D and XT-E LED far field spatial distribution curves. Compared to typical XP LEDs (with the EZ chip), there is more light at a wide angle for the XLamp XB-D and XT-E LEDs. This can be attributed to the bevel cut on the top surface of the LED chip.

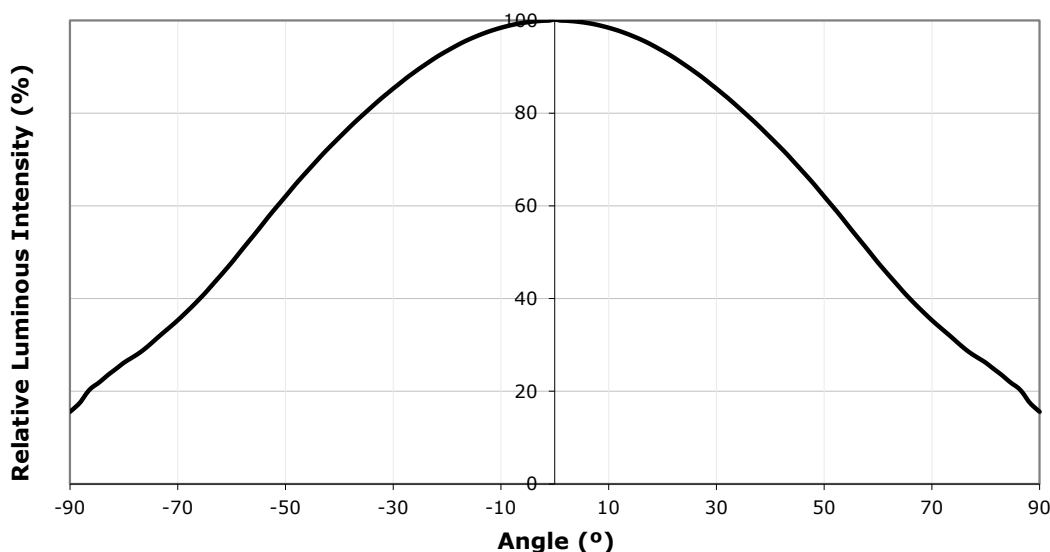


Figure 5: XLamp XB-D LED spatial distribution

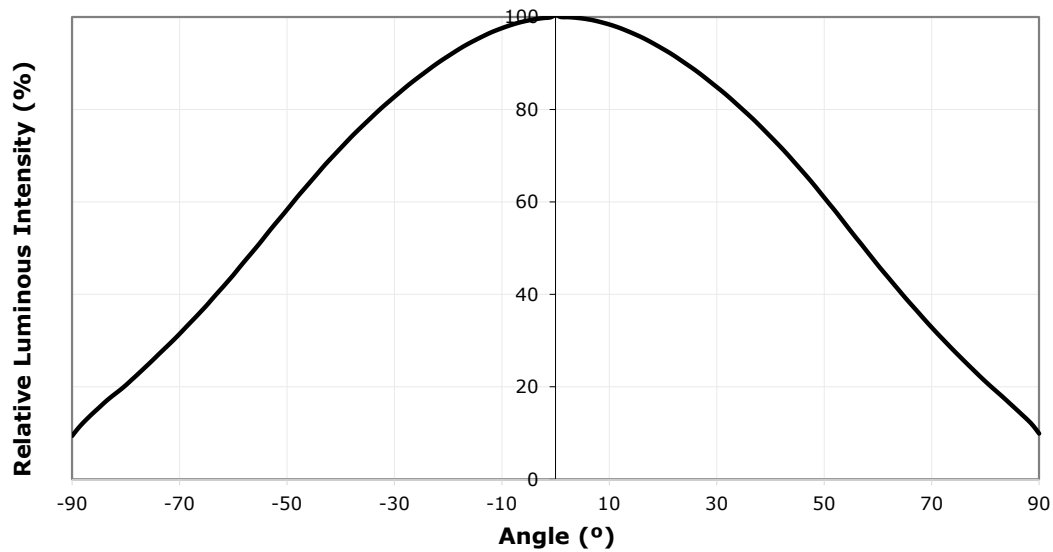


Figure 6: XLamp XT-E LED spatial distribution

The phosphor deposition process is different on DA chip based white LEDs than on previous-generation EZ LEDs. Due to the special chip cut on DA chip LEDs, phosphor is deposited on the bevel cuts on top of the SiC.

Although EZ chip based white LEDs and DA chip based white LEDs are both blue LEDs with phosphor, they present different optical design challenges. For EZ chip based XP products, the blue light and yellow light are emitted from nearly the same surface, however a DA chip based white LED acts like a small-scale remote-phosphor emitter. For DA chip based products, the blue light is emitted from the InGaN epi layer and the yellow light is emitted from the top of the bevel cuts on the top surface of the DA chip. This poses an optical design challenge to design very narrow beam optics that produce a uniform beam pattern in both intensity and color. Figures 7 and 8 illustrate of how light emanates from both XLamp XP (EZ chip) and XLamp XB-D and XT-E (DA chip) LEDs.

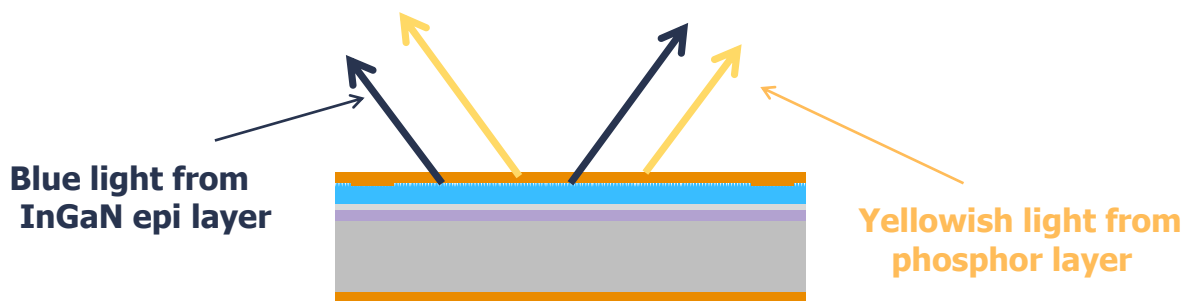


Figure 7: Light from EZ chip based XP LED

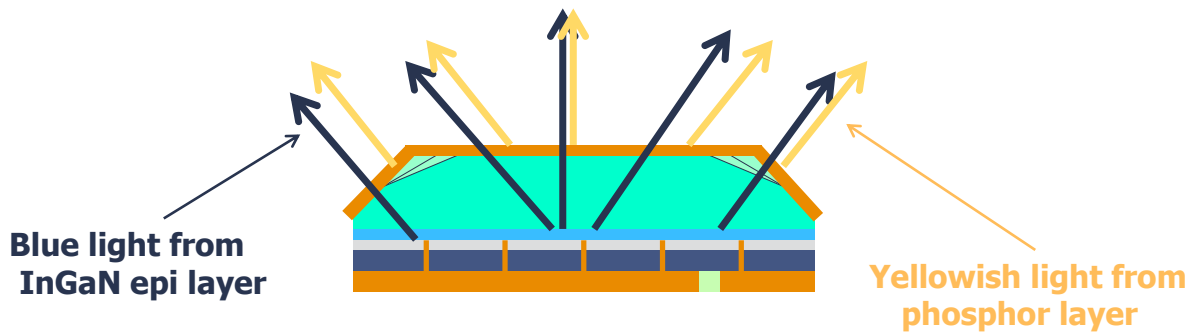


Figure 8: Light from DA chip based XLamp XB-D and XT-E LEDs

To improve light extraction, there are bevel cuts on the top surface of a DA chip LED. These make the phosphor thickness across the chip not so uniform. Figure 9 shows a near field view of the XT-E LED when lighted. Note the yellow color crossing at the center of the view. This indicates that there is a thicker phosphor layer on the crossing.

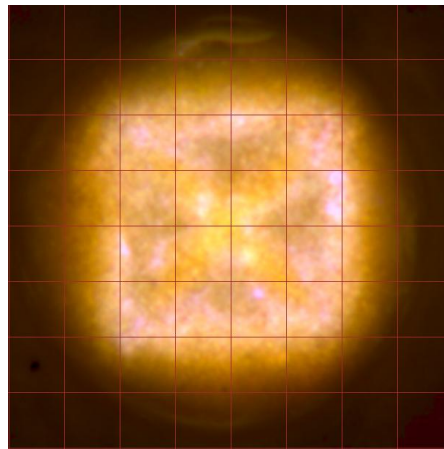


Figure 9: Near-field view of DA white chip LED

For optical design purposes, Cree uses Radiant Imaging [Source Imaging Goniometers](#) (SIG) to create LED Radiant Source Model™ (RSM) data files. The SIG system captures a precise model of a light source's near-field output. The image data and RSM file generated from it provide a complete characterization of the light source output that can be used for design evaluation and imported into any major optical design package to allow accurate design of LED optical systems.

In addition, ray set files containing an arbitrary number of rays can be generated by ProSource® Software for export to other optical and illumination system design software packages such as ASAP, FRED, LightTools, LucidShape, TracePro, Zemax etc. All Cree XLamp LED RSM files, LED 3-D models and basic ray set files (up to 1 million rays) are available from the Cree website.¹

The XLamp LED Photopia source model is available directly from LTI Optics. XLamp XB-D and XT-E LED Photopia models are available directly from [LTI](#).

¹ At the [Cree website](#), select the LED of interest, then the Documentation tab. The files can be found under the Design Files heading.

LED SECONDARY OPTICS

If an LED light pattern does not fit a particular application, secondary optics are needed to change the light pattern from the LED. Secondary optics are used to modify the output beam of the LED such that the output beam of the finished lamp efficiently meets the desired photometric specification. To direct light onto a target, it is necessary to use secondary optics to collimate the light into a controlled beam illuminating the targeted area. Collimated light rays propagate in parallel, although perfect collimation is not possible due to diffraction and the finite size of the emitter. However, the smaller the light source, the more effective the collimating optics can be. Besides collimating light, secondary optics can also be designed to improve color uniformity and light distribution within the target area.

The basic functions of LED secondary optics are:

- Collimating - Maximizing the amount of light applied to the target, as in a flashlight or spotlight.
- Diverging or diffusing - Spreading light in a wide pattern or hiding/obscuring LED point sources, as in a linear light or LED lamp.
- Illuminating - Controlling the distribution of light, usually spreading it evenly over some areas and blocking it from others, as in a street light or area light.

LED secondary optics include lenses/reflectors generally held in place by a holder. Figure 10 shows a typical example of an LED with a secondary optical system.

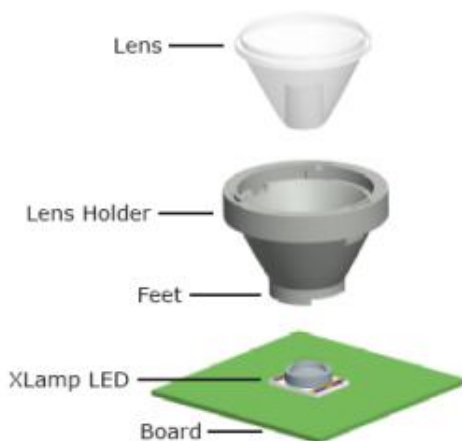


Figure 10: Typical LED secondary optical system

LED secondary optics can be categorized as being one of the following.

- Reflector, specular or diffused
- Lens
- Combination of lens and reflector, such as a total internal reflection (TIR) lens
- Diffuser

Each optics style manages light differently and has associated manufacturing techniques and costs.

Figure 11 is an example of a typical LED reflector.

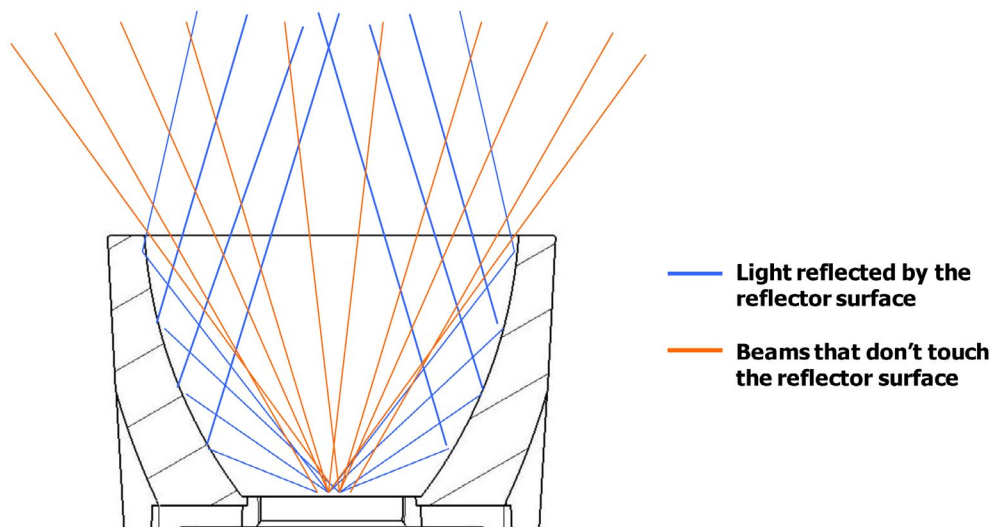


Figure 11: Typical LED reflector (picture courtesy of [LediL](#))

The parabolic reflector has proven over many years to be very efficient at directing the light from a light source. The reflector is relatively easy to make and costs less than a traditional lens. However there are some disadvantages to reflector optics. A reflector has only one surface to control light beams and a large amount of the light originating from the center of the emitter passes out of the system without ever touching the reflector surface. The beams hitting the reflector surface are controlled and collimated. The center light beams do not touch the reflector surface and are not controlled; this light is called spillover.

Conversely, as shown in Figure 12, the traditional lens system can control the center light beams very well but may not control some high-angle light due to the size of the lens.

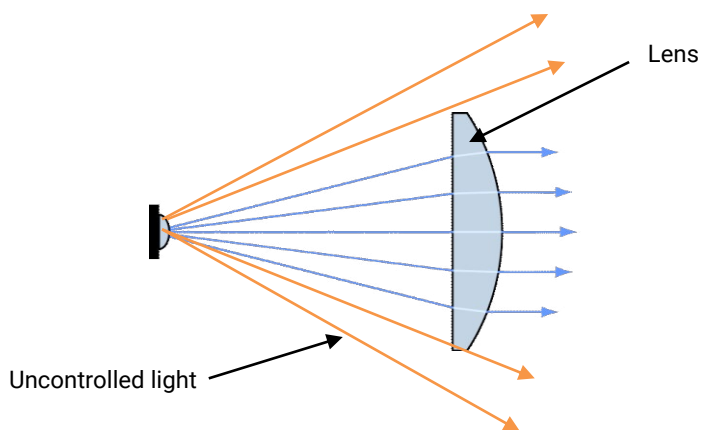


Figure 12: Traditional lens system

BASICS OF TIR OPTICS

A TIR lens is a secondary optic element that combines the best of both a reflector and a lens. A TIR lens:

- Can manage both direct and reflected light
- Causes light to travel through at least 2 surfaces (often more), before leaving the system
- Can be efficient even if the lens size is small (efficiency will be limited by the source emitting size also)
- Is relatively expensive compared to a reflector.

Figure 13 is a diagram showing light emanating from a typical TIR lens.

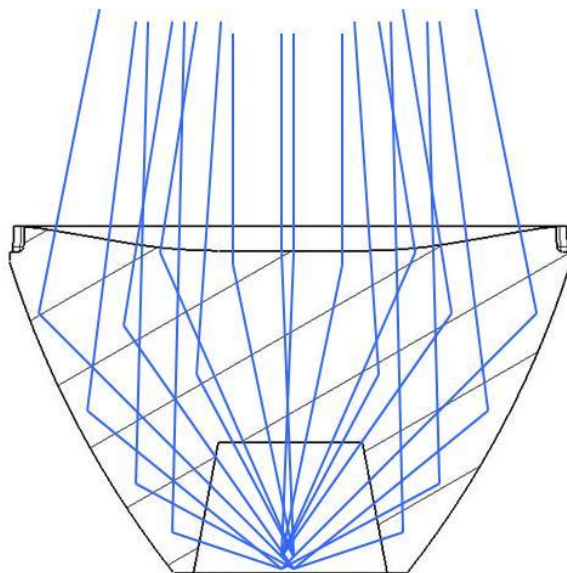


Figure 13: Typical TIR Lens

The diagrams in Figure 14 show that a TIR lens contains a TIR surface part and a refractive lens part. The lens part is made up of entrance and exit surfaces. This part manages the light from the center parts of the LED beam. The TIR surface acts as a reflector and the resulting beam angle depends on the curvature of the TIR surface.

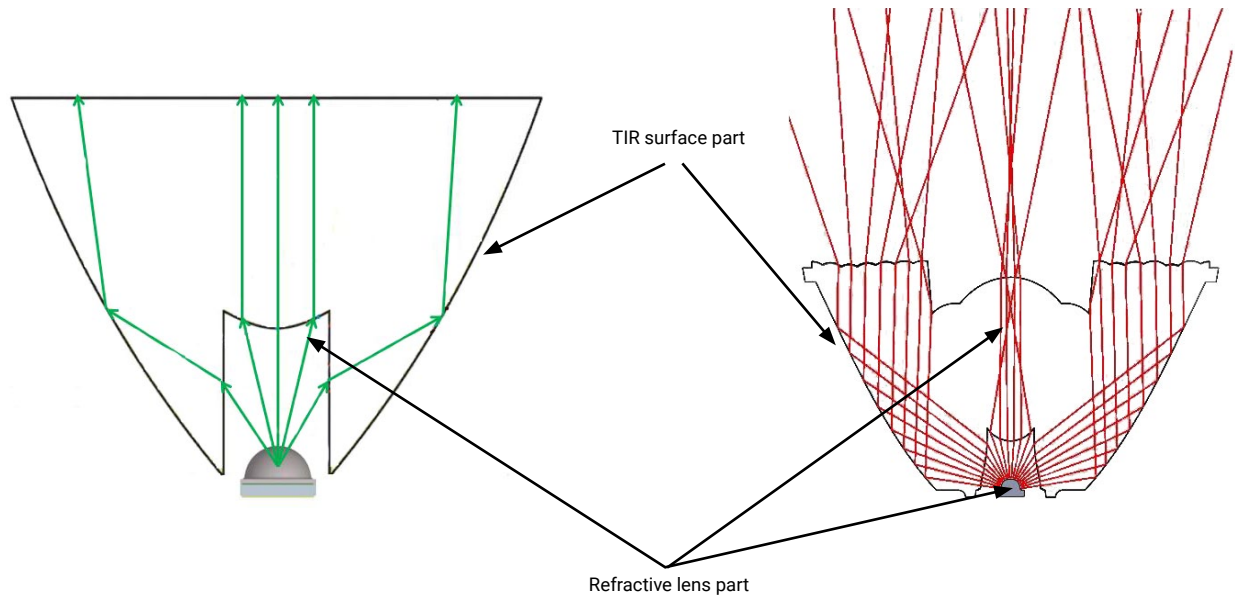


Figure 14: Illustration of TIR lens structure with LED package

Lenses can capture and concentrate light, but they also can magnify the effect of imperfections or irregularities in an LED when the beam angle is narrow. This is also true when a lens is used to collimate the light from DA chip based LEDs.

TECHNIQUES TO DESIGN GOOD OPTICS FOR XLAMP® XB-D AND XT-E LEDs

As mentioned for DA chip based XLamp XB-D and XT-E LEDs, the optical source acts as a small-scale remote phosphor emitter. Some special color mixing is needed to generate a good, uniform narrow beam. For a TIR lens, there are several ways to mix color. One way is to add diffuser textures to the top of the lens. When diffusion/texture is applied on the lens surface, the amount of diffusion must be balanced with light loss. Too much diffusion causes the finished beam angle to be too wide and have too much loss. Conversely, too little diffusion does not mix color well, resulting in a non-uniform beam.

Figures 15 and 16 are pictures of typical top lens diffusion and texture.



Figure 15: Smooth diffusing
(example courtesy of [LediL](#))



Figure 16: Small detail texture features
on the lens surface
(example courtesy of [Gaggione](#))

Another way to mix color is to add diffusing features on the refractive lens part of the TIR lens, as shown in Figure 17.



Diffusing feature
on lens part

Figure 17: Diffusing on TIR lens
(example courtesy of [Illumination Machines](#))

Another color-mixing option is to add diffusing features on the TIR surface. Figure 18 shows an example.



Figure 18: Faceted TIR surface
(example courtesy of Ledlink Optics)

In addition to adding diffusing features on different lens surfaces, optical software can be used to design TIR surface curvatures that match the different angles of the color rays from the LED and make the final beam more uniform.

REAL PRODUCT EXAMPLES

Using these color mixing technologies and modern lens design tools, many optical companies have already developed very good TIR optics for Cree XLamp XB-D and XT-E LEDs. Following are three examples. Performance data was provided by the optical companies.

Example 1: From Illumination Machines

This 12° TIR optic, designed for the XLamp XT-E LED, produced a very uniform 12° full-width half-maximum (FWHM) beam and achieved 12.5 cd/lm and 89% overall efficiency.



Figure 19: Example 1 TIR optic



Figure 20: Field illuminance image

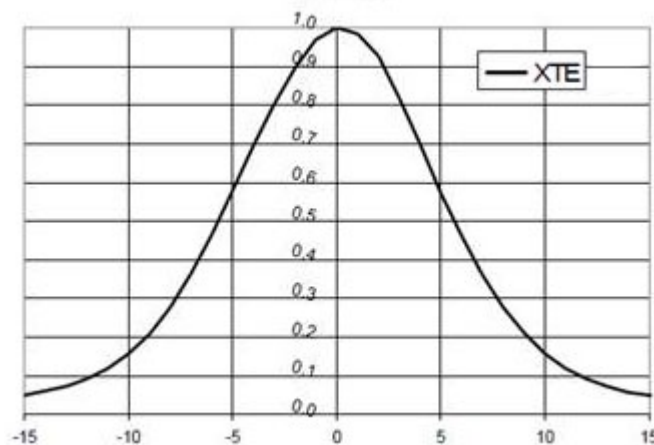


Figure 21: Beam relative intensity distribution

Example 2: From [LedLink Optics](#)

This 20-mm TIR optic, designed for the XLamp XT-E LED, produced a 14° beam angle (FWHM) and a 29° field angle with uniform color and achieved 8.3 cd/Im.²



Figure 22: Example 2 TIR optic

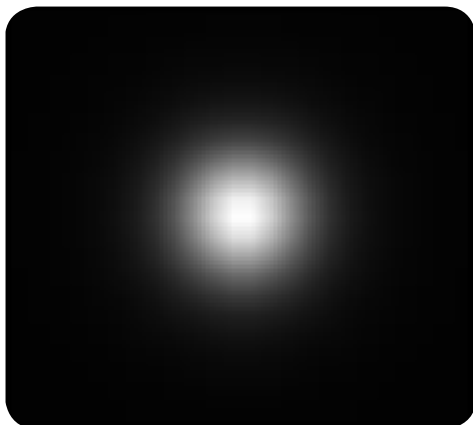


Figure 23: Field illuminance image

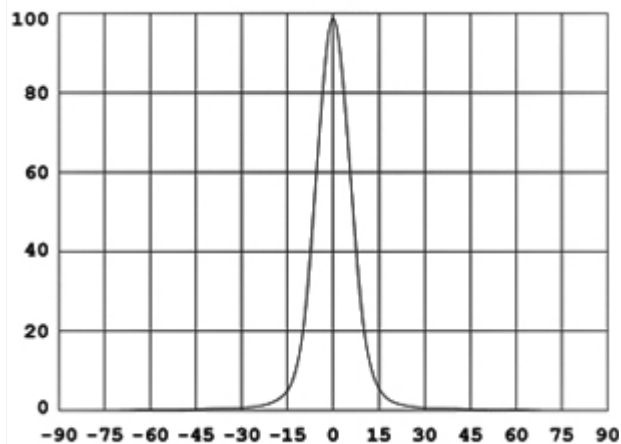


Figure 24: Beam relative intensity distribution

Example 3: From [Gaggione](#)

Cree has used Lednlight optics for our XLamp XB-D and XT-E LEDs. This 16-mm TIR optic for the XLamp XB-D LED produced a 20° x 30° elliptical beam with 3.2 cd/lm.³

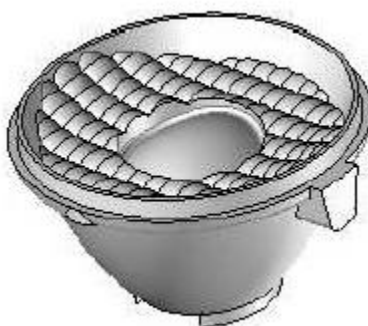


Figure 25: Example 3 TIR optic



Figure 26: Field illuminance image

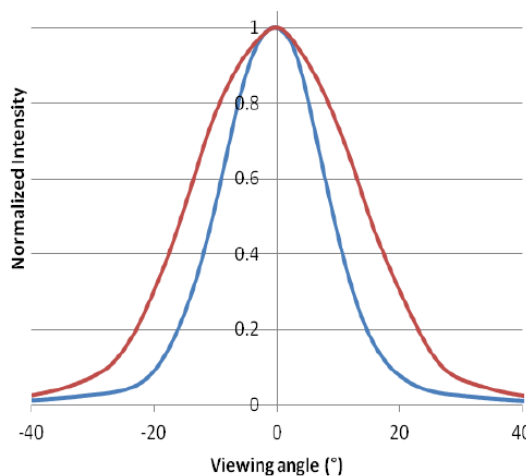


Figure 27: Beam relative intensity distribution

Cree has an extensive optical solution provider network. All members of the network get early LED samples and optical modeling information. They have developed numerous kinds of optics to meet different custom application needs and most have already developed XLamp XB-D and XT-E LED optics with multiple beam patterns. Cree LED optical solution providers are listed on our [website](#).

CONCLUSIONS

Cree XLamp XB-D and XT-E LEDs are built with the latest SC³ Technology Platform. The core of the SC³ Technology Platform is Cree's latest generation of silicon carbide based DA LED chips that deliver industry-leading performance.

Cree XLamp DA chip based LEDs have some unique features that can make it a challenge to design good, uniform narrow beam optics. This application note discusses some basic techniques to create a TIR lens to achieve a good, uniform narrow beam and high efficiency.

Cree maintains an extensive optical solution partner's list. Most of our optical solution providers have their own unique solutions to develop good secondary optics for DA-based XLamp XB-D and XT-E LEDs. Please refer to our [optical solution provider list](#) on our website for more optical design and LED optics information.