Predicting Scatter of Light Shaping Diffuser® Angles Using Luminit's Proprietary Optical Model and OpticStudio

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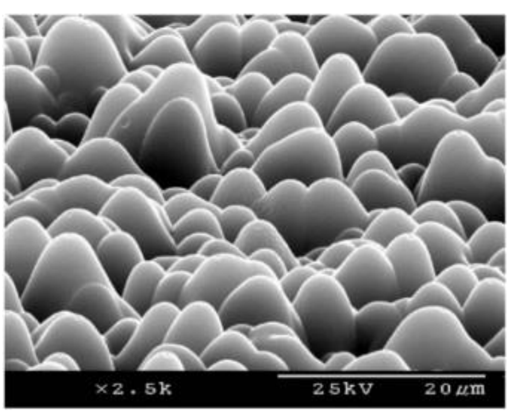
Introduction

To help our customers predict scatter patterns of our most common Light Shaping Diffuser angles, Luminit developed a proprietary scatter model for users of Zemax OpticStudio (Professional and Premium versions only). Unlike most conventional optical design programs that provide bulk scatter and surface scatter models based on mathematical probabilities tables that "predict" output distribution, Luminit's proprietary optical model accurately calculates surface effects so users can choose which angle LSD offers the most optimized performance. This white paper describes the characteristics of the LSD scatter model as it pertains to Luminit products and the level of accuracy that can be achieved during this critical stage of the design cycle.

Overview of Luminit Light Shaping Diffusers®

Luminit Light Shaping Diffusers® (LSDs) use holographic diffuser technology to create pseudo-random micro-lens structures that scatter incoming light when it strikes the surface. These pseudo random, non-periodic micro-structures are replicated on polyester or polycarbonate films as thin as 50-250 microns. Because the principle of surface scatter is used instead of volume or bulk scatter, our LSDs tend to have a much higher transmission efficiency (~92%) than conventional diffusers. Luminit has the largest catalog of diffuser angles and formats used for LED lighting, architectural lighting, bio-medical illumination, semiconductor metrology, aerospace, automotive, laser and display applications.

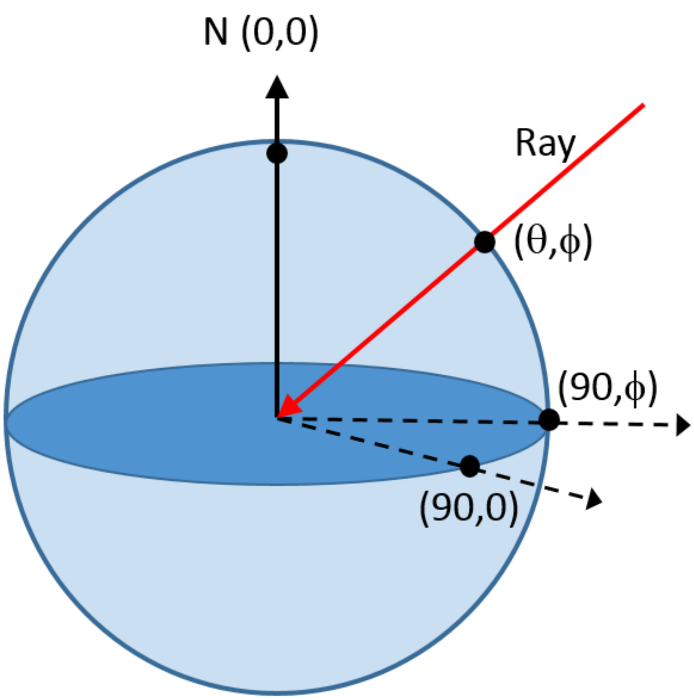


SEM view of a Light shaping Diffuser surface microstructure.

Overview of Optical Scatter and BSDF

Bi-directional Scatter Distribution Function (BSDF) describes the general characteristics of optical scatter. Imagine a global coordinate system where the North Pole is designated 0° latitude (θ) instead of the equatorial line, the longitudinal (ϕ) lines (or azimuth) go from 0° to 360° and the optical surface is the plane of the equator. Bi-direction indicates the latitude and longitude direction of rays intersecting the surface of the globe and center of the sphere. The S stands for the general Scatter which T and R can replace to describe the Transmitted and Reflected component of scatter (BSDF=BTDF+BRDF). Therefore, the BSDF is a function that has four coordinates which describe the direction of inbound and outbound light and an average value for its outbound light.

BSDF (θi, ϕi ; θo, ϕo)=average value.



Overview of Zemax bsdf

The Zemax optical design program describes the scatter of a surface in several ways. One type is called bsdf, which is formatted in text (with the appendage *.bsdf) to describe the values at output coordinates for every input coordinate. (Note: For clarity, this article designates the Zemax bsdf with lower case and generic optical scatter BSDF with upper case.)

For example, given a ray coming in at (θi=0, ϕi=0), the table will contain values at given (θo=(0 to 180 degrees), ϕo=(0 to 359 degrees)).

(Eq. 1) $179 \times 360+2 = 64,442$

There are over 64 thousand unique data points per table for each input ray direction (θi, ϕi). The 2 points (in eq. 1) are for the North and South Pole positions. The previous equation applies if the outgoing resolution is 1°.

These values can be input from a measurement instrument, such as Radiant's integrating sphere device. The outbound coordinates actually follow the undeviated ray (whether reflected brdf table or transmitted btdf table) as its (0,0). A separate set of tables must be generated for each mode (T, R), and these tables can be ported to any raytracing platform (such as LightTools, Optis, etc.) that follows this convention.

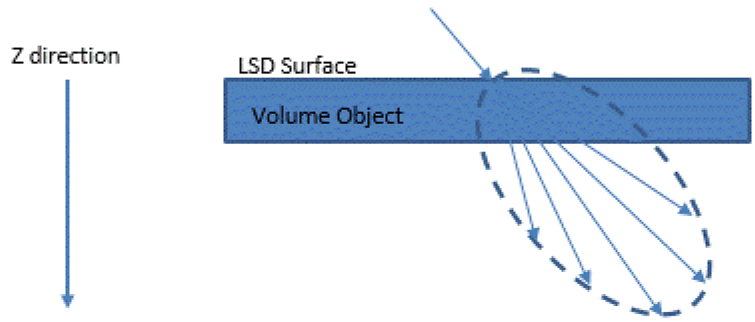
Similarly, the resolution of the input directions will determine the number of tables generated. For asymmetric systems with a resolution of 1 degree increments, the number of input directions equals 64,442, or approximately 4.15 billion unique data points.

For a more practical number, the previous output tables are generated with only 10 input directions (10° separation) on rotationally symmetric diffusers. With a rotationally symmetric diffuser, the azimuth direction is not impacted, and because there are only 10 input directions, the text file is approximately 6 MB in size. A full measurement set for each 1° on an asymmetrical diffuser would produce a file approximately 38.7 GB, which would be impractical to execute.

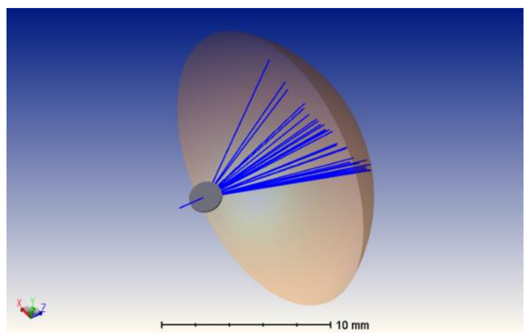
Another type of scatter function in Zemax is called the "User Defined" DLL, or Dynamic Link Library. The files in Luminit's LSD model take the form of DLL which are native to the operation of Zemax OpticStudio.

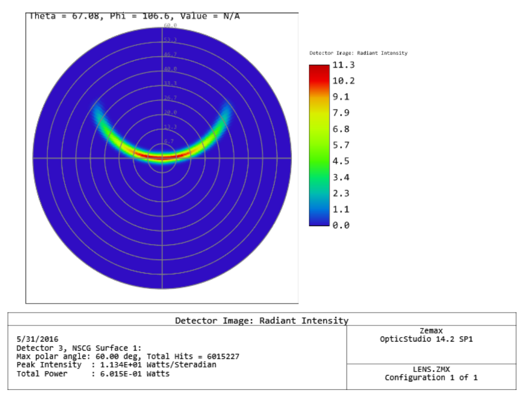
How Luminit's LSD Scatter Model Works within OpticStudio

DLLs are sophisticated subroutines and compute the results of ray tracing very quickly. The 'User Defined' type scattering function can model circular and elliptical LSDs alike while accurately emulating the performance of Luminit's LSD product line. Similar to our LSD product, the LSD model takes the rays which strike the surface of a volume object and scatters the direction of the light.



Since this a random statistical model, each ray that strikes the surface will take a different path to exit, even if it has the same exact path in. The LSD model scatters the rays in such a way as to emulate the shape of the statistical distribution of the Luminit LSD.



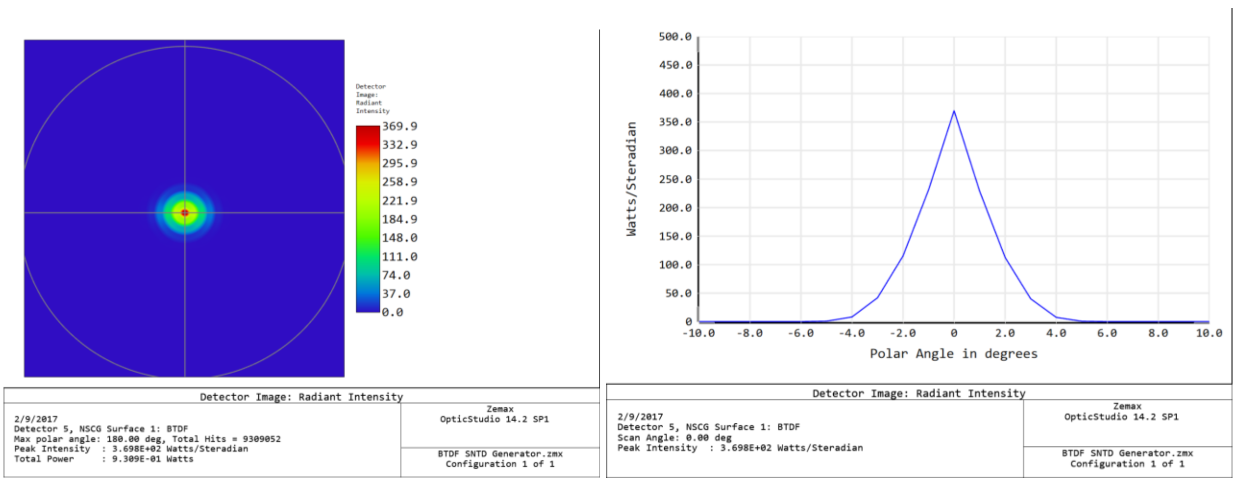


A basic example using Luminit LSD scatter function in OpticStudio. Notice that the input ray angle is highly oblique from the surface normal.

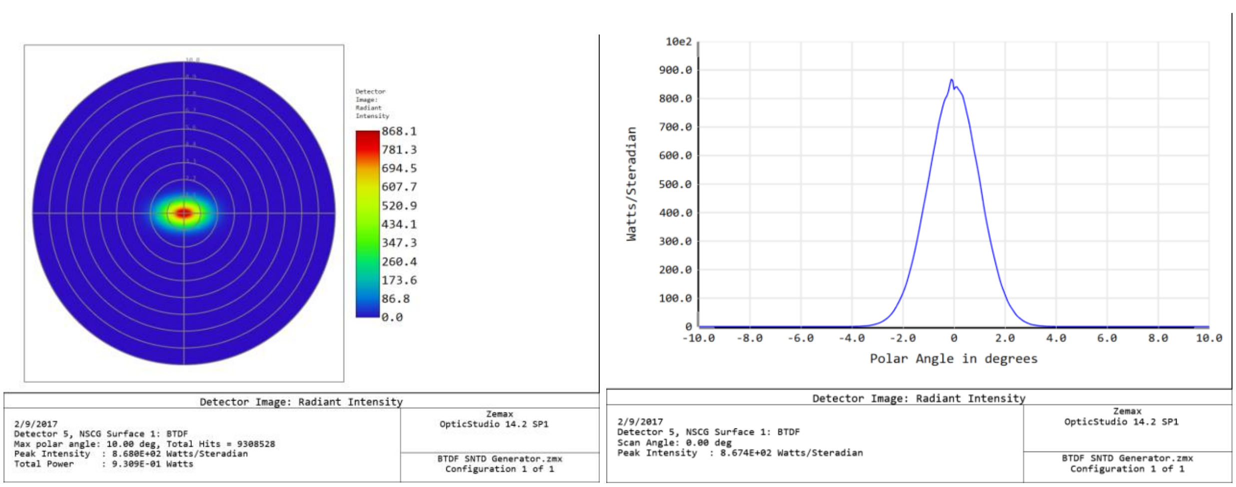
Advantages of the User Defined DLL over the Tabled bsdf

While there are a number of scattering models that perform specific functions, bsdf tables of distribution patterns with (ϕ, θ) coordinates are most commonly used. Tables can be executed quickly once the data is entered; however, the process to acquire the data can be labor or time intensive due to the fact that individual tables must be entered for each possible input ray direction.

For example, if you have a circular diffuser, you can enter tables for input ray angles every 10° of tilt (θi). This would mean 10 entries if the last entry is at 85°. However, if the diffuser is elliptical, the distribution is no longer circularly symmetric. Then the azimuth angles (ϕi) must also be entered. Maintaining every 10° in the azimuth direction equates to 10 x 36 or 360 tables to generate. Not only is this extremely data intensive because each table can contain 180 x 360=64,800 data points, the tables are only accurate with rays that enter at the precise angles in which they are recorded. In addition, the level of resolution in table measurements can be unprecise or "granular" in nature with wider parameter spacing. For instance, a 1° FWHM diffuser distribution in a grid that measures at every 1° offers only a rough estimate of the distribution pattern. Below are pictures of a 1° diffuser captured at 45° angle of incidence. The first set is with 1° resolution capture. The second set is with 1/18° resolution capture.



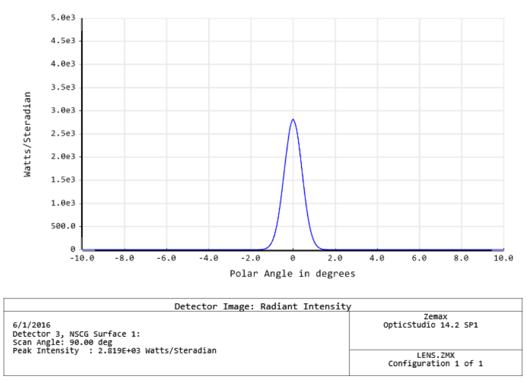
1° Diffuser profile with 1 degree resolution

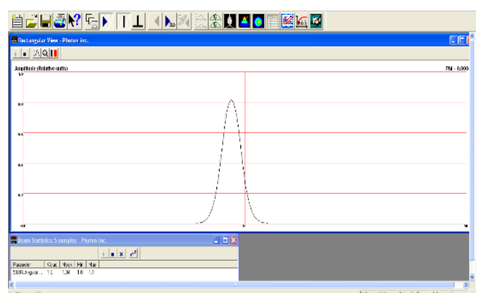


1° Diffuser profile with 1/18 degree resolution

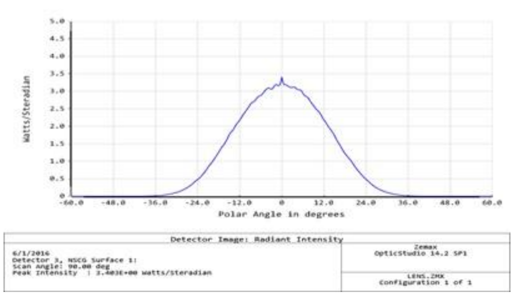
Using a formula within the “User Defined” DLL, on the other hand, produces more refined distribution patterns where the shape of that distribution will have higher fidelity with very fine features, thus producing more accurate results. If the output were to be examined every 0.05 degrees, it would look statistically continuous and smooth. In addition, the accuracy of the DLL model is not dependent upon the input angle, since that is also a smooth and continuous function. This allows any angle of incident light direction, which in turn allows the output light to be precisely distributed. In a real illumination system, the angle of light incident on the diffuser can come from anywhere and is continuous in angular spectrum.

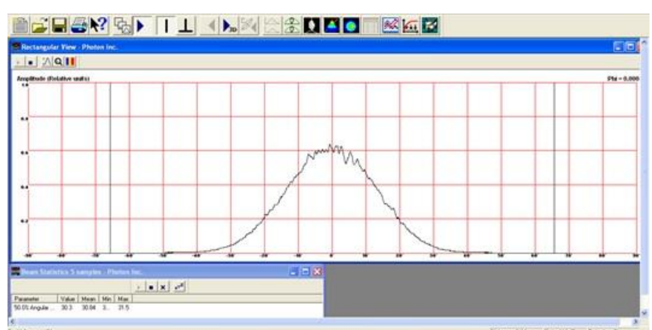
Following are examples of simulated profiles of Luminit’s Light Shaping Diffusers in Zemax OpticStudio. The images on the left are from our DLL scatter model; the images on the right are measured goniometer readings. Luminit LSDs are very Gaussian in shape from near zero to 30 degrees but as you migrate to 60 degrees, the shape starts to resemble a rounded trapezoid. Go to higher angles and the center dips. These shapes are replicated in the optical model so customers can view an accurate representation of how a particular angle of LSD will perform.



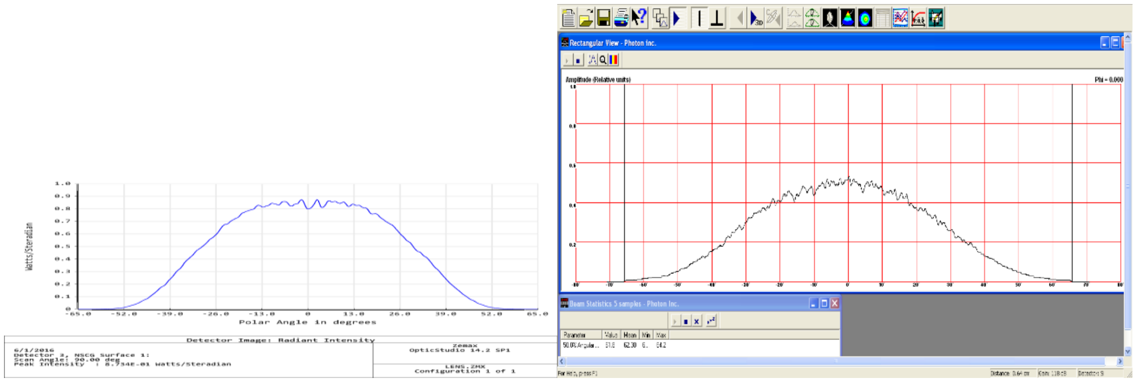


1° Diffuser

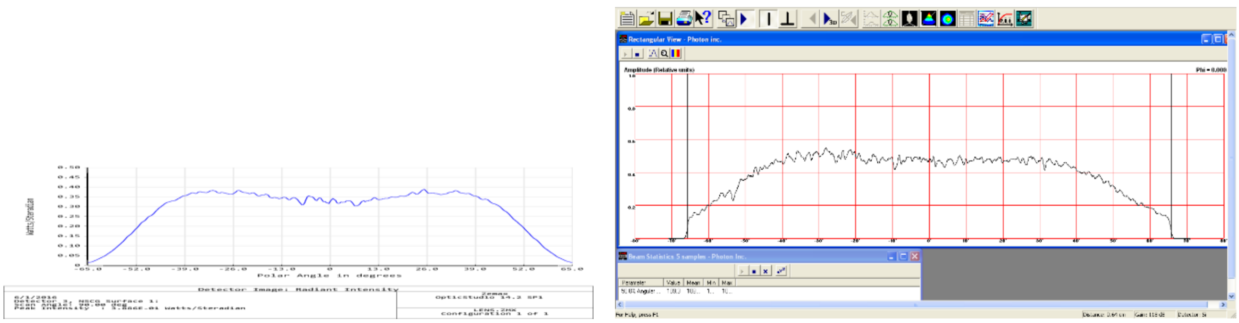




30° Diffuser



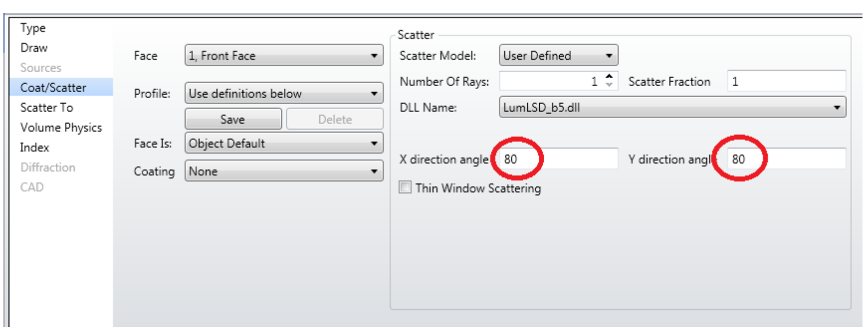
60° Diffuser



100° Diffuser

A comparison of Luminit's optical scatter model (left) and goniometer readings (right). Note how the shape changes from Gaussian in smaller angles to trapezoidal in larger angles.

As can be seen from these figures, the fidelity of rays produced from the 'User Defined' type DLL models are highly accurate compared to the rays produced by the bsdf type of scatter model.



Since the formulas and algorithms are already imbedded, there is little additional effort needed to change the modeled diffuser's output characteristics. For the user, it is two simple entries of the desired X and Y spread angle.

Table of Comparison		
Parameter	**bsdf Table**	**User Defined DLL**
Generating model	Labor or measurement intensive	User enters 2 numbers
LSD Type	Circular	Circular & Elliptical
Angular Res I/O	*10 deg/*1 deg	No limit/Zemax 5 x 10 arcsec
File Size	6MB for 10 input angles	<200KB
Substrate	Flat or curved surface 0 thickness	Flat surface on volume object
Input Direction	Diffuser side	Either side
Spectrum	Visible	Source & index
Trans/Refl	T&R	Only T
TIR	N/A	No
Polarization	Random	Random
Speed	Similar	Similar
*Practical limit.		

Conclusion

Although statistical random numbers are never 100% accurate due to the mathematics of probabilities, Luminit's DLL Optical Scatter Model allows engineers to visualize the output distribution of our Light Shaping Diffusers with an unprecedented level of accuracy. The more rays that are entered the more consistent the data will be. Keep in mind that only catalog angles are available (see below). Coatings, TIR and curved surfaces do not apply.

Available angles:

- 0.5, 1, 2, 3.5, 5, 7.5, 10, 20, 30, 40, 60, 80, 100 degree (circular)
- 15x1, 30x1, 30x3, 30x5, 40x1, 40x10, 50x3, 60x1, 60x10, 60x30, 75x45, 80x50, 90x60, 90x25 (elliptical)
- 0.5, 1, 5, 10, 15, 20, 30, 40, 50 (glass)

The DLL Optical Model is available for free on the Luminit website but requires the Premium or Professional versions of Zemax. Note that the scatter feature is not available in the Standard Edition of Zemax. Go to www.luminitco.com\downloads\dll to download the files. For customers who require modeling beyond our standard catalog angles, Luminit offers a fee-based service. To learn more about this service and to receive a quote, send an email to: sales@luminitco.com with Optical Model in the subject field.

For our customers who want to export the diffuser model to platforms other than Zemax using a Zemax bsdf type, Luminit is working on expanding its library of angles for this purpose; however, only circular angles will be available. Go to http://www.luminitco.com/downloads/btdf-bsdf-data to download the files.

About the Author

Anthony Ang serves as Senior Optical Engineer at Luminit and has extensive experience in technology management and optical science. Responsible for creating large-size master holograms for Luminit's Light Shaping Diffusers°, Mr. Ang earned his Bachelor's Degree in Optical Engineering at the University of La Verne and is a Certified Black Belt in Design for Lean Six Sigma. Mr. Ang is considered a subject matter expert in system engineering, analysis and optical science and has authored patents in both the U.S. and Europe.