TECHNICAL ARTICLE
March, 2015

TracePro's accurate LED source modeling improves the performance of optical design simulations.

Modern optical modeling programs allow product design engineers to create, analyze, and optimize LED sources and LED optical systems as a virtual prototype prior to manufacturing the actual product. The precision of these virtual models depends on accurately representing the components that make up the model, including the light source.

This paper discusses the physics behind light source modeling, source modeling options in TracePro, selection of the best modeling method, comparing modeled vs measured results, and source model reporting.

Ray Tracing Physics and Source Representation

In TracePro and other ray tracing programs, LED sources are represented as a series of individual rays, each with attributes of wavelength, luminous flux, and direction. To obtain the most accurate results, sources are typically represented using millions of individual rays.

Source models range from simple (e.g. point source) to complex (e.g. 3D model) and can involve complex interactions completely within the source model. For example, a light source with integrated TIR lens can effectively be represented as a "source" in TracePro. However, sources are usually integrated with other components to represent the complete optical system. We will discuss ray tracing in this context.

Ray tracing engines, in their simplest form, employ Snell's Law and the Law of Reflection to determine the path and characteristics of each individual ray as it passes through the optical system. Figure 1 illustrates a simple optical system with reflection and refraction.

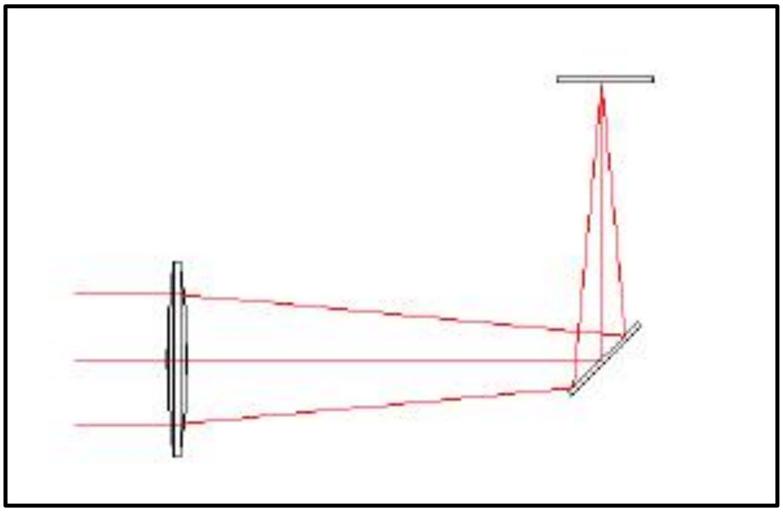


***Figure 1* – Simple ray trace with refraction and reflection**

TracePro's sophisticated ray tracing engine incorporates specular transmission and reflection, scattered transmission and reflection, absorption, bulk scattering, polarization, fluorescence, diffraction, and gradient index properties. These factors can also vary as functions of wavelength, temperature, temperature distribution, and incident direction. The more accurately the physical properties of the objects in an optical system are defined, the better the likelihood for obtaining an accurate representation of the system. Figure 2 illustrates a more complex ray trace example using TracePro's ray-tracing engine.

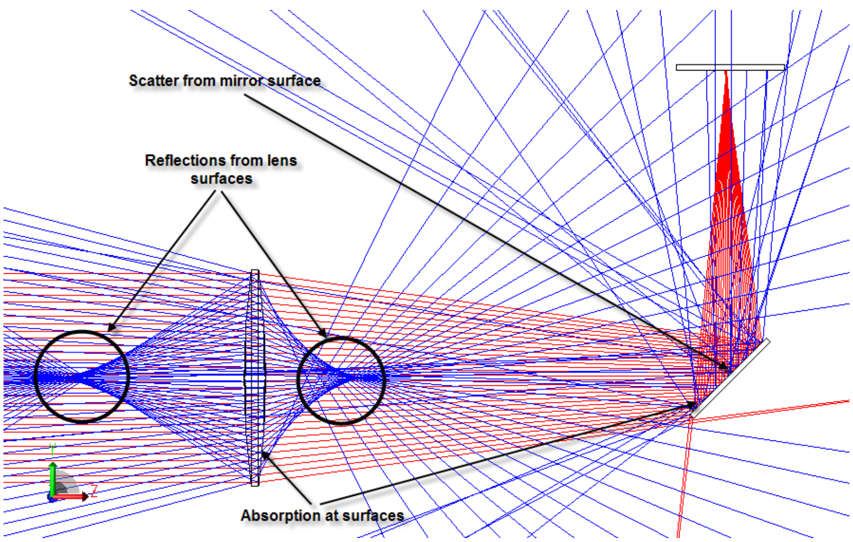


***Figure 2* – More complex ray trace example**

Figure 3 illustrates the five optical phenomena that can occur when a ray intersects a surface, and each can happen at every surface. All of these phenomena vary as a function of temperature, wavelength, and incident direction.

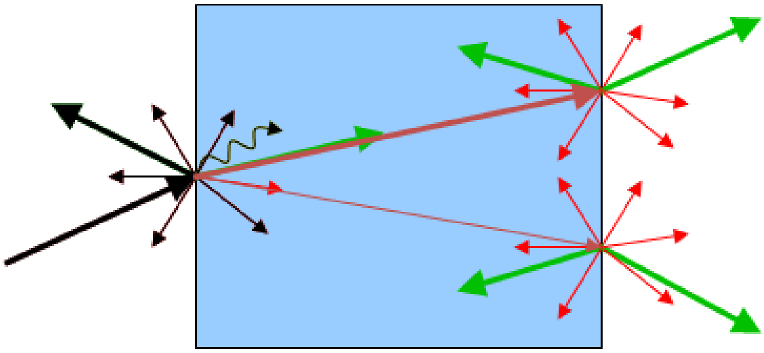


***Figure 3* – Surface Interaction Optical Phenomena**

1) ***Refraction***
2) ***Reflection***
3) ***Absorption***
4) ***Forward Scatter***
5) ***Backward Scatter***

The accuracy of optical system ray tracing results is dependent upon the accurate representation of:

1) **Geometry**
   - Created in TracePro
   - Imported from CAD programs such as SolidWorks, Pro/ENGINEER, CATIA, Inventor, etc…
2) **Properties**
   - Surface – absorption, reflection, transmission, scattering
   - Material – index of refraction, absorption/extinction coefficients
   - Bulk Scatter – anisotropy, scatter coefficient
   - Fluorescence – excitation, absorption, and emission spectra, concentration
3) **Source Models**
   - Spectrum
   - Beam pattern – azimuth and polar
   - Emitted flux or illuminance/irradiance

Source Models

Point Source

In TracePro, light source models can run the gamut from simple to complex. The simplest LED source model is the point source where all rays are emitted from a single point. Figure 4 illustrates the representation of a TIR hybrid lens with a point source. A point source is not a realistic model of a physical source and the results obtained when using a point source may not be accurate. Figure 4 shows that the TIR hybrid lens produces an illuminance pattern that is smaller and with higher illuminance and a higher intensity value when compared with more accurate source models as shown in Figures 5, 7, and 9. For example, the peak intensity is more than 4x higher with the point source compared with more accurate models.

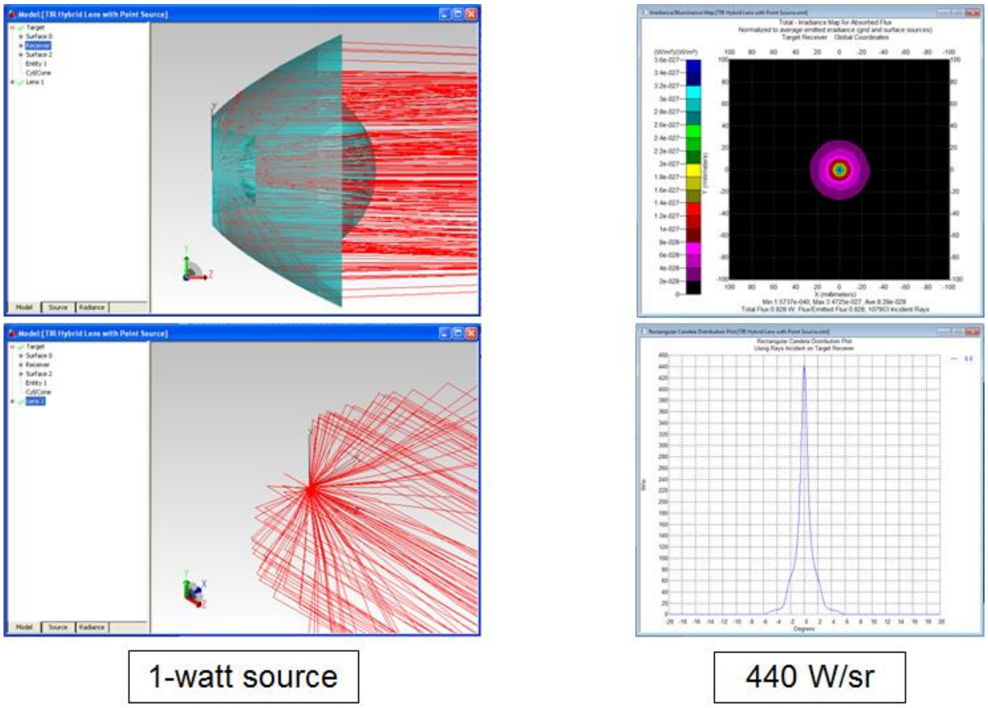


***Figure 4* – TIR hybrid lens with point source**

Grid Source

The next level of complexity is the Grid Source which is effectively represented as a two-dimensional array of point sources. The grid source is more representative of the actual LED being modeled since the extents of the grid can represent the physical size and shape of the physical LED, although the rays each start from a common 2D plane.

A Grid Source can be a more accurate model of a LED source as it adds physical size to the source representation. Figure 5 shows a 1mm x 1mm Grid Source to model the emitting surface of the LED. Compared to Figure 4, the illuminance pattern is larger, the illuminance value is lower, and the intensity is also lower. These results compare favorably with the results based on the rayfile model shown in Figure 7. The ray file is based on actual measurements of the spatial and angular distributions of the LED source. A Grid Source may not be a good choice if the boundary of the emitting surface is irregular, or is 3-dimensional.

Typically, point and grid sources can be defined at multiple wavelengths with wavelength weights applied to represent the spectral power distribution of the source.

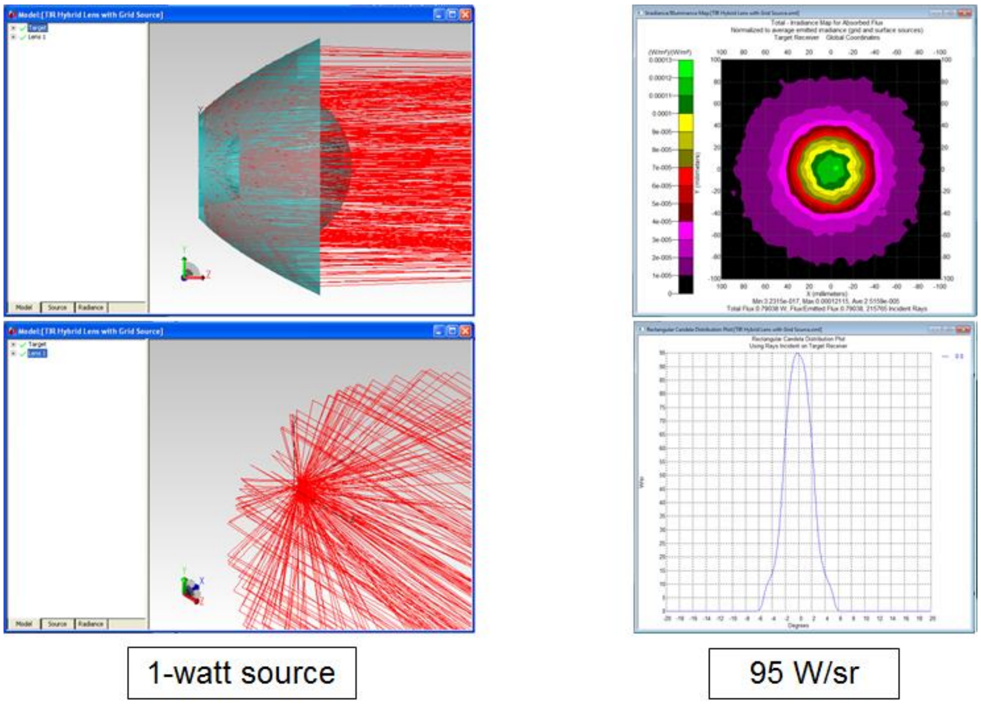


***Figure 5* – TIR hybrid lens with 1mm x 1mm grid source**

Ray Files

A very accurate way to represent the LED source is with a ray file. The LED source is measured with a goniophotometer or similar instrument to determine the luminous flux in a 360 degree sphere about the source. This information is then translated into a series of individual rays and captured into a computer file. Ray files are also typically available for download from LED manufacturer websites (see Figure 6). Ray files include a 3D starting point for each ray along with direction vector and flux values. Since ray files are based on measured data of complete sources, they include the effects of lamp packaging. Since the goniophotometer only measures luminous flux, one major drawback of ray files is that they are typically defined monochromatically. However, it is possible in most modern optical simulation software tools to represent a source with multiple ray files, each with a different wavelength, to represent polychromatic sources.

```
!! source file:

TracePro Release: 6 0 2
Data for Block 1 Surface 1
Linear Units in mm
Data generated at 15:51:06 January 20, 2010
X Pos.                  Y Pos.                  Z Pos.                  X Vec.                  Y Vec.                  Z Vec.                  Inc Flux
 0.000000000000000e+000  0.000000000000000e+000  4.900000000000000e+001  0.000000000000000e+000  0.000000000000000e+000  1.000000000000000e+000  9.164210624726462e-001
 3.241904746004420e-002  0.000000000000000e+000  4.900000000000000e+001 -1.943468304810075e-002  0.000000000000000e+000  9.998111287112282e-001  9.164242320047675e-001
 1.620952373002205e-002  2.807571866689163e-002  4.900000000000000e+001 -9.717341524050380e-003 -1.683092923415404e-002  9.998111287112282e-001  9.164242320047675e-001
-1.620952373002205e-002  2.807571866689163e-002  4.900000000000000e+001  9.717341524050373e-003 -1.683092923415404e-002  9.998111287112282e-001  9.164242320047675e-001
-3.241904746004420e-002  1.158548475946197e-016  4.900000000000000e+001  1.943468304810075e-002  0.000000000000000e+000  9.998111287112282e-001  9.164242320047675e-001
-1.620952373002205e-002 -2.807571866689174e-002  4.900000000000000e+001  9.717341524050387e-003  1.683092923415403e-002  9.998111287112282e-001  9.164242320047675e-001
 1.620952373002205e-002 -2.807571866689163e-002  4.900000000000000e+001 -9.717341524050380e-003  1.683092923415404e-002  9.998111287112282e-001  9.164242320047675e-001
```

***Figure 6* – Sample Ray File**

Figure 7 illustrates the representation of a TIR hybrid lens with a ray file source. Since ray files are derived from the measurement of the actual LED emission, they have the potential to be the most accurate, and easiest to use for LED source representation. The previously mentioned limitations of ray files, that they are typically monochromatic and that they do not model the physical structure of the LED, may not be limiting factors in many applications.

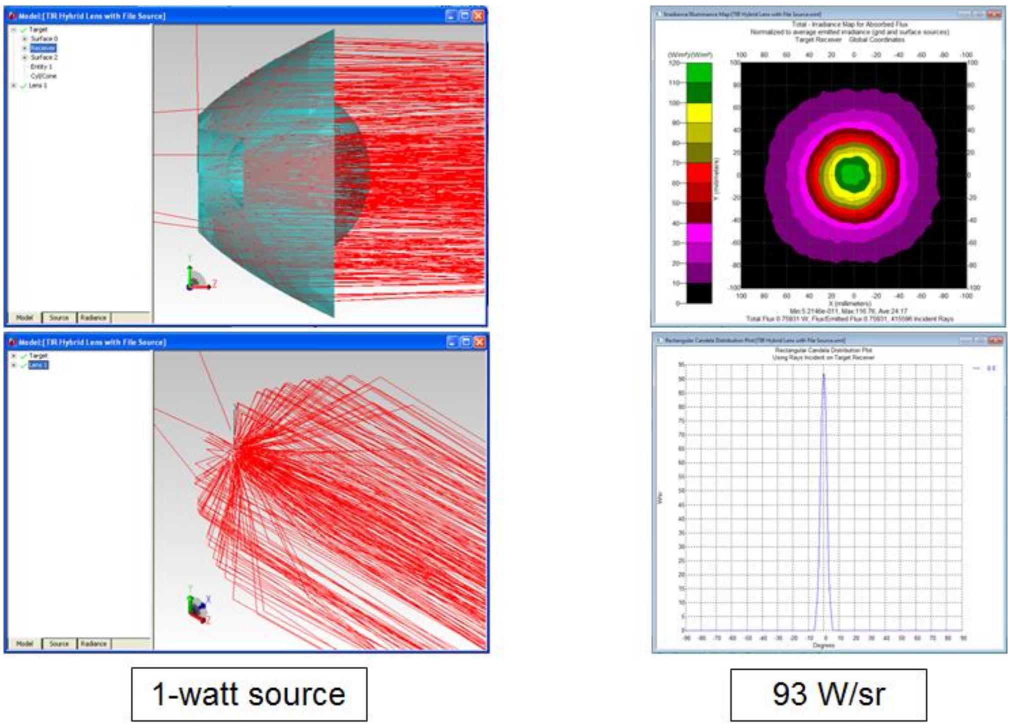


***Figure 7* – TIR hybrid lens with Ray File source**

Surface Sources

Surface sources are light emitting surfaces that have angular and spectral power distribution properties. In TracePro, a surface source can be applied to any surface shape, including flat and curved surfaces. Surface sources allow the designer to define complex angular distributions, including polar and azimuth angles, and to model sources with non-uniform emissions. Spectral distributions can also be included in the property to accurately model polychromatic sources.

Temperature	Wavelength	PolarAngle	AzimuthAngle	Emissivity
300	0.2683	0	0	0.004471306
300	0.2683	3.103	0	0.004462601
300	0.2683	6.207	0	0.004437427
300	0.2683	9.31	0	0.004398287
300	0.2683	12.414	0	0.004348366
300	0.2683	15.517	0	0.00428925
300	0.2683	18.621	0	0.00422081
300	0.2683	21.724	0	0.004141673
300	0.2683	24.828	0	0.004049205
300	0.2683	27.931	0	0.0039418
300	0.2683	31.034	0	0.003820064

***Figure 8* – Example of data from a surface source property**

Figure 9 illustrates the representation of a TIR hybrid lens with a surface source. Modeling the LED using a Surface Source Property produces illuminance patterns, illuminance values, and intensity values, similar to the Grid Source and Ray-File models, making this method another valid option for modeling LED sources. In addition, the Surface Source Property allows you to fully model the spectrum of the source. Since the Surface Source Property is applied to a physical object or surface in a model, the interaction of light with source packaging can be modeled as well.

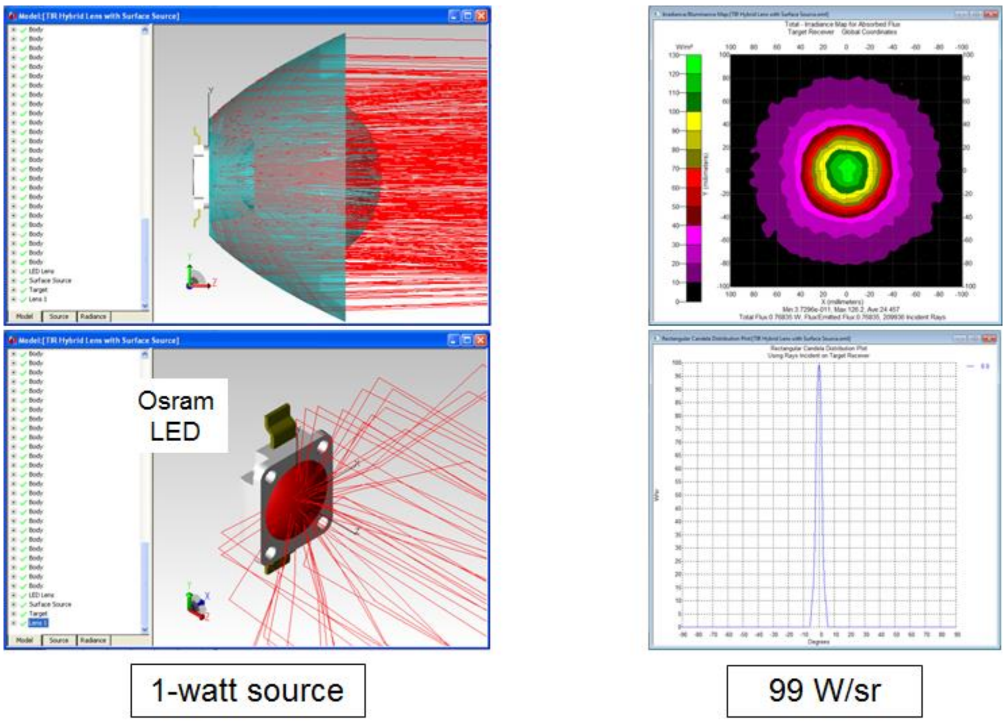


***Figure 9* – TIR hybrid lens with surface source**

Figure 10 illustrates another use of a surface source in an arc model. The luminous intensity distribution around the source is shown in the lower box.

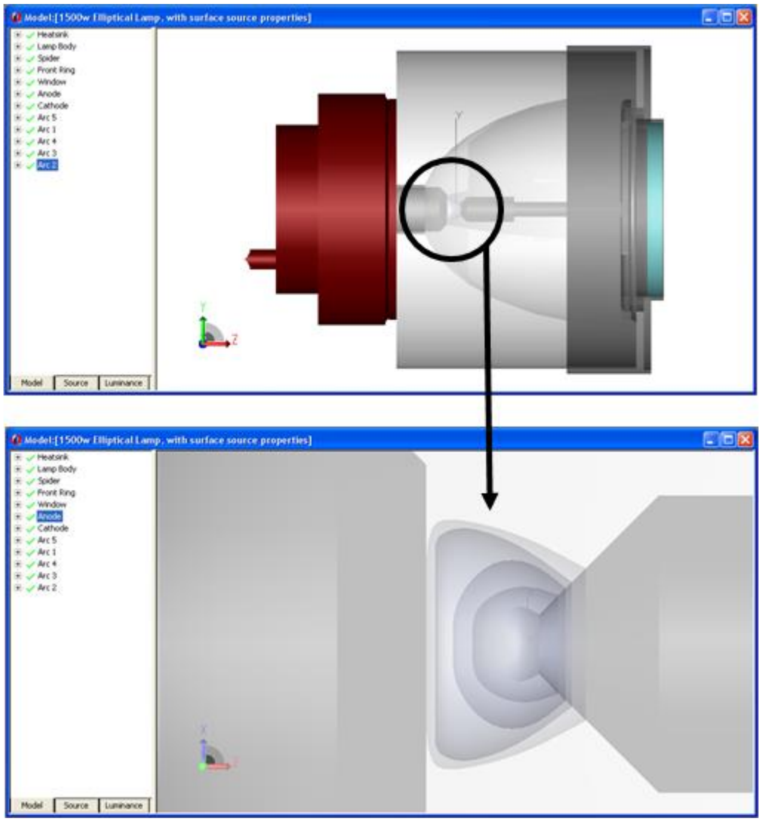
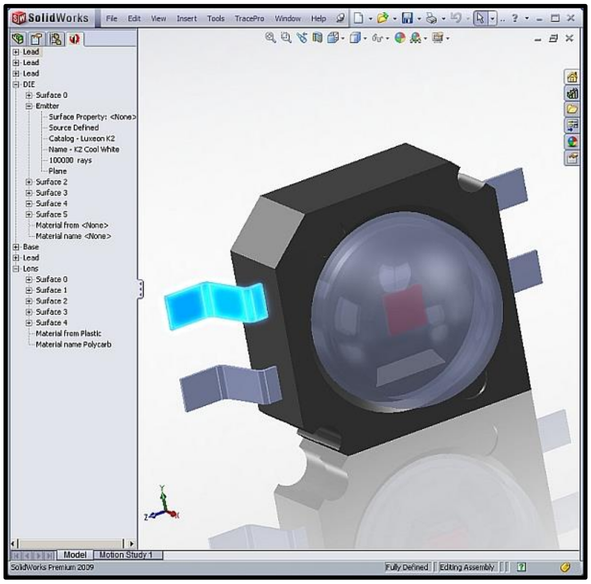


***Figure 10* – Arc model with surface source**

3D Solid Model

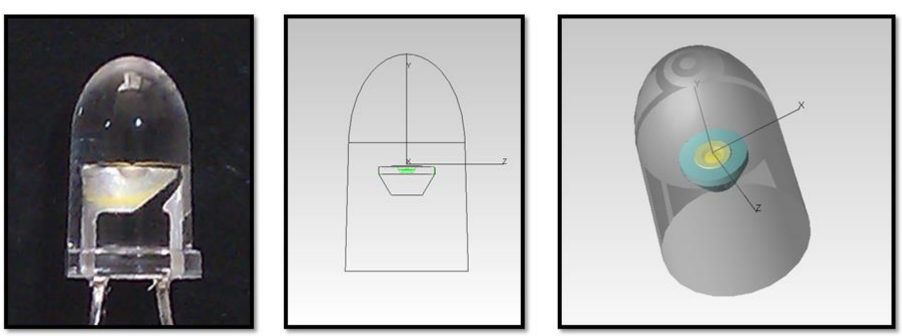
Surface sources can be combined with 3D solid models of lamp geometry to achieve very accurate source representation. These models include the following material and surface properties: glass or plastic types, reflective coatings, paints, diffusers, bandpass and dichroic filters, hot and cold mirror coatings, and surface finishes. Figure 11 shows a model of a Luxeon K2 LED as modeled in SolidWorks using the TracePro Bridge for SolidWorks with a surface source property to model the LED emission characteristics.



[Figure 11](#) – Luxeon LED as modeled as a surface source using the TracePro Bridge for SolidWorks

Figure 12 illustrates a 3D Solid Model of an LED. Using this approach, a very detailed and accurate representation of the LED is achieved. This includes:

- Physical information about LED model including the die and mount
- Optical properties such as surface properties, material properties, and emitted flux
- Geometric shape of the optical components, such as the epoxy or secondary optics
- Specifications of phosphor material including excitation, absorption, and emission spectra
- Experimental/measured data for calibrations



[Figure 12](#) – 3D LED Model

In addition, the TracePro Fluorescence Property Generator Utility is used for:

- Color analysis (CIE, CCT, CRI)
- Prediction of mixed color
- Estimation of the thickness and concentration of the phosphor layer

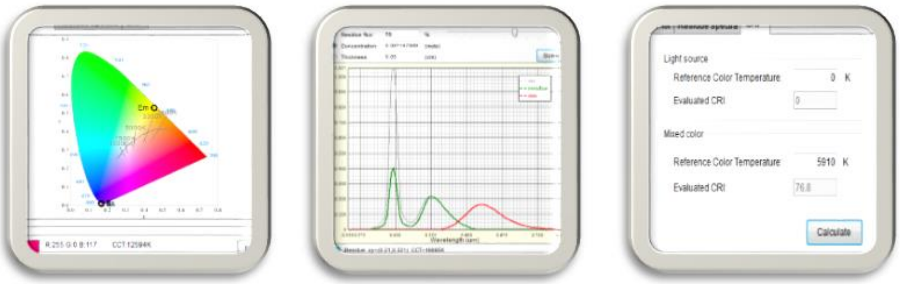


***Figure 13* – TracePro Fluorescence Property Generator**

Choosing the Right Source Model

With a better understanding of how to model LED sources correctly, designers have a stronger grasp on how to add the lenses and reflectors to complete an LED lighting system. The following can be used as a rough guide when determining which source representation type to use.

Point and grid sources are easy to represent, and are generally adequate for planar sources that have a well-defined boundary and for sources that emit in a Lambertian, Gaussian, or uniform manner. Both monochromatic and polychromatic sources can be specified. Point and grid sources are not the best option for a 3D source or one with more complex angular distributions. Fiber optics and laser diodes are good applications for point and grid sources.

Ray files (typically from a source or luminaire manufacturer) provide an accurate representation for both planar and 3-dimensional sources with complex angular emission patterns. Such sources can include lenses and other structural elements. Ray files are defined monochromatically, and therefore are not useful for polychromatic source representation unless multiple ray files are incorporated to represent emission at different wavelengths. It is also not a good choice if emitted light interacts with the source. LEDs and luminaires are often represented as ray files available from the source or luminaire manufacturer.

Surface source property representation is best for detailed source models with complex angular and spectral distribution patterns, and where modeling the interaction of light with the source structure is important. Surface source properties are more complex in nature than point and grid sources and thus more difficult to specify. Accurate material and surface properties are required to utilize this method. LEDs, arc and filament lamps, and complete optical systems are often represented as surface sources.

Using TracePro, you can combine 3D geometry modeling with the surface source property capability to create a highly accurate source representation. Multiple surfaces are used to represent source geometry, and material and surface properties are identified independently for each object and surface. Virtually any source can be represented in this manner with known geometry and surface/material properties.

Measured vs. Modeled Results

The LED shown in Figure 12 was modeled in TracePro as a 3D model with surface source properties specified. Figure 14 shows a comparison of measured vs modeled results. The first image in the figure is an actual photo of illumination on a target surface measured at 2.2cm distance. The second image shows the TracePro TrueColor Irradiance Map resulting from the ray trace for the modeled source at the same distance from the target surface.

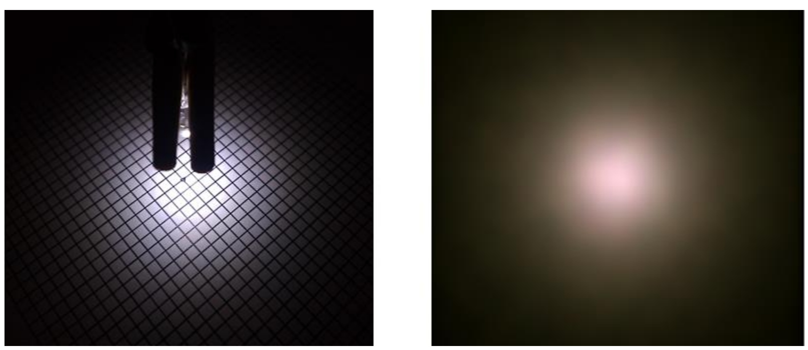


***Figure 14* – LED Measured vs Modeled Results at 2.2cm from target surface**

As can be seen in Figure 14, 3D solid models in conjunction with Surface Source Properties can be used to produce highly accurate models of LED sources, including such complex effects as the yellow ring typically seen around the central portion of a white LED projected illumination pattern. This type of model can also be used to model the conversion of light from a blue LED chip through a yellow phosphor to produce white light.

Lamp ("Source") Information Reporting

Lamp characteristics can be exported directly from TracePro in IES or Eulumdat standard formats (Figure 15). Data can also be viewed using the TracePro IES and Eulumdat viewer or used in lighting applications for photometry analysis. These reports are customizable and the user can incorporate multiple Illuminance and candela reports.

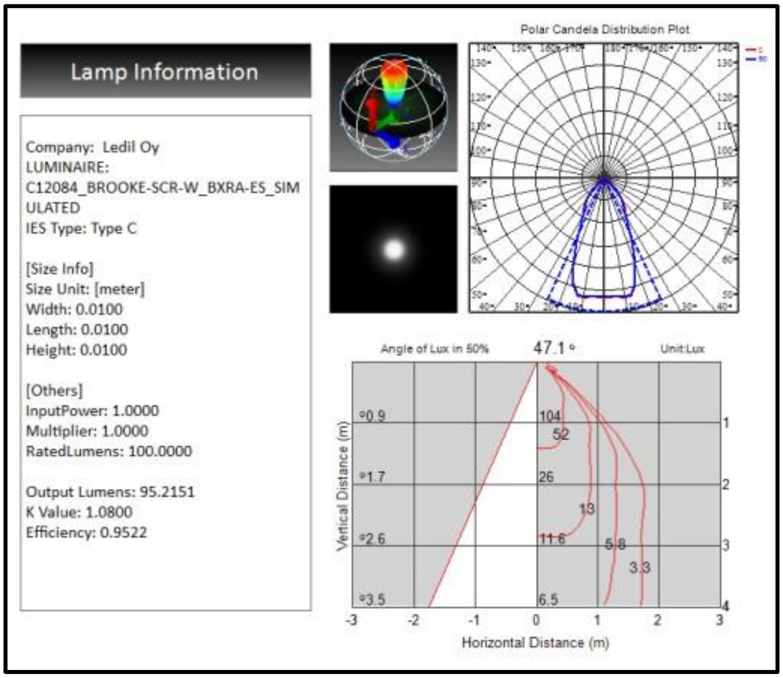


***Figure 15* – Lamp information report for a Bridgelux BXRA LED array and LEDIL OY Lens**

Conclusion

Appropriate LED source representation is an important consideration in the virtual representation of LED optical systems, and can have a significant effect on the accuracy of the overall model. Depending on the application, an LED source can be represented as a point source, grid source, ray file based on measured luminance, or as a 3D model with surface source properties. Polychromatic LEDs with complex emission patterns are typically represented as planar or 3D surface sources. From simple to complex LEDs, careful consideration and selection of the source modeling method can help make appropriate tradeoffs between modeling effort and complexity, and accurate results.

About Lambda Research Corporation

Lambda Research Corporation, a privately-held company founded in 1992, is an industry leader in light analysis, illumination system design and analysis, and custom software development. Lambda Research Corporation publishes TracePro®, an award-winning opto-mechanical design software used for designing and analyzing illumination and optical systems. TracePro streamlines the prototyping to manufacturing process by combining an intuitive 3D CAD interface, advanced utilities, and seamless interoperability with other mechanical design programs.

25 Porter Road
Littleton, MA 01460 USA
Phone: +1 (978) 486-0766
Fax: +1 (978) 486-0755
www.lambdares.com
sales@lambdares.com