Application Note for LED modeling

Light emitting diodes (LEDs) have come a long way from the small 5mm bulb-like indicator LEDs of the last century. They have now become powerful enough to be considered a "stand alone" light source in commercial applications. Today they are found everywhere, in many shapes and forms, and cover a wide range of output power and color. Within the next decade, they will begin to seriously compete with other light sources, such as fluorescent lights and incandescent bulbs for general lighting applications. The need for accurate design and analysis software is now obvious, as these small and versatile light sources are far more difficult to model than the other more conventional light sources.

TracePro is an illumination design and analysis tool that enables the user to analyze and design LED models as a light source. TracePro's flexibility in the area of source design can really make a difference in these models, as LEDs have very different optical characteristics from one model to the next. Depending on the preferences and needs of the user, there are many ways to model LEDs. This application note will offer exposure to different methods and considerations, which must be taken into account in order to achieve realistic LED models.

LED structure

An LED is a semiconductor component that emits light. LED sources are available as dies made from layers of semiconductor materials called homo junctions, hetero junctions or double hetero junctions. Depending on their nature, composition, and assembly, these junctions can emit light from within the material and gets out through either their surfaces and/or their edges. Materials used are typically made out of different proportions of Ga, As, In, P, AL, Zn, S and Si depending on the output wavelength desired. In commercial applications, the die is placed on a substrate, connected to an anode and a cathode, and then covered with a transparent epoxy. The newest high intensity applications require specially packaged LED models, which are sometimes mounted inside modular form factor assemblies with heat sinks.

LED design considerations

LEDs, especially the bare dies, are quite small, for effective design of optical systems that employ LEDs, one must model the emission characteristics of the LEDs. The following section will illustrate two high intensity LED designs built from the same manufacturer specifications in TracePro.

For multicolor LED design, multiple dies (red-green-blue combinations) can be packaged within a single device. For white LEDs, a single blue or UV emitting diode die is used over which a phosphorous material is deposited. When illuminated by the radiation from the die, this phosphor generates what is perceived by the human eye to be white light. For example, phosphors emitting more in the red spectrum will make a "warm white", closer to the light emitted by an incandescent light source. These effects can be simulated in TracePro using its integrated macro language.

LED examples: Luxeon® Star White side emitting model

The first example is a detailed Luxeon Star White LED model with a side-emitting lens from Lumileds Lighting, built entirely in TracePro (see Fig. 1a). The datasheet (DS25, see ref.) lists mechanical design data, which enables users to build the part within TracePro using the different tools available. Since manufacturer specifications are often incomplete (lacking material data and emission measurements for confidentiality reasons) and manufacturing tolerances of the LED die mass-production process creates characteristic variations, the resulting model may perform differently from the datasheet. Contacting the manufacturer could provide more information to help design a more accurate model, but one can use TracePro to bring the optics model into agreement with lab measurements.

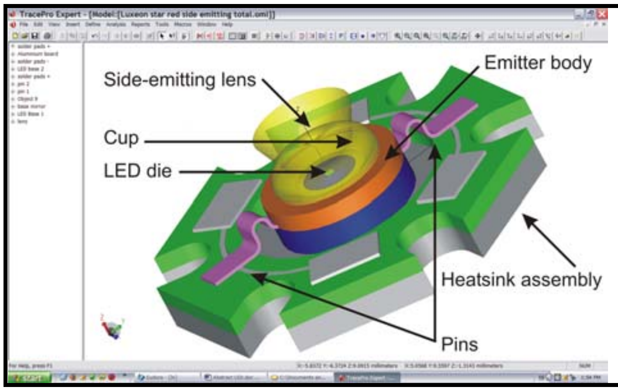


Figure 1a. Completed geometrical LED model: The emitter (Center structure) includes a side-emitting lens, a cup, the emitter body and the pins. The outer area is the form factor assembly, which includes solder pads on an FR4 board, under which is an Aluminum heat sink. The die is the central block seen through the lens.

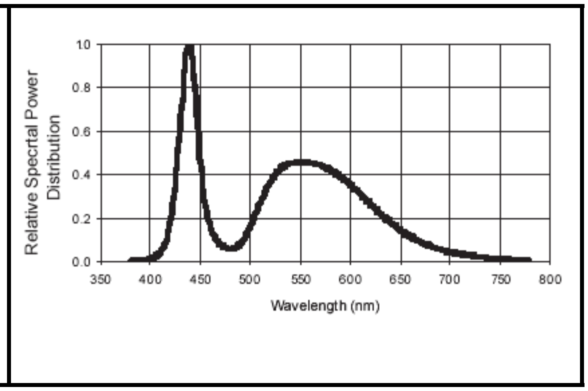


Figure 1b. White spectrum: The modeled LED will emit a cold white light spectrum due to its blue-white light appearance seen by the human eye. The spike at 440nm is what is emitted by the die. The part between 500nm and 650nm is generated by the phosphor material over the die.

The LED shown in Fig. 1a is side emitting, meaning that most light will be sent to the side (at an angle around 80 degrees off the surface normal). Modifying the lens on top will change the angular light distribution significantly (see angular distribution and spectral emissions in Figures 7a and 7b). By adding a phosphor over the die, one obtains a nominal spectral distribution as shown in Fig. 1b. This spectrum is the one used in our ray traces for these examples.

This model was built according to the manufacturer's specifications. The sapphire-based die inside the LED is modeled as an emitting block with general optical properties. A higher level of detail would include the thin film layer structure of the die, complete with material properties and the micro-wiring between the pins and die and the exact measurements the optical and geometrical properties of each aspect of the LED. The die and reflector inside the emitter were fitted into the original geometry. For this example, we will consider the die's side surface light emissions to be negligible. The side-emitting lens was developed to go on top of the emitter geometry. Once the geometry is built, different optical properties are applied to complete the model.

Here are some pointers to consider when modeling LEDs:

-An LED die generally can be considered a top surface emitter. Using the side surfaces as emitters to varying degrees can improve the accuracy of the angular distribution patterns out of the mode depending on he technology used by the manufacturer. Some LEDs emit as much as 50% of their light through the sides (since their layers can serve as light guides), with the remaining light going out their top surface. However, in our case here we only used a 90 degrees Gaussian-like emission pattern on the top surface of the die as side surface losses are negligible.

-The die is usually encased in an epoxy which serves both to protect the die and as a lens / light guide. The specifications rarely list the lens index of refraction or the actual material the epoxy is made from, which can cause problems for proper coupling into a light guide. Typical epoxies have indices of refraction ranging from 1.49 to 1.65. The shape of the epoxy is critical to an accurate model reproduction, but the manufacturer may provide its general shape and dimensions.

- Optical properties of the reflector (or cup) can be varied by changing the reflectivity and scattering properties, enabling users to further enhance their model's accuracy when compared to the LED's angular light distribution data.

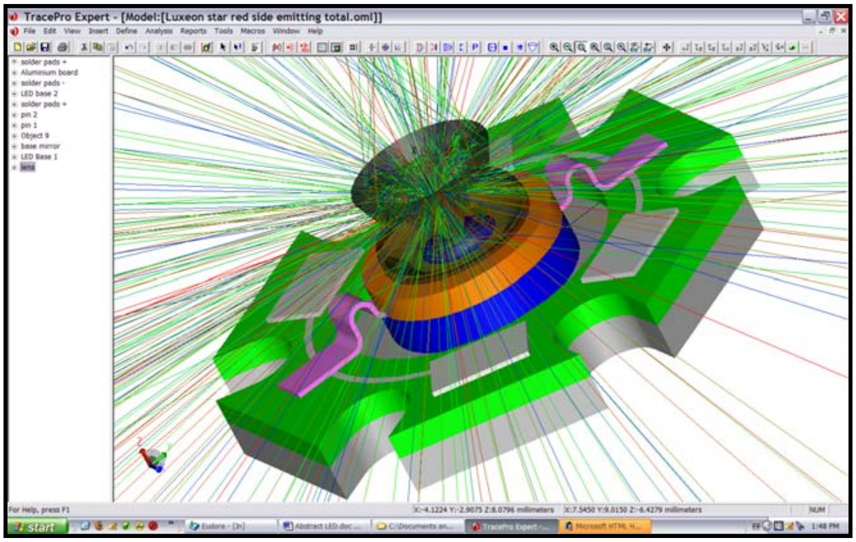


Figure 2. Lighting up the LED: This image shows the rays generated by the LED. The large majority of the rays leave the lens through its sides

LED examples: Point Source LED

The second example is much simpler. This LED is built by applying a Surface Source with a Surface Property to a disk-shaped object. The Surface Property is constructed to describe the angular distribution of the LED by weighting the property's absorption (see Fig. 3). This angular distribution is obtained using the LED's datasheet for guidance. This example effectively creates a point source when used in a far field model. The design ignores the geometry of the part such that the part is merely a placeholder to position and orient the LED. This method works for general lighting applications by using only the average angular distribution of mass-produced LEDs.

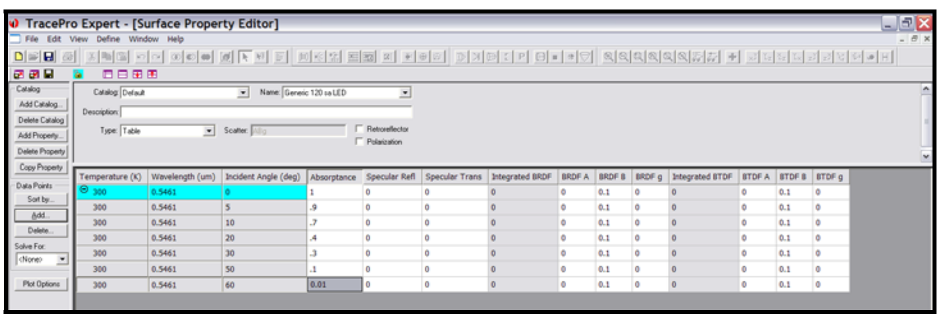


Figure 3. Surface Property with weighted absorption. To improve the model's accuracy, many angles are used, keeping the LED model true to the manufacturer's specifications relative to the angular distribution.

Figure 4 illustrates the model's ray output. The property data is applied to one surface of the planar-disk. During the ray trace, TracePro will consider the applied surface property and modify the ray distribution according to the table of absorption values entered. For a more thorough and exact analysis, the previous method based upon development of the entire LED geometry is recommended. Combining the two methods – i.e., providing an emission (absorption) pattern on the surfaces of the die solid - is frequently used to control the die's angular distribution along with the complete geometrical model.

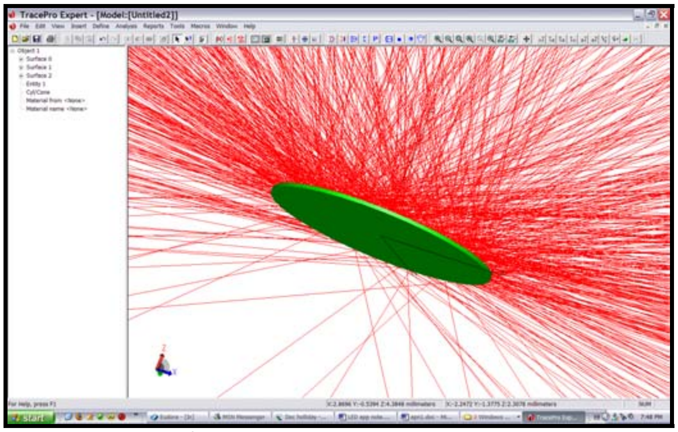
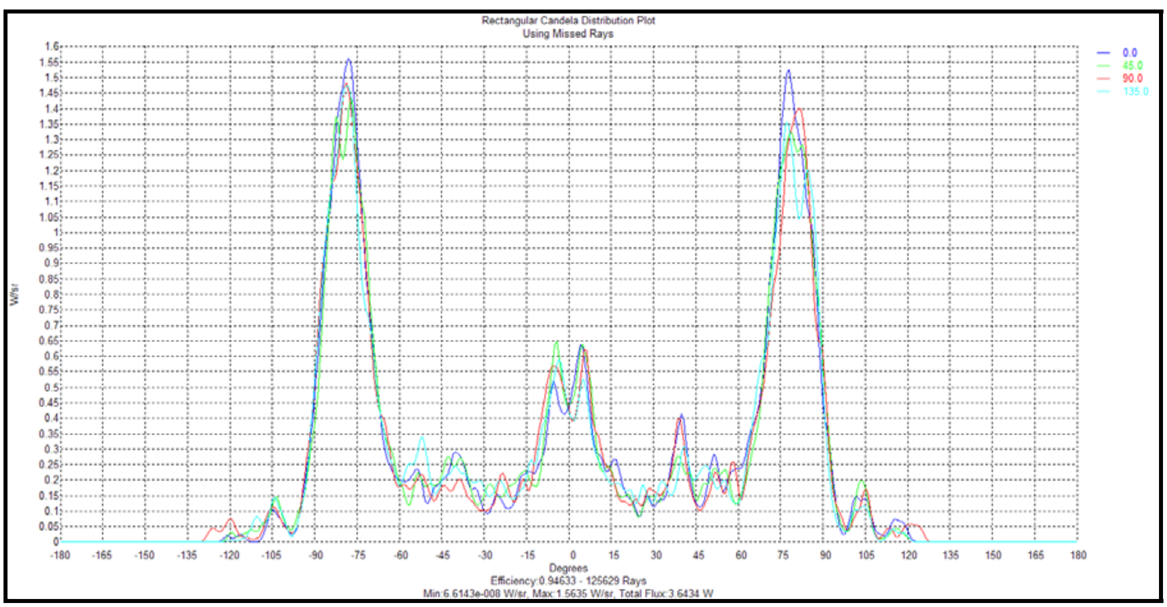


Figure 4. Ray trace of the simple LED model: the light distribution pattern is defined by the surface absorption directly as opposed to our first model, which used a geometrical approach by developing solids for the die and lens.

Design Analysis

The next step is to compare the model's performance to the manufacturer's specifications. During the detailed analysis of the output, modifications to the geometry and/or distribution are made in an iterative way to achieve the desired accuracy. Candela plots in TracePro are very useful tools for the analysis of the design. In this case, polar and rectangular Candela distribution analysis is used in TracePro, indicating the luminous intensity of the light being emitted (see Fig.5). Comparing these results with the graphs contained in the specifications will validate the accuracy of the model versus the manufacturer's data.



Figures 5 Rectangular Candela plot from the first LED model resembles the specification angular distribution provided by the manufacturer (see figure 9b)

For the first model, the results given by TracePro approach the specifications of a side-emitting LED. The peaks at approximately 80 degrees off-axis are located correctly and the distribution looks like the one from real LED.

The results may vary due to the use of estimated dimensions, such as the shape and size of the inverted epoxy cone in this example. Designers can refine the models by getting the most accurate measurements possible. Remodeling the lens should spread the light in a more even distribution near the axis, matching the manufacturer specifications. While this modeling method is more time-consuming, it is necessary for the proper design of LED lenses, tolerance analysis and light pipe coupling studies. For further adjustments to the first model, the die's angular distribution on the top surface of the die can be changed to emit an altered pattern.

The second model gives us satisfactory results as shown in Fig. 6; it is an excellent far field source model for multiple LED, large scale systems in general lighting applications. Modifying the surface property will modify the light output to recreate the angular distribution desired. Many more angles can be entered in order to shape a more precise angular distribution of the LED, but for accurate coupling of this LED model and a light guide model, the geometric details lost can affect the final ray trace results. The second method does not model correctly the spatial emission distribution from the outer packaging of the LED, thus incorrect results in the near field are to be expected.

Please go to our website (www.lambdares.com) for complete tutorials detailing on these two LED designs.

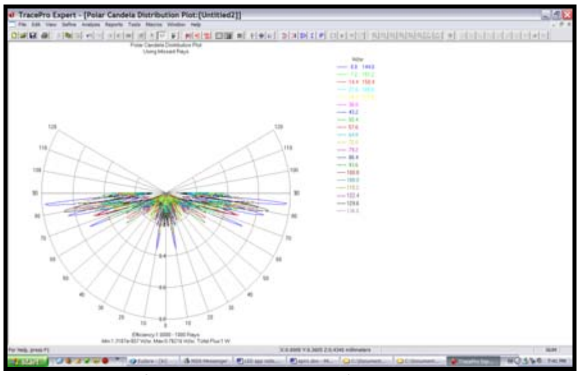


Figure 6a. Polar Candela Plot (simple surface absorptance LED): The plot shows the angular distribution as well as the intensity of the rays emitted in their respective direction.

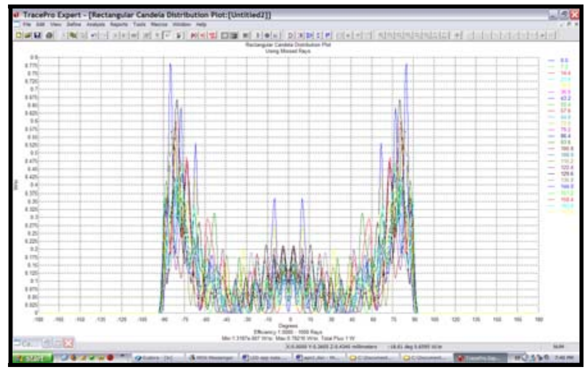


Figure 6b. Rectangular Candela Plot (simple surface absorptance LED): This plot also is roughly similar in shape to the actual specifications

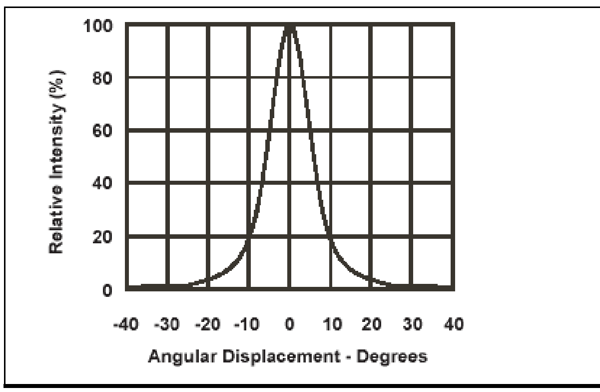


Figure 7a) Angular distribution of the naked LED die. While this emission pattern is Gaussian, copying this pattern onto the die of the detailed model may not reproduce the expected results, as some details and dimensions are missing.

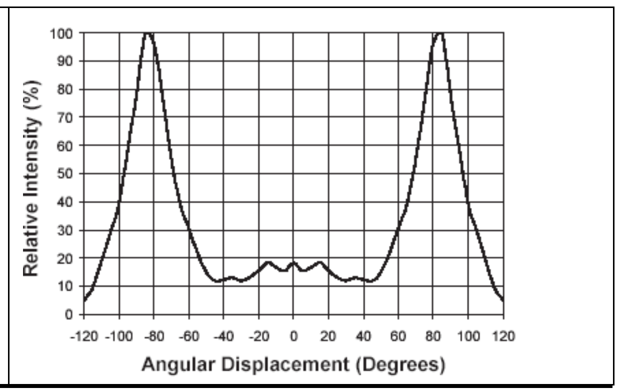


Figure 7b). Measured Angular distribution of the side-emitting LED. More light is emitted around 45 degrees off the central emission axis than on the TracePro model.

Luxeon is a registered trademark of Lumileds Lighting U.S., LLC. Information used in the modeling of this LED was found in Datasheets DS25 and DS23 found on www.lumileds.com