The Effects of UV Glass Optics on UV LED Arrays

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Maximizing the peak irradiance of a UV LED array is imperative in many UV curing applications. More power can improve production speeds and increase the depth of cure. UV LEDs are often arranged into linear arrays, where they are placed side-by-side in a row and are usually protected by a flat window or optic.

However, in many cases, optics used with the UV LED system are not designed efficiently. Therefore, we investigated the efficiency of two common optic types: Rod and TIR optics. Each optic's primary function is to increase peak irradiance at the cure surface and increase working distance. We examined which optic performs this task more efficiently and what the subsequent effects might be on the LED array.

One of the most common optics for increasing peak irradiance is the rod optic, which is often made from quartz. Rods are normally consistent in their diameter offering good optical performance and are resistant to thermal or mechanical stress. Glass TIR optics are an exciting technology that can be used for a number of performance improvements including increased uniformity and peak irradiance. These optics are new to the UV curing industry but offer a combination of array protection and improved optical performance.

A ray trace analysis of the optics while paired with a linear LED array was performed. The peak irradiance produced by each optic is noted with a thorough analysis of the efficiency of the optics performed. The array and fixture set up in the ray trace are identical for each optic.

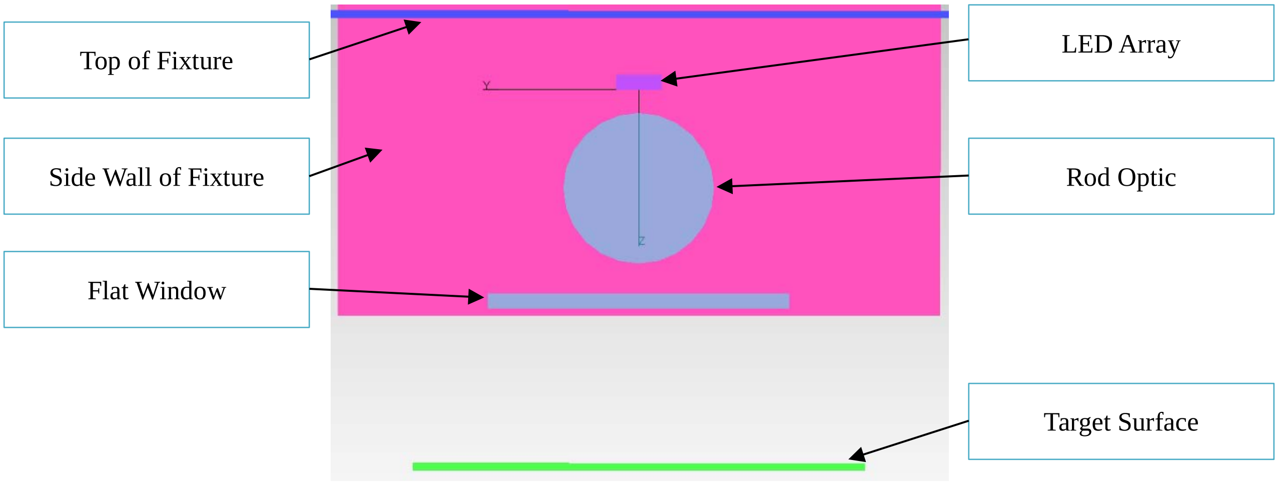
Description of Ray Trace Set Up

21 UV LEDs with a peak wavelength of 395 nm were placed in a linear row at a pitch of 4.5 mm on center. Each LED is designed to be driven at 1000mA / 3.5V producing 3W of optical power in a 120° beam angle. The array spanned 73 mm and was placed 24.75 mm away from the target (cure) surface.

Explanation of the Quartz Rod Optic

The rod optic used in this study is 100 mm long and 10 mm in diameter. The rod was paired with a 1 mm thick window, and both were placed in front of the UV LED array. (See Figure 1) A flat window is often used as a protective cover with a rod optic. The window protects the rod and the LED array from splatter or other chemicals used in the curing process. In addition to the rod, window, and cure surface, two other surfaces were added to the ray trace that represented the fixture walls around the LED array. These additional surfaces were used to capture some of the rays that missed the optic and used to calculate the amount of backward reflected rays.

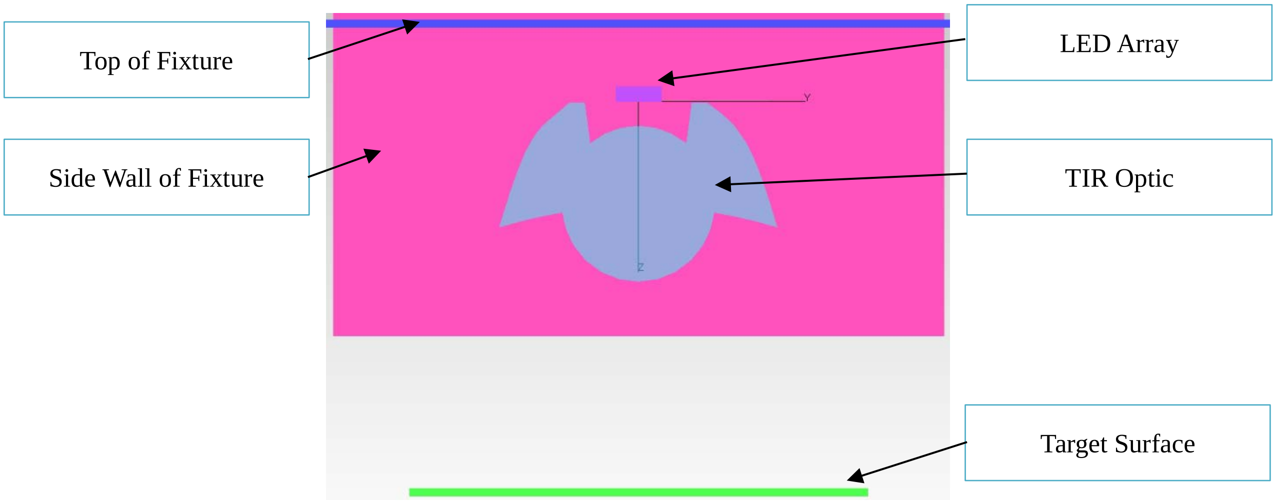
FIGURE 1: Rod Optic Set Up (Front view)



Explanation of the TIR (Total Internal Reflection) Optic

The Total Internal Reflection, or TIR, optic is a highly efficient lens that has traditionally been used in general lighting applications since the adoption of LEDs. This optic has been adapted for use with UV LEDs. A TIR optic manufactured as a ‘strip’ (or linear) lens can be paired with a row of UV LEDs. In this study, the TIR optic was designed to be 100 mm in length. The same ray trace set up as the rod optic was used. (See Figure 2) The flat window was removed because the TIR optic also serves as a protective window unlike the rod and will prevent foreign objects from entering the LED assembly.

FIGURE 2: TIR Optic Set Up (Front view)



Ray Trace Analysis

UV ray trace simulations were performed using 210,000 rays. The peak irradiance and flux were examined on the target surface as a preliminary comparison. The initial measurement is shown in Table 1.

TABLE 1

Optic	Peak Irradiance	% flux to reach target surface
No Optic	2.30 W/cm^2	60.8%
Rod Optic	7.65 W/cm^2	70.9%
TIR Optic	10.11 W/cm^2	86.9%

Both optics increased the peak irradiance and refracted more energy towards the target surface than the LED array without an optic. When comparing the two optics, it is evident that the TIR optic is more efficient than the rod. The ray trace was examined to find where the inefficiencies were within the optical systems. It was found that there are four main areas to which energy is lost and are labeled as follows: optic design, missed rays, flat window, and fixture walls with summaries provided below.

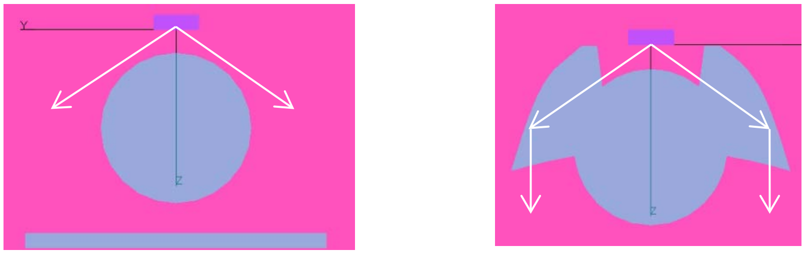
Optic Design

The design of an optic will likely have some inefficiency by increasing the number of rays lost to both reflection and absorption. In the case of a simple rod optic, some of the rays are reflected backward off the incident surface. Additionally, some rays that enter the optic are absorbed, and others are trapped within in the material because of the rod curvature. Approximately, 9.4% of the emitted flux was lost because of the rod design. Consequently, the TIR optic is more complex in design, which causes a reflection and absorption of 11.9%.

Missed Rays

Although the rod design appears to be slightly more efficient, the rod actually misses a large portion of the rays emitted by the 120-degree beam UV LED. 10.1% of the rays emitted by the LED do not contact the rod; meaning they are lost either within the fixture or, as in our case, they miss the target surface completely. The TIR optic attempts to capture the rays the rod misses. Figure 3 helps depict this distinct advantage. The rays (white arrows) miss the rod. The same rays are captured by the additional surfaces molded into the TIR optic, and the rays are refracted towards the target surface.

FIGURE 3: Rod Optic (Left), TIR Optic (Right)



Flat Window

A flat window cover is necessary with a rod in many applications. This window is a protective barrier that prevents foreign objects from penetrating into the LED array housing. The TIR optic does not utilize a flat window because the exit surface of the optic also acts as a protective cover. The flat window reflects and absorbs up to 8% of the incident energy. The refractive index and thickness of the flat window material plays a factor in this percentage.

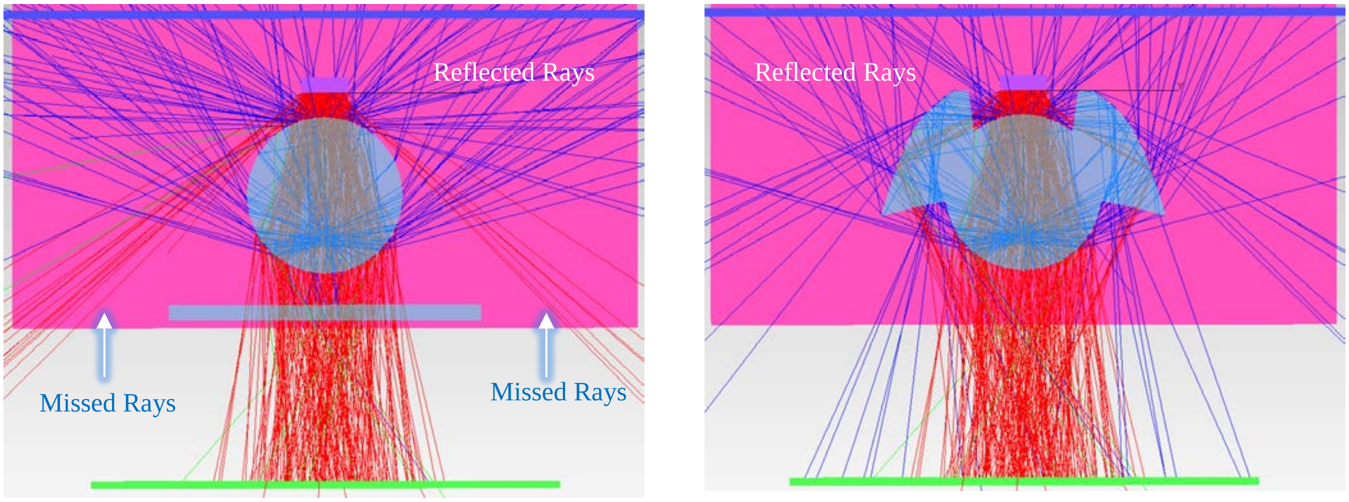
Fixture Walls

Some of the light emitted by the LEDs does not contact the optic directly and may reflect off of the walls of the fixture. In this study, we examined the side walls that would be located at the very edge of the optics. The incident light on the fixture walls was minimal: 1.6% for the rod and 0.7% for the TIR. The difference in incident light is likely do to the design of the TIR lens that prevents some of the light from reaching the sidewalls of the fixture.

Diagram of Ray Trace

The two main contributors to inefficiencies of the optics are missed rays and optic design. In Figure 4, the blue rays are reflected rays that have first contacted the optic but were reflected back towards the LED array. By tracing the ray path, you can see that the incident and the exit surface of the optics cause a significant amount of reflection. The missed arrays (red rays that labeled “missed rays”) are evident in the rod ray trace. Notice how they miss the rod completely, but the TIR optic does not have this issue.

FIGURE 4: Ray Trace



Summary of Results

TABLE 2

	Rod	TIR
Optic Design	9.4%	11.9%
Missed Rays	10.1%	<0.5%
Flat Window	8.0%	0.0%
Fixture Walls	1.6%	0.7%
Total:	29.1%	13.1%

The TIR optic is 16.0% more efficient than the standard rod in this scenario. However, the question remains, what effect does this efficiency have on the LED array?

Based on the Forward Current vs. Normalized Radiant Power measurement for the UV LED used in this study, the LED would have to be driven 160mA more than with the TIR optic in order to account for the 16% loss in efficiency when using the rod. To determine the excessive wattage required to achieve equal radiant flux, we can multiply the voltage by the current. The forward voltage for the LED is 3.5 V. Therefore, 160mA * 3.5V = 0.56W required to match the flux emitted through the TIR optic.

In this simulation, there were 21 LEDs which means this array requires (0.56W*21 LED) 11.76 additional watts of power. The additional wattage increases quickly when considering systems that have hundreds or even thousands of LEDs. This inefficiency can escalate rapidly and hinder LED systems that are meant to be power saving devices.