



THE EFFECTS OF UV GLASS OPTICS ON UV LED ARRAYS

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INTRODUCTION

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.

EXPERIMENT

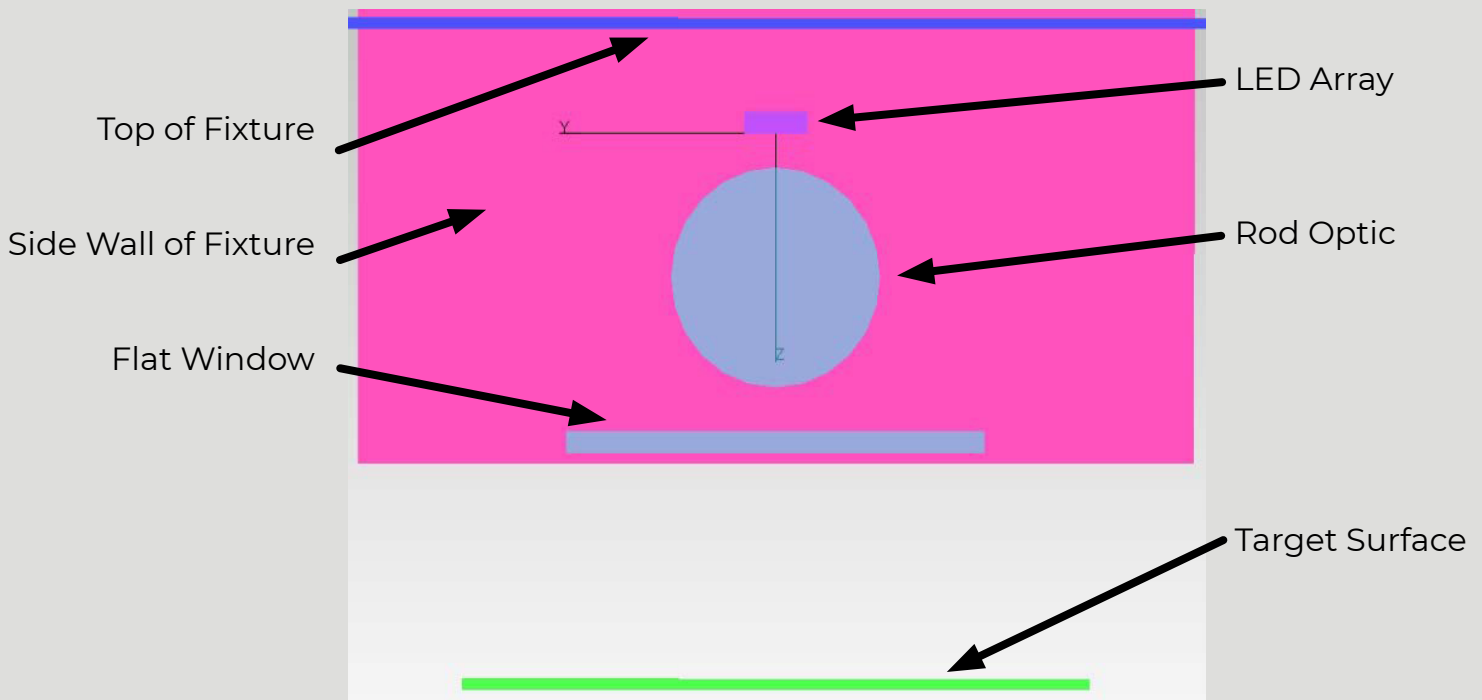
DESCRIPTION OF RAY TRACE SET UP

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.

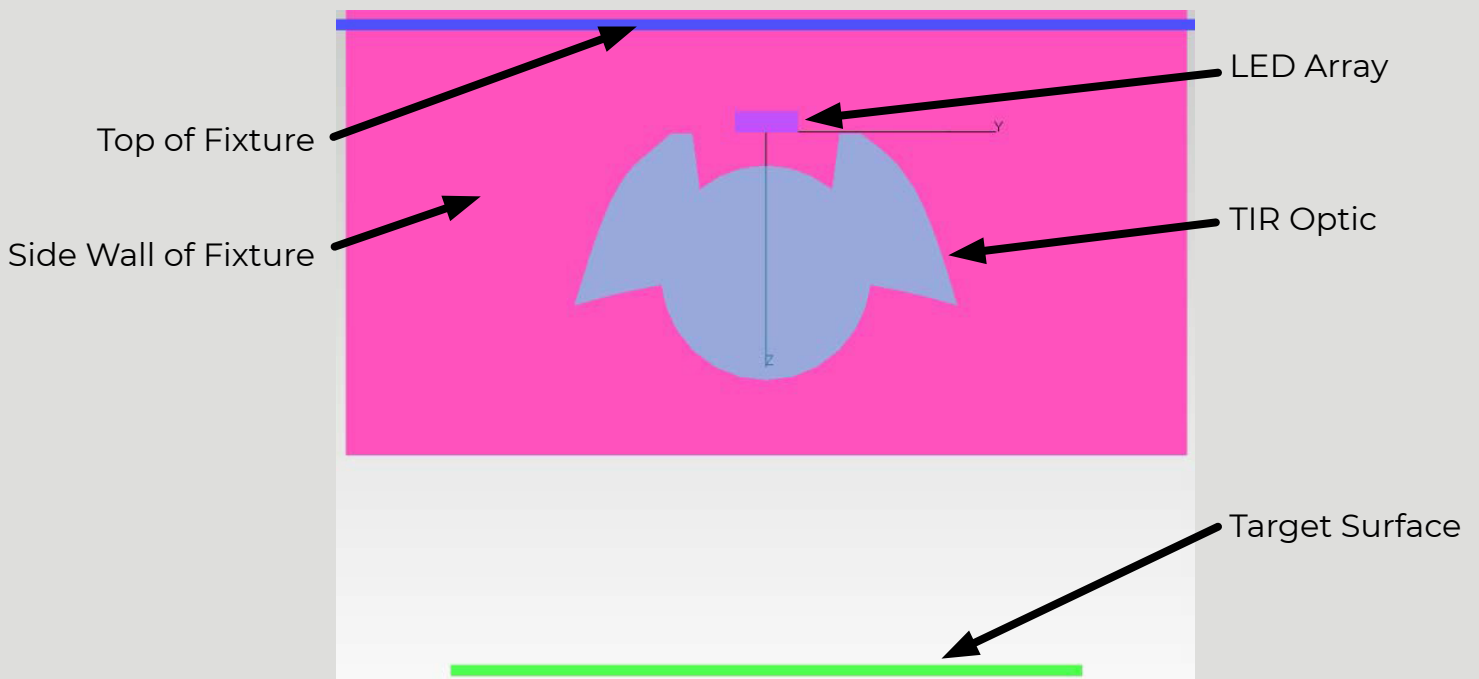
Figure 1: Rod Optic Set Up (Front view)



EXPLANATION OF THE TOTAL INTERNAL REFLECTION (TIR) 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.

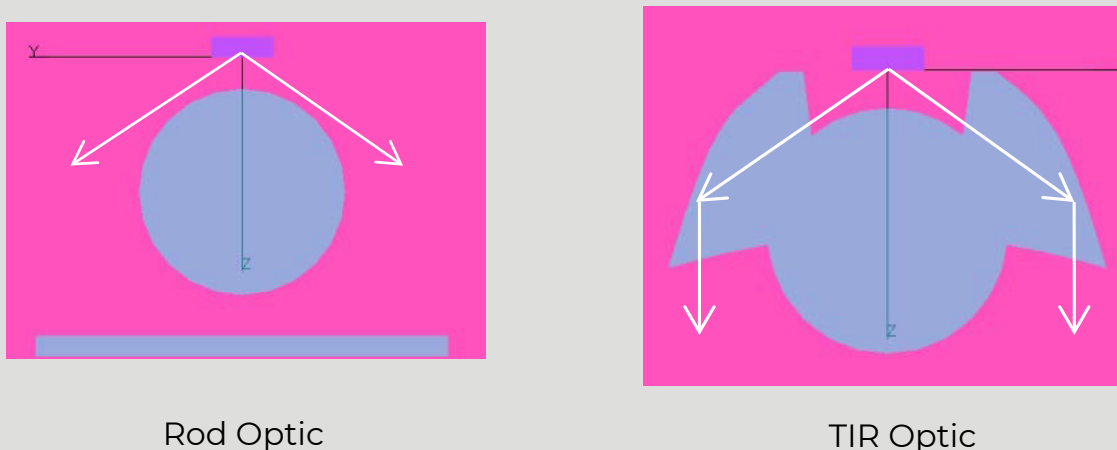
OPTIC DESIGN

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 vs. TIR Optic



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

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Figure 4: Ray Trace

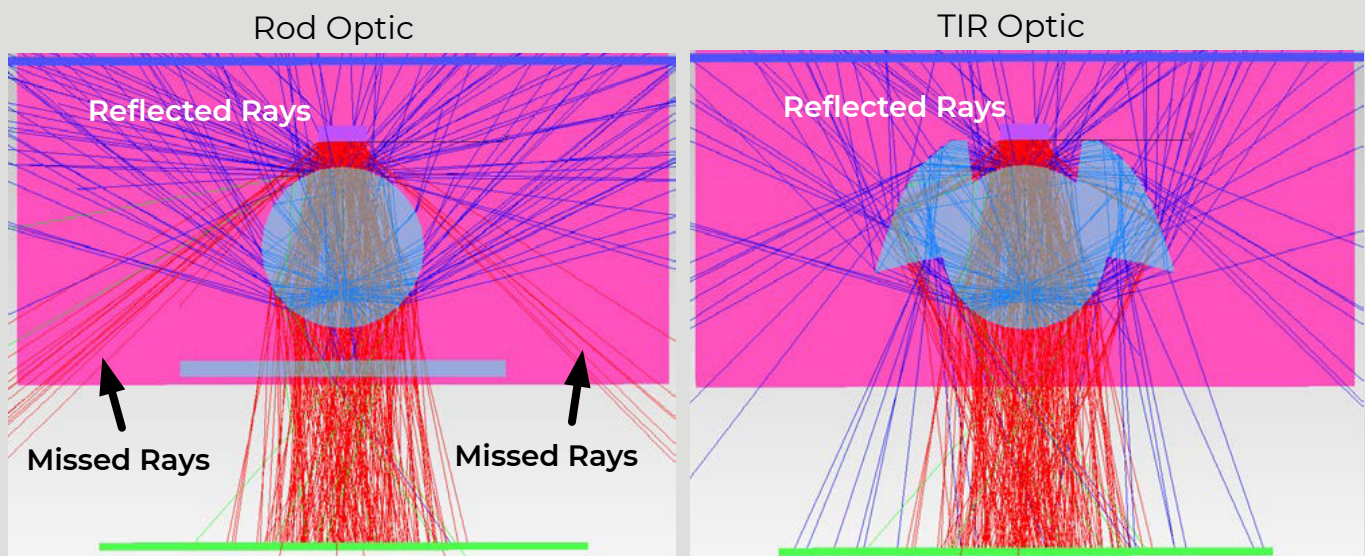


DIAGRAM OF RAY TRACE

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.

SUMMARY OF RESULTS

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?

Table 2: Results

	Rod Optic	TIR Optic
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 %

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, $160\text{mA} * 3.5\text{V} = 0.56\text{W}$ required to match the flux emitted through the TIR optic.

In this simulation, there were 21 LEDs which means this array requires $(0.56\text{W} * 21 \text{ LED})$ 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.



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Location Pittsburgh, PA USA

No. of Employees 85

Mfg. Sq. Ft. 127,000

Quality System ISO: 9001:2015

The Effects of UV Glass Optics on UV LED Arrays

RadTech 2018

May 8, 2018



OVERVIEW

- UV Applications and Technology
- Fused Silica Rods and UV Glass Optics
- Material Properties of Glass
- Simulation and Results



UV APPLICATIONS

- How do UV LEDs fit into current applications?

Analytical
Instruments

Laboratory
Testing

Phototherapy

UV Curing

Counterfeit
Detection

Water & Air
Purification



TRADITIONAL TECHNOLOGY

Traditional
Lamps

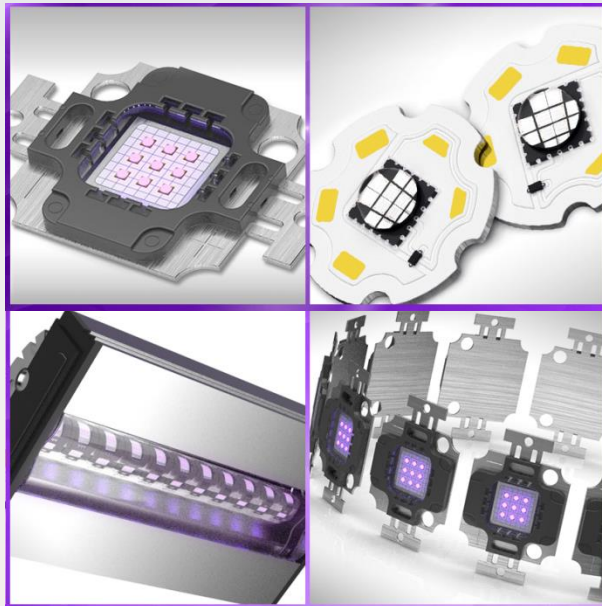


Fused Silica
Sleeves and
Tubes



ENABLING TECHNOLOGY

UV LEDs

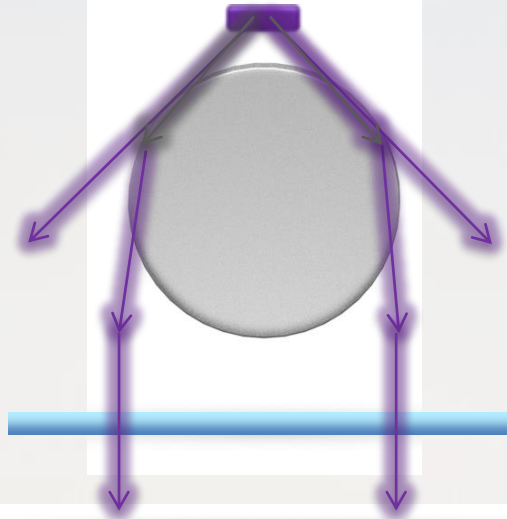


Molded UV
Glass Optics

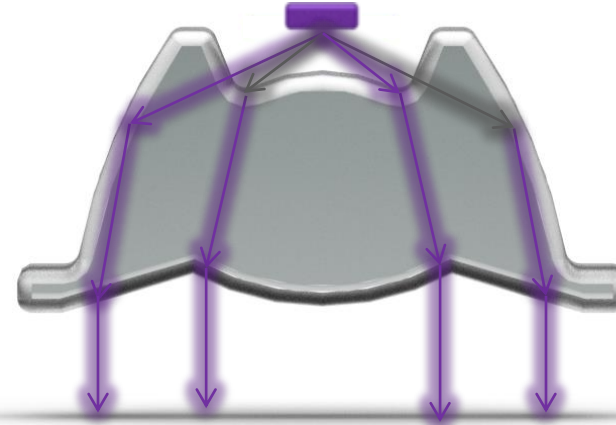


UV OPTIC MATERIALS

Fused Silica



UV Glass

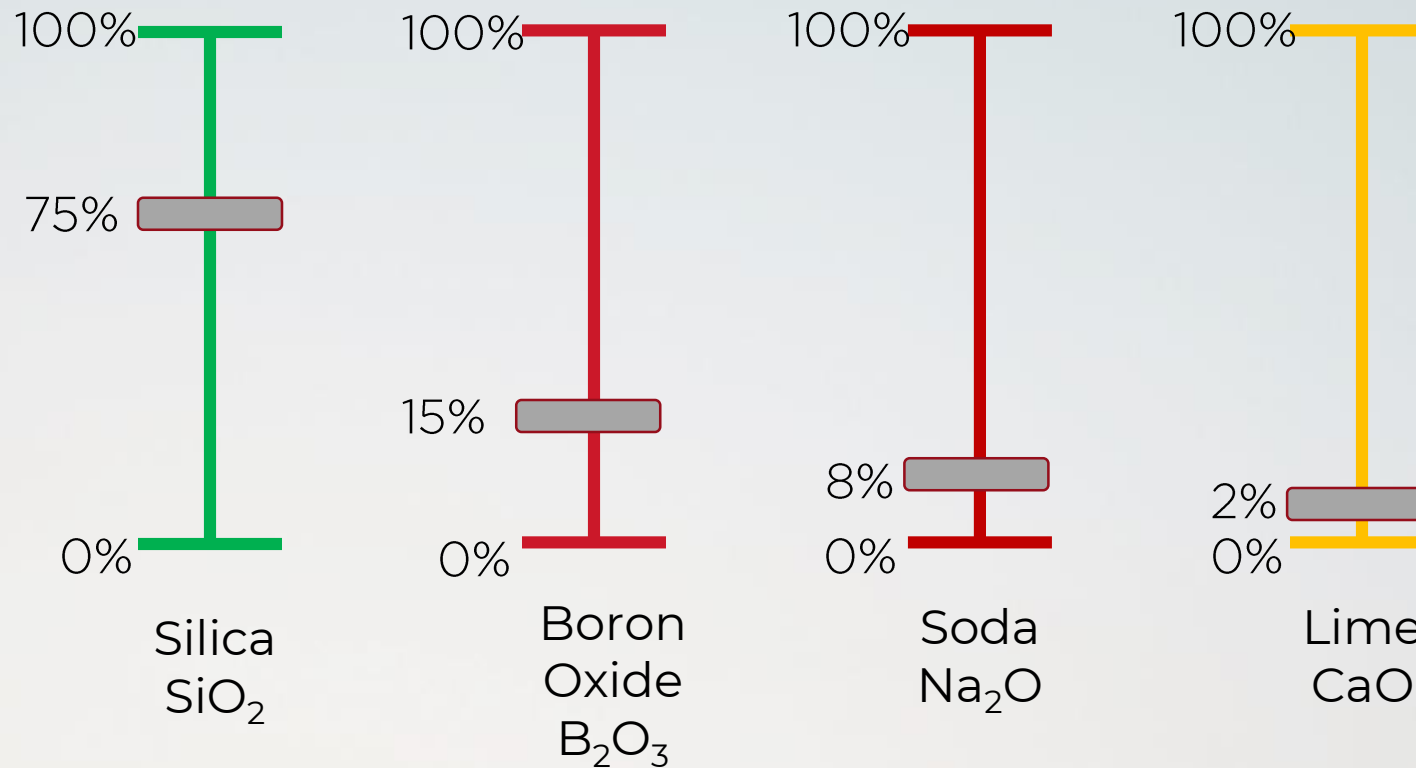


COMPARING THE TYPES OF GLASS

Glass Type	Glass Components	Applications
Borosilicate	SiO ₂ (silica) B ₂ O ₃ (boron oxide)	Industrial equipment, Exterior lighting, Laboratory glassware, Kitchenware, UV glass
Soda Lime Silicate	SiO ₂ (silica) Na ₂ O (soda) CaO (lime)	Food and beverage containers, Windows
Phosphates	P ₂ O ₅ (phosphorous oxide)	Internal lighting – (NVIS), UV glass, Optical Fiber, Biological material, Heat absorption
Fused Silica	100% SiO ₂ (silica)	Optical fiber, Astronomical mirrors, UV glass



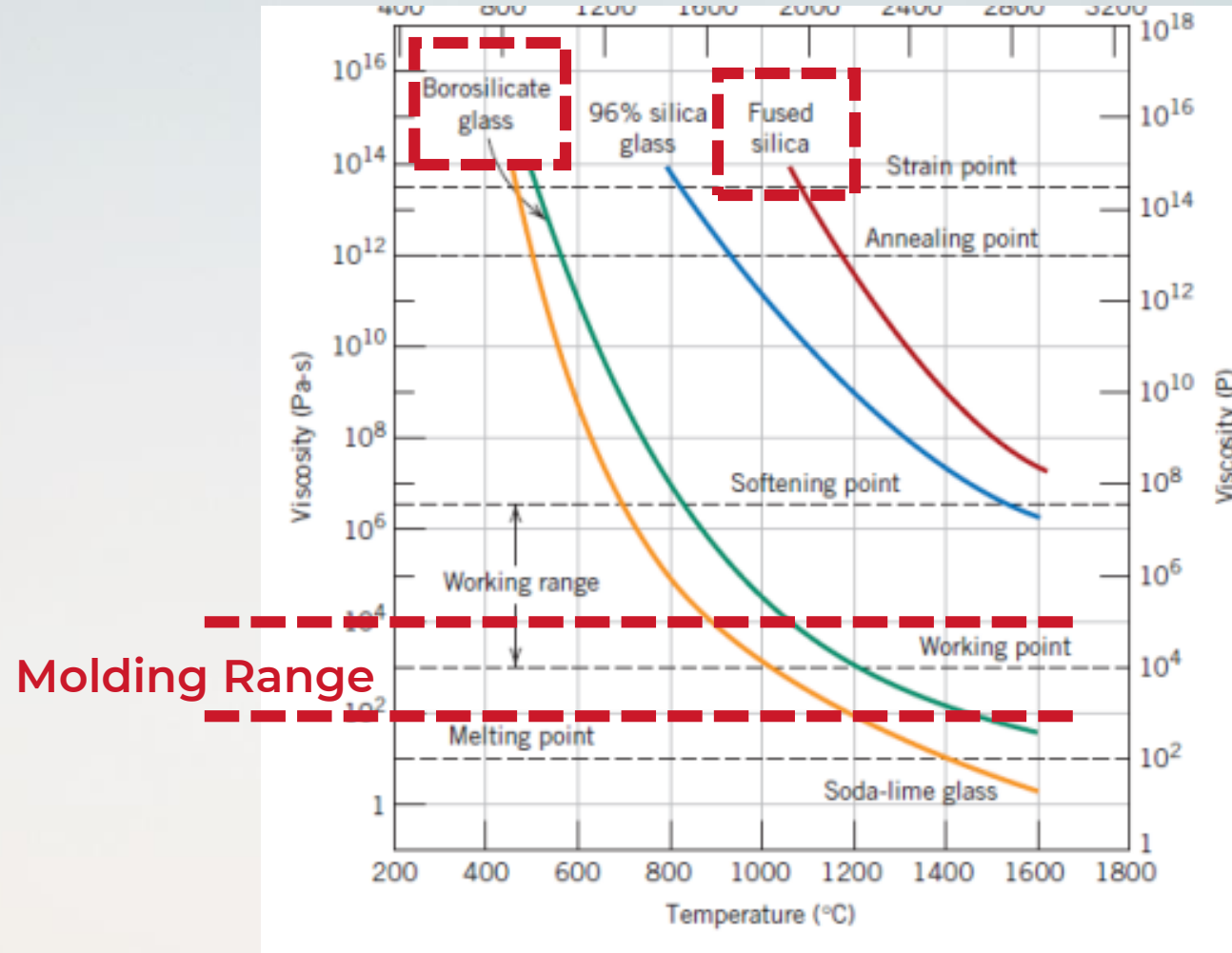
AMOUNT OF OXIDES DETERMINES PROPERTIES



Properties are *customizable* by precisely changing the oxide percentages



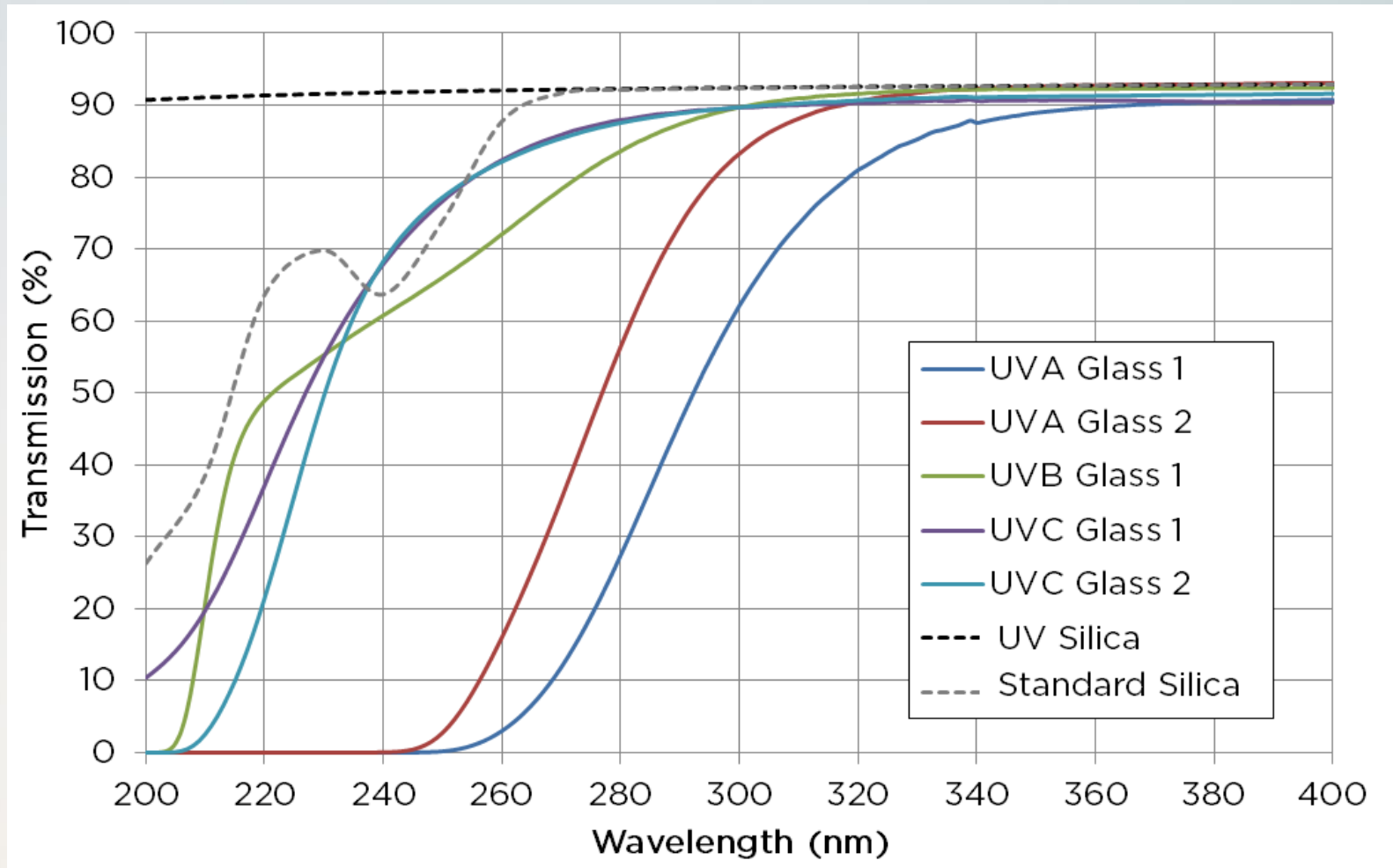
GLASS VISCOSITY ALLOWS MOLDING



From EB Shand, *Engineering Glass*, Modern Materials, Vol. 6 Academic Press, New York, 1968 p 262



UV GLASS OPTICAL PROPERTIES



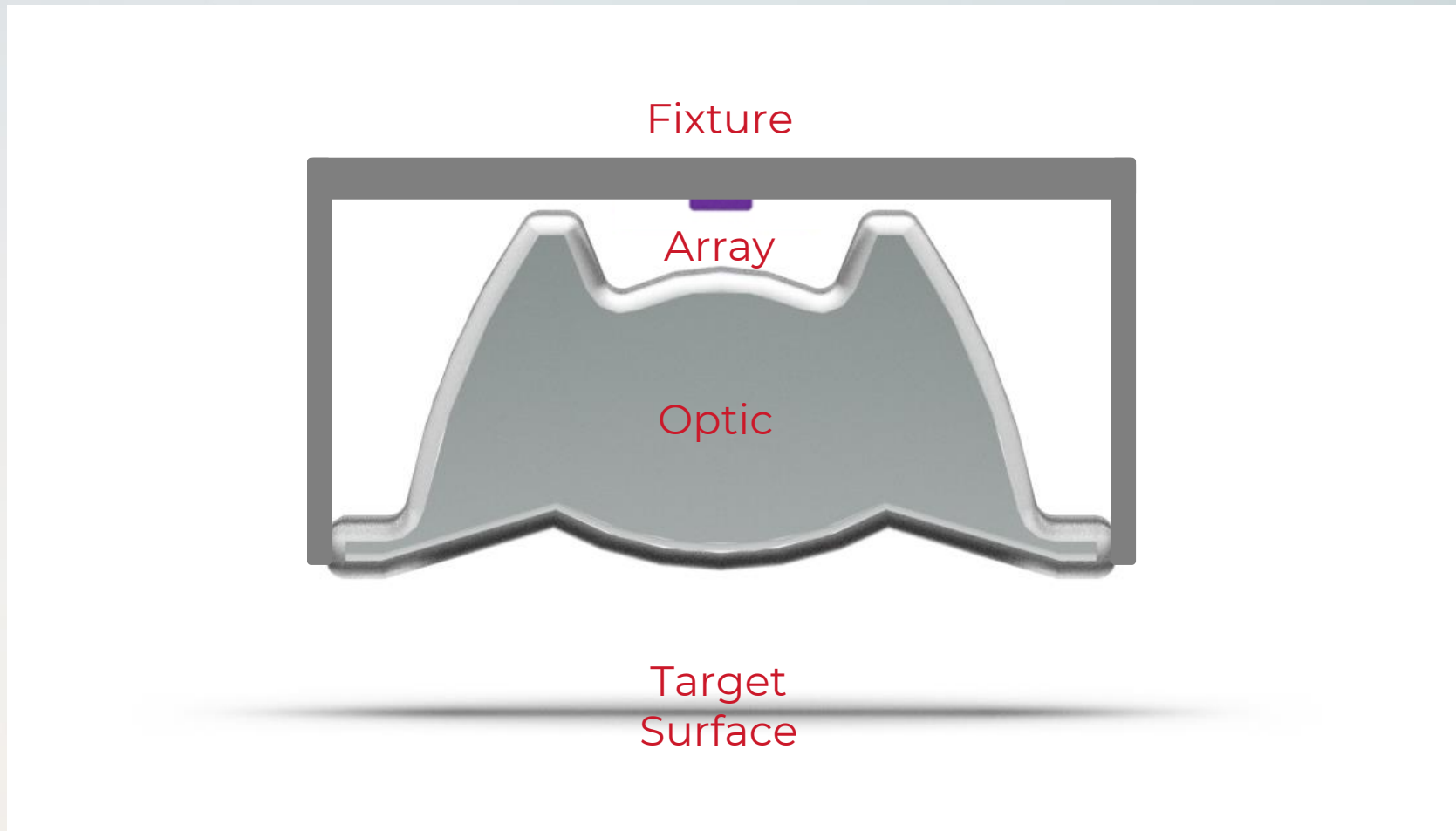
UV GLASS OTHER PROPERTIES

- Point 1

	UV Borosilicate	UV Soda Lime Silicate	Fused Silica
Refractive Index	1.46	1.51	1.40
Coefficient of Thermal Expansion	30-60 E-7/°C	80-100 E-7/°C	5 E-7/°C
Thermal Shock Resistance	Average-High	Low	High
Chemical Resistance	High	Average	High
Shapes	Custom Molded Optics, Rods and Tubes, Windows	Custom Molded Optics, Rods and Tubes, Windows	Fabricated Optics, Rods and Tubes, Windows,

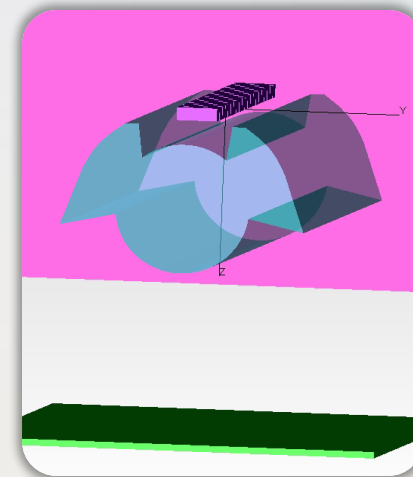
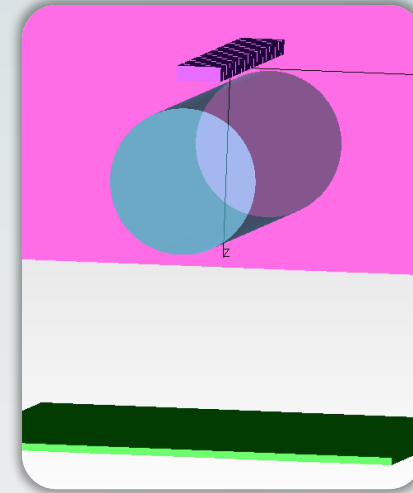


SIMULATION DESIGN AND SET-UP



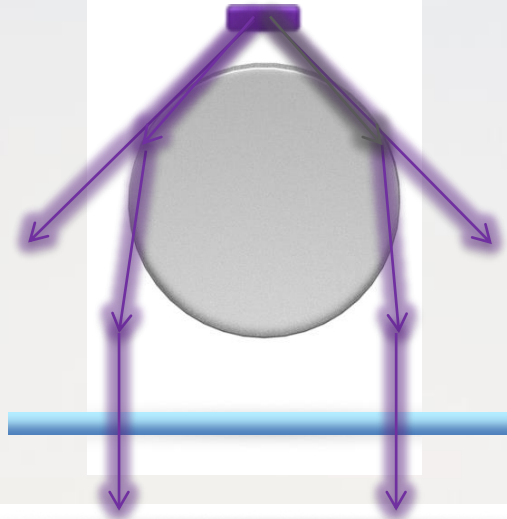
SIMULATION PARAMETERS

- TracePro
- 210,000 rays
- 21 LEDs
- Target Area: 30 x 100 mm
- Working Distance: 25 mm
- Wavelength: 395 nm
- Radiant Flux: 3W / LED

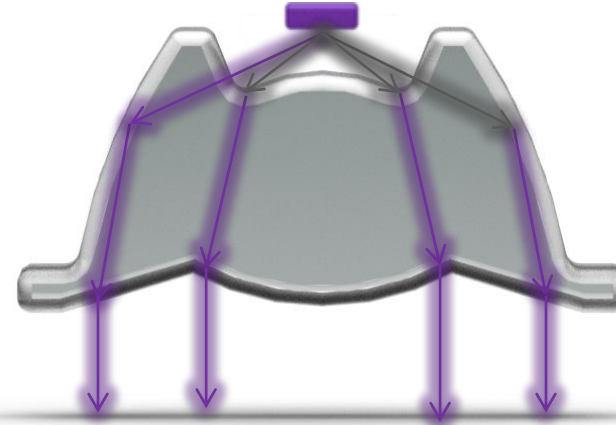


OPTICS USED IN THE SIMULATION

Rod



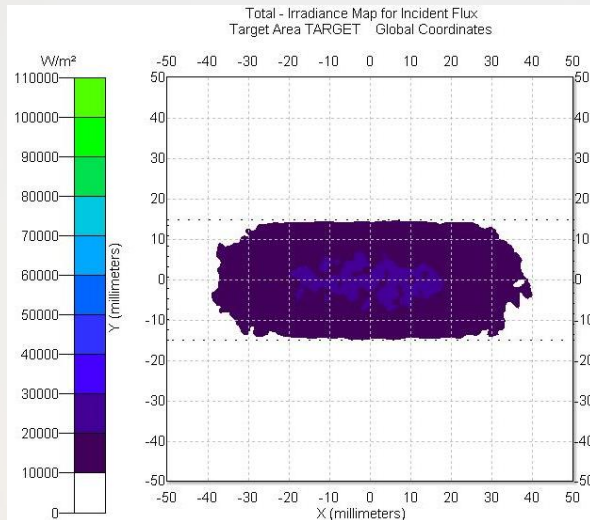
TIR Optic



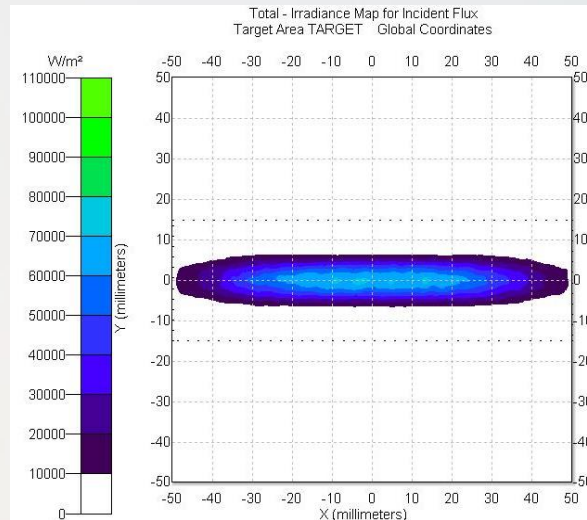
SIMULATING RESULTS

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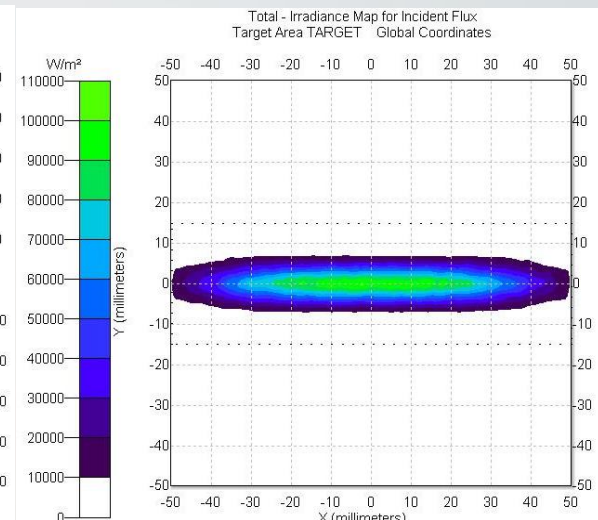
No Optic



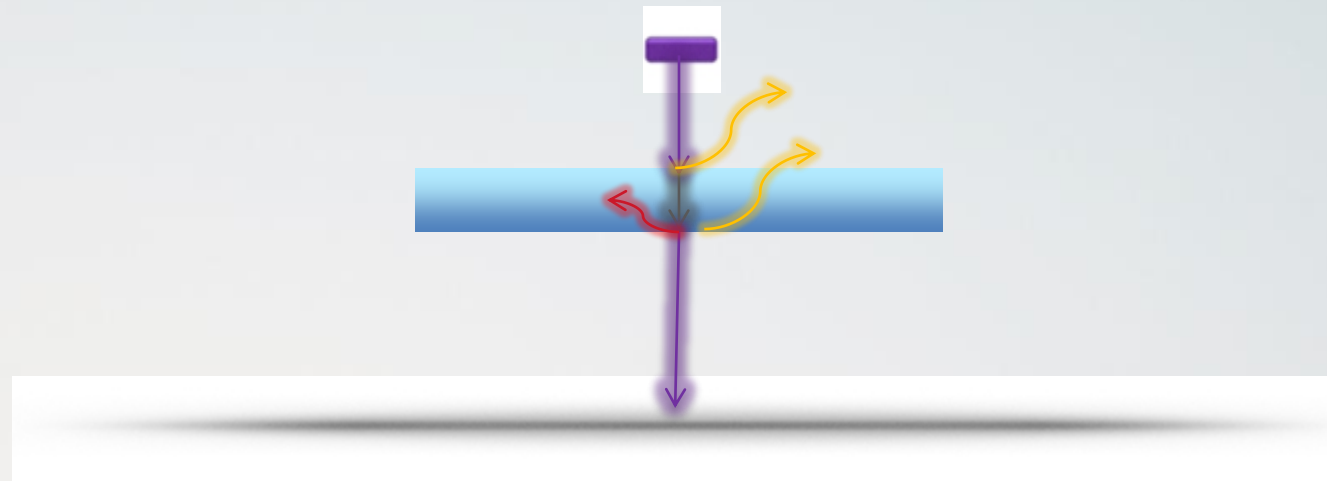
Rod Optic



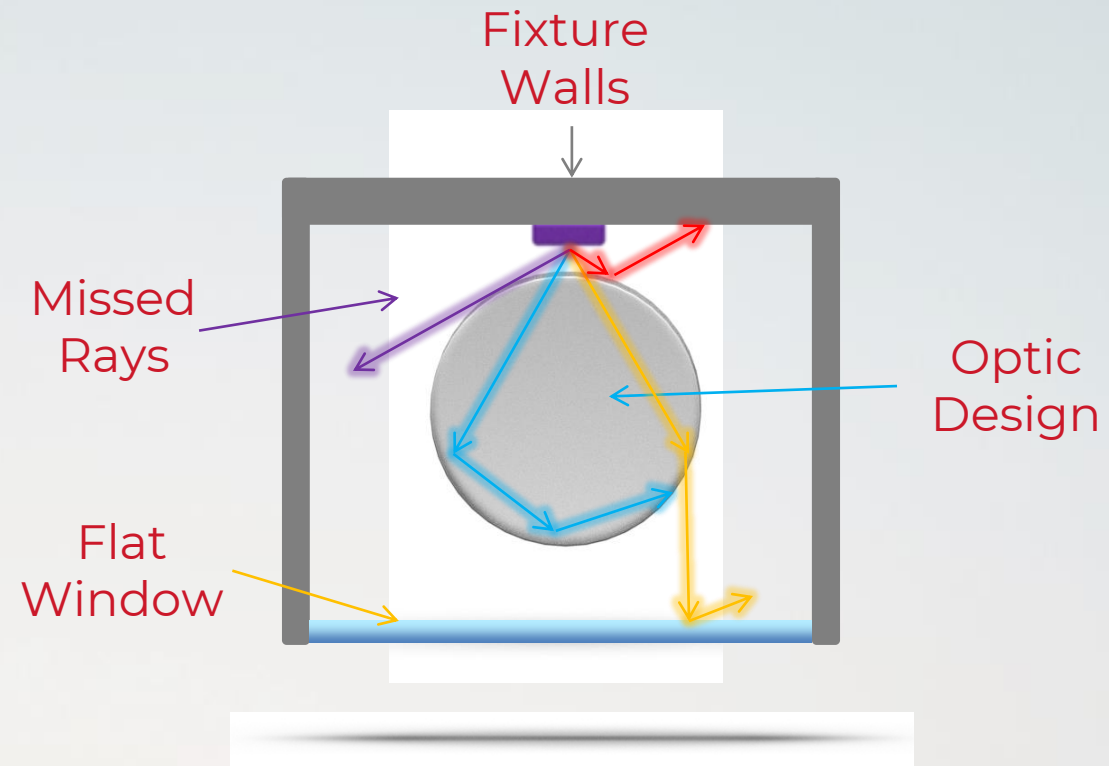
TIR Optic



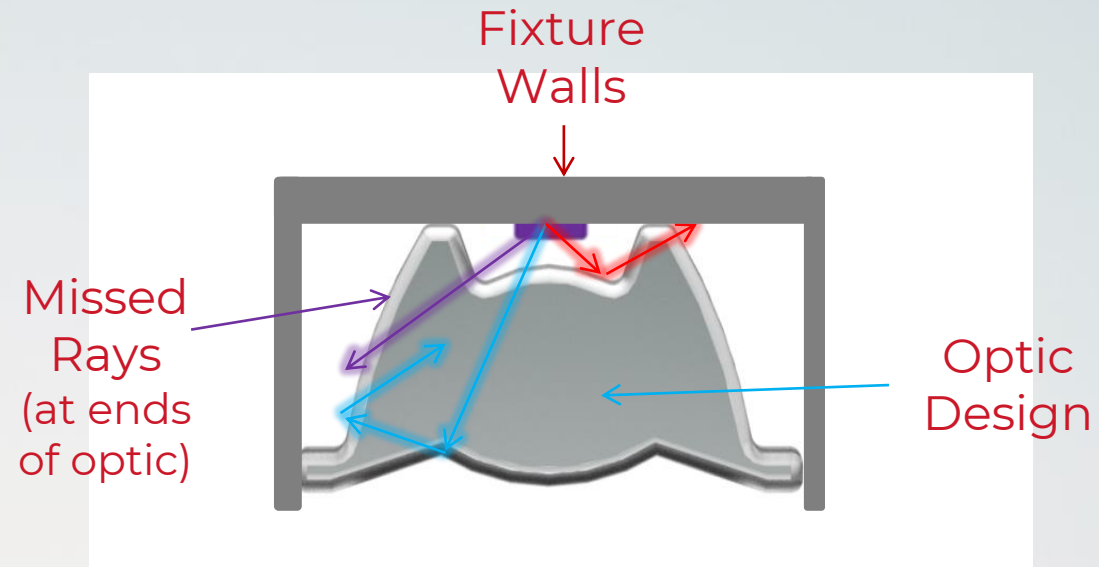
ENERGY LOST: REFLECTION AND ABSORPTION



ENERGY LOST: ROD OPTIC DESIGN

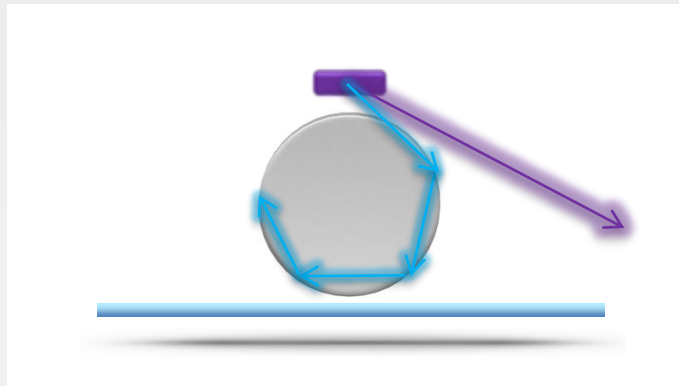


ENERGY LOST: TIR OPTIC DESIGN



SUMMARY OF OPTIC EFFICIENCY

	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%



WHAT EFFECT DOES EFFICIENCY HAVE ON THE LED ARRAY?

- The rod optic requires an additional 160mA per LED.
- Using 3.5V per LED, this requires a 0.56 W increase in power.
- 21 LEDs in our simulations require 11.76W more with a rod vs. a TIR optic.



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- Increased flux on target surface
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