APPLICATIONS NOTE

Mixing Chamber Design Considerations for

ChromaLit™ Remote Phosphor Light Sources

7/07/2011

Introduction: This document contains technical information for mixing chamber materials and designs. The mixing chamber is a critical component along with the high output blue LED excitation source and high conversion efficiency ChromaLit remote phosphor. With a properly designed mixing chamber, light sources with extremely high luminous efficacy, low glare, and uniform light output are possible. With a properly designed mixing chamber and high wall plug efficiency LED, efficacy improvements of 30% over white LED systems can be achieved.

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Specular and Diffuse Reflectance

Specular and diffuse reflections are shown in Figure 1. The mirror-like reflection of the specular ray (blue) has the same incident and reflected angles. The diffuse rays are spread over a wide angle. If Lambertian, then the observed brightness is independent of viewing angle. Reflection from an irregular surface will provide a diffuse reflectance that can be designed to be nearly perfectly Lambertian. Most surfaces used for mixing chambers have microscopic features such as ceramic particles or microscopic surface texture that results in high diffuse reflectivity.

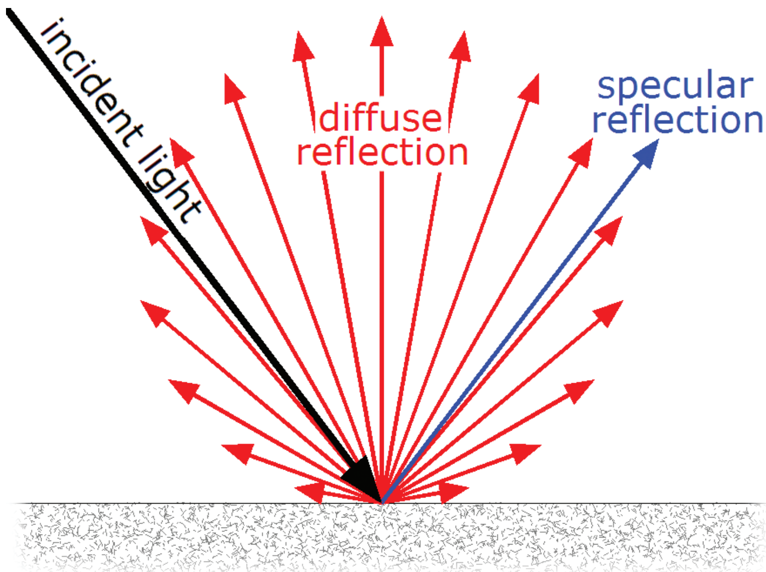


Fig 1.

Basic Theory of Mixing Chamber Operation

Standard white LED light source systems require diffuse optics to properly distribute the light from the individual LEDs. Typical losses due to the diffuse optics are 8-10% or higher depending on the uniformity requirement. The alternative system approach as shown in figure 2 is a blue LED pump which illuminates a phosphor source (ChromaLit) that is remote from the LED die. The blue LED and remote phosphor approach provides a low glare system capable of up to 30% higher luminous efficacy.

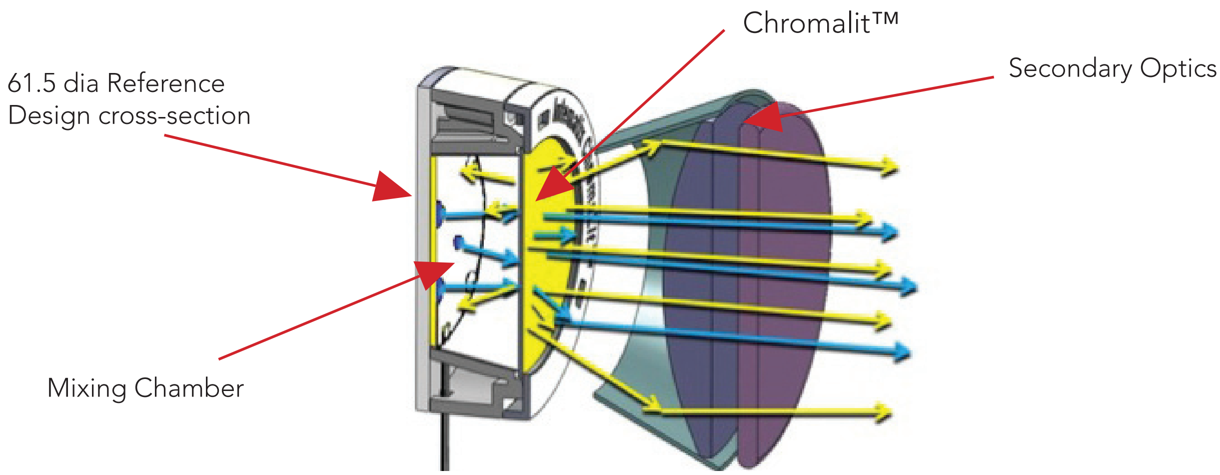


Fig. 2 LED rays – blue, down converted rays - yellow

Reflectivity of mixing chamber	Remote phosphor system improvement
99%	30%
98%	22%
97%	19%
96%	15%
95%	11%

Fig. 3

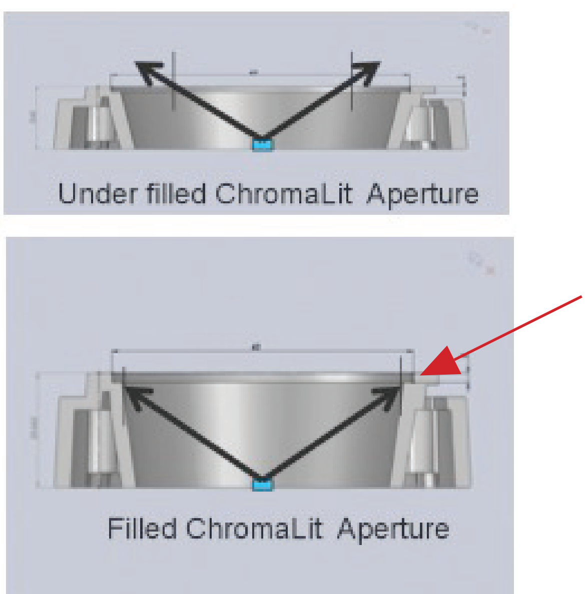
The mixing chamber in a blue LED system with remote phosphor requires a broad spectrum high reflectivity material between the blue LED(s) and the remote phosphor source. With this configuration, the color and spatial mixing of the light is optimized. The output beam is then exceptionally uniform with regard to color and brightness across the exit aperture of the remote phosphor.

The output efficiency of the ChromaLit LED lighting system is impacted by the reflectance of the mixing chamber material. Figure 3 above shows the approximate improvement in system efficacy for the remote phosphor system compared to an equivalent white LED system as a function of mixing chamber diffuse reflectance. With 99% reflective mixing chamber material a 30% gain in efficacy is achievable.

A diffuse reflectance material as opposed to specular is recommended so that a uniform Lambertian distribution is obtained. Use of any specular reflector material is not recommended in the mixing chamber since most specular materials will have significantly lower reflectivity. Furthermore, since the down converted rays directed back into the mixing chamber are highly diffuse already, a specular reflector will simply create a return of diffuse rays. The distance between the LED and remote phosphor is also less sensitive when using a diffuse material that creates additional ray bounces before exiting the remote phosphor.

The mixing chamber is best designed so that its aperture size and shape matches the remote phosphor size and shape. Maximizing the mixing chamber reflective surface area surrounding the LEDs and keeping LED surface area low ensures a higher efficiency mixing chamber. For large LED arrays, some chamber efficiency is sacrificed due to this lower reflective surface area around the LED. It is good practice to leave about 1mm around the LED emitting region, cover any non radiating portions that would absorb light, and minimize any ray trapping around the LED by using thin material and chamfers on the leading edge near the LED.

Figure 4 shows cross sections of mixing chambers with a single LED. The mixing chamber at the bottom ensures that the LED viewing angle fills the ChromaLit aperture. The mixing chamber at the top does not provide sufficient distance and the remote phosphor is underfilled. A good starting point for height to width ratio is 1:3. Output will drop for deeper mixing chambers due to more ray bounces along the walls of the chamber prior to impinging the remote phosphor.



About 3.5% greater output for this 10mm high low profile design compared to 20mm high standard shown below due to reduced ray bounces.

Note: its good practice to use a reflective material surrounding the outer diameter of the remote phosphor light source to reduce edge losses.

Fig. 4

The graphs below show the performance differences in terms of total luminous flux and CCT for the standard height (20mm), half height (10mm), and quarter height (5mm) mixing chamber reference designs. Total luminous flux is up about 3.5% from 20mm height to 10mm height with little additional increase under 10mm height. The CCT is nearly identical for all.

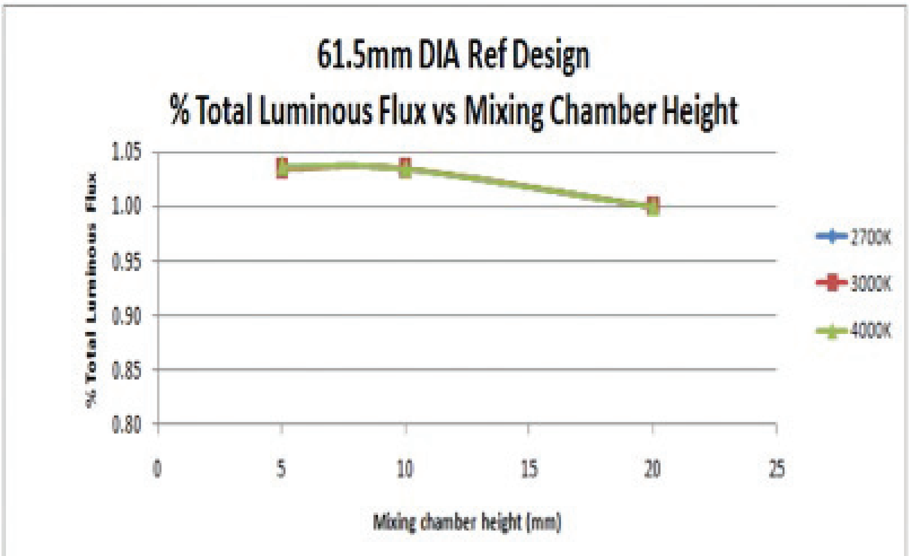


Fig 5.

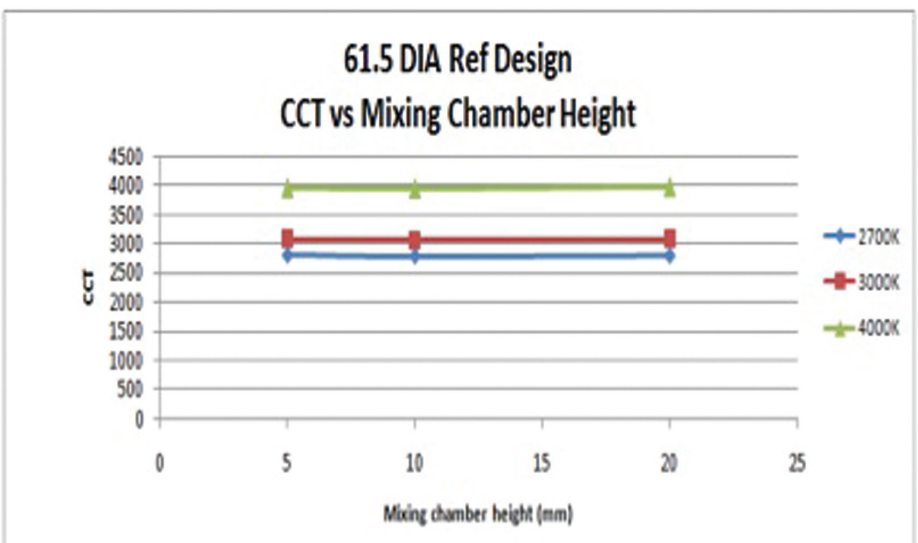


Fig. 6

The photograph below shows a 6 LED round Intematix reference design. The mixing chamber consists of a bottom reflective MC-PET (Furukawa) material die punched or laser cut and a side reflector band. A chamfer around the LED opening is recommended to minimize light loss at high angles from the LED.

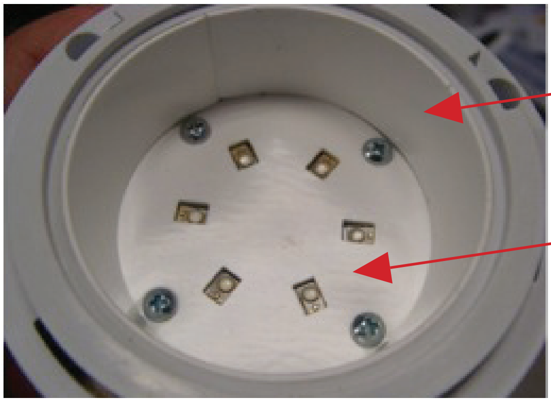


Fig. 7

The data below shows the impact of removing the bottom reflector in the assembly in fig. 7. With the diffuse reflector in place the lumens are 240 and without the reflector it drops to 209.9.

Test Configuration

Number	I(A)	U(V)	P(W)	Lumens	x	y	Tc(K)	Ra	Eff.(lm/W)
Standard reflector	0.1601	16.69	2.673	240.0	0.433	0.400	3032	79.5	89.81
PC board only	0.1601	16.7	2.673	209.9	0.422	0.394	3192	80.4	78.54

Data measured at battery current equivalent

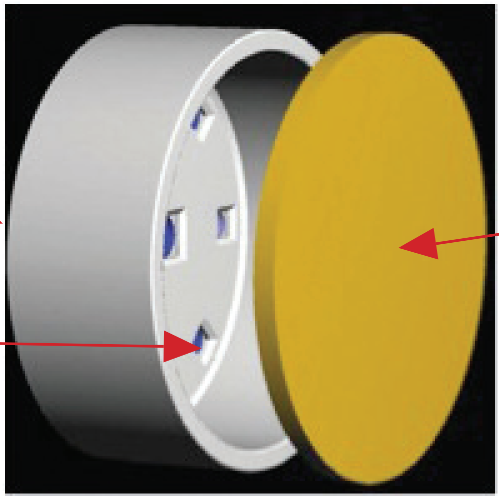


Fig. 8

Figure 8 shows an example of a one-piece CerFlex mixing chamber with remote phosphor source.

The CerFlex mixing chamber combines the bottom and side reflector into one piece. The bottom is designed in such a way that is has an exact and tight fit with the LEDs. The edges of the LED apertures have a small chamfer to maximize utilization of the generated light.

For linear LED arrays as shown in figure 9, a mixing chamber will have a bottom reflector strip covering the LEDs as well as side reflectors. The design could also be a one piece trough with cut outs for the LEDs. As with the round remote phosphor, a pressed one piece U-shape trough design could be utilized but might have to consist of multiple sections depending on the overall length.

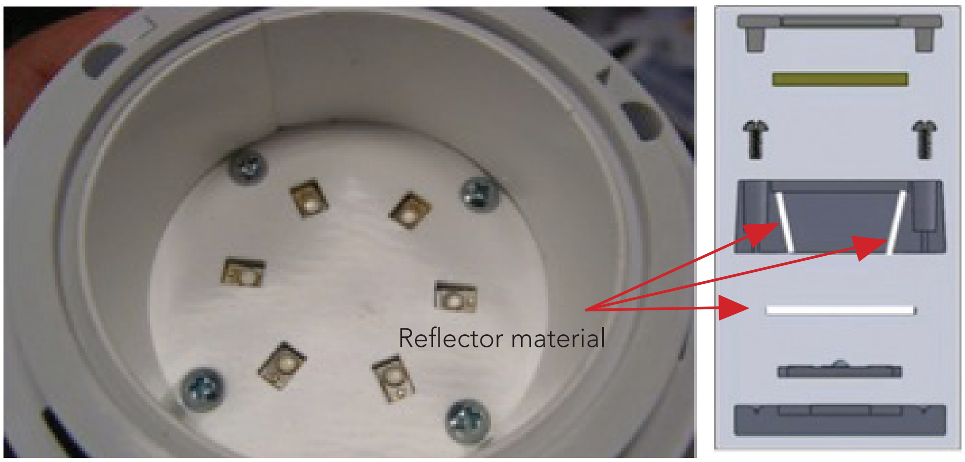
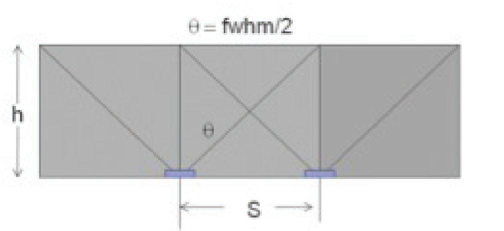


Fig. 9

The surface luminance uniformity of light for the linear case is a bit more sensitive to LED separation and mixing chamber height; however, far field beam pattern can still be quite uniform. Some indirect applications may in fact not be sensitive to surface luminance. In general, the remote phosphor design approach lends itself to linear lighting with reduced multiple shadowing even when some surface luminance variation is observed.

A good starting point for the linear array is to design the mixing chamber height and LED separation as to overlap the full width half maximum of one LED over the peak of the subsequent LED as shown in fig.10 below. Using this method, for a chosen mixing chamber height of 12mm, and with an LED with fwhm = 120 degrees, the recommended LED separation is 21mm. Without advanced optical modeling, experimental verification of uniformity is recommended for the specific lighting requirements.



$$S = h \times \tan(fwhm/2), \text{ or } h = S/(\tan(fwhm/2))$$

Fig 10. Side view of Linear Design

Mixing Chamber Materials

CerFlex International manufactures mixing chambers based on a highly reflective (99.2%) ceramic material. This patented material called CerFlex®TECH is produced in different shapes and sizes according to your needs. CerFlex®TECH can withstand any temperature and is extremely stable over life. The material produces a 100% diffuse reflectance and has a very flat reflectance curve.

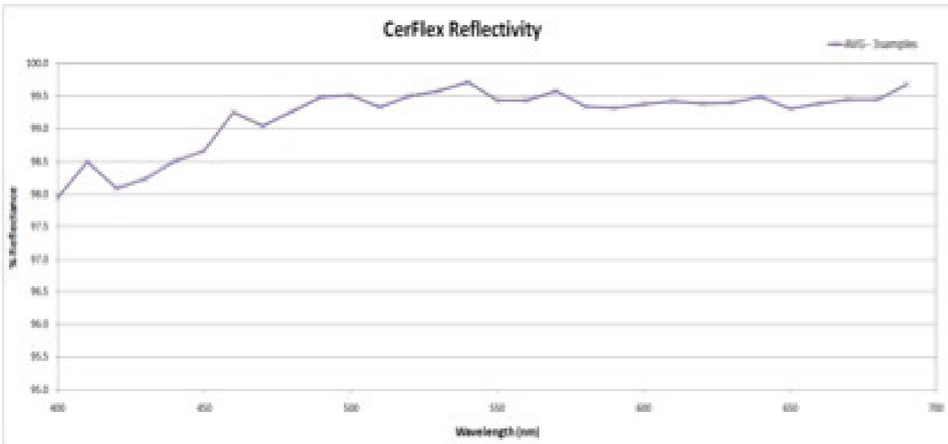


Fig 11. CerFlex Reflectance Data

Figure 11 shows typical reflectance curves for CerFlex. With CerFlexTECH it is possible to decrease the price of your application while increasing the efficiency and durability. Contact CerFlex International for further information.

Furukawa produces a micro cell - polyethylene terephthalate (MC-PET), which is a microfoamed material with typically less than 10 micron feature size. After processing, it provides a flat reflectance curve verses wavelength. PET refers to the base material of polyethylene terephthalate in which the microbubbles are formed with the use of clean carbonic acid. Performance is rated at 99% total reflection with 96% of that being diffuse reflectance. This material has a maximum temperature rating of 177° C.

WhiteOptics White97 film is a high density polyethylene material with a UL Relative Thermal Index of 100°C/110°C and a deformation temperature of 124°C. The material can be provided in rolls, die cut and thermoformed shapes with and without adhesive backing and has a reflectivity of 97.4% at 550nm. Its reflectance is fully diffuse which can be used for efficient cavity mixing while diffusing individual lamp image.

W. L. Gore & Associates DRP Diffuse Reflector material is an expanded PTFE (ePTFE) which has polymeric nodes interconnected by fibrils, which results in a microscopic structure. The material can be supplied with or without an adhesive. The material is non-yellowing per their specification sheet and is rated over 200°C (280°C without adhesive). The material is available from .5mm to 3mm thicknesses. It has good reflectance properties from 240nm to 2500nm.

Light Beam provides PolarKote material which can be painted on. It should be 0.5mm thick for proper reflectance and should have some surface texture for best results. Materials are listed with reflectance levels of 90-97%, which for coated materials depends on the thickness applied and surface texture. See Light Beam's application note for paint application details.

Genesis has a high diffuse reflectance material sold as Valar with 96.6 diffuse reflectance. The material has been tested at 90C, 1500 hours for discoloration testing. See the Genesis Valar Environmental data sheet online for additional test details. Valar is available in 0.55 and 0.8 mm starting thicknesses. Specification sheets and listed properties are based on formed reflectors. The Genesis Valar reflectors are formed with pockets to mask the attachment screws, wires, or any other hardware. This improves the efficiency of the chamber. Furthermore, using a formed approach, elimination of light loss seams is accomplished.

The material used in the mixing chamber must be stable under long term operation free from yellowing or corrosion. Maximum operating temperature for the material must be selected based on the expected operating temperatures in the application, which is determined by the size and power density of the light source. It is recommended that the material of choice be life tested at maximum operating temperatures to ensure degradation free performance.

Trouble Shooting

If the color temperature measured is significantly higher than that specified for the remote phosphor, it is likely that the mixing chamber reflectivity is low or spectral reflectance is not uniform. With low reflectance, the mixing chamber will not efficiently recycle the returning down converted light. The spectral output will then have more blue spectral energy than normal, and a higher measured color temperature results. Color temperatures for low reflectivity mixing chamber systems can easily be 800K higher than expected.

Reflector Material Source/Material	Web page URL	Contact Name/#
CerFlex/ CerFelx TECH	http://www.cerflex.nl/	Martijn Pieterse +31 61 5084 678
Furukawa/ MC-PET	http://www.furukawa.co.jp/english/index.htm	Tina McLaughlin (734) 446-2226
WhiteOptics/ White 97	http://www.whiteoptics.com/	Mark Teather (541) 228-3650
Light Beam/ PolarKote	http://www.lightbeaminc.com/polarkote.html	Nick Liebrecht (541) 228-3650 x122
Genesis/ Valar	http://genesisplastech.com/lighting-products	Customer service (970) 356-3487 x212
W.L. Gore/ ePTFE Diffuse Reflector Product	http://www.gore.com/en_xx/products/electronic/specialty/specialty.html	Customer service 1(800) 445-4673

Note: These materials are listed for reference only. Final mixing chamber material choice and life test qualification must be completed by the lighting designer under the environmental conditions defined by the application.

Plastic molded parts shown in the reference design in figure 7 were provided by ProtoLabs.

Plastic Molding	Web page URL	Contact #
ProtoLabs	http://www.protomold.com/	877-479-3680

For more information on ChromaLit solutions please visit our website **www.intematix.com/chromalit** or Future Lighting Solutions website at **www.futurelightingsolutions.com/remotephosphor**