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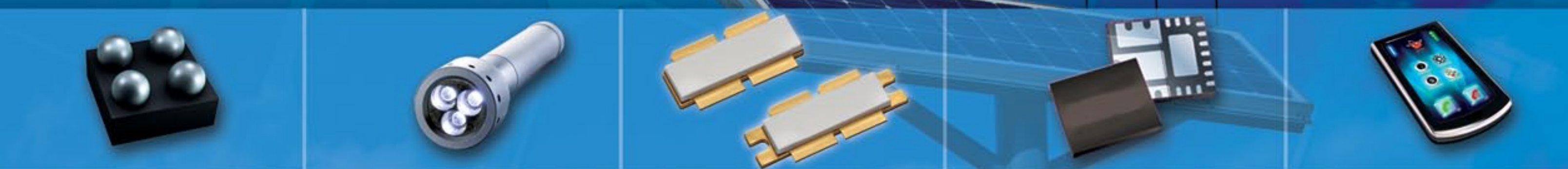

FUTURE ELECTRONICS

Creating White Light Utilizing Remote Phosphor Technology

By: Osama Mannan, Technical Marketing Engineer, Future Lighting Solutions

In the solid-state lighting industry, white light is created by either mixing multiple colors e.g. red, green and blue, or by leveraging a royal blue die coated with a layer of phosphor. The latter approach is done by depositing the phosphor on the royal blue LED die within the same package, as shown in Figure 1. This is a very common approach in manufacturing white LEDs due to its high reliability, low cost, and the convenience of having everything embedded in one package. However, applying phosphor directly on the die of the LED has its limitations. Such limitations include the degradation of the phosphor due to the temperature rise, since it's in direct contact with the LED die. This in turn will cause a light output degradation and possible color shift over time. Another limitation could be the challenge of consistently producing a specific color temperature (CT) and color rendering index (CRI) white light.

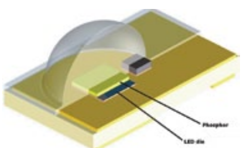

Figure 1. Cross section of LUXEON Rebel

These two limitations, in addition to other potential ones, can be eliminated by detaching the phosphor layer from the LED die and making them two separate components in a lighting system. This approach of having a remote phosphor layer can be leveraged to generate white light while making use of the same phenomenon of generating the white light from a royal blue die. Future Lighting Solutions currently provides "**ChromaLit™**" remote phosphor elements from Intematix to leverage that approach and enable applications to make use of this technology.

What is Remote Phosphor and Why Use It?

The technology of remote phosphor is simply achieved by bonding phosphor to a specific type of substrate. A typical remote phosphor system is shown in Figure 2 and consists of an LED board, a mixing chamber and a remote phosphor element.

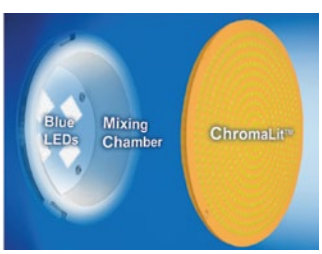

Figure 2. Remote phosphor system with ChromaLit disc (1)

But why would someone choose to go with the seemingly complex path of remote phosphor when white LEDs are readily available? The advantages of leveraging the remote phosphor technology can form the answer to that argument. These advantages include:

- Simplified LED inventory management
  - Alleviates binning challenges by utilizing only two royal blue wavelength bins
  - The ability to target specific CCTs and CRI by replacing the remote phosphor element and without changing the LED bins
- No visible point sources
  - Remote phosphor element already diffuses the light exiting from it
- Higher system efficiency
  - Blue light rays bouncing off the phosphor are reflected back to exit the fixture, hence collecting more light and adding to the overall efficiency
- More reliability and less color shift over time
  - Lower phosphor temperature, resulting in less light output degradation and color shift over time

Typical Remote Phosphor-Based LED Lighting System

While Intematix can basically make the remote phosphor products in different forms and sizes, it offers the ChromaLit elements in four categories, namely round, square, linear, and panel formats. These categories are intended to be used for different applications. These form factors are shown in Figure 3.

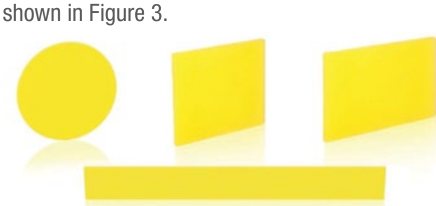

Figure 3. Different forms of ChromaLit phosphor (1)

One application that can make use of these standard offerings is downlights. Remote phosphor designed in a downlight enables higher output density since the reflected power is spread over a much larger phosphor area and is efficiently recycled to exit the fixture. The LEDs, the phosphor element, the mixing chamber, and the reflective material all play a vital role in influencing the overall efficiency of the fixture.

The 61.5mm ChromaLit disc is a common size for typical downlight modules. This disc is offered in different color temperatures and CRIs to meet the need of the downlight application. The lumen output range that this disc is capable of delivering is between 1000 and 1300 lumens. The following table shows the characteristics of the ChromaLit disc:

Color Designation	CCT[1] (K)	Color Consistency[2]		CRI[1]	Viewing Angle[1] (deg)	Conversion Efficacy[3] (lm/W_{rad}) at 25°C		Conversion Efficacy[3] (lm/W_{rad}) at 80°C	
		SDCM	CCT (K)			Minimum	Typical	Minimum	Typical
CL-827	2700	3	±70	80	115	165	180	160	175
CL-927	2700	3	±70	90	115	145	160	140	155
CL-830	3000	3	±90	80	115	185	200	180	195
CL-930	3000	3	±90	90	115	155	165	150	160
CL-835	3500	3	±110	80	115	190	205	186	200
CL-840	4000	3	±120	80	115	195	210	190	205
CL-750	5000	4	±170	70	115	215	230	210	225

Table 1. ChromaLit portfolio (2)

As shown in Table 1, each version has a different conversion efficacy which is dependent on the CRI and CCT combination. This brings us to another important component to be used for an efficient remote phosphor downlight system, namely the royal blue LEDs. While the peak wavelength of the LED is important for radiometric requirements, dominant wavelength is the pure (monochromatic) wavelength that has the same perceived color as the source. Therefore, this is the important parameter for the phosphor disc. Intematix specifies a dominant wavelength range between 450-460nm, targeting 455nm for optimal performance of their remote phosphor products. Philips Lumileds LUXEON® Rebel ES Royal Blue offers two bins (namely, 4 and 5) that provide the wavelength required for these phosphor elements. This LED, shown in Figure 4, provides a typical flux of 1030mW at 700mA and has a superior hot/cold factor that enables it to maintain the high flux even at elevated temperatures.

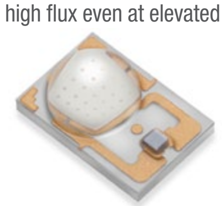

Table 4. LUXEON Rebel ES Royal Blue

One final essential component of a remote phosphor based downlight is the mixing chamber. The LED angular distribution has to be considered so it fills the entire ChromaLit entrance aperture. From that point, the chamber can have a lower profile for better efficiency, or a higher one for better uniformity and a more even distribution. Tapered walls may also be considered to increase efficiency and reduce ray bounces.

The mixing chamber also has to be covered by, or even made of, a highly reflective material to make use of all the light emitted from the LED source to the phosphor disc. Different materials can be used as long as they have a high reflectivity to enhance the system's efficiency. Furukawa Electric Co. produces a PET-based reflective material that can be die punched to any shape depending the chamber dimensions. This material has a 99% reflectivity and can handle temperatures up to +177ºC. Similarly, Cerflex has developed a proprietary ceramic-based material that has reflectivity up to 99.2% and can be molded to the shape required to make up the whole chamber itself instead of covering one that is made of a different material. This ceramic-based mixing chamber is best suited for applications that experience higher temperatures, as it can handle temperatures of up to +1000ºC.

Future Lighting Solutions Remote Phosphor Stack Design Concept

To combine all these components in a downlight lighting system, Future Lighting Solutions has developed a reference design to bring all these parts together. For the purpose of this article a 4000K downlight system with 1100 lumens output is to be developed using that reference design. The Usable Light Tool (**www1.futurelightingsolutions.com/ult**) is leveraged to determine the number of LEDs and the radiometric power required to achieve the 1100 lumens for the downlight application. Figure 5 shows the ULT analysis.

The results show that with six LEDs at 700mA, the radiometric flux is 1.002mW per LED, leading to a total flux of 6.012mW. Using the ChromaLit conversion efficacy of 205lm/Wrad for the 4000K phosphor disc at +80ºC, the calculations yield 1232.46 lumens. If we want to add a reflector loss of 10% we finally get 1109.2 lumens which will achieve the light output target required.

Input Variables:	LXML-PR02-1000	
Power LED Manufacturer:	Philips Lumileds	
Power LED Product Family:	LUXEON Rebel (ES - Color)	
Power LED Color:	Royal Blue (455nm)	
Power LED Part Number:	LXML-PR02-1000	
Current Optimization Algorithm:	Maximize Current	
Number of Power LEDs:	6	
Ambient Temperature:	40	(°C)
Circuit Board R_{th} for Single LED:	7	(°C/W)
Heat Sink Thermal Resistance:	6	(°C/W)
Maximum Allowable Tj:	135 (default)	(°C)
Maximum Allowable Drive Current:	700 (override)	(mA)
Typical Vf at Nominal Current:	3 @700mA (default)	(V)
Typical Flux at Nominal Current:	1030 @700mA (default)	(mW)

Calculated Results:	LXML-PR02-1000	
Calculated Drive Current:	700	(mA)
Calculated Forward Voltage:	2.82	(V)
Calculated LED Power Consumption:	1.97	(W)
Calc. Array Power Consumption:	11.83	(W)
Calculated LED Radiometric Flux:	1.002	(W)
Calculated LED Efficiency:	50.9%	(W/W)
Datasheet Junction-to-Case Rth:	6	(°C/W)
Calc. Junction-to-Ambient Rth:	8.17	(°C/W)
Calculated Case Temperature:	82	(°C)
Calculated Junction Temperature:	87	(°C)
Calculated Usable LED Flux:	34	(lm)
Calculated Usable Array Flux:	201	(lm)
Calculated Usable Efficacy:	17.02	(lm/W)

Figure 5. Usable Light Tool analysis for remote phosphor based system

The Future Lighting Solutions design is shown in Figure 6. Along with the 61.5mm ChromaLit disc (p/n:**CL-840-LR-PC**) and the LUXEON Rebel ES Royal-Blue (p/n: **LXML-PR02-1000**), the design utilizes the Cerflex ceramic-based mixing chamber and an Alux-Luxar reflector.

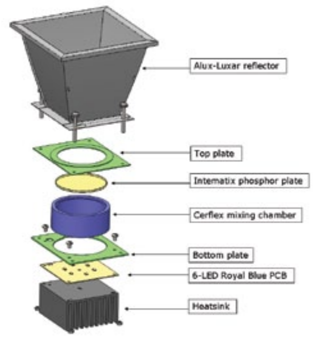

Figure 6. Future Lighting Solutions remote phosphor stack design

To demonstrate the advantage of using a remote phosphor approach versus a direct white LED approach, the following is a ULT analysis of the white LEDs that are needed to achieve the 1100 lumen light output required for the downlight design (Figure 7).

Input Variables:	LXW8-PW40	
Power LED Manufacturer:	Philips Lumileds	
Power LED Product Family:	LUXEON Rebel (ES)	
Power LED Color:	Neutral White (4100K)	
Power LED Part Number:	LXW8-PW40	
Current Optimization Algorithm:	Maximize Current	
Number of Power LEDs:	8	
Ambient Temperature:	40	(°C)
Circuit Board R_{th} for Single LED:	7	(°C/W)
Heat Sink Thermal Resistance:	2	(°C/W)
Maximum Allowable Tj:	135 (default)	(°C)
Maximum Allowable Drive Current:	700 (override)	(mA)
Typical Vf at Nominal Current:	3 @700mA (default)	(V)
Typical Flux at Nominal Current:	190 @700mA (default)	(lm)

Calculated Results:	LXW8-PW40	
Calculated Drive Current:	700	(mA)
Calculated Forward Voltage:	2.83	(V)
Calculated LED Power Consumption:	1.98	(W)
Calc. Array Power Consumption:	15.84	(W)
Calculated LED Radiometric Flux:	0.515	(W)
Calculated LED Efficiency:	26%	(W/W)
Datasheet Junction-to-Case Rth:	6	(°C/W)
Calc. Junction-to-Ambient Rth:	3.62	(°C/W)
Calculated Case Temperature:	74	(°C)
Calculated Junction Temperature:	82	(°C)
Calculated Usable LED Flux:	172	(lm)
Calculated Usable Array Flux:	1372	(lm)
Calculated Usable Efficacy:	86.62	(lm/W)

Figure 7. Usable Light Tool analysis for white LED based system

From the analysis, we notice that, under the same driving conditions, the LED count needed to be increased to eight, as compared to six of the Royal Blue LEDs used in the remote phosphor design. The total lumen output of the eight white LEDs is 1372 lumens. Adding the same reflector loss of 10% yields 1234.8 lumens. However, we have to keep in mind that one advantage of the remote phosphor approach is that it eliminates the visibility of any point source since it diffuses the light across the phosphor disc. To achieve the same effect, a diffuser needs to be added in front of the LEDs. If we assume a diffuser loss of 10%, the effective lumen output coming out of the downlight system with white LEDs becomes 1111.32 lumens. Therefore, counting in all the losses in the system, we need more white LEDs as compared to blue LEDs to achieve the same light output.

Conclusion

As the lighting industry advances, new technology is developed to improve the quality of lighting systems and achieve the targets required by the different applications. Remote phosphor technology is becoming more common in many lighting applications such as downlights, spotlights, task lighting, panel lighting, and even high bay lights. This article demonstrated the advantages that a remote phosphor approach can bring to an application, such as downlights, and how it compares to using direct white LEDs in the same system.

(1) Taken from Intematix ChromaLit Cut Sheet (**www.intematix.com/uploads/files/chromalit _cut_sheet.pdf**)
(2) Taken from Intematix ChromaLit Datasheet (**www.intematix.com/uploads/files/chromalit _datasheet.pdf**)