SOLAIS
LIGHTING GROUP

LED Color Shift –
Causes and Management

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Misleading information abounds in the LED industry regarding color shift in phosphor-coated (PC) white LEDs. Since it is not a topic generally discussed by LED chip manufacturers, real data and answers are hard to come by. This paper will explain color shift, its causes, and steps manufacturers can take to minimize the impact of color shift.

Color shift is not unique to LED light sources. In fact, it occurs with any light source utilizing phosphors and/or gas mixtures to generate white light, including fluorescent and metal halide technologies. In a limited test by the National Lighting Product Information Program (NLPIP), metal halide lamps measured up to a 772K color shift after only 8,000 hours of testing. *

The primary determinants of color shift in PC LEDs are the quality of the materials and the construction. Assuming LEDs are purchased from one of the leading LED chip manufacturers, the two operating parameters that can be correlated to color shift in PC LEDs are forward current and temperature. The forward current is directly proportional to the power used by the LED, and this power is divided between processes that produce light and processes that produce heat. The more efficient the LED, the greater the percentage of power that is converted to light. Even the best PC LED, however, is less than 50% efficient in producing light; hence a major portion of the energy consumed by the LED is expended as heat. Using the manufacturers' data, the greatest rate of change in color quality is occurring at the highest powers, which corresponds to the highest temperatures and radiative emissions.

High radiative flux and temperature contributein several ways to a shift in color under high-load conditions:

- Discoloration of the encapsulant (Fig. 1) and/or lens under high-load conditions may lead to a color shift. Recent advances in materials have significantly reduced this defect in the better-quality products.

- Phosphors are sensitive to both temperature and high-radiative flux. Generally, more than one phosphor is used to obtain a given color temperature of the PC LED. If one phosphor were to depreciate more quickly than the others, a color shift would occur that could render the light quality unacceptable without affecting the projected life. This emphasizes the importance of manufacturers' providing color quality metrics on life tests as their products age after 6,000 hours.

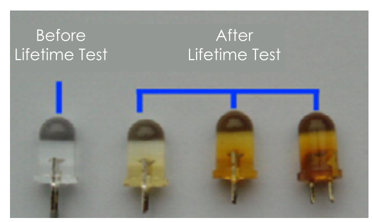

Fig. 1 - Encapsulant Discoloration

- Since temperature plays such a significant role in product life relative to color quality, the construction of the LED and the associated thermal management system of the lamp must be optimized to dissipate the heat. Poorly designed systems will only contribute to accelerating the color shift process.

Proper design can result in a product with minimal color shift for the useful life of the product.

The Illuminating Engineering Society of North America (IESNA) developed a method for testing LED lumen maintenance called LM-80-08: Approved Method for Measuring Lumen Maintenance of LED Light Sources. LM-80 prescribes uniform testing methods for determining the amount of light output maintained over time (lumen maintenance) for LED packages, arrays or modules (i.e., devices). A given LED device is operated for at least 6,000 hours at representative operating temperatures. During this time, photometric and correlated color temperature (CCT) data are collected at least every 1,000 hours, providing luminous flux. While some LED chip manufacturers provide up to 10,000 hours or more of testing data, they are required to provide only 6,000 hours of testing to produce LM-80 results.

* http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/mwmhl/appendix.asp

The LM-80 standardized testing was developed to provide some understanding as to how an LED device will perform over time, in terms of lumen maintenance and color shift. The standard TM-21 was developed as a way to project the L70 lumen depreciation (end of life) of the LED fixture/lamp based on the LM-80 data results (Fig. 2). Unfortunately, there is no similar standard currently developed to project the expected color shift beyond the LM-80 data. Such a metric is necessary because of color-sensitive lighting applications, such as retail, museums and residential.

Developing a standard to project the color shift of a PC LED will be difficult to accomplish. Myriad approaches and differences in materials when manufacturing an LED fixture/lamp result in color shift variations. For example, a single-die, high-output PC LED could have a diode, a phosphor coating and a lens. However, the phosphor can be directly on top of the diode (Fig. 3) or on the lens (Fig. 4); the lens can be flat or a solid dome (Fig. 5); or the diode can be cut and mounted in many ways. In addition, each component can be made from different types of material, and each LED fixture/lamp manufacturer has its own blend of material and proprietary information.

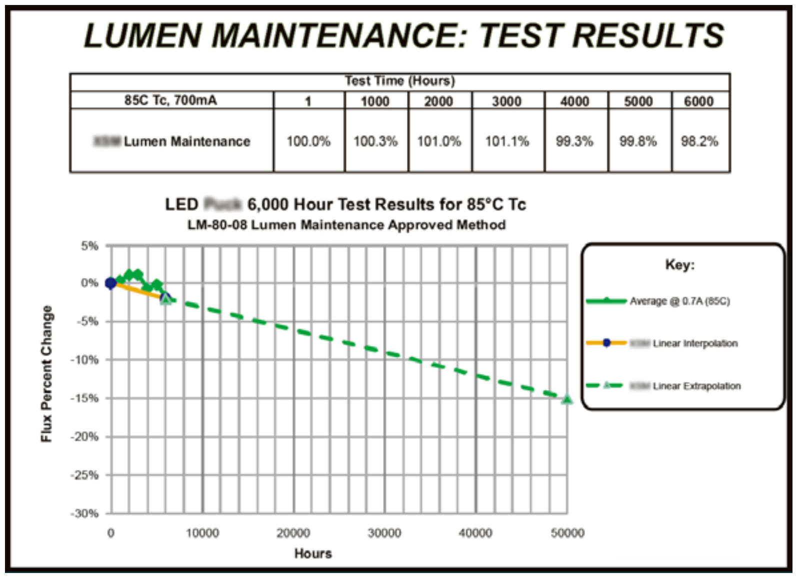

Fig. 2 - Example of L70 projection based on LM-80 data

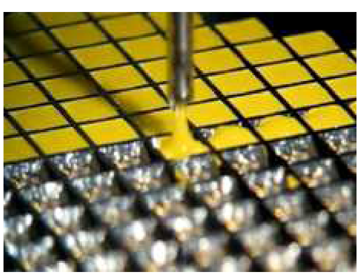

Fig. 3 - Phosphor on diode

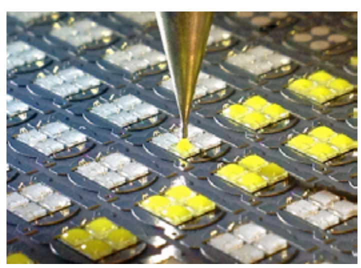

Fig. 4 - Phosphor on flat lens

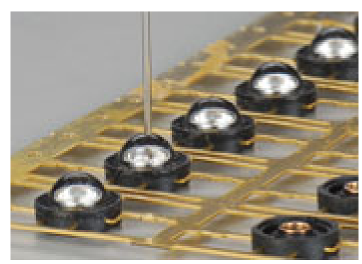

Fig. 5 - Solais dome lens

LEDs, like all electronics, have gone through substantial improvements in technology over the recent years. This has subsequently resulted in better color maintenance.

In terms of single-die, high-power PC LEDs, an important breakthrough occurred with the launch of 2mm x 2mm diode packages. This breakthough allowed typical maximum forward-current ratings to increase by 50%. Previous single-die, high-power LEDs had 1mm x 1mm diodes and were therefore not as robust at equivalent forward currents. Along with advances in the actual packaging techniques of the LED, the change to the larger diode size helped slow the rate of color shift over time. This can be seen fwhen comparing original LM-80 data from any of the major LED suppliers in early 2010 to the LM-80 data of today.

Testing standards are advancing and are being used to help push quality improvements among LED lighting products. For example, when the LM-80 standard was originally written, it allowed all CCTs of the same product series to be represented by one collection of data testing. This resulted in some manufacturers testing products at extreme CCTs (over 10,000K). Problems arose because different types and/or amounts of phosphors were used to obtain the different CCT bins, so each bin had the potential to change and deteriorate differently over time. An LED over 10,000K CCT requires very little phosphor and can, therefore, have better performance with less color shift.

The standard has since been redefined and currently requires the LM-80 testing to be done for specific CCTs that are most commonly used for indoor lighting applications. LM-80 testing also requires manufacturers to test the PC LEDs at standard forward current and temperature levels common to actual values used in lighting applications. All of these advancements help to normalize the testing data so that lighting manufacturers can more successfully use the data to design more robust products.

LED manufacturers claim to improve color maintenance; however, technological explanations are limited. To date, the primary focus of the LED industry has been to improve efficiency by producing more light out of less wattage. If similar effort is expended improving color maintenance, LED manufacturers are not sharing data publicly.

Light-producing and color-changing phosphors shift color and will continue to do so. It’s all a matter of when and to what extent. Manufacturers can take specific steps(of which end users should be aware) to maximize the useful life of an LED product from a color-consistency standpoint:

- Design products using only proven LED technologies from top-tier LED manufacturers

- Try to use products with 10,000-hour CCT data at 105°C and high currents. If chips possess only LM-80 data at lower temperatures and lower currents, it is likely a sign of hyper-sensitivity to heat and current.

- Underdrive LEDs. It’s recommended that no more than 50% of maximum rated current and absolutely no more than maximum tested current with LM-80 data should be provided by the manufacturer.

- Manage the thermals in design

While color shift over time can’t be avoided, quality design by reputable partners can ensure a long life with limited color shift.