The Adoption of Lighting-Class LEDs into General Illumination Applications

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Abstract

While the use of LEDs for indicators in consumer electronics is well known and their use in automotive lighting is gaining acceptance rapidly, the use of LEDs for general illumination is still relatively new. Most lighting technology is about 100 years old. The rapid pace of innovation in semiconductor-based LEDs is simply unprecedented in the lighting industry. This rapid innovation in technology has enabled lighting-class LEDs to begin replacing incumbent lighting technologies. Today's LED light systems can save money through energy savings and maintenance avoidance. The growing supply of high quality LED lighting products, combined with increasing public awareness and demand for energy efficient products, has created a rapidly growing market for LED lighting in general illumination applications.

INTRODUCTION

General illumination refers to any lighting application where light is needed to make an area useful. One obvious example of general illumination is the fluorescent troffers in an office building used to light up hallways, lobbies and work areas. Another obvious example is a roadway light that lights up a city road to increase driver safety. General illumination also refers to other less obvious applications, such as the lights that illuminate the meat display case in a grocery store and lights that mount onto mining helmets.

"Lighting-class" LEDs are a subset of high power packaged LEDs, which are LEDs that consume 0.5 W of power or more. High power LEDs, like all LEDs, emit light that is essentially monochromatic. LEDs are available in a variety of colors, including blue, green, amber and red. "White" LEDs do not directly emit white light. Instead, the majority of white LEDs are created from blue LEDs coated with a yellow phosphor. The combination of blue light from the LED and the yellowish light from the phosphor combine to create white light.

In fact, white LEDs are composed of three main subsystems: the LED chip, the phosphor and the LED package. In general, the radiant power of the LED chip is the primary factor that influences the brightness & efficacy of the complete packaged LED. The phosphor and package are the primary drivers of other package LED characteristics, including the quality of emitted light, LED beam angle, lifetime and reliability. While brightness and efficacy of the LED are certainly important, the entire packaged LED system must be taken into account when considering the use of LEDs in traditional lighting applications.

Lighting-class LEDs are the high power LEDs that have the right combination of brightness, efficacy, quality of light and reliability to enable the replacement of incumbent lighting sources with LED light. LED light has many advantages that are readily apparent, including light that is inherently efficient and directional without the use of reflectors. In addition, lighting-class LEDs can last for at least 50,000 hours under certain conditions and do not contain mercury, as most fluorescent and HID light sources do. However, some benefits to LED light are unique among all light sources, such as reaching full brightness in nanoseconds, having no fragile filament to break and having better efficiency in cold temperatures. All of these advantages of LED light have started a revolution in the lighting industry – an industry that is still using technology that is over 100 years old!

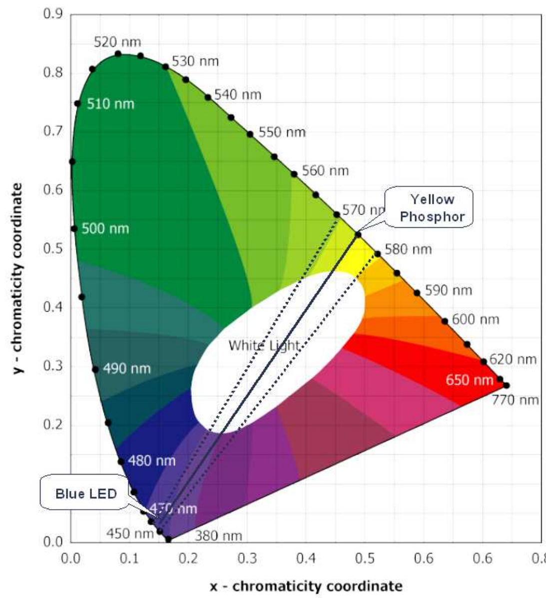

Figure 1 – Blue LED & Yellow Phosphor Create White Light

History of LEDs in Lighting

The first uses of high power LEDs were in niche applications where no other light source could offer the same combination of light output, durability, efficacy and quality. Decorative color mixing – the use of multi-color light on building exteriors, pools and spas – started using color high power LEDs because they offered higher efficacy and longer lifetimes than using white light bulbs with color filters. Portable lights, including flashlights, lanterns and headlamps, began using white LEDs to increase run time per battery and offer higher reliability than fragile incandescent light bulbs. Transportation lighting, including semi-tractor-trailer and emergency vehicle lighting, switched to LEDs due to increased reliability and operating lifetimes, as compared to light bulbs.

While earlier high power LEDs could offer a technical solution for most lighting applications, these LEDs had trouble creating a viable business case for lighting replacement. The main obstacle was the high initial cost of LED luminaires when compared to the traditional luminaires. An inflection point occurred in October 2006, when Cree launched the XLamp® XR-E LED in cool white (5,000K to 10,000K CCT). The XLamp XR-E LED was the first LED that had high enough performance and long enough lifetime to create total-cost-of-ownership (TCO) savings in outdoor lighting. Six months later, Cree released the XLamp XR-E LED in neutral and warm white (2,600K to 5,000K CCT). This breakthrough enabled similar TCO savings and reduced energy efficiency in many more applications, including indoor lighting and retail display lighting.

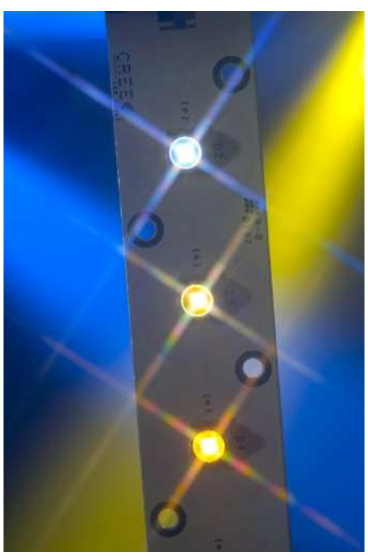

Figure 2 – Cree's lighting class XLamp XR-E LEDs in cool white (top), neutral white (middle) and warm white (bottom)

Adoption of Lighting-Class LEDs

Despite all the advantages of LED light, there are some who believe that the high initial cost of LED lighting products will limit their adoption in mainstream lighting applications. While initial cost is an important factor in most consumer-level buying decisions, not all lighting buyers place a high priority on initial cost. Other lighting buyers, such as the municipalities and power companies that own the majority of outdoor lighting fixtures, as well as business owners that construct factories and office buildings, are much more likely to examine the total cost of a lighting solution. The total cost does include the initial cost of the fixture, but it also includes many other factors: the cost of the energy used to create light, maintenance costs associated with changing bulbs and cleaning the fixture, and the disposal costs for materials that need servicing over the life of the fixture.

Lighting-class LEDs enable reduction of all other life-cycle costs of lighting to the point where the higher initial cost for LED lighting is more than offset by the cost savings over time. Several "macro" factors have created an environment conducive to the quick adoption of LEDs in lighting. First, the cost of energy is increasing worldwide. Since lighting-class LEDs are more energy efficient than the lighting sources they replace, as energy costs increase, the payback period for using LED lighting decreases. Second, standards & regulations – including the United States Department of Energy's ENERGY STAR program and California's Title 24 building codes – are in place to separate out good LED products from lower performance ones and to enforce the use of energy efficient lighting. Third, there are various public education efforts designed to educate everyone about the inefficiency of existing lighting technology. While compact fluorescent (CFL) bulbs are generally presented as the solution, these programs are raising awareness and education levels about inefficient lighting and the forecasted energy crisis.

While every lighting application and every LED solution is obviously different, there are three common ways that LED lighting creates value. Each of these qualities will be examined in more detail in the following sections.

1. Energy savings
2. Maintenance avoidance
3. Quality of light

Energy Savings

When most people talk about the energy consumption of a light fixture, usually the attention is focused on the efficiency of the light source used in the fixture. For example, promoters of CFL light bulbs usually state that CFLs are four to five times more efficient than an incandescent light bulb. However, what really matters in talking about the efficiency of a light fixture is how much light ends up where it is actually needed and useful. All light bulbs are essentially omni-directional light sources, but most the majority of lighting applications are directional in nature. Therefore, in these applications, some of the light from the light bulb ends up going in the wrong direction or simply being wasted inside a fixture.

When considering the energy efficiency of a lighting fixture, the entire system must be considered and not just the light source itself. Any lighting system will contain at least the following three basic parts: a ballast or driver, a light source and a fixture. The fixture includes the housing as well as any optical elements, such as a diffuser, a lens and/or a reflector. The fixture and optical elements can greatly affect the efficiency of the overall system. For example, CFL downlights can range in fixture efficiency anywhere from 70% down to just 30% efficient. Some of these lights are wasting over two-thirds of the light inside the fixture!

Lighting-class LEDs create energy savings relative to traditional lighting in two ways. First, LED light is already directional, so the losses associated with using an omni-directional light source with a reflector are greatly reduced. Second, LED light has quickly progressed to become one of the most efficient artificial light sources on the planet. LED lighting systems, like all lighting systems, have the same three basic parts: driver, LED and fixture. The efficiencies of the driver and fixture are high relative to the LED efficacy and are not likely to change much in the near future. Therefore, the brightness and efficacy of an LED lighting system is driven mainly by the LED itself.

One of the primary factors in LED chip brightness is the external quantum efficiency (EQE) of the LED die. The United States Department of Energy (DOE) states that in 2006, the LED industry had generally reached an EQE of 42%[1]. Cree's own EZBright® 1000 LED chip, which is used in the XLamp XR-E LED, is around 50% EQE @ 350 mA with a next generation LED die projected to reach EQE of about 58% at the same current. The DOE projects the LED industry will reach EQE of 81% by the year 2013 – almost double the efficiency level of 2006. This continuous increase in efficiency will make LEDs a more efficient light source and continue to reduce the cost of energy needed to provide light.

MAINTENANCE AVOIDANCE

Maintenance avoidance refers to the TCO savings realized by not having to replace a light bulb. The exact amount saved depends on the application and installed location. While changing the light bulb in a bedroom lamp is relatively easy and inexpensive, think about both the explicit and implicit costs associated with closing a lane of traffic in a tunnel to send a maintenance crew to change the light bulbs. In many lighting applications, the maintenance costs can quickly become much larger and more important than the initial fixture cost.

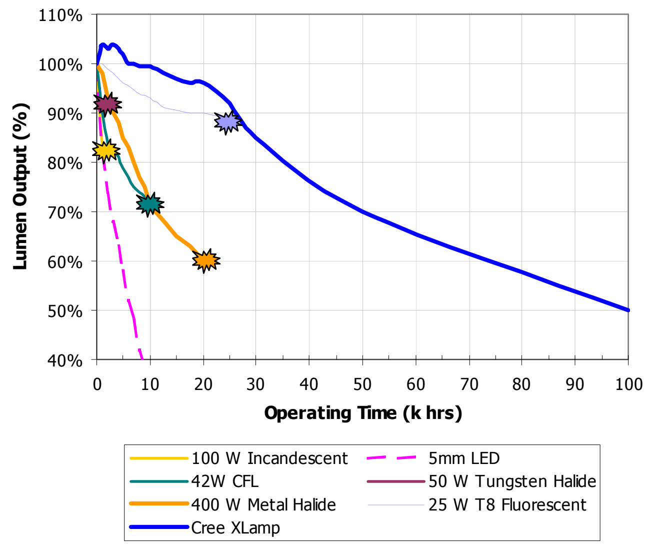

Figure 3 – Lumen Maintenance for Common Lighting Technologies[2]

Lighting-class LEDs create maintenance avoidance because they do not "burn out" like a traditional light bulb. These LEDs will continue to put out light for an extremely long time but the amount of light output slowly decreases over operational life. The end of life for a light bulb is easy to define because it simply breaks and ceases light output. The end of life for LEDs is defined differently. The term lumen maintenance refers to the relative percentage of light emitted when compared to a light source's initial light output level. The average human will not detect a difference in brightness until a light source reaches 70% lumen maintenance (denoted as L_{70}), or 70% of the initial light output level.

The lumen maintenance of a lighting-class LED is complex and depends on several factors. However, it is common knowledge in the LED industry that LED lumen maintenance is temperature dependent. The hotter the LED and its junction temperature are, the shorter the lifetime until the LED will reach L_{70}. Lighting-class LEDs make it practical to design an LED lighting system that can last at least 50,000 hours until the entire system reaches L_{70}. This lifetime is at least twice as long as almost any bulb-based lighting system and can save money in the long-term by avoiding expensive maintenance events, eliminating the need to stock spare bulbs and cutting out hazardous waste disposal expenses.

QUALITY OF LIGHT

In contrast to the semiconductor industry, where metrics and objective measures usually dominate buying decisions, buyers in the lighting industry tend to be very subjective. One concept from the lighting world, quality of light, is universally understood but tends to mean different things to different people. In general, quality of light refers to a combination of factors, including the specific color of light output, the uniformity of intensity, the uniformity of color and the ability to properly illuminate specific colors.

Certain design constraints may limit the choice of lighting technology that is used in a specific lighting application. For instance, the lights in an elevator are usually halogen lights because they are relatively small, not very tall and provide a pleasing color of light output. Other types of lights would require either much taller fixtures or not offer the same quality of light. There are many applications like this where lighting-class LEDs offer another choice to the existing technology. Lighting-class LEDs come in a wide variety of color temperatures, render colors very well, are very small and generally use less power than traditional lights. Designers can use these attributes to create lighting systems in different color temperatures, sizes, light output levels, and power ratings than was possible with any other lighting technology.

CONCLUSIONS

The process of converting general illumination from traditional lighting technology to LED lighting in an equal lumen-for-lumen replacement is actually just the first order effect of what Cree calls the LED lighting revolution. This first order effect is what happens when the use of LED light reduces the amount of energy needed to provide a certain amount of light and reduces the amount of light bulb waste that must be captured and disposed of properly. However, this is just the beginning of how LEDs can change how light is created and used.

The unique properties of LED light also open up the possibility for two major second order effects to reduce the amount of light needed (and thus energy). First, since LEDs use less power and do not require the big, bulky reflectors that omni-directional light bulbs do, LED light fixtures can easily be moved out of ceilings and placed closer to the intended target. Most modern kitchen designs use this principle by making extensive use of under-cabinet lighting. The close task lighting reduces the need for high output lighting in the ceiling. Second, LED lights come up to full brightness almost instantly. These lights can be integrated into intelligent systems that use sensors in order to only output full brightness when someone is actually using the target lighting area. These systems can reduce the time that the lighting system spends at full brightness.

All the pieces of the LED lighting puzzle, from the growing public awareness of the impending energy crisis to the rapid development of high quality LED products, come together to show that the LED is going to play a key role in the future of lighting and in the future of energy efficiency all around the world.

ABOUT CREE, INC.

Cree is a market-leading innovator and manufacturer of semiconductors and devices that enhance the value of solid-state lighting, power and communications products by significantly increasing their energy performance and efficiency. Cree's product families include blue and green LED chips, lighting LEDs, LEDs for backlighting, power-switching devices and radio-frequency/wireless devices. Cree's Solid State Lighting (SSL) division was launched in 2003 and released the first XLamp LED in 2004. Cree SSL is focused on enabling the adoption of LEDs into general illumination applications – the LED lighting revolution.

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ACRONYMS

CCT: Correlated color temperature
CFL: Compact fluorescent
DOE: Department of Energy
EQE: External quantum efficiency
LED: Light emitting diode
TCO: Total cost of ownership