LED Lighting in the ΔDelta SmartHouse

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Abstract

The main motivation for this project is to explore the feasibility and practicality of an LED lighting system in the Delta SmartHouse. Since it is a goal of the Delta project to design systems that will be commonly used in households of the future, another goal is to try to forecast how this technology will evolve, and so emphasis is placed on the future potential as well as the current limitations. One way of determining whether or not LED light systems are useful is through the rigorous review of academic and industry research. Therefore, this report comprises of summaries of current state of the art research. In addition, a prototype LED desk lamp was built using industry leading LEDs to tangibly observe its potential.

1. Introduction

The basic structure of a light emitting diode (LED) is shown in fig. 1. It is comprised of a simple PN junction that is covered in a semiconductor dye material that produces monochromatic or single wavelength light when the diode is forward biased. An epoxy material that serves both to protect the PN junction and focus and reflect the light at a desired angle surrounds the dye.

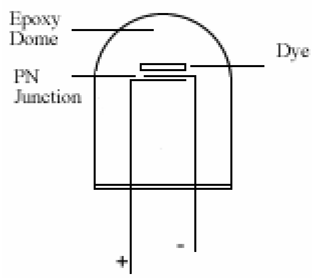

Figure 1: Simple LED

LEDs were first developed in the 1960s by using gallium, phosphorus and arsenic (GaAsP) at the junction that produced the first red LED (655nm). Since the emergence of LED until only recently they have served primarily as indicator lights for electronics. Today, technology has allowed the creation of virtually any visible wavelength of light and emerging applications are being realized.

Presently, aside from electronic indicator lights, LEDs are useful for a variety of applications including: exit signs, traffic signals, airfield lights, LCD backlighting and task lighting. In the future, LEDs seem promising to provide a new means of general day-to-day lighting. The implications of using LEDs for general lighting are enormous and include a new standard of efficiency, environmental improvements, and virtually eliminating the need to change light bulbs as the typical LED can run for ten years continuously before degrading significantly.

2. Generating White Light

2.1. Red, Green, Blue (RGB) LEDs

A very hot topic of research is trying to solve the problem of how to most efficiently mix light emitted from red, green and blue LEDs in order to create light with a wavelength spectrum similar to commonly used light sources. This method of creating white light is the efficient, yet most cumbersome method of the two described in this paper. RGB-LEDs are already used for very large screen monitors such as those used in stadiums.

One important feature of color mixing is the ability to control the color of the light source by the user to his or her preferences. This feature may create a new market in home lighting for “mood” lighting, as studies have shown that the light illuminating the area that we work or play has important implications on our productivity and utility. Rather than merely dimming the lights, the user would be able to “tune” to his or her preferred white point or color.

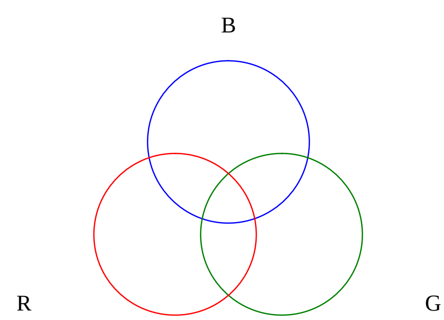

Figure 2: RGB Color Mixing

A major drawback of mixing colored LEDs is controlling the color over time. Red LEDs tend to degrade at a faster rate than do blue or green. For this reason, a light system implementing color mixing needs some sort of feedback control in order to vary current through the diodes to maintain a stable white point, color temperature and luminescence.

2.2. White LEDs Using Phosphors

The quick and easy way to produce white light is to use violet or ultraviolet LEDs to shine light onto yellow phosphors in order to create the wavelength spectrum as shown in fig. 2. Though this creates a white light that is useful for many applications such as desk lighting, the fundamental problem is that low efficiencies of approximately 10% result due to energy lost of non-visible photons at the subatomic level.

White LEDs are also being creating using ultraviolet LEDs and a mix of red, green and blue phosphors. These lights produce the best color rendering; however they are the least dependable because the interface between the phosphors and packaging requires more complicated design and tends to degrade faster.

A new and exciting research topic is being developed at the Sandia research labs that have shown to produce efficiencies of up to 60%. This new technology uses quantum sized phosphor particles ("quantum dots") that are spaced evenly on a surface. The basic premise behind this technology is to increase the surface area of phosphors being exposed to the UV light so as to improve overall efficiency. Quantum dots used on LEDs may prove to be even more efficient than color mixing.

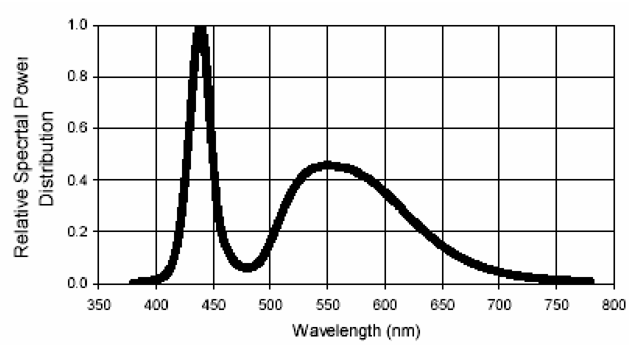

Figure 3: Yellow Phosphor White LED

3. Market Potential

LED technology seems to be following a Moore's law of sorts; a plot of efficiency over the past four decades (fig. 4) reveals that efficiency seems to be improving by a factor of 30x per decade whereas cost per lumen seems to be reducing by a factor of 1/10x per decade. Extrapolation of this data demonstrates what industry experts have been predicting; by ~2010 LEDs will be efficient and cost effective enough to replace fluorescents for general lighting.

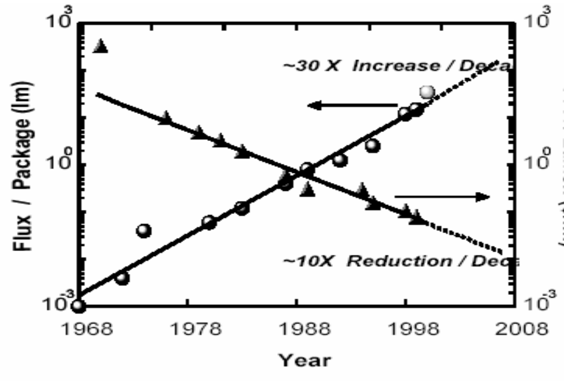

Figure 4

4. Competing Technologies

Although the future looks bright for LEDs, it is important to consider alternative technologies that may be making similar improvements in efficiencies and cost. One such technology is compact fluorescent lamp (CFL) which boasts an industry leading efficiency of approximately 65 lm\watt. This compares to the white LEDs used in this project which use 3 watts to generate 65 lumens: an efficiency of about 22 lm\watt. Although this is clearly a more efficient light source, it does not match the color rendering capabilities of a mixed LED light system. Color control for fluorescent lights has been one its major drawbacks. In fact, a round table forum to discuss CFLs sponsored by the EPA took place on the campus of Rennselaer Polytechnic Institute in February of 2004. When the attendees were asked if color consistency is a problem for the marketability of CFLs, the common census was in the affirmative.

5. Case Study: LED Desk Lamp

The prototype LED desk lamp shown below demonstrates the LED as a viable source of white light for the work environment. It was built using four white Luxeon III emitter stars provided my LumiLeds and a 700mA current source provided by Future Electronics.

Figure 5: Prototype LED Desk Lamp

This image, taken in a perfectly dark room, shows the luminescence of these 3 watt LEDs. Ergonomics was an important design consideration of this task light; in a work environment, it is important to be able to comfortably illuminate the work area. An important property of LEDs is that they can be dimmed without the addition of expensive or complicated electronics, as is the case with fluorescent lighting. Another important consideration of designing an LED light for the workplace is the color rendering index (CRI). The CRI is a measure how a light source renders the true colors of the objects in an environment relative to another light source such as the sun. For the desk lamp, although no tests were made to measure its CRI, seemed to illuminate objects in the room similar to a fluorescent light, although a bluish tinge was observed whereas the fluorescent light in the room had a warmer color.

A drawback of this task light arises from the nature of the light source. Since light is emitted from four very small (virtually) point sources, additional optics may be needed to spread and diffuse the light at wider angles. Dark shadows tend to arise when there is not much ambient light due to the relatively narrow angle at which the lights shine.

Conclusion

The current state of the art in white LEDs for use in general lighting is such that it is cost prohibitive in most applications. While this may sound severe, the good news is that the current market for LEDs for use in applications such as LCD backlighting and automotive lighting is just starting to spurt and is expected to grow even more within the next two to four years. Below is a chart of the expected market expansion within the next six years. As more players in the LED industry are starting to create LEDs for general lighting, such as North Carolina's Cree Inc., it is apparent that this is a technology that is starting to take off.

I strongly encourage engineers working the on the Delta SmartHouse to consider designing an LED light system for the future as the environmental implications are important. In addition to energy savings on a monthly basis, LEDs do not contain toxins such as mercury that fluorescent lights do. Also, an LED light system would eliminate the need to change lights for at least eight years.

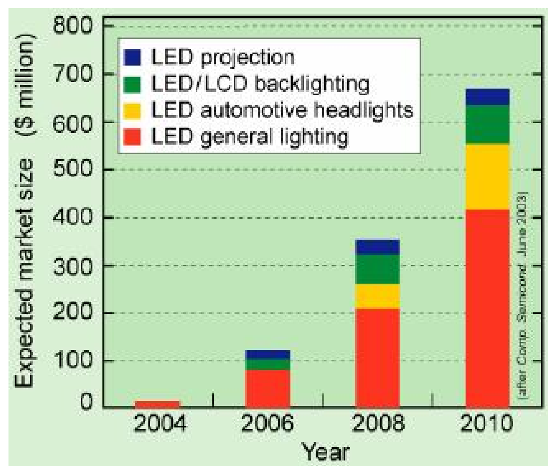

Figure 6: LED Market Forecast

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