Using LEDs to their Best Advantage

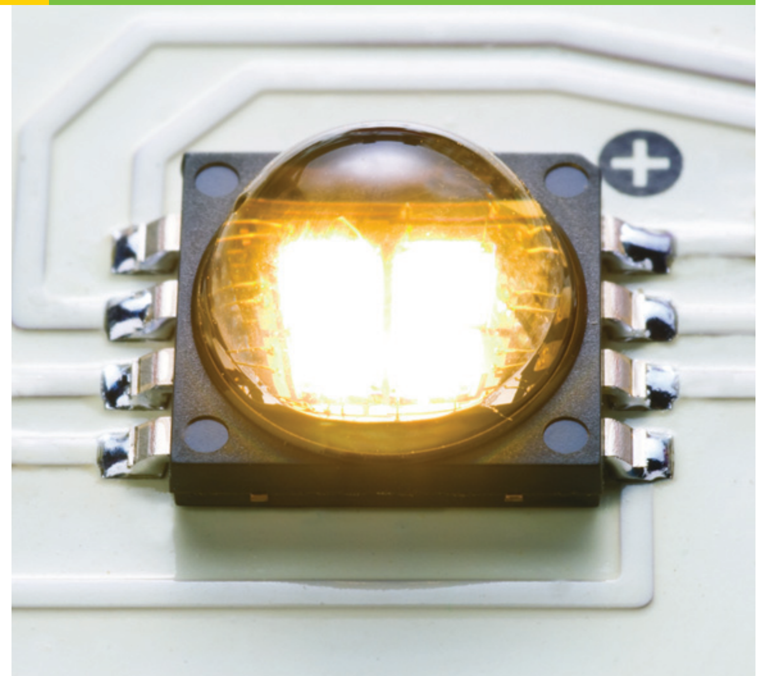


Image Credit: Cree

Light-emitting diodes (LEDs) are often touted for their energy efficiency and long life. Although these are important considerations, selecting a light source should involve many other factors. This fact sheet explores some of the unique attributes of LEDs, which may make them the best choice for a given application.

Introduction

Financial considerations—namely, purchase price and operating costs—always figure in the selection of lighting products, but many other aspects also come into play, varying in importance depending on the application. LEDs have several unique attributes, and it is critical to understand how they can be used advantageously. Some considerations are dependent on product design, but others amount to using LEDs in appropriate situations. Some of the potentially favorable characteristics of LED sources compared to traditional lamps include:

- Directional light emission
- Size and form factor
- Resistance to mechanical failure (i.e., breaking)
- Instant on at full output
- Rapid on-off cycling capability without detrimental effects
- Improved performance at cold temperatures
- Dimming and control capability
- Opportunity for color tuning
- Minimal nonvisible radiation [e.g., ultraviolet (UV), infrared (IR)]
- Extended lifetime

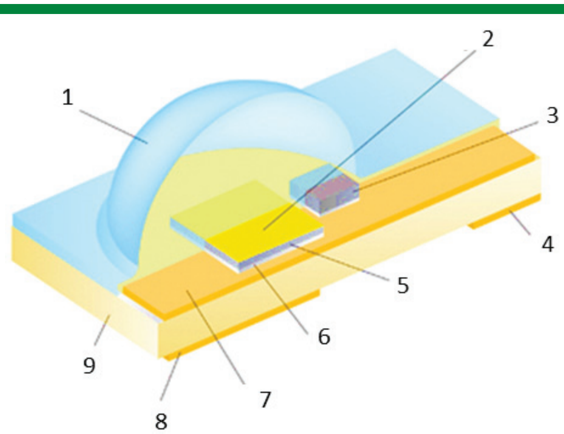
LEDs are semiconductor devices that emit light through electroluminescence.[1] This basic fact is the foundation for many of the advantages of LEDs, since it is different from traditional light sources. For example, incandescent lamps rely on a heated filament to emit light, fluorescent lamps create light using a gas discharge to excite phosphors, and high-intensity discharge (HID) lamps utilize an electric arc discharge. All of these traditional technologies require a glass bulb to contain essential gases and/or coatings.

In contrast to the large form factors of traditional lamps, LED lighting starts with a tiny chip (also called a die; most commonly about 1 mm^2) comprised of layers of semiconducting material—the exact material determines the wavelength (color) of radiation that is emitted. At the next level are LED packages, which may contain one or more chips mounted on heat-conducting material and usually enclosed in a lens or encapsulant. The resulting device, typically less than 1 cm^2, can then be used individually or in an array. Finally, LEDs are mounted on a circuit board and incorporated into a lighting fixture, attached to an architectural structure, or made to fit the form factor of a traditional lamp (or as it is colloquially known, a light bulb).

1 LEDs rely on injection luminescence, a specific type of electroluminescence. In this case, light is generated directly when electrons recombine with holes, in the process emitting photons. For more on the physics of LED light generation, see the *IES Lighting Handbook* or other reference sources.

LED Package Design

Although not all LED packages are built the same way, the basic components are often similar. Besides the chip that is responsible for emitting light, the various components are needed for thermal regulation, producing the desired spectrum, regulating electrical characteristics, or creating the appropriate distribution of light. All these components must work in harmony to produce a high-performance product. Many of the advantages of LEDs are derived from their unique physical attributes.



1. Silicone Lens
2. Phosphor Plate
3. Transient Voltage Suppressor
4. Cathode
5. LED Chip
6. Bond Layer
7. Metal Interconnect Layer
8. Thermal Bed
9. Ceramic Substrate

Image Credit: Philips Lumileds

Directional Light Emission

Traditional light sources emit radiant energy in all directions. As such, an optical system—a lamp housing or a luminaire, with elements such as a reflector or lens—is typically necessary to direct output in the desired direction. Because no optical system is perfectly efficient, losses in efficacy result. Further, if the optical system is not well designed (or is not present), light can be wasted, going in undesired directions.

Due to their physical characteristics and because they are mounted on a flat surface, LEDs emit light hemispherically, rather than spherically. For task lighting and other applications requiring directional lighting, this may increase the application efficacy[2] of the source. In contrast, with LEDs it is more difficult to obtain an omnidirectional distribution when it is desired, although innovative system designs now provide this capability.

Size and Form Factor

The small size, scalability of arrays, and directional light emission of LEDs offer the potential for innovative, low profile, or compact lighting products. This advantage can be aesthetic, but may also be functional. For example, reducing the depth of a luminaire may allow more room for ducts, conduit, or other building systems in a ceiling cavity. It is even possible that the size of the ceiling plenum could be reduced. In contrast, the unique form factor of LEDs can be a disadvantage when competing with high-wattage HID sources. To match the lumen output, a very large array of LEDs is necessary.

2 Application efficacy is defined as the lumens delivered to the target plane divided by the input watts to the lamp (or the ballast or driver, if applicable).

Source Type:
LED
Dimensions:
6.1” deep
17.5” square
Input Watts:
133
Lumen Output:
10,575

Source Type:
Metal Halide
Dimensions:
11.5” deep
15” round
Input Watts:
175
Lumen Output:
10,400

The physical characteristics of LEDs allow for the design of luminaires that are different shapes and sizes compared to those made for conventional lamps. In this example, the depth of the LED parking garage luminaire is significantly less than a more traditional luminaire with a metal halide lamp.

Achieving small form factors requires careful design, specifically with regard to thermal management. Although LEDs used for general lighting do not emit infrared radiation (i.e., heat), they do generate thermal energy that must be moved away from the chip by a mass of material, which is called a heat sink. In order to produce more light output, LEDs are often grouped into arrays, which dictate the use of additional heat-sinking material. Thus, although LED packages are small, matching the performance of small traditional lamps, such as MR16s, can be challenging.

Breakage Resistance

LEDs are largely impervious to vibration because they do not have filaments or glass enclosures. The life of standard incandescent and discharge lamps may be reduced by vibration when operated in vehicular or industrial applications, although specialized vibration-resistant lamps can help alleviate this problem. The inherent vibration resistance of LEDs may be beneficial in applications such as transportation lighting (planes, trains, or automobiles), lighting on and near industrial equipment, or exterior area and roadway lighting.

In addition to benefits during operation, LEDs offer increased resistance to breaking during transport, storage, handling, and installation. LED devices mounted on a circuit board are connected with soldered leads that may be vulnerable to direct impact, but no more so than cell phones and other electronic devices. Because they do not contain any glass, LED fixtures may be especially appropriate in applications with a high likelihood of lamp breakage, such as sports facilities or vandalism-prone areas, although they are not indestructible. LED durability may also be beneficial in applications where broken lamps present a hazard to occupants, such as children’s rooms, assisted living facilities, or food preparation areas.

Instant On

Most fluorescent lamps do not provide full brightness immediately after being turned on. This is particularly relevant to amalgam compact fluorescent lamps (CFLs), which can take three minutes or more to reach full light output. HID lamps have even longer warm up times, ranging from several minutes for metal halide to ten minutes or more for high-pressure sodium (HPS). HID lamps also have a restrike time delay; if turned off, they must be allowed to cool before turning on again, usually for 2 to 20 minutes, depending on the ballast. In contrast to traditional technologies, LEDs turn on at full brightness almost instantly, with no restrike delay. This advantage can be simply aesthetic or a user preference, but can also be beneficial for emergency egress or high-security situations. It is also especially important for vehicle brake lights—LED versions illuminate 170 to 200 milliseconds faster than standard incandescent lamps, providing an estimated 19 feet of additional stopping distance at highway speeds (65 mph).[3]

Rapid Cycling

LEDs are impervious to the deleterious effects of on-off cycling. In fact, one method for dimming LEDs is to switch them on and

3 See *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications* at *http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/niche_final_report.pdf*.

off at a frequency that is undetectable by the human eye. For fluorescent lamps, the high starting voltage erodes the emitter material coating the electrodes. Thus, lifetime is reduced when the rate of on-off cycles is increased. Due to the long warm up and restrike times, rapid cycling is not an option for HID lamps. Because of their operating characteristics, LEDs have an advantage when used in conjunction with occupancy sensors or daylight sensors that rely on on-off operation. Whereas the lifetime of fluorescent sources would diminish, there is no negative effect on LED lifetime.

Cold Temperature Operation

Cold temperatures present a challenge for fluorescent lamps.[4] In contrast, LED light output (and efficacy) increases as operating temperatures drop. This makes LEDs a natural fit for refrigerated and freezer cases, cold storage facilities, and many outdoor applications. In fact, CALiPER testing of an LED refrigerated case light measured 5% higher efficacy at -5 °C compared to operation at 25 °C.[5] Conversely, operation of LEDs in hot environments or use of products with poor thermal management characteristics can lead to undesirable performance attributes ranging from reduced lumen output to premature failure.

Image Credit: GE Lighting Solutions

Dimming Performance

Dimming is often a desirable operating characteristic, but most energy-efficient technologies have challenges that must be overcome or mitigated. Many (but not all) LED products can be dimmed, although great care must be taken to ensure compatibility between the different hardware devices (e.g., the driver and dimmer). Incompatible lamp and dimmer combinations may result in flicker, color shift, audible noise, premature lamp failure, very limited or no range of dimming, or failure to light. These problems may manifest themselves at full output and/or when dimmed. Furthermore, they are typically dependent on the number of lamps connected to the dimmer. The best performing LEDs, when matched with a compatible dimmer, have better dimming performance than CFLs (limited range) or HID lighting (limited, if any, dimmability). However, there is a substantial performance differential among LED products and for various LED-dimmer combinations.

Tunability

One of the most significant advantages of LEDs is the ability to mix chips of multiple types in a single product. For example, red, green, and blue (RGB) chips can be combined to make white light (and any color within their gamut), or two shades of white LEDs can be combined and adjusted independently to create light with varying color temperatures (i.e., warmer or cooler in appearance). Combining multiple fluorescent lamps also provides this capability, but in practice, it is seldom utilized. Although the idea of tunable light sources is not prevalent today, it is a tool that can be used to increase occupant satisfaction in a variety of settings, such as offices, hotels, restaurants, and homes. Thus, as LEDs become more widely used, the concept may see increased recognition and application.

In addition to color customization, the output of LEDs can also be altered over the course of their lifetime. In this manner, it is possible to prevent color shift and/or greatly reduce lumen depreciation. Eliminating lumen depreciation is particularly advantageous because it would allow for the removal of lamp lumen depreciation from design calculations, reducing initial over-lighting. This technology is not currently in widespread use, but as the equipment becomes less expensive, the potential advantage may be realized.

No Infrared or Ultraviolet Emissions

Ultraviolet and infrared radiation bookend the spectrum of visible light, but do not contribute to humans' ability to see. Ultraviolet radiation can damage artwork, artifacts, and fabrics, as well as causing skin and eye burns. Similarly, excessive infrared radiation from lighting presents a burn hazard to people and materials. With traditional sources, ultraviolet and infrared emissions are either necessary to generate visible light (e.g., fluorescent lamps) or simply an unavoidable component. The consequences of these undesirable emissions include reduced efficacy and/or the necessity of providing additional safeguards. For example, the infrared radiation generated by incandescent lamps accounts for more than 90% of the power they draw. Metal halide lamps require an ultraviolet-blocking outer bulb (or to be operated in an enclosed

4 At low temperatures, a higher voltage is required to start fluorescent lamps and luminous flux is decreased. A non-amalgam CFL, for example, will drop to 50% of full light output at 0°C. The use of amalgam (an alloy of mercury and other metals that is used to stabilize and control mercury pressure in the lamp) largely addresses this problem, allowing CFLs to maintain light output over a wide temperature range (-17 °C to 65 °C). The trade-off is that amalgam lamps take a noticeably longer time to reach full brightness.

5 The summary report for CALiPER Round 2 can be found at *http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cptp_round_2_summary_final_draft_8-15-2007.pdf.*

APPLICATION: MUSEUM LIGHTING

Museums often display artwork that is highly sensitive to both ultraviolet and visible radiation. The ability to carefully tune the spectrum of LED products (and essentially eliminate ultraviolet radiation) give them a unique advantage in this application.

LEDs are used to illuminate the Rose Gallery at the Smithsonian American Art Museum. Lighting and photography by Scott Rosenfeld.

fixture) due to the significant level of ultraviolet radiation emitted from the inner arc tube.

Based on how they generate radiant energy, LEDs chosen for general lighting applications do not emit much (if any) ultraviolet or infrared radiation. This helps boost efficacy and reduces the potential for undesirable consequences.

Extended Lifetime

The rated lifetime of LED products is at least comparable to other high-efficacy lighting products, if not better, and for many specific product types, LEDs have the highest rated lifetime. This attribute can be especially important where access is difficult or where maintenance costs are high. In fact, several U.S. Department of Energy GATEWAY demonstrations have revealed that maintenance savings, as opposed to energy savings, are the primary factor in determining the payback period for an LED product.

Conclusion

The LED product market continues to grow rapidly. In many applications, today's high-quality LEDs can outperform traditional technologies when evaluated with conventional metrics including efficacy, color quality, and operating cost. However, LED products have significant variation in performance from one product to the next. Thus, generalized comparisons are often misrepresentative. When purchasing or specifying LED products, it is essential to evaluate appropriate data and, if necessary, conduct a physical evaluation of a mock-up.

The attributes discussed in this fact sheet are predominantly a result of the physical characteristics of LEDs, and may not show up in a catalog or on a specification sheet. It is critical to understand the specific needs of a given application in order to select the most appropriate technology. Considered holistically, the best option may not always be the most efficacious. No matter how much energy can be saved, a product that does not meet the performance requirements is not a good choice.

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