quick study

LED luminaires—a whole new light

Kevin Dowling

The light-emitting diodes that sit at the heart of integrated solid-state lighting systems, or luminaires, allow for novel applications but also present engineers with particular challenges.

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A light-emitting diode is a semiconductor device that converts electrical energy into a discrete color of light. At the turn of the century, LEDs were used primarily for indication, as in, for example, clock radios; their use in lighting was still relatively new. An article in the December 2001 issue of PHYSICS TODAY (page 42) described the rapid progress in LED development. Since that article was published, LEDs have continued to advance in all areas of performance and economics: Light output and quality, cost, use, and availability have all improved markedly. Now LEDs are beginning to be applied for general illumination. Moreover, the economics of energy and maintenance allow their use in many other ways—for example, as objects embedded into surfaces or structures. (See also PHYSICS TODAY, December 2007, page 25.)

In addition to LED technology, the systems, or luminaires, into which LEDs are integrated have markedly evolved. No longer relegated to niche products, LED luminaires are now available for a growing number of applications. Figure 1 shows a representative luminaire, designed to emit white light. LED-based lamps will evolve, and new types will emerge onto the market. The future will see new fixtures that house high-intensity LEDs and lamp replacements that provide light similar to traditional sources of illumination. As a result of technological improvements in both LEDs and the systems that incorporate them, solid-state lighting is one of the fastest-growing segments of both the semiconductor and lighting industries.

An integrated system

Generally, LEDs behave like other kinds of diodes. They are low-voltage devices that require 2.2–3.5 V depending on the wavelength of the light they emit. Currents range from a few tens of milliamps up to 1 A or more on high-power packages. LEDs can be linked together in series to obtain higher voltages across the string and reduce system losses.

Solid-state lighting, however, is not just about LEDs. Clearly, the LED is an important part of a luminaire, but it is only one element of a system with many features. Figure 2 illustrates how an LED luminaire incorporates everything needed, first to manage the stream of electrons, then to convert electrical energy into photons and heat, which necessarily arises because the conversion process is not perfectly efficient, and finally to manage that light and heat output.

Below the LEDs in the figure are drivers and devices for control and sensing. The drivers take power and possibly a control signal and provide voltage and current to control the LEDs. Nearly all high-brightness LEDs are driven at constant current, since changes in current result in changing outputs and, in particular, shifts in wavelength.

Drivers may be controlled by so-called dimming signals. The drive current doesn't change, but it is modulated so that the LED rapidly turns on and off; the more time the LED is off, the dimmer the light appears. The frequency of the modulation should be above perceivable flicker frequencies to avoid annoying visual artifacts. But that's not a problem for LEDs, which can be switched on and off thousands of times per second or more without compromising performance or lifetime.

Much of the work surrounding LED-driver development is to provide efficient, reliable electronics for those long-lived devices. Efficiencies are typically 80–90%, and some new configurations promise better than 90% efficiency. If those promised efficiencies are reached, drivers will need power levels of only tens of watts to provide general-purpose illumination.

Some LED systems have little in the way of control. But nowadays many LEDs in architectural and entertainment settings require coordinated effects. Typically, communication capability is built into the fixture; for example, an Ethernet connection allows the luminaire to accept data and enables external control of the LEDs.

Thermal management appears to the left of the LEDs and drivers in figure 2. LEDs are efficient converters of electricity into light—in many cases they are four or five times more efficient than traditional incandescent and halogen white-light sources. But they are not perfectly efficient. Temperatures inside an LED can exceed 100 °C, and elevated temperatures quickly reduce the LED's light output and lifetime.

Engineering the thermal path from the LEDs to the environment is critical to good fixture design. Visible-light LEDs radiate only in the visible spectrum; they do not radiate heat. They do, however, conduct heat. Thus, although active schemes such as fans or cooling cycles are sometimes used for thermal management, most LED cooling is in the form of heat sinks, gap pads, and other materials that wick the heat away from the package. In well-designed systems,

Figure 1. The light fixture of the future may look very different from the lamp of today. Form will follow function to reflect the many ways in which LEDs can be used. In this fixture, the white bulbs incorporate blue-emitting LEDs, each covered by a phosphor that converts the blue light to white.

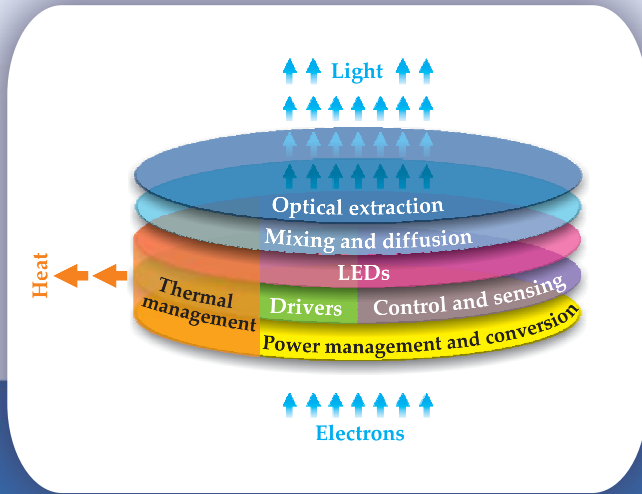

Figure 2. An LED luminaire includes a number of tightly integrated technologies, discussed in the text, that work together to convert electrical energy into light.

those materials are directly coupled to large-area plates and heat sinks that are integral to the housing of the luminaire. Indeed, such plates are a prominent feature of the luminaires illustrated in figure 1. Without the coupling of LED and housing, the heat has nowhere to go, and the LED will stew in its own juices.

Getting the most out of LEDs

Once light emerges from the LED, mixing, diffusion, and collimation help provide high-quality light. An additional goal is to minimize photon losses and maximize light output. The techniques used to achieve quality and quantity are often at odds. For example, most applications use multiple LEDs to produce the needed light. By using diffusion to make the emitted light homogeneous, a manufacturer could avoid multishadowing effects associated with the multiple point sources. But that technique reduces the total light output. Other undesired effects associated with multiple LEDs include concentric halos on lit surfaces and visible individual sources, dubbed the “Lite-Brite” effect after a children’s toy. Efficient diffusing materials, lensing, and good optics are critical to light quality, uniformity, and the avoidance of the aesthetic problems just described.

LEDs are already in widespread use in many applications, including entertainment, hospitality, architecture, and theater; even artists are using them. Many tens of thousands of installations are in operation worldwide, and the number is growing rapidly. Architects and lighting designers are growing comfortable with specifying LED lighting systems, and residences are increasingly using solid-state lighting.

Most color LED systems on the market use independent control of the three primary colors of light: red, green, and blue. That capability allows for an extended gamut of colors, including white, with varying degrees of saturation, light quality, and color fidelity. With good control, a fixture can seamlessly wash through a full color spectrum. For many general lighting applications, however, white-light systems will be the preference. White-light LEDs, which use blue LEDs and a phosphor, are improving rapidly. The conversion mechanism in the phosphor is similar to that in a fluorescent lamp. The blue light that hits the phosphor is reemitted as a broad range of colors across the visible spectrum, and appears white.

Many control effects originated in theatrical and entertainment lighting systems, so most control protocols are the ones widely used in those markets. However, today’s larger installations include many hundreds of thousands of individually controllable LEDs and cover entire building facades and room interiors. Those systems are using Ethernet as the basis for shipping data around conventional computer local area networks to control LED systems. They integrate graphics, text, images, and video into dramatic multimedia installations.

Standard time

These days, when the applications and markets for LED systems are growing rapidly, there is a strong need for standards. Otherwise, the difficulty in specifying LED luminaires is exacerbated by the inability to compare those luminaires with each other. Claims of light output, efficacy, lifetime, and more are nonsensical if manufacturers use different criteria or, worse yet, no criteria at all. The good news is that standards for a variety of LED characteristics are being developed through organizations such the Illuminating Engineering Society of North America, the American National Standards Institute, and the National Electrical Manufacturers Association.

For decades the incandescent bulb has been the symbol of electrical lighting. Yet, in the not-too-distant future the incandescent bulb will all but disappear. Will lighting get a new symbol? Or will the icon outlive the lamp? If the icon does survive, a future generation may ask their grandparents about the odd, pear-shaped object that floats above someone’s head to designate a bright idea.

Additional resources

▶ US Department of Energy Building Technologies Program, solid-state lighting, http://www.netl.doe.gov/ssl.
▶ *LEDs Magazine*, http://www.ledsmagazine.com.
▶ K. Dowling, “LED Essentials,” 11 October 2007 webinar, http://www.netl.doe.gov/ssl/PDFs/DOE-Webinar-2007-10-11.pdf.