Photo: Courtesy of OSRAM Opto Semiconductors

THE CUSTOMER IS ALWAYS RIGHT

Even with all the chatter surrounding OLEDs, proponents are well-advised to remember this simple maxim: people buy luminaires, not technology

BY IAN ASHDOWN AND BRENT YORK

Organic light-emitting diodes (OLEDs) are currently a hot topic in the lighting industry. With companies such as OSRAM, Philips and General Electric displaying prototype products and announcing commercial availability of OLED panels for prototype lighting applications, it is difficult to ignore the industry buzz: “OLEDs are the future of lighting!”

But wait, we have been here before. Ten years ago, the industry buzz was, “semiconductor LEDs are the future of lighting!” Today, solid-state lighting (SSL) has become a commercial reality and it may well overshadow fluorescent lamp technology in the future. However, we learned an important lesson along the way: *People do not buy technology; they buy luminaires.*

The importance of this lesson cannot be overstated. Referring to the IES Lighting Handbook, a luminaire (light fixture) is defined as “a complete lighting unit consisting of a lamp or lamps and ballast(s) (when applicable) together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply.”

Architectural lighting has always been about more than just the lamp technology. We rely on the luminaire to properly distribute the light, both to provide desirable levels of horizontal and vertical illuminance, and to control visual glare. Lighting designers specify–and people buy–luminaires.

The lesson we learned with SSL is that advances in LED technology were important only within the context of SSL luminaires. This applies equally to OLED technology. In particular, we need to look beyond the technology and ask what it is that an OLED luminaire needs to do.

A typical OLED device consists of laminated organic thin films sandwiched between two electrodes and deposited on a glass or plastic substrate (**Figure 1**). When a voltage is applied to the transparent electrodes, the current flow through the organic layers generates light as the electrons and holes recombine in the emissive layer.

If this looks familiar, it is because the principle of operation is identical to that of semiconductor LEDs. The transport and emissive layers are the organic equivalent of the indium gallium nitride (InGaN) thin films used in blue and green LEDs. There are, however, important differences. While semiconductor LEDs are limited in size to roughly a square millimeter or so, organic LEDs can (in principle) be fabricated by the square meter using various manufacturing techniques. Moreover, the plastic substrates can be flexible.

Depending on the choice of organic materials for the emissive layer, OLEDs can be designed to emit any color, including white light with various color temperatures. This, in combination with high luminous efficacy and long lifetimes, reputedly makes OLEDs ideal candidates for architectural lighting applications.

But again, wait. As we learned with semiconductor LEDs, having light sources with high luminous efficacies and long lifetimes is only the beginning of the story. We need to consider how OLEDs will function as light sources in luminaires. From a luminaire design perspective, we are interested in the optical characteristics of any light source (**Table 1**).

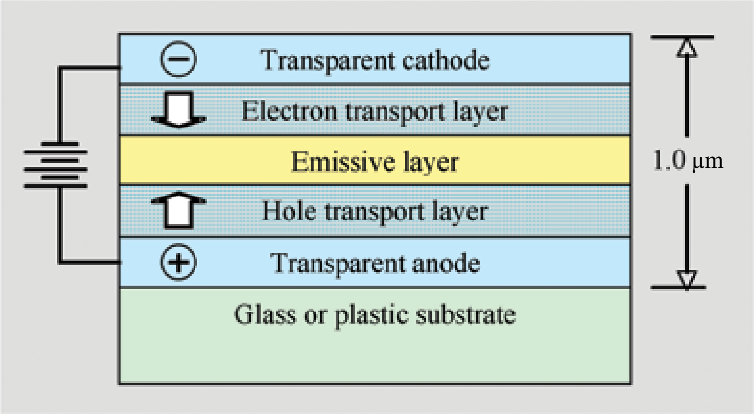
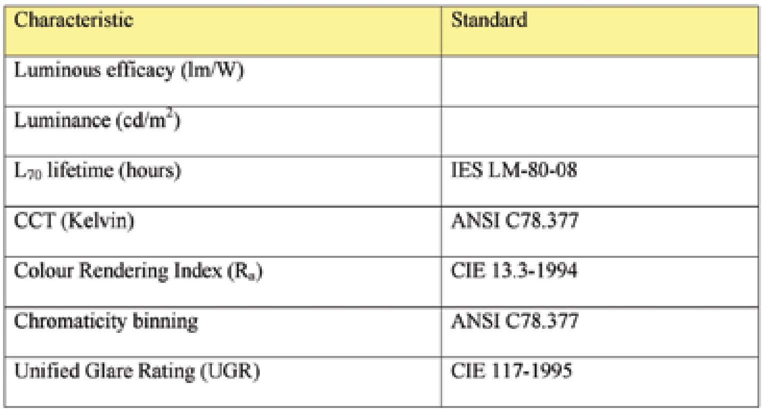


Figure 1 - Typical OLED device.



Characteristic	Standard
Luminous efficacy (lm/W)	
Luminance (cd/m^2)	
L_{70} lifetime (hours)	IES LM-80-08
CCT (Kelvin)	ANSI C78.377
Colour Rendering Index (R_a)	CIE 13.3-1994
Chromaticity binning	ANSI C78.377
Unified Glare Rating (UGR)	CIE 117-1995

Table 1 - Light source optical characteristics.

OLED manufacturers today typically quote three parameters for their white light products: luminous efficacy (lumens per watt), luminance (candelas per sq meter) and lifetime (hours). The first two are familiar, but some care needs to be taken with lifetime values. As defined in IES LM-80-08, the rated lumen maintenance life Lρ is the "elapsed operating time over which the LED light source will maintain the percentage, p, of its initial light output." For lighting display purposes, the L_{50} (50 percent lumen maintenance) value is used, while for architectural lighting the L_{70} (70 percent lumen maintenance) value is required.

Reflecting OLEDs' heritage as a display technology for television and mobile devices, many manufacturers state or assume L_{50} for their lifetime values. Converting these into L_{70} values is easy–just divide the L_{50} value by two.

Six months ago, the most state-of-the-art white light OLED lighting panels commercially available featured 15 lumens per watt luminous efficacy, 1,000 candelas per sq meter luminance and an L_{70} lifetime of 5,000 hours. However, OLED technology is advancing rapidly. For example, OLED manufacturer Visionox has demonstrated prototype desk lamps featuring white light OLEDs with 40 lumens per watt and an L_{70} lifetime of 50,000 hours (**Figure 2**).

Applying Haitz's Law (which successfully predicted that LED luminous intensities would double every

36 months), an optimist might reasonably conclude that architectural OLED luminaires are “just around the corner.” (The OLED manufacturers themselves are predicting another three to five years.) However, this begs the question: what is an OLED luminaire?

LIGHTING WALLPAPER

Many OLED manufacturers do not see their products as being used as lamp replacements. In a recent interview with *www.dvice.com*, OLED scientist Anil Duggan of GE Research said “the big fantasy product that we always talk about is lighting wallpaper. We want all offices and homes to have this very flexible light source. When I say flexible, I mean a mechanically flexible light source that you can just paste wherever you want it and turn it on.”

But does this make sense? Will lighting designers and, more important, consumers, accept “lighting wallpaper”? We have, after all, spent over a century designing and specifying luminaires that control the light emitted by bare lamps, mostly while shielding the lamps from direct view. Will we accept such a radically different design paradigm?

To answer this, we can look back 50 years to a time when “luminous ceilings” were in vogue. These consisted of white plastic diffusion panels backlit by linear fluorescent lamps. At the time, they were popular for residential kitchens and in the futuristic space stations depicted in movies such as *2001: A Space Odyssey*. Today, you will be hard-pressed to find any examples; most people do not like them.

One notable exception is the Modern Wing of the Art Institute of Chicago, where the soft and essentially shadow-free lighting is well-suited for displaying sculptures and paintings. For most applications however, we prefer lighting with directionality and shadows to define the visual environment. (As a counterexample, consider a uniformly overcast sky. While the horizontal illuminance may be 50 to 100 times greater than what we expect for indoor environments, we often complain about the weather being “dark and dreary.”)

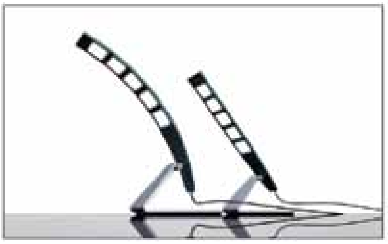


Figure 2 - Visionox prototype desk lamps.

Remember the lesson: *People do not buy technology; they buy luminaires.* Whether OLED manufacturers can produce lighting wallpaper or luminous ceiling panels is immaterial if there is no significant market for their products.

VISUAL GLARE

While people may not accept lighting wallpaper or luminous ceilings, there is certainly a market to replace the millions of linear fluorescent lamp troffers in existing office buildings throughout the world. Energy-efficient OLED panels as retrofit luminaires would seem to be an ideal solution. It is here, however, that we encounter another problem: visual glare.

Linear fluorescent troffers are designed to limit their luminous intensity distributions at high viewing angles in order to prevent visual glare in the field of view. ANSI/IESNA RP-1, for example, specifies the maximum intensity to range from 300 cd at 65 deg to 60 cd at 85 deg. CIE 117 is even more specific with its Unified Glare Rating (UGR) for direct luminaires.

To quantify this issue, we used Lighting Analysts’ AGi32 to model two empty rooms measuring 24 by 24 meters with 64 1-ft by 4-ft direct linear fluorescent troffers. In the first model, we used photometric data for a typical commercial luminaire, while for the second model we assumed a hypothetical 53-in. by 7-in. OLED panel with a luminance of 3,700 candelas per sq meter to produce the same horizontal workplane illuminance of 320 lux.

For the first model, the UGR values rarely exceeded 18 (“acceptable” visual glare). For the second model, the UGR value was 22 to 24 (“unacceptable” to “just uncomfortable”) throughout the floor space, regardless of viewer orientation. (Somewhat surprisingly, the intensities of the OLED panel were 283 cd at 65 deg and 58 cd at 85 deg, which satisfied RP-1 requirements.)

Quite simply, we cannot employ OLED panels as replacements for direct linear fluorescent troffers without some form of optical control to limit their luminance at high viewing angles. Unfortunately, the only way to do this without sacrificing some of the light emitted by the panels is to increase their luminance to that of T8 linear fluorescent lamps–10,000 candelas per sq meter.

It is possible that OLED panels can be used as light sources in suspended indirect linear luminaires, but these typically require batwing luminous intensity distributions to avoid unsightly "hot spots" on the ceiling. Past experience in designing such luminaires indicates that OLED panel luminances on the order of 10,000 candelas per sq meter will still be required.

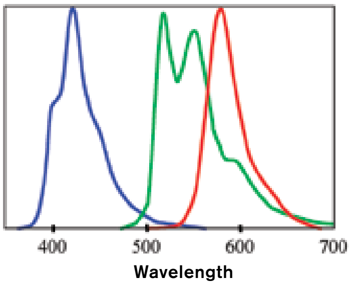


Figure 3 - Typical white light OLED spectrum.

COLOR ISSUES

Today's white-light OLEDs typically employ different electrophosphorescent materials to generate red, green and blue light (**Figure 3**). By balancing the light output from each material, the OLED manufacturer can adjust the correlated color temperature (CCT) over a wide range. To meet the expectations of the architectural lighting market, this range should be within the range of 2,700 to 6,500K (ANSI C78.377). The problem with this approach is that each electrophosphorescent material has a different L_{70} lifetime, with blue OLED materials typically half that of red and green OLED materials. As the OLED panels age, there will inevitably be significant color shifts.

This is not an important issue for OLED television displays, as each pixel color is driven independently by the video controller. All that is required is to occasionally adjust the display color balance. For white light OLED panels, however, there is no color control. As a result, the panels may exhibit unacceptable color shifts long before their L_{70} lifetime is reached. (A rough calculation indicates that this may happen after a lumen depreciation of only 2 to 3 percent.)

Whether OLED manufacturers can produce lighting wallpaper or luminous ceiling panels is immaterial if there is no significant market for their products

What constitutes an "unacceptable" color shift? ANSI C78.377 permits white light LEDs to have variations in chromaticity within the limits of seven-step MacAdam ellipses. This may be compared with ANSI C78.376, which specifies smaller four-step MacAdam ellipses for linear and some compact fluorescent lamps.

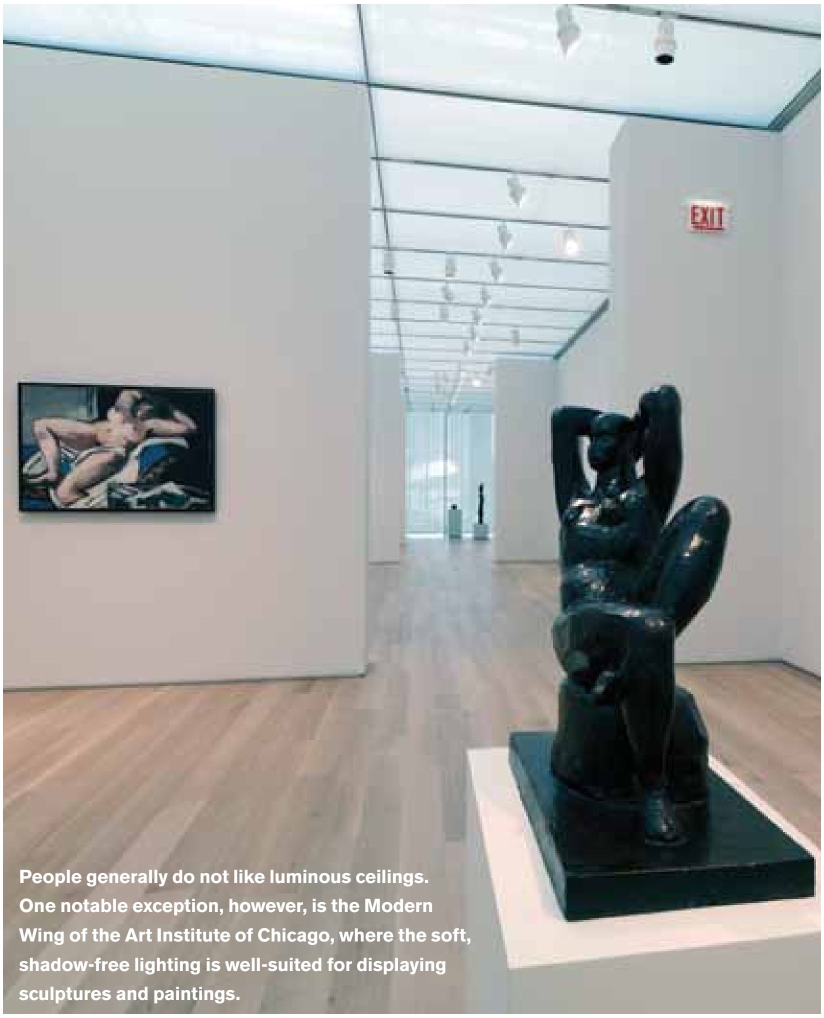
ANSI C78.377 implicitly recognizes the technical difficulties of chromaticity ("color") binning for semiconductor LEDs, which is why it allows seven-step MacAdam ellipses. Seen side-by-side, however, two colors that are seven MacAdam ellipses apart are easily distinguishable. If OLED panels are intended to be viewed directly, then four-step MacAdam ellipses will likely define the limits of acceptable color shifts.

One potential solution to the problem of color shifts is to employ narrow stripes of red, green and blue OLED materials with separate electrical drivers for each color and optical feedback, similar to what is done with high-end SSL luminaires with RGB LEDs. However, this takes away from the simplicity of OLED panels.

DEEP CONCERNS

Our goal in writing this article has been to review the architectural lighting requirements for future OLED-based luminaires. Visual glare and color shifts with aging are important, but not the only issues. Other compelling factors include CIE Colour Rendering Indices (CRI), luminance uniformity, as well as low-voltage power supply and thermal issues. (Claims of "no heat" for OLEDs notwithstanding, whatever electrical power that is not converted to light is necessarily converted to heat.)

While we are encouraged by the ongoing development of OLED technology, we fear that OLED manufacturers may not fully appreciate the needs of the architectural lighting industry. To wit, we do not believe that the availability of lighting wallpaper and luminous ceiling panels will result in a paradigm shift to-



People generally do not like luminous ceilings. One notable exception, however, is the Modern Wing of the Art Institute of Chicago, where the soft, shadow-free lighting is well-suited for displaying sculptures and paintings.

Photo: Dave Jordano

wards radically different lighting designs. The technology to create such designs has been available for over half a century, and they are not at all popular.

We are concerned that if OLED panels are to be employed as linear fluorescent lamp replacements, their luminance will have to be improved from the current 1,000 to perhaps 10,000 candelas per sq meter–a 10-fold improvement. At the same time, the L_{70} lifetimes will have to be improved five-fold or more. Luminance and lifetime are interdependent characteristics of OLEDs, and so these requirements will likely present a considerable challenge to OLED manufacturers.

As luminaire designers, we are also very much concerned about potential color shifts as the white light OLED panels age. We have seen little relevant discussion of this topic in the OLED research literature, but it is a critical issue that has to be addressed.

So what is the future of OLED lighting? Although we remain hopeful, we honestly do not know. We have expressed our concerns based on our decade of experience in SSL research and development. All we hope for is that the architectural lighting industry, including everyone from lighting designers to luminaire manufacturers, will discuss the issues and communicate with the OLED manufacturers.

Whatever we say, our message has to be clear: *People do not buy technology; they buy luminaires.*

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