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LEDs MAGAZINE®

TECHNOLOGY AND APPLICATIONS OF LIGHT EMITTING DIODES

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LED lighting lifts the mood P.15

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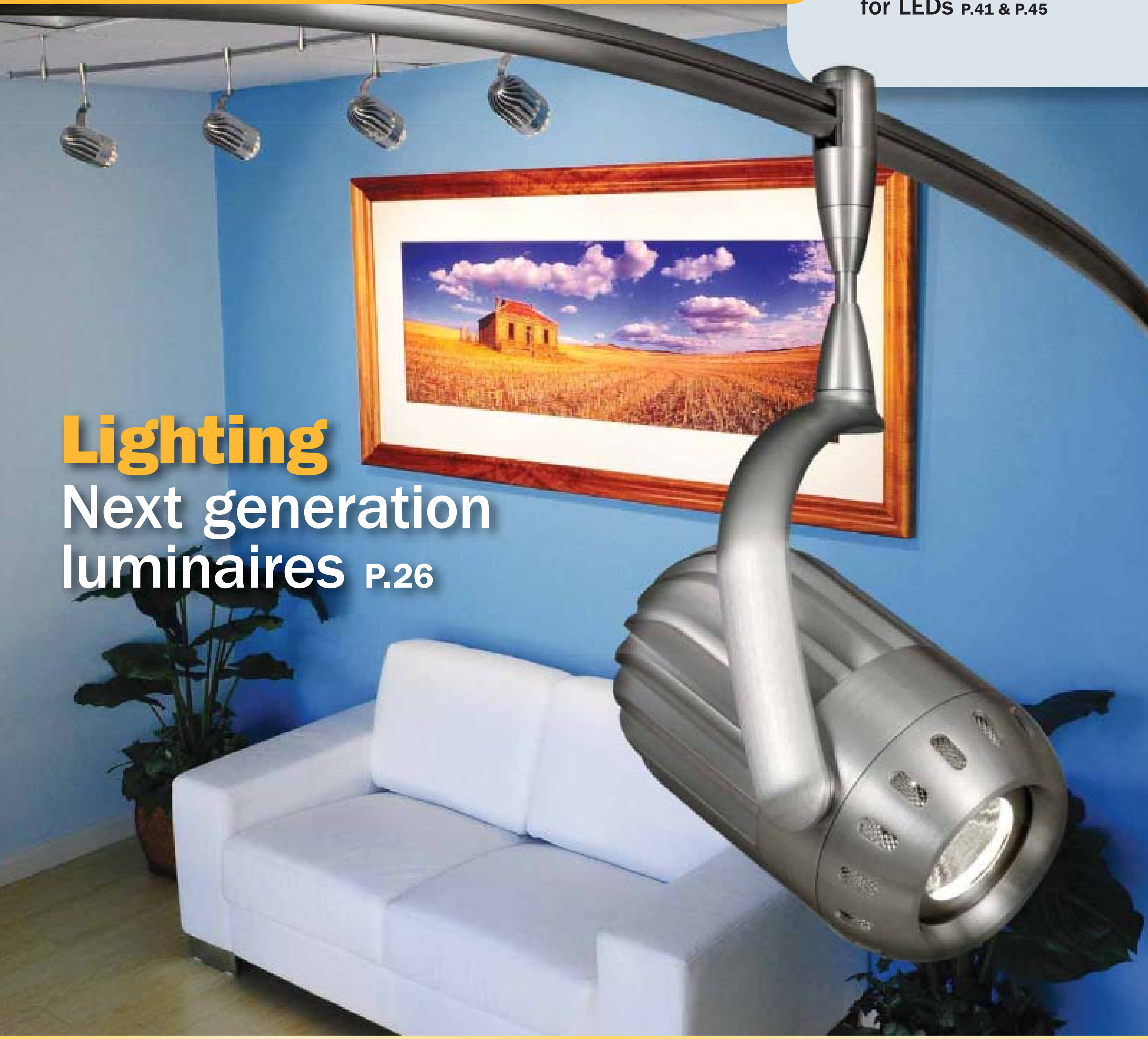
Heat management for LEDs P.41 & P.45



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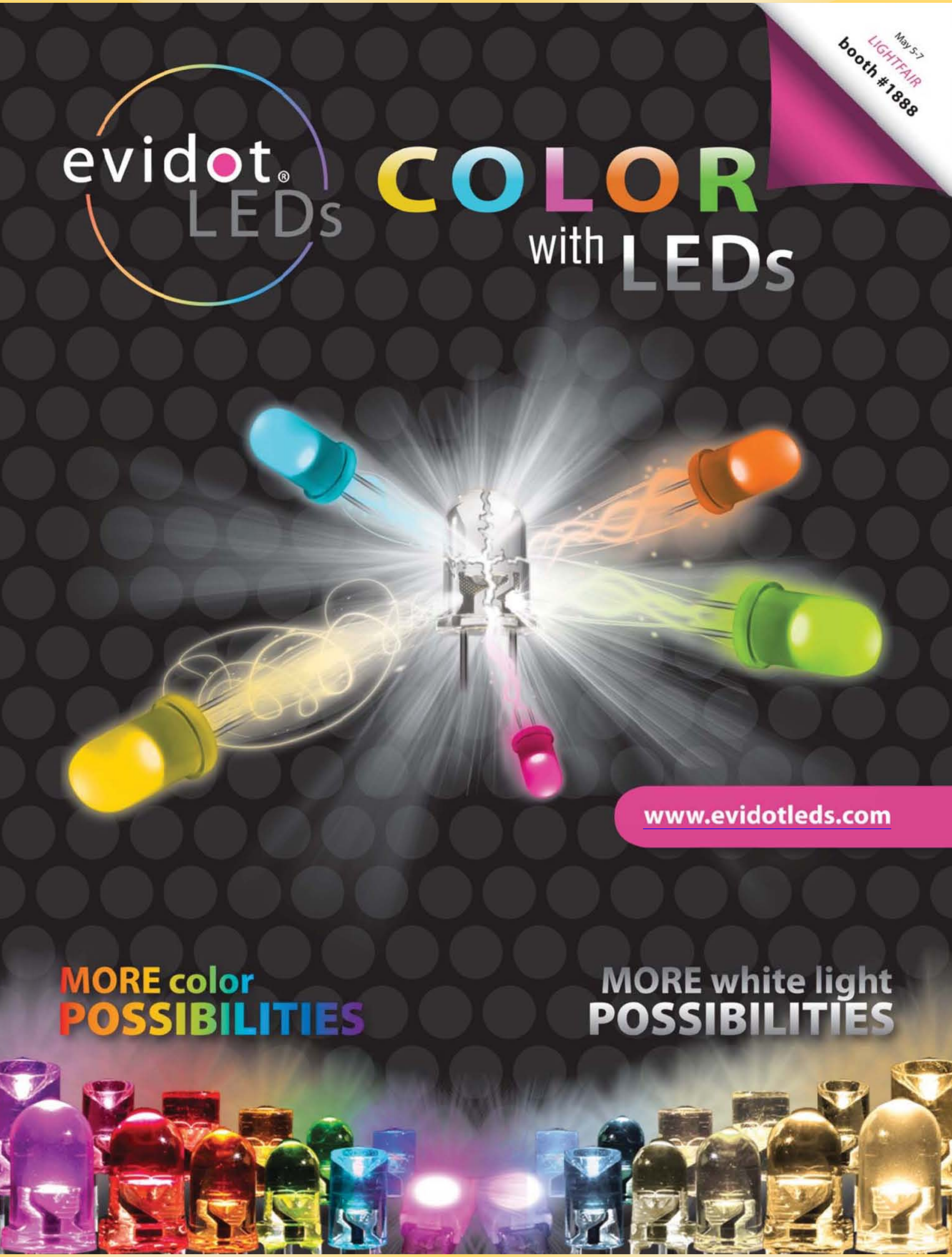
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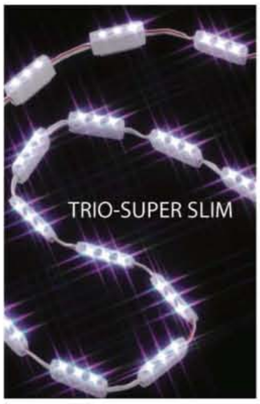

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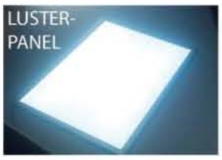

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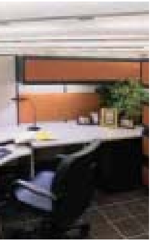
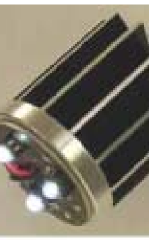
LEDs MAGAZINE®
ISSUE 26
April 2009

Cover Story

Journée Lighting won a Best in Class Award for its AZARA track-mounted luminaire (p.26). Photo by Holland Alexander.

features





columns/departments

LEDs MAGAZINE *online*

Webcasts

LED Lighting Fixture Market — Challenges and Opportunities

DATE: May 2009

PRESENTER: Vrinda Bhandarkar, Senior Market Research Analyst, Strategies Unlimited

LED Luminaire Photometry & Performance Testing

ORGINALLY BROADCAST: March 2009

PRESENTATIONS FROM: Intertek and SphereOptics

Visit www.ledsmagazine.com/webcasts to access all of our archived presentations.

Articles

Future remodels HQ building with LEDs
www.ledsmagazine.com/features/6/3/8

Energy Star Lighting Partner Meeting remembers the Alamo
www.ledsmagazine.com/features/6/3/5

Alamo revisited: Further notes from Energy Star meeting
www.ledsmagazine.com/features/6/3/9

Alliance Optotek's LED street light design technology
www.ledsmagazine.com/features/6/3/1

Featured Companies & Profiles

The following have recently been added to the LEDs Magazine *website as Featured Companies (see www.ledsmagazine.com/buyers/featured):*
American Bright Optoelectronics Corp. • Endicott Research Group (ERG), Inc. • Helio Optoelectronics Corp. • Opto Diode Corp. • RECOM Power, Inc. • Signcomplex Ltd. • Vossloh-Schwabe Optoelectronic

Company Profiles have also been added for the following (see www.ledsmagazine.com/Profiles):
Endicott Research Group (ERG), Inc. • RECOM Power, Inc. • Signcomplex Ltd.

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news views

MARKETS

LED lighting lifts the gloom

Although the high-brightness LED market looks set to deflate in 2009, the general industry mood remains positive, with certain sectors such as LCD backlighting, and lighting in particular, providing cause for optimism. Bob Steele of Strategies Unlimited, a market research firm, says that the market for packaged HB-LED devices grew by 11% in 2008, but is likely to shrink by 5% in 2009 (see p.15). The fastest growing sector of the device market in 2008 was lighting, although this remains small in size (below $0.5 billion). However, a separate market study by the same firm indicates that the market for LED lighting fixtures will reach $2.14 billion in 2009 and grow to $5.33 billion. At the LED device level, visibility remains poor. Steele expects growth to resume in 2010, assuming the economy as a whole recovers. Between 2008 and 2013, the compound average annual growth rate is predicted to be 19.3%, with the market reaching $12.4 billion in 2013. ◄

OUTDOOR LIGHTING

LA looking at LED street lights

The City of Los Angeles, with help from the Clinton Climate Initiative (CCI), has unveiled what could turn out to be the largest LED street lighting retrofit project ever undertaken by a city to date. Over a five-year period, beginning in July 2009, the city's Bureau of Street Lighting plans to replace 140,000 existing streetlight fixtures in the city with LED units that will improve LA's lighting quality, reduce electricity usage, and ease what is known as sky glow — the artificial illumination of the night sky.

The City of LA believes that the $57 million overhaul will lead to a 40% reduction in electricity for street lighting, while reducing carbon emissions by 40,500 tons a year. Through energy and maintenance savings the project is expected to pay for itself in 7 years. Upon full implementation, the city will save $10 million annually.

The City plans to install 20,000 fixtures in the first year beginning July 2009, with 30,000 in subsequent years. More than half will replace 100-175W lamps, with a further 40% in the 200-250W range. The project also will include the installation of remote monitoring units at all 140,000 fixtures to automatically report failures, enabling immediate repairs.

"If every city followed the example of Los Angeles and reduced the electricity used by their streetlights by 50 percent, it would be equivalent to eliminating over 2.5 coal plants per year," said President Clinton at the project launch. "We would do that while saving taxpayers money...[and] we would also reclaim our night sky." CCI's Outdoor Lighting Program works with partner cities to improve the energy efficiency of street and traffic light systems through a combination of technical, purchasing, and project assistance. ◄

MORE DETAILS: www.ledsmagazine.com/news/6/2/16

BUSINESS

PerkinElmer buys Opto Technology

PerkinElmer has acquired Opto Technology Inc., a supplier of LED-based lighting components and subsystems based in Wheeling, Illinois. The deal adds optical subsystems to PerkinElmer's portfolio of high-brightness LED components, and will help PerkinElmer provide SSL products to OEMs serving the health, safety and security markets. Both companies exhibited at Strategies in Light 2009; the photo shows an Opto Technology LED-based in-ground taxiway light, which requires little or no maintenance over 5 years and meets the applicable standards for color and narrow beam patterns.

Taxiway light on show at Strategies in Light.

"The addition of Opto Technology expands PerkinElmer's presence in the solid-state specialty lighting marketplace and broadens the portfolio of LED subsystem capabilities that we can provide to our OEM customers," said David Nislick, president of PerkinElmer's Illumination and Detection Solutions business. ◄

MORE DETAILS: www.ledsmagazine.com/news/6/2/3

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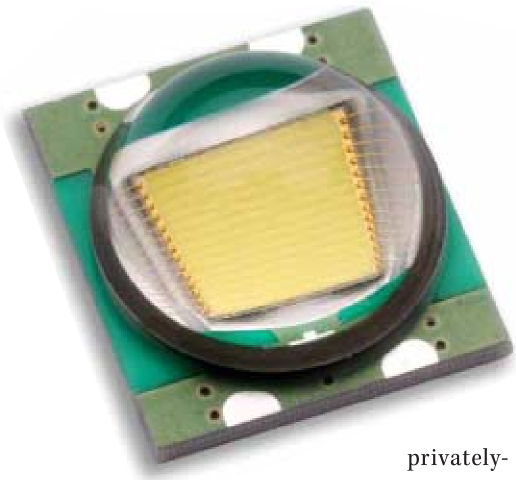
news+views

COLLABORATIONS

Nichia and Luminus form partnership

Two LED manufacturers, Japan's Nichia Corporation and US-based Luminus Devices Inc., have announced an alliance based on cross-licensing of IP, technology sharing, and a manufacturing partnership. Details of the business agreement between these two



privately-held companies are confidential, although they say that the shared objective is to accelerate the adoption of solid-state lighting by combining their technologies, including Nichia's phosphors and epitaxial materials and Luminus' large-chip technology.

Nichia and Luminus said they would cross-license IP and share critical process knowledge, resulting in new and innovative products. The first two examples have already been released; in mid-February Luminus launched two products including the SST-90, a large-chip white LED in a new surface mount (SMT) package (see www.ledsmagazine.com/press/18086). The package contains a single, monolithic die that is nine square mm in size, and produces 1,000 lumens with 10 watts input and 2,250 lumens at its maximum rated drive current, with a color temperature of 6,500K. The companies say they have also established a manufacturing partnership, and each company will "contribute the resources, materials and capabilities needed to meet the quality and performance requirements for the products." ◄

MORE DETAILS:
www.ledsmagazine.com/news/6/2/2

PATENTS

Seoul and Nichia sign cross-licensing agreement

Two rival LED makers, Seoul Semiconductor Co., Ltd. of Korea and Nichia Corporation of Japan, have settled all their various patent disputes currently pending in the USA, the UK, Germany, Japan and Korea. The settlement includes a cross-licensing agreement covering LED and laser diode technologies, which will permit the companies to access all of each other's patented technologies. A Seoul Semiconductor spokesperson told LEDs Magazine that its customers will now be more "comfortable" in buying Seoul's LED products, because any possible supply or litigation problems have been removed (at least with respect to Nichia). Another consequence will be that Seoul is now in a stronger position to defend its IP rights against third-party companies, particularly those selling AC-driven LEDs that are similar to Seoul's Acriche products. Two weeks after the cross-licensing announcement, however, Nichia issued a statement (www.ledsmagazine.com/news/6/3/3) saying that, despite the deal, there were no "understandings" or "cooperative marketing arrangements" between the two companies, who would remain "law-abiding competitors."

More Patent News:

- **Toyoda Gosei and Showa Denko sign patent cross-licensing agreement**
- **Cree and Honeywell end their patent dispute**
  SEE www.ledsmagazine.com/news/6/3/21
- **Lynk Labs awarded AC LED technology patent**
  SEE www.ledsmagazine.com/news/6/2/7
- **Evident Tech issued patent for nano-crystal synthesis**
  SEE www.ledsmagazine.com/press/18034

VENTURE CAPITAL

TerraLUX receives funding

Access Venture Partners, a venture capital fund, has closed an investment with TerraLUX, which designs and manufactures high-power LED OEM solutions. The funds will speed up TerraLUX's expansion into the portable and general lighting markets. TerraLUX plans to add senior management plus development, manufacturing and engineering talent, and will also expand its inventory to meet the increasing demand for its patented LED light engines. "The tremendous demand for LED lighting in the USA is not being met today in quality, performance or efficiency by current providers," said Carl Kalin, VP of sales and marketing.

web exclusive

LIGHTING

Future remodels with LEDs

At the Future Electronics EMEA headquarters near London, it was decided to use SSL products to create a new lighting ambience and to replace many of the existing halogen and CFL fixtures. One goal was to promote the mission of Future Lighting Solutions by turning the building into a billboard for Luxeon-based lighting applications. The photo shows the boardroom, in which each of the three drum-shaped fixtures hanging above the conference table is fitted with six warm-white Dialight Lumidrives MR16-compatible light engines for task lighting. The fixtures are topped with 18 blue Luxeon I LEDs embedded in a custom light engine that bathes the ceiling in blue. Also, the 19 perimeter MR11 fixtures were retrofitted with blue LED lamps to create a blue wash on the walls. Independent switches make it possible to turn on only the blue lights when the room is not in use. ◄

MORE DETAILS: www.ledsmagazine.com/features/6/3/8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"TerraLUX is entering 2009 with a plan to capitalize upon this situation by providing a new breed of OEM LED light engines for the general lighting industry." ◄

MORE DETAILS: www.ledsmagazine.com/news/6/2/26

RETROFITS

CRS claims record for MR16

An LED-based MR16 replacement has achieved a temperature-stabilized light output of 325 lm at a color temperature of 2850K, according to a report from LTL Testing Laboratory Inc., a US Department of Energy CALiPER-qualified facility. CRS Electronics, located in Welland, Ontario, Canada, says the lamp has a center-beam candlepower of 1800, a color rendering index (CRI) of 88, and an efficiency of 53 lm/W, more than 4 times the efficiency of many halogen MR16 lamps. ◄

MORE DETAILS: www.ledsmagazine.com/news/6/2/15

ENTERTAINMENT

ETC buys Selador product line

Entertainment lighting company ETC has entered the LED market by acquiring the Selador product line. Fred Foster, CEO of ETC, says the company was looking for a "significant innovation in lighting" and that the Selador product line produces a "far superior quality of color and light to anything that we had seen before in LEDs." Selador's x7 Color System™ seven-hue technology produces bright, broad spectrum whites and intense colors equally well, rendering pigments and skin tones in a more natural way than other LED systems, says ETC. Color matching and HSI (hue, saturation and intensity) control of Selador products have already been integrated into the latest software releases of ETC's Eos® and Congo® lighting control console lines. Selador co-founders Rob Gerlach and Novella Smith will both join ETC. ◄

MORE: www.ledsmagazine.com/news/6/2/22

LIGHTING

Cooper Lighting acquires IMS

Lighting manufacturer Cooper has acquired Illumination Management Solutions, Inc. (IMS), an Irvine, California-based company specializing in optics and system design for LED fixtures, and best know for its innovative LightBAR™ technology. Terms of the transaction were not disclosed. Cooper Industries' CEO Kirk Hachigian said that LED technology is a key growth platform for the company, which over the past two years has acquired io Lighting and UK-based Clarity Lighting.

The deal will enable Cooper "to bring more LED-based solutions to the market faster," said Hachigian, and "positions the company to meet the expected global demand for more energy-efficient solutions and infrastructure investment." More details at www.ledsmagazine.com/news/6/3/10.

In related news, Cooper Lighting says that its Halo® fixture (see photo) is the first LED-based recessed downlight to meet Energy Star® requirements for solid-state lighting (SSL) luminaires (specifically the DOE's SSL v1.0 criteria). See www.ledsmagazine.com/news/6/2/5. ◄

VISION & MEASUREMENT

ASSIST guidelines shed light on nighttime illumination

The Alliance for Solid-State Illumination Systems and Technologies (ASSIST) has published a new volume in its "ASSIST recommends" series, "Outdoor Lighting: Visual Efficacy." Developed by the Lighting Research Center (LRC) the document describes a unified system of photometry that characterizes the often tricky photometric performance of light sources under nighttime conditions.

The human visual system uses two types of photoreceptors, cones and rods, found in the retina. Cones are used to process visual information under daytime or "photopic" light levels, while rods work under completely dark "scotopic" conditions. There is, however, a range of light levels called "mesopic," where both cones and rods together provide input to the visual system. Mesopic light levels are typically found outdoors at night, where streetlights, cars, and buildings all contribute to the total light level. Since commercial photometry is based entirely upon the photopic, or daytime, luminous efficiency function, it may miss-estimate the effectiveness of some light sources used at night, says LRC Director Mark Rea, one of the authors.

The proposed unified system of photometry integrates both the scotopic and photopic luminous efficiency functions into a complete system that can be used across the entire range of light levels available to the human visual system. The system differentially weights the two efficiency functions depending upon light level. "In effect, it is a system for choosing among commercially available light sources to deliver the same unified, rather than photopic, photometric quantity," says Rea.

The ASSIST publication provides step-by-step instructions for calculating the unified luminance of a given light source based on light level and the scotopic-to-photopic ratio of the light source. Different combinations of light sources and light levels may produce the same unified luminance, which indicates photometric equivalency. Therefore, the system can serve as a simple method for trading off light sources and light levels under mesopic conditions, and thereby aid in the selection of light sources for a given application. ◄

funding + programs

French CITADEL project looks at LED lighting in buildings

The research will help French laboratories to qualify commercially available LED lighting products, writes CHRISTOPHE MARTINSONS.

Currently the field of lighting is in the midst of a technological revolution, unique in its history, with the advent of new generations of systems based on LEDs. Significant progress achieved by semiconductor specialists has led to robust and compact light sources, offering attractive control capabilities. In laboratory conditions, white LEDs reach luminous efficacies greater than those of most lamps used in lighting, and, above all, they exhibit far greater life expectancy. LEDs are therefore considered, as they well should be, as a major component in future solutions for interior and exterior lighting.

Despite all these advantages enthusiastically put forward by the semiconductor industry, it is commonly reported that the use of LEDs in buildings is slowed down by a certain number of complicated problems. The requirements for successful building integration are very specific and often unrecognized by LED makers. Several constraints occur in building applications: visual comfort, performance sustainability over time, real-life expectancy, total cost assessment, and compliance with building standards and codes.

LED lighting products should be able to fulfill the fundamental requirements described in well-established European lighting standards such as EN 12464-1 for indoor lighting of work places. For instance, LEDs should provide the required "quality of light" that is associated with a minimum color rendering index and a range of color temperature.

Glare is a critical phenomenon often associated with the use of LEDs. Satisfying conditions of visual comfort cannot be reached when sources of very high luminance are in the field of view. This is the case for "naked" high power LEDs with luminance levels measured in millions of cd/m^2 (nit). Naked LEDs or LED arrays (products with insufficient optical design) may present visual risks. Safer products with better optical designs can still exhibit discomfort glare, which is not very well characterized by the standard UGR (unified glare ratio). Its calculation method fails when applied to a multitude of source points such as an LED array.

LED products are very thermally sensitive. LED junction temperature critically affects light output and color, as well as life expectancy. Many LED products are designed to be integrated in walls, ceilings or floors, and these elements are often very well insulated (acoustically and thermally). This means that heat generated by LED products might not properly dissipate. Generated heat can even endanger the integrity of building elements, causing for example cracking of materials or deterioration of sealants, allowing migration of humidity.

CHRISTOPHE MARTINSONS *is head of the Lighting, Electricity and Electromagnetism Division of CSTB, St Martin d'Hères, France. Email: christophe.martinsons@cstb.fr.*

CITADEL key parameters

PROJECT BUDGET: 1.5 million Euros (~$2M)
FUNDING: ADEME (French Environmental Agency)
START DATE: 9 February 2009
DURATION: 3 years
MORE DETAILS: ledsmagazine.com/news/6/2/14

CITADEL consortium

The CITADEL consortium is formed by several public research laboratories, public institutions and a major lighting company. The partners have complementary skills and each specializes in a key aspect of LED lighting and building integration:

CSTB: Centre Scientifique et Technique du Bâtiment (Centre for Building Science and Technology), Grenoble, France. Project leader. In charge of photometry of luminaires, building integration, aging protocols, risk analyses and effective life expectancy, life cycle analysis.

LASH: Laboratoire des Sciences de l'Habitat (ENTPE and CNRS), Lyon. Building integration (visual aspects), light quality indices, photo-realistic simulations, experiments on subjects, total cost of ownership.

CEA-LETI: Grenoble. Microelectronics expertise on LEDs, degradation and breakdowns mechanisms of chips/packaging.

LNE: Laboratoire National de Métrologie et d'Essais, Trappes. Traceability of measurements, design and construction of high power LED standard devices.

LAPLACE: University of Toulouse and CNRS, Toulouse. Expertise on electronics aspects of LED lighting products (power supply and controls). Accelerated aging of LEDs and LED modules.

Philips Lighting, Luminaire division, Miribel: Philips Lighting is committed to providing the CITADEL partners with the required product data (bill of materials, industrial processes, etc.) necessary to perform life-cycle analyses and environmental impact studies. ◄

Footnote: CSTB, LNE, LAPLACE and Philips are actively involved in national and international normalization activities (AFNOR in France, CEN in Europe, CEI and CIE worldwide)

Although LED lighting products sold in Europe bear the CE label, electrical compliance must be thoroughly checked before installation. CE marking is neither a certification nor a quality mark. It is based on a self-declaration procedure, relying on tests carried out by the manufacturer or the import company on a limited number of chosen samples. Numerous low-cost LED lighting products exhibit very bad power factors, introduce unacceptable harmonic distortions in the mains current, and generate high level of electromagnetic fields.

As the American program CALiPER revealed, specifications given by some manufacturers are often misleading, especially when dealing with LED substitution lamps (designed to replace incandescent or fluorescent lamps). Anyone responsible for prescribing LED solutions in a building project should first send the products to an independent laboratory for objective measurements.

Research carried out in CITADEL

The objective of CITADEL is to promote the optimal integration of LEDs in buildings through research, with a view of supplying crucial information to all those concerned by lighting. The goal is to fully characterize LED lighting products, keeping in mind the specific needs of buildings and their occupants.

Research is necessary to provide unambiguous characterization techniques (optical, thermal and electrical metrology traceable to national standards). At the moment, there is a lack in Europe in the field of normalization related to the measurement of LED luminaries. (In the US, IESNA has provided LM-79 and LM-80 standards that specifically concern LED lighting products.)

Research is also important in order to determine the complete set of relevant performance criteria (quality of light, visual comfort, electrical parameters, energy-efficiency, and thermal aspects) in buildings.

The degradation of these criteria will give the true value of the lifetime of LED lighting products. This very important aspect will be investigated by defining the most appropriate aging methods, using climatic testing (accelerated aging) and endurance testing (ON-OFF cycles, voltage variations, etc).

The optical and electrical measurement methods will be devised in such a way as to supply results that present the true performance of LEDs at their real working temperature. Aging procedures will then be developed depending on the usage frequency of the products and the environmental factors which act upon them. Applying these procedures will enable us to analyze and identify, while adhering to a rigorous methodology, the diverse physical mechanisms of the LED breakdown. These steps of physical experimentation will allow us to determine and optimize the life expectancy of LED products and establish the total lighting cost. The CITADEL project will also involve analysis of LED product life cycle in order to ascertain their environmental impact during manufacturing, use and end-of-life.

Primary goals of the CITADEL program

- Identify the requirements and constraints leading to a successful integration of LED lighting product in buildings.
- Compare existing and recently proposed indices for describing quality of light (e.g. color rendering index) and visual comfort (e.g. UGR or unified glare ratio). Build new criteria adapted to LED lighting systems.
- Establish reliable methods for physical characterization of LEDs and LED-based luminaries (optical, thermal, electrical aspects).
- Determine accelerated aging protocols (climatic and endurance testing) based on real-life usage and solicitations met in building applications (indoor and outdoor).
- Better understand the degradation and breakdown phenomena observed in the course of the product lifetime.
- Determine effective life expectancy of complete LED lighting systems based on a multi-criteria risk analysis.
- Provide tools for estimating total cost of LED lighting solutions.
- Perform life-cycle analysis of a limited number of well-known, commercially-available LED lighting systems.

The research carried out in the CITADEL project will help French laboratories to qualify commercially available LED lighting products. A certification and labeling activity will be created during the course of the research program.

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Lighting on track to provide bright future for LEDs market

The LED lighting market continues to generate positive vibes for the industry, as **HASSAUN JONES-BEY** and **TIM WHITAKER** found out at the 10th annual Strategies in Light conference.

The mood was buoyant at Strategies in Light 2009 despite predictions that the overall LEDs market could fall by 5% in 2009. While some applications for LEDs, such as automotive lighting and mobile phones, have been badly hit by the current recession, the lighting sector is in good health. LEDs continue to penetrate an increasing range of lighting applications, with greater use of white LEDs in areas such as street lighting and even indoor illumination.

At Strategies in Light, held February 18-20, 2009 in Santa Clara, California, attendees and exhibitors were optimistic about the potential for growth in the lighting market. The 2009 event, in its 10th year, is organized by market research firm Strategies Unlimited and supported by *LEDs Magazine* as the flagship media sponsor. There were more than 2000 registrants this year, up by more than 33% over 2008.

A new parallel session, the LED Lighting Track, was particularly well attended, drawing in architects and lighting designers to contribute to the discussion. "If there is one thing to take away from this track, it's that LED lighting is about much more than just LEDs," said Vrinda Bhandarkar, senior analyst at Strategies Unlimited and the opening speaker of the track (see "Analyzing the LED lighting fixtures market" sidebar). "If the LED isn't designed well into the fixture to properly throw the light, if the drivers aren't designed to be efficient, and if the thermal properties are not matched to the LED design, the light fixture won't deliver the efficiency and lifetime promised." (See Fig. 1.)

LED-Linear GmbH, an exhibitor at SIL 2009, won a Recognized award in the Next Generation Luminaires competition (see p26) for Xoolux. This low-profile (0.94 x 1.49-inch cross section) IP54-protected LED luminaire can be used for undercabinet, task and display case lighting, and has a simple connection and rail-mounting system for easy installation.

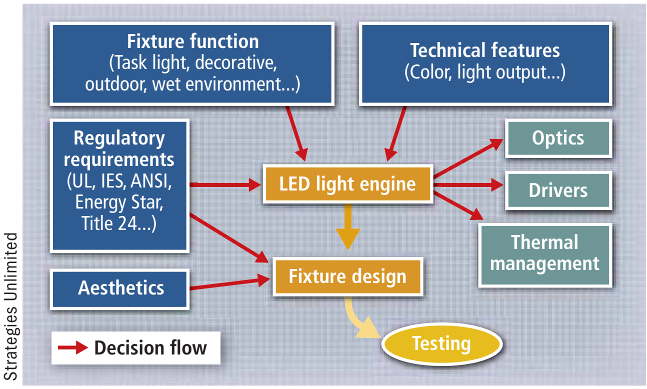

FIG. 1. LED lighting is about much more than just LEDs, and designing a successful LED fixture involves a series of key decisions.

Market forecast

The main conference was opened by Robert Steele of Strategies Unlimited, who presented his annual high-brightness (HB) LED market review and forecast. Steele said the market for packaged HB-LED devices grew by 11% in 2008, but is likely to contract by 5% in 2009. If this happens, it will mark the first

HASSAUN JONES-BEY *is a contributing editor and* TIM WHITAKER *is editor of* LEDs Magazine.

Lutron showcased its Hi-lume LED driver, a universal-voltage dimming driver that provides LED dimming from 100% to 1% of total light output. The driver can be used in meeting rooms, corridors, restaurants, hotels, and many other areas where dimming performance and energy efficiency are valued.

time the overall market has declined since Strategies Unlimited started to publish data on the HB-LED market in 1999.

Steele gave a historical perspective on the HB-LED market, which was a mere $820 million in 1999. Between 1999 and 2008, said Steele, the HB-LED market grew by a factor of 6.2, reaching $5.1 billion last year. Year-on-year growth has varied dramatically; approximately 50% growth in 2000, 2002 and 2003 was driven by strong demand in the mobile phone market, but in between the market saw virtually zero growth in 2001 as the tech sector went into recession. The growth rate dropped to below 10% in 2005, but has since risen gradually, and in 2008 the market increased by 11% compared with 2007. However, the fourth quarter of 2008 showed signs of market deterioration, particularly in the automotive lighting and mobile phone sectors.

Unit sales of LEDs grew by more than 25% in 2008, reaching 48 billion units. Mobile appliances remained the largest application, with 43% of the overall market, compared with 9% for lighting (see Fig. 2). The mobile appliances sector showed the first positive growth (8.3%) since 2004 because of the growth in non-phone products (smartphones, MP3 players, laptop PCs, GPS, digital cameras). Not surprisingly, the highest growth sector was lighting, up 39% over 2007, although the sector only reached $460 million.

Looking forward, said Steele, the "negative economic environment and bleak outlook for many LED end-use sectors indicate a lower market in 2009." Visibility is very limited, and conditions could worsen. "Recovery could be delayed beyond 2010," said Steele. "The only 'bright spots' are backlights for LCD TVs, and of course lighting."

Steele expects the penetration of LEDs into the lighting market to continue into 2009, but with a lower growth rate of 17%, compared with the level of 35% that was forecast previously. In the longer term, there is a positive outlook for the lighting sector, and Steele said that the market will get back on track, following the economic recovery.

The prediction that the overall market will decline by 5% in 2009 includes a conservative forecast for growth in LCD TV backlights. This is the most uncertain of all LED application sectors; when this application is excluded, the remainder of the HB-LED market will shrink by 10% in 2009.

Looking further out, Steele expects growth to resume in 2010, assuming the economy as a whole recovers. Between 2008 and 2013, the compound average annual growth rate is predicted to be 19.3%, with the market reaching $12.4 billion in 2013.

Illuminating consumer preference

LED market penetration for lighting applications remains small and highly fragmented into numerous application niches, said Bob Steele, and architectural lighting at 43% of the lighting market represents the largest niche. But the highest growth applications in 2008 (cumulatively accounting for 16% of the SSL market) were outdoor area, replacement lamps, commercial/industrial and entertainment.

Numerous technology improvements during the last decade have contributed to the rapid growth of LEDs in the lighting market, including development of high-power LEDs; increased luminous efficacy by a factor of 6.7 for cool-white LEDs; and introduction of warmer whites mid-decade, which have doubled in luminous efficacy since 2004, Steele said. And most of the major solid-state-lighting players have 100-lumen products on the market. As a result, the industry focus is shifting away from technological issues such as achieving higher light output and increased efficiency, to customer satisfaction issues, said Erik Milz, strategic marketing manager with Philips Lumileds. These include the quality and uniformity of white light, the elimination of binning, enabling simplified system design, phosphor systems, forward voltage and supply chain safety (reliability).

The three primary LED aspects to consider — flux, forward voltage and color — create a 3-dimensional (3-D) binning matrix, while the lamp matrix for luminaire manufacturers includes factors such as shape, direction, style, warm or cool coloration, and power. CCFLs took a step towards improving energy efficiency and also simplifying the matrix, Milz said. But, except for places like California where government support encourages their use, CCFLs remain a small, single-digit percentage of the market because lighting performance is not predictable, or perhaps predictably unpleasing: "We don't want solid state lighting to make the same mistake," he said.

Outdoor area lights

Perhaps nowhere is the story more dramatically told than in beleaguered municipalities trying to keep their street lights on during hard economic times. George

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• AC Input Voltage Range	90~264Vac	90~264Vac	90~264Vac	90~264Vac
• Wattage Range	60W~150W	30W~100W	30W~60W	18W~60W
• Built-in active PFC function	✓	✓		
• Output Voltage Range	12V~48V	9V~48V	5V~48V	5V~48V
• Constant Voltage / Consant Current	CV+CC	CV+CC	CV+CC	CV or CC
• Short Circuit / Overload Protection	✓	✓	✓	✓
• Over Voltage Protection	✓	✓	✓	✓
• Over Temperature Protection	✓	✓		
• Adjustable Output Voltage / Current	✓(150W)	✓	✓	
• Optional Dimming Function			✓	
• Protection Level	IP65 / IP67	IP64	IP64	IP67
• UL 1310 Class 2 Compliant	✓(60/100W)	✓	✓	✓
• Input / Output Connection	Cable: 18AWG, 30cm	Cable: 18AWG, 30cm	Cable: 18AWG, 30cm	Wire: 18AWG, 60cm

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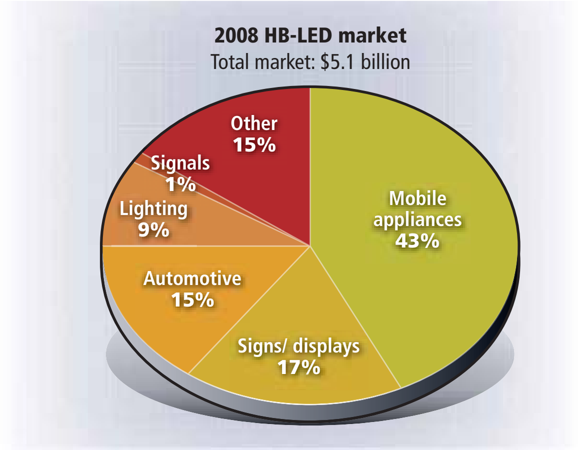


Courtesy of Strategies Unlimited

FIG. 2. Mobile appliances remained the largest HB-LED application in 2008, although Lighting showed the most rapid growth.

Woodbury, director of energy services with Republic ITS, provided the perspective of a former public works director turned consultant who has completed conversions of over 45,000 street lights. He warned of the bad taste that can be left in the mouth of a municipality that invests in LED street lights and gets stuck with disappointing performance.

"In terms of reliability, we have to get the bad product out of there, and get reputable companies in there with good products," Woodbury said. He talked about the importance of avoiding "LED hype" when promising energy savings, maintenance savings and even life cycle costs, which for various practical reasons can turn out to be disappointing once lighting is installed.

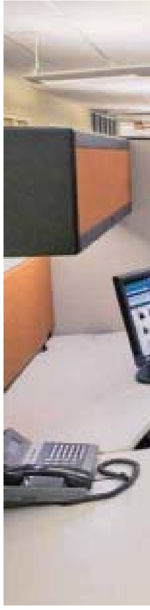
All of that said, LED street lights can be quite successful and are becoming more so with time. Currently, LEDs are bright enough for street light applications, but are still on the expensive side both initially and in terms of actual energy savings, he said. In addition, LED performance data needs standardization, and lighting industry guidelines need to be developed to account for factors such as light measurement under mesopic conditions. However, Woodbury expects the current rapid pace of technology change to address such issues significantly in the next couple of years, saying, "LEDs are getting there."

Replacement lighting

A key factor for LEDs in replacing conventional light bulbs is the ongoing transition from LED bulbs (standard LED components arranged to mimic conventional bulb shapes) to SSL sources (lighting fixtures designed specifically for LEDs), according to Mark McClear, business development director with Cree. "A bulb is an adaptor, a bridge to the real LED fixtures," he said. "But we're stuck with it for now." LED bulbs potentially provide longer life and much better efficacy than their conventional counterparts, but thermal limitations inherent to the form factor will eventually drive a transition to SSL sources.

For instance, in attempting to simulate an MR16 using an LED bulb, McClear and colleagues at Cree realized that since they could only drive the LED device at 5 or 6 W, the performance was only equivalent to a 20 W MR16 at an industry-standard 3000K color temperature. "35 W might be available later," he said. "But 50 W does not look possible using standard components." They found similar limitations in attempts to simulate both A19 and PAR 38 bulb designs.

Not everyone agreed with McClear's conclusions about thermodynamic limits to LED bulb brightness. Densen Cao, president of CAO Group, described 3-D LED-based light sources for direct replacement of traditional incandescent lamps in standard sockets, such as candelabra, S14, 1156 and others (Fig. 3). The 3-D LED and driver element essentially takes the place of the filament in a standard bulb structure. Ten and 25 W replacements are currently available and the company expects to have direct replacements for the majority of bulbs (40 and 60 W) within the next two years. "The key is not the LED but heat management," said Cao.



Commercial and industrial lighting

Currently, LED bulbs can use inherent directionality to improve their performance with respect to conventional lighting sources, said McClear. LED bulbs are highly suited for refrigerated high-bay applications because they have already achieved energy parity with the most efficient alternative — T8 fluorescents — but do not suffer from cold temperature sensitivity, as fluorescents do. Initial cost

a)

b)

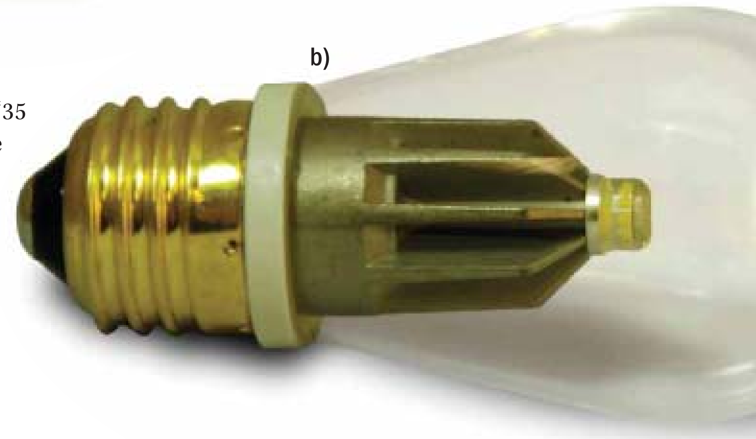


FIG. 3. CAO Group's a) Dynasty S14 and b) 1156 LED bulbs are designed as direct replacements for incandescents, and contain a replaceable LED source with a 360-degree beam pattern.

© Gregory Blore Photography

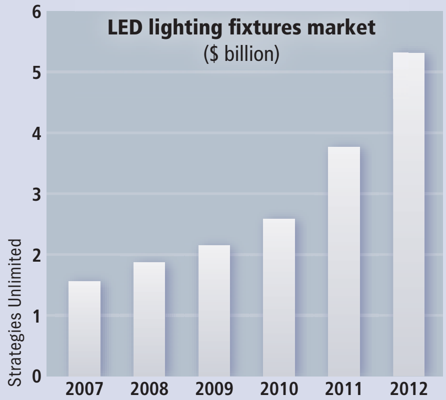
FIG. 4. Using LED task lighting for workstations combined with individual controls, the California Department of Motor Vehicles in Sacramento was able to lower the ambient lighting levels and also save energy. See www.finelite.com/about-us/success-stories.

Analyzing the LED lighting fixtures market

Opening the LED Lighting Track at SIL 2009, Vrinda Bhandarkar of Strategies Unlimited estimated that the total global market for LED lighting fixtures will exceed $5 billion in 2012. Bhandarkar is the author of a new report entitled "LED lighting Fixtures – Market Analysis and Forecast." As LED lighting extends beyond single color and color-changing applications into general illumination, the market will grow at a compound annual growth rate (CAGR) of 28% between 2008 and 2012 (see graph). However, many challenges face LED fixture suppliers, for example high initial cost; product quality and reliability; the (relative) lack of standards; the poor availability of high-performance warm-white LEDs; and competing lighting technologies.

Through 2007, LED lighting applications included niche markets such as exit signs, architectural lighting, accent and decorative lighting and entertainment lighting, many of which used red, green, and blue LEDs. However, white LED fixtures have begun to capture a strong market position in selected applications such as consumer portable lighting (e.g. flashlights, headlamps) and solar landscape lighting, and more recently have begun to be used on a limited basis in applications such as retail display lighting, commercial and industrial lighting, and outdoor area lighting. In 2008, white LED fixtures accounted for just over 50% of the total LED lighting fixture market, said Bhandarkar. The penetration of white LED lighting fixtures into general illumination applications will accelerate when such fixtures offer quantifiable energy and cost savings relative to the use of conventional light sources.

Bhandarkar described a series of assumptions built into the market forecast. These include continuous improvement in the efficacy of LEDs and LED fixtures; price erosion; and incorporation of standards into codes and practices in 2009 and beyond. Also assumed is a continuing focus on energy efficiency, including fiscal stimulus by various governments to provide investment in infrastructure. ◄



LED lighting market will grow at a CAGR of 28% between 2008 and 2012.

is still the major hurdle for LEDs in unrefrigerated high-bay lighting, McClear said. But improvements in efficiency through factors such as optical directionality control may make LEDs a compelling choice for hi-bay applications in general in the next 3 years.

Citing 10 billion square feet of commercial office space in the US alone, Terry Clarke, CEO of Finelite, described his company's successful approach to reducing lighting power density by 50% and achieving overwhelming customer acceptance, while keeping installed costs the same as with conventional light sources. The first step in Clarke's process is to design the task lighting, which is currently the last step in most office lighting design situations.

LED task luminaires already have conventional fluorescent task luminaires beaten, not only in energy efficiency but also in consumer acceptance, he said. Fluorescent task luminaires produce so much excess light and glare that 80% of people working in office situations simply turn them off. So LED task lighting reduces the energy budget, not just for task lighting but for the entire lighting design, because ambient lighting no longer has to be bright enough to also provide task lighting (Fig. 4).

However, warns Clark, "the changeover is extraordinarily difficult. You need to get everyone on board: building owners, design professionals and contractors." Evidently, as is still true with cell phones, the ultimate success of LED technology in general illumination applications will depend on a lot of talk. ◄

LINKS AND DATES

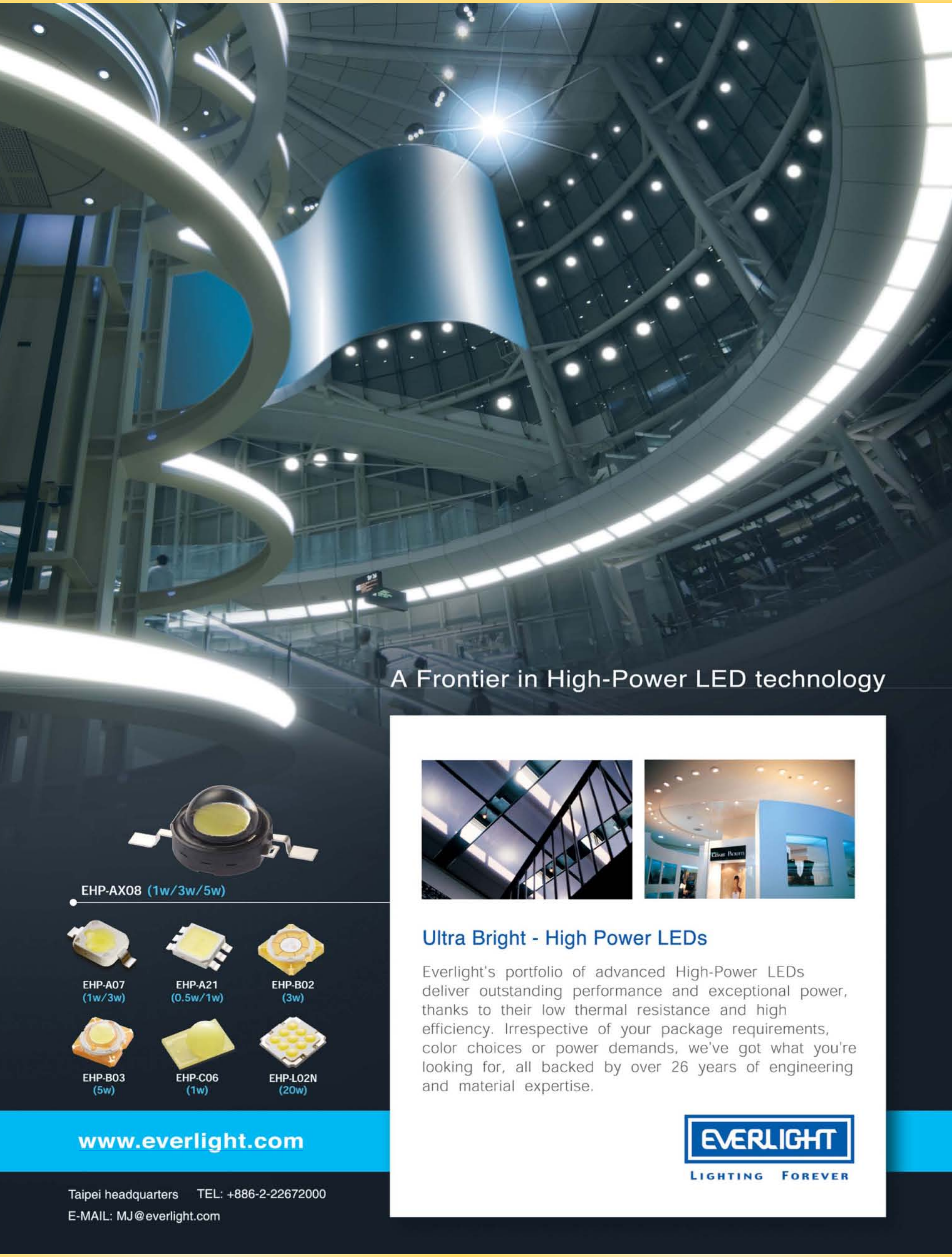
Strategies in Light: www.strategiesinlight.com

LED Japan/SIL Japan 2009: September 16-17, Yokohama

SIL 2010: February 10-12, 2010, Santa Clara, California

Video clips from SIL 2009: www.ledsmagazine.com/video

News from SIL 2009: www.ledsmagazine.com/features/6/1/1



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Controlling consumers' expectations of LED lighting: why dimming is so important

Manufacturers of LED lighting products need to consider the control options for their products and understand the applications in which their products will be used, say **CHRIS SALVESTRINI** and **AMANDA BEEBE**.

The US Census Bureau estimated that there are over 75 million owner-occupied homes (2007) and almost 5 million commercial buildings (2003) in the United States. Many of these buildings, both commercial and residential, already have dimmers installed. These existing dimmers are controlling a multitude of light sources, from incandescent to fluorescent and now LEDs, which is why the capacity to dim must be designed into an LED product from the beginning. Consumers, professionals, teachers and occupants expect to have control of their lights, and LEDs must meet this expectation if LED lighting solutions are going to succeed.

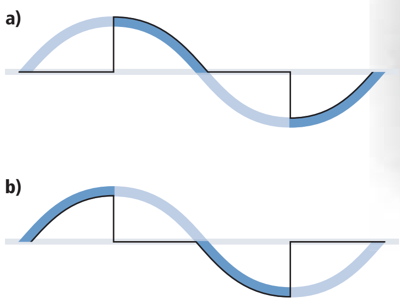


FIG. 1. a) Forward phase control and b) reverse phase control. Light blue shows when the control is open (off) and dark blue shows when the control is closed (on).

Why dim?

The story of why to dim your lights has been around for a long time, and many people know that lighting controls can improve personal comfort, increase occupant productivity, extend luminaire lifetime and save energy. However, with the introduction of new lighting technologies it seems that this story is often forgotten, at least until the market is full of disgruntled consumers and building occupants.

The LED industry is heading toward the same negative experiences as the screw-in CFL industry and needs to correct its course now, before consumers become averse to LEDs. LEDs are a promising new technology that will eventually influence, and even change, the lighting industry. However, they will not reach that point as quickly as their potential suggests unless the industry begins to pay attention to consumer expectations.

So what are those expectations?

In the home, consumers expect their light source to act like the incandescent lamp that they have lived under for 100 years, meaning that they want two things — color, and ambiance created with dimming. The screw-in CFL lamp continues to fall short of expectations because it has failed to meet either of these criteria. Some LED makers understand the desire for the perfect color temperature and are creatively using technology to provide the exact color of light that a consumer wants. However, these same manufacturers do not understand that dimming is equally as important as color — consumers want just the right amount of light for whatever they are doing.

Commercially, the lights are on in a building to allow people to be productive. Too often we think of energy-saving techniques that are only about turning the lights off. However, this tactic does not apply when a building or space is occupied, which makes the ability to dim an equally important energy-saving technique.

Dimming can be a manual choice by a user, a tuning decision by a building owner, or an automatic change due to the amount of sunlight. However, no matter which dimming technique is used, it will save energy. While additional energy savings for an LED (which already save energy by replacing a 100-W incandescent with a 25-W LED array) may seem less important, consumers do not agree. They are looking for every possible way to save energy, and dimming will save an additional 20%-30% on average without sacrificing comfort.

In addition to energy savings, the occupants of these buildings are the same people who expect control in their homes, so why should they sacrifice this control at work? Dimming allows for increased productivity, which is paramount in a working environment. Everyone has different visual abilities and comfort levels, and being able to optimize your environment goes a long way.

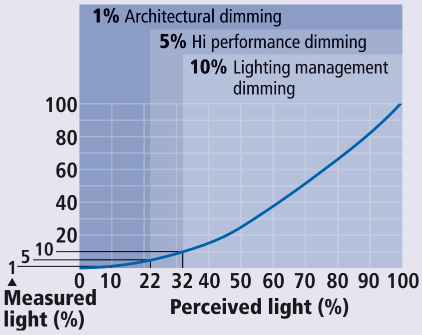
Now that you understand why dimming is important, you should also know that simply being "able to dim" is not good enough. Dimming is a quantifiable term and it should always be associated with a dimming range, such as 100% to 1% of light output, as well as other terms that describe that range (e.g. smooth and continuous). An LED array manufacturer would never merely state that their product "provides light" because that doesn't tell the user anything, and the same goes for saying a fixture is simply "dimmable."

LED control types

Once you have accepted that high-quality

AMANDA BEEBE *is LED product manager and* CHRIS SALVESTRINI *is a senior design and development engineer with Lutron Electronics (www.lutron.com).*

Dimming: critical term definitions



Determining perceived light. Source: IESNA Lighting Handbook, 9th Edition (New York, 2000), 27-4.

Measured vs. perceived light:
Measured light output is the quantifiable value of light measured by a light meter or similar device. This is the dimming percentage indicated on LED product specification sheets. Perceived light is the amount of light that your eye interprets due to dilation. The eye's pupil dilates at lower light levels, causing the amount of perceived light to be higher than measured (e.g. 20% measured = 45% perceived). The equation for determining perceived light is to take the square root of the measured light percentage (e.g. $\sqrt{0.2} = 0.447$) – see figure.

Pop-on:
If the voltage at which a light source begins operation is higher than the voltage of the dimmer's lowest setting, then the lights will initially "pop-on". This means there will be a section of the dimmer that will not turn on the light until suddenly the light "pops-on."

Drop-out:
If the voltage at which a light source stops operating is higher than the lowest setting on the dimmer, the light source will turn off before the dimmer has turned off. The lights will effectively "drop-out" before the slider on the dimmer reaches the bottom.

Flicker:
Flicker is the unexpected modulation of light level that is visible to the human eye. Flicker can be caused by multiple factors, including: line noise, control noise, circuit noise, component tolerance, and circuit design. Flicker can be continuous (happening all of the time), or intermittent (only happening some of the time).

Smooth and continuous:
Smooth and continuous describes the expectation of performance based on the public's knowledge of incandescent dimming. A proportional change in control (dimmer) position should be reflected by an equal change in light level. There should be no abrupt change in light level as the light source is being dimmed.

Dead travel:
Dead travel is the amount of change in the control before there is any change in the light source. In a vertical slide dimmer, if you can slide the dimmer halfway down before the light starts to dim, there is 50% "dead travel" on the dimmer. ◄

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dimming is an essential part of any good lighting solution, and understood some of the critical terms (see p. 22), the next step is to gain awareness of what types of dimming controls currently exist. Selecting the appropriate control depends on the light source, the degree of flexibility needed in the space, and whether an interface (ballast, driver, or transformer) is needed. Below is an overview of each of the main control types that exist today, indicating where they are most commonly used:

a) Two-wire control

Two-wire control is the most commonly used control method today, and simply indicates that there is a single wire between the device and the light source. It is the control type of a standard light switch, where power comes into the switch through one wire and leaves through another. Within two-wire control there are two different control methodologies:

i) Forward phase control: The more prominent of the two, it is also called leading-edge control. In this control scheme the control begins each half-cycle in the open position and then turns on and remains on for the remainder of the half-cycle. This is illustrated in Fig. 1a, where the light blue shows when the control is open (off) and the dark blue shows when the control is closed (on). This method works well for controlling inductive loads, and as a result forward phase control is required to control magnetic low-voltage lighting transformers. It is also the dominant method used to control incandescent lights.

ii) Reverse phase control: Also called trailing-edge control, it is used to control electronic low-voltage light sources. As shown in Fig. 1b, this is the exact opposite of forward phase control. While this control type can be used on incandescent lights it typically provides the ideal control signal for capacitive loads, such as many LED drivers.

b) Three-wire controls

Three-wire controls are primarily used to control fluorescent light sources because the power requirements of the ballast will not impact the dimming performance of the light source. One of the wires provides power to the light source whenever it is on, regardless of the light level, while the other wire provides the control signal that sets the light level at which the fixture should be operating.

In all of the following approaches (0-10V, DALI, and DMX), the control exists on an isolated low voltage link from the power to the light source. One of the benefits of this is that the system can be interfaced with a variety of other devices such as occupancy sensors, daylight sensors, and infrared receivers.

c) 0-10V control

0-10V control is an analog control that sets the voltage to the light source between 0V (minimum light output) and 10V (maximum light output). IEC standard 60929 specifies exactly what control requirements exist for this control type.

d) Digital control

i) DALI: This Digital Addressable Lighting Interface control standard, which emerged from Europe, allows for digital control of separate fixtures. This added level of control provides increased space flexibility, especially in commercial spaces.

ii) DMX: This digital control type came from theater lighting control, and allows for multiple channels of light (both color and intensity) to be controlled. It is typically used when trying to achieve complicated lighting effects such as LED color mixing.

Conclusion

LEDs are a promising new light source for general illumination, but they will never excel unless manufacturers understand consumer expectations. Having control is a basic human desire, and lighting is no exception. Stereos would be limited without volume controls; ovens would be dysfunctional without temperature controls, so why should lights be used without controls?

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focus on Luminaires

The winners of the 2008 LED Next Generation Luminaires design competition were announced at Strategies in Light in mid February. The competition is sponsored by the US Department of Energy (DOE), the Illuminating Engineering Society of North America (IESNA), and the International Association of Lighting Designers (IALD). Of the 68 entries submitted, three were chosen as "Best in Class" in the market-ready category and a further 19 were "Recognized." Five other products were selected as "Noteworthy" in the emerging products category.

MORE WINNERS: www.ngldc.org

Photometric testing was carried out by independent testing laboratories using IESNA test method LM-79-08. Where this data was lacking, luminaires were tested through DOE's CALiPER testing program.

Best in Class

"Immersion" by GE Lighting ►

GE says that its Immersion LED jewelry display case lighting brings out more sparkle than competing fluorescent systems. Light output: 1494 lm. Power: 42.5 W. Efficacy: 35.1 lm/W. CCT: 3515K. CRI: 72. Lengths: from 24–72 inches. **www.gelighting.com**

"LED Pendant" by Tech Lighting ►

Tech Lighting has introduced over 40 decorative pendants that utilize a 5.8-W LED module — developed with Lighting Science Group — that is easily field replaceable and the heat sink remains with the fixture. Light output: 200 lm. Power: 5.6 W. Efficacy: 35.7 lm/W. CCT: 2968. CRI: 80. **www.techlighting.com**

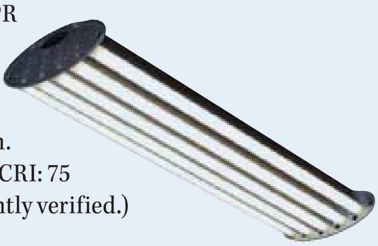
Recognized

"Calculite LED downlight" by Lightolier ▼

These 4-inch LED downlights use Lightolier's remote phosphor technology to redefine how light from blue LEDs is converted to white while providing good glare control and consistent color. Light output: 1032 lm. Power: 20.1 W. Efficacy: 51.3 lm/W. CCT: 3015. CRI: 80. **www.lightolier.com**

"C-Series LED High Bay" by Albeo Technologies Inc. ▼

This LED high bay luminaire, using TEMPR thermal management technology, is a low-maintenance, energy-efficient alternative to traditional HID or high-intensity fluorescent light fixtures. Light output: 18,268 lm. Power: 362 W. Efficacy: 50.4 lm/W. CCT: 5000. CRI: 75 (CCT and CRI values have not been independently verified.) **www.albeotech.com**



▲ **"STEP03" by Winona Lighting**

The STEP03 series of step lights with three different styles provides good lateral distribution, integral drivers, and the flexibility to modify. Light output: 454 lm. Power: 21.7 W. Efficacy: 21.3 lm/W. CCT: 2996 CRI: 71.
www.winonalighting.com

◄ **"AZARA" by Journée Lighting**

At the heart of the AZARA's retro, yet functional styling is Journée's replaceable Sprocket LED light engine. AZARA's housing performs as an active heat sink. Light output: 249 lumens. Power: 6.9 watts. Efficacy: 36.1 lm/W. CCT: 2911K. CRI: 85.
www.journeelighting.com

◄ **"LED72" by MP Lighting**

The 12 x 1.2 W LED72 works well for accent lighting and general directional illumination and mounts to a standard j-box or MP Lighting rail system with a remote driver. Light output: 373 lm. Power: 18.3 W. Efficacy: 20.4 lm/W. CCT: 2953. CRI: 96.
www.mplighting.com

▼ **"LR24" by Cree LED Lighting**

The LR24 2 x 2-foot architectural layin is designed for new construction and retrofit applications in offices, schools, hospitals, and retail environments. Light output: 3237 lm. Power: 44.7 W. Efficacy: 72.4 lm/W. CCT: 3491. CRI: 89.
www.creelighting.com

▲ **"Evoke 2.9" by Amer Lux Lighting Solutions**

The Evoke 2.9 LED, available in round or square aperture, features a field serviceable seven-diode cluster measuring 1.25-inches (dia.) and produces uniform light in a 60° beam spread with negligible heat and UV output. Light output: 913 lm. Power: 25.1 W. Efficacy: 36.3 lm/W. CCT: 2700. CRI: 83.
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Why 2008 was the Year of LED Standards

In the first of a series of articles, **KEVIN DOWLING** explains the importance of standards for LED lighting and looks at the significant progress that has been made so far.

In an era of rapid performance improvement, 2008 is likely to be remembered as the Year of LED Standards, which are a critical ingredient in the market use and adoption of LED lighting technology. Last year saw the publication of several performance standards as well as guidelines that required the use of these standards — in effect, standards based upon standards. It is a good start, but only a start. However, many other standards are in process, and remarkable progress has been made.

Importance of standards

Standards are very important for several reasons. Without standards, comparison is difficult or impossible. In many cases product specifications are not traceable to an authoritative reference, making all such data suspect at best, and disingenuous at worst. Furthermore, some manufacturers play specification games; this is unacceptable. Without standards, customers and specifiers are uneasy about specifying and purchasing LED-based products. Emplacing standards lessens this issue and, as this community grows comfortable with the standards-based approach, they will specify more, not less. The market grows; adoption increases and the results benefit both users and manufacturers. Subsequently, LEDs can also provide societal benefits in terms of energy saved and carbon footprints reduced. This chain of reasoning is not to be taken lightly. Without standards, LED lighting will become a "Wild West" of disorder and confusion.

The US Department of Energy's CALiPER program reveals that many LED lighting products already suffer from a "truth-in-advertising" issue with regards to published specifications versus actual testing laboratory measurements. Some use the performance of an independent device (i.e. the LED itself) as a proxy for the performance of the fixture. Unsurprisingly, the real performance does not live up to advertised claims. Without dwelling on all the reasons why, it is clear that the numbers are determined through means that are both inconsistent and even irrelevant. It comes down to trusting the numbers; consistent and practical testing methods are needed.

Standards emerge in 2008

So what happened in 2008 to improve this situation? Through the solid-state lighting (SSL) committees within the National Electrical Manufacturers Association (NEMA), the American National Standards Institute (ANSI) and the Illuminating Engineering Society of North America (IESNA), we crafted three important standards milestones — ANSI C77.78, IESNA LM-79 and IESNA LM-80 — see "Standards finalized in 2008". Additionally, the IES Testing Procedures Committee worked on definitions around LED systems to provide a consistent vocabulary around this technology (IESNA RP-16 Addendum A).

ANSI C78.377-2008: Chromaticity

This standard defines eight bounded regions that identify particular color temperature values for white LED sources. These regions were chosen, after much discussion, to be based upon similar regions used for compact fluorescent lamps (CFLs), which are defined by 7-step MacAdam ellipses. One additional region, 5700K, was added for LEDs to provide a continuum of color temperature ranges. The use of these definitions for LED color temperature regions is a good beginning, and LED manufacturers are already providing LED binning that is ANSI-compliant for their customers.

IESNA LM-79: Luminous flux

LM-79 provides methods of determining the lumen output of LED luminaires and integrated LED lamps. The products must require only line voltage or a DC power supply to operate. LM-79 does *not* cover SSL products requiring external operating circuits or external heat sinks, such as LED chips, packages, and modules. It also does not cover fixtures designed for SSL products that are sold without a light source.

Traditionally, photometric measurements are made separately for lamps and luminaires using different test methods. However, for many SSL products, LED lamps *cannot* be separated from luminaires, and none

Standards finalized in 2008

Chromaticity: **ANSI C78.377-2008**
"Specifications for the Chromaticity of Solid State Lighting Products"

Luminous Flux: **IESNA LM-79**
"Electrical and Photometric Measurements of Solid-State Lighting Products"

Lumen Maintenance: **IESNA LM-80**
"Measuring Lumen Maintenance of LED Light Sources"

Definitions: **IESNA RP-16 Addendum A**
"Nomenclature and Definitions for Illuminating Engineering" ◂

KEVIN DOWLING *is the VP of innovation at Philips Color Kinetics (www.colorkinetics.com) and has been active in SSL for over 10 years. He founded and chairs the IES SSL Committee and the NEMA SSL Committee, and is a past Chairman of the Next Generation Lighting Industry Alliance.*

of the existing standards for lamps or luminaires are directly applicable to SSL products. What this means is a method of measurement not commonly used — absolute photometry.

Under a relative measurement, the most common form of light output determination, the luminaire under test and the lamp(s) are measured separately. Then the luminous intensity distribution data are normalized by the total luminous flux of lamps used in the tested luminaire. Under the absolute method, the luminous intensity distribution of a luminaire is measured without separate measurement of the lamps.

Section 9.3 of LM-79 details the measurement and the Annex goes into the reasoning behind the requirement for absolute photometry. LM-79 recommends using an integrating sphere with a spectroradiometer, but other alternatives are provided including a sphere with a photometer and the use of a goniophotometer for measurements. The spectroradiometer returns the full spectral power distribution from which several characteristics are calculated, including chromaticity, CCT and CRI. For the goniophotometer, the result may be spatially non-uniform, but must be spatially averaged, weighted to intensity, over the angular range of measurement.

Another key difference in photometry measurements for SSL devices is thermal stabilization, which is determined by repeated sequences of measurements until the difference over two measurements is below a specified amount. In LM-79, the unit is stabilized when three readings of light output and electrical power over 30 minutes, taken 15 minutes apart, fall within a 0.5% variation.

The combination of the thermal stabilization, absolute photometry and other elements in LM-79 have made for a reliable test method for LED light sources.

LM-80: Lumen maintenance

Lumen maintenance is the gradual fading of the light output from an LED device over time. Many LED product specifications use lumen maintenance to indicate product lifetime, but this is only one aspect of lifetime and not a complete measure of life. It does not, for example, provide a true measure of reliability. Lumen maintenance does, however, provide an indication of the fading of LED package light output over time. When properly controlled and thermally managed, many high-brightness LEDs can last many tens of thousands of hours, but we need a consistent method to provide that information. Hence the need for LM-80.

The causes of this fading are only partially understood, but the primary cause relates directly to heat generated at the junction within the LED. It includes materials clouding, which is affected by package and system design. A number of LED manufacturers, for example, have switched encapsulant material to silicone from epoxy, which was prone to yellowing from the light energy.

The measurement of lumen maintenance is relatively straightforward in concept — run the LEDs over a long period of time and measure the change in light output. Since it is impractical to measure these devices for a decade, because they will be surpassed by new generations of LEDs, some form of prediction or extrapolation is necessary.

LM-80 was created for one important reason — to ensure consistency of the testing regime. LM-80 does not predict lumen maintenance beyond the testing period. In the process of creating LM-80, further discussion around the extrapolation model was necessary, but it was important to get the testing method out so that testing could begun immediately across a wide range of devices. The more data we have, the more likely it is that we can develop a good prediction model. Another committee, TM-21, is in the process of developing such a model now.

LM-80 measures lumen maintenance of LED light sources including LED packages, arrays and modules only. It does not include luminaires. LM-80 specifies a number of electrical and thermal measurements such as voltage and current (AC or DC levels), voltage waveshape, etc.

The case temperature is obtained from a test measurement point designated by the manufacturer. A key aspect of LM-80 is the value of the temperature measurement levels. They include 55°C, 85°C and a third temperature selected by the manufacturer. During testing the airflow in the region must be minimized, and any specifications for operating orientation and spacing can be provided by the manufacturer.

LM-80 currently requires 6000 hours of testing time, which is a long time. Some have argued that this is too long, but unless a better way comes along to predict lumen maintenance from a relatively short testing time then there is no means with strong confidence that provides an accurate measure of lumen maintenance. It is very likely, without a lot of supporting data, that any prediction method will be limited to some multiplier of the testing period. The testing interval for the photometric measurements is a minimum of 1000 hours, so that sufficient data points can be collected for a good sequence from which trends can be calculated.

Coming in part 2

The next part of this article will cover further details on LM-80 as well as looking at the various Guidelines (e.g. Title 24, Energy Star) that call on the Standards described above. The article will also look at the impressive array of standards that are currently in process, and the need for harmonization on a global basis.

LINKS

Webcast on photometry and standards: www.ledsmagazine.com/features/6/2/15

More information and images: www.ledsmagazine.com/features/6/4/1

design forum | **DRIVING STRINGS**

Avoiding thermal runaway when driving multiple LED strings

The use of a current mirror configuration and additional circuitry can ensure current balancing through parallel strings of LEDs, writes **STEVE ROBERTS**.

An increasingly common method of increasing the light output from a high power LED cluster is to run parallel strings of LEDs from a single constant current source. But this option is not without its hazards. A typical high-power 350 mA white LED has a forward voltage (V_f) of about 3.3 V, so if a cluster of 10 LEDs were required in an application, connecting all of the LEDs in series would require a driver capable of delivering at least 33 V. If the supply voltage is 24 VDC, then an expensive boost converter would be required with all the attendant electromagnetic compatibility (EMC) problems it creates.

Connecting the 10 LEDs as two strings of 5, wired in parallel, requires a 700 mA constant-current source but only 16.5 V output voltage. This means a low-cost buck converter running from 24 VDC can be used. This circuit configuration can be found in many manufacturers' datasheets. There is a basic assumption that the 700 mA regulated current will be shared approximately evenly across both strings of LEDs, i.e. each string of LEDs will see 350 mA of current.

However, this is rarely the case. Even if the LEDs are all from the same production batch and sequentially manufactured, the V_f of individual LEDs still has a ±20% tolerance. The tolerances mean that the total V_f for each string can be very different, resulting in significant current mismatch.

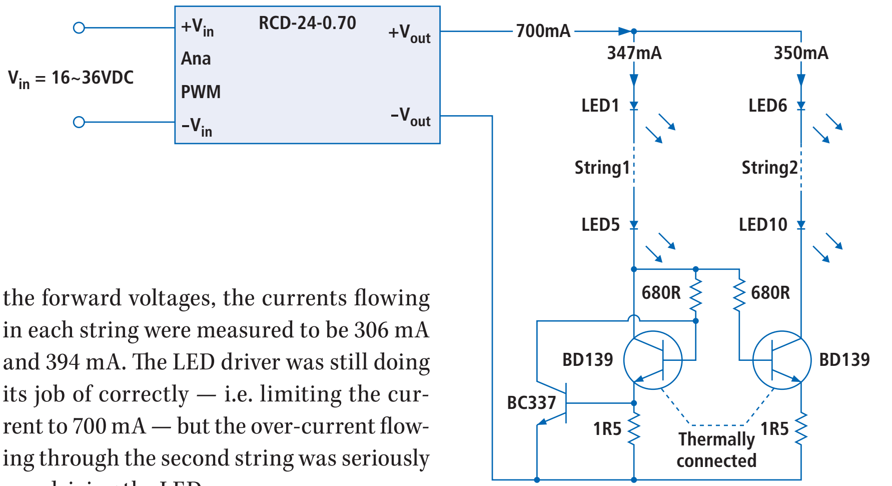
Overdrive situation

A test was carried out using identical SMD LEDs from a single production batch, with 10 LEDs connected as two strings of 5 in parallel. Using 1 Ω resistors to help balance out the forward voltages, the currents flowing in each string were measured to be 306 mA and 394 mA. The LED driver was still doing its job of correctly — i.e. limiting the current to 700 mA — but the over-current flowing through the second string was seriously overdriving the LEDs.

Worse, as the LEDs started to get warm, the combined V_f of the higher-current string started to decrease. This increased the imbalance and more current started to flow through the already over-driven string. The current through the other LED string reduced as the constant current driver compensated, so they started to cool down and their V_f increased.

The net result was thermal runaway, with the majority of current flowing through one string only, even though the LEDs were mounted on a large metal heat sink. The test was stopped when the current imbalance was 600 mA to 100 mA. Obviously, if this situation was allowed to continue, the over-driven string would eventually fail and then the entire 700 mA would flow through the remaining intact string and destroy that as well. And this circuit is often given as a recommended application example!

What is required is a way of balancing the currents flowing through the two strings to ensure that they remain approximately equal, even if the combined V_f values are mismatched. The balancing circuit must also continually compensate for changes in V_f caused by changes in the operating temperature and by aging of the LEDs.



The final version of the current balancing circuit.

Using a current mirror

Fortunately, there is a very simple transistor circuit that will do this job admirably. It is called a current mirror and "reflects" the current flowing through one reference transistor onto the current flowing through a second transistor. As long as the transistors are reasonably well matched in terms of their V_{be} values, the currents will also be reasonably well matched.

In tests using Recom's 700 mA LED driver and two strings of 350 mA Osram LEDs, the currents flowing through the two strings were matched to an accuracy of about 87% over the entire input voltage range of the

STEVE ROBERTS *is technical support manager in Europe for RECOM GmbH (www.recom-international.com). He is based in Gmunden, Austria.*

driver from 16 VDC to 36 VDC. The LED currents were stable as the LEDs warmed up and no thermal runaway was observed. It is important that the two transistors are both at the same temperature, so a copper clamp was used to thermally connect both transistors together to keep their V_{be} voltages stable.

Over-current protection

However, the circuit still requires over-current protection. The diagram (p.33) shows the final version of the current balancing circuit. The addition of 1.5 Ω resistors in the emitter paths makes the circuit less sensitive to small V_{be} changes and balances the currents in the two strings to 99% accuracy.

The addition of a small-signal transistor as a current monitor protects the LEDs from being overdriven in the case of any LED failures. If any LEDs in string 1 (LED1 - LED5) fail open-circuit, then the current in string 2 falls to zero. However, if any LEDs in string 2 (LED6 - LED10) fail, then the current increases in string 1 until the voltage developed across the 1.5 Ω emitter resistor reaches around 0.7 V, thus turning on the BC337 transistor and pulling the base voltage of the power transistor to ground and limiting the current. With the component values given in the circuit, the measured current limit was 445 mA with string 2 open circuit.

The circuit shown can theoretically be extended to any number of LED strings by adding an NPN transistor and emitter resistor to each additional string and tying the transistor bases together. The current flowing through the reference transistor will be faithfully mirrored by all of the other transistors.

However, considering that LEDs are high-reliability illumination sources, and the driver and associated components need to be equally reliable to get the maximum lifetime out of the system, it is recommended that the circuitry be kept as simple as possible and restricted to only one or two strings per driver.

Further reading

A more detailed version of this article with additional circuit diagrams can be viewed online: www.ledsmagazine.com/features/6/2/2.

Designing with LED directional lights: the importance of delivering lux on target

The quality of light and the amount of light reaching the targeted area are the most important factors in directional lighting applications, explains **QUATA OCANO**.

LEDs are known for their potential energy savings and long service life, and LED lighting is often touted for its luminous efficacy as measured in lumens per watt (lm/W). However, lm/W is not the best performance measure for directional lighting applications (Fig. 1) such as spot, accent and task lighting. In these applications, manufacturers need to design lamps and modules that maximize the delivered light or "usable lumens" rather than the lm/W value.

FIG. 1. Directional lighting applications.

Focus on usable light

The two most important things to consider when working with directional light are, firstly, the amount of light reaching the targeted area and, secondly, the quality of that light.

"Unless LED products satisfy our intensity, distribution and color rendering expectations, we will not consider installing LED lamps and modules regardless of their efficiency or cost-savings," says Bradley Bouch, Senior Lighting Designer for Wynn Design and Development. "Designers have been disappointed with LED lights that do not live up to their own specifications, much less the designers' expectations. LED manufacturers should simply take their product and shine it on a wall next to a similar halogen MR16."

He adds, "When the quality of light from the LED lamp is comparable to the halogen lamp and the product is dimmable, we will be happy to use them. We are always looking for ways to improve energy efficiency, but not at the expense of the lighting quality."

In short, LED lighting manufacturers need to design products with the emphasis on the delivered light, and to provide the necessary specifications that the designer can use to incorporate LED lights into their overall plans.

Illuminance

The "Holy Grails" for LED lighting over the last 10 years have been lumens and luminous efficacy to compete with incandescent, halogen and CFL products in general lighting applications. LEDs are inherently directional and make excellent spot and flood lights if designed properly. However, traditional LED light measurements are not appropriate and may be counterproductive.

In a spot or accent fixture, the objective is to highlight a specific feature or item such as a painting or architectural element. *The only light that matters is the light that illuminates the feature.*

The light in the target area, or illuminance, is measured in footcandles (lm/ ft^2), or lux (lm/m^2). Rather than focus on lumens or lm/W, light sources designed for directional lighting should emphasize beam angle and lux or footcandles in the center beam to provide suitable solutions.

Quality of light

The quality of the light in the beam is also important to accent lighting. This is much more subjective than the quantity of light and encompasses light uniformity,

QUATA OCANO *is senior product marketing manager with LedEngin Inc. (www.ledengin.com), a solid-state lighting company based in Silicon Valley, California.*

a)

b)

FIG. 2. LedEngin's LuxDot (a) is a direct replacement for a halogen MR16, while the LuxSpot (b) is a compact MR16 integrated module.

color rendering of objects or features, color homogeneity throughout the beam, contrast at the beam edge and glare. LED solutions have the opportunity to surpass halogen and incandescent sources with respect to the quality of light. For instance, many halogen MR16 lamps exhibit hot spots, shadows, dark rings and fringe edge patterns. Because of the directional nature of LEDs, well-designed LED sources can produce a uniform beam with a smooth gradient of light with well-controlled beam and without the stray light that creates an uncomfortable glare.

Lighting design specifications

LED sources need to adopt lighting industry standards and specifications so that designers can more readily specify them. When selecting accent light sources, designers consider footcandles (lux) in the target area. They work with center beam footcandles (lux) and the light distribution in distance from the source and center beam. IES light distribution files make it easy to design with lamps and modules. Light color measurements that help a designer know how to use a light source include color temperature (CCT) with binning aligned with ANSI color bins and color rendering index (CRI).

Directional lights are traditionally MR16 or PAR incandescent or halogen lamps defined by wattage and beam angle. Although there is a wide range of performance even within the halogen and incandescent manufacturers, it is presumed that 35 W halogen from one manufacturer will perform similarly to a 35 W lamp from a second manufacturer. LED solutions need to be characterized in halogen or incandescent equivalent watts with comparable color and color quality. For consistency, LED products need to follow the newly established IESNA standards for LED testing.

Types of LED directional lighting

The easiest solution to speed adoption of LEDs is a direct replacement of the MR16 halogen lamp in a standard form-factor such as the MR16 bi-pin (GU5.3) standard. The compact size offers a challenge for LED solutions accommodating sufficient thermal heat sink and the transformer. However, several LED solutions are very close, and at least one product, the LedEngin LuxDot ™, does conform to the fit, form and function of a true halogen MR16 (see Fig. 2).

There are two predominant types of LED solution. The most common has multiple 1 W or 3 W high-efficiency emitters packed within a 2-inch radius surrounded by a complex optic to try to make a uniform beam pattern. These products will meet or exceed both the lumens and lm/W standards, but will usually fail to deliver the needed footcandles (lux) to the targeted area in a well-controlled beam.

The second design approach is a single emitter made of multiple LED chips closely packed within a small footprint. The thermal challenges are greater because of the dense packing but the optics are much better and the beam much more uniform in color, light gradient and overall efficient use of light. Figure 3 compares LEDs from both designs.

While it is expedient to design drop-in replacement lamps that fit into existing sockets, such solutions do not take full advantage of all LEDs have to offer. The long lifetimes of LEDs let us change the way we think about lighting, in that the light source is not a consumable but an integral part of design, and lighting fixtures need not be designed with replacements in mind.

The real breakthroughs will come when new integrated modules take full advantage of LEDs, accommodate their unique issues and provide attractive alternatives to current lighting designs. Integrated LED lighting modules can optimize the thermal management and drive electronics to provide maximum efficiency and usable light. From low-profile under-cabinet lighting to accent or task lighting, integrated solutions that break away from the existing constraints will ultimately provide the best solutions.

Challenges of working with LEDs

Like virtually every other new technology, LED lighting has challenges to overcome. The good news is that evolving complementary products such as electronic controls, thermal management solutions and optics will support the adoption of LED lighting solutions.

Low voltage AC infrastructure: LEDs require a direct current driver to operate, but line voltages are either 120 V AC or 220 V AC. There are many low-voltage applications today using halogen lamps, particularly in spot and accent lighting. These use transformers that are either electronic or magnetic and typically convert line voltage to 12 V AC. LED drive electronics must work with a wide range of non-regulated low voltage AC transformers and convert the voltage into direct current to drive the LEDs. A second issue with these transformers is that they usually require a minimum power load that is larger than the high-efficiency LED products consume. LED drivers need to address the potential flicker caused by some of the "dirtier" transformers. Lastly,

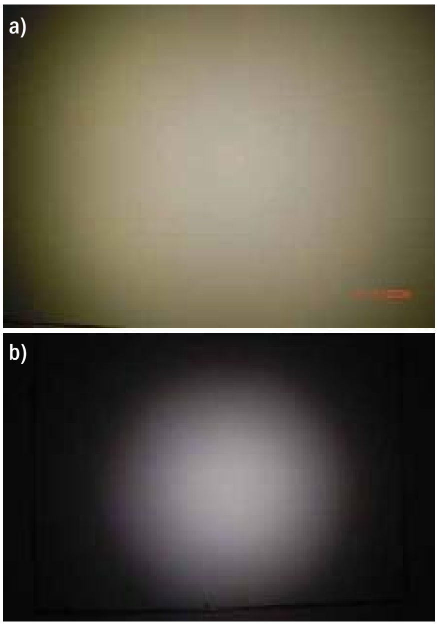


FIG. 3. Typical beam patterns from (a) a multi-emitter vs. (b) a single emitter.

LED products must maintain a power factor > 0.9 to be acceptable in commercial installations.

Dimming capabilities: Individual LEDs are capable of dimming ranges from 100% to 0% through the traditional use of pulse-width modulation (PWM). However, for general lighting, it is best to work with commercially-available offline wall dimmers. Wall dimmers adjust power to the lighting system and have been designed for halogen loads >20 W. LED MR16 solutions typically run in the 6–7 W range. This can lead to limited dimming capabilities, flickering at low dimming levels and non-start of the transformer. Wall dimmers have a turn-on threshold around 3 W, so a 20 W halogen lamp can be dimmed down to about 15%. With LED lamps, this threshold translates dimming to 30–40%. This is true for single LED lamps on a dimmer, but multiple lamps on a single transformer/dimmer will reach lower dimming levels as the load increases.

Thermal considerations: LED products are more efficient than their incandescent counterparts and require a unique approach to thermal management. Rather than the radiated heat from the infrared energy that incandescent sources emit, most of the LED heat is generated from the LED die and must be conducted away. LED packaging technology is becoming a key part of the overall thermal solution. Designs that manage the heat most efficiently can extend the limits of the system and increase the light output without sacrificing long-term reliability. Depending on the size or power of the lamp, there will either be passive or active cooling. Passive cooling is simply a relatively large metal heat sink, usually with fins to increase the metal surface area for better heat dissipation. Active cooling solutions can be fans or a diaphragm. Passively cooled solutions are quiet but somewhat bulky, while active cooling systems allow for a more compact stylish light module.

Both require some installation consideration for proper airflow around the fixture to dissipate the heat.

LED advantages incorporated in products

Similar design considerations apply to many LED-based directional lighting solutions. As examples, we will look at two products designed and manufactured by LedEngin, namely MR16 halogen lamp replacements (the LuxDot brand) and integrated MR16 fixtures (LuxSpot brand) — see Fig. 2.

High flux density: Inside the LedEngin modules, a single, multi-chip emitter is coupled with a secondary lens that controls and shapes the emitted light into a high-lux, high-quality beam for the most efficient use of lumens. This results in a well-controlled light gradient, a smooth transition at the beam edge and uniform color over the beam angle. This provides better light quality than most halogen lamps that have hot spots, dark rings and fringe patterns around the edge and is preferable to LED solutions that must align multiple beams into a single radiation pattern.

High quality color rendering: Taking advantage of high performance LED chips and unique phosphor recipes, LedEngin products have CRI values >80 across all color temperatures, with a CRI of 90 available in warm white. Designers will not consider lamps with CRIs less than 80, and 90 is better. However, CRI does not provide a complete gauge of true color rendering; the quality of light in the warmer red and flesh-tone regions is also important.

Thermal management: Proprietary packaging produces a very low thermal resistance emitter, and in turn this allows the LED to be driven harder to provide a greater amount of directed light in the beam without sacrificing the long service life and while still maintaining a small form factor. Compact packaging allows LedEngin modules and lamps to conform to existing MR16 fixtures and PAR fixtures.

Momentum builds for LED lighting

LedEngin has coined the phrase "Lux on Target" to reinforce the importance of delivering true quality light when implementing directional lighting solutions. "We achieve Lux on Target by integrating a small, powerful LED with optimized optics, heatsinks and driver for an overall reliable, compact system," said Uwe Thomas, director of technical marketing.

Improvements in LED lighting performance and the development of complementary technologies make solid-state lighting an increasingly attractive option, particularly for the many directional lighting applications that play so well to LED strengths. Add the steadily increasing demand for sustainable design, and LEDs will become the first choice for more and more lighting applications.

Taking the heat out of LED fixtures

Heat sinks, heat pipes and synthetic jets are among the technologies being used by LED fixture makers to remove heat from their products and enable them to operate correctly, reports **FRANÇOISE VON TRAPP**.

FIG. 1. Flared-pin fin heatsink.

Temperature has a direct impact on the optical and electrical performance of LEDs, as well as the overall quality and reliability of LED-based products. In a typical LED-based lighting fixture, thermal energy is generated within the LED chip, travels through the LED package, over the interconnect path and into a metal-core PCB, where it must have some means of escape. From a thermal management perspective, the biggest challenge in designing LED-based fixtures is maintaining the LEDs at a specified operating temperature. LED chips are highly temperature-sensitive; as the temperature increases, the lifetime of the LED is reduced, and at higher temperatures the overall light emitted from the LED is reduced.

Additionally, LED lighting fixtures often contain multiple LEDs, which can result in very high levels of dissipated power. Standard light fixtures with well-defined form-factors tend to be restricted by size, which reduces the cooling capacity and necessitates innovative cooling solutions.

Designing for LEDs

Effective cooling of LED fixtures begins with a good design that generally includes some form of heatsink to remove the thermal energy from the fixture body. In many fixtures, the heatsink is an integral part of the housing design.

For electronic devices in general, a passive heatsink that relies on cooling by air flow over a large-surface-area structure is often assisted by active cooling using fans or liquid cooling via a coldplate with liquid loops. However, LED system designers tend to shy away from traditional active devices, due to a number of concerns such as acoustic, reliability, form factor, and cosmetic considerations. "Telecom has learned to adjust to the inadequacies of fans," said Mick Wilcox, director of marketing for Nuventix, a thermal management company based in Austin, Texas. He explained that they've learned to compensate by building in redundancies and can swap out fans when they fail. This is not a good solution for LED lighting, which needs devices that have a similar lifetime to the emitters.

Liquid cooling has not been readily adopted by LED fixture makers either, because a leak in the pipe can wreak havoc on the fixture. Luckily, as the LED industry matures, solutions more suited to its particular concerns are being addressed. Two emerging technologies available to enhance traditional LED cooling designs include synthetic jet coolers and copper heat pipes that use phase-change processes in lieu of liquid to move heat away from the source.

Heatsinks: the thermal workhorse

Since the LED industry – especially the high-brightness sector – is relatively young, there are a multitude of possibilities for both new and old companies that manufacture heatsinks, notes Lars-Erik Lindström, market development manager with Sapa Thermal Management, a Swedish manufacturer of extruded aluminum heatsinks.

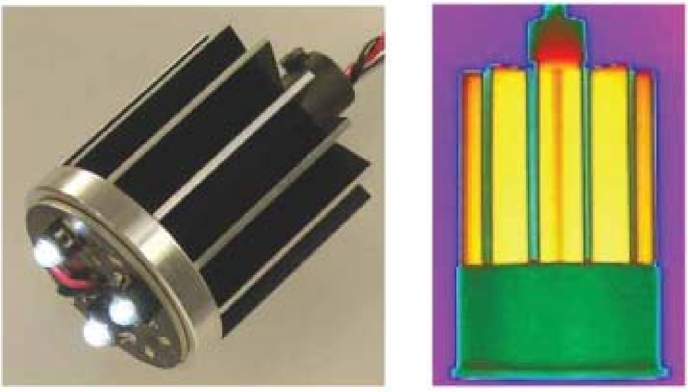
What makes a good heatsink? Factors to take into consideration are their shape, design, and material properties. Die-cast aluminum provides benefits including form factor and "almost limitless" shaping possibilities, but is poor at conducting heat. "Normal die casting alloys have a heat dispersing coefficient of about 120 W/mK," said Lindström. "If you use extruded aluminum instead, the same coefficient can be as high as 210 W/mK." Also, the height-to-width ratio, and therefore the efficiency, of die-cast heatsinks is limited by the release angle needed to get the finished part out of the die.

The extruded aluminum heatsinks developed by Sapa have a high fin ratio, and are adaptable to the particular design of the LED fixture. Lindström notes that for industrial use, the surface finish of a product is probably not the highest priority, compared with functionality and cost efficiency. "However, for home use and architectural solutions, we can add high surface finish and design possibilities to the equation," he said.

A line of heatsinks featuring a flared pin design has been introduced by Cool Innovations, an Ontario-based heatsink manufacturer (Fig. 1). According to CTO Barry Dagan, these flared-pin fin heatsinks are suitable for LED assemblies because they're designed to provide optimal performance

FRANÇOISE VON TRAPP *is a contributing editor of* LEDs Magazine.

in the natural convection mode. The flared structure has a large total surface area combined with a wide spacing between pins that allows air to circulate in a significantly more efficient manner than in a heatsink with vertical pins. The staggered pin design and the omni-directional structure, which allows air to enter and exit the pin array from any direction, both contribute to the efficiency.



Advanced Thermal Solutions

FIG. 2. An LED-based spotlight with a round, finned heatsink. An IR view is shown at right.

Dagan claims that flared pin fin designs often can be used in situations that would otherwise require a much larger conventional heatsink, or an additional cooling device such as a fan. He said that flared pin fins are a great fit for extreme, high-temperature outdoor environments, for very hot LED applications, and for large LED assemblies. "Although the LED market wasn't an initial target for these devices," said Dagan, "the calls started pouring in" when the products were unveiled (see www.ledsmagazine.com/press/17958).

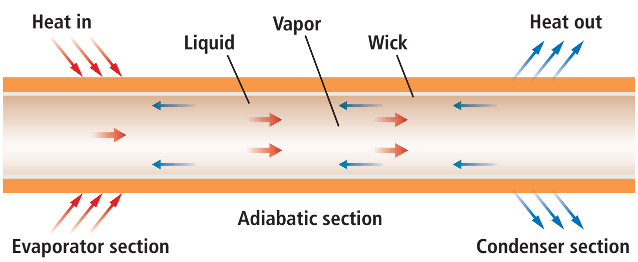
Advanced Thermal Solutions, based in Norton, MA, offers several heatsink options for use in LED fixtures of different types. For example, the company's linear heatsinks are available specifically for LED strips, which are widely used in architectural lighting. Its patented spread-fin array reportedly maximizes surface area for more effective convection cooling, particularly when air flow is limited, such as inside display cases. The company also offers round heatsinks specifically for round LED boards, which are used to replace halogen lamps in applications such as spotlights and down lighting. The round heatsink (see Fig. 2) has a special star-shaped profile fin design that maximizes surface area for effective convection and radiative cooling in the vertical mounting orientation, for example, inside ceilings.

Heat pipes

When heat is concentrated in an area where adequate airflow is limited, heat pipes can be used to move the heat to where it can be efficiently removed by either a stand-alone heatsink, or a heatsink with a fan. Additionally, as heat pipes can be formed into different shapes, they can be incorporated into the heatsink design, allowing for a smaller heatsink to be used.

According to Dennis Scott of Noren Products, a heat pipe manufacturer based in Menlo Park, California, copper heat pipes are isothermal structures that utilize a phase-change process to create a passive heat pump that moves heat from the source (e.g. an LED board) to the output (e.g. a heatsink). Inside the copper tube is a wick structure, along with enough fluid to "wet the wick". When heat is introduced to the copper tube, the water in the wick vaporizes and pushes the heat down the length of the tube to the outlet. As it cools, vapor condenses and re-wets the wick, creating a closed loop system (Fig. 3).

Scott points out that the heat pipe by itself is not a cooling device, but requires a heat source at the input, and method of removal at the outlet. The way in which the pipe is attached to the heat source and to the outlet is important, and Noren works only with custom designs. "As simple as the concept is, it provides a pretty complex solution," said Scott. "Once it's in place, it's a passive solution. But putting it in place isn't as easy as most people think."



Noren Products

FIG. 3. Heat pipes use a phase-change process to transfer heat from the source to the output device. See www.ledsmagazine.com/news/6/2/10 for an example of a street lighting fixture in which a heat pipe transfers thermal energy from the optical module to the heat sink.

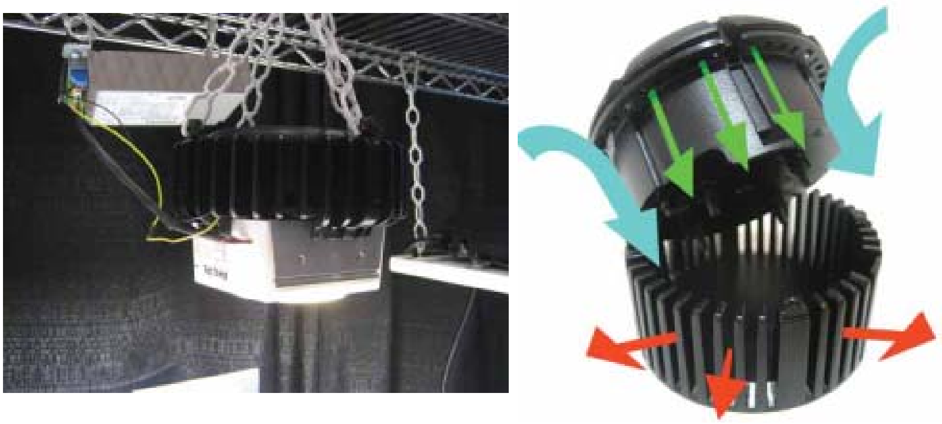
Scott said heat pipe technology is fairly new to the LED industry, and is proving to be especially suited to high power LEDs in applications such as street lighting, where a longer lifetime of cooling is required – such as 10 or more years. Heat pipes can distribute heat over an LED street light's housing for 10-15 years. Another LED application suited to heat pipes is track lighting. "Instead of individual heatsinks for each light, heat pipes can be used to move the heat to a single, efficient heatsink," explained Scott.

Synthetic jets

Synthetic jets are an alternative option to fans as a method of active cooling. This proprietary technology, developed by Nuventix, comprises a module that creates turbulent, pulsated air-jets that can be directed precisely to locations where thermal management is needed. According to Mick Wilcox, reliability is the biggest advantage synthetic jets have over fans, because their lifetime is twice that of the LEDs themselves.

Here's how it works. Wilcox compared it to the simple act of breathing, with inflow and outflow through the same opening, and pulses of air being created by a diaphragm. In the case of a SynJet (Fig. 4), the chamber is powered electromagnetically, oscillating a diaphragm made of elastomer up and down at 50 Hz to propel rapid-fire pulses of turbulent air out of the chamber and through the heatsink. The pulses maintain a higher heat coefficient, and therefore can cool the same amount of air with half the airflow of a fan.

Acoustically, the 50 Hz frequency is below human



Nuventix

FIG. 4. Nuventix has supplied SynJet cooling modules to a number of luminaire manufacturers. A black SynJet and heat sink (left) are attached to a Fortimo light engine from Philips. Synthetic jets (right) are created by rapid-fire pulses of turbulent air produced by an oscillating diaphragm.

hearing levels, while fans run at a higher RPM right in prime hearing frequency, explained Wilcox. The form-factor advantage is that it cuts the size of the heatsink by 2 or 3×, including the SynJet module. Wilcox said this allows system integrators to design much more compact lighting fixtures, and allows them to shrink or mold the heatsink to suit the aesthetic appeal of the fixture.

Synergies exist between different technologies, and several can be included in the design of one LED cooling solution. According to Wilcox, one scenario might involve attaching the heat source to a heat sink with an integrated heatpipe and then attaching the synthetic jet module to the heatsink. He added this solution would be proposed in a "very thermally challenging situation" due to its cost. The heat pipe would be eliminated, if possible, to keep the cost down.

Conclusion

As the LED market matures, so do the solutions to thermal management limitations. Advancements in heatsink technologies, copper heat pipes and synthetic jet modules are paving the way for aesthetically pleasing, efficient, acoustically tolerable, reliable LED fixtures that light our way.

Managing heat in power LED systems for optimal performance

When designing a solid-state solution with power LEDs, one cannot underestimate the importance of the thermal system design, as encapsulated in the phrase "Think Thermal First". **RUDI HECHFELLNER** explains.

To understand the role of thermal design in LEDs, it's important to review how system and electronic drive conditions influence light output performance and long term behavior of high-power LEDs. The parameters shown in Fig. 1 are all influenced by the junction temperature of the LEDs, demonstrating the importance of this subject.

Temperature has a direct impact on optical and electrical performance as well as on the overall quality and reliability of an LED-based product. Therefore, it is critical that engineering teams understand the system's thermal parameters, and focus on thermodynamic competencies.

These parameters are all interconnected. For example, a higher drive current should increase the light output of the LED. However, the higher current increases the dissipated power, causing heating within the LED, which has a negative impact on light output. Also, conversely, a higher junction temperature (caused for example by a higher ambient temperature) causes a reduction in the LED's forward voltage, reducing the dissipated power for a constant-current source.

The parameter dV/dT (the change in forward voltage as a function of temperature) is not constant from LED to LED, unlike in a standard silicon CMOS diode. For this reason, we do not suggest using multiple high-power LEDs in parallel, even when forward-voltage bins are selected very carefully at room temperature. When the system reaches its operating temperature, the different dV/dT values can cause significant current mismatch between parallel paths, resulting in different light outputs from LED to LED.

SSL thermal systems

A typical thermal system is shown schematically in Fig. 2. The thermal energy generated in the LED junction 'travels' through the LED package, over the interconnect thermal path and into the PCB. The PCB conducts the heat through the thermal interface material (TIM) and into the heat sink, which increases the surface area for ambient air exposure.

When evaluating the system for possible performance improvement, we find that multiple factors contribute to the system's total thermal path. To reduce thermal resistance, there are several routes that may be used individually or in combination:

1. Optimize the entire system for thermal performance: For example, when designing the physical system of a luminaire, shorten the thermal paths to the best of your ability, while still meeting the design specification.
2. Optimize each thermal path component to improve performance: For example, use copper vs. aluminum.
3. Remove components to eliminate their resistances: For example, eliminate thermal interfaces by mounting the LED directly onto the heat sink.

Selecting from these options, the design engineer will need to weigh the trade-offs between performance, cost and industrial design to achieve the desired results for the specific application.

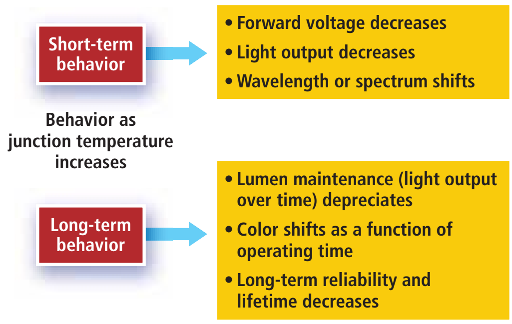


FIG. 1. A number of LED operating parameters are affected by an increase in the LED junction temperature.

To optimize the entire system for thermal performance, a good understanding of the actual operating environment is a requirement. Factors that need to be considered include airflow, as well as regulatory parameters such as UL or CE certifications that limit the maximum temperature of the system. Without even touching on the choice of LED, three factors come to mind as vital to the optimization of a circuit for thermal performance. As discussed below, these factors are heat sinks, choice of PCB, and testing.

Heat sinks

Heat sinks or heat spreaders are the part of the thermal system that distributes the heat energy to the ambient air. Active airflow dramatically increases the effectiveness, but in most SSL applications this is not an option because of lifetime, form factor and noise limitations. Therefore, surface area is of the

RUDI HECHFELLNER *is technical marketing manager with Philips Lumileds Lighting Company (www.philipslumileds.com), San Jose, California, USA.*

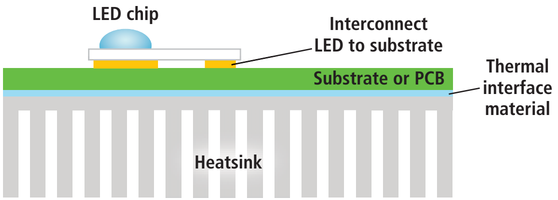


FIG. 2. Schematic showing main elements of an LED thermal system.

essence and often the limitation of the entire thermal system. Even though a heat sink seems to be the most straightforward component, it also has the highest potential for optimization. Engineers are on the look out for new and advanced materials and methods to differentiate their heat sink design.

For example, the introduction of thermally-conductive plastics opens a new dimension of lighting solutions. Thermal systems can now be integrated into the enclosure of products manufactured in high volumes by injection molding with the added benefit of less weight. According to Jeff Panek, GM of Cool Shield Inc., "Most of today's SSL applications are convection-limited rather than conduction-limited. Therefore at less than 300 linear foot/minute (1.52 m/s) of air, a 20 W/mK thermal plastic heat sink can work as well as a 180 W/mK aluminum heat sink. This is because the system is not constrained by how quickly the heat can move through the thermal system, but rather constrained by how effectively it can convect the heat of the surface into the ambient air."

The most efficient way to improve the resistance in the thermal path is to eliminate certain thermal interfaces. This can be achieved, for example, by completely removing the PCB and soldering the LED directly onto the heat sink. Of course, this creates the problem of connecting the LED to the power supply in the absence of a PCB. One solution is a molded interconnect device (MID) that enables higher currents and higher light output with increased drive current while keeping the junction temperature the same. In such a case the use of advanced materials and methods can become the main enabler in meeting a specification like Energy Star® or reducing the component count for a more cost-effective solution.

Thermal materials

The thermal characteristics of power-LED-based systems have caused engineers to adopt the metal-clad PCB (MCPCB) as a primary material instead of FR4 boards. The MCPCB "Star" board is a commonly-used format, but it raises system cost, resulting in ongoing work to reduce it without sacrificing performance. As shown in the table on p.48, using MCPCB as the index reference for star board designs, there are now several alternatives that offer similar or even improved thermal performance at lower cost ratios.

Thermal interface materials (TIMs) are used to connect a solid-state lighting assembly to an external heat sink. Depending on

the application, different types of TIMs are available on the market. In general, this layer should be very thin but able to increase the conducting surface areas by eliminating air gaps that would otherwise add to the thermal resistance.

Material performance and cost comparison of PCB alternatives

PCB material	Average thermal resistance (K/W)*	Relative cost per "Star" board
Metal-core (MC) PCB	20	100%
High performance MCPCB	15	150-200%
FR4 open vias	17	18-60%
FR4 filled and capped vias	13	25-85%
Ceramic (AlN)	11	200-300%
Ceramic (Al_2O_3)	16	60-70%

* Junction to bottom of board

Virtual testing

Testing for thermal performance is an expensive and time-consuming process that requires prototypes to be built and that uses various measurement technologies such as infrared cameras. Evaluation programs specifically developed for solid-state lighting, such as QLED® from Future Lighting Solutions, provide engineers with thermal simulation tools, which can deliver results based on custom conditions within minutes. Changes can be implemented and analyzed to execute different case studies. Such an approach is also very useful in applications with pulsed operating conditions, for example, automotive turn indicators or cell phone camera flashes.

Summary

The solid-state lighting industry recognizes the importance of thermal systems, but the complexity of these systems is often underestimated, and the impact on the performance of power LEDs is not well documented. However, the mantra "Think thermal first" is becoming more embedded in the SSL engineering community. Pushing product performance and lifetime by optimizing the drive current and emitter count is resulting in new materials and implementation methods. Companies that historically focused on electro-mechanics (i.e. connector companies) now seem to be shifting to thermo-electric systems to meet the SSL industry's needs. Materials and methods primarily used in very advanced, high-volume products are now becoming available to the SSL engineer and designer. In the end, "Think thermal first" may not be just an engineering motto, it possibly could be a key differentiator that will trigger development of a successful product in the emerging SSL industry.

continued from page 52

move very rapidly. Although this is a positive trend, it can also create issues. For example, customers may want to wait for the next technology step before committing themselves to an LED-based solution. There is tension between the fast pace of technology change, and customer and product requirements.

We should be able to provide intelligent upgradeability for customers, to allow the easy incorporation of new technology. One example is a board layout that can incorporate different Dragon LEDs that operate at different power levels from 1 to 5 W.

For cool white LEDs, customers are starting to become satisfied with the efficacy (lm/W value), but for warm white, the performance is borderline for many applications, and definitely needs improvement. But in addition to lm/W, there are many aspects of LED performance that need further work — for example binning, lifetime and reliability. Simultaneously, there is further work to do throughout the whole value chain — for example in drivers, or thermal management — so that people can realize the full value of the LEDs' high efficacy.

We continue to work on many aspects of technology, for example new chip technology with much better linearity of efficiency versus current density. We can't share all the details of our R&D program, but we certainly have enough LED development work to keep us very busy for at least the next five years.

OLED lighting

OLED lighting is still in the R&D phase, and we are now trying to validate the many potential applications. Even the simple concept of a glass plate that emits light creates lots of opportunities, and we are working with designers to explore these possibilities. For example, we are trying to determine ways to use attributes such as a window-like panel that is transparent when switched off, but can emit light at night.

In parallel, we are working on technology issues, and achieved 62 lm/W last year for a white emitter. We have to develop low-cost encapsulation schemes, for example, and improve and optimize the substrate and the emitter stack. The highest priority is to reduce the manufacturing cost of the panels, but we also need to improve features such as efficiency, lifetime and color stability. And this work needs to be done in tandem with a consideration for customer-required features. For example, a bottom-emitting structure might be the easiest to implement in production, but does not necessarily offer all the features that customers want.

With funding from German and EU bodies, we are progressing along our project timeline and passing through various gates that will eventually move OLED lighting products into full production. There is a healthy community making good progress in this area, with a number of competitors racing to become leaders in the field.

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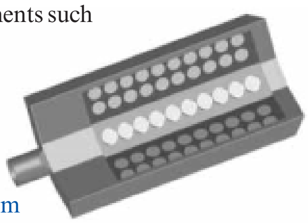

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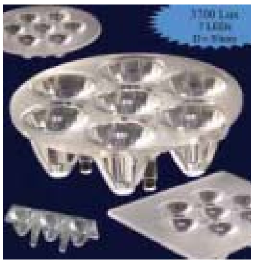

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last word

Lighting market presents numerous opportunities for LED manufacturers

The prospects are good for strong growth in certain lighting sectors, says **BERNHARD STAPP**, vice president, solid state lighting, **OSRAM OPTO SEMICONDUCTORS**.

Within the general illumination market for LED lighting, Osram Opto Semiconductors sees three main areas for growth in the shorter term. The first of these is outdoor lighting, including streets, roadways, parking lots and tunnels; the second is professional indoor lighting, including offices and retail; and the third is LED retrofits.

Looking further ahead, residential lighting will clearly become a major market. This is connected to building and design cycles, and the buying decision is based much more on an emotional response, providing what the customer actually likes, for example sparkling light and vivid colors. This contrasts with the current growth markets, where there is usually some form of milestone or performance criteria that need to be met, for example energy-efficiency targets or specific light distribution patterns.

For outdoor applications, the ability to provide cool white LEDs with a performance level of ~100 lm/W has created a sweet spot that is now being exploited. There is a great deal of momentum, particularly in Asia, where a huge amount of new infrastructure is being installed. Another factor is that many Asian countries are comfortable with cool-white light, where efficiency is best. We have been involved in a number of trial street-lighting installations, perhaps 20 to 30 poles at a time. Now this is becoming a volume business. Lifecycle cost calculations are the overriding factor, and the total cost of ownership must be below five years.

In tunnel lighting applications, LEDs provide long lifetime and low maintenance, as well as much better color rendering, which is very important in emergency situations. For example, after an accident, it would be very important to tell whether a spilt liquid was blood or fuel.

For professional lighting, a major factor is directionality — the ability to put the light where it is required, for example to illuminate a desk or work surface. LEDs eliminate reflector designs, and office lighting power densities can be cut in half. Success requires professional fixtures that are built from scratch, in order to take advantage of the properties of LEDs. It's possible to achieve 60 lm/W at the system level, and this compares very well to existing technologies.

Studies need to be made into human acceptance of LED lighting in professional environments — looking for example at the effect of different illuminance levels in different areas — and results need to be incorporated into standards. In modern building, LED lighting is likely to be part of an overall solution that includes adaptive lighting and daylight control.

Project and customer feedback

We are at the stage where LEDs have been incorporated into fixtures that have been deployed in reference projects, and we are now receiving feedback from these projects. With each project, the argument for LEDs becomes stronger.

The LED retrofit market is clearly very important, although such applications don't harvest the full potential of LED capabilities and performance. Current LED retrofits struggle with price and performance issues; it's possible to have good performance or low cost, but usually you can't find both together.

In terms of performance, color quality is a top priority for our company, and we are working on areas such as color-conversion (phosphor) technology and tailoring the spectral output, as well as binning and consistency. As a semiconductor manufacturer, our company benefits from economies of scale, so that as the volume grows there is scope for price reduction. Higher volume also makes it easier for us to deal with custom requirements, for example specific binning requests. These issues currently add a burden to our overall costs.

LED lighting is characterized by low lifecycle costs, and the potential for significant energy savings, but with higher initial costs. One of our jobs is to convince stakeholders, such as politicians, architects, light planners, and municipalities, of the value of LED illumination. They are definitely becoming more receptive, but they need to see reference projects.

Some street lighting projects have been in place for two or three years, so these are providing results and data, but when these were installed, the efficiency of the LEDs was typically half of the values today.

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