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LEDs MAGAZINE™

Technology and applications of light emitting diodes

PennWell

Issue 18 January/February 2008

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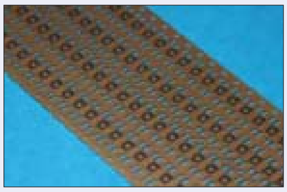

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Editor: Tim Whitaker
twhitaker@pennwell.com
Tel. +44 (0)117 941 5378

Sales Manager: Joanna Hook
joannah@pennwell.com
Tel. +44 (0)117 941 5378

US Sales: Mary Donnelly
maryd@pennwell.com
Tel. +1 603 891 9398

Studio Manager: Karl Weber

Design: Scott Jones

Production: Becky Crews

Group Publishing Director:
Christine Shaw

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Warlies Park House, Horseshoe Hill, Upshire, Essex EN9 3SR, UK
Email: info@ledsmagazine.com

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On the cover: Todd Dacquisto/ Sentry Equipment (main), LRC (bottom left).

Support for energy-efficient lighting

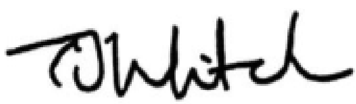
Governments around the world are continuing to support the development of LEDs as one of the more promising future technologies for energy-efficient lighting. The potential savings that can be made in energy consumption, with the consequential effect on CO_2 emissions, are invariably cited to justify this support. Energy savings are also a key driver for lighting installations that use LEDs – see pages 15 and 30 for examples. Last year's calls to "ban the bulb" attacked the energy-guzzling incandescent and created a large amount of positive PR in the mainstream media for the compact fluorescent lamp (CFL), with some ill-informed comments suggesting that LED technology would quickly become dominant. You won't be surprised to hear that we are strong advocates of LED lighting, when and where it makes sense. But for replacing incandescent lamps, or for that matter CFLs, direct LED replacements invariably struggle because they simply can't match the lumen output of the competition.

There are other areas of concern, not least the issue of upfront price. High-quality LED replacement lamps such as those sold by Lemnis Lighting (see page 48) are relatively expensive, although the company suggests new ideas as to how the products might be retailed. Prices will undoubtedly fall as the LED makers continue to move down the price/performance pathways laid out in their roadmaps, and the activities of the Clinton Climate Initiative won't hurt either. If "ban the bulb" legislation goes through as planned, LED lamps will not immediately plug the gap. Some don't think CFLs are up to the task either, and believe that this type of legislation is ill-founded – see for example www.savethebulb.org, produced by lighting designer Kevan Shaw. However, in the USA, the Energy Star program has enjoyed success in promoting CFLs. Sales of Energy Star-qualified CFLs doubled in 2007 and accounted for approximately 20% of the lightbulb market in the USA. Energy Star-qualified CFLs have a minimum lifetime of 6000 hours, and the Energy Star website says a 23-30 W CFL can replace a 100 W incandescent producing 1600 lm. The CFL page (www.energystar.gov/index.cfm?c=cfls.pr_cfls) also contains handy hints on how to dispose of CFLs, since they do of course contain mercury (a fact that could prove to be their ultimate downfall).

Recently, the DOE finalized a new Energy Star specification for solid-state lighting luminaires. The criteria will go into effect September 30, 2008, unless the new IESNA testing procedure for SSL (LM-80) is delayed. Details and the final specification document can be found at www.energystar.gov/index.cfm?c=new_specs.ssl_luminaires. The Energy Star SSL criteria is also the basis of one of the categories in the 2008 Lighting for Tomorrow competition (see www.ledsmagazine.com/news/5/1/23). The competition aims to encourage innovation and new designs using SSL, and hence to increase the market availability of energy-efficient residential lighting fixtures. The other categories are for lighting fixtures that use LEDs with a minimum luminous efficacy of, respectively, 50 lm/W and 90 lm/W.

However, a far more lucrative prize was included in the Energy Independence and Security Act, signed into US law in late December 2007 (see page 12). The Bright Tomorrow Lighting Prizes for a 60-watt incandescent replacement lamp, a PAR type-38 halogen replacement lamp, and a "Twenty-First Century Lamp" (capable of producing more than 1200 lm with 150 lm/W efficacy at 2800-3000K) have a cash reward of 10, 5 and 5 million dollars, respectively. The dollar figures grabbed the headlines but behind this was an instruction to develop, within 5 years of the date of the award, government-wide Federal purchase guidelines. These will have the goal of replacing 60 W incandescents and PAR-38 halogens in Federal Government buildings with the winning SSL products.

Other countries are also providing funds to develop SSL, for example Denmark, which is funding Martin Professional to develop intelligent LED lighting (see www.ledsmagazine.com/news/5/1/21). In the UK, the Technology Strategy Board is also busy offering funds for suitable programs in SSL and related fields (see page 13). Investment in this area has the double benefit of helping to create a strong domestic infrastructure in an emerging technology, hopefully resulting in long-term business growth, and at the same time pushing the right buttons in terms of having a positive effect on climate change.



Tim Whitaker
Editor, LEDs Magazine
twhitaker@pennwell.com

Whole lotta LEDs

(Photo credit: Getty Images) The LED Zeppelin reunion concert at The O2 in London (see also page 9) featured a giant 280 m^2 LED backdrop provided by Creative Technology. The 28 x 10 m screen was composed of Stealth fixtures from Element Labs, which are partially transparent, allowing lighting to be rigged behind the screen for an added dimension to the stageshow.

BUSINESS

Philips buys US-based luminaire maker Genlyte for $2.7 billion

In November, Philips Electronics announced its latest spending splurge in the lighting market, when it entered into a definitive merger agreement with North American luminaires company Genlyte Group Inc. The Netherlands-based lighting giant offered USD 95.50 per share, or a total of approximately USD 2.7 bn (EUR 1.8 bn) to be paid in cash upon completion. Philips says that the proposed transaction builds on its earlier acquisition of Color Kinetics and provides the company with a leading position in the North American luminaires (lighting fixtures) market.

Although the deal is not all about solid-state lighting by any means, this was an important aspect. Theo van Deursen, CEO of Philips Lighting, described the deals as "another major step for Philips in executing its strategy to establish a global leadership position as a provider of energy efficient, solid-state lighting solutions in key application areas. It follows on our recent acquisitions of Color Kinetics, TIR Systems, Partners in Lighting International, as well as our earlier investment to acquire full ownership of Lumileds."

Van Deursen also said that, as well as growing the company's presence in North America, the deal deepens Philips' contacts to end users, such as wholesalers, contractors, architects and lighting designers, which will help speed up the market rollout of more energy efficient lighting.

Based in Louisville, Kentucky, USA, Genlyte designs, manufactures and sells lighting fixtures, controls and related products for a wide variety of applications, including solid state lighting.

In the year ending September 2007, Genlyte had revenues of around $1.7 billion. Genlyte's lighting products are sold under many different brand names. Several brands have launched LED-based products, notably Ardee Lighting and Lightolier, which took part in Lightfair 2007 (see www.ledsmagazine.com/features/4/6/3).

Just under 90% of Genlyte's 2006 revenues were related to commercial and industrial applications, with the remainder for high-end residential applications. A leader in the North American construction luminaires market, Genlyte sells to distributors and electrical wholesalers. The company's products are also promoted through architects, engineers, contractors, and building owners. Genlyte employs approximately 6700 people.

- More details: www.ledsmagazine.com/news/4/12/9

Philips Solid-State Lighting Solutions, formerly Color Kinetics, has unveiled its new 50,000-square foot corporate headquarters in Burlington, Massachusetts - merging the principles of "green" design with innovative uses of its LED lighting technology. More details at www.ledsmagazine.com/news/4/12/28. Lighting design was by Focus Lighting, Inc. of New York, who also designed the LED lighting for the Times Square New Year's Eve Ball (see www.ledsmagazine.com/news/4/11/28).

AWARDS

Osram LED researchers win German Future Prize 2007

The German Future Prize, the most prestigious award for research and development in Germany, has been awarded for the development of thin-film LED chip technology and its application in the Ostar family of LEDs. The prize, worth EUR 250,000, was awarded by the German President Horst Köhler to Klaus Streubel (right) and Stefan Illek (center) from Osram Opto Semiconductors in Regensburg, together with Andreas Bräuer (left) from the Fraunhofer Institute for Optics and Precision Engineering in Jena.

- More details: www.ledsmagazine.com/news/4/12/9

LIGHTING

LLF reports 113.6 lm/W from warm-white LED lamp

In late November LED Lighting Fixtures, Inc. (LLF) announced a new performance milestone for a prototype LED luminaire, which smashes existing records. LLF built a prototype PAR 38 self-ballasted lamp, which was tested under steady-state conditions by the National Institute of Standards and Technology (NIST) in Washington, DC.

The LRP-38 lamp set a new standard for energy efficient lighting by producing 659 lumens at a mere 5.8 watts of wall-plug power, resulting in 113.6 delivered lumens per watt. The lamp emitted a warm incandescent-like color of 2760 Kelvin with a superb color rendering index of 91.2.

The LLF lamp would use less than 9% and 30% of the energy consumed by incandescent and fluorescent sources, respectively. Gerry Negley, LLF's Chief Technology Officer said, "The results of this prototype clearly demonstrate that LLF's LED technology will surpass all existing forms of lighting in terms of performance."

Negley's article on page 17 describes the company's proprietary method to obtain simultaneously very high efficacy and color rendering, using a combination of blue-shifted yellow Cree Xlamp LEDs and red Golden Dragons from Osram Opto Semiconductors.

LLF's Tony van de Ven said, "We are very encouraged by our LRP-38 technology demonstration, as it is clearly the most energy efficient, high CRI white lighting solution ever developed. While there is currently no timetable for a production release, this result shows that LLF's technology with LED light sources has the ability to surpass 100 lumens per watt from a fixture, which is a revolutionary milestone for significant world-wide energy savings."

DISTRIBUTORS

Anglia launches specialized division for LED lighting

UK-based distributor Anglia has launched Anglia Lighting, a new division dedicated to providing products and technical support to manufacturers, contractors and installers of LED lighting systems. Angila has a strong optoelectronics portfolio that includes LEDs from Cree and Avago; drive circuitry from Zetex and Power Integrations; microcontrollers from ST and Microchip; thermal management products in the form of heatsinks from Aavid Thermalloy and Calinar; and fans from NMB Minebea. In addition, Anglia has partnerships with a supplier of aluminum clad PCBs and a range of optics from Polymer Optics, who can provide standard or customized lenses to give optimum performance for a particular lighting design.

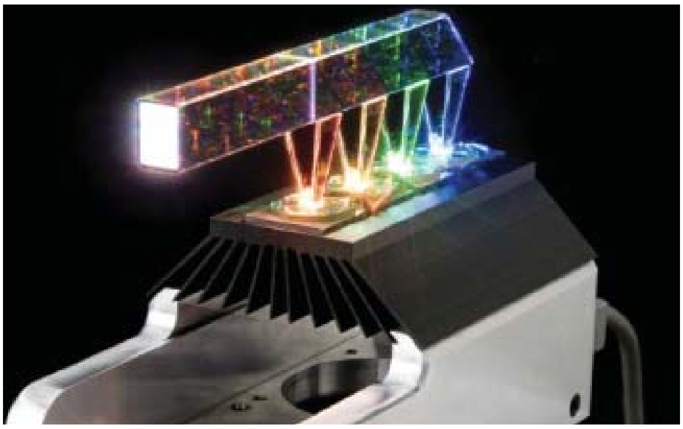
• More details: www.ledsmagazine.com/news/4/11/23

FUNDING

Element Labs wins $12.75 m

Venture capital firms have invested $12.75 million in Element Labs of Santa Clara, CA, a leading provider of creative LED solutions for entertainment, architecture and signage applications. Expansion Capital Partners LLC led the Series B Preferred round, with a $10 million investment from its Clean Technology Fund II, and existing investor Sierra Ventures and lender Gold Hill also participated. Element Labs will use the proceeds to expand its sales team, extend its international reach and enhance its suite of creative lighting products for cutting edge LED and video applications, such as concert tour and music video staging, film and TV production lighting, permanent media wall installations on large buildings, architectural decorative design elements, and other large-scale energy efficiency applications.

• More details: www.ledsmagazine.com/news/4/12/33



MEDICAL

Bookham unveils novel LED multiplexing module

Using novel multiplexing filters, Bookham's LED module can combine up to six wavelengths in the visible range and is designed for bio-analytical applications and medical instrumentation. Rather than using lenses to capture light in free space, the ZoroLight LED module traps light in a tunnel of highly-reflective dielectric coated surfaces that are geometry optimized for efficient source light collection and filter performance.

• More details: www.ledsmagazine.com/news/5/1/16

PRIZES

LEDdyamics and CeramTec win awards for LED products

LEDdynamics has been awarded the "Best of 2007 Innovation Award" by Popular Science, a US-based magazine, for its EverLED-TR product line, an LED-based fluorescent tube replacement.

Separately, CeramTec AG has received the Manufacturing Excellence Award for product innovation for CeramCool, its ceramic heat-sink for high-power electronics. The award is presented in Germany by a panel of representatives from science and industry.

• More details: www.ledsmagazine.com/news/4/12/16

BUSINESS

Cooper acquires Clarity

Cooper Industries, Ltd. (NYSE:CBE) has acquired UK-based Clarity Lighting, a designer and manufacturer of LED architectural lighting and control solutions. The deal follows Cooper's acquisition in August 2007 of Io Lighting. Cooper Industries chairman and CEO Kirk Hachigian, said "Clarity Lighting, which will report through Cooper Menvier, specializes in white light and red/green/blue LED color-changing technical lighting for commercial construction applications and signals our ongoing commitment to further strengthening our existing global offering in LED solutions."

• More details: www.ledsmagazine.com/news/4/12/17

DRIVERS

HB LED driver IC market to exceed $1.9 billion in 2011

Dramatic improvements in the performance of HB LEDs will open up new high-growth opportunities for driver ICs over the next five years, according to a new report from market research company Strategies Unlimited. The total market for HB LED driver ICs is forecast to grow to more than $1.9 billion in 2011.

The $865 million market for driver ICs in 2006 was dominated by the maturing mobile phone application. In the 2007-2011 period, however, market growth will be driven by general illumination, signs and displays, and automotive applications, which will register a combined CAGR of 38%.

The report provides analysis of the market for LED driver ICs by application and geographic region, as well as a detailed market forecast. According to the report's analysis, mobile applications, which accounted for 77% of the market in 2006, will grow at a CAGR of 7% in the forecast period, but by 2011 its share of the total market will decline to less than 50%. Among mobile appliances, LED driver ICs for laptop display backlight applications will see dramatic increases in revenue.

Automotive applications will be a key element of market growth, mainly due to the increasing penetration of LED headlamps, as well as the increasing use of LEDs in interior lighting. Another key aspect of market growth will be the use of driver ICs in single-color and full-color outdoor signs and in the emerging application of LED backlights for LCD TVs. Finally, lighting applications will constitute a major growth driver, as HB LEDs move from niche lighting applications into general illumination.

•"HB LED Driver IC Market Review and Forecast – 2007" is available from Strategies Unlimited (www.strategies-u.com) or by contacting Tim Carli, Sales Manager, at tcarli@strategies-u.com.

DISPLAYS

Symphonica in Rosso makes spectacular use of LEDs

JVR audiovisual provided a giant LED backdrop for Symphonica in Rosso, a five-day music festival in the Netherlands. 3589 Barco Mitrix LED tiles and 300 m^2 of Mitsubishi OD10 LED screens were turned into a stunning piece of video decoration.

- More details: www.ledsmagazine.com/news/4/12/22

ARCHITECTURAL LIGHTING

LEDs in concert at the O2

No longer a white elephant, the Millenium Dome in London is now a hugely successful concert venue known as the O2, and the overhaul has included the extensive installation of LED lighting and displays. Philips Lighting created a striking visual design made up of a combination of floodlighting and LEDs. Each of the 12 masts emerging from the dome were fitted with a Martin 1200 color-changing uplighters at the base, six Philips blue BendiLED hoops staggered up the mast, and seven Philips ArenaVision 1kW white floodlights as a skin wash.

Philips has also designed open-mash LED Vidiwall displays wrapped around the 12 external cylinders around the perimeter of the dome. Rowena Preiss, Philips UK Innovations Manager, explained that each 7m-high display is a giant mesh with LEDs positioned at each cross-point. The nodes have a pitch of 100 mm and contain four LEDs – red, green, blue and white. The displays carry images and messages from different sponsors. The power consumption for each LED display is 2.1 kW per cylinder, compared with 7 kW for the internally-lit signage that was proposed as an alternative solution. Likewise, the entire lighting scheme, consumes only 27 kW, compared with 400 kW for the originally-proposed solution. "This would have made the O2 visible from the moon," jokes Preiss.

Infact, the owners AEG were very sensitive to local residents. "The Dome had been dark for several years, so this scheme represents a big change," she says. "There was also a very strict requirement to prevent spill upwards, due to aircraft flying overhead."

The lighting control system was provided by UK-based Architen Landrell, which installed a 1024-channel Pharos control system for the external lighting of the entire structure (see www.ledsmagazine.com/news/4/12/6). The control system also has an internal link with the O2's Wi-Fi infrastructure which allows for programming to be done anywhere on site with a laptop.

DEVICES

Osram single-chip Dragon LEDs operating up to 2 A

At the start of 2008, Osram Opto Semiconductors says that it will launch the Diamond Dragon, its latest single-chip white LED in the Osram Dragon series. The LED is based on a 2 mm^2 chip manufactured in Thin-GaN technology with chip-level phosphor coating. Other Dragon and Ostar packages from Osram use 1 mm^2 chips.

The LED will produce a luminous flux of 250 lm at a typical operating current of 1.4 A in continuous operation, says Osram. The corresponding color temperature was not discussed. The maximum rated current is 2 A. The LED has a very low specific thermal resistance of 2.5 K/W in an SMT package, enabling the heat produced in the chip to be efficiently removed. The maximum junction temperature is 175°C, allowing the LED to be used in situations where ideal cooling cannot be achieved.

These properties enable the LED to be easily integrated for example in small spotlights, retrofit applications and recessed ceiling luminaires, where they can potentially replace small halogen lamps. The typical power rating of the Diamond Dragon is in the 5 to 8 W range. This LED is intermediate between Osram's 1-3 W single-chip LEDs (Platinum Dragon) and the 10 W, multi-chip Ostar LEDs. The Diamond Dragon will be compatible with the other Dragon footprints and can therefore be integrated in existing designs without modification. Osram says that the new LEDs will be available in the entire white range and all other colors.

• More details: www.ledsmagazine.com/news/4/11/24

MANUFACTURING

Lumileds recalls some Luxeons, halts production

Philips Lumileds has been forced to recall certain Luxeon Rebel and Luxeon K2 LEDs, and halt production until a problem with epoxy material is resolved. Production of these specific products is anticipated to resume in March 2008.

In a letter to a small proportion of its customers, Philips Lumileds has initiated a Return Request Action for certain LUXEON Rebel (with TFFC) and LUXEON K2 with TFFC LEDs manufactured from late October to early January. The letter listed a series of specific part numbers, and recommended that all the listed products within the affected date codes should be returned.

Lumileds told *LEDs Magazine* that it contacted all customers affected by this return request, which constitute about 5% of its total customer base, within one week of discovering the problem. Customers that have not been contacted are not affected by the return request. Also, there are many Lumileds products that are unaffected by the recall.

Perhaps more significantly, Philips Lumileds has temporarily suspended production of LUXEON Rebel (with TFFC) and LUXEON K2 with TFFC emitters. The company said that production will remain on hold until it has resolved the issue. This is a packaging problem that arose in Lumileds' packaging facility in Malaysia. The company says that verification of the exact root cause of this quality issue is under rigorous investigation. The letter to customers said, "We anticipate that our production line will resume sometime in March 2008."

The letter explained that the company has "identified a batch of non-conforming epoxy material used in the production of LUXEON Rebel (with TFFC) and LUXEON K2 with TFFC products…This non-conforming epoxy material has the potential to cause the TFFC die to crack and fail during short-term operation. We have seen a failure rate that exceeds our specifications."

• More details: www.ledsmagazine.com/news/5/1/19

NEWS & ANALYSIS

MATERIALS

IPO funds growth for Rubicon

Rubicon Technology, Inc (NASDAQ: RBCN), a manufacturer of monocrystalline sapphire substrates, conducted a successful initial public offering (IPO) in November with an offer price of $14 per share. The share price has been above $20 during 2008. The company, located in Franklin Park, Illinois, claims to have a 30-35% market share of sapphire substrates in terms of volume. Rubicon's sapphire wafers are sold as substrates for LED growth, and are also used to make silicon-on-sapphire ICs and optical windows. 70% of Rubicon's revenue is from the LED and solid-state lighting market.

Raja Parvez, president and CEO of Rubicon, told LEDs Magazine that the company made a decision 2 years ago to sell its material to companies that polish the wafers, rather than dealing directly with LED makers. "We avoid competition with customers, but we still maintain a strong relationship with major LED makers and we know that our material is used by many of them," he says.

Rubicon manufactured more than 3 million two-inch equivalent wafers in 2007 and expects this number to be close to 4 million in 2008, following an investment in manufacturing capacity (see www.ledsmagazine.com/press/15080). 50% of Rubicon's revenue comes from 2-inch wafers, and 50% from 3-inch and larger. Around 80% of all nitride-based LEDs are manufactured using sapphire, and many facilities still use 2-inch wafers.

However, many major manufacturers use 3-inch wafers, and Parvez knows of 2 to 3 that use 4-inch wafers in production. "There are a couple of companies that are looking at 6-inch wafers [for future production]," he says. Rubicon already supplies 6-inch wafers to silicon-on-sapphire IC makers, with 8-inch on the roadmap. For LED production, the main roadblock for the use of larger wafers is seen to be the uniformity of MOCVD epitaxial growth.

Parvez believes that Rubicon's ES2 crystal growth process produces material with the best quality in terms of defect density, which in turn leads to higher LED yield for customers. He explains that polished 2-inch wafer costs about $20, but after processing and test the value is around $150 – with this much value added by the customer it is especially important that the wafers are not lost due to defects. The ES2 technology also allows the production of large-diameter wafers with high quality, which is difficult using other technologies

- More details: www.ledsmagazine.com/news/4/11/22

On our website – Outdoor lighting

We publish a wide variety of articles and news on our website every week; see below for some recent highlights. For a regular update on news and articles, sign up for our free weekly email newsletter at www.ledsmagazine.com/newsletter.

HOLIDAY LIGHTING

LEDs transform a White Christmas into a Green Christmas
See www.ledsmagazine.com/features/5/1/1

LED holiday lighting in Toronto: the Gateway to a Green Way
See www.ledsmagazine.com/news/4/12/27

STREET LIGHTING

Lumecon, Relume to supply 1000 LED street lights to Ann Arbor
See www.ledsmagazine.com/news/4/12/26

Welland, Ontario launches first phase of LED lighting scheme
See www.ledsmagazine.com/news/4/12/10

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Prize fund provides $20 m incentive to develop efficient LED lamps

The new energy bill contains details of the Bright Tomorrow Lighting prizes totaling $20 million, to encourage US companies to develop efficient LED lamps to replace 60 W incandescents and PAR-38 halogens.

On December 19, 2007, President Bush signed into US law a new piece of energy legislation that contains some significant sections relating to lighting, not least a prize fund totaling $20 million for the development of new solid-state lighting lamps. However, it is important that this is a policy bill, rather than an appropriations bill; in other words this describes what the government would like to achieve if they can find the cash.

Among the stated purposes of the Energy Independence and Security Act of 2007 (EISA) are to move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to increase the efficiency of products, buildings, and vehicles, and to improve the energy performance of the Federal Government. Details of the bill can be found at http://energy.senate.gov.

The Bill contains a number of sections that define how the US government would like to deal with current lighting technologies, and in particular defines energy efficient standards for general service incandescent lamps. While these provisions have an impact on solid-state lighting, the Bright Tomorrow Lighting Prizes have attracted most attention. There are three prizes, one for the replacement of 60 W incandescent lamps, one to replace PAR-38 halogen lamps, and a third entitled the "Twenty-First Century Lamp" prize. The proposed awards are 10, 5 and 5 million dollars respectively, and the prizes are due to be established before the end of 2008.

The Table summarizes the requirements for the three prizes. They all relate to lamps with a warm-white color temperature (less than 3000K) and a high color rendering index in excess of 90. But the figures that will grab attention are the luminous flux and efficiency requirements. Clearly, there is some way to go before these performance numbers can be achieved. 900 lumens from an LED lamp with the same form-factor as a 60-watt incandescent A19 bulb and a single-contact medium screw socket? This is a level of performance that will stretch the capabilities of the LED industry and fully demonstrate the capabilities of solid-state lighting.

There is of course a strong argument that LED lighting is not well-suited to existing form-factors such as 60 W incandescent and PAR-38 halogen lamps, particularly due to thermal management issues. The alternative approach is a purpose-built, integrated approach to light engine design that can simultaneously deal with thermal and optical issues in the most efficient manner. However, this prize fund will certainly provide the incentive for a huge amount of further development in the replacement lamp area.

LLF Inc has described some highly impressive results for a PAR-38 replacement (see page 4), which produced 659 lumens at 113.6 lm/W. The efficiency is approaching the desired level while the lumen output is just under half the specified figure. However, color temperature and color rendering met the specifications in the Table. Another point to note is that this is in effect an R&D result, so the performance of lamps in production would be lower.

Also in the Bill, the 60 W incandescent and PAR-38 replacements are defined as having the same size, shape and light distribution patterns as current standard products. The winning products must also be capable of mass production within a competitive market, via the manufacturing of commercially-accepted, quality-controlled lamps that match or exceed the criteria in the Table.

For both the 60 W incandescent and PAR-38 replacements, the Bill also looks ahead to using the successful products in Federal Government buildings. As soon as practicable after the successful award of the prizes, the Bill calls for the development of government-wide Federal purchase guidelines with a goal of replacing the two lamp types in Federal Government buildings with LED lamps, by not later than 5 years after the award is made.

Bright Tomorrow Lighting Prizes

	60-watt incandescent replacement	PAR type-38 halogen replacement	Twenty-first century lamp prize
Minimum luminous flux (lm)	900	1350	1200
Maximum power (W)	10	11	
Minimum efficiency (lm/W)	90	123	150
Minimum color rendering index	90	90	90
Correlated color temperature (K)	2750-3000	2750-3000	2800-3000
Minimum life (hours to 70% depreciation)	25,000	25,000	25,000
Prize	$10 million	$5 million	$5 million

UK allocates GBP10 million to improve energy efficiency of light sources

The UK's Technology Strategy Board (TSB) plans to make a £10 million investment to support collaborative research and development projects in Advanced Lighting, Lasers and Displays. Naturally, this is expected to include projects that involve solid-state lighting. Explaining the background to the decision to invest in this area, TSB Chief Executive Iain Gray said: "Lighting accounts for up to 20% of the UK's power. As we move towards a lower carbon economy, and recognize the need for more efficient energy use, developing advanced light sources becomes increasingly important."

The challenges of this funding competition - part of the TSB's autumn 2007 call for proposals in diverse innovation and technology areas - are (a) to establish solutions which reduce energy consumption by improving device efficiency, and (b) successful integration of new and existing component technologies to provide proof of principle and demonstrations of practicality.

The TSB is a business-led, non-departmental public body established by the UK government and sponsored by the Department of Innovation, Universities and Skills (DIUS). Its mission is "to promote and support research into, and development and exploitation of, technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life."

Last year, the UK government funded several LED- and OLED-related projects as part of the Technology Programme within the now-defunct DTI – see Links, below – and these projects now come under the wing of the TSB.

Applicants must register their intention to apply for funding, and submit an outline of their proposal, by 22 February 2008. The final closing date for applications is 27 March 2008.

Promoting innovation

Mike Biddle, a Technologist for Electronics, Photonics and Electrical Systems with the TSB, describes the TSB's role as "stimulating wealth by promoting innovation" and "acting as a catalyst" for industrial growth. The body will have a budget of around £1 billion for the period 2008 to 2011 to fund all its programmes. This includes £130m and £180m from, respectively, the Research Councils and Regional Development Authorities towards the Board's science-to-business collaborative research and development programme.

Funding in the area of energy-efficient lighting is expected to contribute to the UK's climate-change goals as well as creating major business opportunities for the UK. Advanced light sources are seen by the TSB as an area where the UK has both a high reputation for world-class research activity and a healthy industrial base with the capability to exploit the results globally. Biddle explains that the TSB determines the appropriate areas for investment by speaking with businesses and many other interested parties such as government-funded Knowledge Transfer Networks (KTNs), for example the Photonics KTN and the UK Displays and Lighting (UKDL) KTN. The TSB also consults with advisory bodies such as the Electronics Leadership Council and the Photonics Leadership Group.

The TSB's investment will provide partial funding for winning projects that involve businesses working collaboratively with other businesses and/or research organizations and academic institutions. Projects funded by the TSB typically last 2-3 years and receive a contribution of £500k - £2 million, and they must demonstrate a clear exploitation path. "We expect to see a significant business benefit in a 5-7 year timeframe," says Biddle. "If a proposal has a clear path to market in 1 year's time, the company should be funding it themselves."

"We expect to see a significant business benefit in a 5-7 year timeframe" **Mike Biddle**

Scope for applications

The TSB invites projects that will result in improvements in the overall efficiency with which light is generated, across a range of applications from solid-state lighting through brighter displays to laser systems. Projects that demonstrate system-level improvements in light generation/extraction techniques are particularly welcomed in areas including;

• Electronic, packaging and optical coupling techniques to enable reliable, sustainable, cost-effective, high-brightness, quality, high-efficiency organic and/or inorganic [LED-based], general and task lighting systems as well as mood lighting, indicator lighting and display lighting systems.

• Integration of component technologies to provide physical proofs of principle and demonstrations of practicality. Proposals could involve advances in thermal/power management, packaging technologies, improved optical extraction technologies, driver integration or other techniques.

Links

TSB: www.technologyprogramme.org.uk

UK-based NoveLELS project earns government backing
www.ledsmagazine.com/news/4/7/30

UK group plans to develop LEDs on 6-inch silicon wafers
www.ledsmagazine.com/news/4/6/3

UK OLED project targets replacement conventional lighting
www.ledsmagazine.com/news/4/7/19

Toronto condominium adopts LED lamps for interior lighting

LED lighting has been employed to illuminate the interior corridors throughout a 44-floor condominium building, writes Brian Owen, our Canadian Columnist.

The Palace Pier, Toronto's premiere waterfront condominium, has become the first residential building in Canada (and likely North America) to convert to LED technology for interior lighting, as part of a $2.4 million renovation to the interior corridors. "This is the largest residential interior lighting conversion to LED in Canada and North America," claims Jim Lord, President of the Palace Pier Condominium Board, adding "The (Palace Pier) Board and residents were committed to finding a 'green' solution for the new lighting, and LED proved to be the answer."

The lighting project employs close to 1300 LED-based MR16 lamps in the hallways on all 44 residential floors. Compared with traditional 35-watt halogen MR16 lam ps, the new LED product, supplied by Canadian company CRS Electronics, requires only 4 watts.

The lamps have a correlated color temperature (CCT) of 3000 and a color rendering index (CRI) of 92+, two important lighting metrics for designers as they determine the color and quality of light and how it reflects on other surfaces to truly represent the color of the finishings and treatments.

Fig. 1. LED fixtures illuminate interior corridors of the Palace Pier condominium

Fig. 2. Replacement MR-16 lamp from CRS Electronics

Design requirements

The designer of record for the entire renovation project is Toronto firm Heather Ann Scott. "Above and beyond all of the other components of the entire project, a great amount of time was devoted to researching LED technology and suitability for our application, as well as current and available products and solutions," said the firm's principal, Heather Ann Scott. "Determining who was a reputable company and the verity of their product performance claims was critical and essential. Lighting quality was very important. We believe the solution provided by CRS represents the very best."

The CRS LED MR16 has a lumen maintenance rating of 70% at 40,000 hours, equivalent to 5 years continuous use. In this application the lighting operates 24 hours per day. Halogen lamps have a lifetime of just 2000 hours. Using LED technology, relamping maintenance costs such as lamp purchase and labour will be drastically reduced.

During the review process, CRS Electronics contacted greenTbiz, a Toronto program that provides energy conservation and efficiency assistance to businesses and commercial property owners and facilitates the LED City Toronto initiative. "greenTbiz was instrumental in assisting us and guiding us in the right direction." said Scott Riesebosch, CRS president. "We recognized that they [greenTbiz] had the experience in working with LED technology, products and suppliers and could provide us with an independent overview."

Chantal Brundage, Program Manager of greenTbiz, says that her organization facilitates and undertakes a number of LED pilots and projects every year. "The Palace Pier is special because it demonstrates how urban residential energy conservation can work on a large scale," she said "There is no shortage of inferior product or overstated performance claims. Our experience dictates caution and an unbiased evaluation protocol."

Energy savings

The difference between halogen and LED will save the Palace Pier residents approximately $40,000 per year. Electricity demand is approximately 40 kW less, and overall annual consumption will be around 349,226 kWh less per year. This translates into approximately a 110 tonne reduction in greenhouse gas emissions. When considering both the reduced energy as well as maintenance costs, payback of the initial purchase will be within 9 months.

Peter Love, Ontario's Chief Energy Conservation Officer of the Ontario Power Authority commented, "It is exciting to see energy efficiency projects of this nature, which merge the very best in commercial energy-efficient technology and residential property design. This project will provide insight, lessons learned and best practices for other residential developments."

About the author

Brian Owen is the Principal of LEDesignWorks and Program Advisor to greenTbiz (www.greentbiz.org). He is actively involved in the development and operation of energy conservation programs for government, municipalities and utilities. Email: Brian@greenTbiz.org or bkowen@firsteam.ca.


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Exterior architecture photo courtesy of the Hotel Gansevoort.
CREE LED Light

Essentials of designing efficient luminaires with LEDs

A systems-level approach for LED luminaire design is required to achieve all the expected benefits of LED lighting, say **Gerry Negley** and **Antony van de Ven**.

The promise of solid-state lighting (SSL) is here today. From the marketing hype of LED chip and component manufacturers, the expectations are long-life and high-efficacy light sources. It is not uncommon for LED packagers to claim >50,000 hrs lifetimes, and the race for the highest efficacy (without regard to cost or manufacturability) has added to the expectation of light sources exceeding 150 lumen per Watt. This marketing hype is exacerbated by exaggerated claims of LED Luminaire performance by SSL fixture manufacturers.

As demonstrated in the first three rounds of the Department of Energy (DOE) CALiPER reports [1], the difference between claimed and actual performance of SSL luminaires has been as large as a factor of two for either efficacy and/or lumen output. The DOE CALiPER reports should reset the expectations of the industry and the consumer. Performance for existing SSL fixtures range from products just better than incandescent lamps to products better than compact fluorescent lamps (CFLs), the incumbent replacement for incandescent (see figure 1).

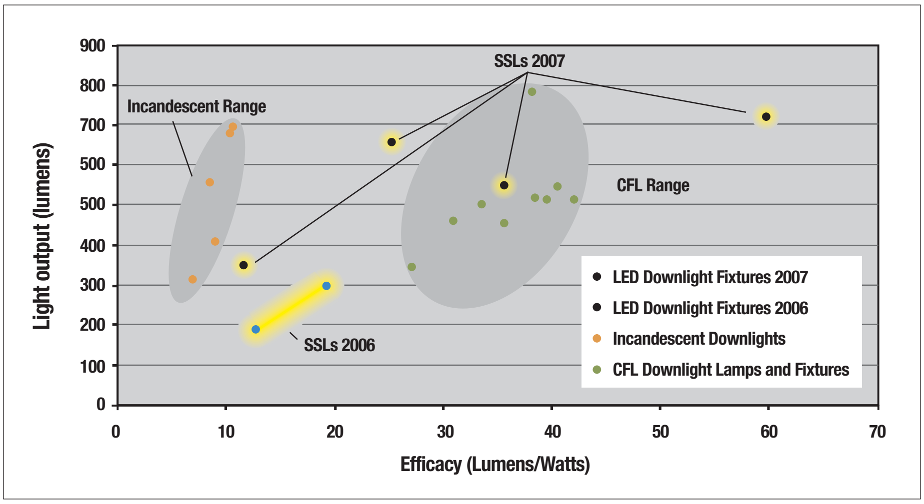


Fig. 1. Department of Energy performance comparison of downlights [ref 2].

The key attributes of SSL include color quality (CRI/Ra), lumen output, power consumption, efficacy and lifetime. Features include the ability to function on existing dimmers, the ability to change color temperature or color chromaticity, the ability to maintain color chromaticity unit-to-unit, the ability to maintain color chromaticity over the expected lifetime of the product, and creating a source or fixture that provides a familiar look to the end user.

Design considerations

Existing luminaire manufacturers typically integrate a lamp ballast with a light source to create the final system. As simple as this sounds, there have been years of lessons-learned owing to failures related to poor design.

Unfortunately, the same story holds true to SSL inasmuch as incumbent technology luminaire manufacturers DO NOT understand the important design aspects of LED components, and LED component manufactures do not understand the details of the luminaire manufactures.

The design rules for an SSL luminaire can simply be stated:
1.Thermal - LED's lifetime is severely affected by temperature
2.Electrical - Power not used to create photons is wasted as heat
3.Optical - photons per source are limited, so use them efficiently and effectively.

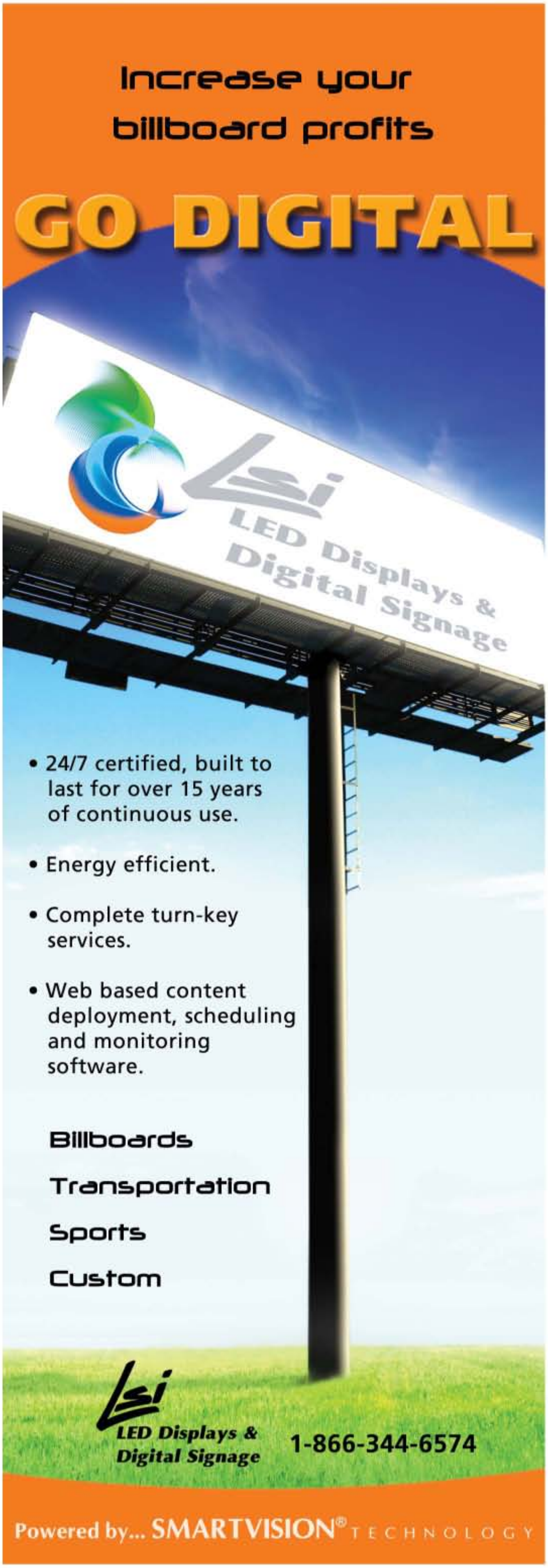
The attribute of color quality will be discussed separately as this is a critical element for SSL to replace incumbent technologies in high-end applications.

Thermal

To achieve the expectations by the LED component manufactures for long life performance (>50,000 hrs) requires careful design consideration. Measurement of the junction temperature (Tj) of the LED component itself is necessary; measuring the fixture surface temperatures is truly inadequate. This measurement is tedious, but not difficult. Nonetheless, it is impractical for anyone other than the system designer to easily measure. The Lighting Research Center (RPI, Troy, NY) compromises by measuring the temperature of the substrate (printed circuit board) upon which the LED components are attached [3].

Although Tj is the figure of merit, the degradation observed in most LED systems is not the LED dice/chip itself, but rather the packaging material (epoxies, silicones, phosphors) surrounding the discrete chip.

Data from LED component manufacturers and independent testing laboratories support the long lifetimes; however, the devil is in the details. Ambient temperatures and drive currents are the parameters of interest while Tj is still the figure of merit. For example, the Cree XR-E power LED has an expected lifetime 50,000 hrs (with a lumen maintenance of 70% of original output) as long as Tj does not exceed 80˚C [4].



The challenge to the thermal solution is (a) for what ambient condition is the fixture designed; (b) what is the thermal limit of the LED component chosen for the fixture; and (c) for what application is the fixture designed.

If the fixture is designed for an insulated ceiling (IC) and an ambient of 65°C, then a component such as the Cree XR-E has 15°C between maximum operating ambient temperature of the fixture and the thermal limit of the component.

The thermal resistance of the component must be taken into account. The component will be rated from "junction-to-solder point", but the application truly requires "junction-to-ambient" (e.g., component to PCB, PCB to heatsink, heatsink to ambient or $R_{thermal} = R_{LED} + R_{PCB} + R_{heatsink}$). Additionally, the heat generated by the power supply must be added to the thermal design of the system. For light fixtures, the most challenging application is an IC-rated fixture. In this application, the effectiveness of a radiating surface (e.g. heatsink) into insulation is quite low.

Electrical

The power conversion for SSL luminaires is something that is often overlooked. Many off-the-shelf drivers are available; however, since the overall technology is in its infancy using an off-the-shelf driver results in a performance compromise to the system.

Power conversion consists of a few necessary blocks: rectification, power factor correction and regulated current (or voltage) control of the LEDs. Other features may be implemented, for example as color changing, color control and dimming.

Some LED luminaires try to use matched strings to the line voltage or a discrete AC-LED to eliminate the loss typical in rectification and to simplify the overall supply. However, owing to nominal variation of the AC voltage on the AC grid, without regulation there can be a +/- 25% swing in optical output, which would be noticeable to the observer. Additionally, the thermal design would have to take into consideration the maximum voltage available on the AC line.

There are various topologies that can be used to control the LEDs, each with their attributes and issues. Using off-the-shelf power converters, one can expect to end up with a conversion efficiency of ~80%.

Optical

The optical system includes the fundamentals of the LEDs themselves and the bounds of physics such as the etendue of the optical system. The photons per source are limited by diminishing returns. As the current density of the LEDs is increased, the photon flux is sub-linear at high injection ratios. If one doubles the nominal drive current of a power LED, the light output increases by ~67%. If you double that drive current again, the light output increases by another 50%. The added power is lost in the form of heat. The selection of drive current for the LED system must take into account the cost per lumens and the cost to adequately take care of thermal design.

In addition to the efficacy of the LED package, most luminaires require more than one LED to achieve useful light output. Multiple sources are most times coupled with an optical system (lens and/or reflectors) to direct the photons to the point of use. Also, this lens system can be used to create a non-pixilated light source to mimic a typical, existing light fixture. Each optical interface in a lens system provides the potential for wasting photons.

A final aspect of the optical system is the source luminance. Requirements from the architectural community suggest limiting the luminance of the source to 9,000 cd/m^2. Otherwise the source will be too bright and distracting. By the nature of the small source sizes of the power LEDs, the fixture will most likely require an obscuring optic to meet this requirement for high-end applications.

Color quality

The primary method for determining color quality in the industry is Color rendering Index (CRI). CRI is a number indicating how accurately the color of an object looks under illumination as compared to under incandescent lights or daylight. It is effectively a measure of the color fidelity. Incandescent lights produce a very warm white light which is comfortable and naturally appealing.

The CRI test compares the color look of 14 different color swatches. The difference between how the first 8 swatches look under a "perfect lamp" versus the lamp being tested is calculated to get a number of merit. A value of 100 means that the color of objects is exactly the same as if they were viewed under an incandescent source or daylight.

The trend of acceptance is given by: 100 is perfect, >90 is excellent, >80 is acceptable in some circumstances, >70 is poor and below 70 is very poor. Incandescent lamps have a CRI Ra of 100, most fluorescent lamps range from 70 to 82.

General illumination with lamps having values of Ra less then 50 is of no use for color differentiation – the light has no color quality. Illumination of this poor quality is only used when there is no economic alternative, and is very uncomfortable and extremely non-productive to work under. Illumination with CRI Ra between 50 and 70 can be used where some "color" is perceived but the accuracy of the perceived actual color is not important.

Illumination with light having a CRI Ra between 70 and 80 makes some colors look very grayish and others may look too vivid. CRI Ra below 80 is poor color quality and not generally acceptable for commercial or residential application. The majority of white LEDs, fluorescent tubes and CFLs have a CRI between 70 and 85, and are generally not good enough for indoor applications.

A high quality light suitable for general indoor illumination needs a CRI of >90. It is also preferable to have a good rendering index for R9. As the 9th swatch of the CRI test, R9 gives an indication of how well the lamp makes deep red colors look. Most white LEDs do not show red very well.

It is also important that the actual color of the illumination be close to the black-body locus. Incandescent light sources and daylight naturally are very close to the black-body curve. Fluorescent tubes have generally been designed as such also. LEDs however, in particular RGB types, can make colors almost anywhere in the color gamut.

It is important that the color of the light be within 0.01 Du'v' of the black-body locus. For high quality light it is preferable that the color point be within 0.002 Du'v' to match the color quality and consistency performance of incandescent lamps.

In addition to the necessity for color quality, color consistency is an additional requirement. Fixture-to-fixture color consistency and maintained color consistency are added design constraints.

Summary of design rules

Solving the thermal issues for a SSL luminaire is essential to achieve the lifetimes associated with LEDs. Assuming a thermal solution, the performance of the packaged LED components is typically ~93%

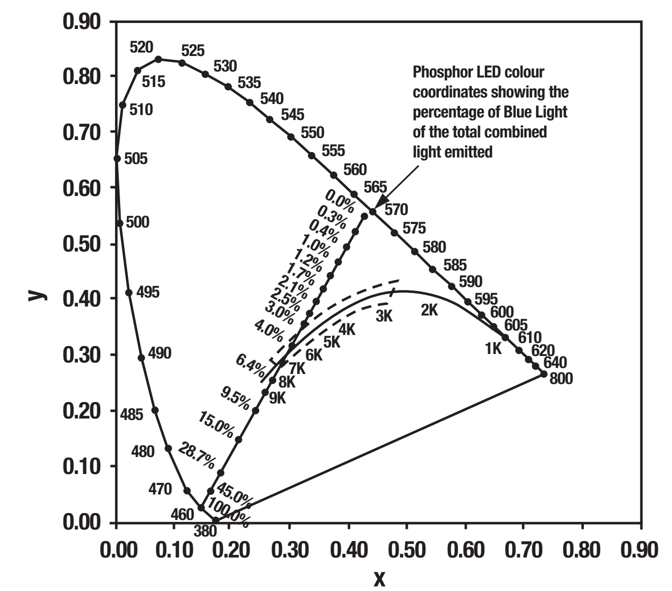


Fig. 2. CIE (x,y) diagram with tie-line for standard phosphor-converted LEDs. The dashed-line boundary about the curved black-body locus is the area within Du'v' -- the region of interest for high quality general illumination.

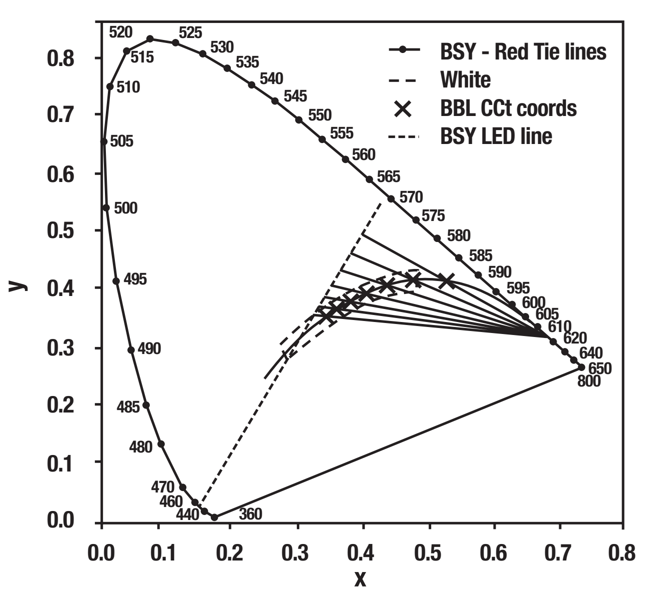


Fig. 3. LLF's unique approach to high efficacy and high color rendering (see U.S. Patent 7,213,940). The combination of a red AlInGaP LED and a blue-shifted yellow (BSY) LED enables warm-white illumination very close to the black-body curve.

of the specified performance owing to thermal equilibrium. An off-the-shelf driver solution will provide an efficiency of 80%. Coupling this with an optical efficiency of 80% nets an overall system performance of ~60%. With detailed effort to each of the design parameter, efficiencies greater than 90% for the electrical and optical components can be achieved.

In addition to these aspects, the choice of the LED device will ultimately determine the overall system efficacy. The efficacy of warm-white LEDs is roughly 30% lower than their cool-white counterparts. Additionally, selecting the requirement of high CRI (>90) will again provide a 30% reduction [5] in performance. Hence, the selection of components and technical approach will be the limiting factors to overall luminaire efficacy.

LEDs for solid-state lighting

One of the most commonly-used type of LEDs in solid-state lighting are phosphor-excited LEDs. A yellow phosphor (typically YAG: Ce or BOSE) is coated on a blue InGaN LED die. The resultant mix of yellow phosphor-emitted light and some leaking blue light combines to produce a white light. This method typically produces light >5000K CCT and has a CRI of between ~70 and 80.

For warm-white colors, an orange phosphor or a mix of red and yellow phosphor is used. UV-based LEDs combined with red, green and blue phosphors offer quite good CRI, similar to fluorescent; however, due to increased Stokes losses they have lower efficacies. Using a pure phosphor-converted approach to achieve white LEDs with high CRI (Ra>90) usually results in a 30% reduction in efficacy [5].

Light made from combinations of standard "pure" colors, normally red, green and blue, exhibit low efficacy due primarily to the poor quantum efficiency of green LEDs. They also suffer from lower CRI Ra, in part due to the narrow full width at half maximum (FWHM) values of the green and red LED spectra. Very specific combinations of LEDs can be used to achieve better CRI values. The lack of spectral content and the missing colors between the RGB spectra results in poor rendering. However, owing to the contrast differences between the LED spectra and lack of spectra in the gaps, the apparent vividness of the RGB colors is enhanced.

High efficacy and high color rendering

The highest efficiency LEDs today are blue LEDs made from InGaN material. Commercially available devices have external quantum efficiency (EQE) as great as 60%. The highest efficiency phosphors suitable for LEDs today are YAG:Ce and BOSE phosphor with a peak emission around 555nm. YAG:Ce has a quantum efficiency of >90% and is an extremely robust and well-tested phosphor. Using this approach, almost any color along the tie line on the CIE diagram between blue and yellow is possible (see figure 2).

If the portion of the lumens of blue light is approximately greater than 3% and approximately less than 7% then the combined emitted light appears white and falls within the generally acceptable color boundaries of light suitable for illumination.

Efficacy as high as 150 lm/W has been reported for LEDs made with this method, which typically have a CRI of between 70 and 80. For phosphor-converted LEDs the primary omission from the spectral content is the red color components.

Red AlInGaP LEDs have very high internal quantum efficiency, however due to the large refractive index mismatch between AlInGaP and suitable encapsulant materials a lot of light is lost due to total internal reflection (TIR). Regardless, red and orange packaged LEDs are commercially available with efficacies higher than 60 lm/W.

Warm-white light with high CRI and efficiency

We combined YAG:Ce phosphor with 452nm peak blue InGaN LEDs such that the color point fell well above the black body locus and the

color was distinctly yellow. Importantly this point coincides with the peak efficacy for the Blue + YAG:Ce system, but this was not a white LED; it is a yellow lamp. We call this color BSY (Blue Shifted Yellow).Mixing this BSY light with the reddish light from an AlInGaP LED, we were able to pull the yellow color back to the black body curve and produce warm white light. Figure 3 shows the tie lines between a red LED and various BSY points on the blue/YAG tie line. With this approach, high-efficacy warm white light with an unexpectedly exceptional CRI is achieved [6].

Commercial LED fixture

Using the patented approach described above, LED Lighting Fixtures, Inc. (LLF) has introduced the LR6, a 6-inch diameter recessed downlight for residential and commercial applications. Table 1 shows the performance attributes of different versions of the downlight, which combine high efficacy and high color rendering.

LR6 highlights essentials

The design of the LR6 highlights many essential aspects of LED luminaire design:

Thermal: The LR6 is designed so that the junction temperature (Tj) does not exceed the rated specification of the LED component. Even in an insulated ceiling (IC) application with the plenum at 65ºC and the room at typical 25ºC ambient, the Tj condition is satisfied. This is achieved by utilizing surfaces both in the plenum and in the room to dissipate heat.

Electrical: The LR6 uses a custom-made application-specific integrated circuit (ASIC). A block diagram of the LR6 unit is shown in figure 4. Features of the overall design include (1) Power Factor Correction (PFC), (2) an open-loop system for color consistency, and (3) provisions for factory-setting the color of each fixture.

LLF believes that each of the features is essential for LED-based luminaires:

1. In the USA, PFC is typically a requirement for commercial applications. Nonetheless, the power company is interested in the Volt-Amps load (VA or kVA) of an electronic unit, not just the rated wattage. For example, a 26 watt Compact Fluorescent Lamp with a poor power factor (e.g., PF ~0.5) will produce an apparent load (the true sizing requirement) of 52 watts.

2. The open loop system is designed to maintain color consistency over the lifetime of the product. Some existing lamp technologies (e.g. MR-16s) have significant color shifts over the lifetime of the product. This creates the noticeable perception of different color sources if units are replaced at various times, or requires all units to be replaced (100% re-lamping) to maintain color consistency.

3. Color consistency at initial operation is as important as color consistency over the lifetime of the product. Owing to the large bin distributions of LED component manufacturers, the ability to consistently reproduce the same color (as perceived by the observer) is required.

Performance of LLF downlights

	LR6	LR6C
CCT	2700 K	3500 K
Flux (lm)	650	650
Ra	> 92	> 90
Efficacy (lm/W)	~59	~61

Table 1. These parameters are measured at thermal equilibrium and independently verified by various laboratories in the USA.

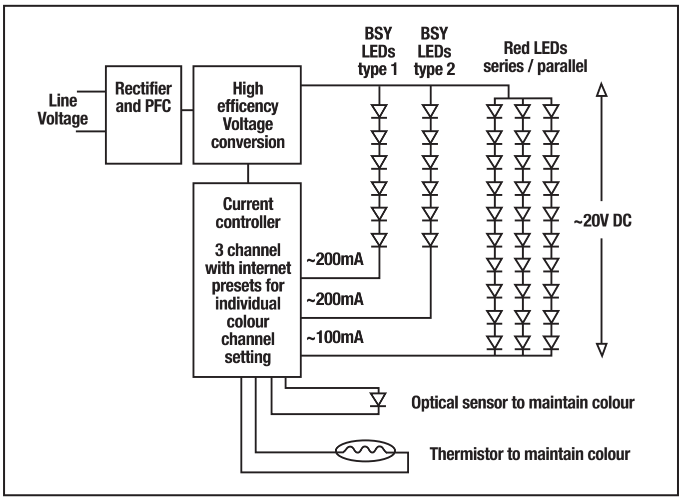


Fig. 4. A block diagram of the LR6 unit, which includes an open-loop system for color consistency. Color control is possible due to the inclusion of two types of blue-shifted yellow (BSY) LEDs that emit slightly different colors.

Optical: The LR6 utilizes a diffuse optic to obscure the individual LEDs. This was done to both mimic existing lighting technologies and to tone down the luminance of each individual source.

Discrete sources can be a distracting element in lighting designs and may also produce glare. Using an optic to both create the desired illumination pattern and average the luminance over an area are features designed into the LR6 product.

Color Quality: The LR6 has a CRI Ra of between 90 and 94. It provides excellent color accuracy and displays strong colors accurately as well (e.g. R9 ~80).

Conclusions

LED technology has advanced to the realm of general illumination. The ability to achieve the market requirements of color quality, power consumption, efficacy and lifetime can be achieved if attention is given to every aspect of the overall design. Unlike a simple incandescent light bulb, a systems approach is required to maximize performance and to achieve the expected attributes of SSL.

Further reading

[1] DOE SSL Commercial Product Testing Program (now CALiPER) results at www.netl.doe.gov/ssl/comm_testing.html. Pilot Round Dec 2006, Round 1 Mar 2007, Round 2 Aug 2007.
[2] As above, Round 3 Oct 2007, Summary of Results, p10.
[3] Detailed review at www.ledsmagazine.com/features/4/12/1.
[4] www.cree.com/products/pdf/XLamp_Reliability.PDF, p7.
[5] www.lumination.com compares Vio high-power white LEDs. Performance of 70 CRI (45 lm/W) and 85 CRI (38 lm/W).
[6] Van de Ven, A.P. and Negley, G.H., U.S. Patent 7,213,940.

About the authors

Gerry Negley is Chief Technology Officer and Tony van de Ven is Managing Director of Asia Pacific for LED Lighting Fixtures Inc (LLF) of Morrisville, NC, USA (www.llfinc.com).

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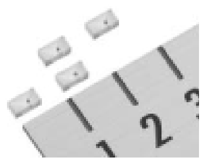

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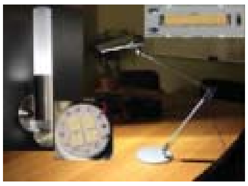

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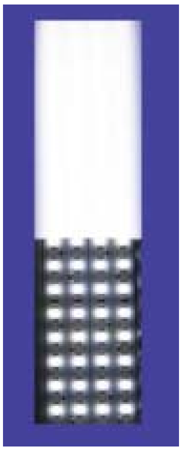

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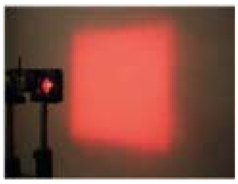

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Tokyo illuminated by white LEDs

The White-LEDs conference in Tokyo provided a unique opportunity to meet key players in Japan's LED lighting industry, writes **Tim Whitaker.**

The First International Conference on White LEDs and Solid State Lighting took place in Tokyo on November 26-30, 2007 and featured an international line-up of speakers, as well as solid representation from Japanese companies. For non-Japanese speakers, this offered a rare and very welcome opportunity to meet with many companies and researchers that have made a significant contribution to the field of LED technology.

One such contributor is conference chairman Tsunemasa Taguchi of Yamaguchi University, who said that the event was intended to increase mutual understanding among international researchers on the latest research findings on white LED lighting. "For future development of lighting applications, we will need the definition of infrastructure and international performance standards for white LED lighting technologies and systems," he said. "In order to accelerate the LED lighting system and design concept, market and culture, we also need the good collaboration among semiconductor engineers, lighting engineers and lighting designers in the world." The follow-on event in this series will be held in December 2009 in Taiwan.

The Chanel store in the Ginza district of Tokyo has a 10-storey media facçade comprising arrays of white LEDs sandwiched inside the store's multilayer glass front. The main façade is 188 pixels tall by 98 pixels wide, with each pixel containing 72 LEDs. The LED lighting and control systems were supplied by LED Effects, now part of Lighting Science Group

It goes without saying that Japanese countries were, and continue to be, at the forefront of white LED development. In fact, Taguchi pointed out that it was already 10 years since the Ministry of Economy, Trade and Industry (METI) funded the Japanese national project "The light for the 21st century", which started in 1997.

The conference featured a wide variety of international speakers, including big names such as Shuji Nakamura of University of California, Santa Barbara. He discussed the performance of GaN-based LEDs grown on non-polar or semi-polar substrates, and also claimed that the performance of UCSB's "ordinary" GaN LEDs (i.e. grown on c-plane sapphire) matches or exceeds the best research results for 20 mA operation published by Nichia. (Unfortunately, Nichia didn't participate in White-LEDs 07, possibly because Nakamura was the plenary speaker.)

Elsewhere, representatives from Korea, China, Taiwan and the UK spoke about the national programs in their respective countries. Lumileds explained more about their Lumiramic phosphor technology, and LLF Inc reported their LED-based PAR 38 lamp with 113.6 lm/W efficacy (see page 4). This was an excellent conference offering a huge wealth of information, but we have decided to focus here on presentations from various Japanese companies.

Large chips versus arrays

Masayoshi Kanamori of Citizen Electronics provided a comparison of high-power white LEDs using either large chips or multiple smaller chips. The latter approach is used by Citizen in its production devices, for example a 48-chip array driven at 44 mA that produces 540 lm for a case temperature of 20°C; the flux is 10% lower when the temperature is 70°C. The large chip approach enables higher brightness (cd/m^2) and is particularly suitable for automotive headlights and projector light sources. However, said Kanamori, the small chip method is more suitable for applications that emphasize high light output and luminous efficiency, even though the luminescence area is relatively large i.e. features that match the properties of most general lighting equipment.

Citizen investigated the effect of increasing either the number of small chips or the drive current. For high efficiency, it is more effective to incorporate more chips that operate with low current. For example, with a 12-chip array, an increase from 20 mA to 60 mA increases the total flux by 2.39. However, at a constant 20 mA, an increase from 12 to 36 chips results in a 2.8x increase in flux.

Luminaire development – Matsushita

M. Sugimoto of Matsushita Electric Works, Osaka described the design of a compact LED luminaire that was on show at the company's stand in the exhibition (see figure 1). The 165 mm-diameter circular luminaire contains 8 "chip units" and is only 10 mm thick. The total flux was around 600 lm at an input power of 17.5 W, and the average illuminance of a 2m^2 area at a distance of 3m was 70 lx. A new blend of phosphors was developed to increase Ra from 71 to 91 and R9 from -44 to 61.

MEW has developed a color-matching fabrication system in its assembly process. Phosphor parts containing different concentrations of phosphor are fabricated separately from the packaging line.

Fig. 1. M-force LED lighting fixtures from Panasonic including the 10-mm thick circular downlight containing 8 LEDs.

Fig. 2. Pansonic's LUGA multichip LEDs measure 12 x 37 x 2.3 mm and operate with a forward voltage of 10.6 V and 0.8 mA current. The natural white (5000K) version has an output of 400 lm and the warm white LED yields 280 lm. The average color rendering index of these LEDs is 67 and 84, respectively.

Fig. 3. LED light panels and fixtures from Opto Design Inc that are designed to convert the LED point light source(s) into uniform surface illumination. LEDs are placed a highly reflective thin box (known as a "flattener" and light undergoes multiple scattering before exiting through an aperture mask on the top surface. Uniform illumination is realized at a diffusion plate.

After die bonding, the wavelength of each LED package is measured, and a suitable phosphor part is selected and assembled into the package. In previous designs, MEW placed a flat phosphor sheet across the opening of a cavity package containing the chip. But, said Sugimoto, light passing through different sections of the phosphor plate has different optical path lengths within the phosphor, creating chromaticity differences. For the new chip unit, MEW eliminated the cup and developed an aspheric dome shape for the phosphor cap.

Sugimoto also said that MEW had paid special attention to thermal management, choosing an aluminium diecast casing for the luminaire to enhance radiation from the outer surface. A copper plate was placed between the sub-mount and the isolation sheet to expand the thermal conduction cross-section. And chips with a substrate of silicon, rather than sapphire, were chosen to obtain high thermal conductivity.

Luminaire development – Toshiba

Keiichi Shimizu of Toshiba Lighting & Technology Corp explained that the goals of the Kyoto Protocol were a driving force to develop LED lighting equipment with not more than one-fifth the energy consumption, and not more than 3.8 times the price, of current fixtures. Shimizu described a 4-LED downlight similar to Toshiba's range of E-core products (figure 5). The crucial areas for development were miniaturization, high efficiency and low cost.

The main-frame of the downlight has a H-shaped cross-section, with the LEDs mounted on the horizontal bar to allow efficient heat conduction to the outer edges. Toshiba set the target efficacy for the fixture as 50 lm/W. The LED manufacturer rated the LEDs at 100 lm/W, but Toshiba allowed a 20% reduction for operation at high drive current and high operating temperature. The efficiency of the optical and power supply systems was 83% and 80%, respectively.

The downlight had a luminous flux of 265 lm at 5.3 W, with an efficiency of 50 lm/W and lifetime of 40,000 hours. In comparison, said Toshiba, a downlight with a mini-krypton 40 W lamp would produce 230 lm at 36 W, or 6.4 lm/W, with 2000 hours lifetime.

OLED development - Matsushita

Like Europe and the USA, Japan is also investing in the development of OLED technology for lighting applications, and two national OLED projects are supported by NEDO (the New Energy and Industrial Technology Development Organization). Most recently, Matsushita Electric Works, Idemitsu Kosan and Tazmo started a NEDO project in September 2007. The project aims to develop high-efficiency OLED lighting i.e. 35 lm/W with a lifetime to fall to 50% initial brightness of 10,000 hours at 1000 cd/m^2. Innovative production processes such as wet coating, vacuum deposition and encapsulation will also be developed.

T. Komoda of MEW gave the following performance metrics for OLEDs (EQE= external quantum efficiency, measurements at 100 cd/m^2 with consideration to angular distribution of emission):
Blue: EQE = 30%, efficiency = 54 lm/W
Green: EQE = 29%, efficiency = 133 lm/W
Red: EQE = 25%, efficiency = 49 lm/W
White: EQE = 28%, efficiency = 53 lm/W
For white, the chromaticity coordinates were (0.36, 0.41). With light-coupling enhancement the efficiency was boosted to 64 lm/W.

MEW also described the development of "multi-unit OLEDs" with alternate stacked emissive units and transparent connecting layers.

Emissions from each unit are stacked within the same area, so the brightness is enhanced. Komoda described this as a key technology for obtaining high performance OLEDs with long lifetime at high luminance.

Phosphors – Mitsubishi Chemical

Although Ce-doped YAG is widely used as a down-conversion material for many white LEDs, other phosphors are being developed that give improved color rendering for general lighting applications. Of course, any new phosphor material should also exhibit high luminous efficacy and low thermal quenching (reduced light output when the temperature of the material is increased). For white LEDs used as the backlights in LCD displays, the requirements of phosphors are a little different. Here, in order to obtain good color reproducibility, a broad spectrum with good color rendering is less desirable than a series of narrow emission peaks that match the color filters in the LCD backlight.

Researchers from Mitsubishi Chemical described new red and green phosphor materials that are appropriate for lighting and LCD backlighting applications. The red phosphor $(Sr,Ca)AlSiN_3:Eu$ has a broad excitation spectra from 300-500 nm. Compared with $CaAlSiN_3:Eu$, the replacement of 80% Ca^{2+} with Sr^{2+} results in a higher intensity and also shifts the emission peak from 650 nm to 628 nm, where the eye sensitivity is higher. The result is 1.9x increase in brightness.

New green phosphors include $Ca_3(Sc,Mg)_2Si_3O_{12}:Ce$ and $CaSc_2O_4:Ce$. A third green phosphor, $Ba_3Si_6O_{12}N_2:Eu$ is excited in a broad band from 250 to 500 nm and has a green emission peak at 525 nm with CIE coordinates of (0.274, 0.644), making it suitable for LED backlighting for LCDs.

Automotive headlamps - Koito

Launched in mid-2007, the Lexus LS600h was the first vehicle to feature LED headlamps, although only for the low-beam lighting function (see www.ledsmagazine.com/features/4/12/6). S. Kajiyama of Koito described the development of the headlamps; these contain five Nichia LEDs, one in each of the three projector units and two in a small reflector underneath the projectors (see figure 4). The low-beam light distribution pattern is a combination of the four beam patterns from the 3 projectors and the reflector. The projectors contain a beam-shaper that redirects light falling above the cut-off line in the beam pattern. In a conventional projector, the shader would eliminate this light completely.

The LEDs contain 4 chips in a linear arrangement and are designed for extremely high reliability. Kajiyama said that the brightness "hardly changes" after remaining lit for 10,000 hours with a drive current of 700 mA and a junction temperature of 115°C. The LEDs themselves have been specially designed by Nichia in partnership with Koito to operate at higher temperatures. In the projector units, the LEDs are fixed directly to the heat sink unit, and cooling is achieved by natural air convection without a fan.

The LEDs produce more than 400 lm with a brightness of 25 cd/mm^2 (25 Mcd/m^2). The color temperature is 4300K. The power consumption for the whole system with driver is 50 W, so the overall efficacy is 40 lm/W. Kajiyama said that Koito can envisage an improvement to 80 lm/W in future, coupled with a decrease in cost.

Fig. 4. Koito's LED low-beam headlamps for the Lexus LS600h. At right is a Koito fog-lamp module with a built-in driver.

Fig. 5. Toshiba's E-core 60 downlights are LED replacements for 60W incandescent fixtures. The 5000K version produces 390 lm at 7.8 W (50 lm/W) with 40,000 hour lifetime, compared with 380 lm at 54 W and 2000 hours for the incandescent. Warm-white versions produce 290 lm at 2800K. The listed price is ¥23,800 ($225). Version with Ra of 92 are also available.

Fig. 6. Seiwa Electric showcased a wide range of modules and fixtures for general lighting, including these variants incorporating 7 power LEDs. The company is highly vertically integrated, producing LED chips and packages, all the way through to systems such as LED traffic signals and road information displays.

LEDs help Sentry create greener workplace in Wisconsin

Interior and exterior LED lighting in Sentry Equipment's new manufacturing facility are part of a green lighting scheme to reduce energy usage.

Energy efficiency was a key focus for Sentry Equipment Corporation, a leading supplier of sampling components and systems, when it built its new 51,000-square-foot manufacturing and office building in Oconomowoc, Wisconsin. The company went to great lengths to choose everything from window glass to office ceiling materials in line with its commitment to create an energy-efficient environment, and as a result a significant proportion of the building's interior and exterior artificial lighting uses LED technology.

The building's original lighting design indicated that the company's fixtures would require about 75 kW. The company reduced their actual lighting load, however, to only about 30 kW through effective use of daylight and high-efficiency artificial lighting. Michael Farrell, CEO of Sentry Equipment Corp., was largely responsible for driving forward the building's green design.

On the exterior of the building, Sentry has installed eight LED pole-mounted lights for parking lot and general area illumination, seven LED wall packs for egress and building exterior illumination, seven LED bollards for walkways and eight under-canopy LED recessed cans. These fixtures were all supplied by Beta LED.

Inside the building, there are 91 recessed cans from LLF, Inc for aisle lighting, bathroom lighting and conference room lighting and three 8-foot long LED strips for accent lighting in the entry area. "The internal LED lighting is 3500K and it accents well with the 5100K indirect fluorescents in the main office space," says Farrell. "3500K is our lowest [color] temperature." The main criteria for lighting performance were illuminance and energy savings. "Color rendering was a nice added feature and it looks very sharp both internally and externally," says Farrell.

LED illumination was not used everywhere in the facility. "We have high-bay fluorescents in our shop area and indirect fluorescents in our main office," explains Farrell. "We virtually have no incandescent fixtures in the entire building with the exception of the

flag-pole light (this will change to LED next year) and a handful of MR16 pendants for accent. We used the fluorescents because there

Interior and exterior lighting at Sentry's new facility in Oconomowoc, Wisconsin. [Outdoor photo credit: Todd Dacquisto.]

were no comparable LED luminaires available at the time we were building."

Payback and feedback

For the LED fixtures alone, the installed wattage is 4kW compared with more than 14 kW for the equivalent non-LED fixtures in the original design. Using a conservative estimate of daily usage of 12 hours and a per kWh cost of $0.10, the annual saving on energy usage is approximately $4400. The estimated additional first cost of the LED fixtures was approximately $7000, so the raw payback is about 1.6 years, says Farrell. "In reality, the added life of the LED source and lower maintenance costs make this number quite a bit lower. Selecting LEDs is an easy decision financially, especially when you include the maintenance." He adds that further savings were made by switching from HID to high-bay fluorescents in the factory, but this is not included in the above calculation.

Farrell says that he has received positive feedback on the light quality of the LED installations. "The lighting in the parking lot and on the building exterior is very crisp and clean. It mimics daylight very nicely and that is nice since we don't get much sun here in the winter!" As mentioned above, the color temperature difference between the interior LED cans and the indirect fluorescents gives a nice accent, says Farrell. "As well, since the fixtures are so efficiently designed, they don't have glare spots or reflector bounce that you get from CFLs. It seems you get every bit of energy into light, and they don't offend your eyes when you look at them."

• Sentry facility is one of several locations featured on Cree's LED Workplace site – see www.ledworkplace.org/Sentry.htm.

LED luminaire performance: changing traditions can set the right expectations

LED technologies can show radically different photometric performance and life when used in different application environments. Consequently, photometric data produced according to traditional testing standards are not very useful for LED luminaires, say **Nadarajah Narendran**, **Jean Paul Freyssinier** and **Jennifer Taylor**.

Those working at the forefront of LED technology know that LEDs are certain to become one of the light source choices for general illumination. Over the next few years, we can expect to see an increasing number of LED luminaires in the marketplace. Already today we are seeing LED luminaires challenging traditional light sources in several general and niche lighting applications.

LED device manufacturers have to be commended for their persistence in improving white LED performance over the last decade. The year 2007 may be when LEDs began to seriously take on traditional light sources in general lighting applications. Downlighting and street/parking lot lighting are two applications for which several manufacturers have released LED products to compete with traditional lighting.

However, as with many traditional luminaires, not all LED-based luminaires provide reliable performance. While the LED itself may have good quality and performance as a bare device, its integration into a luminaire and that luminaire's installation environment are key to the final product performance and whether it will stand up to customer expectations. Luminaires that do not meet customer expectations can turn off users from promising LED technology.

Fig. 1. LED downlight test rack at the Lighting Research Center.

So, the questions become:
- How do we differentiate product performance in terms of life and light output?
- How can we keep the market transformation of LED technology from facing early setbacks?

The answers to these questions may rest upon changing the tradition of photometry as we know it today.

Traditional testing

Those knowledgeable in lighting use photometric data to select and use suitable luminaires. Traditionally, photometric testing of light sources and luminaires is performed at an ambient temperature of 25°C. This temperature typically is measured at a position up to 1 meter away from the light source or luminaire and at the same height as the midpoint of the light source or luminaire (e.g. IESNA LM-9-99; "IESNA Approved Method for the Electrical and Photometric Measurements of Fluorescent Lamps" published 1999 by the Illuminating Engineering Society of North America).

Photometric data collected according to such testing standards have been useful for selecting and specifying technologies, such as incandescent, whose performances are not affected by the ambient temperature surrounding the light source.

However, such data are not very useful for LED technologies, which can show radically different photometric performance and life when used in different application environments. Selecting LED downlights for an application on the basis of published photometric data could result in considerably lower light levels in the space than designed, leading to disappointment.

Temperature affects LEDs

In an LED, the temperature of the junction between the semiconductor's light-producing layers (p and n materials) is known to be good predictor of performance. The junction temperature depends on the drive current supplied to the LED and the application environment where the light source or luminaire is installed.

Usually, a lighting system can experience different thermal environments depending on where it is installed in the application. To obtain realistic performance data for a lighting system, the test environment must mimic the actual environment where the luminaire would be used. To address this concern, in 2006 researchers at Rensselaer Polytechnic Institute's Lighting Research Center (LRC), together with sponsors of the Alliance for Solid-State Illumination Systems and Technologies (ASSIST), recommended the creation of three environmental conditions to test the performance of directional lighting systems (e.g., downlights and track heads) that are applicable to any light source and address the specific concerns of LED systems.

These recommended testing conditions were based on the typical operating environments of indoor lighting systems. These testing conditions were described and published in "ASSIST recommends. . . Recommendations for testing and evaluating luminaires used in directional lighting", which is available on the LRC website (www.lrc.rpi.edu/programs/solidstate/assist/directional.asp).

Test environments

The test environments proposed by the LRC and ASSIST are open air, semi-ventilated, and enclosed. In the case of open air, the light source and the current driver have plenty of ventilation around them for convection heat transfer. Convection heat transfer is important for LEDs because they do not radiate heat out from the source like incandescent lamps do. The open-air testing condition is most similar to the traditional photometric testing environment.

In the next environment, semi-ventilated, the light source and the driver have limited ventilation around them for convection heat transfer. In enclosed environments, the light source and the driver have almost no ventilation around them for convection heat transfer. As an example, in practice these three environments can be thought of as luminaires operating in a suspended track lighting system, as recessed downlights in non-insulated ceilings, and as recessed downlights in insulated ceilings, respectively. (See Box "Recommended luminaire testing environments" for more information.)

In general, the three testing environments and recommended test methods published in "ASSIST recommends" were designed to:

- Provide more useful information for selecting and using LED directional lighting
- Help differentiate between good and poor performing LED luminaires in terms of light output and life
- Simplify and improve photometric data accuracy by controlling the board temperature of LED luminaires with a smaller volume test chamber instead of controlling the ambient temperature of the room while gathering data.

To understand more clearly how LED luminaire performance varies under the three environmental conditions, the LRC began test-

Recommended luminaire testing environments

The three recommended testing environments described cover the typical indoor applications of directional lighting. These conditions provide a range that allows users to estimate the performance of a downlight in any application condition if the specific operating board temperature is known. If a particular application falls outside of the temperature range of the three recommended environments, the same principle for testing can be applied:

1) Install the luminaire in a way that is representative of the actual application

2) Allow the light source to stabilize and measure the board temperature (for LEDs) or other point known to have a direct relationship with the performance of the light source (e.g. the cold spot for fluorescent lamps)

3) Test the luminaire photometrically and electrically at the same board temperature found in the previous step

One of the advantages of the three testing environments as described by ASSIST recommends is the use of small testing chambers to control more precisely the temperature, as opposed to controlling the room's ambient temperature as is typically done with traditional photometry. Additionally, the point where the temperature is monitored is defined unequivocally because of its location within the luminaire rather than in the ambient environment.

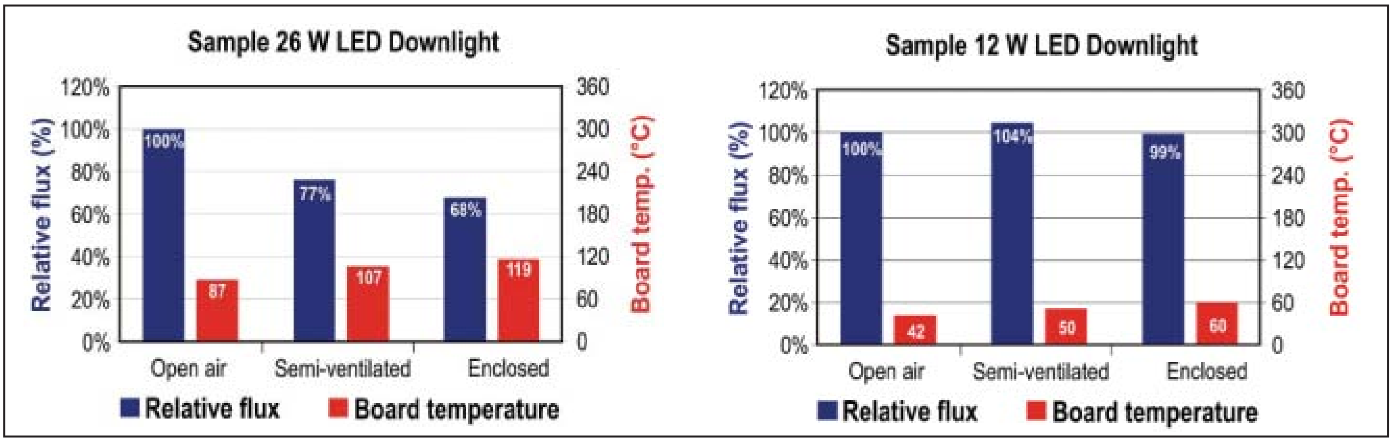
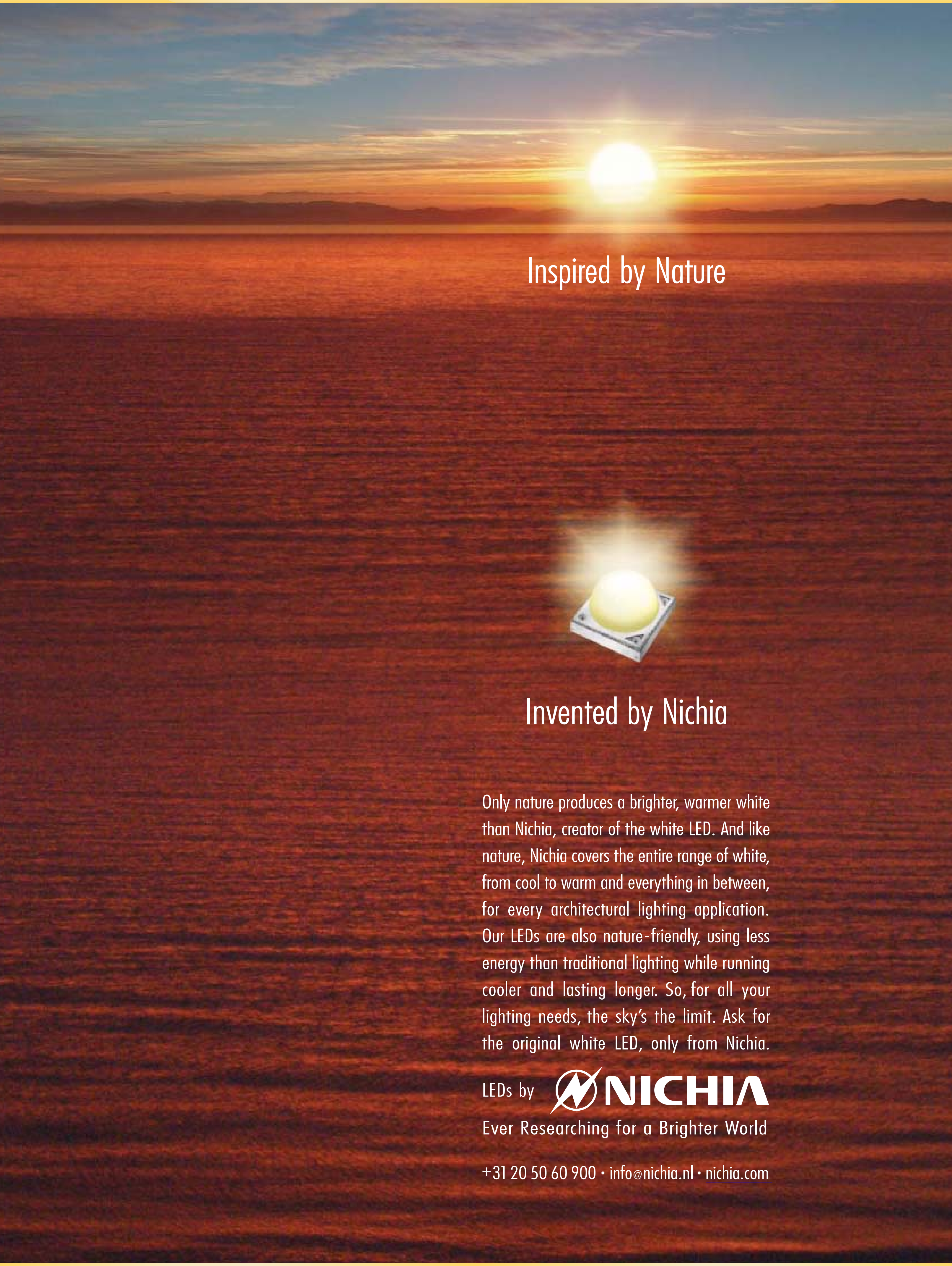


Fig. 2. Measured luminous flux and board temperatures for two commercial LED downlight products tested in three different temperature environments.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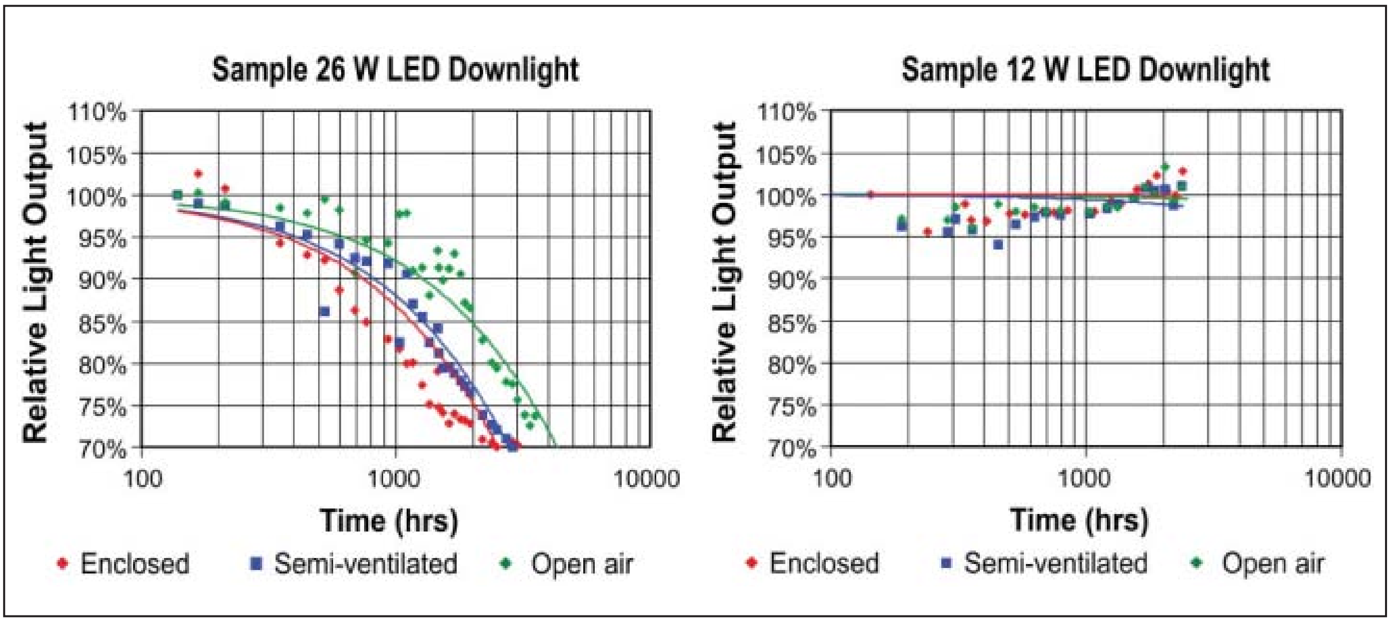

Fig. 3. Measured and extrapolated light output over time for the two commercial LED downlight products tested in three different temperature environments.

ing commercial LED downlight luminaires according to ASSIST's recommendations. The LED downlights selected for testing were IC-rated. These luminaires were mounted and operated in the three different testing environments (open air, semi-ventilated, and enclosed) per ASSIST recommends.

Testing methodology

A temperature sensor was attached to the LED circuit board of each downlight to measure the board temperature of the luminaires while operating in the testing environments. After an initial 100-hour seasoning period, the LED downlights were turned on and allowed to stabilize for 24 hours. The board temperature values for the three testing environments were then measured to obtain baseline temperature data for the luminaires. From the board temperature, the LED junction temperature could be estimated.

Next, the LED downlights were mounted inside a specially designed heated chamber that maintained the same board temperatures found previously. The board temperatures were monitored and maintained throughout the test period via a feedback control circuit that provided a signal to a supplemental heater built inside the chamber. This procedure ensured that the LED junction temperature remained equal to what it would be if the LED downlights were mounted in an actual application.

An integrating sphere with an optical spectrometer attached to one of the ports was placed below the LED system, as shown in the photo of the downlight test rack (Figure 1). Light output from the LED downlights entered the integrating sphere through an entrance port large enough to accept most of the flux. At regular intervals, the integrating sphere was positioned under each of the LED downlights and measurements were taken for light output and spectrum.

The use of the integrating sphere ensured good mixing of light output to obtain average values for flux and color. Generally, the spatial distribution of light level and color of an LED luminaire beam is non-uniform and therefore can lead to large measurement errors if the detector sees only a portion of the beam.

Test results

The two parts of Figure 2 illustrate measured performance data for two commercial LED downlight products: a 26-watt dedicated LED downlight luminaire and a 12-watt LED retrofit system inside an incandescent-based downlight. These two sample data were selected to illustrate the performance of a not-so-good LED luminaire product and a good LED luminaire product.

Figure 2a shows that the light output of the 26-watt LED product differs radically in each of the three testing environments. On the other hand, the 12-watt product provided very similar light output in all three environments (figure 2b). The measured board temperatures in the three environments (open air, semi-ventilated, and enclosed) were 87°C, 107°C, and 119°C, respectively, for the 26-watt product; and 42°C, 50ºC, and 60°C, respectively, for the 12-watt product.

Figure 3 illustrates the relative light output over time for the 26-watt and 12-watt LED downlights in the three testing environments. Lumen maintenance is an important performance metric for luminaires. For LEDs, the light output decreases over time and at some point the light level is no longer sufficient for the application. At this point, the light source or luminaire is considered to be at the end of its useful life and should be replaced.

ASSIST defines LED life by the time, in hours, that it takes for a light source or system to reach 70% of its initial light output (L70). For more information about ASSIST's definition of LED life, see www.lrc.rpi.edu/programs/solidstate/assist/ledlife.asp.

In terms of expected life for the 26-watt LED downlight (figure 3a), even though the number of hours for data collection is still very low, extrapolated data indicate that this downlight will reach its end of life, L70, within 2500 hours for an enclosed application, 2800 hours for a semi-ventilated application, and 4300 hours if placed in open air with plenty of ventilation. These expected life figures are much shorter than the 40,000–50,000 hours published by the manufacturer. Such a short useful life is due to high temperatures at the LED junction. On the other hand, the 12-watt downlight product has not shown any appreciable diminishing of light output to date

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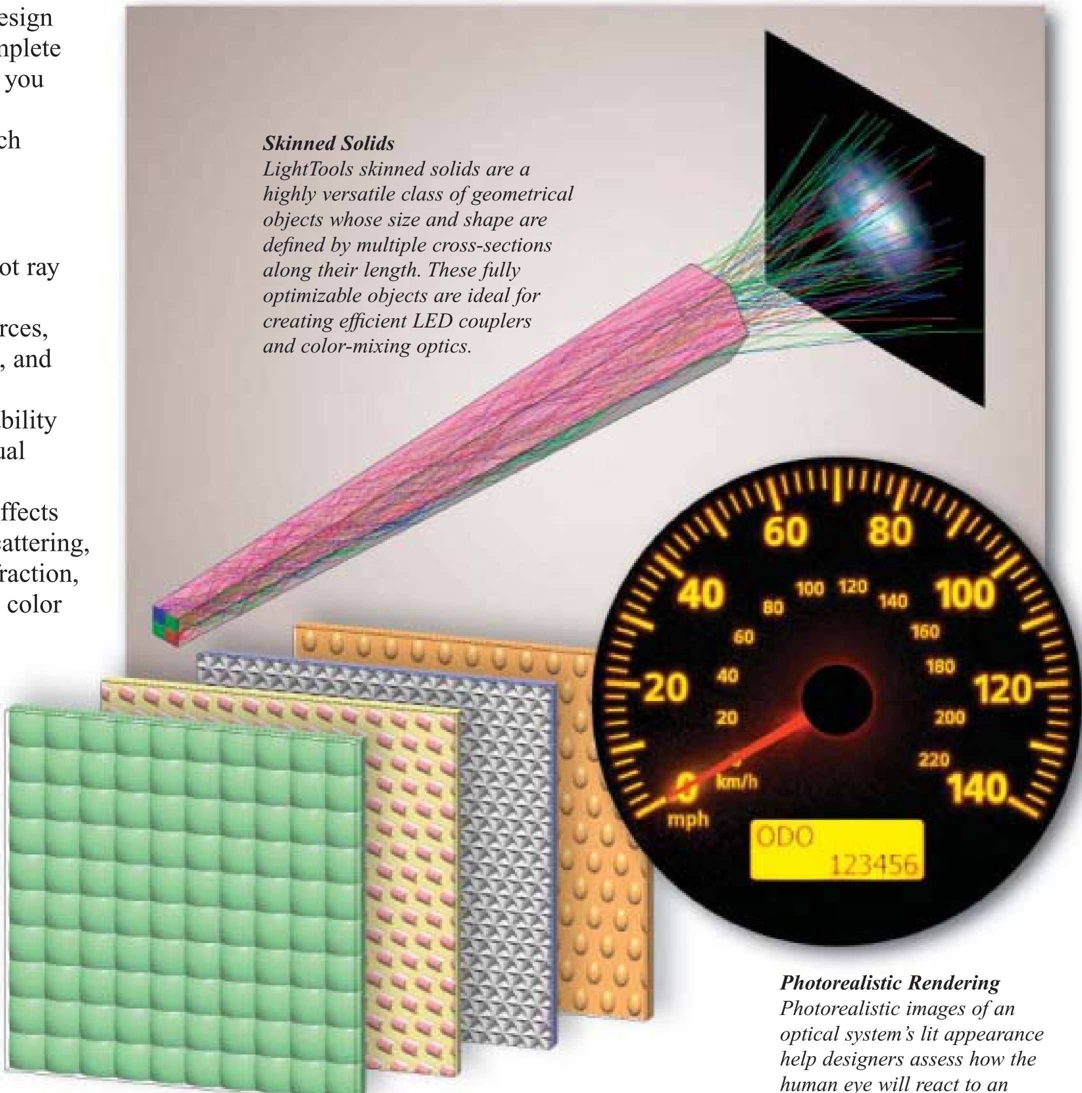

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Alliance for Solid-State Illumination Systems and Technologies (ASSIST)

ASSIST (www.lrc.rpi.edu/programs/solidstate/assist) was established in 2002 by the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute, Troy, NY as a collaboration between academic researchers, manufacturers, and government organizations, ASSIST's goal is to facilitate the broad adoption and effective use of reliable, energy-efficient solid-state lighting and to speed its market acceptance. ASSIST is active in a number of research projects and other activities to advance and promote LED technology. Research, education, and industry collaboration have been the key activities of the program, which seeks to reduce many of the technical hurdles standing between LEDs and their market acceptance.

As part of these activities, ASSIST has developed a publication program called ASSIST recommends to provide a set of formal recommendations to the LED and lighting communities about issues important for the reliable performance of LED lighting and its comparison to other light source technologies. The publications include recommendations for LED life definition, testing and measurement, best practice guides for different lighting applications, and recommendations for selecting LED lighting. These publications are developed under the guidance of ASSIST sponsors using research conducted by the LRC.

Each ASSIST recommends publication undergoes internal review, first by LRC researchers and then by ASSIST sponsors. Industry input also is gathered during the writing process through one or more roundtable sessions hosted by ASSIST and the LRC. Based upon this industry input, the publications are revised and then published electronically for free download (see www.lrc.rpi.edu/programs/solidstate/assist/recommends.asp). As warranted, the publications are updated from time to time to reflect new research, technologies, methods, and equipment.

ASSIST recommends is sponsored by Cree; Federal Aviation Administration (FAA); Lite-On; GE Lumination (formerly GELcore); New York State Energy Research and Development Authority (NYSERDA); Northwest Energy Efficiency Alliance; Osram Sylvania; Philips Lighting/Color Kinetics, now Philips Solid-State Lighting Solutions; Photonics Cluster (UK)/The Lighting Association; Seoul Semiconductor; and the U.S. Environmental Protection Agency (EPA).

because the junction temperatures are much lower.

Outcomes

To illustrate the point, if one were looking for a 600-lumen downlight luminaire for a residential application with insulated ceilings, both luminaires considered here would have qualified based on their published photometric data, measured according to traditional practice. However, the 26-watt downlight product would have led to disappointment on two fronts, initially with a 30% lower light level in the space and in the longer term with frequent replacement due to a much shorter life than advertised.

The testing data reported here illustrate why photometric data produced according to traditional testing standards are not very useful for LED luminaires. LEDs have great potential to provide customized, dynamic, and energy-saving illumination—if the technology can be presented using relevant and meaningful photometric data and installed in optimal applications.

Changing traditions by testing and reporting data per ASSIST recommends will assist end-users in selecting appropriate LED luminaires by providing more useful information. In turn, this can help set the right expectations and ultimately lead LED technology to widespread acceptance and use.

About the Authors

Nadarajah Narendran, Jean Paul Freyssinier and Jennifer Taylor are with the Lighting Research Center (LRC) at Rensselaer Polytechnic Institute (RPI). Narendran is an associate professor at RPI, the director of research at the LRC, and the organizer of ASSIST. He leads a team of researchers and educators in the area of solid-state lighting at the LRC and conducts research and educational programs to accelerate the development and market transformation of this promising technology. Freyssinier is a research assistant professor at the LRC and conducts research on LED lighting technology and applications. Taylor is a senior communications specialist with the LRC and works on publications for the LRC's Solid-State Lighting and ASSIST programs.

Thermal design considerations for high-power single-chip LEDs

With advanced high-power packaging technology, large-area chips offer a number of advantages over arrays, according to Bob Karlicek, John Graff and Dave Sciabica.

For general illumination, conventional LEDs are desirable for their high efficacy and color-changing capability, but low-lumen output per lamp continues to be an issue. The increasingly maligned 100 W incandescent lamp can produce around 1700 lm (and with ideal color rendering and a desirable color temperature). By contrast, even the best high-power white LEDs (~100 lm/W) only produce 100 lumens of relatively inferior light (poorer color rendering with high color temperature). To reach lumen levels required for general illumination, many LED chips or lamps need to be combined in arrays.

PhlatLight™ LEDs from Luminus Devices are designed specifically to replace arrays of smaller LED chips or lamps in almost any application requiring high lumen output in a small area. By using photonic lattice technology, advanced wafer bonding techniques and high-power packaging technology, these devices can easily be made more than ten times (10X) larger than conventional LED power chips and can be driven reliably at much higher current densities than conventional LEDs (see Further Reading).

These characteristics enable PhlatLight LEDs to replace HID lamps in projection TV (PTV), and they are now replacing lamps in front projection systems as well. In these applications, raw lumens per unit area is the most important figure of merit, so PhlatLight LEDs are reliably driven at current densities exceeding 1.5 A/mm^2 (up to 2.5 A/mm^2 in pulsed mode) to achieve the required brightness.

Large chips versus arrays

Before discussing some of the optical and thermal advantages of large power chips versus small chip arrays, it is important to note that PhlatLight LEDs can offer higher efficacies and production yields than traditional chips.

- PhlatLight large chips are often more efficacious than smaller chips. The impact of chip size on efficacy is dependent on the chip design. For typical "anode up" designs, efficacy decreases as chip size increases. By contrast, PhlatLight LEDs are true surface emitters and their efficacy is independent of chip size.

- Yield is very good for properly designed large chips (and will improve even further as LED wafers migrate to 100 mm diameters). The processes developed by Luminus using photonic lattice technology have led to yields that are comparable to those that are characteristic for 1 mm chips. Furthermore, though the concept of a photonic lattice on an LED sounds exotic (and it is), the processes used to form the lattice are easily manufactured and can be done at very low costs.

Almost all SSL applications today focus on the use of chip or lamp arrays simply because of their availability. While arrays are attractive for some applications, a single high-intensity point source has some significant advantages. For example, binning is critical to achieve uniform color or hue with LED arrays, but is much less important for a single-source approach. Also, series/parallel configurations are more susceptible to single lamp failure, while PhlatLight LEDs have a significantly reduced number of points of failure, and do not use an encapsulant, as discussed below.

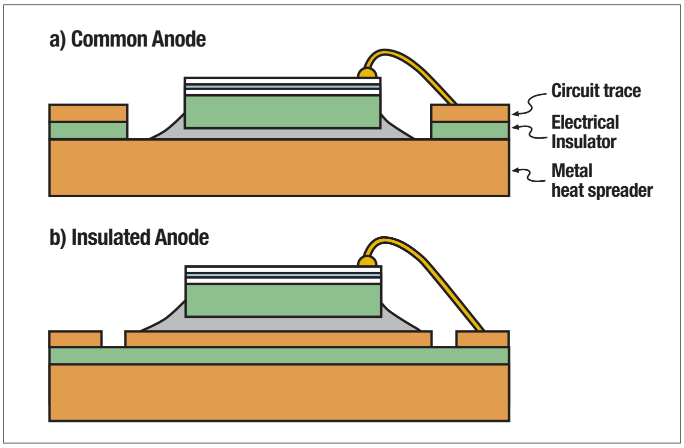

Figure 1. The PhlatLight common anode package (a) has a significantly improved thermal performance compared to arrays that require an insulated anode (b); this approach uses electrically insulating materials with lower thermal conductivity.

Thermal issues in package design

PhlatLight LEDs are designed specifically to deliver thousands of lumens/cm^2 from a single chip/package configuration. The devices operate reliably at low voltage (< 5V) and high currents, with single device power dissipation as high as 100W for some applications. Superior thermal performance is critical to long LED lifetime. The Luminus PT120 package designed for RPTV applications has typical thermal impedance of ~0.6 °C/W, the lowest in the industry.
In order to achieve the lowest thermal resistance from junction to heatsink, two main considerations are important. First, the thermal conductivity of the materials between the LED chip and the heatsink must be maximized. Second, the number of interfaces between the heat-generating region and heatsink must be kept to a minimum. PhlatLight LED packages achieve high thermal performance by optimizing both of these parameters.

Material selection starts with the chip itself, where high thermal conductivity metal substrates are used in a vertical chip configu-


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Figure 2. A planar waveguide illuminated from one edge with a PhlatLight RGB module. The waveguide is approximately 40 mm by 800 mm and be fabricated in many other sizes and shapes.

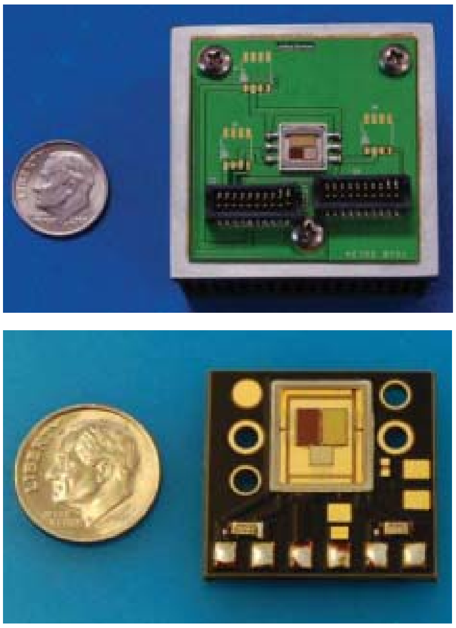


Fig. 3. Prototype packages delivering from 500 lm (plastic package, left) to over 2000 lm (copper package, right) under development for entertainment and compact SSL applications.

ration, providing a low resistance path for heat flow. Die are then attached to the metal heat spreader with materials chosen both for high bulk thermal conductivity, and for minimum interfacial resistance (which can be a significant bottleneck). The thickness and footprint of the metal substrate is chosen in order to minimize the impact of the relatively high resistance thermal interface materials (TIMs) used between the metal substrate and heatsink.

Large monolithic LED chips have an inherent thermal advantage over small chip arrays. PhlatLight chips can be attached directly to a metal substrate, with the LED anode common to the substrate (Figure 1a). Conversely, small chip arrays require electrical isolation between the die so that they may be operated in series ("insulated anode" in Figure 1b). Even the best high thermal conductivity dielectrics can severely limit the thermal performance of the package. PhlatLight LEDs operate at very low voltage and generate extremely high lumen output, so they do not need to be connected in series and the anode can usually be grounded in most applications. When electrical isolation is required, the metal heat spreader can be mounted to a non-conductive interface with only a slight reduction in the overall thermal performance.

Beyond the package, users can employ commonly used active and passive thermal management methods for heat dissipation, as has been demonstrated in numerous commercial products (PTV and pocket projectors) already on the market.

One unusual but advantageous aspect of PhlatLight LEDs is that the photonic lattice is designed to extract directly into air. The resulting air cavity package has two key advantages over encapsulated package designs: reduced optical extent (because optical designs can be more efficient) and improved reliability (since there are no encapsulation degradation issues such as discoloring or delamination). PhlatLight LEDs are extremely reliable in air cavity operation through a combination of the fundamental design and the intrinsic environmental stability of their semiconductor materials.

System level considerations

The low thermal impedance and high drive current of PhlatLight LEDs requires some consideration of electrical driver design. Because of their commercial success in PTV and front projector designs, driver solutions are becoming available from several of the large power-semiconductor companies. Luminus has also developed RGB devices with three chips in a single package in a common-anode configuration. These packages are intended for LCD backlighting and other solid-state lighting applications. The need for grounded common anode configurations has recently been addressed by National Semiconductor with the introduction of their LM3433 device designed specifically for high-current common-anode applications.

From a thermal perspective, the use of LED arrays is thought to have a design advantage by spreading heat over a larger area. However, chip and lamp arrays limit the optical design flexibility and aesthetics of lighting applications by requiring the fixture design to spread the heat and the light. By centralizing the light and the heat generation with a single large LED, design is free from optical and thermal management issues, resulting in simple, elegant, more compact designs.

This concept is shown in Figure 2 with an illustration derived from Luminus' LCD backlighting solution where a PhlatLight RGB module is used to edge light a planar optical waveguide. Optical features on the waveguide can be used to direct the light. Note that the actual lighting surface doesn't require thermal management, and does not even need to be planar. Although waveguides are used with LEDs in many applications, the very high lm/package and lm/cm^2 capability of PhlatLight LEDs can couple high intensity light into the small waveguide input aperture for high brightness, diffuse lighting applications.

New applications

Luminus is now developing new packages and designs for a host of new applications outside of the projection and LCD backlighting space. These compact modules (figure 3) deliver high lumen output from a very small footprint. These prototypes and other concepts now under development at Luminus are being directed toward entertainment, medical and general illumination applications. ●

About the authors

Bob Karlicek, John Graff and Dave Sciabica are with Luminus Devices Inc (www.luminus.com).

Further reading

"Photonic Lattice LEDs are New Class of Light-Emitting Device," Bob Karlicek, LEDs Magazine, July/August 2007. See www.ledsmagazine.com/features/4/8/6.

LCP materials for power LED packages

Vectra LCP liquid crystal polymer materials from Ticona are used by Spectrum Plastics to create open-cavity packages for power LEDs.

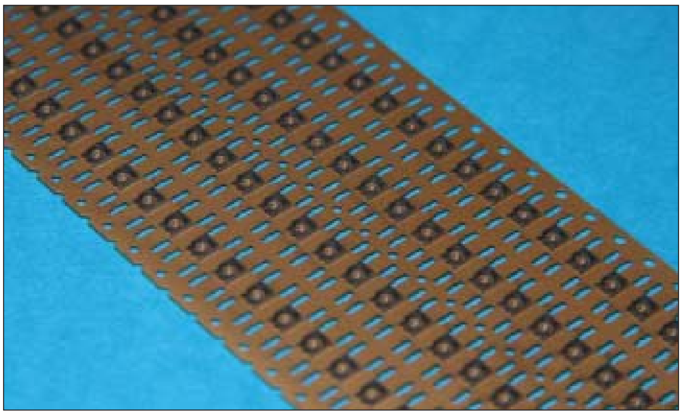
The use of lead-frame molding principles for LED packages can enable a high-volume, automated process that minimizes part handling and enhances quality. With the correct choice of materials, it is now possible to mass-produce packages for power LEDs in fine detail with great precision using this technique.

The widespread introduction of lead-free soldering means that injection-molded LED packages for high-brightness lighting applications must withstand temperatures above 260°C. Of course, thermal issues are paramount when the device is operating, and the package itself must tolerate the effects of high drive currents, encapsulation and high ambient temperatures (for example, direct sunlight for outdoor lighting applications).

Ticona Engineering Polymers, the Florence, Kentucky-based subsidiary of Celanese Corporation, has developed liquid crystal polymer (LCP) materials that are suited to the demands of power LED devices. Edson Ito, a Technical Marketing expert for Ticona's Vectra® LCP products, says that the Vectra S series can withstand higher temperatures compared with other types of materials or different grades of LCP. "Also, it's a high flow material, which means it can be molded into complex shapes with thin walls and tight tolerances," he says. The materials undergo minimal dimensional change in molding and end use and they also have negligible outgassing, so their volatiles do not fog lenses or degrade contacts.

Ticona has been working closely with, and supplying Vectra S series LCP materials to, Spectrum Plastics. This Ansonia, Connecticut-based subsidiary of Barnes Group Inc produces millions of open-cavity LED packages each year. "Polymer performance is critical for our high-brightness and ultra-high-brightness LED cavities," says Kurt Weber, manager of automation at Spectrum Plastics. "These are often used in applications such as automotive lighting, consumer electronics and mobile phone handsets, and must perform reliably for the life of the product."

Weber says that unlike most other materials, including other LCPs, the Vectra S resins provide a wide thermal margin during lead-free



A metal lead-frame containing open-cavity packages made by Spectrum Plastics via injection molding using Vectra LCP.

reflow soldering. "They also give us high yields at high volumes, since they have a wide processing window, rapid cycle time and create almost no flash," he says.

The two companies routinely approach potential customers together with a view to initiating joint product development. Their target market is high-end, power LED packages that require optimum materials. "This is a new market, and we need to offer a whole-product solution," says David Kelly, Spectrum VP of Sales & Marketing.

High volume molding

Spectrum Plastics fabricates open-cavity LED packages in a continuous molding process, using a proprietary reel-to-reel technology. This process overmolds open cavities onto strips of lead frames in a multi-station line using multi-cavity tools.

The lead frame strips are supplied to LED packaging customers who populate the cavities with LED die. The customer then wire-bonds the unit, adds a lens (also molded by Spectrum), and stamps the completed package out of the strip.

The lens is molded from an optical grade of silicone rubber that withstands reflow soldering. In a process developed by Spectrum, the company overmolds lenses on metal rings on a stainless steel strip. The ring supports the lens when the customer assembles it to the LCP open-cavity package.

Background

Injection molding is simple in concept — plastic is melted, injected into a cavity and released when it has sufficiently hardened. Molding machines have an injection section that plasticizes and pushes the resin into the mold, and a clamping mechanism that opens and closes the mold. LCPs consist of rigid, rod-like macromolecules, which align in the melt and order themselves into fibers and fibrils during a typical thermoplastic processing operation. Properties of LCPs include low melt viscosity, excellent dimensional stability, very low heat of fusion (resulting in extremely short cycle times), and very high tensile strength.

Links

Ticona: www.ticona.com
Spectrum Plastics: www.spectrumplastics.com

NuSil evaluates phosphor mixing

Many white LED manufacturers working with phosphors in powder form and transparent silicone encapsulants have addressed the problem of mixing the materials to obtain a uniform dispersion. To complicate matters further, the silicone is usually a two-part system that begins to cure as soon as it is mixed.

The goal is to achieve a uniform, suspended dispersion that can be dispensed into the LED package during assembly. Commonly encountered problems include how to effectively add phosphor to the silicone encapsulant without having it settle or cause processing problems such as curing too soon or bubble formation.

Recently, NuSil Technology performed a study to investigate whether it was possible to formulate a one-part phosphor dispersion to address these manufacturing concerns and improve LED production for some customers. The goal would be a pre-mixed, one-part material that would not need to be mixed or handled in any way other than dispensed directly into the LED.

The ability of the silicone to keep the phosphor in suspension is determined at least in part by the silcone's viscosity, and this was one property that was investigated by NuSil. Other important parameters include the temperature and cure rate. Although curing starts once the two-part silicone system is mixed, the cure can be arrested by placing the mixture in a -40°C freezer, and under these conditions the material should have a shelf life of around 6 months.

NuSil evaluated two silicone materials and determined that its LS3-3354 was better for maintaining the phosphor in suspension. The company has now produced a developmental phosphor gel, GEL8-9617-30, which is a pre-blend of its LS3-3354 silicone and 11% phosphor. The phosphor is supplied by Intematix. NuSil recognizes that some customers will have different requirements for the precise phosphor material and the percentage in the blend, but the new material allows evaluation of the pre-mixing concept.

- More details: www.nusil.com/events/spiephotonicswest.aspx

Low power "green" cooling for LEDs

SynJet cooling modules enable LED lighting to dissipate more power, says **Jim Balthazar**, CEO of Nuventix.

LED lighting has the potential to replace both incandescent and fluorescent lighting as brighter lamps are developed. The luminous efficacy (perceived brightness per watt) of LED lighting currently surpasses incandescent but in most cases is far from approaching that of fluorescent. Effective cooling is essential to enable LEDs to operate at high input power with high efficacy and high lumen output. The SynJet cooling module creates turbulent, pulsated air-jets that can be directed precisely to locations where thermal management is needed. Compared with conventional air movers such as fans, SynJet cooling modules have much higher reliability, lower power consumption and effectively silent operation.

Lighting examples

An ANSI standard size LED MR-16 lamp dissipates 5 to 6 W through natural convection. With a SynJet cooler, an LED MR-16 lamp can dissipate 15 to 20 W, increasing the lumen output 3 to 4 times while using only 750 mW of power for cooling. Similarly, in a LED PAR 38 lamp, natural convection might dissipate 15 to 20 W under ideal conditions and less in applications such as recessed lighting. With a SynJet cooler, an LED PAR 38 lamp can dissipate 35 to 50 W, increasing the lumen output 2 to 2.5 times while only consuming 2 W of power for cooling.

Example 1: MR16 LED lamp

Assume that a retail space uses 10 banks of three MR16 halogen lamps each, for accent spotlighting. Each lamp produces 900 lm and uses 50 watts, so the total wattage consumed is 1500 W. Passively cooled LED MR-16s are not currently capable of producing enough lumens to replace 50-watt halogen lamps. However, active cooling using a SynJet cooling module makes this market possible today. If the 50W halogen lamps are replaced with actively cooled LED MR 16s that produce 900 lumens, at today's top achievable efficacy of 40 lm/W, an LED MR-16 would use 22.5 watts. Add 750 mW for the SynJet cooling module, and the total energy use is 23.25 W per lamp or just under 700 W for the entire store (30 lamps). In total, the LED lamps use 54% less electricity than the halogens.

Example 2: PAR 38 LED lamp

Assume that a hotel uses 500 PAR 38 incandescent lamps for general lighting. Each lamp produces 1800 lumens and consumes 120 W, so the total wattage consumed is 60 kW. The passively cooled LED PAR 38 lamps that are currently available consume about 8-12 W, but use a large array of LEDs and only produce 200 lumens. This lumen output is not enough to replace existing 120W PAR 38 lamps.

However, with active cooling using a SynJet cooling module, an LED PAR 38 can operate at much higher power and produce enough lumens to compete with 120W incandescent lamps. At 40 lm/W efficacy today's top achievable output of 40 lumens per watt, an LED PAR 38 would use 45 watts to produce 1800 lm. Add 2 W for the SynJet module, and the total energy use is 47 W per lamp and just under 23.5 kW for the entire hotel (500 lamps). In total, the LEDs use 61% less electricity than incandescent lamps.

As the examples above show, switching out incandescent and halogen lamps with SynJet-cooled LED lamps can greatly reduce electricity costs. The future of lighting will be even more ecologically sound when fluorescent lamps, with their mercury hazard, are replaced with long-life, efficient LED lamps.

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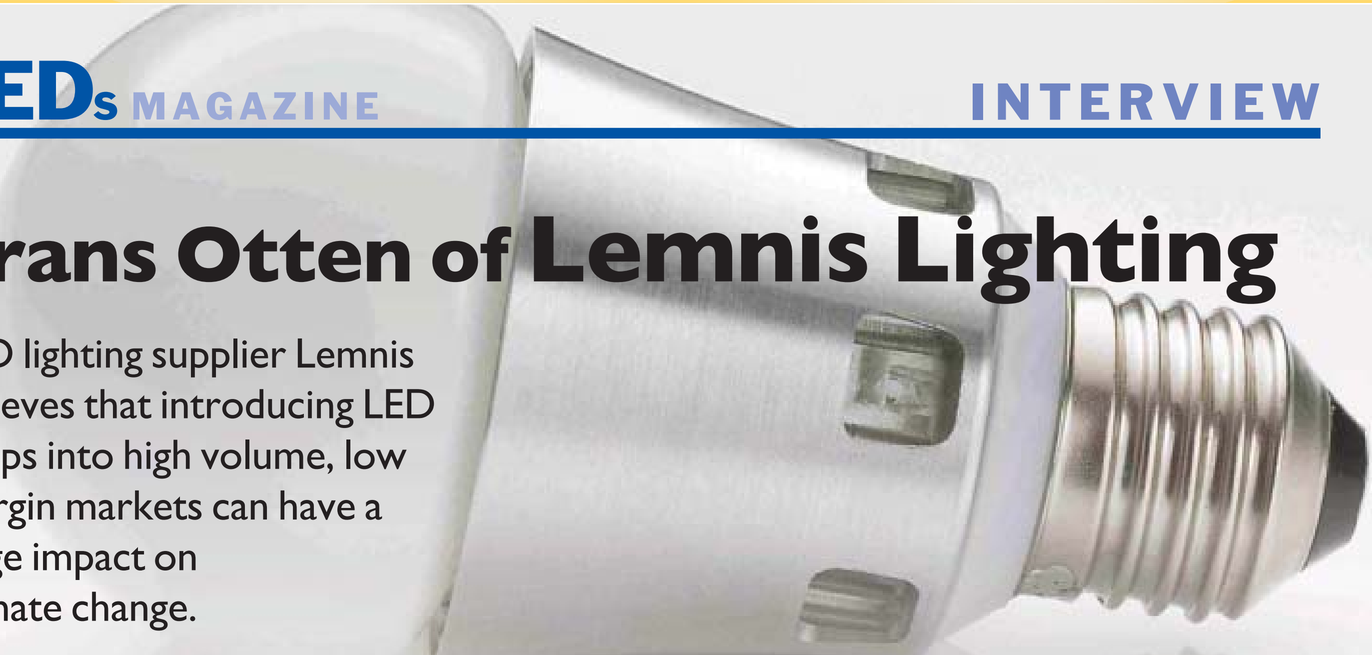
Frans Otten of Lemnis Lighting

LED lighting supplier Lemnis believes that introducing LED lamps into high volume, low margin markets can have a large impact on climate change.



The 40 W Pharox lamp.

In November 2007, Lemnis Lighting, a Netherlands company that is developing sustainable lighting solutions based on LEDs, was selected by the Clinton Climate Initiative (CCI) to be a supplier of LED lightbulbs. CCI has created a network of providers that enables cities around the world to purchase energy-efficient technologies at lower prices (www.ledsmagazine.com/features/4/11/1).

Lemnis introduced its Pharox LED light bulb in November 2006 as a direct replacement for incandescent lamps, and has also developed products for other applications such as outdoor and greenhouse lighting. Lemnis (www.lemnislighting.com), describes the Pharox lamp as the first LED-based lamp to offer light quality comparable to that of a traditional 40W light bulb, while being 90% more energy-efficient.

(top) Lemnis founder Frans Otten, left, and President Clinton.

"We are proud that the Clinton Climate Initiative recognizes our high product quality standards," said Frans Otten, chairman of Lemnis Lighting. "This is an important step forward in fulfilling our broader mission of introducing this revolutionary LED technology and contributing to energy efficiency around the world."

LM: How did Lemnis become involved with CCI?

Frans Otten: The focus of CCI and Lemnis is aligned in the sense that we are seeking to reduce the level of CO_2 emissions through the use of energy-efficient technologies, in this case LED lighting. CCI wants to encourage the use of the newest and best technologies in its vendor programs. We both want to use LEDs because of their potential impact on climate change, not just because they are an exciting technology.

How does CCI operate?

CCI combines the purchasing power of different organizations, in this case a number of very large cities. This creates a large and viable market and allows suppliers to cut prices. The same approach has already been used successfully with anti-Aids drugs.

How does this fit with your business model?

Many current LED-based lighting applications are low-volume projects with high margins. Lemnis is targeting the introduction of LED lamps into high volume, low margin markets, particularly retrofit 40 W and 60 W incandescent lamps. This will have the biggest impact on climate change.

Can LED lamps compete with CFLs?

We see CFLs as a transition from incandescent to LED lamps. In the coming months and years, LED efficiency will continue to improve. We want to position LEDs to be more efficient ultimately.

What is the performance of Pharox?

We have introduced a 4-watt lamp as a replacement for a 40 W incandescent. The light output is 230 lumens, with a color temperature of 2800 K. The color rendering exceeds 85 and the lifetime is 50,000 hours, compared with 1000 hours for an incandescent lamp.

The light output level is not great, and you wouldn't use this lamp to read a book, but it would be very suitable for lighting a hallway for 7 hours per night every day, for example.

How does this translate into savings?

We estimate that if every Dutch household were to replace 4 incandescent bulbs with 4 Pharox lamps, the country would save 1.5 billion kWh of energy per year. This energy saving is equal to the annual energy consumption of all households in Amsterdam.

Will LED lamps be sold in the same way?

A lifetime of 50,000 hours translates into significantly more than 10 years for household use. This means there will be much less need for retail shops to carry replacement bulbs. Retailers make a huge margin on lamps, for example a CFL costs about 30 cents to make and retails at $3-4. With LED lamps, more logical distribution models are likely to emerge. One example would be for utility companies to supply light sources as well as energy. We have been involved in a program with a Dutch energy company (Oxxio – see www.oxxio.nl/lamp) where the customer receives 4 LED lamps and then pays for them over a period of 4 years, as part of their energy bill.

What about pricing?

The Pharox bulbs are priced around EUR 25 in The Netherlands. Of course with time and increasing volumes the price will go down, but we are dependent of the general LED industry in that case.